COMPOSITE MATERIAL IN REPAIR OF REINFORCED CONCRETE STRUCTURES

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Abstract

This paper presents an experimental study of damaged reinforced concrete structures strengthened by gluing carbon fibers composite fabrics. This study is especially interested in repairing reinforced concrete beams and corbels by bonding composite materials. The purpose of the investigation was to better understanding the material behavior of strengthened damaged structures and fatigue effect on strengthened structures.
Five of each of reinforced concrete corbels and beams are tested under three-points bending to failure. Four of each are damaged at different load level up 80% before strengthening. The reinforcement by gluing the unidirectional carbon fabrics was subjected. Test results show that strengthened specimen using adhesive material indicated an interesting way to significant member performance. This paper shows it would be possible to reinforce structures (beam and corbel) up to 80% of mechanical damage. The results show an increasing of load up 50%. Cracking of beam and corbel are presented with different failure modes. The ultimate load and strain of the specimens are compared to the reference specimen. Carbon fabrics gluing technics could be a convenient and effective method of strengthening of concrete structures in which epoxies and level load steel bar plaid a major role.
A theoretical analysis describing behavior of strengthened damaged concrete structures using the damage theory was proposed.

1. Introduction

Many of these concrete structures no longer meet the current safety standards or have excessive cracks. Steel corrosion, concrete carbonation, 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 sometimes, even by inadequate ultimate strength.

According to the European standard (BS EN 1504-9), the main causes of deterioration of reinforced concrete and reinforcement are: mechanical damage, chemical attack, physical deterioration, degradation frames, and improper repairs. Concrete are then subjected mechanical-type attacks.

The introduction of composite carbon fiber in the 1980s in the field of Civil Engineering helps strengthen or repair structures in concrete or reinforced concrete with adhesive. Carbon fiber materials have many advantages: their weight, flexibility, implementation easier and also their physicochemical properties (corrosion) interesting.

Maintenance of civil engineering works is to protect them by ensuring better sealing or limiting corrosion, to repair [1-3] them by trying to compensate for the loss of rigidity and resistance to cracking due to the strengthening and improving performance and durability of structures. This technic carries out a program of strengthening reinforced concrete corbels [4-5] was much more attractive.

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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. The corbel is cast monolithic with the column element or wall element. It is interesting to study damage and mechanical behavior of this very short element of structure reinforced by gluing carbon fiber materials [6-9]. The costs of these materials become available [10-12].

The parameter study is conducted to examine the effects of design on ultimate load, cracking and collapse mechanism under flexural bending. Local behavior investigation by using the deformation gauges to measure strains in the steel, concrete and carbon fiber sheets is investigated. In this investigation, damage effect on ultimate load and deformations, cracking and ultimate failure are studied.

2. Experimental program

2.1. Test specimens

All the beams were tested in four point bending over a span of 2400 mm (fig. 1), giving constant bending moment over the middle third of the span. Load was applied in equal increments and at each increase, readings were taken of the strains on concrete surface, CFC sheet and internal bars. The readings were measured at midspan of the beams. The deflection was obtained by installing a displacement captor at center of the specimen.

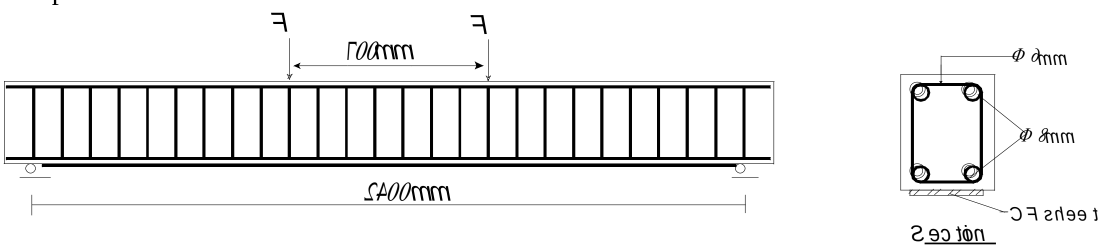

Figure 1: Details of strengthened reinforced concrete beams

The beams A2, A3, A4 and A5 were first damaged at various loadings, 40 %, 55 %, 70 %, 80 % relatively of ultimate force causing failure of the beams shown in figure 2. After this operation, damaged beams were strengthened and tested.

First, the reinforced concrete corbel model ensures a right anchor sufficient given the length of post section, and secondly a better symmetry tensile forwarded to corbels. Indeed, it facilitates the testing device.

Five strengthened or repaired reinforced concrete corbels were tested. One is corbel reference without strengthening. The second reinforced concrete corbel was strengthened by bonded carbon fibres composite materials. Then the other three are damaged at 30%, 60% and 80% of the maximum ultimate tensile stress, (fig.2).

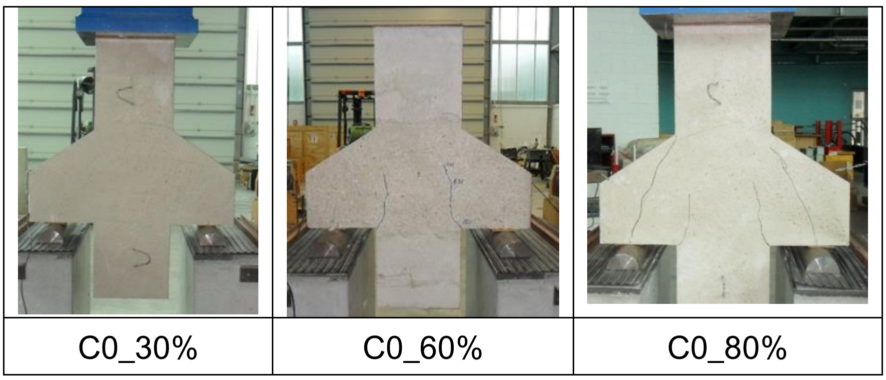

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Figure 2: Comparison of load-deflection behavior of strengthening injured beams

2.2. Materials

The experimental results obtained for carbon composite unidirectional and bidirectional are showed in Table1. 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 and the other characteristic properties of composite materials are presented in Table 1.

The carbon fiber fabrics were adhered to the lower surface of the reinforced concrete structures using an epoxy resin. This technique is used increasingly in the field of civil engineering for the rehabilitation of old structures. It thus allows to increase the resistance to bending and shearing of the structures. Though of course, this approach also contributes to the durability of these structures by strengthening with respect for the environment.

Table 1. Properties of materials

Material	Young's modulus [GPa]	Strength [MPa]	Poisson ratio
Concrete	30	33	0.25
Steel bar	200	610	0.30
Adhesive	4	36	0.41
UCFC sheet*	86	1035	0.45

*UCFC sheet: Unidirectional Carbon Fibers composite sheet.

The extensometer technique based on electrical strain gauges was used to study the local behavior of the structures. This technique allows to measure the strain of steel, carbon fabrics and concrete. In fact, the load versus strain in cross section between column and corbel are plotted.

2.3. Preparation of the surface

The surface preparation was of primary importance. The concrete surfaces is 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, to smooth the corner in order to avoid stress concentrations and to prevent tearing of the composite material. Just prior to the bonding operation the corbel was cleaned with compressed air to remove any dust or other loose sediment that may have been on the bracket surface.

The concrete surface has already become roughened and then leveled before sticking on the wraps using epoxy adhesive. Was used epoxy adhesive is Sikadure-330 composed of two components laminating compound on epoxy resin. Resin components A and B were thoroughly mixed at a ratio 4:1 proportion. The resin and hardened glue is just mixed before the gluing operation, because, the pot life is not long. The greater the amount of material mixed, the shorter was the pot life. To achieve a longer pot life at high ambient temperatures, the mix may be divided into smaller units or the components cooled before mixing. The epoxy was first applied to the concrete with a brush. Then, the fabric was placed on the epoxy and a second coat of epoxy was rolled into the fabric. The fabric was wrapped completely around the corbel, and the fabric was overlapped on the face of the corbel. Pressure must be applied to squeeze out excess glue. The second strip of fabric was then applied and a third coat of epoxy was rolled into the second strip of fabric. The same operation is repeated for the third strip of fabrics. The epoxy was allowed to cure well before testing.

2.4. Testing procedure

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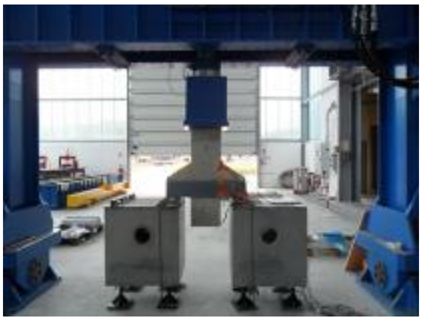
The same device such as in the case of a monotonous load is used. Figure 3 a shows the reinforced concrete corbel tested and which serves as reference for the other enhanced highlight the strengthening effect by bonding. We have an acquisition "Wishay" (fig. 3b) data of 24 ways to save local strain points wisely where are bonded strain gauges.

All the corbels are tested under tree-points load. At each test, concrete strain distribution, strain of carbon composite sheet and cracking are noted. Nonetheless, the strain of concrete, carbon fibers composite sheet and steel are measured at embedding section (where the deformations are high) using strain gauges.



a) Test specimen

b) Data recording

Figure 3 : Bending device for strengthening reinforced concrete corbel

All tests are performed with a loading speed average of 0,2kN/s. The data acquisition system called "System Vishay" is recorded every 0,1second. The maximum load capacity of the test bending is 1000kN.

3. Results and discussion

3.1 Reinforced concrete beam repairing

In figure 1, experimental results of the beam unstrengthening A0 and beam with strengthening A1 were compared. The ultimate load of reinforced concrete beam A0 was significantly increased by gluing CFC sheets on the tensile face e.g. 116%, and strengthened beams were considerably stiffer than the basic section, adhesive being the more effective. Deflection of A1 was decreased by a third.

Considering damaged beams A2, A3, A4 and A5 in figure 4, the results showed the same performance than the comparable beam without damages above 30 kN. Below this value, the behavior was bound to damaged concrete state before strengthened. The failure of all beams was obtained by a rupture of the concrete layer situated between the reinforced steel and CFC sheet.

Initial flexural cracks developed in the pure bending region of beams as the load increased. When the load was increased, flexural cracks in the pure bending region propagated, more obvious and flexural cracks were observed up to the shear region. Afterwards, when the load was added, several diagonal tensile cracks occurred in the middle of the beam on the shear span, which developed into diagonal tensile cracks at 45 degrees from the neutral axis of the beams. The diagonal tensile cracks developed simultaneously towards both the loading point and the supports. Then, a rupture of the concrete layer, situated between the reinforced steel bars and the CFC sheet, appeared. The appearance of first flexural cracks in the concrete were delayed with gluing carbon fiber sheet. The results for the beams A2, A3, A4 were not presented here, but the following general comments could be made. Damaging had little effect on ultimate load. The number of cracks was relatively insensitive to the bonding of CFC sheet. Yielding of steel bar in tensile zone was achieved before the beam failure. Type of RC beams failure changed with gluing CFC sheet on RC beams.

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So, the choice of glue was very important. The results of normal strength concrete and high strength concrete showed the same collapse mechanisms.

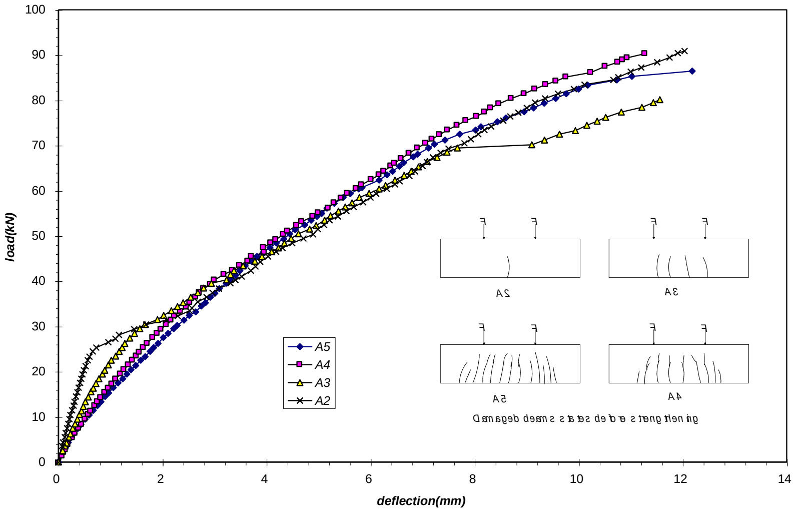

Figure 4: Comparison of load-deflection behavior of strengthening injured beams

When beams are unloaded, an instantaneous residual strain seems, still in without of load. If the test is extended by increasing the load, there was an increase of permanent deformation. At the beginning of loading, the tensile concrete, the adhesive and plate are deformed in the same way. Concrete cracking does not cause an fragile stress redistribution with a significant increase in the tensile lower frames (which blocks the opening of cracks) and the maximum compression stresses of the concrete of the upper fiber. The tensile and compression stresses remained quite low, the concrete, steel and composite plate continued to behave elastically after cracking. If discharge the reinforced beam, cracks close almost completely (fig. 5) and the deformation is canceled again. Also note that the opening of a crack resulting from either side, a progressive tearing of the armature of the concrete sleeve. Unloading, the frame is not up perfectly in his broken sheath. It remains a permanent opening

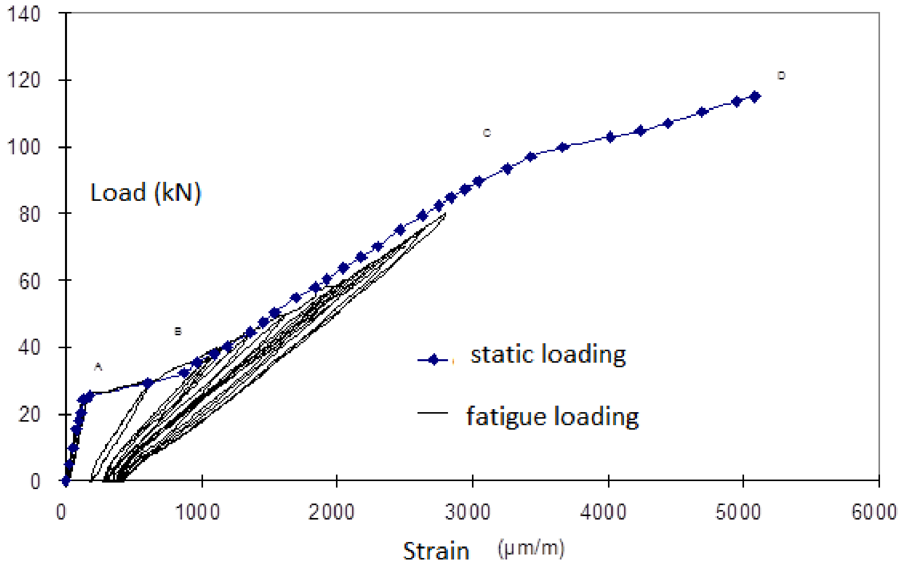

Figure 5: fatigue test on strengthened reinforced concrete beams

3.2 Corbel repair

The maximum ultimate moment of the reference reinforced concrete corbel is noted M0 equal to 26.8 kN.m. Yielding of the main reinforcement was hardly occurred at failure for all specimens. All strains were measured with strain gauges putted on steel reinforcement.

Three reinforced concrete corbels (CB3u_30%, CB3u_60%, CB3u_80%) were first damaged at various loading of 30%, 60%, 80 % relatively of the failure reference concrete corbel load. Secondly, damaged corbels were strengthened and tested. The value of corresponding load of 30, 60 and 80% are 110kN, 220kN and 331kN.

The results show in (Fig. 4) that the ultimate load of reinforced concrete corbel was significantly increased by gluing carbon fibers plates on tensile face e.g. to 82%, and strengthened corbels are considerably stiffer than the basic section, adhesive being more effective. Deflection of strengthened reinforced concrete corbel was decreased to third

The load-strain curves of steel tie and concrete in compression of unstrengthened and strengthened reinforced concrete corbels were show in (fig.6). Three main fields were found as elastic field, field cracking and recovery loading by the steel bar, and the last field of rapid crack propagation until the sudden corbel failurel.

The first major crack appeared at 130 kN and it was a vertical crack appearing approximately at the corbel face close to column side. The other crack was a diagonal crack almost at an angle of 45 degrees; at a load level of 65% of ultimate failure load. Diagonal shear cracks formed at a load level of 240 kN. As the load increased, this crack started to widen and propagated leading to failure. The maximum applied load was 368 kN.

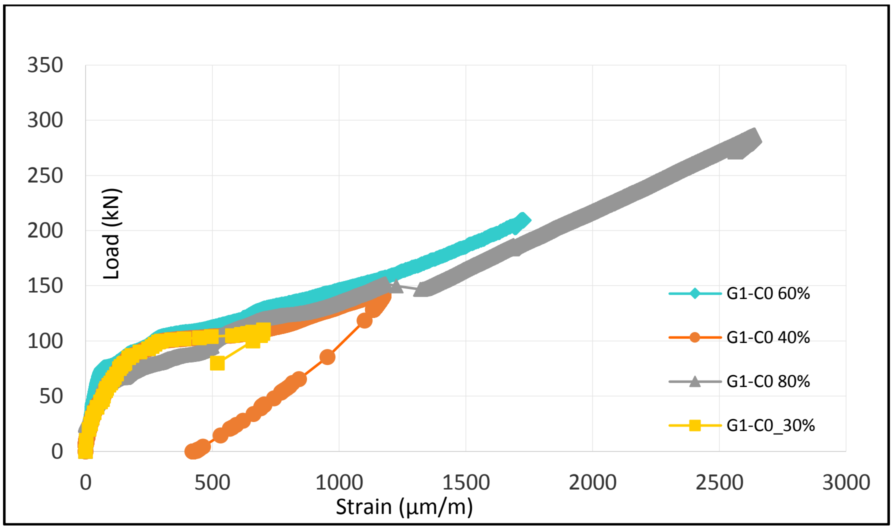

Figure 6: Comparison of load-deflection behavior of strengthening injured beams

The corbel damaged by 80% of failure load was strengthened successfully below 10%. Consider the mechanical behavior in the case of repair, the cracks are initiated and then the elastic field of concrete disappears.

However, mechanical damage of strengthened reinforced concrete corbel have few effect on ultimate load. The number of cracks was relatively insensitive to the bonding of CFC sheet. Yielding of steel bar in tensile

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zone was achieved before the corbel failure, (fig.7). Type of reinforced concrete corbel failure changed with bonded carbon fiber fabrics on reinforced concrete corbels. So, the choice of glue and fabrics was very important.

CB3u_40% - Shearing and splitting failure	CB3u_60% - Shearing and splitting failure	CB3u_80% - Shearing and splitting failure

Figure 7: Failure modes of repaired strengthened reinforced-concrete corbels

3 Conclusion

The results of the tests performed in this study indicated that a significant increase in the flexural strength could be achieved by bonding composite sheets to tensile face of reinforced concrete beams. The choice of adhesive, surface preparation and damaged steel state were very important in the strengthening technique. Considerable reductions in the deflection and cracks, under loading, were produced by the application of epoxy bonded sheets

The beam damaged at 80% of its ultimate capacity was strengthened successfully. However, any effect on ultimate load of damaged concrete was being noted. No different of failure load between normal strength concrete and high strength concrete. The failure of all beams was obtained by a rupture of the concrete layer situated between the reinforced steel and the carbon fiber sheet.

The contribution of strengthening or repair reinforced concrete short corbels as shown in 'Fig 1' is very significant and interesting. The result showed an increase in failure tensile strength to 82% by bonding carbon fibre fabric.

Three main fields are found: 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 corbel.

The corbel damaged at 80% of reference failure load. The results show that the strengthening was successfully below 10%. Beyond this valor, mechanical damage has little effect on the tensile strength.

Repair or strengthening are the real solutions in the field of civil engineering and building to rehabilitate structures and buildings.

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