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# EXPERIMENTAL STUDY OF LOCAL BEHAVIOR OF STRENGTHENED REINFORCED CONCRETE SHORT CORBEL BY BONDING CARBON FIBER FABRICS

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## INTRODUCTION

Most of the structures in civil Engineering, after 50 years old, meet the current safety standards or have excessive cracks. Steel corrosion may also cause the occurrence of high deflection or instability of the structure itself. It is generally manifested by poor performance under service loading in the form of excessive deflections or cracking. The introduction about 34 years ago of composite materials in the field of Civil Engineering allows other strengthening orrepair of reinforced concrete structures by bonding composite carbon fiber fabrics (Abdul Wahab, 1989; ACI, 2000; Chris, 2007). Carbon fiber materials have many advantages (Ivanova, 2013): their weight, flexibility, implementation easier and also their physicochemical properties (corrosion) interesting. This technical of strengthening compensate the loss of rigidity and resistance to cracking due to the strengthening and improving performance and durability of structures.Corbel is one important element of structureto support the pre-cast structural system such as pre-cast beam and pre-stressed beam (Anis, 2012 and Rejane, 2005). The corbel is cast monolithic with the column element or wall element. It is interesting to study the local mechanical behavior of this very short element of the structure using carbon fiber materials (Mohammed, 2005; Futtuhi, 1987; Gampione, 2005; Erfan, 2010). This paper is mainly interested in the study of three types of reinforcement: by bonded carbon fiber fabrics, wrapping of carbon fabrics and by bonding plate in shear area, under flexural bending. Local deformation using strain gauges to measure strains in the steel, concrete and carbon fiber sheets of strengthened reinforced concrete short-corbel, is also investigated. In this investigation, deformations, cracking modes and collapse mechanism are studied.

## EXPERIMENTAL PROGRAM

This technic for carrying out such improvement was that which involved bonding of steel plates to structure surfaces. An effective way of eliminating the corrosion problem was to replace steel plates with corrosion resistance materials such as fiber composite materials.Many advantages are: low density, corrosion, mechanical properties, good resistance to fatigue and ease of handling. Materials 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. Four 200 x 200 x 200 mm3 concrete cubic were also cast and are tested when each short corbel is tested to determine the compressive strength of the concrete at 28 days of age. The glue used for the CFC sheet bonding technique are generally two part systems, a resin and a hardener, and when mixed. The elastic modulus and yield stress are presented in Table 1. Steel bars, S500 are used of different diameters: 6, 10, 14 mm. The steel specimens are characterized by simple testing tensile. The stress fu and the modulus of elasticity Es values are in Table 1. The high deformation of this steel at the failure is 11.04%.

**Table 1: Properties of Materials**

| Material | Young's Modulus (GPa) | Strength (MPa) | Poisson Ratio |
|---|---|---|---|
| Concrete | 30±2 | 33,2±2 ($f_c$) | 0,25 |
| Steel bar | 200±1 | 610±10 ($f_u$) | 0,30 |
| Adhesive | 4,1±1 | 36±1 ($f_u$) | 0,41 |
| UCFC sheet* | 86±1 | 1035±63 ($f_u$) | 0,45 |
| BCFC sheet** | 87±1 | 720±50 | 0,35 |

**Note:** * UCFC sheet: Unidirectional Carbon fiber composite sheet; ** BCFC sheet: Bidirectional Carbon fiber Composite sheet.

The unidirectional and bidirectional fibers are used. The experimental results obtained for carbon composite unidirectional are showed in Table 1. The yield strength corresponds to the tensile strength. The carbon composite sheets have a linear elastic behavior up to failure. The high elongation at failure is 0.8% for the unidirectional carbon fiber sheet and 0.5% for the bidirectional carbon fiber sheet. Table 1

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shows the characteristic properties of used composite materials. The surface preparation was of primary importance and calls for care (Figure 1). Preparation of 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 anycontamination. After, the contamination can be avoided by applying the glue to the concrete

**Figure 1: Surface Treatment by Sandblasting**

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.

**Experimental Device**

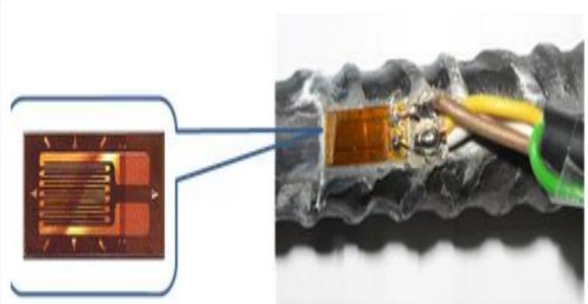
All the corbels are tested under tree-points load. The specimen is submitted to a vertical load equivalent to the response of the bearing which is half of the load jack. All tests are performed with a loading speed average of 0.2 kN/s. The registration system “system Vishay” data is recorded every 0.1 s. The load capacity of the test bending is 1000 kN.

**Electric Gauges**

We present 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

**Figure 2: Position of electric gauges on underwood of reinforced concrete corbel**

**Figure 3: Detail of bonded and welding of electric gauge**



gauge factor 2.09. The strain gauges are attached to each of the experimental specimen. Precision strain gauges length of 5 mm (Figure 3) are used to measure the strain on the main steel reinforcement (Figure 2) as well as horizontal frame, steel tie rod placed along the tension and the compression strut. The strain gauges on the face of the corbel are placed in shear span between the corbel and the column. Two of gauges length of 10 mm are placed on the composite fibers plate surface and one gauge length of 30 mm on the concrete.

**Interpretation of curves**

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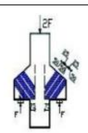
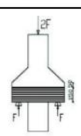
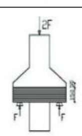
The curves F=f(ε) describing the local behavior of the composite plate, steel and concrete material is presented (F is the applied load and the strain ε indicated by the gauge located at x). The change of slope dF/dε corresponds to the appearance of micro cracks or a change of state. The change of sign of dF/dε corresponds to the initiation of the rapid crack propagation around of the ultimate failure of the structure. The control specimen without strengthening is denoted “C0”, the letter “C” means Corbel, zero 0 indicate without strengthening.For the designation of the strengthened reinforced concrete corbel, 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, wrapping). Then, digit indicates the number of layers (e.g.: 1, 2, 3, 5). Finally the small letter indicates the type of composite material (e.g. u for Unidirectional and b for Bidirectional).

## RESULTS AND DISCUSSION

From the large amount of data obtained from testing, only typical data are reported here in Table 2. This paper present the results on the type of strengthening on bending and shear, bonding directly carbon fiber fabrics on either surfaces or full wrapping of short reinforced concrete corbel. Four concrete corbels were tested. Three of them are strengthened bonding carbon fiber fabric as in Table 2 and one control specimen without reinforcing. The results show that there is a very significant increase in capacity loading for the three types of reinforcement 41 to 82%.

**Table 2: Design of Testing Specimen**

| $F_R/F_0$ | Design | Designation | |
|---|---|---|---|
| 1,41% |  | Strengthened corbel by bonded Inclined bidirectional carbon fiber fabrics on both sides | CI2b |
| 1,55% |  | Strengthened corbel by bonded unidirectional carbon fiber fabrics on both sides. | CP3u |
| 1,82% |  | Wrapping strengthened corbel by bonded composite plates on both sides. | CB3u |

**Note:** $F_R$: ultimate load of strengthened reinforcement concrete corbel; $F_0$: ultimate load of unstrengthened reinforcement concrete corbel

FR : Ultimate load of strengthened reinforcement concrete corbel. F0 : Ultimate load of unstrengthened reinforcement concrete corbel. The ultimate strength of reference corbel is F0 , equal to 357 kN. The results show an increase in the load FR /F0 to 1.41 for CI2b to 1.82% for CB3u. In the former case, the plates 45 are bonded to the sewing degrees oblique fissure. The bonded fabric of carbon fibers area represents 32.5% of corbel total area. While the second case is that of strengthening then, represents the area 51, 6%. In the latter case, the complete tire of the console, this area is 60.0%. The results show that strengthening is more effective wrapping trough the confining effect of concrete and a resumption of efforts by carbon fiber fabric. Doubling the bonding surface, the tensile strength is increased by14%. Of course, in the case of the containment, are double ultimate load. Accordingly, the test result shows, that composite plates judiciously suitable on surface more effectively, load capacity is increased. Figure 4 shows the deformation in recessed section of the corbel. Deformations are higher in the tension of the console until mid-height, so bond a plate that you can reconnect efforts more effectively. The results shown in Figure 5 the comparison of local steel deformation in cross section of strengthened reinforced concrete corbels CB3u, CP3u, CI2b and C0. Containment effect is evidenced by the reduction of deformations and a third of charge more than twice between Cb3u and C0. In the case of strengthening, CI2b configuration appears effective, insofar as crack is sewn by

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Figure 4: Local Strain of Steel in Cross Section of Reinforced Concrete Co

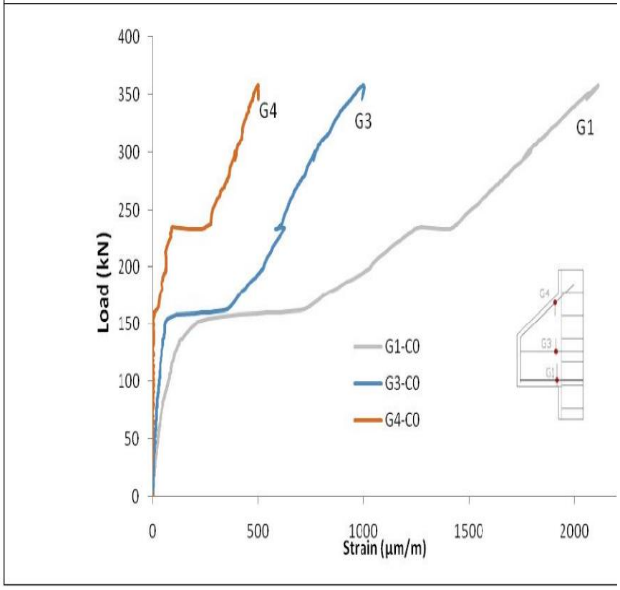
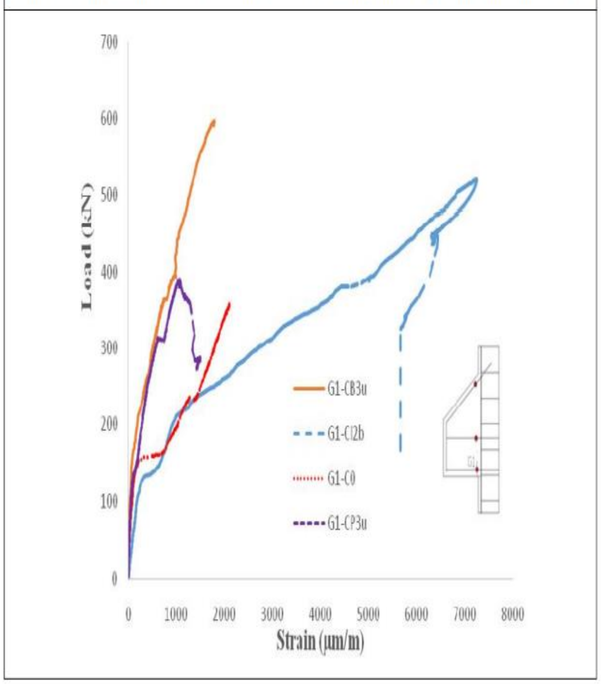



Figure 5: Comparison of Steel Strain in Cross Section (point G1) of Strengthened Corbel




bonded carbon fiber fabrics to 45°. Confinement effect disappears as in the other two cases. Strains are more important (~7000 μm/m). Recovery strengths in the tie rod steelcauses a local yielding which causes high deformations. Strengthened reinforced concrete corbel by bonded carbon fiber fabrics trips to 45° has a ductile mechanical behavior. However, the result that CP3u shows a similar behavior as CB3u, provided to ensure an anchor to prevent detachment of the plate

**Specimen CP3u**

This specimen was strengthened with externally bonded tree horizontal fabric strip. There is 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 appears at a load of 310 kN and causes failure of the corbel. The corbel failed at an ultimate load of 380 kN. When the number of fabric strips is increased, the ultimate deformation of the corbel is caused by peeling off the strips of cloth. The accumulation of several strips of fabric on top of each other results in a thickening of the layer as a whole, and therefore, they peel off easily and cannot reach to the maximum load-bearing capacity of the composite. There was no apparent damage to the fabric, just concrete cracked major diagonal shear crack beneath the fabric. The concrete crack caused of debonded fabrics on the front and rear face of the corbel.

**Specimen CB3u**

First flexural cracks appear at 140 kN and then appearance of the bearing at 365 kN. Probably the appearance of diagonal cracks plays a lot because of the positive move in after the landing. It 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 third reduction of deformation. The failure and crack patterns of the group strengthening with externally bonded one horizontal strip of fabric. In all four cases, first micro cracks is started at approximately the same load between 130 and 140 kN. There is one main diagonal shear crack almost at an angel 45 degrees and this crack is started at the bearing plate. This crack caused failure of the corbel. Corbel failed at ultimate loads at 651 kN.

**Specimen CI2b**

First flexural cracks appear at 116 kN. As with the above specimen CP3u, there is only one major diagonal crack started at the bearing plate, and

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propagated towards the junction of the column and face of the corbel. This crack appears at a load of 380 kN and causes failure of the corbel. The corbel failed at an ultimate load of 520 kN. There was no apparent damage to the fabric, just concrete cracked major diagonal shear crack. The collapse of CI2b is appeared by Shear failure diagonal crack of CFRP fabric

**Position of the Neutral Axis**

Concrete surface strains at a section close to column face of the tested corbels were measured by using three strain gauges over the depth of the corbel. Figures.6 and 7 show the concrete strain distribution over the corbel depth for all corbels at different load levels. In these figures, it can be seen that the strain distribution was approximately linear in tensile and compressive zones at low load levels, and then became increasingly nonlinear at the tension zone at higher loads due to cracking effect.For all tested corbels, the neutral axis was shifting upwards after increasing the load beyond than the load at first crack. The position of the neutral axis for small load (10 kN) is about 15 cm, for which reason the width of the plate is less than or equal to this value.

**Modes of Failure**

The results, as shows in Figure 8(a), 8(b), 8(c) and 8(d), distinguished mainly three types of failure: flexion failure, shear and fabrics peeling off and compression failure. Although, CI2b and C0 were the same rupture, noted that cracking

**Figure 6: Position of Neutral Axial Versus Applied Loa**

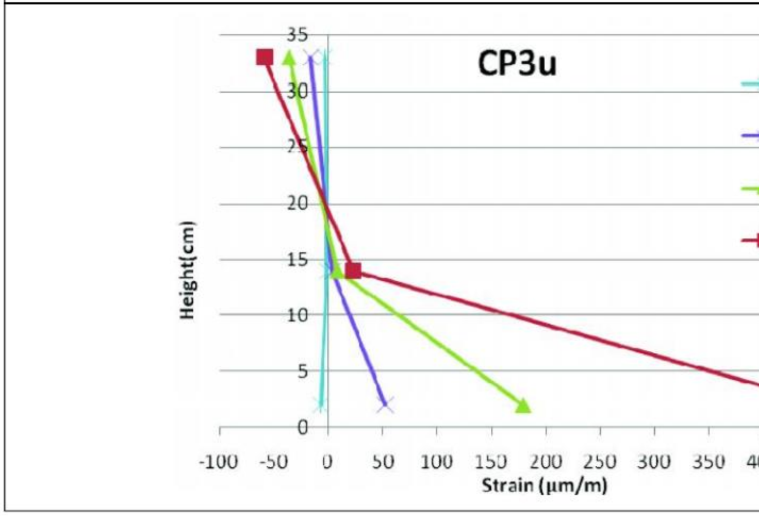
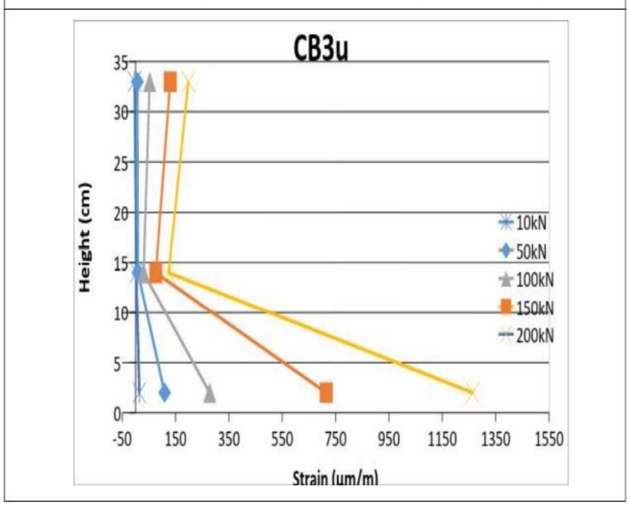



**Figure 7: Position of Neutral Axial Versus Applied Load for CB3u**



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a) C0 : Flexion failure

b) CB3u : Compression failure

c) CP3u : Shear collapse with fabrics peeling off


was different with appearance of a slight compression in CI2b.

## CONCLUSION

The contribution of strengthening reinforced concrete short corbels is very significant and interesting. Result shows an increase in failure tensile strength more than 1.82 by bonding carbon fiber fabric. The bonding composite carbon fiber fabrics slightly changes the position of neutral axis. But for loads

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less than 150 kN, the strain distribution in cross section appears linear. Beyond this value, the strain distribution is nonlinear as in Figure 6 and 7. Result show that strengthening by wrapping remains still best configuration. Effect of containment by wrapping provides higher values than those at which the plates are glued directly on the front breaking loads. Corbel CI2b the configuration presents a ductile behavior and avoids the sudden shear failure of unstrengthened reinforced concrete corbel. There are mainly three types of strengthened reinforced concrete corbel failures: flexion failure, shear and fabrics peeling off failure, compression failure with two diagonal cracks, figure 8. This article shows that it is possible to enhance or repair a reinforced concrete structure by bonding composite carbon fiber plate. This technique provides better stress distribution and implementation easier even if it requires careful preparation.

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