Utilizing CFRP Sheet for Strengthening Extended Concrete Beams

Zaid A. N. Mhawesh[1, a]*, Sadjad A. H.[1, b] and Wajde S. S. Alyhya[1, c]
[1]Civil Engineering Department, University of Karbala, Karbala, Iraq
[a] zaid.azzam@s.uokerbala.edu.iq, [b] sajjad.a@uokerbala.edu.iq, and [c]wajde.alyhya@uokerbala.edu.iq
*Corresponding author

Abstract. This research investigates the behavior of extended reinforced concrete beams that have been enhanced using CFRP at the extension points. Five reinforced concrete beams with measurements of 2500 mm in length, 150mm in width, and 260mm in height were built and extended in different types. The studied cases included varied CFRP strengthening schemes for the splice joints. The findings conclude that the inclusion of horizontal stirrups on the complete top of the beam produced comparable results to those of the reference beam. Additionally, the spliced beams glued at their lateral faces and strengthened by vertical CFRP laminates provided a marginal increase in their ultimate loads. The results also showed that the strengthening with carbon fibers exhibited lower crack width than the reference beam in general.

Keywords: CFRP Sheet; RC Beams; Strengthened Technique; extended beam.

1. INTRODUCTION

Worldwide, there is a significant need to reinforce concrete structures, and several justifications exist. Usually, deficiencies are the consequence of functional changes, such as a higher permit load requirement, increased traffic brought on by a rising civilization, or degradation brought on by aging and exposure to harmful environments [1]. As a result, there is a great deal of concrete highway bridges that require repair or replacement [2]. The concept of externally bonded FRP systems for concrete structure reinforcement was created as an alternative to traditional external reinforcing techniques like steel plate bonding and concrete or steel column jacketing [3]. As a result, attaching CFRP laminates to the concrete surface as an external reinforcement at the hogging moment zone can boost the beam's capacity by avoiding any existing fractures in the concrete flange produced by service loads. The advantages of employing CFRP laminates for strengthening include their low weight, high strength, resistance to corrosion, rapid application, conventional use, and ability to be molded into various forms on-site [4]. Existing weak structures can be strengthened using a variety of techniques. A straightforward and time-tested way of reinforcing a concrete building is to increase its cross-section [5]. Sarsam's evaluation of seven single reactive powder concrete beams reinforced by exterior joined CFRP in flexure was published in 2015 [6]. One of the seven was used as the control beam, and the other six were assessed against it. The test program's experimental parameters included the number of layers of CFRP strip, its width, and whether or not it had external anchorages.

In comparison to the un-strengthened reinforced concrete beam (control beam), the trial findings revealed that the ultimate loads were raised by up to 64.29% for the beams strengthened using bonded CFRP sheets and external anchoring. Additionally, the initial breaking load for these reinforced beams increased by up to 100%. However, compared to a similarly loaded, un-strengthened reinforced (reference beam), there is less deflection. There is a lack of information on how to repair previously damaged members, even though many studies have addressed external strengthening of undamaged concrete members having various spacing of wrappings, design considerations like member cross-section, stirrup and reinforcement ratio, and level of strengthening. Innovative bridge designs and building methods to retain structural integrity and cost-saving and cost-effective maintenance are crucial since roughly one-third of the highway bridges in the United States now need repairs or replacements [7]. Six continuous steel-concrete composite beams were tested to determine the effects of using CFRP sheets to support the composite action at the hogging moment area [8]. According to the test results, CFRP laminates effectively maintain composite action for continuous steel-concrete composite beams and prevent crack start in the concrete flange under applied loads. A specific type of drillable FRP laminates was employed to investigate the potential improvement in the beam stiffening strengthened using mechanically anchored CFRP-GFRP laminates [9].

This paper presents the test results of five extended beam specimens strengthened by carbon FRP sheets. The effectiveness of CFRP sheet externally bonded flexural strengthened reinforced concrete beams is the focus of this paper's investigation as the forms of failure of these beams.

2. EXPERIMENTAL PROGRAM

The experimental work consists of preparing five reinforced concrete beams. One of these beams was cast monolithically (without join) as a reference, while the other four beams were joined together from one precast segmental beam. The splice sections in these beams were created using dowels, cast-in-place, employed in all extended continuous beams. Each extended and non-extended continuous beam had a total length of 2500 mm with three supports; the distance between the interior and the edge supports was 1250 mm. All beams have been constructed using a 260 mm height and 150 mm wide rectangular cross-section. Flexural steel reinforcement consisting of two bars of 10 mm diameter at the top and bottom of the beam section. The stirrups were 6 mm in diameter and spaced 100 mm apart throughout the beam length. The control beam was designed in accordance with the ACI 318 Code [10]. The length of the splice region was equivalent to the development length of the expanded longitudinal bars. The descriptions for the extended and non-extended continuous beams were illustrated briefly in Figures 1 and 2 and Table 1.

Table 1: Specifications for the beams' reinforcing and carbon fiber strips.

No.	Beam symbol	Length splice region (mm)	Adding bars in neutral Axis	Type of concrete in extended region and non - extended	Strengthening techniques
1	CB	-	2Ø16	Normal concrete	-
2	BF10	200			Horizontal CFRP sheet placed at the top of the beam
3	BF12	210			Horizontal CFRP sheet placed at top of the beam
4	BFL10	200			Breaking part of the beam in an L shape in the middle of the distance of the beam followed by attaching by CFRP at a distance of 2000 mm and vertically
5	BFL12	210			Increasing the diameter of the reinforcing steel in the extended beam and breaking part of the beam in the shape of a letter L in mid span with a distance of 200 mm After that, the beam is bandaged with CFRP at distance of 700 mm from the beam center

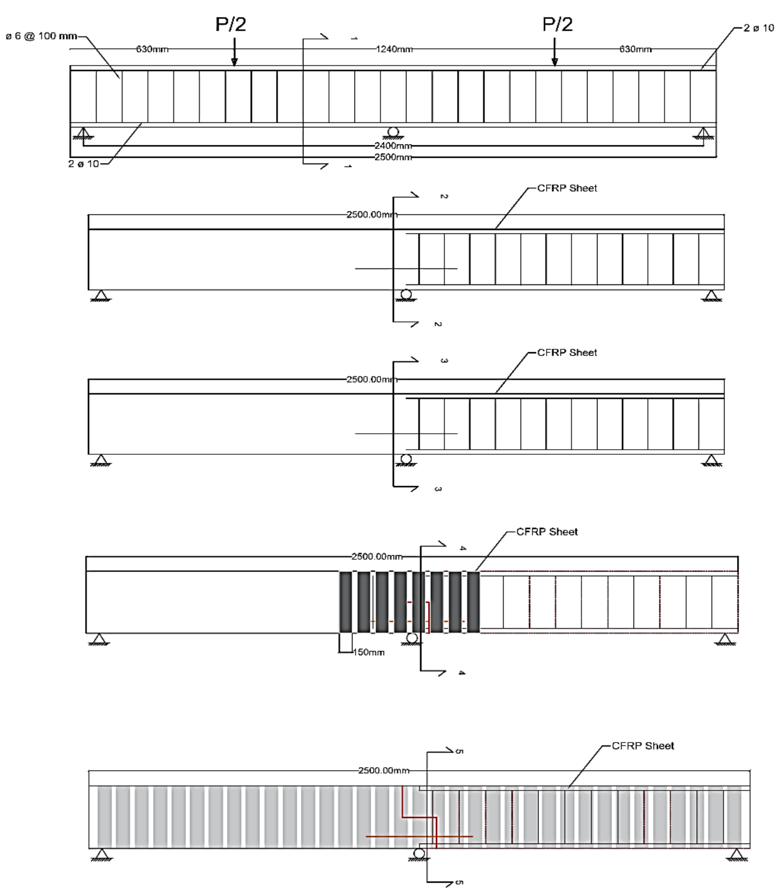


Figure 1: Specifics on the beam segment's reinforcing.

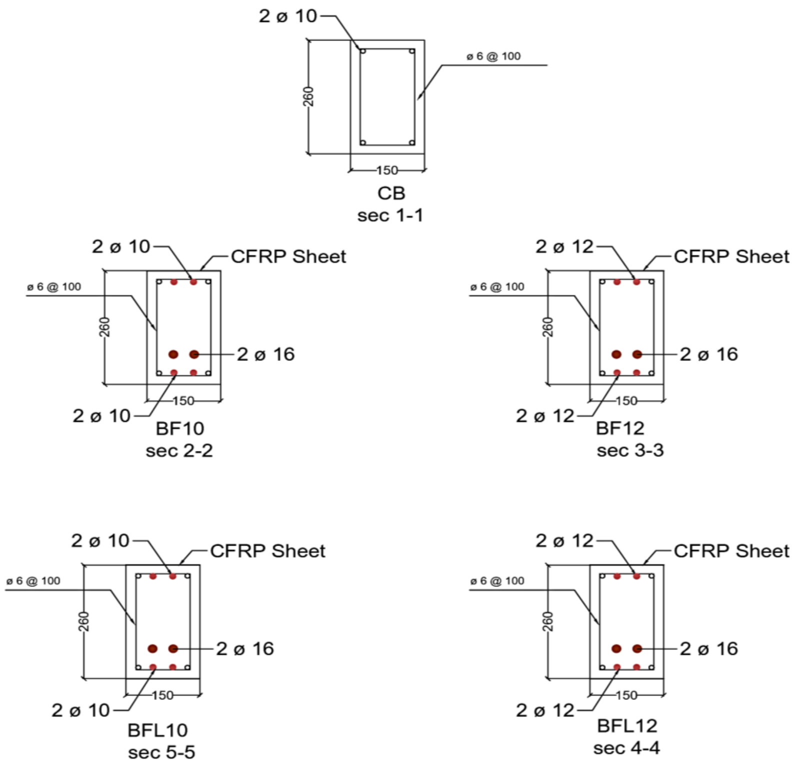


Figure 2: Reinforcement details in the beam segment portion (all measurements are in millimeters).

2. MATERIALS PROPERTIES

Carbon fibers that were used for the two models marked with (BF10 and BF12) were used along the upper surface of the beam with dimensions of (150×2500)mm. The concrete mix was (1:1.33:1.3) using a super plasticizer-to-cement ratio of 1% and a water-to-cement ratio 0.3. For all beams, ready-mixed, standard-weight concrete is utilized. With a 100 mm slump, the concrete's compressive strength was 36 MPa. The Sika Wrap®-300 C, a CFRP, was employed in this investigation. The type epoxy adhesive Sikadur®-330 is a two-component, solvent-free, moisture-tolerant, high strength, high modulus structural epoxy adhesive, as shown in Figures 3 and 4.

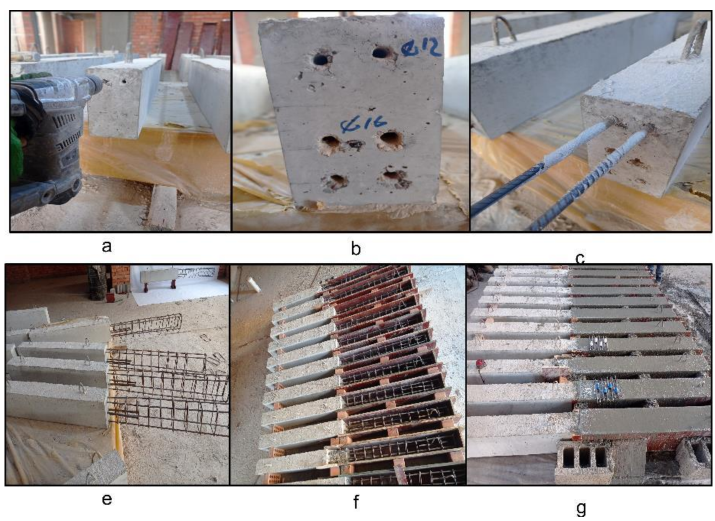
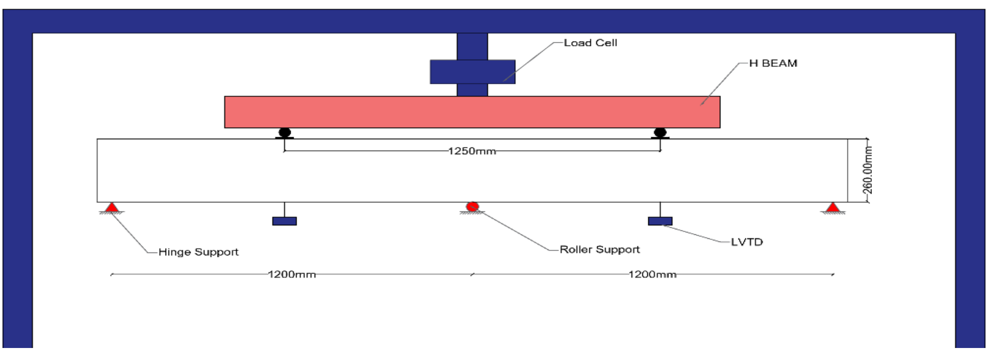


Figure 3: The application of extended region.

Figure 4: The application of CFRP Sheet.

2.1 Testing Procedure

A 2000 kN capacity servo-hydraulic actuator was used to test the beams. The beams were loaded monotonically in 10 kN increments. Deflection measurements at mid-span and the breadth of the fractures were taken at each load stage, as shown in Figure 5.



(a) Setup for testing.

(b) Beam segment before applying the load.
Figure 5: Preparation for loading.

3. TEST RESULTS AND DISCUSSION

3.1 Cracking Pattern and Mechanisms of Failure

The extended reinforced concrete beams begin to collapse as the tensile stress approaches the maximum strength of the concrete. Numerous fractures, including flexural, diagonal, and interface cracks at the junction of the precast section at the splice zone, appeared in the beams as a result of the applied load. The findings for all of the beams in this group are shown in Table 2, along with the first cracking load, ultimate load, and failure modes.

Table 2: The extended beams' first breaking load, maximum load, and failure type.

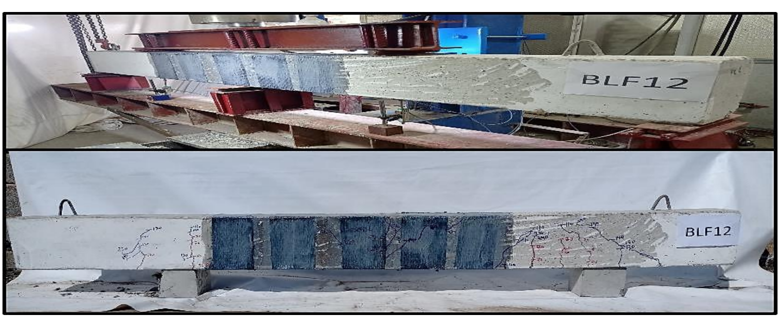
No.	Beam symbol	First Crack Load (Pcr) (kN)	Ultimate Load (Pu) (kN)	$(\frac{Pu(i)}{Pu(R)})^*$	Failure Type
1	CB	50	250	1	Flexural failure
2	BF10	50	248	0.99	Flexural followed by direct shear
3	BF12	45	250	1	Flexural followed by direct shear
4	BFL10	110	255	1.02	Flexural failure
5	BFL12	50	252	1.008	Flexural followed by direct shear

* Pu (i): The ultimate load of the proposed beam.
Pu (R): the control beam's maximum load.

According to the experimental findings, three different types of cracks were developed in the extended beams due to loading. The most frequent forms of cracks were flexural, diagonal, and interface cracks. First, flexural cracks were seen at the middle span joint, followed by further cracks on the lower face. Several cracks began to move diagonally when the load was around 80% of the maximum load. During this phase, the precast segment's interface experienced cracks. Figure 6 displays the failure mechanisms and crack patterns for the extended beams. It was found that while extended beams collapsed via flexural followed by direct shear, non-extended beams fractured due to a failure in the tension steel reinforcement (control specimen).

The splicing technique typically impacts the performance of the spliced beams. The tests showed that the extended strengthened beams' ultimate load was close to the non-extended beams. The non-extended beams typically failed through flexural failure, whereas the spliced strengthen failed through flexural failure and direct shear.

(a) Cracks pattern of CB.



(b) Crack patterns in the tested extended continuous beams at the failure stage (BLF12).
Figure 6: Crack patterns in the tested extended continuous beams at the failure stage segment.

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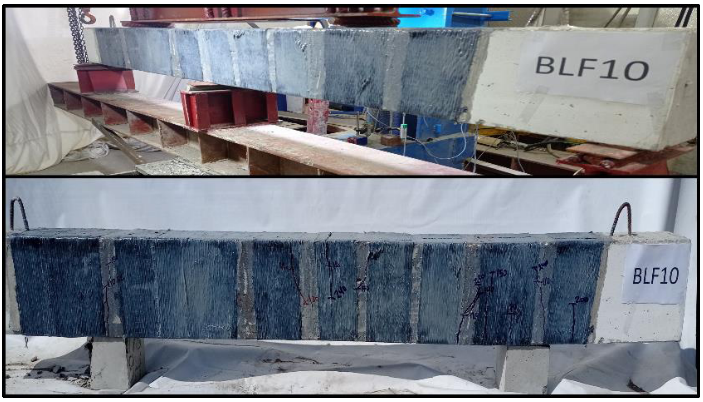
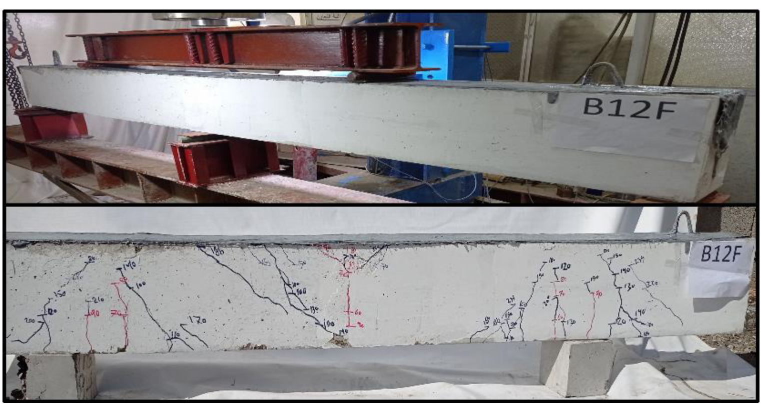


(c) Crack patterns in the tested extended continuous beams at the failure stage (BLF10).

(d) Crack patterns in the tested extended continuous beams at the failure stage (BF10).



(e) Crack patterns in the tested extended continuous beams at the failure stage (BF12).
Figure 6: Continued.

3.1.1 Load-Deflection Behavior

Under the impact of the applied loads, the load-deflection curve significantly impacted the general behaviors of the concrete beams. According to the findings, the control beam experienced a flexural failure at a load of 248 kN, while the ultimate load of the strengthened beam spliced in was either less or more than the non-extended beam by 1.5%. Figure 7 displays the load-deflection curves for extended reinforced concrete beams, the effects of the method, and the addition of CFRP sheet reinforcement in the splice zone.

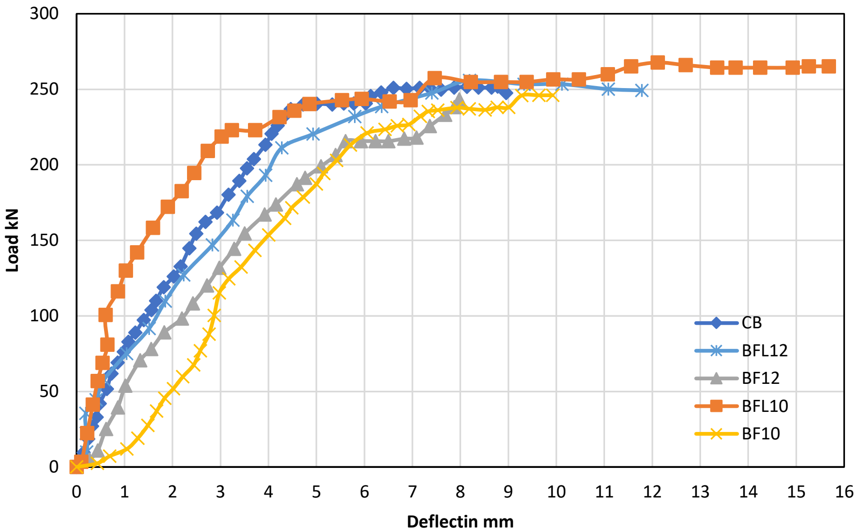


Figure 7: Load-deflection curves for extended reinforced concrete beam CB.

4. CONCLUSIONS

- At a range of 1.5%, the maximum load difference between the strengthened beams spliced and the reference beam was small. Due to this small variation, the splicing strengthen procedure is an efficient way to extend the span range of concrete beams slightly.
- According to an analysis of the failure modes, each beam experienced flexural failure, mainly in tight positions. The CFRP sheets deboning from the concrete base or the steel yielding were responsible for the tension breakdowns. There were no ruptures of the CFRP sheets in the strengthened beams.
- The carbon fiber sheets' surrounding concrete substrates showed some light peelings. It shows that epoxy was more durable than concrete when paired with a CFRP sheet.
- Compared to the control beam, CFRP sheet strengthening shows lower crack width and more cracks overall.

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