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STUDY ON STRENGTHENING OF RC BEAMS BY HYBRID FRP BARS

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Abstract - *RC structures are suffering from various deteriorations like corrosion, cracks, large deflection etc. These deteriorations are caused by various factors such as ageing, corrosion of steel reinforcement, environmental effects and accidental impacts on the structure etc. Such deteriorative action is unavoidable for an RC structure. Such deteriorated structures require immediate attention, enquiry into the cause of distress and suitable remedial measures, so as to bring the structures back to their functional use again. Dismantling the structure is not economical. Hence retrofitting the existing structure is the only remedy for this problem. Through this project work the study is only considering the strengthening of RC beams. For any structure beam plays a major role in the load transfer mechanism. Main objective of this project is to evaluate the behaviour of Retrofitted beam using CFRP bars with panels. The suitability in the application of FRP materials for the flexural strength increment and their bond behaviour are being evaluated.*

Key Words: **FRP, RC Beam Strengthening, FEA, Bond behavior, FRP bars, FRP Laminates, FRP panels**

1. INTRODUCTION

High-performance materials that include advanced composites can have very high strength-to-weight ratios and are suitable for efficient structural repair of deficient members. These materials allow for rapid placement and require minimal labour compared to traditional methods. The use of fiber-reinforced polymer (FRP) laminates and fabrics to repair and strengthen reinforced concrete (RC) structures is well established, with design guidelines in the form of ACI 440.2R-08 (ACI Committee 440, 2008), Technical Report 55 (Concrete Society, 2012), and European fib bulletin 14 (Fe´de´ration internationale du be´ton (fib) Task Group 9.3, 2001). Over the past decade, carbon fiber–reinforced polymer (CFRP) composites have proven to be a cost-effective and successful retrofit method for buildings and bridges. The primary advantages they offer over other materials include their noncorrosive properties, magnetic transparency, high strength, low weight, high durability, and ease of application. Many bridges around the world have been repaired and/orFibre reinforced plastic (FRP) reinforcement plays a very important role in the retrofitting and rehabilitation of reinforced concrete (RC) structural elements as an external and near surface reinforcements.

Recent developments in these fields have a wide range of application. Several investigators carried out experimental or theoretical investigations on concrete beams and columns retrofitted with carbon/glass fibre reinforced polymer (CFRP, GFRP, and HYBRID) composites in order to study their characteristics. Many practical applications worldwide now confirm that the technique of bonding FRP laminates or plates to external surfaces and usage of internal bars is a technically sound and practically efficient method of strengthening and upgrading of reinforced concrete load-bearing members that are structurally inadequate, damaged or deteriorated. Of all the materials used as reinforcement, carbon fibre reinforced polymer (CFRP) and glass fibre reinforced polymer (GFRP) composite materials have found special favour with engineers and applicators because of their many advantages. After that over a period of time some researchers started doing their work on Hybrid FRP (combined layer of FRP bars and laminates).Such kind of a material is a carbon rod panel (CRP). It consists of small diameter carbon rods attached with a backing .These panels are then externally bonded to the structures to strengthen them.

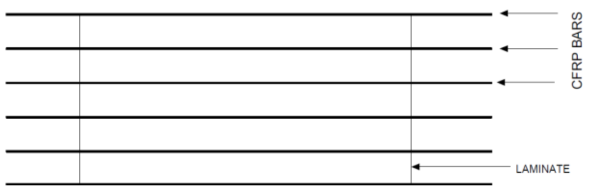

Fig -1: Carbon Rod Panel

2. HYBRID BAR TECHNIQUE

Hybrid bar system is a technique in which the NSM and external bonded approach is used in combination. Here, CFRP bars and CFRP laminates are used to form a panel namely ; Carbon Rod Panel. The CRP is then used to retrofit any structure. CRPs are produced using small-diameter CFRP rods mounted on a laminate backing. The spacing is greater than the rod diameter between individual rods. Several sizes of rods were used in this investigation, with diameters varying from 2mm to 4 mm. The analytical data presented here are for rods 2 mm in diameter, with a manufacturer-reported tensile modulus of 134 GPa and an ultimate tensile strength (f u) of 2200 MPa. Each rod had a capacity of a minimum of 6.8 kN . Each CRP was 1220 m in length and had a CFRP laminate backing, and also provided required bond length for the finger joint on either side of the panel. Each alternate panel was produced with an extra rod to establish symmetry at the finger joint. An extra rod to establish symmetry at the finger joint. The overlap for the finger joint is based on the results of the double-lap shear tests.

Rod spacing was calculated to maintain a minimum clear distance of 1.25 mm between rods at the finger joint. Figure2 illustrates the layout of the CRPs and the modular construction,. The CRPs are bonded to concrete or other substrate using an epoxy resin. A layer of epoxy, approximately the same thickness as the rod diameter, is applied to the substrate, and the rods are placed against the epoxy and pushed in until the rods and the outer laminate are covered with epoxy.

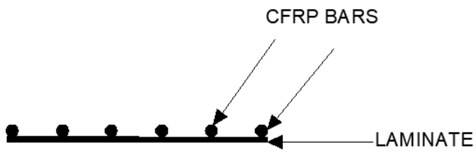

Fig- 2: Cross sectional view of panel

The success of the CRP system is a product of the bond and its ability to transfer stresses between the substrate and the CFRP rods that adhere to it. This study investigated the bond characteristics between the concrete and the CFRP rods used in the CRP structural strengthening system. It also examined the performance of the CRPs under flexural loads in strengthened RC beams. CRPs may be provided in the following ways to strengthen a beam as shown in figure.

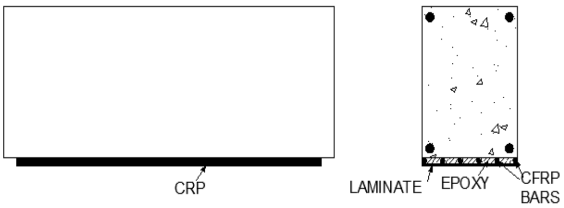

Fig3: CRP attached to bottom of beam

2.1Different configurations of CRP

CRP panel may be attached in different configurations to a beam. The panel may be provided along the full length of the beam at the bottom face. It can also be used as a spliced panel. The method of using the panel in spliced manner comes in handy when the span of the beam is too long and also when it is not easy to provide a full length panel in a stretch. This may be due to the surrounding conditions of the beam. For example: Providing a full length panel below a log span beam of bridge is a difficult process. In that case the panel can be used comfortably as a spliced one. Reducing the requirement of labor intensive work. The splicing is done by providing an overlap length such that an effective transfer of stress occurs at the intersection.

The joint of panel is shown in figure 3.The panel may be two spliced or three spliced depending on the need. In this study analytical modelling of double lap shear test is done and the required failure load and bond length of panel is thus obtained.

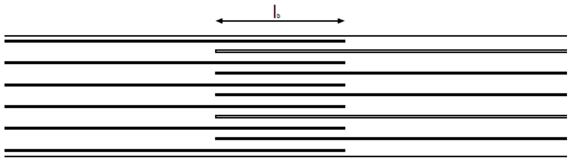

Fig -3 : Two spliced panel

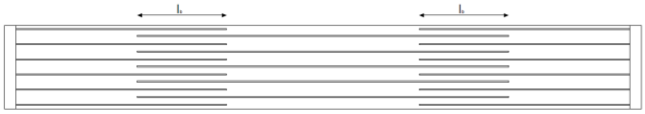

Fig- 4 : Three spliced panel

Mainly two types of panel are studied here. The panels are classified based on c/d ratio. The 'c' represents the center to center distance of bars while 'd' denotes the diameter of panel. The panels used are namely panel 1 and panel 2.Panel 1 has bars of diameter 2 mm spaced at 6.25 mm center to Centre(Fig 5), while panel 2 has bars of diameter 2mm spaced at 8mm center to center(Fig 6). The bond length of these panels where estimated and they were implemented in flexural strengthening.

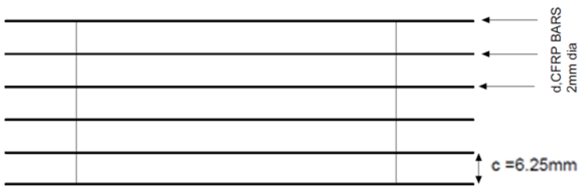

Fig- 5. Panel 1

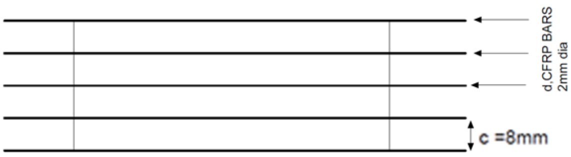

Fig- 6.Panel 2

3. DOUBLE LAP SHEAR TEST –ANALYTICAL STUDY OF BOND EHAVIOR

The objective of the double-lap shear test was to evaluate the bond length required to achieve full load transfer between the substrate and the CFRP rods. While extensive research on bond strength and effective bond length has been conducted for CFRP laminates and fabric . Double-lap shear specimens have a symmetric arrangement with an inner adherend centered between two outer adherends. Two layers of epoxy complete the joint. The test setup used was similar to ASTM D3528 (American Society for Testing and Materials (ASTM), 2008), but it was modified to evaluate bonded rods as shown in Fig 7. The analytical test results were used to develop the required finger joint length for continuity and load transfer between the CRPs. By varying

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the bonded length (Lb) of the double-lap joint specimen, the test evaluated the development length and ultimate bond strength.

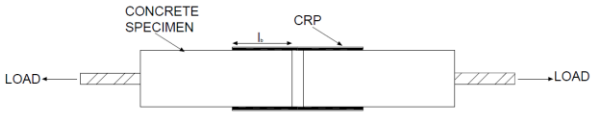

Fig-7. Double lap shear test setup

An analytical model of the test was developed on Ansys. The panel was fixed in concrete by varying the bond length L_b, and the failure loads where obtained from defined failure criterion. The deformation was permitted only in the x direction and other directions where restrained. The analysis was done in static structural. The Model developed is shown in Fig 8

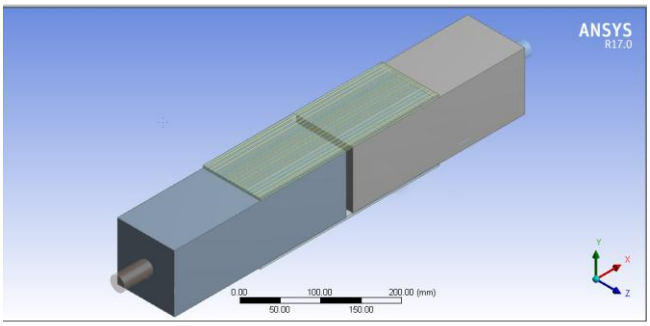

Fig -8: Double lap shear model

The analysis was done for both panel 1 and panel 2.The bond length were increased from 2.5mm and the failure loads were noted. The specimen is assumed to attain failure when the tensile stress in the epoxy reaches the max. allowable tensile stress in epoxy which is provided by the manufacturer. The failure occurs because of the debonding that occurs between the epoxy and surrounding material. Thus the observations for panel 1 and panel 2 are given in figure 9 and 10 respectively.

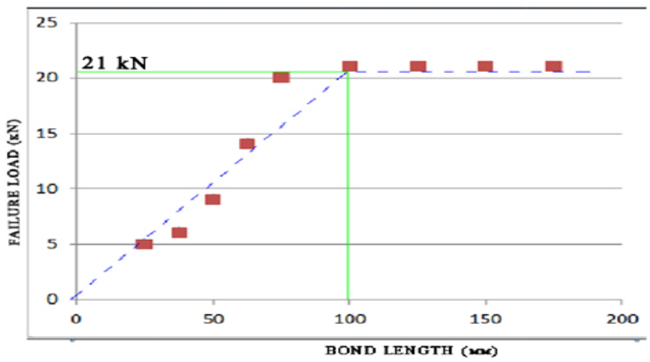

Fig -9: Failiure load Vs bond length of panel 1

From the above graph it can be understood that increasing bond length after specified length doesn't have an influence over failure load . Thus the minimum bond length for effective stress transfer in case of panel 1 is 100mm and it has a failure load of 19 kN

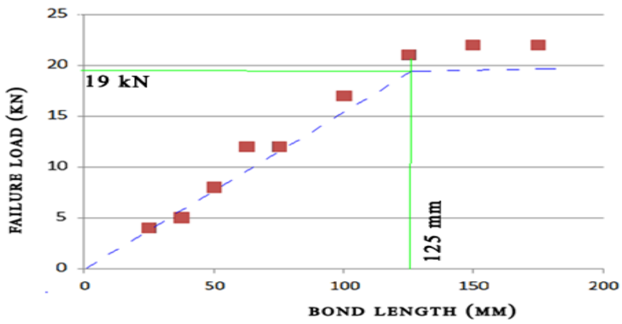

Fig -10: Failiure load Vs bond length of panel 2

The analysis resluts for panel 2 is shown in figure 10 .From the graph it is observed that the bond length required is 125mm and he failure load is 19 kN

4. FLEXURAL STRENGTHENING BY CRPs

A comprehensive three dimensional (3D) finite element (FE) models of RC beams, flexurally strengthened with CFRP rod panels (CRP's), were developed. The models consider the nonlinearity of concrete material, including: concrete nonlinear stress-strain behaviour in compression. The structural behaviour of CRP's, especially the overlap region, was explicitly captured by modelling CFRP rods as discrete reinforcement embedded inside the adhesive layer.

The CRP are externally adhered to the bottom of beam surface for strengthening it in flexure. Attachment of CRP onto a structural substrate can be summarized as such: (1) a uniform layer of adhesive is applied onto the substrate. (2) CRP is then brought to its correct position and pressed gently, forcing the adhesive to flow around the rods and fill completely between the rods. Adhesive thickness will approximately be 2-to-3 millimeters greater than rod diameter. Neighbouring panels are brought together and made continuous by overlapping the rods. The overlap length, conservatively selected based on preliminary double-lap shear tests. The CRP adhered to RC beam is shown in figure.2.The configurations are as shown in figure 3 and 4

4.1Analytical modelling

The RC beam model for flexural analysis is fig .11. The boundary conditions (B.C's) of the tested beams are simple-supports. The full-beam FE model was also constructed with similar conditions. A pin-type B.C's was assigned to the left support, and a roller-type B.C's was assigned to the right support. For nodes located along the plane of symmetry (at beam's mid-width), displacement in the direction perpendicular to the plane was assigned a zero value.Three type of panel arrangements were modelled and they are

i) A full length panel throughout the beam

ii) Two spliced panel arrangement

iii) Three spliced panel arrangement

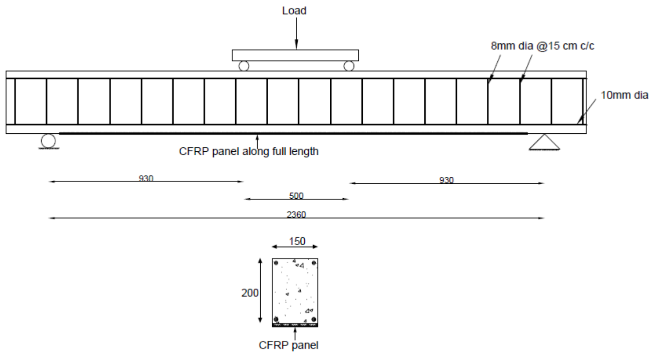

Fig -11: Model for flexural test.

Two type of panels are used

i) With c/d ratio 3.25,panel 1

ii) With c/d ratio 4,panel 2

The modelled beams with specification is given in the below table

Table 1: Beam specifications

Beam ID	Description
CB	Control beam
P1-1	Panel 1 ,full length
P1-2	Panel 1, two spliced
P1-3	Panel 1 ,three spliced
P2-1	Panel 2 ,full length
P2-2	Panel 2, two spliced
P2-3	Panel 2 ,three spliced

The problem was analysed in static structural. The load vs deformation values of beams were obtained. Figure 12 shows the analysis of a typical beam.

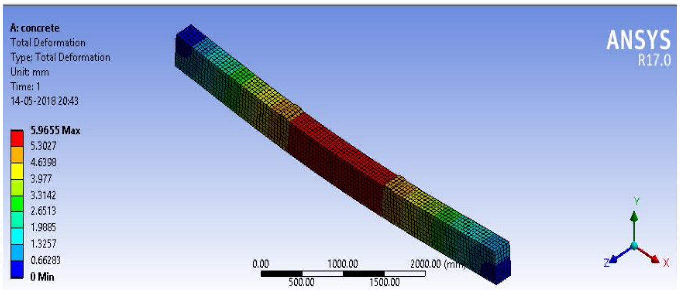

Fig -12: Analyzed beam showing deformation.

Table 2 shows the deformation values corresponding to the load increment of all the listed beams. The figure 13 compares the results of control beam and beams strengthened with panel P1. The figure 14 compares the results of control beam and beams strengthened with panel P2.The figure.15 compares the results of beams strengthened with panels p1 and p2

The comparison of From the above graphs we can understand that ,the proposed 125 mm overlap for panel 2 and 100mm overlap for panel 1 seems to be sufficient in transferring forces between spliced panels and maintaining composite action throughout loading stages. Notably, specimens strengthened with spliced CRPs or full length CRPs, both showed comparable load deformation patterns . Panel 1 has more capacity when compared to panel 2.This is due to the fact that the rods are more closely spaced in panel 1, resulting in more area of CFRP .Both panels effectively restricted the deformation to 1/3rd of deformation of unstrengthened beam.

Table 2: Results from Ansys

Load (kN)	Deformation(mm)						
	CB	P1-1	P1-2	P1-3	P2-1	P2-2	P2-3
0	0	0	0	0	0	0	0
6	4	1.5	1.53	1.55	1.59	1.61	1.64
12	15.23	5.2	5.26	5.28	5.51	5.57	5.59
18	30.1	9.5	9.61	9.64	10.07	10.12	10.21
24	40.31	13.84	13.95	14	14.67	14.75	14.81
30	50.22	18.1	18.21	18.23	19.18	19.28	19.3
36	60.2	22.79	23.12	23.17	24.15	24.29	24.36

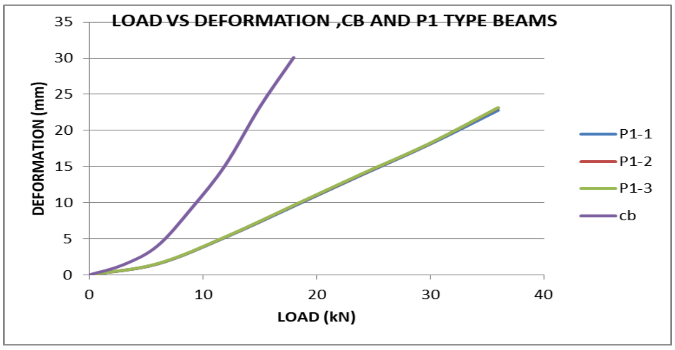

Fig -13: Comparison of CB and P1 type.

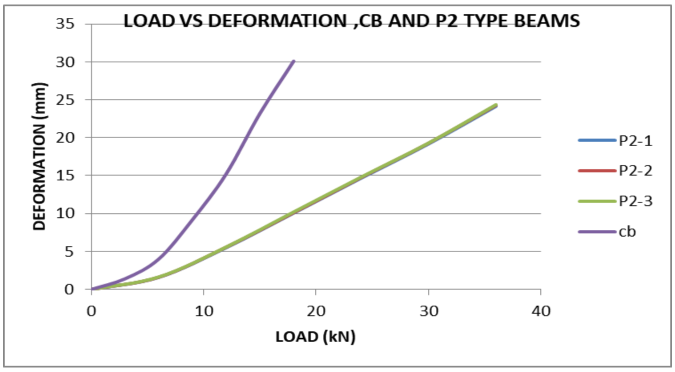

Fig -14: Comparison of CB and P2 type.

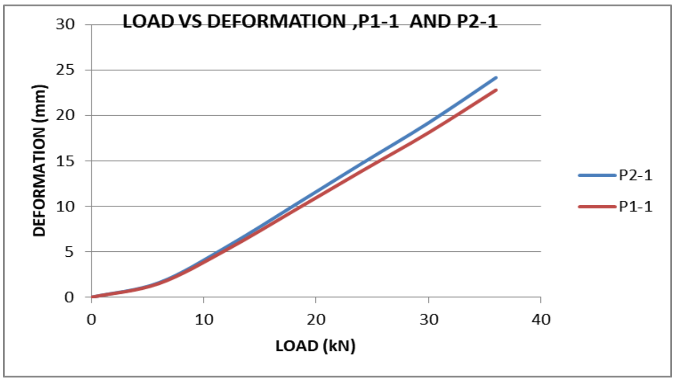

Fig -15: Comparison of P1 and P2 type.

The comparison of From the above graphs it can be understood that ,the proposed 125 mm overlap for panel 2 and 100mm overlap for panel 1 seems to be sufficient in transferring forces between spliced panels and maintaining composite action throughout loading stages. Notably, specimens strengthened with spliced CRPs or full length CRPs, both showed comparable load deformation patterns. Panel 1 has more capacity when compared to panel 2.This is due to the fact that the rods are more closely spaced in panel 1, resulting in more area of CFRP .Both panels effectively restricted the deformation to 1/3rd of deformation of unstrengthened beam.

5. CONCLUSION

The study of bond behaviour of CRP panels where done. Two different panels were analysed .It was found that the panel with lower spacing of CFRP rods required less bond length and also had higher failure load when compared to panel with higher CFRP rod spacing. The panels were used to retrofit an RC beam .The deflection in beams where reduced to 1/3rd of original deflection. The spliced panels and unspliced panels behaved in a similar way as the bond length provided was sufficient.

6. FUTURE WORKS

As the retrofitting using panel reinforcement is a new area, a wide range of studies are possible. The effects of using panel for shear strengthening can be studied. The type and size of bars in the panel may be varied. The panel used for backing may be changed to fabric or laminates of different materials. More importantly a design chart can be developed suggesting the ways the CRP can be implemented.

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