Strengthening of RCC Beams with FRP

Ratheesh G
PG Student
Department of Civil Engineering
Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

Shibi Varghese
Professor
Department of Civil Engineering
Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

Abstract

The use of fiber reinforced polymer in the repair and strengthening of reinforced concrete members is currently being discussed worldwide. Fiber reinforced polymer application (FRP) is a very effective way to repair and strengthen structures that have become weak due to life span and design defects. FRP repair systems provide an economically viable alternative to traditional material and repair system. Experimental investigations on the flexural behavior of RC beams strengthened using continuous fiber reinforced polymer (FRP) sheets were carried out. Externally reinforced concrete beam epoxy-bonded GFRP (Glass fiber reinforced polymer) sheets are tested to failure using symmetrical two point concentrated static loading system. Three sets of beams were casted for this experimental test program and tests were carried out by varying the number of fiber layers.
Keywords- Glass Fiber Reinforced Polymer, U Wrap, Control Beams, Strengthened Beams

I. INTRODUCTION

The maintenance, rehabilitation of structural members, is one of the most important problems in civil engineering. A large number of structures constructed in the past using the older design codes are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. FRP s exhibit several improved properties such as high strength-weight ratio, high stiffness- weight ratio, flexibility in design, non-corrosiveness, high fatigue strength and ease of application. The use of fiber composites does not significantly increase the weight of the structure of a member. Because of their light weight, the transportation of FRP materials has minimal environmental impact. These various factors in combination lead to a significantly simpler and quicker strengthening process than when using steel plates. . Research has shown that FRP can be used very efficiently in strengthening the concrete beams weak in flexure, shear and torsion. The current Indian concrete design standards do not include any provisions for the flexural, shear and torsional strengthening of structural members with FRP materials.

II. DETAILS OF MATERIALS USED

The specifications and the properties of materials used for casting and strengthening of specimens are:

A. Cement

In the test, Ordinary Portland Cement (OPC) of 53 grade conforming to IS: 12269-1987 was used for the casting of specimens. Properties of cement used are given in the table given below.

Table 1: Properties of Cement

Sl. No.	Properties	Test results	IS specification
1	Specific gravity	3.023	3.15-3.19
2	Standard consistency (%)	32	26-33
3	Initial setting time (minutes)	76	>30
4	Final setting time (minutes)	360	<600

B. Fine Aggregate

Manufactured sand was used for the study. It is crushed aggregates produced from hard granite stone which is cubically shaped with grounded edges, washed and graded with consistency to be used as a substitute of river sand. The properties of coarse aggregate used for the study are given in table.

Table 2: Properties of fine aggregate

Sl. No.	Properties	Test results
1	Specific gravity	2.74
2	Water absorption	2.47%
3	Fineness modulus	3.07
4	Grading zone	Zone II

C. Coarse Aggregate

Coarse aggregate used are two types, 20mm and 12mm.The properties of coarse aggregates are given in the table.

Table 3: Properties of coarse aggregate

Sl. No.	Properties	Test results
1	Specific gravity	2.75
2	Water absorption	1.11%
3	Aggregate crushing value	29.82

D. Reinforcing Steel

HYSD steel bars of 415 grade of 10, 8 and 6 mm diameter were used as reinforcement for the beam specimen.

E. Concrete

The concrete mix was designed as per standard design procedure. The mix used was M25.The mix proportion was 1:2.18:3.74 and a w/c ratio of 0.45 were adopted.

F. FRP (Fiber Reinforced Polymer)

FRP used was a composite material made by combining glass fiber sheet and epoxy resin to give a new combination of properties. Fiber sheet used in this experimental study was E-Glass, bi directional woven mat. The properties are given below.

Table 4: Properties of Glass fiber

Modulus of elasticity	72KN/mm²
Tensile strength	3445N/mm²
Density	2.55g/cm³
Colour	White
Thickness of sheet	0.8mm
Width of sheet	1000mm
Ultimate strain %	4.5

The epoxy resins are generally two part systems, a resin and a hardener. The resin and hardener used in this study - Araldite AW 106 and Hardener HV 953. The ratio of mixing of resin and hardener was Araldite AW106– 100 parts by weight and Hardener HV953– 80 parts by weight.

III. EXPERIMENTAL PROGRAMME

The experimental program included three set of beams. The beams in SET I were designed as controlled specimen (CB1, CB2), where no FRP application was carried out, the beams in SETII were designed to investigate the effect of full wrapping technique 90º(3 sided U wrap), for flexural strengthening provided by using single layer Glass FRP (SB1,SB2) and SETIII were double layer wrapped beams(SB3,SB4).The entire reinforcement details, which were followed for all the three groups of beams are given below.

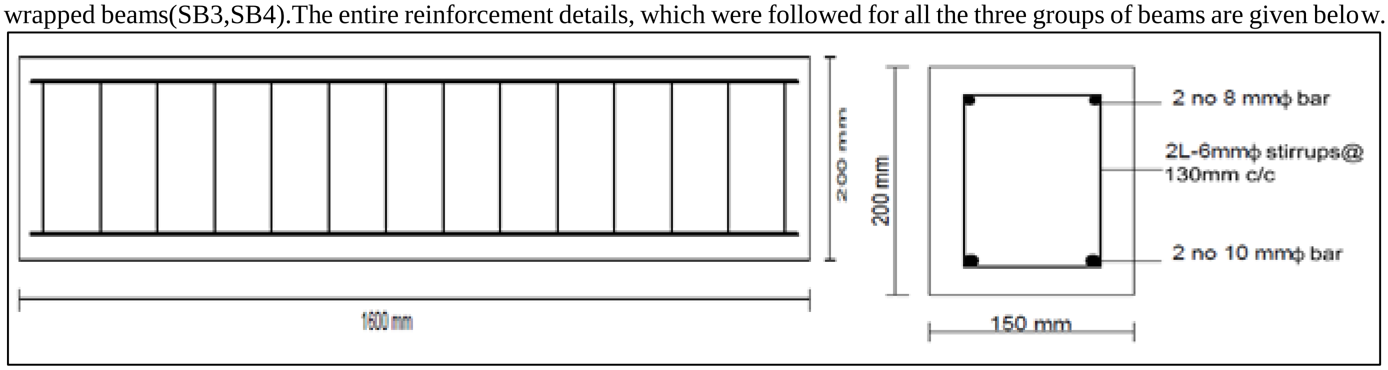

Fig. 1: Detailing of Reinforcement

Beams were casted using ply wood form work. After demoulding the specimens were cured for 28 days. The beams were prepared by grinding three side surfaces; this was done so as to roughen the three sides of the beam where FRP application would be carried out. After grinding, all the three side surfaces of the beams were cleaned to remove any dust particles .In the same way circumferential area of the columns were prepared. The ratio of mixing of resin and hardener was also followed as per the manufacturer guide-line, Araldite AW106– 100 parts by weight and Hardener HV953– 80 parts by weight. The epoxy resin was applied to the concrete surface and on the fiber sheet which was cut in the desired dimension. Fiber sheet was wrapped below the neutral axis of beams. The glass fiber sheets were wrapped in the specimens. Air bubbles entrapped at the interface were also eliminated. All the strengthened concrete beams were cured for 24hours at room temperature before the beams were tested.

Fig. 2: Casting of Beams

Fig. 3: Casted Beams

Fig. 4: Applying Glass Fiber Sheet on Beams

Fig. 5: Strengthened Beams with FRP

IV. EXPERIMENTAL SETUP

A two-point loading system was adopted for the test of beams. The specimen was placed over the two steel rollers bearing leaving 100 mm from the ends of the beam. The remaining 1400 mm was divided into three equal parts. Loading was done by hydraulic jack of capacity 500 KN. One dial gauge was placed just below center of the beam. At the end of each load increment, deflection, ultimate load, type of failure, etc., were carefully observed and recorded.

Fig. 6: Testing of Control Beam

Fig. 7: Testing of FRP Wrapped Beam

V. RESULTS AND DISCUSSIONS

The average value of ultimate load carrying capacity of all set of beams along with the nature of failure and deflections are described in the table

Table 5: Summary of Results

Group designation	*Failure of FRP*	*Deflection at mid span (mm)*	*Ultimate load(KN)*	*Strengthening effect (%)*
SET I	-	*18.25*	*54*	-
SETII	*Yes*	*26.18*	*79.5*	*48%*
SETIII	*Yes*	*28.65*	*86*	*60%*

A. Load vs. Deflection

Variation of deflection with load is rapid for control beam compared to single and double layer wrapped samples. Gradual variation of deflection with load is for double layer wrapped beam compared to single layer wrapped samples. For a certain value of load, deflection is maximum for control sample followed by single layer sample and double layer sample.

B. Ultimate Load Carrying Capacity

The strengthen beams had the higher load carrying capacity compared to the control beams. Control beam, single layer FRP wrapped beam, double layer FRP wrapped beam has ultimate load carry capacity of 54 KN, 79.5KN, 86KN.

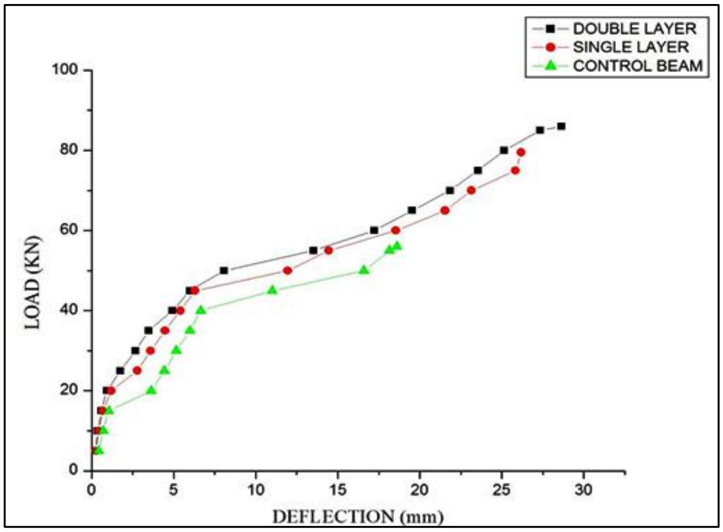

Fig. 8: Comparison of Load vs. Deflection of Samples

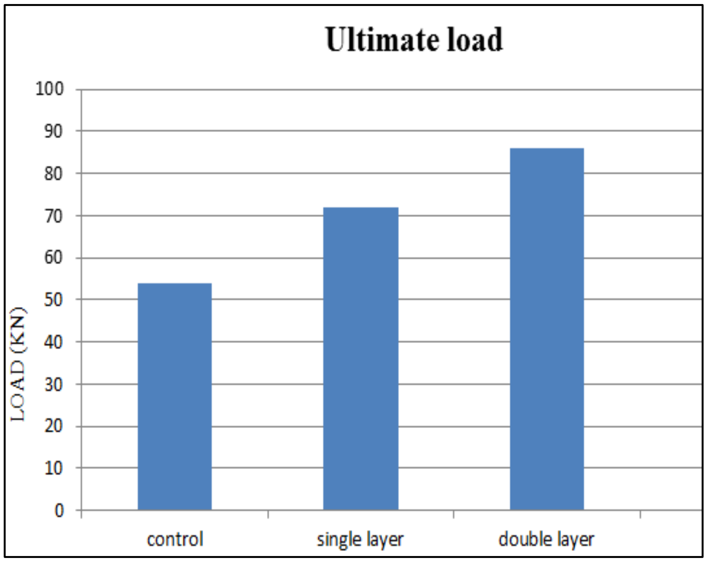

Fig. 9: Ultimate Load

C. Modes of Failure

Since all the strengthened and unstrengthen beams were simply supported, hence large number of flexural cracks developed in the tension zone and these cracks propagates during the increase in loading. The beam curvature and deflection increases and the collapse by yielding of steel and crushing of concrete in compression zone. In the case of strengthened beams, cracks were not visible due to the GFRP wrapping. Cracking sound could be heard during loading. During loading of specimen, then firstly the rupture of FRP was observed at the center followed by FRP deboning .Deboning occurred at the two sides as well as on bottom side of the beam. Ultimate load capacity was reached and failure occurs. Rupture of the FRP laminate is assumed to occur when the strain in the FRP reaches its design rupture.

Fig. 10: Flexural cracks on control beams

Fig. 11: Fracture on fiber sheet

Fig. 12: Fiber sheet debonding from sides

Fig. 13: Fiber sheet debonding from bottom

VI. CONCLUSION

- The single layer glass fiber wrapped beams can carry 48% extra load than the control beams
- The double layer glass fiber wrapped beams can carry 60% extra load than control beams
- The deflection of single layer glass fiber wrapped beams at a certain load is lesser than that of control beams
- The deflection of double layer glass fiber wrapped beams at a certain load is lesser than that of single layer glass fiber wrapped beams
- FRP debonding, failure by FRP rupture are the important mode of failures of FRP
- There remains substantial reserve capacity of beam even after the yielding of steel

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