INFLUENCE OF FABRICS LAYERS ON STRENGTHENED REINFORCED CONCRETE SHORT CORBELS

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ABSTRACT

The present paper investigates the experimental study of strengthening reinforced concrete short corbel by bonding composite carbon fiber fabrics, including the local and global strain distribution, load-carrying and mode of failure. The influence of some parameters on mechanical behavior of strengthened structure is examined, as such as, carbon fiber fabric effect with different number of layer, type of strengthening effect by gluing directly carbon fiber fabrics on concrete corbel or by wrapping. The ultimate strength and displacement of the specimen are compared to the reference structure under monotonically increasing static bending load. The cracking and failure mode are presented.

Keyword: Strengthening, Short Corbel, Reinforced Concrete, Composite Materials, Damage, Mechanism of Crack and Break.

1. INTRODUCTION

Indeed, reinforced concrete short corbels often are used in civil engineering, in buildings or structures. Corbel is one important element of steel or concrete structure to support the pre-cast structural system such as pre-cast beam and pre-stressed beam. Many concrete structures no longer meet the current safety standards or have excessive cracks. Steel corrosion may also cause occurrence of high deflection or instability of structure itself. It is generally manifested by poor performance under service loading in the form of excessive deflections or cracking. Sometimes, even by inadequate ultimate strength.

The use of composite materials is alternative to carry out a program of strengthening [1] was much more attractive. Maintenance of civil engineering works is to protect them by ensuring better sealing or limiting corrosion, to repair them by trying to compensate for the loss of rigidity and resistance to cracking due to strengthening and improve performance and durability of structures.
The problem of increasing concern since the cost of new structures is becoming higher and repair conditions increasingly difficult [2].

In this paper, the structure is a reinforced concrete short corbel. The corbel is cast monolithic with the column element or wall element. Corbel is reinforced concrete member [3], who is a short-haunched cantilever used to support the reinforced concrete structural element. It is interesting to study the mechanical behavior of this very short element of the structure (corbel) using carbon fiber materials [4]. Most of the existing research [5],[6]and[7] discussed mechanical behavior of strengthened reinforced concrete corbels.

2. EXPERIMENTAL RESEARCH

2.1 Geometric description of test specimens

The test specimen represents a column supporting two short trapezoidal corbels cantilevering on either side was 150 by 300mm in cross section and 1000mm long. Corbels had cantilever projection length of 200mm, with thicknesses of 150mm at both faces of column and free end. Details and dimensions of corbels are shown in figure 1. All reinforced concrete corbel specimens have the same dimensions and are reinforced alike. The specimens were tested using a single patch load with a shear span to depth ratio a/d equal to 0.45 (a is distance of the embedding section at the bearing point and d is the height of the corbel to steel tie rod point).

![Test Specimen](a) Steel reinforcement; b) Details of corbel geometry)

2.2 Materials properties

The eight test specimens were made in Laboratory of Civil Engineering, URCA, France. Normal strength concrete materials are rolled gravel dried sand and ordinary Portland cement. The cement:sand:gravel proportions in the concrete mix were 1:1.73:2.93 by weight and the water/cement ratio was 0.50. Portland cement type CEM II was used and the maximum size of the aggregate was 12.5 mm.

The concrete cubes were cast and tested at 28 days of age by compressing test. The steel specimens are characterized by simple testing tensile. The stress f_c, f_u, the modulus of elasticity E_s and Poisson ratio values are in Table 1.
### Table 1: Properties of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (GPa)</th>
<th>Strength (MPa)</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>30±2</td>
<td>33,2±2 (f_{c})</td>
<td>0.25</td>
</tr>
<tr>
<td>Steel bar</td>
<td>200±1</td>
<td>610±10 (f_{u})</td>
<td>0.30</td>
</tr>
<tr>
<td>Adhesive</td>
<td>4.1±1</td>
<td>36±1 (f_{u})</td>
<td>0.41</td>
</tr>
<tr>
<td>CFRP fabric*</td>
<td>86±1</td>
<td>1035±63 (f_{u})</td>
<td>0.45</td>
</tr>
</tbody>
</table>


The glue used for the CFRP fabric bonding technique are generally two part systems, a resin and a hardener, and when mixed. Only unidirectional fibers is used. The experimental results obtained for adhesive and carbon composite unidirectional is showed in table 1. The CFRP fabric have a linear elastic behavior up to failure.

#### 2.3 Preparation of the surface

The surface preparation was of primary importance and calls for care (figure 2). Preparation of the concrete surfaces must be carried out to remove any loose or weak material, oil, grease etc... In this case grit blasting was being the good method. The four corners of the corbel are rounded to reduce the decrease in strength and to prevent tearing of the composite material. Preparation of surface should be carried out just prior to the bonding operation to prevent any contamination. After, the contamination can be avoided by applying the glue to the concrete and carbon fiber fabrics is applied with the brush. The concrete surface has already become roughened and then leveled before sticking on the wraps using epoxy adhesive. Pressure must be applied to squeeze out excess glue and held the plate in place until the glue has hardened. Resin and hardened glue is just mixed before the gluing operation.

![Figure 2: Surface of Corbel blasting](image)

#### 2.4 Strengthening configurations

From the large amount of obtained data from tests, only typical data are reported here. The following classifications have been made according to the number of laid layers. Test specimens were strengthened with externally bonded CFRP fabric in horizontal form (front and rear face) and in wrapping form.

The control specimen without strengthening is denoted “C0”, the letter “C” means the Corbel, zero 0 indicate without strengthening.
The name of strengthened test specimens is made as follows: The first letter "C" is, as previously, Corbel, and the second letter represents the type of strengthening (e.g.: P for Plate, B for Bandage). Then, digit indicates the number of layers (e.g.: 1, 2, 3, 5) and finally, the small letter indicates the type of composite material (e.g. u for unidirectional).

Test specimens were strengthened with externally bonded CFRP fabric to front and rear face of the corbel (CP1u; CP2u; CP3u), with externally horizontal wrapping around entire corbel (CB1u; CB2u; CB3u; CB5u). The widths were extended 150 mm cemented to the corbel face. A specimen was strengthened with unidirectional CFRP fabric in which the fibers resist the applied load.

2.5 Testing procedure

All the corbels are tested under tree-points load (figure 3a). At each test, concrete strain distribution, strain of CFRP fabric and cracking are noted. Concrete, CFRP fabric and steel strain were measured at embedding section (where the deformations are high) with strain gauges. The specimen is submitted to a vertical load equivalent to the response of the bearing which is half of the load jack. All tests are performed with a loading speed average of 0.2 kN / s. The registration system "system Vishay" data is recorded every 0.1 seconds (fig.3b).

![Figure 3: Bending device for strengthened reinforced concrete corbel](image)

(a) Test Specimen. b) Vishay data acquisition chain

3. RESULTS AND DISCUSSIONS

From the large amount of data obtained from the tests, only typical data are reported here. Comparable shear behavior, including the cracking pattern and failure mode were recorded for the test specimens considering the strengthening adopted method.

3.1 Effect of Strengthening of reinforced concrete short corbel

Test specimens were strengthened with externally bonded CFRP fabric on front and rear face. The wraps were extended 150 mm cemented bonded to front and rear face. The specimens were tested to show the CFRP fabric effect on ultimate loads.

Eight concrete corbels were tested. Seven strengthened with carbon fiber fabrics and one control specimen. Three strengthened by bonded to front and rear face at reinforced concrete corbel and four were strengthened with different CFRP fabric layers by wrapping respectively, one, two, three and five layers. The results show an increase in the load of 35 to 82% with a rupture of the CFRP fabric for one layer.
3.2 Carbon fibers fabrics bonded to front and rear face

In this part of test, specimens were strengthened with externally bonded CFRP horizontal to front and rear face to corbel specimens. The height of carbon fiber fabric was 150 mm. Different layers of fabric are used. In Table 2, the ultimate loads of strengthened reinforced concrete corbel, are noted. The results show an optimum value of carbon fiber fabric thickness to 2mm. Beyond the second layer of carbon fabric thickness, there is a peeling of fabric. This phenomenon is accentuated even more when the carbon fabric thickness increases, so the efficiency of the strengthening is limited by two layers.

Table 2: Influence of number of carbon fiber fabric layers (n= number of layers)

<table>
<thead>
<tr>
<th>Configuration of concrete corbels</th>
<th>2F_c(kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0 without strengthening</td>
<td>357</td>
</tr>
<tr>
<td>CP1u strengthening by fabrics (n=1)</td>
<td>532</td>
</tr>
<tr>
<td>CP2u strengthening by fabrics (n=2)</td>
<td>552</td>
</tr>
<tr>
<td>CP3u strengthening by fabrics (n=3)</td>
<td>380</td>
</tr>
</tbody>
</table>

3.3 Carbon fibers fabrics bonded by wrapping

This group of test specimens was strengthened with externally bonded CFRP horizontal by wrapping. The height of carbon fiber fabrics was 150 mm wrapping all-around to corbel specimens. Different layers of fabric are used. The results show the optimum value from the third layer after from which there is a slight decrease of the maximum tensile strength. The composite sheet 3mm (three layers of fabric) provides the ultimate optimal loads of strengthening reinforced concrete short corbels. In addition, the ultimate maximum load decreases as the thickness of the CFRP fabric increases. When the thickness of the carbon fabric is high, the CFRP fabric becomes more rigid and causes damage to prematurely concrete corbel. The stiffness of the increases as the fabric thickness increases. The rigidity was significantly reduced about one-thirds.

Table 3: Influence of number of carbon fiber fabric layers

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<tr>
<td>C0 without strengthening</td>
<td>357</td>
</tr>
<tr>
<td>CB1u strengthening by bandage (n=1)</td>
<td>488</td>
</tr>
<tr>
<td>CB2u strengthening by bandage (n=2)</td>
<td>508</td>
</tr>
<tr>
<td>CB3u strengthening by bandage (n=3)</td>
<td>651</td>
</tr>
<tr>
<td>CB5u strengthening by bandage (n=5)</td>
<td>626</td>
</tr>
</tbody>
</table>

3.4 Mechanics behavior of strengthened reinforced concrete corbel

Local behavior investigation by using the strains gauges to measure deformations in the steel, concrete and carbon fiber sheets is investigated. In this investigation, deformations, cracking and ultimate failure are studied. The result of extensometer technique based on deformation gauges, strain versus applied load used to study the local behavior of structure. Strains were measured by strain gauges of 120 Ω and gauge factor 2.09. The strain gauges are attached to each of the experimental specimen. Precision strain gauges length of 5 mm are used to measure the strain on the main steel reinforcement as well as horizontal frame, steel tie rod placed along the tensile and the compression strut. The curves \( F = f(\varepsilon) \) describing the local behavior of the CFRP fabric, steel and concrete material is presented (\( F \) is the applied load and the strain \( \varepsilon \) indicated by gauge located at \( x \)). The change of slope \( dF/d\varepsilon \) corresponds
to the appearance of micro cracks or a change of state. The change of sign of \( dF/d\varepsilon \) corresponds to the initiation of rapid crack propagation around of ultimate failure of the structure.

It appears three main fields: the elastic field, field cracking and recovery loading by the steel bar, and the last field of rapid crack propagation until the sudden rupture of the specimen. The results show in figure 4 an increase more than 82% of the maximum load when the reinforced concrete corbels were strengthened by gluing carbon fabrics. From these curves, there are three main domains:

- Elastic Domain until the appearance of cracks
- Crack and Propagation Domain, absorbing load by steel tie rods and the carbon fiber composite plate, marked especially by the appearance of an oblique crack
- Unstable Domain which causes the corbel collapse.

**Figure 4:** Load-strain curves by means of strain gauges bonded on steel tie rod of unstrengthening and strengthening reinforced concrete corbels.

The rigidity is improved by strengthening. There are renewed strength as gauge indicates the two stuck on the drawing from 360kN. The particular configuration of corbel indicates the occurrence of the opening and the diagonal crack. The results showed that the bonding sheet to the tensile face of the concrete beams has a greater effect on the first visible crack load. The load to create the first crack for strengthened beams was about 1.5 times greater than the control specimen.

### 3.4.1 Specimen C0, without CFRP

This specimen was tested as « Control specimen ». Figure 4 shows the local deformation of the steel rods. The first major crack appeared at 130 kN and she was a vertical crack appearing approximately at the corbel face close to the column side. The other crack was a diagonal crack almost at an angle of 45 degrees, this was at a load level 35% of the ultimate failure load diagonal shear cracks formed at a load level of 240kN. As the load increased, this crack started to widen and propagated leading to failure. The maximum applied load was 357kN.
3.4.2 Effect of carbon fiber fabric layer on strengthened corbel to front and rear face

Figure 5 shows strain curves of the tested concrete - CP1u, CP2u and CP3u and their behavior during loading. The first cracks for specimen CP1u, CP2u and CP3u were respectively 140 kN, 145kN and 145kN, but they are very small compared with the first crack in the control corbel and they are not seen.

Actually in these three reinforced corbels, it is observed only one major diagonal crack appeared at a load level of 246 kN, 325 kN and 310 kN respectively for specimen CP1u, CP2u and CP3u. Ultimate load increased to 532 kN, 552 kN and 380 kN.

Three specimens are shared similar failure patterns. Significant increase in the corbel deflection was observed near failure as shear strain became dominant once the governing inclined crack has being developed. The strain of flexural main steel markedly increased at this step of loading. The ultimate loads of failure are significantly different because when CP3u observed debonding of composite material, while CP1u observed splitting.

This strengthening method showed the ultimate load in the specimen CP2u. In section cracks in figures 5 illustrate the load-strain curves of strain gauges of the composite plate and concrete of strengthened reinforced concrete short corbel as CP1u, CP2u and CP3u.

Specimen CP2u similar failure patterns. Flexural cracks were observed first, at approximately a load level 145 kN and then a few diagonal cracks were observed. With increasing load the flexural cracks grew upward and became wider. The first major crack appeared at a load level of 325 kN and ultimate load increased to 552kN. The figure 5 shown curves of load-strain relationship for corbels CP1u, CP2u and CP3u.

Figure 5: Comparison of load-strain relationship for corbels C0, CP1u, CP2u and CP3u

3.4.3 Effect of carbon fiber fabrics layers on strengthened corbel by wrapping

The figure 6 shows the comparison of curves obtained by gauges “G1” (steel tie local deformation) for four different corbels. These curves are compared to reference reinforced concrete corbel without strengthening. The results show that curves are similar and ultimate load increases with a 1/3 reduction of strains. The curve of the three layer (CB3u) presents less strain (<2000 µm/m) and highest ultimate load 651 kN.
4. MODES OF FAILURES

Specimen C0, without CFRP fabric – This specimen was tested as « Control specimen ». The ultimate load failure was 357kN. Type of failure for this corbels is classic failure shear with two major cracks, as depicted in figure 7. The first major crack appeared at 60 kN and it was a vertical crack appearing approximately at the corbel face close to the column side. The other crack was a diagonal crack almost at angel of 45 degrees with load level at 43% of the ultimate failure load. The diagonal shear crack appeared at a load level of 235 kN. As the load increased, this crack started to widen and propagated leading to failure (figure 7).

Specimen CP1u – For to enhance the ultimate load capacity this specimen was strengthened with externally bonded one horizontal strip of CFRP fabric. The first cracks are very small and are not detected. Only one major diagonal crack started at the bearing plate, and propagated towards the junction of the column and face of corbel. This crack appeared at a load of 246kN and causes failure of corbel. The corbel failed at an ultimate load of 532 kN with an increase in strength of about
(49%) compared to unstrengthened corbel specimen C0 (control corbel). The results show a rupture of carbon fiber fabrics at 532kN (figure 8).

**Specimen CP2u** - The ultimate load capacity this is specimen was strengthened with externally bonded two horizontal strip of CFRP fabric. Only one major diagonal crack started at the bearing plate, and propagated towards the junction of the column and face of the corbel. This crack appeared at a load of 325kN and causes collapse of the corbel. The corbel failed at an ultimate load of 552 kN with an increase in strength of about 55% compared to unstrengthened corbel specimen C0. The results show a specific rupture by splitting and CFRP fabric peeling off, which explains the higher value of the maximum capacity (figure 8).

**Specimen CP3u** – This specimen was strengthened with externally bonded three horizontal CFRP fabric. As with the above specimen CP1u and only one major diagonal crack started at the bearing plate, and propagated towards the junction of the column and face of the corbel. This crack appeared at a load of 310 kN and caused corbel failure. The corbel failed at an ultimate load of 380 kN. When the number of CFRP fabric increases, the rupture of corbels is caused by peeling off the strips of cloth. The accumulation of several strips of fabric on top of each other results for high thickness of CFRP fabric, the peeling off easily cannot reach to the maximum load-bearing capacity of the composite carbon fiber fabric. No apparent damage the fabric, just cracked concrete with major diagonal shear crack beneath the fabric. The concrete crack induced by debonded fabric on the front and rear face of the corbel (see Figure 8).

<table>
<thead>
<tr>
<th>Carbon fibers fabrics bonded to front and rear faces</th>
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<tr>
<th>CP1u - Fabric failure</th>
<th>CP2u - Splitting and CFRP fabric peeling off</th>
<th>CP3u - CFRP fabric peeling off</th>
</tr>
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</tr>
</tbody>
</table>

**Figure 8:** Modes of failure in strengthened corbel CP1u; CP2u; CP3u
Specimens strengthened by wrapping-.Study the effect of strengthening reinforced corbel with horizontal externally bonded carbon fiber reinforced polymer (CFRP) fabric wrapping several corbel specimens CB1u, CB2u, CB3u and CB5u with one, two, three and five layers. The failure and crack patterns of the group strengthening with externally bonded one horizontal strip of fabric shown in figure 9.

In all four cases in this group the first micro cracks started at approximately the same load between 130kN and 140kN. There is one main diagonal shear crack almost at angle 45 degrees and this crack started at the bearing point. This crack caused failure of the corbel. The corbels failed at ultimate loads were 488kN, 508kN, 651kN and 626 kN for CB1u, CB2u, CB3u and CB5u respectively. Figure 9 show different failures of corbels.

<table>
<thead>
<tr>
<th>Carbon fibers fabrics bonded by wrapping</th>
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<tbody>
<tr>
<td>CB1u- CFRP fabric failure</td>
</tr>
<tr>
<td>CB2u - Compression failure</td>
</tr>
<tr>
<td>CB3u - Shearing and Splitting failure</td>
</tr>
<tr>
<td>CB5u - Compression failure with two diagonal cracks</td>
</tr>
</tbody>
</table>

Figure 9: Modes of failure in strengthened corbel CB1u; CB2u CB3u; CP5u

5. CONCLUSION

The contribution of strengthening reinforced concrete short corbels is very significant and interesting. The result showed an increase in failure tensile strength more than 82% by bonding CFRP fabric.

This experimental study of the influence of CFRP fabric thickness showed that the plate of 2 layers of fabric bonded to front and rear face allowed to obtain an optimum value of the ultimate load. The results of strengthening by wrapping, show the optimum value from the third layer after from which there is a slight decrease of the maximum flexion strength. The thick CFRP fabric of 3mm (tree layers of fabrics) provides the ultimate optimal load of strengthened short reinforced concrete corbels. It is the optimum value from the third layer from which the ultimate load is a slight decreased. Result show that strengthening by wrapping of fabrics remains still the best configuration. The effect of the containment by wrapping provides higher values than those at which the CFRP
fabrics are glued directly on the front rupture loads. The results show also three main domains: Elastic domain, Crack and propagation domain and Unstable domain.

In conclusion, the results show 5 modes of failure. For the eight strengthened reinforced concrete short corbel, mainly the following failures are observed:

- Rupture of sheet and a rupture of the concrete layer situated between the reinforced steel and CFRP fabric.
- CFRP fabric peeling off.
- Splitting failure and Compression which often causes a tearing of CFRP fabric or the failure of rupture of the composite material.
- Failure bending strength shear whit one splitting failure.
- Failure by compression with two diagonal cracks.

REFERENCES