Investigation of Shear Behaviour of Corbel Beams Strengthened with CFRP

Saeed Ahmad, Ayub Elahi, Samiullah Kundi, Waseemul Haq

Department of Civil Engineering, University of Engineering and Technology Taxila 47050, Pakistan
ayubelahi2000@yahoo.com

Abstract: In this research work, the investigation of shear behavior of corbel beams strengthened with Carbon Fibers Reinforced Polymer (CFRP) is carried out. The research objective was to study the effectiveness of wrapping of D-Regions of Corbel beams with CFRP, in increasing the shear strength of Corbel beams. To achieve these objectives, twelve corbel beams were tested which were divided into 4 groups. The beam samples were first designed by Strut and Tie Method. The theoretical values of strut and tie forces obtained during the design of corbel beams were compared with the strut and tie forces obtained on the basis of load at 1st shear crack and failure loads. It was concluded that loading capacity as well as energy absorption of corbel beams can be increased by using CFRP wrapping techniques.
[Ahmad S, Elahi A, Kundi, S, Haq, WU. **Investigation of Shear Behavior of Corbel Beams Strengthened with CFRP.** *Life Sci J* 2013;10(12s):961-965] (ISSN:1097-8135). http://www.lifesciencesite.com. 156

Keywords: High Strength Concrete, Corbel, Disturbed Region, Strut & Tie Model, Carbon Fiber Reinforced Polymer (CFRP).

1. Introduction

Brackets and corbels are short-hunched cantilevers that project from the inner face of columns or concrete walls to support heavy concentrated loads of pre-cast beams, gantry girders, and other pre-cast system loads. The ratio of shear span to depths in these member is often less than 1.0 (Mattock et al., 1976). The analysis and design of these corbels and other non-flexural members, like corbel beams, dapped ended beams, deep beams, pile caps and openings in slabs, becomes difficult with ordinary flexural analysis as the true behavior of the member cannot be anticipated with the ordinary flexure theory. Different empirical approaches have been used for the design of such non-flexural members.

There are various approaches for the design of disturbed regions such as Strut and Tie Model (STM), code provisions, modified compression field theory and some empirical equations. Out of these, STM is one of the rational and relatively simple design approaches for non-flexural members (Ahmad and Shah, 2009), where traditional beam theory cannot be applied. STM is based on lower bound theory of plasticity, which assumes that steel and concrete are frequently plastic at the limit state. Efficiency factors are then applied to uni-axial strength of concrete to account for concrete softening and cracking. STM is based on load path method, where the path is developed by tracing the forces through structure. STM uses a model comprising of struts and ties as shown in Fig. 1.

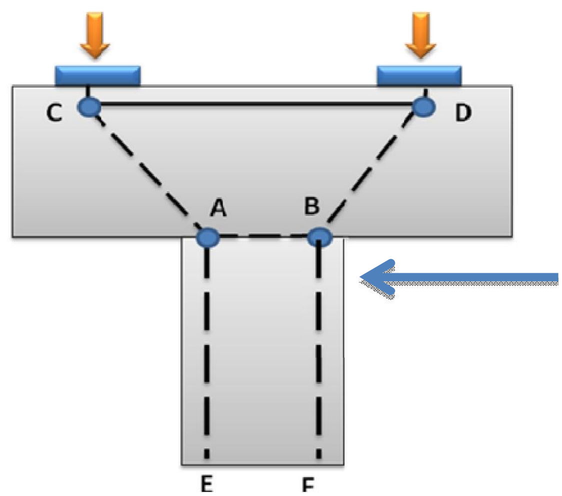


Figure 1: Strut & Tie Model in a Corbel

Many types and shapes of FRP materials are now available in the construction industry. For the purposes of external reinforcement of concrete, there are essentially two classes of FRP materials currently available: plates and sheets. Plates are rigid FRP strips that are manufactured using a process called pultrusion. Sheet FRPs are supplied as flexible fabrics of raw (or pre-impregnated) fibers. The sheet FRP materials are applied by saturating the fibers with an epoxy resin and laying-up the sheets onto the concrete surface. In both of the above applications, the FRP materials used are usually unidirectional (with all fibers oriented along the length of the sheet).

Depending on the type of fiber, composite materials are referred to as: carbon fiber based (CFRP), aramid fiber based (AFRP) and glass fiber based(GFRP) (Bisby and Fallis, 2006).

High strength Concrete (HSC) is attaining much popularity because of different benefits associated with it (John and Denis, 2001). There is no clear cut definition for HSC. In the North American practice (ACI 318, 1999), high strength concretes are those that attain cylinder compressive strength of at least 41 MPa at 28 days. In the FIP/CIB (1990) state-of-the art report on high strength concrete, it is defined as concrete having a 28-day cylinder compressive strength of 60 MPa. High-strength concrete is made by loweing the water-cement (W/C) ratio to 0.35 or lower.

Different researchers conducted series of research work in order to study the effect of various strengthening techniques. Khalifa and Nanni (2000) presented an experimental investigation in which continuous reinforcement concrete beams without shear reinforcement were externally bonded by CFRP. The beams were tested and the results obtained indicate that the externally bonded CFRP enhanced the shear strength of the beams both in positive and negative moment regions. CFRP increased the shear strength of the beam range from 22% to 135%. The test results also indicate that the contribution of CFRP without stirrups increase the shear capacity of beam to a large degree than the beam with adequate shear steel reinforcement. Fattuhi (1994) conducted an experimental study in which vertical loading tests were carried out on 250 x 150 x 300-mm concrete corbels with main bars only, with main bars and steel or monofilament polypropylene fibers, or with main bars and plastic mesh. The fibers or strips of plastic mesh were used as secondary (shear) reinforcement, and both volume of main bars and shear span-to-depth ratio were varied. The tests indicated that corbels reinforced with main bars only failed in an explosive manner suddenly and catastrophically, and the mode of failure was by diagonal splitting. The addition of secondary reinforcements generally resulted in enhancements in both strength and ductility of corbels, the degree of enhancement being dependent on the type and form of secondary reinforcement. The results also show that the strength of corbels failing in flexure can be predicted with reasonable accuracy by using simple beam theory while accounting for the secondary reinforcement.

Zhang et al., 2004 carried out an experimental study including 16 deep beams without steel shear reinforcement were cast at the concrete laboratory of New Jersey Institute of Technology. After the beams were kept in the curing room for 28 days, carbon fiber strips and fabrics were applied outside of the beams at various orientations with respect to the axis of the beam. Results of test demonstrate the feasibility of using externally applied, epoxy-bonded CFRP system to restore or increase the shear capacity of deep beams. The CFRP system was observed to significantly increase the serviceability, ductility, and ultimate shear strength of a concrete beam, thus restoring deep beam shear strength using CFRP is a highly effective technique. Valle and Buyukozturk (1993) **c**reported the results of an investigation on the strength and ductility of fiber reinforced HSC under direct shear. Both experimental and modeling studies were performed. In the experimental study, fiber reinforced HSC push-off specimens were tested. Two types of fibers, polypropylene and steel fibers, in conjunction with or without conventional stirrups were used In general, fibers proved to be more effective in high- strength concrete than in normal strength concrete, increasing both ultimate load and overall ductility. For the specimens with steel fibers, significant increases in ultimate load and ductility were observed. In the tests involving the combination of fibers and conventional stirrups, there were slight increases in ultimate load while major improvements in ductility were observed, in comparison to the values for plain concrete specimens with conventional stirrups. (Pham and Al-Mahaidi, 2004) carried out research work testing including 18 rectangular RC beams to investigate the failure mechanisms. Results showed that end cover separation started from FRP ends and failed in the form of shear failure at steel reinforcement level at the root of the concrete teeth between shear cracks. Shear crack deboned failure was due to the opening of one of those inclined cracks.

The effect of CFRP strengthening technique for existing structures is yet not fully clear especially for members not fulfilling normal beam theory. Therefore, this study has been carried out to know the effect of CFRP wrapping on loading capacity and energy absorption of PCC as well as RC corbel beams. The expected results may contribute in understanding the behavior of PCC and RC corbel beams with and without CFRP wrapping.

2. Experimental program:

Out of twelve corbel beams, six corbel beams were cast as PCC and other six beams were cast as RC. Out of six PCC corbel beams, CFRP are fixed on three corbel beams and other three corbel beams were left without CFRP. Similarly in RCC corbel beams CFRP are fixed on only three corbel beams. A clear cover equal to 75mm has been provided in RC beams. Concrete of composition equal to 1:1:2 was prepared in a concrete mixer and poured manually in the form. In order to prepare HSC by reducing water–cement ratio (w/c), admixture (Super plasticizer 858) is used during the mixing of the concrete. Compaction of the concrete was done by using vibrator. RC and PCC beams were then de-moulded after 24 hours. All the beams are then cured properly for 28 days before testing. Now these beams are divided into four groups. G1Consisted of three PCC corbel beams (B1, B2 and B3). G2Consisted of three RCC corbel beams (B4, B5 and B6). G3Consisted of three RCC corbel beams strengthened with CFRP (B7, B8 and B9). G4 Consisted of three PCC corbel beams strengthened with CFRP (B10, B11 and B12)

In order to strengthen the corbel beams of G3 and G4 in shear using hand lay-up technique in the laboratory conditions of 30°C and 34% humidity. The surface was cleaned and a two parts epoxy Sikadur was applied where required. After preparation of the surface, the CFRP sheet was cut to the proper lengths and the fabric was then applied on the projected portion of the corbel beams as shown in Figure 2 below. The sheets were pressed firmly in place with a plastic roller to remove air bubbles and excess epoxy.

Figure 2: CFRP applied on the Projected Portion of the Corbel Beam

The beam specimens were then tested under the application of concentrated loading at the centerline of the bearing plate placed on both side of the projection portion of the corbel beams through hydraulic system, transferring the load through calibrated proving ring, to evaluate the Shear Behavior of corbel Beams. The load was gradually increased and cracks developed in the beams specimens were closely observed and noted.

3. Results and conclusions:

Load Carrying Capacity

Load carrying capacity of various groups is shown in Fig. 3. Each bar represents average load carrying capacity of three identical samples of each group. With the application of load on the corbel beam samples of G1, beam specimens failed after carrying a very little load and without any appearance of rich cracks. This brittle failure occurred at an average load of 86.07 kN.

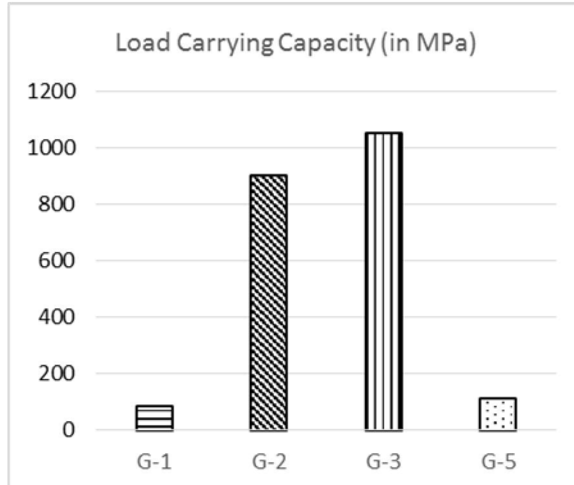


Fig. 3: Load carrying capacity in MPa

Similarly the RCC corbel beam samples of Group G2 exhibited much more loading capacity under the application of load as compared with un-strengthened PCC specimens of G1. These beam samples failed at an average load of 900.85 kN. With the increase of applied load, different shear cracks appeared on the face of the corbel beam samples. It can be seen that average load carrying capacity of RCC corbel beams of G2 increased by more than 10 times. It can be observed that steel reinforcement designed by STM considerably enhanced the load carrying capacity of Corbel beams.

Similarly when the CFRP strengthened RCC corbel beam samples of Group G3 were tested under the application of load, the load carrying capacity increased as compared with specimens of G1 and G2. In this case beam failed at an average load of 1050 kN. Hence, CFRP strengthening technique further improved the load carrying capacity of RCC corbel beam by 17%.

In case of CFRP strengthened PCC corbel beam samples (G4), the average load for which beam failure occurred was 115 kN. So CFRP contributed the load carrying capacity of PCC corbel beams by 33% which is much less than enhancement observed by embedding steel reinforcement. Steel reinforcement caused 28 times more enhancement as compared to that observed due to CFRP strengthening.

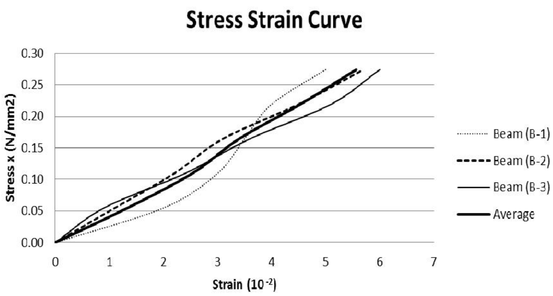


Figure 4: Load Strain Curves of Group G-1

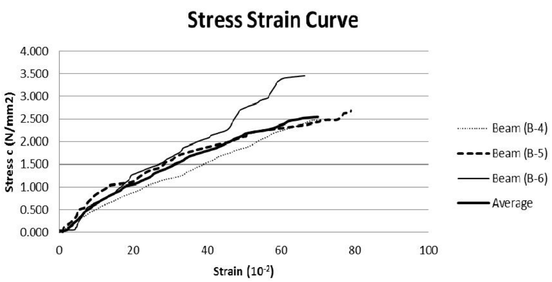


Figure 5: Stress Strain Curves of Group G2

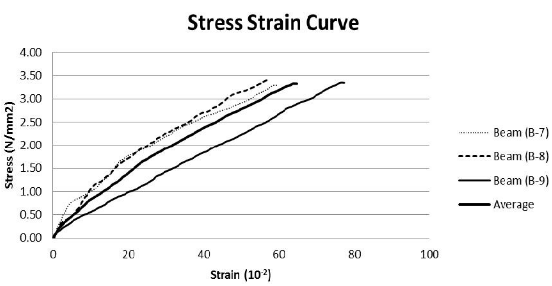


Figure 6: Stress Strain Curves of Group G3

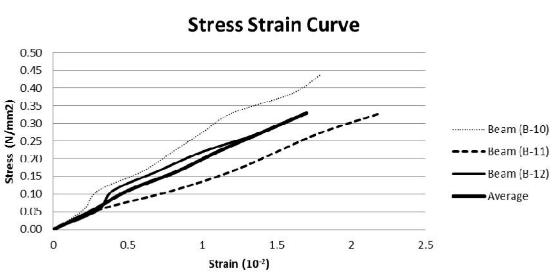
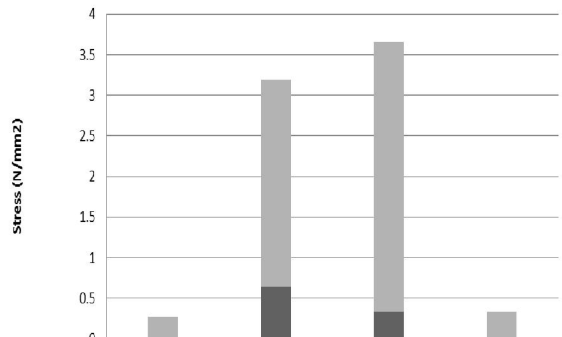


Figure 7: Stress Strain Curves of Group G-4

Energy Dissipation of Corbel Beams:

With the application of load on the corbel beam samples, the cracks appeared in the beam samples and strain energy is absorbed. The energy absorption of the corbel beam samples at 1st shear crack and at failure load are reported by the stress strain curves as shown from Figures 4 to 7. Stress strain curves for all the three samples of each group along with curve representing average values have been shown in these Figures. Area under the curve is calculated from the trend line equation of each stress strain curve by using MAT LAB software. All the un-strengthened and strengthened PCC specimens showed brittle mode at the time of their failure. Average area under the curves for each group represents strain energy at 1st crack and total energy (at failure) for respective group. These strain energy values are presented in Fig. 9.



	PCC	RCC	RCC + CFRP	PCC + CFRP
Failure	0.27	2.548	3.33	0.33
1st shear crack	0	0.640	0.33	0

Figure 9: Stress at 1st shear crack and at Failure

It can be seen from Fig. 9 that strengthened PCC corbel beam samples absorbed more energy (almost double) as compared to its respective un-strengthened PCC corbel beams. This reflects the comparatively less ductile behaviour of un-strengthened PCC corbel beam samples as compared to strengthened PCC corbel beams. Un-strengthened PCC corbel beams also showed a very small amount of energy absorption as compared to RCC corbel beam samples and failed in the brittle mode. RCC corbel beams (B4, B5 and B6) dissipate more energy as compared to PCC corbel beams and showed ductile mode by exhibiting ample warning in the form of a number of very small cracks before failure. Also RCC corbel beams wrapped with CFRP (B7, B8 and B9) dissipate more energy as compared to simple RCC corbel beams. It can be seen from the result that CFRP improved the load carrying capacity of PCC as well as RCC corbel beams. More energy absorption was observed in case of PCC as compared to RCC specimens. More energy absorption can be observed by reinforcing PCC corbel beams with embedded steel reinforcement rather than wrapping with CFRP. A marginal increase in energy absorption (1.01 times) was observed due to CFRP Strengthening of RCC corbel beams.

Conclusion:

- Strut & Tie model provided conservative estimate of the strength of the RC corbels.
- The experimental shear strength of the RC corbels is almost 100% higher than the theoretical shear strength worked out assuming Strut & Tie model (STM).
- Most of the failure in the RC corbels was due to shear. However, pure PCC corbel beams failed abruptly without observing any proper crakes.
- The externally adhesive bonded flexible CFRP can increase the ultimate shear strength of RC corbels.
- CFRP increased.the strength of the corbel beams up to 25% which is less than achieved by embedding steel reinforcement.

References

1. Ahmed Khalifa and Antonio Nanni, “Improving shear capacity of existing RC T-Section beams using CFRP composites.” Cement and Concrete Composites, Vol. 22, No.2, July 2000, pp. 165-174.
2. Cheng-Tzu Thomas Hsu and Jon Moren, “Shear Strengthening of Reinforced Concrete Deep Beams Using Carbon Fiber Reinforced Polymer Laminates”. 10.1061/ (ASCE) 1090-0268(2004)8:5(403).
3. Ahmad, S and Shah Allah Shah, “Evaluation of shear capacity of High Strength Concrete Disturbed Regions using Strut & Tie Model (STM) “
4. M. Bourget, Y. Delmas and F. Toutlemonde, “Experimental study of the behavior of reinforced high-strength concrete short corbels.” Materials & Sturctures, Vol. 34, April 2001, pp 155-162.
5. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (318R-02),”American Concrete Institute, Farmington Hills, Mich., 2002.
6. J.K.Wight and G.J. Parra-Montesonis, “Strut and Tie Model for Deep Beam”, Concrete International, May, 2003, pp. 63–70.
7. J. Schlaich, K. Schaefer, and M. Jennewein, “Towards a Consistent Design of Structural Concrete”, Journal of Concrete Institute 32(1987), pp. 74–150.
8. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary to the Building Code Requirements (ACI 318R-05). Farmington Hills MI: American Concrete Institute, 2005, 446 pp.
9. A.H. Mattock, K.C. Chen, and K. Soongswang, “The Behavior of Reinforced Concrete Corbels”, Journal of Pre-Stressed Concrete International, 2(12)(1976), pp. 52–77.
10. M. Saafi and Houssan Toutanji, “Design of High Performance Concrete Corbels”, RILEM Material and Structures, 31(1996), pp. 612–622.
11. S.J. Foster and R. Adnan Malik, “Evaluation of Efficiency Factor Models used in Strut-and-Tie Modeling of Nonflexural Members”, ASCE Journal of Structure Engineering, 128(2002), pp. 569–577.
12. A.F.N. Shawi, P.S.Mangat, and W. Habibi, “A Simplified Design Approach to Corbels Made with High Strength Concrete”, RILEM Material and Structures, 32(1999), pp.579–583.
13. P. Marti, “Truss Models in Detailing”, Concrete International, 7(1985), pp. 66–73.

7/1/2013