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RESEARCH ARTICLE

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Shear Strengthening of Reinforced Concrete Beams Using Flexural FRP Sheets

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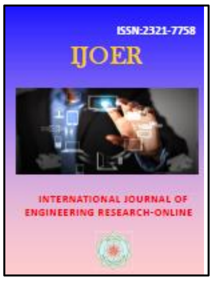

ABSTRACT

Many reinforced concrete (RC) buildings in several countries were recognized as structurally deficient either due to construction faults, increase in live load or by change in the climatic conditions. Due to these reasons, structural strengthening became an essential requirement and different strengthening techniques appeared in market. Fiber Reinforced Polymer (FRP) sheets have become more popular due to their lightweight, high tensile strength and ease to install. These sheets can easily be externally bonded to RC elements. Strengthening of RC beams in flexure using FRP sheets have proved to be effective in increasing their performance in flexure when they were bonded to the bottom portion of beams. However, the contributions of these flexural FRP sheets to shear were not studied much. Shear failures in beams are sudden in nature and hence need to be avoided. This paper studies the shear contribution of flexural FRP sheets when the beams were strengthened in the flexural region. RC beams that were designed to fail under shear were casted and FRP sheets were bonded to the bottom of beams and tested under four-point bending. The beams were externally bonded with single layer of Carbon Fiber Reinforced Polymer (CFRP) and Basalt Fiber Reinforced Polymer (BFRP) sheets. The shear strength of the FRP strengthened specimens was found to be increased when compared to shear critical RC beams.

Keywords— Concrete, Flexural FRP sheets, FRP strengthening, Shear deficient beam, Shear strength

I. INTRODUCTION

Today, many reinforced concrete (RC) buildings are suffering from various deteriorations, cracks, concrete spalling, large deflection, etc. which needs to be repaired or strengthened to support the designed loading. There are several methods for repairing or retrofitting structural members of existing RC members. The commonly used methods are to bond thin steel and/or fiber reinforced polymer (FRP) sheets onto the damaged surface to restrain cracks and to increase the load carrying capacity, ductility and stiffness of structural members that were strengthened. Strengthening of structural members such as slabs, beams, and columns using FRP composite materials such as carbon, basalt, glass etc. has gained wide acceptance due to its high strength to weight ratio, high stiffness, flexibility, ease of installation, and resistance to corrosion as compared to other materials [4, 12]. FRP composites had proved that it could provide an enhanced strength, stiffness and energy absorption characteristics to the deficient structural members [5, 6, 12, 13, 14, 17]. These fibers were found to strengthen the beams in shear, flexure or both [1, 2, 9, 10, 15]. External FRP reinforcement used for longitudinal strengthening of RC beams was found to play similar role as that of the internal longitudinal reinforcement in affecting the flexural performance of the beams. These sheets also have the ability to improve the flexural strength of the beams by transferring the yield points from steel reinforcement to FRP as FRP has higher yield strength when compared to steel bars [1, 16, 19]. The mode of failure of concrete beams could also be changed from a brittle shear to flexure failure [8, 11, 19]. FRP sheets may either be bonded to the soffit of the beam in order to strengthen them in flexure or to sides of the beam to strengthen them in shear [1]. Practically, it is always possible to bond the FRP sheets to bottom portion of beams rather than to the flanks. Therefore, it is expected that flexural FRP strengthening will play similar role as that of the internal longitudinal reinforcement in influencing the shear performance of the beams [3, 7, 18]. Many experiments had been conducted to study the flexural performance of FRP composites when they were bonded to the soffit of the beam. However, only a fewer number of studies were conducted to evaluate the effect of flexural FRP on the shear strength of reinforced concrete beams. Shear failures are sudden in nature and hence they must be avoided. The contribution of FRP flexural strengthening on the shear strength of beams must be investigated so that the shear strengthening procedure could be effectively done.

II. PROPERTIES OF MATERIALS USED

A. Concrete: Concrete used for the experimental study was made from mixing coarse and fine aggregates along with cement and water. In order to obtain workability, admixtures were also added to the fresh concrete. Ordinary portland cement (OPC) of grade 53 was used in the experimental study. The coarse aggregate of nominal maximum size of 10mm is used and the fine aggregate was locally available manufactured sand (M-Sand). The admixture used is MasterGlenium® SKY 8233 for increasing the workability to obtain the required range of slump. Potable water that was free from harmful impurities was used for mixing and curing of specimens throughout the experiment. All the materials conform to Indian Standard specifications. The grain size analysis for fine aggregates was also performed and it belongs to Zone I as per IS 383:1987. The design mix for M25 concrete was performed and the design details were shown in Table I. The compressive strength of concrete obtained for 28 days was 32.89N/mm^2.

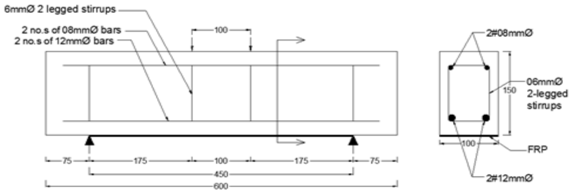

Fig. 1 Reinforcement details of beam specimen

TABLE I: MIX DESIGN DETAILS

Mix proportion	1:3.32:2.72
Mass of cement per m^3 of concrete (kg)	377.267
Mass of coarse aggregate per m^3 of concrete (kg)	860.19
Mass of fine aggregate per m^3 of concrete (kg)	1024.34
Water-Cement ratio	0.45
Percentage of admixtures by weight of cement (%)	0.25
Slump (mm)	135

B. Reinforcement: 12mm and 8mm diameter high-yield strength deformed bars were used as tensile and compression reinforcements respectively. Two-legged stirrups of 6mm diameter mild steel bars were used.

C. Fiber Reinforced Polymer: Continuous fiber reinforced materials with polymeric matrix in the form of polymer sheets were used for the strengthening procedure to the RC beams. Two types of FRP sheets were used in the experimental study namely Carbon FRP and Basalt FRP. CFRP and BFRP sheets of thickness 0.25mm and 0.3mm were used respectively (Fig. 2).

(a) CFRP sheet (b) BFRP sheet

Fig. 2 FRP sheets used in the study

D. Epoxy Resin: Araldite AW106 with Hardener HV 953 IN is used as epoxy resin in order to bond FRP sheets to concrete. Equal quantity by volume of Araldite and Hardener are mixed thoroughly in order get adequate bonding property.

III. EXPERIMENTAL STUDY

A. Specimen Details: Beam specimen size considered for the experiment was 100mm wide, 150mm deep and 600mm long. The specimens were tested under four-point bending with load point spacing of 100 mm with an effective span of 450 mm as shown in Fig. 1. The dimensions and reinforcements of the beam were designed such that the beam is deficient under shear. The details of various specimens casted are shown in Table II.

TABLE II: SPECIMEN DETAILS

Sl no.	Specimen	Mix	FRP sheets provided
1	BO	M25	None
2	BB1	M25	1 layer of BFRP
3	BC1	M25	1 layer of CFRP

B. Preparation of the Specimen: Steel moulds are used for the casting of beams. Reinforcements were tied together as per design and placed in the mould with a concrete cover of 25 mm (Fig. 3). Concrete was mixed and placed in the mould in layers and vibrated thoroughly. The top surface of the concrete is levelled and finished (Fig. 4). The same procedure continued for all the three specimens.

Fig. 3 Mould used for casting beams

Fig. 4 Casted concrete beam

The specimen is demoulded after 24 hours and curing was started after the demoulding of specimen. After curing for 28 days, FRP was bonded to the bottom of all the beam specimens except for the control specimen. The bottom side of the beam is roughened and excess dust is removed and a thin layer of epoxy is coated (Fig 5). The FRP sheet is cut, pasted on the concrete surface and rolled it with a smooth roller to have an effective bond between FRP sheets and concrete (Fig 6).

Fig. 5 Application of epoxy resin

Fig. 6 Application of BFRP sheet

C. Test Setup: The beam specimens were tested under four-point bending test in a universal testing machine (UTM) of capacity 1000kN (Fig. 7). The specimens were simply supported with an effective span of 450mm and the specimens were loaded gradually until failure. The central deflection of the specimens was noted using a dial gauge of least count 0.01mm.

Fig. 7 Loading setup

IV. TEST RESULTS

A. Load Carrying Capacity: The ultimate load and ultimate deflection observed during the test for all the specimens were displayed in Table III.

TABLE III: OBSERVED RESULTS

Sl no.	Specimen	Ultimate load (kN)	Ultimate deflection (mm)	Mode of failure
1	BO	104	3.26	Diagonal shear failure
2	BB1	112	3.45	Diagonal shear failure
3	BC1	123	2.98	Diagonal shear failure

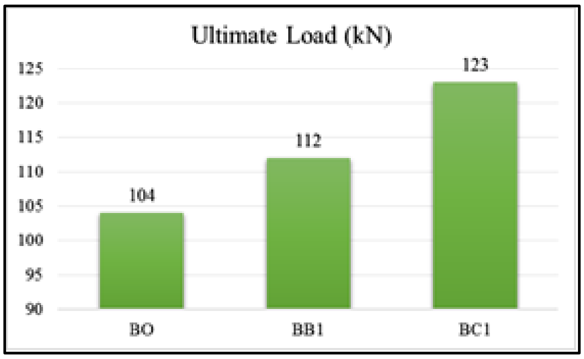

Fig. 8 Ultimate load

The ultimate load of the specimens bonded with FRP sheets (BB1&BC1) were increased when compared to the control beam (BO). The increasing trends and the percentage increase in the ultimate load were shown in Fig 8 and Table IV respectively. CFRP sheets increased the strength of beam compared to BFRP sheets.

TABLE IV: PERCENTAGE INCREASE IN ULTIMATE LOAD

Particulars	**Percentage increase in ultimate load with control beam BO (%)**
In BB1 with BO	7.69
In BC1 with BO	18.27
In BC1 with BB1	9.82

In a reinforced concrete structure, the excessive deflection of the beam may adversely affect the appearance and stability of partitions or finishes provided in the building. The maximum deflection for a beam as per Cl 23.2 of IS 456:2000:

Maximum deflection = span/250
= 450/250 = 1.8 mm

The load values corresponding to the deflection 1.8 mm for BO, BB1 and BC1 were shown in Table V.

TABLE V: LOAD CARRYING CAPACITY OF STRENGTHENED BEAMS

Specimen	Load corresponding to deflection of 1.8mm (kN)	Percentage increase in load with control beam BO (%)
BO	81.25	-
BB1	85.96	5.8
BC1	100.45	23.63

B. Deformation Characteristics: The values of deflection corresponding to load increments during the test were noted and a graph was plotted between load and central defection (Fig. 9).

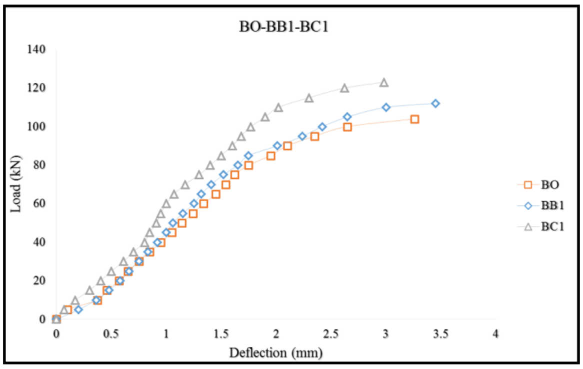

Fig. 9 Load vs deflection curve for all specimens

The path of load-deflection curve for the BFRP strengthened beam (BB1) was similar to that for control beam (BO). However, the CFRP strengthened specimen (CB1) has reduced the early deflection when compared to other specimens.

The deflection for the strengthened specimens for the ultimate load value of control beam (104kN) was compared and found that the strengthened specimens have greatly reduced the deflection for a load of 104kN (Table VI).

TABLE VI: PERCENTAGE REDUCTION IN DEFLECTION

Specimen	Deflection corresponding to load 104 kN (mm)	Percentage reduction in deformation with control specimen (%)
BO	3.26	-
BB1	2.6	20.24
BC1	1.88	42.33

C. Failure Patterns: All the beams failed in shear. The diagonal shear cracks were formed on the sides of the control beam. Similar crack pattern was observed for all the specimens and confirmed that all the beams were failed in shear (Fig. 10). There were no signs of flexural cracks on the beams as the beam's tensile reinforcement was sufficient enough to bear the loads acting on it. The FRP sheets remained bonded to the concrete surface avoiding debonding failure.

Fig. 10 Crack patterns for all beams

V. CONCLUSIONS

The contribution of flexural FRP sheets towards the shear strength of RC beams were investigated and found that FRP sheets not only increased the load carrying capacity but also reduced the deflection of beam. FRP sheets could increase the load carrying capacity in the range of 7% - 18% in comparison with the control beam. CFRP sheets performed much better than the BFRP sheets in increasing the load carrying capacity and reduction in deformation. However, BFRP sheets could reduce the deflection of beams during working loads in comparison with the unstrengthened beam. All the beams were failed in shear as designed forming diagonal cracks on the sides of beam specimens.

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