Experimental and finite element study of Substitution Reinforcement Steel of Reactive Powder Concrete by NSM-CFRP Stripes in corbels

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Abstract*: An experimental and finite elements study of behavior of substitution Reinforcement Steel Reactive Powder Concrete corbel by (near surface mounted approach –carbon fiber reinforced polymer) NSM-CFRP stripes in corbel on six reactive powder concrete corbels were made. The tests parameter was the shear span over depth ratio only. Test results showed that, strengthening the corbels by carbon fiber, improves both shear strength and ductility of the tested corbels, and, it can be show the strengthening by NSM- CFRP can be substitute (to some extent) the lack of steel reinforcement*

Keywords: Corbels, Reactive powder concrete, near surface mounted, Carbon Fibers Reinforcement Polymer (CFRP), Shear strength and deflection.

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1. INTRODUCTION

Reinforced concrete corbels (brackets) which are projecting from the faces of reinforced columns are used extensively in precast concrete constructions to support such elements as beams and floor slabs. These corbels, by virtue of their locations, are kept as small as possible and are heavily loaded. The applications of high strength concrete have been traced in many structural applications such as high rise construction, bridges, columns, beams, slabs and foundations [1]. On the other hand, fiber reinforcement is a relatively recent development and there are many practical applications of this material. The most widespread uses of this material are based on its ability to increase the tensile strength of the concrete; the recognition for its crack and deformation control;

Reinforced concrete (RC) corbels, defined as short cantilevers jutting out from walls or columns having a shear span-to-depth ratio, a/d, normally less than 1, are commonly used to support prefabricated beams or floors at building joints, allowing, at the same time, the force transmission to the vertical structural members in precast concrete construction. Corbels are primarily designed to resist vertical loads and horizontal actions owing to restrained shrinkage, thermal deformation and creep of the

supported beam and/or breaking of a bridge crane. They are becoming a common feature in building construction with the increasing use of precast concrete. Owing to their geometric proportions, corbels are commonly classified as a discontinuity region (D-region), where the strain distribution over their cross section depth is nonlinear, even in the elastic stage (Mac Gregor and Wight 2009)[2].

In reinforced concrete constructions, lateral loads, such as wind and earthquake loads are mainly resisted by shear walls and connections. Failure of precast constructions is mostly caused by connections, in which a corbel could be used.

It was found from the last earthquakes that most collapse of precast buildings was caused by failure of connections. Therefore, an extensive research should be carried out to improve precast concrete connections. A common simple precast concrete connection is corbel.

Reinforced concrete corbels are structural elements widely used in practice. The complex response of these elements is described in design codes in a simplified manner. These formulations are not sufficient to show the real behavior. Experimental and finite element models were carried out on 250 x 300 x 200-mm reinforced concrete corbels by using reactive powder concrete strengthening by carbon fiber polymer laminates. Ratio of primary and secondary reinforcement was varied to predict the ability of CFRP on substitution the lack of steel .

2-LITRUTURE REVIEW

Young et al. [3] in 1985, tested 8 high strength reinforced concrete corbels subjected to vertical loading. They studied the influence of the main reinforcement to the failure load with constant (a/d) ratio. According to test results they concluded that ACI Code 318-77 provisions are conservative for high strength concrete corbels.

Carbon Fiber Reinforced Polymer (CFRP) has been adopted in the field of structural engineering to strength most of the structural elements. Most of the research studies were focused on the behavior of reinforced concrete beams and slabs strengthened with Near-Surface Mounted (NSM) by CFRP. While RC corbels are fundamental structural elements in bridges and pre-cast industry, are very little and not available for me.

The most common method used is represented by externally bonded reinforcement (EBR), in which the composites are applied directly on the face of the RC element to be strengthened, using epoxy adhesives. The research carried out until now has revealed that the full tensile strength of the FRP material is not used, mainly due to their premature debonding (Lorenzis, 2002; Cruz, 2004; Barros, 2005; Ţăranu, 2006; Hollaway, 2008).[4]

Near Surface Monted (NSM) FRP reinforcement has attracted a significant amount of attention in both research and practical applications, as an attempt to overcome the disadvantages of the EBR technique. The principle of this method is to install FRP bars/strips into pre-cut grooves in the concrete cover of the elements to be strengthened. The bond between carbon fiber reinforced polymer (CFRP) and concrete is realized with epoxy adhesive. (Lorenzis, 2007) [5].The absence of relevant provisions, regarding NSM technique, from the existing codes on the FRP strengthening of RC structures (fib TG 9.3; ACI 440.2R-02) [6], makes this method much limited when compared to EBR solutions. However, the international engineering community has become aware of the practical advantages of this method among which: less risk to debonding from the concrete substrate; better protection to accidental impacts and unchanged aesthetic features. (Barros, 2006)[7]

3. Experimental work

A. *Details of Corbels Geometry*

As it is shown in Figure 2, the column supporting the corbel have dimensions 300mm by 200 mm supporting by the sides 200 two corbels have long 250 mm and the depth near column is 300 mm. Column was reinforced with four 16-mm-diameter longitudinal bars and 10-mm- diameter stirrups at each 90 mm distance c/c.

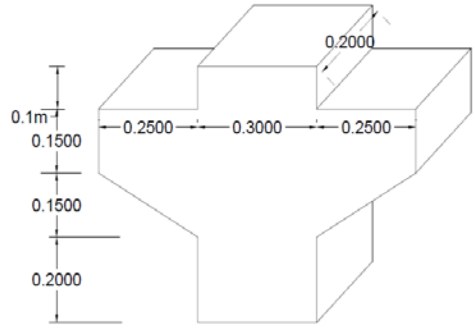

Figure 1 corbel geometry

B. *Reinforcement:*

Group –A-: 3 Specimens have span-depth ratio =0.65

1- Control : minimum steel reinforcement specimen corbel.
2- 50% of the control corbel specimen.
3- 50% of the control corbel specimen + NSM-CFRP stripes.

Group –B-: 3 Specimens have span-depth ratio =0.4,Same the above in all properties.

Firstly the control corbel was reinforced with 100% of the minimum reinforcement by (4-Ø10mm) as main reinforcement and (2-Ø8mm+ 2-Ø6mm) horizontal steel stirrups that's mean As= 470mm2.

One corbel was reinforced with 50% of the control corbel reinforcement having lack of steel with as (2-Ø10mm) as the main tension reinforcement and (2-Ø8mm) horizontal steel stirrups.

Plate 1: steel reinforcement of corbel

C. Properties of hardened concrete and steel

Table1 below shows the concrete & steel properties;

Table 1: material properties

Item	
f c' (28 days)	65 MPa.
fy	550 MPa.
Concrete modulus of elasticity	38000 MPa.

D. CFRP, Plate Properties

High tensile strength "or" stiffness ,Non-corroding ,High fatigue resistance ,Low weight ,Any length available (no joints) Temperature extension ~ 0 ,No yielding like steel ,Small variation of the mechanical properties ,Extreme tension properties, but only in the longitudinal direction ,Very easy to handle[8] .

E. Application of Near Surface Mounted (NSM) Technique :

1- Grooving the concrete by cutter machine as shown in figure 4.

2- The grooves were cleaned with water jet and air blasted to eliminate any residual dust.

3- The CFRP stripes were cut to the desired length
With cross section 1.2mm x 12 mm.

4- The epoxy paste was prepared by mixing the two components (resin and hardener) in 3:1 proportion by weight with a power mixer.

5- Filled the grooves approximately half way with epoxy .

6- The CFRP plate was placed in the groove and lightly pressed..

7- The groove was then filled with more paste of adhesive and the surface was leveled.

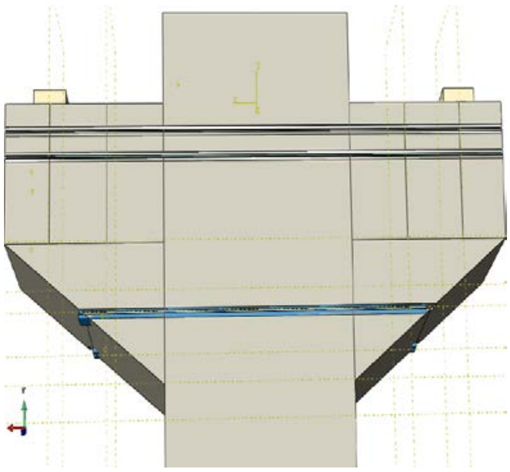

Figure 2 : NSM-CFRP positions in each face

Plate 2 : grooves in concrete corbel in each face

Plate 3: Putting CFRP inside groove with epoxy paste adhesive

4. TESTS AND RESULTS

For each the tested corbels, the load was applied in small increments. Each increment of loading was 5 kN up to 50 kN then 10 kN up to the ultimate load. At each increment, readings were recorded manually, while the deflection versus load and concrete strain were recorded at selected load levels of 100 or 300 kN and observations of crack development on the concrete corbels were traced by pencil. The same test procedure was followed for all corbels. All of the specimens were tested under ramp linearly increasing load up to failure. After failure, the cracks were outlined by thick dark blue marker pen and the corbel was photographed. Plate (3) explains the steps of testing procedure.

Plate 4: loading device

4-1 Experimental results

Examination of 6 corbels was done and recorded the results, ultimate loads and deflection. It can be noticed the CFRP plate can substitute the lack in steel reinforcement. The test of experimental work shown in the tables (2 and 3) and figures (3 and 4).

Table 2: *Experimental test Possibility of NSM-CFRP on substitution of steel reinforcement at a/d=0.65*

item	load(KN) *Pu*	$\frac{P_{u(i)}}{P_{u(r)}}$ *x100%*
Unstrengthened CORBEL REINFORCED 100% As.	699	100
Unstrengthened CORBEL REINFORCED 50 % As.	530	75.8%
Strengthened corbel reinforced 50% As.+NSM-CFRP	658	94.1%

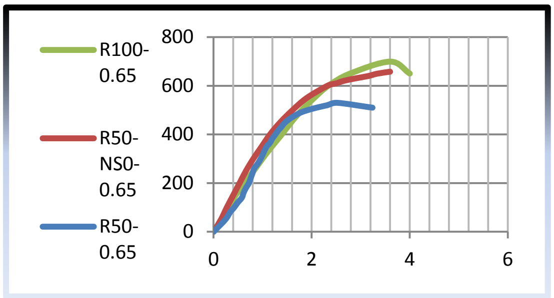

Fig. (3) Load-deflection curves for possibility of NSM-CFRP on substitution of steel reinforcement at a/d=0.65

Table 3: *Experimental test Possibility of NSM-CFRP on substitution of steel reinforcement at a/d=0.4*

item	Ultimate load(KN) *Pu*	$\frac{P_{u(i)}}{P_{u(r)}}$ ***x100%***
Unstrengthened CORBEL REINFORCED 100% As.	1000	100
Unstrengthened CORBEL REINFORCED 50 % As.	811	81.1%
Strengthened corbel reinforced 50% As.+NSM-CFRP	980	98%

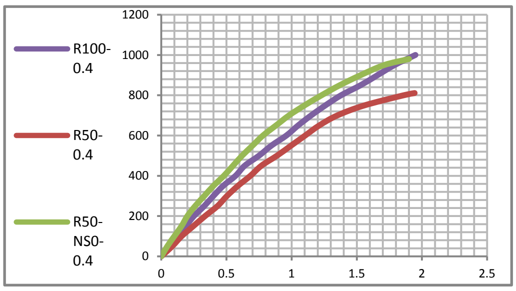

Fig.(4) Load-deflection curves for possibility of NSM-CFRP on substitution of steel reinforcement at a/d=0.4

4-2 Finite element analysis test:

By using a finite elements ABAQUS13.1 program to simulate the specimens using same properties of corbel material simulated in finite elements technique as concrete ,steel ,CFRP, supports and loading plate ,suitable meshes were used for all materials satisfied the calculated matrices, assembling the parts similar the laboratory test ,and by making the same interactions between different materials. The loading was applied with normal ramp increments as shown in figure 5.

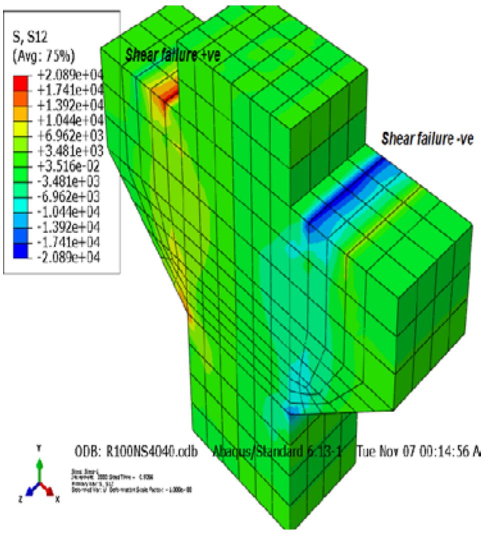

figure 5: finite element corbel model at failure

The finite element analytic results can be appeared good agreement with the experimental test at behavior of the model within applying increment of loads until the failure stage, so that the ultimate load similar the experimental ultimate load about 90% and the corbels failed with same mode . Results of analytic program show the rational values when the models are strengthen by simulate material as CFRP as shown in table (4).

Table 4 : Finite element analytical results

CORBEL	a/d	Finite elements Ultimate load(KN)		
		Corbel steel reinforcement 100% $P_{u(r)}$	Corbel steel reinforcement 50%+NSM - CFRP $P_{u(i)}$	$\frac{P_{u(i)}}{P_{u(r)}}$ *x100%*
1	0.65	673.73	673	99.8%
2	0.4	844.35	856	113.7%

6. Discussion:

Results of experimental and analytical studies showed that the load failure in every group, where the 50% of steel reinforcement strengthened by NSM-CFRP corbels reach (91-98)% of the strength of the control corbel that have 100% of minimum reinforcement, that mean we can substitute the lack in amount of steel reinforcement as a main reinforcement in corbels in cases of different span/effective depth. While the specimen has 50% of steel reinforcement with a/d=0.65 or 0.4 can carry 530kn and 811kn that's represent 78% and 81% of reference corbel respectively. It can be notice the high tensile property of CFRP share with steel to balance the compressive concrete to some extent. The load deflection curves showed the behavior of strengthening corbels was more stiff and same as the corbels of 100 % steel reinforcement. Analytical results show good agreement with experimental results and indicate improvement of corbels strengthened by NSM-CFRP strips that possible to substitute the lack of steel reinforcement in range (99.8- 113) % approximately. Also it can be seen the mode of failure was by direct shear.

7. Conclusions:

1- To repair the corrupted steel in corbels or substitute the lack in area steel reinforcement in such structural members especially that cannot be rebuild by using Near Surface Mounted Carbon Fiber Reinforced Polymers (NSM-CFRP) technique with suitable area depends on the high tensile strength of carbon fiber proportion with the required design strength.

2- The relative increments of strength in different span / depth ratio takes place in every case of low span/depth ratio and high span/length ratio.
3- To predict the required strength that will provided by CFRP ,that can simulated by finite elements programs the supposed different areas of CFRP stripes or stripes that satisfy the required load.
4- More studies needs with this approach by other parameters such as increasing area , number or configuration the CFRP stripes to inspect the range of provided strength in corbels.

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