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STUDY OF CFRP GEOMETRY ON SHEAR STRENGTHING OF RC CORBELS

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A B S T R A C T

This study adapts the geometry of CFRP used as a strengthening material to improve the shear strength of reinforced concrete corbels. The experimental work investigated using CFRP with specific geometry that focused on the size and magnitude of CFRP installation. The sizes are (1/3, 2/3 & full) the height of the cross-section, and the magnitude represented by multi-layers of CFRP. The results of the experimental work revealed that the performance of the CFRP near the neutral axis most contributed to the increase in the shear with 33.6 % in the middle third compared to 46.25 % for fully strengthened. The results also showed that using the second layer of CFRP was less efficient than the first layer due to debonding between the strips and the concrete surface before the rupture of the CFRP strips.

1. Introduction

Corbels are short cantilever elements projecting from columns or walls usually used to transfer bearing load between different structural elements which are widely used structural shear elements and have low cost in construction. Different theories have been proposed to design corbel elements as shear elements that resist vertical and horizontal loads and provide safety in earthquakes [1]. Sometimes it is necessary to increase the bearing capacity of the corbels due to changes in the function of the structure, aging, error in construction, or the possibility of its exposure to harsh conditions such as earthquakes or fire, strengthening is an efficient strategy followed to increase the capacity of the structural members [2].

In the last decades, many researchers utilized different types of materials and different procedures to strengthen and upgrade the shear strength capacity of the corbels [3-11]. Carbon Fiber reinforced polymer is widely used in the field strengthening by researchers because of its efficiency in enhancing the strength capacity and easy application. The studies included that the different configurations of CFRP increase the shear capacity of the corbels, but the failure happens suddenly due to the brittle bond between the CFRP and the application surface of concrete [12, 13]. Whereas others studied the performance of CFRP in strengthening corbels with different locations and directions of the CFRP, in a result, the shear strength capacity was affected significantly by the fibers' direction and location where CFRP perpendicular to shear cracks was the more effective [1].

As a result, most studies focused on the location and direction of CFRP in addition to the number of CFRP layers, however, the investigation of the effect of CFRP geometric and its correlation with the number of CFRP layers was not explicitly addressed. The motivation that leads us to study the geometry of CFRP is the economic and engineering feasibility of using the optimized quantity of CFRP in the optimal location.

2. Experimental work

2.1 Job mixes

Reinforced concrete corbels cast using concrete job mix from local materials (Ordinary Portland cement OPC 350 kg/m3, sand 790 kg/m3, gravel 1050 kg/m3, and water 140 kg/m3) in addition to superplasticizer type F 0.5% from cement weight. The finesse of cement is 245 m2/kg The maximum aggregate size of the gravel was 12 mm and the specific gravity for aggregates is 2.65. The steel fibers are 305 mm in length and 0.45 mm in diameter. The chemical compositions of the used OPC are given in Table 1.

TABLE 1. Chemical composition of OPC.

Oxides %	OPC
Sio2	21.4
Al2o3	5.33
Fe2o3	2.18
Cao	60.8
So3	1.85
C3A	0.26
MgO	3.9
Free Cao	...
Cl-	....
LOI	2.18

2.2 Preparation of specimens

Seven reinforced concrete corbel specimens were prepared and cast in wood form in geometry detailed in Figure 1. All specimens were reinforced in flexure by two bars 16 mm in diameter without transverse reinforcement, the steel rebar had a yield strength of 460 MPa and an ultimate tensile strength of 660 MPa. Cube samples 150*150*150 mm and cylinder samples (100*200 mm) were cast simultaneously with each mix to determine the compressive strength and splitting tensile strength for the concrete at the same age as of the corbel tests. Sikawarp 230 C CFRP was utilized to strengthen the corbels after 28 days using three different strips having widths (50, 100, and 150) mm which represent (1/3, 2/3, and full) height of the corbels respectively, as shown in Figure 1. Also, one and two CFRP laminates were utilized for each strip size. Tables 2 and 3 illustrate the CFRP properties and the geometries of CFRP laminates, respectively.

Table 2. Specifications of CFRP

Property	
Fabric type	Woven unidirectional
Fiber thickness mm	0.167
Density gm/cm3	1.82
Tensile Resistance	Average 452 KN/m

TABLE 3. Corbels with CFRP strips.

ID	Strip height of CFRP	Number of CFRP layers
C-R	---	---
C-1/3-1	50 mm (1/3)	1
C-1/3-2	50 mm (1/3)	2
C-2/3-1	100 mm (2/3)	1
C-2/3-2	100 mm (2/3)	2
C-F-1	150 mm (full)	1
C-F-2	150 mm (full)	2

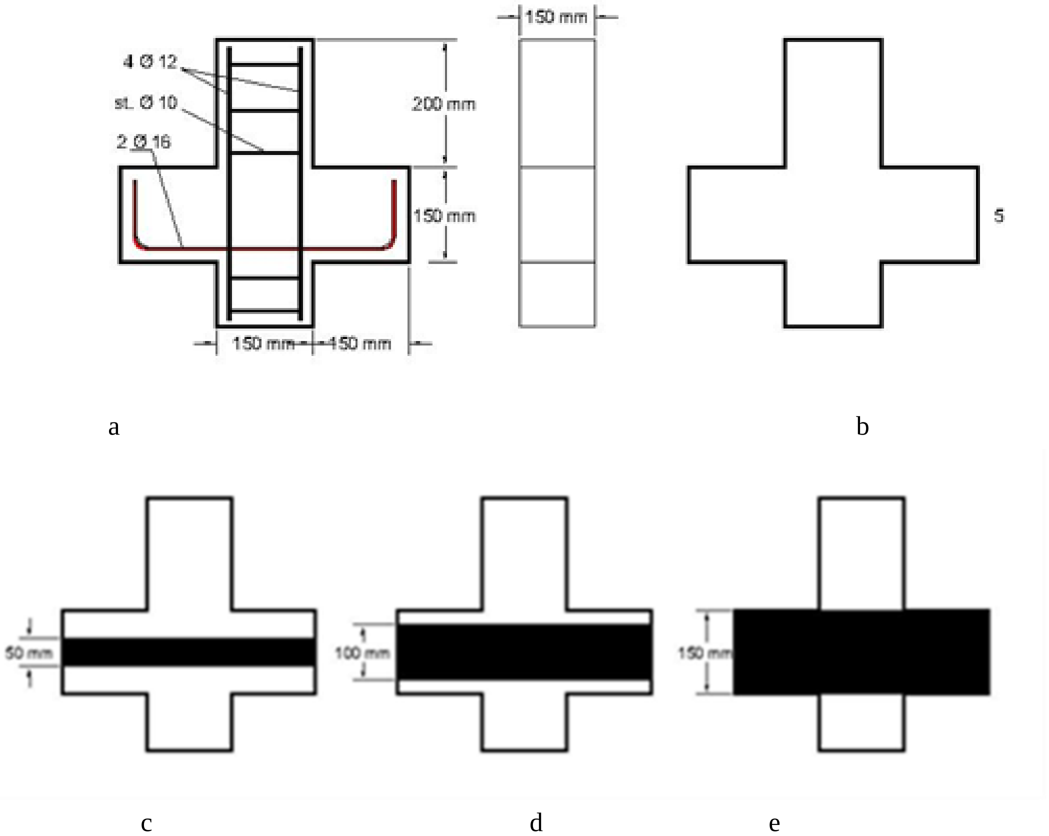


Figure 1. (a) Geometry and reinforcement detail (b) reference specimen (c) 1/3 height CFRP strip (d) 2/3 height CFRP strip (e) full height CFRP strip

2.3 Testing procedure

All corbels were tested using a 1000 kN capacity displacement-controlled flexural test servo-hydraulic machine. The load was applied gradually to failure, and the recorded reading was represented by the applied load and displacement of cantilever parts in both directions. The load and displacement were recorded simultaneously using a sensitive load cell and LVDTs by a datalogger. The test is conducted with a displacement rate of 0.2 mm/min and the load is applied at a span 100 mm. Figure 2 illustrates the installation of the specimen in the testing machine.

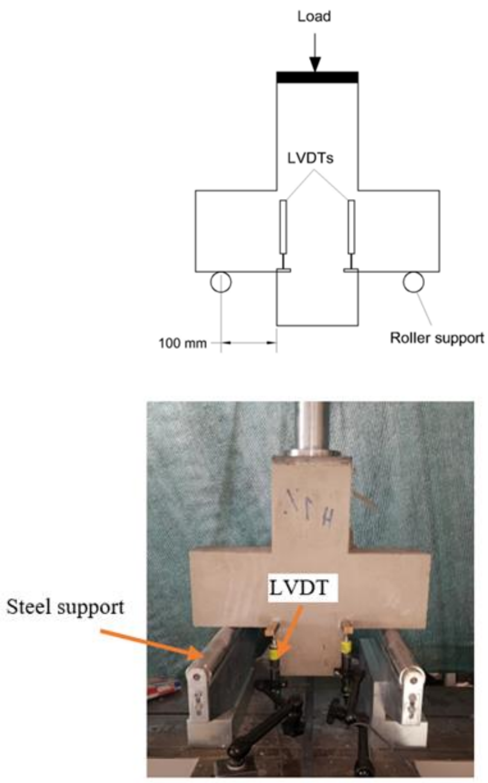


Figure 2. Installation of corbels during test

3. Results and discussion

The results represented by the applied load divided by two to determine the shear strength capacity for each side of the cross shape and the displacement which took the average reading of two LVDTs until shear crack appeared. The discussion of the results focuses on load-displacement response, the influence of the size and location of CFRP, and the number of layers of CFRP. Table 3 presents the results of the tested specimens in terms of material properties, strength capacity, displacement, and failure mode.

4.1. Load displacement response

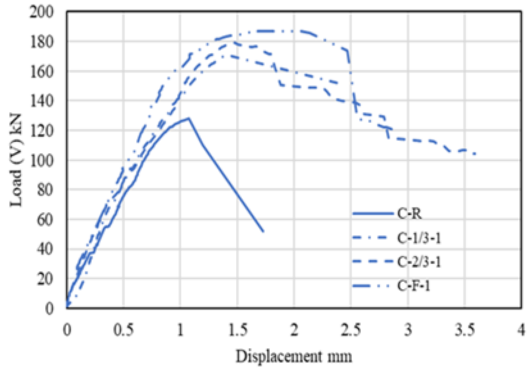
Figure 3(a-d) illustrates the load-displacement response of the tested corbels, where the load represents the shear force for one leg of cross-shaped corbel at the support and the displacement is the vertical movement for the support. All curves were initiated straight and became curved with increasing load increment until failure was reached. Then, the curve toward down with increasing displacement after peak load capacity.

Figure 1(a) shows the comparison of the control corbel and the corbels strengthened by one layer of strip in height (1/3, 2/3 & full) of the corbel depth, the curves explain that using CFRP increases the strength capacity and the stiffness of the corbel, the most prominent observation in these curves is the stiffness of the corbel increases with height of CFRP. In Figures 1(b, c &d) no significant difference was observed in strength capacity when the number of layers is doubled. Whilst the stiffness of the curve increased with layers and the displacement at the failure point decreased especially in fully strengthened corbel C-F-2, the reason is the fiber in the lower edge in the flexural zone and bearing flexural tensile stress. In general, the curves with CFRP-strengthened corbels became more ductile and have more toughness energy.

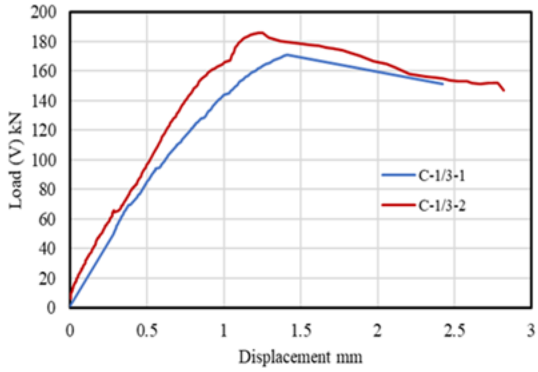
4.2 Shear strength capacity

Table 3 illustrates the outcomes of each corbel tested in the laboratory. The strengthened corbels by CFRP showed increases in shear capacity compared to reference corbel (C-R), the percentages of increase for (1/3, 2/3 & full) height strip were (33.6, 39.8 and 46.25) %, respectively. In the case of comparison between the size of CFRP, becomes clear that the efficiency of the CFRP is higher when being in the neutral axis of the cross section, where the increase in strength capacity was not linear with the quantity of CFRP used. Moreover, the second layer of CFRP was more efficient in (1/3) height where the strength capacity was raised to 45.3%, while the second layer did not provide efficiency when applied in (2/3) height.

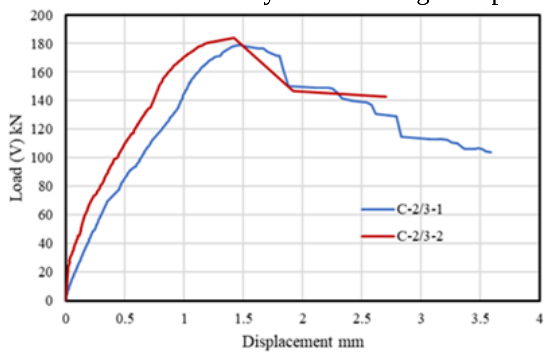
Figure 4 shows the influence of layers on the shear capacity of strengthened corbels for different sizes of CFRP. The efficiency of the second layer relatively is higher in the 1/3 zone and did not show any improvement in the second third because the strips failed in debonding in both single and double layers. In general, the second layer was not as efficient as the first layer because failures occurred in the bonding between the CFRP and the concrete before the double layers reached the maximum strength of CFRP materials.



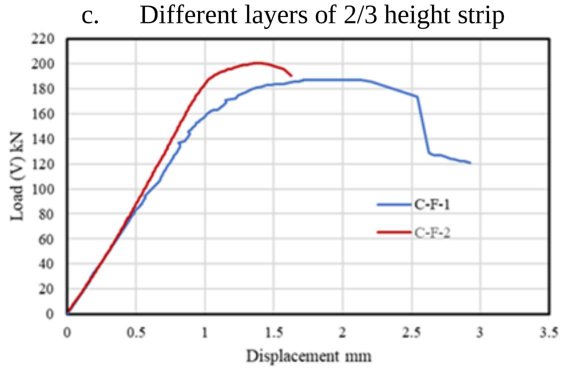
a. Control specimen with different strip strengthening



b. Different layers of 1/3 height strip



c. Different layers of 2/3 height strip



d. Different layers of full-height strip

Fig. 3 Load-displacement response

4.2 Shear strength capacity

Table 3 illustrates the outcomes of each corbel tested in the laboratory. The strengthened corbels by CFRP showed increases in shear capacity compared to reference corbel (C-R), the percentages of increase for (1/3, 2/3 & full) height strip were (33.6, 39.8 and 46.25) %, respectively. In the case of comparison between the size of CFRP, becomes clear that the efficiency of the CFRP is higher when being in the neutral axis of the cross section, where the increase in strength capacity was not linear with the quantity of CFRP used. Moreover, the second layer of CFRP was more efficient in (1/3) height where the strength capacity was raised to 45.3%, while the second layer did not provide efficiency when applied in (2/3) height.

Figure 4 shows the influence of layers on the shear capacity of strengthened corbels for different sizes of CFRP. The efficiency of the second layer relatively is higher in the 1/3 zone and did not show any improvement in the second third because the strips failed in debonding in both single and double layers. In general, the second layer was not as efficient as the first layer because failures occurred in the bonding between the CFRP and the concrete before the double layers reached the maximum strength of CFRP materials.

4.3 Failure Mode

All tested specimens in this study were designed without transfer shear reinforcement to investigate the influence of strengthening in shear. Therefore, whole corbel specimens collapsed in shear where the diagonal crack of shear appeared suddenly as shown in Figure 5. The control specimen without strengthening collapsed directly when achieved the maximum resistance. The other specimens that were strengthened by CFRP also failed in shear with ductility in strength reduction beyond the maximum load. Whenever the CFRP showed different actions between the tested specimens. A single layer of CFRP ruptured in specimen C-1/3-1 parallel with a diagonal shear crack, and the same size strip failed in debonding when applied double layer in the same zone. Two specimens of 2/3 height of CFRP in single and double layers were collapsed by debonding between the strip and concrete, what was observed during the test the debonding happened gradually and the specimen took redistribution for stresses which granted ductility in load-displacement curves. CFRP in the single layer that was fully strengthened was ruptured from the lower fibers in the flexural zone, and the corbel broke suddenly along the diagonal shear crack.

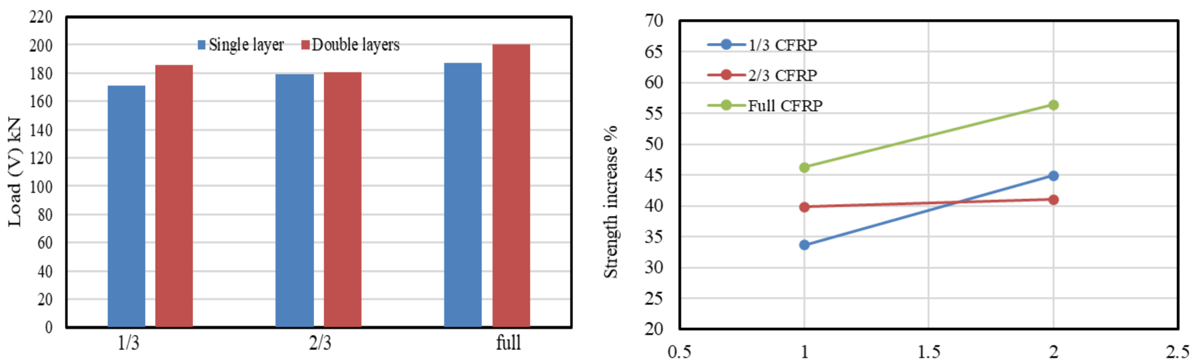


Fig. 4 Influence the layers of CFRP

Table 3. Results and observations of testing

ID	f_c' MPa	f_t MPa	Load (V) kN	Deflection mm	Failure mode	CFRP failure
C-R	36.5	3.68	128	1.075	Shear	---
C-1/3-1			171	1.41	Shear	Rupture in shear
C-1/3-2			185.8	1.22	Shear	debonding
C-2/3-1			179	1.48	Shear	debonding
C-2/3-2			180.5	1.19	Shear	debonding
C-F-1			187.2	2.034	Shear	Rupture in flexural
C-F-2			200.2	1.42	Shear	debonding

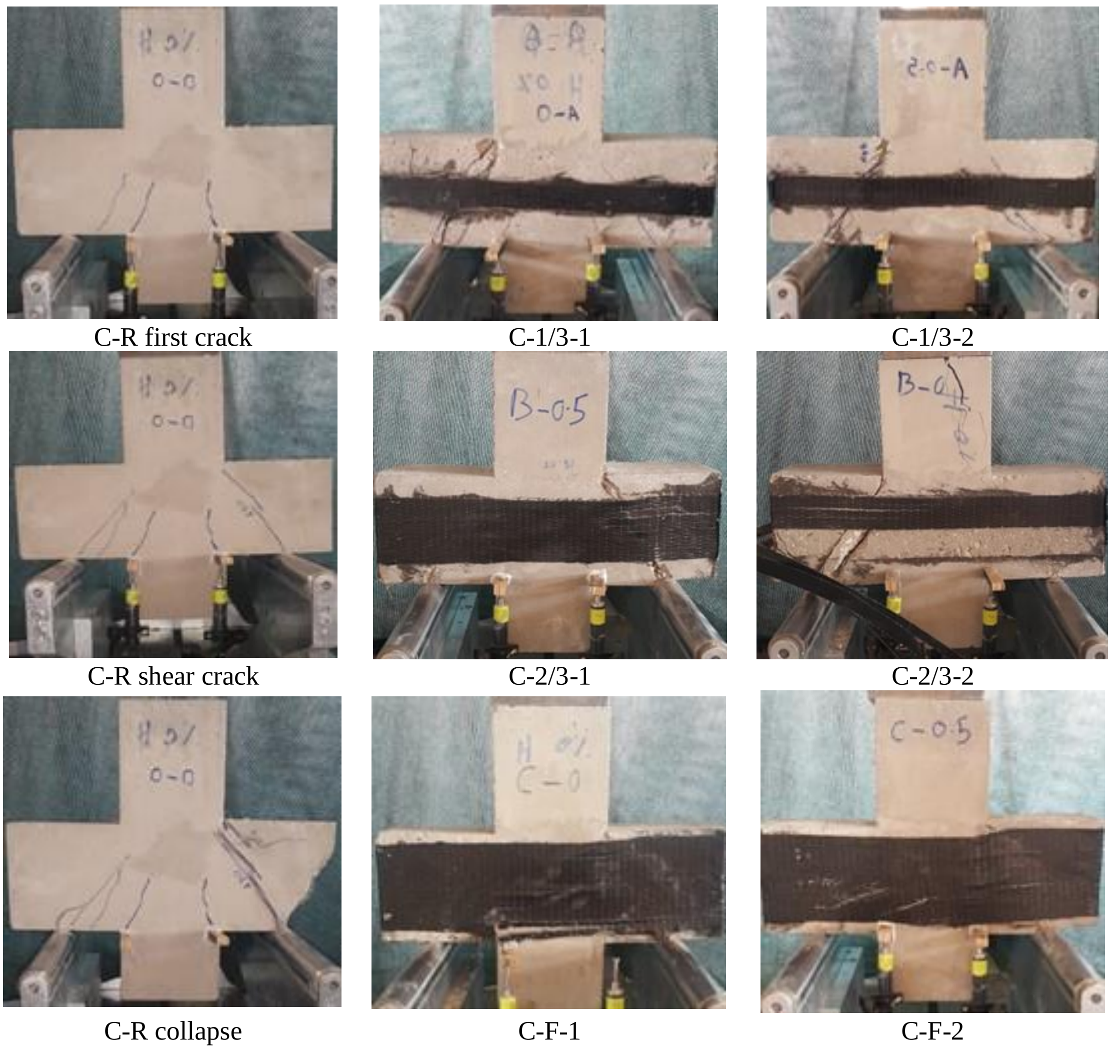


Fig. 5 Failure shape of tested specimens

5. Conclusions

This study investigated the influence of CFRP geometry on strengthened corbels with different CFRP sizes and laminated layers. Seven specimens were designed and tested for failure in shear. The distinguished outcome of the study can be listed as follows:

The most interesting observation is that the position of CFRP application is the most important factor that plays an active role in strengthening efficiency.

1. In general, the corbels that were strengthen by one layer of strips in height (1/3, 2/3 & full) of the corbel depth, the curves explain that using CFRP increases the strength capacity and the stiffness of the corbel.
2. The third middle strip gave the highest relative efficacy in strength compared to other sizes of strips.
3. The ultimate shear capacity improved by (33.6, 39.8, and 46.25) % when using (1/3, 2/3 & full) height strips of CFRP, respectively.
4. The second layer of CFRP was more efficient in (1/3) height where the strength capacity was raised to 45.3%, while the second layer did not provide efficiency when applied in (2/3) height.
5. In general, the second layer was not as efficient as the first layer because failures occurred in the bonding between the CFRP and the concrete before the double layers reached the maximum strength of CFRP materials.

CFRP strips were failed in three modes; rupture in shear for specimen C-1/3-1, bonding failure for specimens (C-1/3-2, C-2/3-1, C-2/3-2 and C-F-2) and rupture in flexural and debonding for specimen C-F-1.

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