

Retrofitting of Reinforced Concrete Beam Using Carbon Fiber Reinforced Polymer (CFRP) Fabric

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Abstract - Worldwide, a great deal of research is currently being conducted concerning the use of fiber reinforced polymer fabric wraps, laminates and sheets in the repair and strengthening of reinforced concrete members. Fiber-reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials. Experimental investigations on the flexural behavior of RC beams strengthened using continuous carbon fiber reinforced polymer (CFRP) fabrics are carried out. Externally reinforced concrete beams with epoxy-bonded CFRP sheets were tested to failure using a symmetrical two point concentrated static loading system. Four numbers of beams are casted and cured for 28 days, one beam CB1 is taken as control beam and is subjected to its ultimate load carrying capacity. The other three test specimens beam S1, S2 and S3 are preloaded for initial crack load, then retrofitted using CFRP fabric. The strengthening is done on beams of different cement constituents by varying cement material with partial replacement of GGBFS and fly ash. Experimental data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of CFRP fabrics for strengthening of RC beams is also included. The effect of CFRP fabric and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated.

Key Words: Retrofitting, CFRP fabric, Initial Crack, Epoxy, RC Beams.

1. INTRODUCTION

One of the most critical issues in the Civil engineering community is Structural rehabilitation. A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as low as twenty five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same. However there are many other techniques for strengthening of existing structure with certain merits and demerits, one of the emerging method is use of FRP. FRPCs help to increase strength and ductility without excessive

increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibers. So concrete members can now be easily and effectively strengthened using externally bonded FRP composites. By wrapping FRP fabric, retrofitting of concrete structures provides a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry.

Beams are the critical structural members subjected to bending, torsion and shear in all the type of structures. Similarly, columns are also used as various important elements, subjected to axial load combined with/without bending and are used in all type of structures. Therefore, extensive research works are being carried out throughout world on retrofitting of concrete beams and columns with externally bonded FRP composites. Several investigators took up concrete beams and columns retrofitted with carbon fiber reinforced polymer (CFRP)/ glass fiber reinforced polymer (GFRP) composites in order to study the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members.

The present study evaluates the performance of RCC beams with bonded CFRP fabric in single layer of the beam under static two point loading. CFRP fabric has shown great promise to upgrade structural systems. An emphasis has been given to the strength and deformation properties of CFRP fabric strengthened RC beams. The load - displacement response, ultimate load carrying capacity of the strengthened beams and control beams were experimentally evaluated.

2. CONSTRUCTION MATERIALS

Ordinary Portland cement type 1 is used in the concrete mix design. The maximum size of the coarse aggregates (crushed limestone) is about 20 mm. The fine aggregates are of natural sand with fines modulus equal to 1.80. Three 12 mm diameter are used as bottom longitudinal reinforcement and two 10 mm diameter are used as top longitudinal reinforcement. 6 mm diameter stirrups are placed at spacing of 180mm c/c. Because one of the goals of the experiment was to determine how to

strengthen concrete reinforced members that might exist on any site, a normal weight concrete mix design was used with a target strength of 20 MPa. The concrete mix design had the ratios of 1: 1.5: 3 of cement, sand, and aggregates, respectively, with a water-cement ratio equal to 0.50. However GGBFS and fly ash materials are also used as cement replacements. Control beam had conventional concrete mix, in beam S1 15% replacement of cement with GGBFS, in beam S2 15% replacement of cement with fly ash and in beam S3 30% replacement of cement with both GGBFS and fly ash in equal proportion is done.

3. COMPOSITE MATERIALS

The type of CFRP material used for flexural strengthening is composed of Tyfo SCH-41 Composite. The properties of the materials are shown in Table . The bonding agent used is Tyfo S Saturant Epoxy and Epoxy hardener. The technical data are shown in Table .

Table -1: Properties of Resin And Hardener

Product Name	TYFO S COMPONENT A	TYFO S COMPONENT B
Chemical Name	Modified Epoxy Resin	Epoxy Hardener
Chemical Family	Bisphenol-AEpiclorohydrin Polymer	Polyetheramine Polyoxypropylenediamine
Appearance	Clear to Amber	Pale yellow to clear-liquid
Odour	Viscous liquid with slight odour	Ammonia-like odour
Boiling Point (760 mmHg)	320 C (608F) DSC	500F/26C

Table -2: Properties of Composite

Fiber Name	Carbon Fiber Reinforced Polymer Fabric
Fiber orientation	Unidirectional(Parallel to beam axis)
Tensile Strength	4000 N/mm ²
Tensile Modulus	230x10 ³ N/mm ²
Ultimate Elongation	1.7 %
Thickness	0.3 mm
Gsm	644 g/mm ²
Youngs modulus	165 KN/mm ²

4. CASTING OF BEAMS

The steel reinforcements were cut on-site to the required length and assembled in cages ready for concrete casting. Plastic spacers were used in formwork as well as corner chamfers to provide beam specimens typical to those found on-site. The concrete was mixed using a small rotary mixer and shoveled into the formwork, and a vibrator was used to minimize air voids in concrete

members. The formwork consisted of mild steel channel section to provide good finishing of substrates. Two beams were cast at a time, and three cubes 150 by 150 mm were retained as samples for compressive strength testing. Four numbers of reinforced concrete beams were casted for this experimental test program. The dimensions of all the specimens, grade of concrete, reinforcement detailing were identical. The cross sectional dimensions of all the beams were 150 by 200 mm and length is 1500 mm.

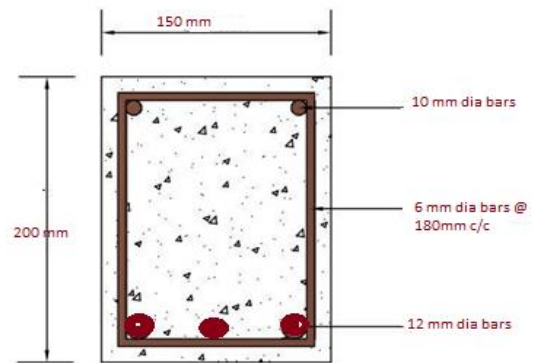


FIG -1: C/S OF BEAM

5. CARBON FIBER REINFORCED POLYMER STRENGTHENING APPLICATION

Four beams of the same reinforced concrete characteristics as previously discussed are constructed. Before bonding the composite fabric onto the concrete surface, the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with manufacturer's instructions. Beam 1 is used as the control beam, Beam S1, S2 and S3 are strengthened with CFRP fabric along the three sides (two sides and soffit). CFRP wrapping is done with 300mm width fabric at 100mm spacing as indicated in application procedure. Following figures present a better view for the actual application.



FIG-2: GRINDING TOP AND SIDE SURFACE OF BEAM



FIG-3: BEAM SURFACE AFTER GRINDING



FIG-4: APPLICATION OF EPOXY AND HARDENER ON THE BEAM

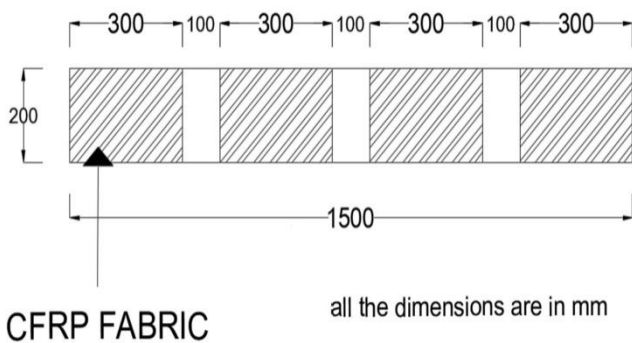


FIG-5 : Orientation CFRP fabric

6. TESTING

All the specimens are tested in the loading frame of the “Structural Engineering” Laboratory of UNIVERSITY VISWESHWARAYYA COLLEGE OF ENGINEERING, BANGALORE. The testing procedure for the entire specimen is same. After the curing period of 28 days was over, the beam is washed and its surface is cleaned for clear visibility of cracks. The most commonly used load arrangement for testing of beams will consist of two-point loading. This has the advantage of a substantial region of

nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. If the shear capacity of the member is to be assessed, the load will normally be concentrated at a suitable shorter distance from a support.



FIG-6 TEST SET UP FOR CONTROL BEAM CB1



FIG-7 TEST SET UP FOR FPR STRENGTHENED BEAM

Two-point loading can be conveniently provided by the arrangement shown in Figure. The load is transmitted through a load cell and spherical seating on to a spreader beam. This beam bears on rollers seated on steel plates bedded on the test member with mortar, high-strength plaster or some similar material. The test member is supported on roller bearings acting on similar spreader plates.

The following measures and characteristics are observed before actual testing:

- Concrete minimum strength was 20 MPa and cured for a minimum 28 days
- Bonding or application of CFRP for 7 to 10 days for proper curing
- Mechanical dial gauges are used for measuring center load deformation
- Supports set up correctly as well as loads at $L/3$ apart

The following procedures were followed during testing

- Beams are loaded in 2 point static loading through two symmetrical concentrated loads applied at one-third the span length
- Load applied at a rate of 10 KN/min
- Deflection was measured and cracks were traced at each load increment
- Experimental data was tabulated

7. CONCRETE PROPERTIES

Compressive strengths are obtained by crushing three 150*150*150 mm cube for each concrete batch. The results revealed concrete compressive strengths at testing ages are slightly higher than the mix design target strength. The average compressive strength at 30 days after casting was about 31.99 MPa.

8. EXPERIMENTAL RESULTS

• Beam CB1 (Control Beam without Carbon Fiber Reinforced Polymer)

Beam 1 is the control beam. This beam is used as a reference for the members strengthened with CFRP materials. From results, one can deduce that the maximum load capacity of the controlling beam is 135 KN. The deflection corresponding to this load is 9.65 mm. Central cracks propagated starting at a 35 KN load and continued until a major failure in the flexure zone occurred as expected. Yielding of steel was at a second stage until total crushing took place.

• Beam S1 (Single layer CFRP Strengthened beam)

The second beam is similar to the first but having a carbon fiber reinforced polymer (CFRP) fabric applied to the both lateral sides and bottom of the beam for flexure. The results indicate that the initial crack is seen in Beam S2 at the load of 40KN before wrapping. Once the beam is unloaded and retrofitted, the results indicated that Beam 2 can handle a 220 KN load with a deflection of 9.1mm at failure. This beam test revealed premature debonding of the strip.

• Beam S2 (Single layer CFRP Strengthened beam)

The third beam is similar to the control beam but having a carbon fiber reinforced polymer (CFRP) fabric applied to the both lateral sides and bottom of the beam for flexure. The results indicate that the initial crack in Beam S2 appeared at the load of 43KN before wrapping. Once the beam is unloaded and retrofitted, the results indicated that Beam 2 can handle a 200 KN load with a deflection of 8.7mm at failure. This beam test revealed premature debonding of the strip, especially at support areas, due to the high shear stress and also widening of flexural cracks at the mid span.

Beam S3 (Single layer CFRP Strengthened beam)

The fourth beam is similar to the control beam but having a carbon fiber reinforced polymer (CFRP) fabric applied to the both lateral sides and bottom of the beam for flexure. The results indicate that the initial crack in Beam S3 appeared at the load of 38KN before wrapping. Once the beam is unloaded and retrofitted, the results indicated that Beam 2 can handle a 200 KN load with a deflection of 9.9mm at failure. This beam test revealed premature debonding of the strip, especially at support areas, due to the high shear stress.



FIG-8: Failure mode of strengthened beam



FIG-9: Failure mode of strengthened beam

9. DISCUSSION OF TEST RESULTS

The percentage of increase in load carrying capacity is significant, as shown in chart 2. The load increased by 63, 49 and 49% between Beams 2 to 4, respectively, when compared to the control beam. An increase in load capacity between each type of beam when compared to each other is also shown. Data collected for deflection shows a drastic improvement in serviceability of strengthened members between the strengthened and control beam at different loads. This is similar to all beams when compared with each other at specific loads. In addition, when conducting the test, again in stiffness of members was one of the most important factors that varied from one specimen to another. All the specimens showed three stages: pre cracking, cracking to yield, and

yield to crushing. Cracking stages improved with improving application of CFRP fabrics on two sides and soffit. The more wrapping used, the better the specimen performed in terms of shear, bondage, flexural strength, and duration for total destruction of reinforced strengthened members.

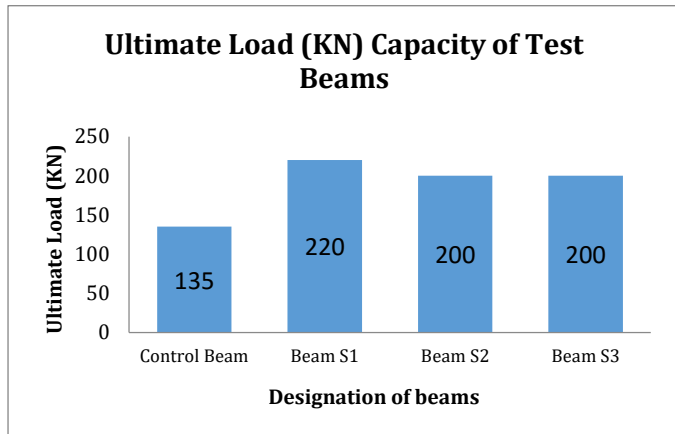


Chart-1: Ultimate Load Capacity of Test Beams

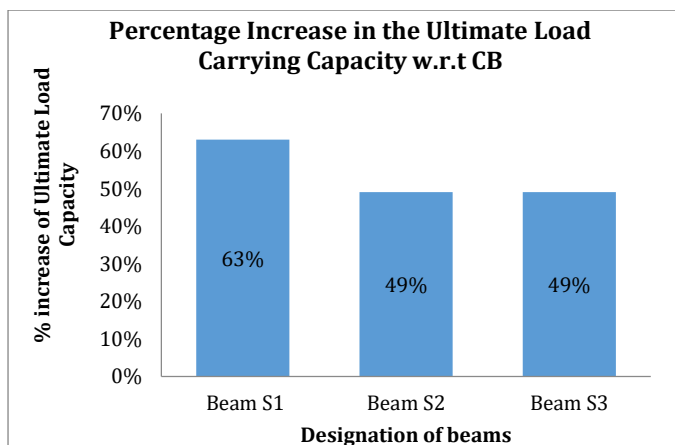


Chart-2: Percentage Increase In The Ultimate Load Carrying Capacity Of Strengthened Beams w.r.t CB

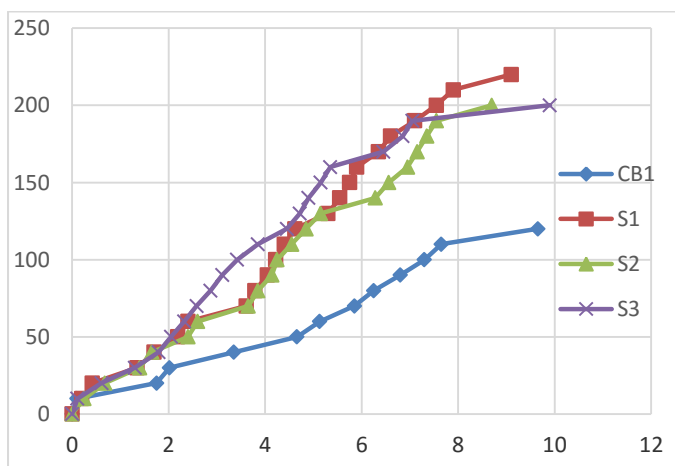


Chart-3: Comparison of load vs deflection curve for four beams

10. CONCLUSION AND RECOMMENDATIONS

It can be concluded from experimental results that the use of CFRP materials is one of the most powerful techniques for strengthening concrete structural reinforced members. Strengthening of RC beam with the CFRP fabric results in an increase in load carrying capacity as well as an increase in stiffness. Better performances and serviceability measures are encountered when wrapping is done on the two lateral sides and soffit. Stiffness and rigidity of members progress with an increased application of CFRP fabrics, which avoids crushing or the total destruction of members without warning.

These results indicate that the application of CFRP fabrics whenever needed, taking into consideration of area of the CFRP fabric, rigidity and stiffness does actually results in an increase of strength of beams and provides additional load carrying capacity.

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BIOGRAPHY



I am Chetan Yalburgimath, ME (structures) pursued my post graduation from UVCE Bengaluru. Currently I am doing research on FRP composites.