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EXPERIMENTAL STUDY OF CORBEL BY STRENGTHENING WITH CFRP

P.A.RANDHAVANE[1], V.R.Rathi[2], P.K.Kolase[3]

[1]Post graduate student, Department of Civil Engineering, Pravara Rural Engineering College Loni, India-413736

[2]Professor, Department of Civil Engineering, Pravara Rural Engineering College Loni, India-413736

[3]Professor, Department of Civil Engineering, Pravara Rural Engineering College Loni, India-413736

Email-praju14257@gmail.com.

Abstract: **The study represents the local behaviour of strengthened reinforced concrete short corbel by external bonding of Carbon Fibers Reinforced Polymer fabrics. For the experimental program total six corbels were casted with two control sample and four strengthened samples with externally CFRP Fabrics. Strut-n-tie method is used for the design of corbel, which is effective method for analyising forces in the corbel. Comparison for the ultimate load v/s deflection graphs were studied for the control and strengthened specimens. Test results showed improvement in the ultimate load carrying capacity for the strengthened samples with horizontal and inclined wrapping on the faces of the corbel. Full wrapping by the unidirectional CFRP Fabrics in the horizontal manner showed higher results compared with the control and inclined (45˚) orientation of CFRP Fabrics.**

Keywords: **Corbel, Strut-n-tie, CFRP, Reinforced concrete, Strengthening, Failure.**

1. INTRODUCTION

Strengthening of reinforced concrete (RC) structures with Fiber-Reinforced Polymer (FRP) composites has been a .popular subject that attracted considerable attention and researchers for the last two decades. The high specific strength, stiffness, environmental resistance, and ease of application make FRP composites highly desirable for strengthening and rehabilitation of RC structural components [1]

Corbels, or brackets, are cantilevers with a shear span depth ratio lower than unity, generally jutting out from walls or columns. They have the principal function of supporting prefabricated beams or floors at building joints, allowing, at the same time, the force transmission to the vertical structural members. [2]

Bond between FRP and concrete is a fundamental property that influences the success and the efficiency of the strengthening system as it controls the composite action development between both material Besides, it affects the load carrying capacity, spacing and width of cracks, as well as the failure mode of the strengthened member [3].

According to Elgwady et al.[4], strengthening enhanced the ultimate load carrying capacity by values ranged from (8-30) %; the cracking loads of most strengthened specimens were about (70-80) % of their ultimate loads. A.A.Mohamad-Ali and Attiya [5] found that the external strengthening technique had a significant effect on the first cracking load, the percentage increase in cracking load for the inclined strips was 51%, and the percentage for the horizontal strips was 19%.. Heidayet et al. [5]investigated that the repair technique may be regarded as an effective and economical technique for strengthening existing structures. Engindeniz et al. [5]presented that externally bonded FRP composites can eliminate some important limitations of other strengthening methods such as difficulties in construction and increases in member sizes. Khalifa [5]proposed maximum vertical load carrying capacity applied on corbels was increased with the increasing of the fiber volume fraction, fiber aspect ratio and the increasing in concrete compressive strength. Yaman Sami Shareef Al-Kamaki et al.[6] Observed that CFRP reinforcement constrained widening and growth of the shear cracks, and hereafter, improved the gain in the load capacity and axial toughness. Karunasenaet al. [7] found that externally bonded composites, CFRP or GFRP, improved the moment capacity of damaged concrete beams. Varinder Singh et al. [7] CFRP retrofitting of the beam-column joint shifted the failure of the joint from the column portion to the beam portion of the joint which will prevent progressive collapse of the structure. S. J. E. Dias et al. [8] found that NSM CFRP laminates is an effective solution to decrease cracking, yielding and maximum loads of beams failing in bending. Furthermore, he concluded that high tensile strength of the CFRP was effectively mobilized and by increasing the CFRP percentage, the load carrying capacity of the NSM beams increased. Ivanova et al.[9] present a study on performance of externally strengthened short RC corbel by CFRP fabrics a horizontal form (front and rear face) and in a wrapping form. The test results stated that the attached fabrics on the tensile face of the corbel have a greater effect. Akram Jawdhari et al.[10]study leveraged four-point bending tests to determine whether spliced CFRP rod panels can effectively serve as flexural reinforcement for concrete members. Giuseppe Campione et al. [11]introduced a strut-and-tie macro-model to determine the flexural response of fiber reinforced concrete (FRC) corbels, reinforced with longitudinal bars and subjected to vertical load. M. Emara et al. [3]showed results in terms of slip evolution with time are presented to explore the effects of the studied parameters on the long-term bond behavior between NSM CFRP laminates and concrete. Hazem A. El-Enein et al. [12] experimental results demonstrated that the flexural ultimate load carrying capacity increased by 33%, 37% and 67% for the tested specimens with central, eccentric, and edge column, respectively, when strengthened using CFRP sheets. Tamer El Maaddawy et al[1] the CFRP-confinement had no significant effect on the flexural capacity but resulted in a remarkable improvement in the member ductility, ranging from 340% to 460% increase in deflection capacity of the members with the rectangular and square cross-sections, respectively. Jules Assih et al [13] presents a study of damaged reinforced concrete corbels, where the corbels are strengthened by bonding carbon fibre fabrics. The contribution of strengthening by gluing carbon fibre fabrics on the behaviour of reinforced short concrete corbels is very significant and interesting. The contribution of the repair by gluing composite materials increased ultimate load from 30 to over 50 %. Mechanical damage up to 90 % has an effect on the ultimate load (less than 20 %).

Based upon the published literature, it can be concluded that, CFRP is a viable alternative material for repair and strengthening of reinforced concrete structures. The RCC structures, which require retrofitting, are already stressed to a particular level due to the loads experienced by the structure in its life span. External strengthening can effectively increase the ultimate load carrying capacity by adopting proper design concepts.

2. MATERIAL AND METHDOLOGY

2.1 Concrete properties:

Normal strength concrete material used is natural river sand, 20mm coarse aggregate, OPC 53 grade cement and portable water. From the properties and result of the material testing the mix design was selected for the concrete. The mix ratio 1: 1.59: 2.64 by weight and the water/cement ratio was 0.45.

The design of corbels is based on the assumptions of strut action recommended by both the British and the American Concrete Institute codes. The procedure follows the recommendations of the British Euro code BS EN 1992-20004.[14]

2.2 Specimen Characteristics:

Steel formwork was prepared with the dimensions of the corbel designed. The 675mm long column supporting two short trapezoidal corbels cantilevering on either side is 200mm by 200mm in cross section. The specimens have cantilever projection length of 275mm,with a thickness of 200mm at both faces of column and free end. All reinforced concrete corbel specimens have same sizes and are reinforced in the same way. Following fig.1.Shows the detail dimension of corbel.

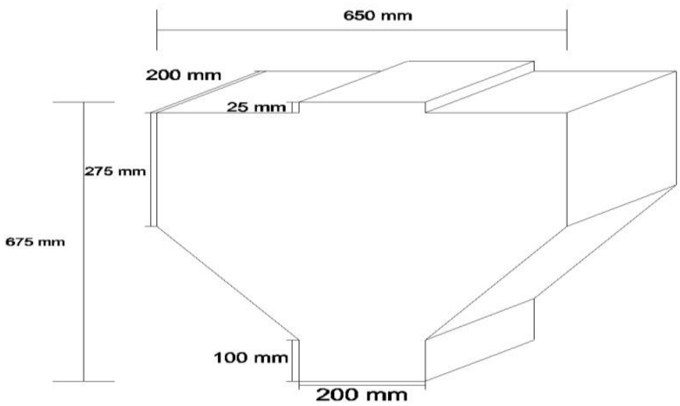

Fig.1. Dimension of corbel.

Column segment was reinforced longitudinally with the 4 Ø 12mm bars with Ø 8mm stirrups throughout the length of column. The tension and compression zone of the corbel was reinforced with the 4 Ø 16mm bars and Ø 8mm stirrups about upper 2/3rd of depth were provided.

Fig.2. Reinforcement of corbel.

2.3. Carbon Fibre Reinforced polymer properties:

Unidirectional woven CFRP fabrics from BHOR FORCE were used as strengthening materials. Fabric design thickness was 0.22mm.The epoxy resin (epoxy adhesive) used to bond the CFRP to the concrete surface was from BHOR EPCH 330 type consisting of two components of resin and hardener (A: B) ratio of 100:30. Table 1 shows the mechanical properties of CFRP.

Table.1. Properties of Unidirectional CFRP Fabrics

Density(g/cm^3)	1.8
Filament diameter(μm)	7
Tensile strength (MPa)	4000
Tensile modulus (GPa)	2.40
Elongation (%)	1.1
Sizing	Epoxy compatible

2.4. Confining of CFRP.

Prior to the bonding of CFRP to the corbel, the surface of the concrete was prepared by thoroughly cleaning the surface. Compressed air was used to remove any dust or other loose sediments on the corbel surface. Then followed covering with primer liquid for hardening of the outer layer of the structure for improvement of cohesion between adhesive and concrete surface. Then the CFRP was cut to the desired length. The CFRP was glued with the **100:30** proportions of the resin and hardener

2.5. Nomenclature of corbel.

Total six test specimens were casted. The test specimens were dived into three groups including control corbel. Remaining two groups were classified based upon the wrapping technique.

Table.2. Nomenclature of corbel

Sr.No.	Nomenclature	Description.
1	CC	Control specimen.
2	HCFRP	Corbel wrapped in horizontal manner
3	ICFRP	Corbel wrapped in inclined manner.

Fig.3. Inclined and horizontal pattern of confining of CFRP

2.6. Testing of corbel.

Corbels are tested on universal testing machine (UTM).The load carrying capacity of UTM is about 1000 KN. The corbels are loaded on the column segment in an upside-down position. The corbels will be seated on steel roller supports at shear span of 100mm. And the one point static loading is given. The results are observed on digital indicator. Load v/s deflection graphs are studied.

Fig.4. Testing of corbel on UTM

3. RESULT AND ANALYSIS

3.1. Testing of control corbel.

All the specimens were loaded monotonically in small increment (1 kN/s) up to ultimate load. At each increment, the readings were recorded and the development of cracks were observed and marked later on the specimens. Failure pattern of corbel is shear failure .i.e. Diagonal shear failure. The crack developed was in the form of diagonal from the support to face of column for the control corbel. Finally after the peak load was reached concrete get crushed at edge and splitting of corbel was observed. The failure pattern of control corbel is shown in the fig.5.

Fig.5. Crushing of compression zone of corbel.

It is observed that control specimens fails at the lower ultimate load than the strengthen specimens. It can be seen that the maximum enhancement in the ultimate load capacity of RC corbels is achieved when external CFRP overlays are applied. CFRP can increase the ultimate load, ductility and enhances the stiffness of RC corbels. The level of improvement depends on the orientation of CFRP fabrics (configuration) and presence of stirrups. In general, the ultimate load was larger in corbels strengthened with CFRP with the presence of stirrups than those of unstrengthen corbel specimen (control corbel).

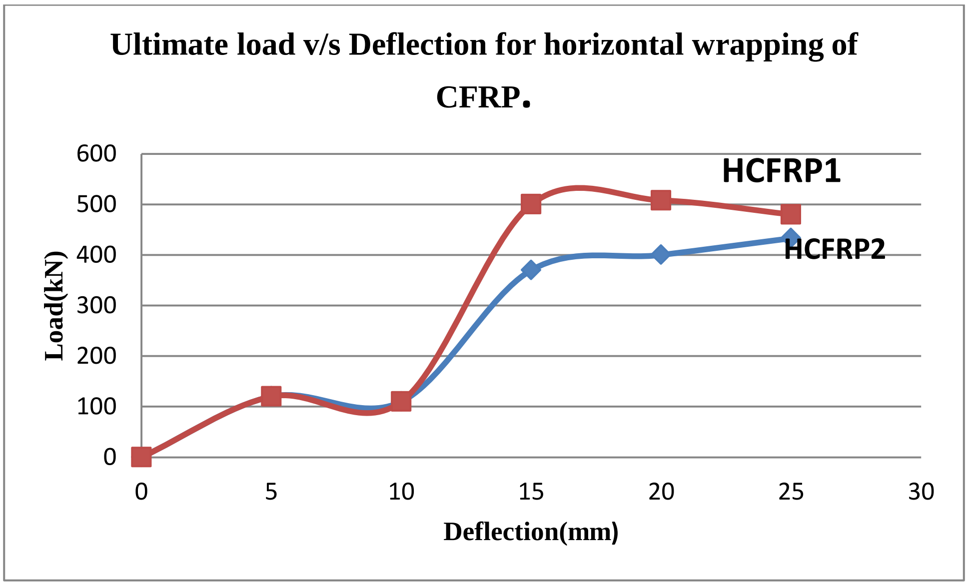

Fig.6. Ultimate load v/s Deflection for horizontal wrapping of CFRP.

The above fig6 shows various changes in the slope. The change corresponds to change from appearance of first mirco crack to the ultimate load and then final crushing of the corbel. The almost linear slope of the second phase indicates that the linear nature of the behaviour of both steel bars (up to yield initiation) and CFRP laminates determined this cracking propagation phase.

3.1. EFFECT OF HORIZONTAL WRAPPING.

For the horizontal wrapping by the CFRP the entire cantilever portion was wrapped. Also the edges were wrapped. Hence the surface area covered by the CFRP was more. Lying of sheet onto corbel are usually unidirectional (with all fabrics oriented along length of sheet), which usually help in controlling the crack width and hence collapsing of the edge is prevented. After applying of the load on the corbel the first crack observed was from the support. Then crack propagated from the loaded area to column. The formation of the crack was found much latter than the control specimen. Due to confining of the CFRP the time covered by the crack to travel from support to the edge was much slower, due to which the load carrying capacity of the corbel increased and the tougher corbel failed at an ultimate load of 508.76kN with an increase in strength of about 27.85% compared to control specimen

The presence of stirrups also played an important role. As the stirrups were provided about upper 2/3rd of depth of the corbel were the CFRP was also wrapped from external side the yield initiation of the longitudinal steel reinforcement was found almost after the concrete cracking, where the CFRP laminates had only a slight effect on the cracking load. The first crack load observed for the HCFRP was at 405kN,which was comparative much higher than the control sample i.e.235kN. Compared to the control sample the first crack load increased was about 72% more, hence the load carrying capacity found for HCFRP was more.

Fig.7. Crack developed for the horizontal wrapping at ultimate load

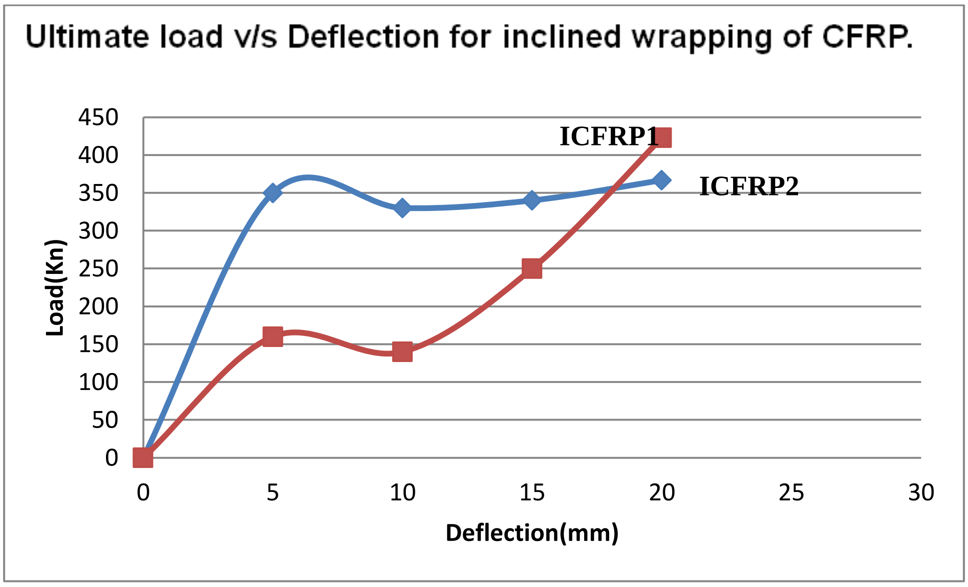

Fig.8. Ultimate load v/s Deflection for inclined wrapping of CFRP

3.2. EFFECT OF INCLINED WRAPPING

The strengthen specimen for the inclined wrapping i.e. ICFRP1 and ICFRP2 failed at 423.84kN and 366.82kN resp. It was clear from the control specimens that shear cracks controlled the failure mode. So the use of diagonal CFRP was assumed to be effective strengthening configuration. One layer of unidirectional strips was applied on the faces of the cantilever section. These strips started from just point below the applied load and continued across the corbel face with 45º inclination (fig3). After applying load the crushing of the edged was found with peeling of the CFRP from the concrete surface. Due to peeling out of the CFRP the propagation of the crack was faster compared to the horizontal as there was not full wrapping to the edge as off the HCFRP. The first crack observed was at 385kN i.e.63% more compared to the control specimen and 4.93% lower than the HCFRP. At the ultimate load concrete crushed at the support and corbel failed.

Fig.9. Peeling out of CFRP after crushing of concrete

4. CONCLUSIONS

1. CFRP full wrap is effective than CFRP wrap up to column-corbel interface.
2. The failure observed in corbel is diagonal shear failure for control specimen.
3. Test results showed that corbels strengthened with horizontal strips gave best results compared with specimens strengthened with inclined strips.
4. The enhancement in the ultimate shear strength of the corbels was about (20-30) % for horizontal strips and about (5-15) % for inclined strips compared with the control specimens.
5. It was concluded as well that the external strengthening technique had a significant effect on the first cracking load, the percentage increase in cracking load for the horizontal strips was 16%, and the percentage for the inclined strips was 2%.
6. The results showed that strengthening by CFRP fabrics can delay the formation of the first crack.
7. The developed cracks are shear crack began to develop at loading area towards the corbel face.
8. Strut-n-tie method is effective method for analysis of corbel.

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