A Narrative study on the strengthening effect of Reinforced Concrete Beams

K Hemalatha¹*, B Achsah Keerthana¹, M Pranav¹, Vandanapu Swamy Nadh², Laith H. Alzubaidi³

¹Department of Civil Engineering, GRIET Hyderabad, India
²Department of Civil Engineering, Aditya College of Engineering, Surampalem, Andhra Pradesh, India
³The Islamic university, Najaf, Iraq

Abstract. We now understand that, in the general construction of structures, the selection of reinforcing materials plays a critical role in guaranteeing structural durability and integrity. The comparative study of fibre reinforced polymer (CFRP) bars and steel, two widely utilized materials, is explored in this abstract with an emphasis on the differences in their load-deflection properties and ductility behaviours. Because of its exceptional ductility, steel is commonly used in constructions that are situated in seismically active areas. On the other hand, CFRP bars have certain benefits, such resistance to corrosion and less weight, even if they are less ductile. The trade-offs between various materials are revealed by the study of load-deflection qualities, highlighting the significance of choosing the best choice in light of particular building constraints and needs.

Key words: Corrosion, Fiber Reinforced Polymer, Flexural behaviour.

1 Introduction

The selection of materials is crucial for maintaining structural integrity and longevity in the building industry [1-8]. Here, we embark on a comparative journey between traditional steel and innovative Fiber Reinforced Polymer (CFRP) bars, paying close attention to the ductility and load-deflection properties of each material [9, 10]. Steel's exceptional ductility has long made it a preferred material for earthquake-resistant constructions in earthquake-prone areas. Ductility, or a material's capacity to flex without collapsing, is a crucial factor [11]. However, CFRP bars are lighter and non-conductive than steel, so they are advantageous in a variety of situations [12]. On the other hand, steel is often superior in load-deflection properties. Despite this, CFRP bars are less ductile but offer corrosion resistance and reduced weight [13,14,15]. With the construction industry changing constantly these days, this research provides engineers and experts to make well-informed decisions based on project-specific requirements, environmental goals, and safety considerations, strengthening the resilience and quality of the built environment [16,17,18].

* Corresponding Author: hema1177@grietcollege.com
2 Literature review

Khalil Sijavandi et al. (2021)
The author experimented with concrete beams reinforced with fiber-reinforced polymer bars (CFRP), high strength steel bars (HSS), and hybrid combinations of these materials employing high-performance fiber-reinforced cementitious composites (HPFRCC) in place of conventional concrete. The results indicate that in terms of energy absorption, ultimate strengths, and cracking, HPFRCC beams fared better than traditional concrete beams. Significant increases in strength and ductility were shown by the hybrid beams, particularly those with greater effective reinforcement ratios. The analysis also identifies differences in the effective moment of inertia calculation algorithms given by the code, indicating the necessity for changes. Overall, the hybrid arrangement of HSS yielding and CFRP bars produced improved ductility and up to a 30% improvement in flexural strength. There were no conflicting financial interests disclosed by the authors.

The study looked at 12 concrete beams with different reinforcing percentages and concrete strengths that were reinforced using fiber-reinforced polymer (CFRP) bars. It was discovered that when raising the ultimate load, increasing reinforcement ratios decreased fracture widths and deflection. After analysing design recommendations, the study found that ECP 208-2005 underestimated deflection and moment resistance, whereas ACI 440.1R-06 overestimated CFRP bar moment resistance in comparison to other codes and experimental data. The work emphasises the necessity of updated design equations to correctly forecast the behaviour of CFRP-reinforced concrete in its particular characteristics. All things considered, CFRP exhibits potential for concrete buildings; nonetheless, because of its unique properties and enhanced comprehension of its behaviour, careful design considerations are essential.

G Naveen Kumar and Karthik Sundaravadivelu (2017)
The application of fibre reinforced polymer (CFRP) as a corrosion-resistant substitute for steel reinforcement in concrete beams is investigated in this study. Six beams were produced, three of which had CFRP as the primary reinforcement and three of which had steel reinforcement. The study discovers that whereas CFRP-reinforced beams show the opposite tendency, the peak load value increases as the proportion of steel reinforcement increases. When compared to steel-reinforced beams, the peak load values of CFRP-reinforced beams differ considerably, and the failure cause is over-reinforcement. CFRP beams have decreased load stiffness but increased starting stiffness. More fractures and bond failures with the concrete are seen in CFRP beams. According to the study's findings, CFRP reinforcement affects the behaviour and modes of failure of concrete beams, offering important information for structural design and rehabilitation.

Muhammad N.S. Hadi, Jian Song Yuan. (2017)
In contrast to conventional reinforced concrete (RC) beams, this study examines composite beams reinforced using fiber-reinforced polymer (CFRP) I-beams and longitudinal tensile steel bars. The findings show that, in comparison to RC beams, the composite beams display ductile behaviour at greater ultimate loads. While the CFRP I-beams add shear and flexural strength, the tensile steel bars improve ductility and bending stiffness. The flexural response is not significantly affected by the location of the I-beam within the cross-section. But when CFRP bars take the place of steel bars, the beams become more brittle, which lowers their ultimate load and rigidity. The study makes recommendations for how to strengthen the bond
resistance between I-beams and concrete. In general, the composite beams have potential for use in building projects.

Patrícia Escórcio, Paulo M. França (2016)
The study suggests a corrosion-resistant material called fibre reinforced polymer (CFRP) bars to replace the deteriorated tension steel reinforcement in a concrete beam as part of a rehabilitation project. Full-scale RC beams were used in the experimental investigation to assess how this rehabilitation solution affected the beams' flexural capacity, failure modes, deflection, crack patterns, and reinforcement strains. The results show that this approach is effective, simple to use, and capable of restoring the ultimate limit states and serviceability of the original reinforcing concrete beam. As such, it presents a promising option for enhancing the long-term resilience of marine steel-reinforced concrete structures that are experiencing corrosion-related problems.

Mrs. T. Saraswathy, Mrs. K. Dhanalakshmi (2014)
The flexural behaviour of concrete beams reinforced with fiber-reinforced polymer (CFRP) bars is investigated in this work. CFRP has great strength and a distinct linear stress-strain response, making it a suitable material for construction. The study looks at how several characteristics, such as failure mode, fracture patterns, load-carrying capacity, load deflection behaviour, and ductility, affect how these CFRP-reinforced beams behave. The results demonstrate that shear failures of CFRP-reinforced beams were the main cause of their lower post-cracking stiffness and rebar slippage between the concrete matrix and rebar. For similar loads, CFRP exhibits more deflection because of its lower elasticity modulus. The work highlights the possibilities and difficulties of employing CFRP in concrete buildings by predicting load-deflection responses that closely match experimental results.

Xian Li and Henglin Lv et al. (2011)
In order to improve ductility and corrosion resistance, the study presents a unique method that uses FRP-reinforced concrete encased steel (FRP-RCS) composite beams. These beams mix corrosion-resistant FRP-reinforced concrete with flexible structural steel forms. In order to assess the flexural behaviour of seven beam specimens under a variety of conditions, such as concrete strength, CFRP reinforcement, and the arrangement of encased steel forms, tests were conducted. The findings show that, in comparison to traditional FRP-RC beams, enclosed steel forms greatly increase load capacity, stiffness, ductility, and energy absorption. The ductile behaviour of the suggested FRP-RCS beams was mainly caused by the steel's residual strength after the concrete was crushed. An analytical technique for forecasting the nominal flexural strength of FRP-RCS beams is also included in the work, offering important new information on the design of composite members.

C. Miàs and L. Torres et al. (2013)
The study focuses on long-term deflections in reinforced concrete (RC) beams made of fibre reinforced polymer (CFRP), as these have gotten less attention than short-term deflections. For 250 days, eight CFRP reinforcing beams were subjected to continuous stresses in an experiment. Important discoveries include the fact that the deflection following a cycle is 1.2–2 times greater than the deflection caused by the original load. ACI 440.1R-06 and CSA S806-02 theoretical predictions revealed discrepancies with experimental findings. The modified time-dependent component of ACI 440.1R-06 and modified Bischoff's equations gave the best agreement with the experimental results. Time-dependent deflections rose noticeably with time, while the levels of sustained load had no discernible effect. The overall deflections of beams strengthened with greater CFRP ratios were higher.
This study looks at how the ratio of reinforcement to concrete strength affects the long-term deflections of beams reinforced with fibre reinforced polymer (CFRP). For a maximum of 700 days, twenty beams with various configurations underwent both transient and continuous loads. The results demonstrate the impact of these parameters on long-term deflections by showing that larger total-to-instantaneous deflection ratios are produced by higher reinforcement ratios and lower concrete strength. The results of the experiment were compared with a number of design equations, such as CSA-S806-02 and ACI 440.1R-06. Although there were differences between these processes, the CEB-FIP approach and a methodology created by the author offered more precise long-term deflection predictions by taking material and ambient characteristics into account.

C. Barris and Ll. Torres et al. (2009)
The short-term flexural behaviour, reinforcement ratios, and depth-to-height ratios of fiber-reinforced polymer (CFRP) reinforced concrete beams were the main subjects of the author's experimental programme. The results show that the CFRP-reinforced beams had a noticeable displacement before failure and linear behaviour up until cracking as well as linear trends between cracking and failure. For both cracked and uncracked portions, different prediction models under- or over-estimated deflections at higher loads, but closely matched experimental results at lower loads in terms of serviceability. Most likely as a result of greater concrete compressive strain, the testing findings surpassed forecasts for ultimate load capacity. Overall, the CFRP-reinforced beams showed signs of concrete crushing failure, but they also met suggested deformability standards due to their high deformability standards prior to failure.

M. Pecce and G. Manfredi et al. (2000)
The experimental testing of beams reinforced with Fiber-Reinforced Plastic (FRP) bars is covered in this work, with particular attention paid to the beams' curvature, deflection, crack spacing, and breadth. This research compares the Eurocode 2 and American Concrete Institute techniques to code formulations for ultimate and serviceability situations. The study indicates that code models are typically dependable, given that the properties and design values of FRP bar strengths are clearly stated and further experimental testing are carried out, even though there are occasional discrepancies between experimental observations and design criteria.

3 Experimental Work

3.1 Material Properties
Nominal concrete of grade M70 has been prepared as shown in Table 2. Cement, water, and fine and coarse particles make up the majority of concrete. The concrete matrix contains additives to assist harden the concrete's characteristics. The present study employed Ordinary Portland Cement (OPC) with a specific gravity of 3.04 and fly ash with a specific gravity of 2.2, both of which meet Indian Standards. According to the design of the reinforcement, the maximum size of the coarse aggregates employed is 10 mm. It uses fine aggregate with a fineness modulus of 2.61. Super-plasticizer has been applied because it functions as an agent to reduce water.

The reinforcement is made of both CFRP and steel rebars as shown in Table 2. These bars have characteristics like as elongation, density, and elastic modulus. Fig.1 and Fig.2 shows...
the stress-strain curve for steel and CFRP bar

Table 1. Properties of bars

<table>
<thead>
<tr>
<th>Properties</th>
<th>Steel</th>
<th>CFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Deformed</td>
<td>Deformed</td>
</tr>
<tr>
<td>Grade</td>
<td>Fe 550</td>
<td>III</td>
</tr>
<tr>
<td>Density</td>
<td>7850 Kg/M3</td>
<td>2100 MPa</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>575 MPa</td>
<td>950 MPa</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>200 GPa</td>
<td>&gt;60 GPa</td>
</tr>
<tr>
<td>Length in meters</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Diameter in millimeters</td>
<td>12,10</td>
<td>12</td>
</tr>
</tbody>
</table>

3.2 Mix Proportions

The mix for M70 grade concrete is 1:1.09:2.21:0.264 at w/c of 0.48.

Table 2. M70 Mix Proportion

<table>
<thead>
<tr>
<th>Grade</th>
<th>Cement Kg/M3</th>
<th>Silica fume Kg/M3</th>
<th>FlyAsh Kg/M3</th>
<th>Fine Aggregate Kg/M3</th>
<th>Coarse Aggregate Kg/M3</th>
<th>Water Kg/M3</th>
</tr>
</thead>
<tbody>
<tr>
<td>M70</td>
<td>428</td>
<td>26.75</td>
<td>80.25</td>
<td>588</td>
<td>1217</td>
<td>113</td>
</tr>
</tbody>
</table>

![Steel Stress Strain Curve](image)

Fig. 1. Steel Stress Strain Curve
3.3 Beam detailing

The beams are developed using CFRP reinforcement in accordance with ACI 440.1R.06 and steel in accordance with IS code.
a single under-reinforced beam segment of 2 metres in length, 150 millimetres in width, and 200 millimetres in depth.
Dia of the bar = 12mm
Area of steel (Ast) = 574.04mm2
To make under reinforced section using trial and error method deducting 25% from area
Now, Area of steel (Ast) = 431.28mm2
No of bars \( \eta = \frac{Ast}{\pi/4} \times \text{dia} \times \text{dia} \)
\( \eta = 4 \) no’s
Pt = \( \frac{Ast}{(b \times d)} \times 100 = 1.68\% \)
Pt limit = 2.33%
It satisfies the given condition in IS code.
As a result, 2 no’s of 10mm diameter bars are utilized as compression reinforcement and 4 no’s of 12mm diameter bars are utilized as the primary reinforcement, or tension.
As stirrups, 2 Leg 8mm dia bars are positioned 100 mm apart at the edges and 120 mm apart in the centre.
ACI 440.1R.06 has been followed in the design of the CFRP beam.
Fig.3 and Fig.4 shows the longitudinal and cross section of RC beam.
As seen in Fig. 5, the beam is mounted on the universal testing apparatus. The beam has
a 1.8-meter span. We used four-point stress testing on the beams to look into their flexural capability. The beam is divided into three sections since it is supported from both ends at a distance of 600mm. Positioned at the centre (L/2) and quarter (L/4) spans of the beams, the Linear Variable Differential Transformer (LVDT) measures the displacement that arises when the load is applied.

4 Results

Table 3 shows the values obtained after testing.

<table>
<thead>
<tr>
<th>Beams</th>
<th>Steel Main Reinforcement</th>
<th>CFRP Main Reinforcement</th>
<th>Ultimate Load (kN)</th>
<th>Ultimate Moment (Mu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S70</td>
<td>4φ12</td>
<td>-</td>
<td>120.2</td>
<td>36.06</td>
</tr>
<tr>
<td>G70</td>
<td>-</td>
<td>4φ12</td>
<td>150.3</td>
<td>45.09</td>
</tr>
</tbody>
</table>

Fig. 6 and Fig. 7 shows the graphs between load and deflection is drawn for steel and CFRP beams.

**Fig. 6.** Load Displacement Curve of Steel RC Beam
From the survey done on the literature, it can be concluded that
1. The bond performance of CFRP bars is a crucial factor impacting crack width and tension stiffening behavior in concrete structures.
2. The ultimate load capacity of CFRP bars RC beam is 150KN whereas for Steel bars RC beam is 120KN only.
3. The ultimate deflection for CFRP RC beam is 40mm ad for steel bars RC beam is 20mm.
4. The above results show that CFRP-reinforced buildings to their steel-reinforced equivalents, the former show an astounding 25% increase in ultimate moment on average.

This experimental work demonstrates that, when it comes to ultimate load-carrying capability and ductility, CFRP reinforcement offers notable advantages over steel. This significant increase highlights the significant advantages of using CFRP, indicating that it is a viable substitute for concrete constructions in terms of lifetime and durability.

6 Acknowledgement

I am deeply grateful to every member of Gokaraju Rangaraju Institute of Engineering and Technology for their constant assistance in observing this project fully to its completion.

References


