# Static and dynamic experimental study of strengthened reinforced short concrete corbel by using carbon fabrics, crack path in shear zone

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**ABSTRACT.** The paper presents an experimental analysis of tracking the path of the cracks and crack growth in strengthened or repair reinforced concrete short corbels bonded by carbon fiber fabrics under static and dynamic loads.

The reinforced short concrete corbel is a used precast element, for industrial buildings and structures. In fact, their functioning interestingly unconventional is compared to classical beam type elements. Then the effects of bending and shearing are combined in this case. The horizontal reinforced steel is localized to resist to tensile strength induced in bending top and a transversal strength-absorbing contribution.

The introduction of carbon fiber composite in the field of Civil Engineering allows to strengthen or repair reinforced concrete structures using adhesive. So the carbon fiber material has many advantages as its low weight, flexibility, easier handling and also interesting physicochemical properties. However maintenance of civil engineering works is to protect them by ensuring better sealing or limiting corrosion. Then strengthening is to repair structures by using bonding technique to compensate their rigidity loss and limit the cracking. This allows to improve their performance and durability. Bonding of composite material in tensile zone of corbel retrieves most tensile stress and allows the structure to extend their load-bearing capacity. The local behavior of the structure is measured by means of the extensometer technique based on electrical strain gauges. This technique allowed to measure strains of steel, carbon fiber fabrics and concrete.

The results of this investigation showed that strengthened reinforced concrete corbel bonded by carbon fiber fabrics can improve the ultimate load to twice and stiffens less than a third. The ultimate load, strain and displacement of the specimen are compared to reference experimental model of monotonic and cyclic applied loads. The success of strengthening depends strongly on surface preparation conditions. The cracking mechanisms and collapse modes under static and dynamic loadings are presented. The strengthened reinforced concrete short corbel behavior can be presented in three areas: overall elastic area, crack propagation area and opening of diagonal crack area.

**KEYWORDS.** Strengthening; Short corbel; Composite materials; Reinforced concrete; Mechanism of crack; Failure.

## INTRODUCTION

In the 20th century the people believed that concrete is eternal material. Nonetheless today everyone knows that all concrete structures and elements have a certain service life. During their life the original quality and sustainability changed. In fact it's necessary to have a good deal of knowledge about the mechanical properties and mechanical behavior of reinforced concrete structures [1] under different environmental conditions. It allows to take timely measures for the protection and extend the life of reinforced concrete.

The reinforced concrete short corbel is one important element as cast monolithic with the column element to wall element like demonstrated by Ivanova and all [2-4]. Corbels are used very often in industrial buildings and structures. For example: a participating corbel in reinforced concrete bridge construction lay on the structural elements of the bridge superstructure (beams and plates). Then they are subjected to repeat varying load of traffic [10]. These stresses on a large scale can lead to reaching the ultimate limit state of fatigue. Indeed the strengthening of concrete elements operating under static and dynamic loads is of special interest for the following reasons: cyclically variable dynamic load caused uniquely or dual significance stress and strain state. The intensity and diversity of dynamic load action create conditions for specific behavior of reinforced concrete elements [8]. Then also the joint work between reinforced concrete and composite material allowed a resumption of fatigue stresses.

The development of new technologies using composite materials leads to improve the load carrying capacity and the mechanical properties of reinforced elements. It is possible also to increase flexural and shear strength to reduce deformations and cracks expected [9, 11]. The carbon fiber fabrics as external reinforcement are bonded with epoxy resin which resumed tensile stress in the fiber direction. In award, carbon fiber materials are characterized by a low specific gravity, a high tensile strength, fatigue performance and anti-corrosion.

This paper presents an experimental study of strengthened reinforced short concrete corbels under static and dynamic loads. The carbon fiber fabrics is applied on a tensile zone where it is located and available supporting tensile steel. So carbon fiber fabrics absorbed more tensile stresses and provided a high strength of element [5, 6 and 7]. Based on the inventory of researches have concluded that reinforcement with carbon fiber fabrics reduced appearance and spread of cracks, provided greater durability and higher maximum load.

## EXPERIMENTAL PROGRAM

Four reinforced short concrete corbels are tested. Among them two specimens without reinforcement and the other two specimens are strengthened by externally bonded carbon fiber fabrics in wrapping. The experimental study is investigated to study the crack path and crack growth in reinforced short concrete corbel. This study is compared with repaired reinforced short concrete corbel bonded with carbon fiber fabrics under static and dynamic loads. The objective of this study was to exhibit strengthened reinforced concrete corbel behavior under repeated load. Then, this study is compared with strengthened reinforced concrete behavior under static loading. Then this paper described also the ultimate load versus the cracking mechanisms and the failure modes.

## TEST SPECIMENS GEOMETRY

The column supporting two short trapezoidal corbels cantilevering on either side was 150 mm by 300 mm in cross section and 1000 mm of length. Corbels had cantilever projection length of 200 mm, with thicknesses of 150 mm at both faces of column and in the free end. All reinforced concrete corbel specimens have the same sizes and are strengthened reinforced concrete corbels in the same way detailed as in Fig. 1. For all specimens are tested using a single load with a shear span to depth ratio a/d equal to 0.45.

The control specimen without strengthening is denoted **"C0"**, the first letter **"C"** means Corbel and **"0"** zero indicates without strengthening. The name of strengthened reinforced concrete corbel **"CB3u"** is made up as follows: The first letter **"C"** is, as previously **C**orbel and the second letter represents the type of strengthening (e.g.: **B** for **B**andage). Then digit indicates the number of layers (e.g.: 3) and the small letter indicates finally the type of composite material (e.g. **u** for **u**nidirectional).

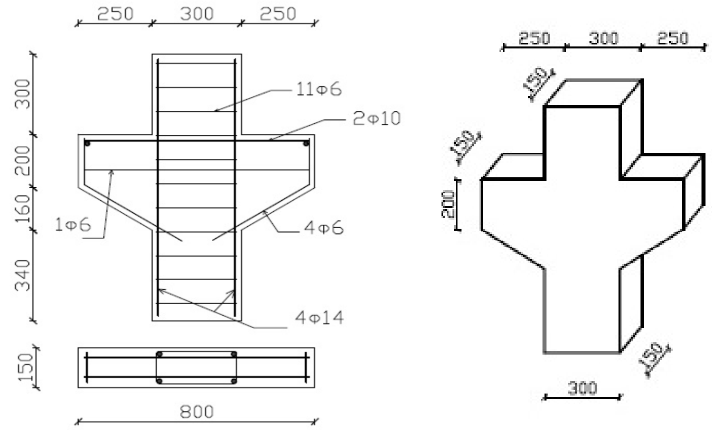



Figure 1: Details of corbel geometry and steel frame.

## MATERIALS

Normal strength concrete materials are rolled gravel, dried sand and ordinary Portland cement. The cement:sand:gravel proportion in the concrete mix are 1:1.73:2.93 by weight and the water/cement ratio is 0.50. Portland cement type CEM II is used and the maximum size of the aggregate is 12.5 mm. Five concrete cylinders 160 mm x 320 mm are also cast and tested when each short corbel is tested to find the compressive strength of concrete at 28 days of age. The actual mean compressive strength was 33 MPa, Young module of 30 GPa and Poisson's ratio is equal to 0.25.
Steel bars, S500 are used for different diameters: 6, 10, 14 mm. The steel specimens were characterized by simple tensile test. The stress $f_u$ and the modulus of elasticity $E_s$ are obtained to 610 MPa and 210 GPa. The Poisson's ratio is equal to 0.29. The high strain in the user steel at the failure is 11.04%.
In fact the experimental results of unidirectional carbon fiber fabrics are given by failure tensile stress of 2000 MPa, elastic modulus of 232 GPa, Poisson ratio of 0.42 and the high strain of $9182.10^{-6}$. But, the glue used for carbon fiber fabrics and for bonding technics are generally into two parts: a resin and a hardener. Then, they are mixed. The glue had an elastic modulus of 8.7 GPa and yield stress of 19 MPa. In according of experimental results yield strength corresponds to the tensile strength. Finally, the carbon composite sheets have a linear elastic behavior up to failure.

## PREPARATION OF THE BONDED SURFACE AND TESTING PROCEDURE

### *Surface preparation and bonding of carbon fiber fabrics.*

The surface preparation was of primary importance and calls for care. However, 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 a good method, Fig. 2a. The four corners of the corbel are rounded to reduce the decrease in strength and to prevent tearing of 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 glue on concrete and carbon fiber fabrics is applied.
The concrete surface 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. The epoxy adhesive used was 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.
So, epoxy is applied on concrete with a brush and then, fabric is placed on epoxy. Second coat of epoxy is rolled into the fabric like Fig. 2b. The fabric is wrapped completely around the corbel and the fabric is overlapped on the face of the corbel. Pressure must be applied to squeeze out excess glue.

Then the second strip of fabric is applied and a third coat of epoxy is rolled into the second strip of fabric. The epoxy is allowed to cure well before testing.

a) b)

Figure 2: Details of bonding system of: a) Sandblasting of corbels and b) Application of carbon fiber on concrete surface by wrapping.

*Testing procedure*

With "Wishay measure" of 24 ways, all data of local strain of electric gauges are saved at different points of structure. All corbels are tested under three points blending load. So, at each test, strain of concrete, carbon fiber fabrics, steel bar and cracking system are noted. The measures of deformation are done at embedding section where strains are high. All tests are performed with a loading speed average of 0.2 kN/s. The data acquisition is recorded every 0.1 second. The maximum load capacity of bending test is 1000 kN.

Firstly, the reference specimen without strengthening is submitted to a vertical load under static loading to collapse. This test enabled to determine the three specific areas: elastic area, crack propagation area and open diagonal crack area showed in Fig. 3. Knowing the load-strain curve, an average value of load is defined. This value is corresponded to average load in between 20 % to 40 % of maximum tensile strength. The magnitude and number of fatigue of the repeated loads are fixed to one million cycles.

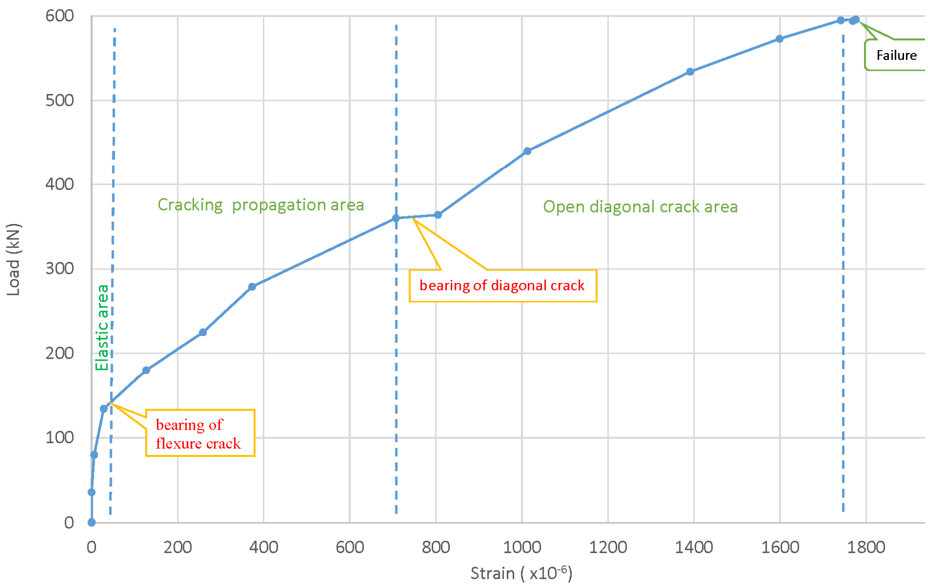



Figure 3: Mechanical behavior of reinforced concrete corbel C0, strain of tensile steel bar.

The results allowed to know when the first crack appeared. This crack is created before fatigue loading. The changed slope is proof that a crack is created. In fact, this study needs to follow crack propagation. Initially, the unarmed concrete corbel is charged up to the initiation of the first crack. It is characterized by a change in slope and then a second time, is applied a triangular signal with a mean stress up to one million cycles. Triangular signal is applied with a mean stress.
Next, reinforced concrete short corbel is subjected to cyclic loading up to one million cycles. After one million cycles, reinforced concrete corbel was static loading until failure.
Secondly, it was the same proceeding with strengthened reinforced concrete corbel "CB3u".
Tab. 1 shows values of ultimate load $F_u$, minimal load $F_{min}$ and maximal load $F_{max}$ in between 20 % and 40 % of maximum load $F_u$. In fact, with a cyclic load in this range, the development of crack can be followed. The previous experimental study identified the occurrence of cracks and their propagations.

| | $F_u$ (kN) | $F_{min}$(kN) 20% | $F_{max}$(kN) 40% |
|---|---|---|---|
| Reference corbel: C0 | 357 | 71.4 | 142.8 |
| Strengthened corbel by wrapping: CB3u | 651 | 130.2 | 260.4 |

Table 1: Conditions of fatigue load.

## Experimental results and discussions

The results showed for static test the ultimate tensile strengths are respectively 357 kN for reinforced concrete corbel without strengthening and 651 kN for strengthened reinforced concrete corbel bonded by wrapping carbon fiber fabrics.

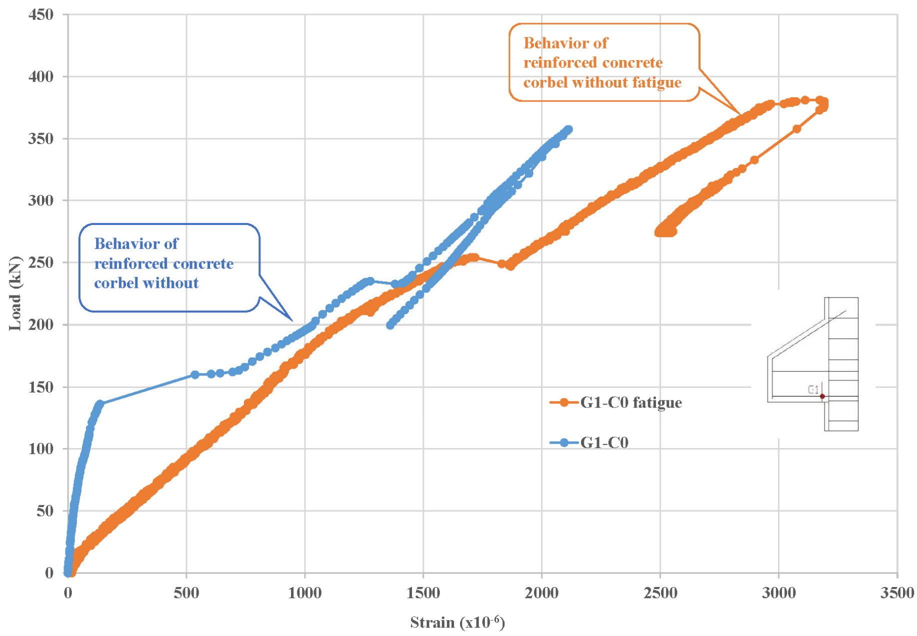



Figure 4: Effect of fatigue on reinforced concrete corbels under static tests.

### *Influence of static and dynamic loadings on reinforced concrete corbels behavior*

Fig. 4 described the comparison of behavior between reinforced concrete corbels "C0" loaded in static and dynamic tests. There is a change in slope at 60 kN for unstrengthened corbel in static loading. In fact, after one million cycles of fatigue,

the reinforced concrete corbel is loaded in simple tensile test to failure. After dynamic loading the curves showed that the range elastic area was lost. The diagonal crack appears at 254 kN more lately than without fatigue at 235 kN as shown in Fig. 4. The fatigue changed the stress distribution in the concrete corbel therefore cracking so, the structure is consolidated further. After one million cycles, the tensile ultimate load of reinforced concrete corbel was 381 kN. However, the test results showed an increase load of 6 % compared with reinforced concrete corbel static loading. Of course, it would be a little impact on the ultimate failure load after one million cycles.
The fatigue results of reinforced concrete corbels on Fig. 5, showed that strains of steel tie are very small (less than $200.10^{-6}$) after one million cycles. The jack displacement was also smallest. One million cycles did not enough increasing to failure. In fact, the experimental tests will continue up to one million cycles. There would be little influence on the ultimate tensile strength of strengthened reinforced concrete corbel after one million cycles.

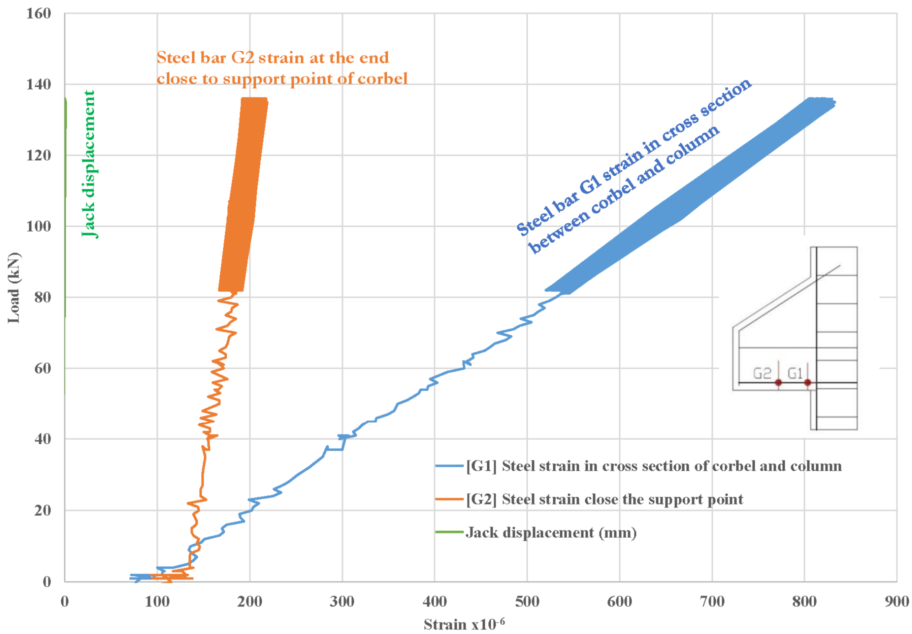



Figure 5: Strains of steel bar in cross section and support load point of corbel ("C0" fatigue).

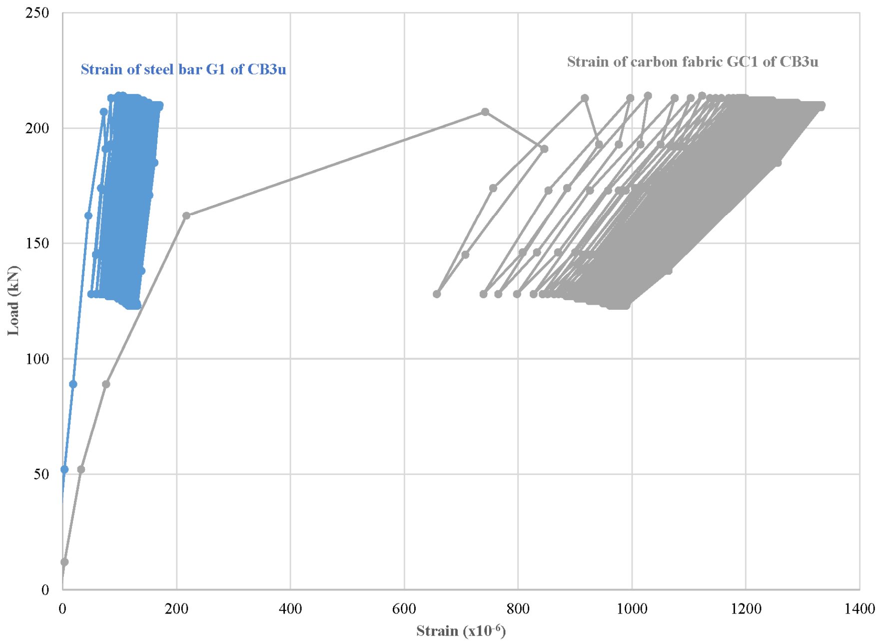



Figure 6: Strains of steel and carbon fiber fabrics of strengthened corbels under fatigue test.

*Influence of cyclic load on strengthened reinforced concrete corbels behavior*

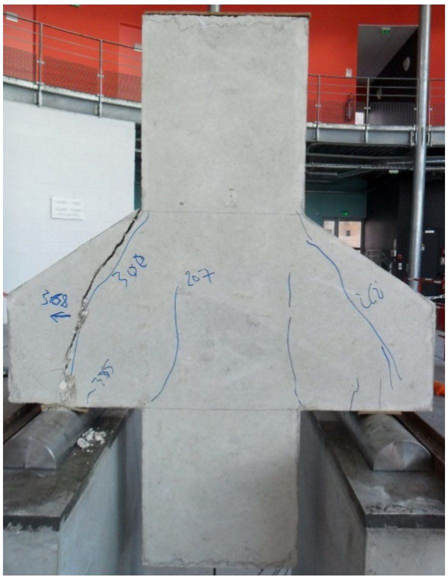
Two strengthened reinforced concrete corbels are tested in static and dynamic loads. The failure load of strengthened reinforced concrete corbel after one million cycles, was 584 kN with fatigue test and 651 kN with static test. That was 11 % less than reinforced concrete corbel under a simple bending test.

The carbon fiber fabrics included the strain of structures about $400.10^{-6}$ while the steel bar is deformed less than $200.10^{-6}$ as shown in Fig. 6.

The appearance of bearing at 365 kN physically characterized by diagonal and deformations reached at $600.10^{-6}$. The carbon fibre fabrics have resumed strain of structure. The strain of steel tie at mounting section is relatively small in the range of $100.10^{-6}$ as shown in Fig. 6. The strain at point G1 pulling close cross section where strains are highest. Deformations are sufficient to cause the disorder in the structure. The investigating did not show failure of carbon fabrics. The strain of carbon fibres fabrics at point GC1, the same position like G1, at least $400.10^{-6}$ between in Fig. 6 of $900.10^{-6}$ to $1300.10^{-6}$, is insufficient to generate cracks in strengthened reinforced concrete corbel.

*Cracking and mode of failure*

Fig. 7 shows two reinforced concrete corbels "C0" (Fig. 7 a) and "C0 fatigue" (Fig. 7 b). The first one is tested up to failure without fatigue and the second one is tested after one million cycles in bending load to collapse. The results showed a new crack is appeared after fatigue testing. Many apparent cracks are showed on reinforced concrete corbel. The difference is depending on the type of loading. Their propagations are different into static tests which proves the fatigue effect with the appearance of a diagonal crack in the concrete column, see Fig. 7b.




a) "C0" static test without fatigue

b) "C0" static test after fatigue

Figure 7: Cracking and failure of reinforced concrete corbel: a) C0 - static loading to failure, b) C0 fatigue - after one million cycles of unreinforced concrete corbel.

The results show in Fig. 8, the cracking and failure modes of strengthened reinforced concrete corbels. After static test, the specimen ruptured in shearing and splitting failures Fig. 8a. Strengthened corbel after one million cycles has no visible cracks, when the corbel is strengthened by wrapping, Fig. 8b. In fact, the results show the same failure cracks as CB3u static test.

## CONCLUSION

This study focused on the strengthening of reinforced concrete short corbel bonded by composite carbon fiber fabrics. Particularly, this paper investigates the effect of damaged fatigue test of strengthened structure. So, this influence of fatigue damage on mechanical behavior and durability of strengthened reinforced concrete corbel under three-point bending test are examined. The adhesion is assumed to be perfect for this type of loading, fatigue is taken into account for the concrete in compression and tensile reinforcement through Wöhler curves associated with the accumulation to deal with law.

a) CB3u static test without fatigue b) CB3u after one million cycles

Figure 8: Cracking and failure in strengthened concrete corbel. a) CB3u-static loading to failure, b) CB3u -after one million cycles.

This paper interested of reinforced short concrete jacket having a defect such as an undersized tensile steel. Carbon fiber fabrics have interesting properties and offer the user new opportunities in the Civil Engineering sector. The preparation of concrete surface described by Ivanova and all [12], was very important in gluing success. The specimens are instrumented with sensors strain electric gauges which allowed to follow strains in several carefully selected points.
In fact, the results show a significant improvement of the ultimate load capacity of up to twice the value obtained by an unstrengthened reinforced corbel. It is increased third of rigidity of strengthened reinforced concrete corbel by wrapping.
The fatigue test had a definite influence on the cracking of reinforced concrete corbel and modified stresses in the specimen. But, the mechanical damage has little effect on ultimate load. Of course, in this case of reinforced concrete corbel, after fatigue damage, the ultimate load is substantially the same as to undamaged reinforced concrete corbel.
The results show also that, the effect of fatigue on reinforced concrete short brackets, in a substantially lower tensile strength to 10 % relative to reinforced concrete short corbel load under monotone static test.
The experimental results of this study are interesting and must be completed by further tests to highlight the significant damage parameters in the numerical and analytical modeling of strengthened corbel.

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