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A STUDY ON THE BEHAVIOUR OF RC BEAMS RETROFITTED USING CFRP LAMINATES UNDER SINGLE POINT LOADING

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ABSTRACT

The technique of strengthening of reinforced concrete beam with externally bonded CFRP has been successfully applied in Civil Engineering. This paper discusses the effect of shear and flexural strengthening of RC beams on the stress distribution, initial crack, crack propagation and ultimate strength. The experimental programme includes testing of five reinforced concrete beams of which three beam specimens are casted with bonding CFRP and the remaining two beams without CFRP which is considered as the control beam and the retrofitted beam. The CFRP epoxy bonded specimens are Semi-wrapped beam (ASW-F), U wrapped beam (AUW-U) and beam wrapped in the flexural zone (AFW-D). The specimens are casted with M20 design mix. The deflection, ultimate load, cracking, shear and flexural failure for rectangular beams bonded with CFRP are investigated. The general and regional behaviour of concrete beams with bonded CFRP are studied with the help of strain gauges. The appearance of the first crack and the crack propagation in the structure up to failure are also monitored. It is concluded that in beams bonded with Semi wrapped (ASW-F) and U-wrapped (AUW-U), there is a delay in the formation of initial crack and the ductility ratio is more, which is desirable in earthquake prone areas.

Key words: CFRP wrap, U-wrap, Carbon fiber reinforced plastic laminates, Composite beams.

INTRODUCTION

Fiber reinforced plastic (FRP) composite is a polymeric matrix that is reinforced with strong stiff-fibers. The main types of fiber used in Civil Engineering applications are

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carbon, glass, and aramid. The most common form of FRP (fiber reinforced plastic) composites used in structural applications is called laminates. Laminates are made by stacking a number of thin layers of fibers and matrix and consolidating them into the desired thickness. Unidirectional FRP sheets made of Carbon fiber (CFRP) bonded together with a polymer matrix (eg. Epoxy, Polyester, Vinly ester) are being used as a substitute for steel plates. Advantages of CFRP fibers are light weight, eco-friendly, easy to handle.

This paper provides the results of an experimental investigation on using CFRP Sheets to prevent local cracks around flexural and shear region in reinforced concrete beams.

Literature review

Bukhari et al. (2010) carried out an experimental programme which evaluated the contribution of CFRP sheets towards the shear strength of seven, two-span concrete continuous beams with rectangular cross-sections. The control beam was not strengthened, and the remaining six were strengthened with different arrangements of CFRP sheets. The experimental results showed that the shear strength of the beams was significantly increased by the CFRP sheet and that it is beneficial to orientate the FRP at 45^0 to the axis of the beam.

Ehsan Ahmed et al. (2011) experimentally investigated the flexural behaviour of five reinforced concrete beams strengthened with CFRP laminates attached to the bottom of the beams by epoxy adhesive subjected to transverse loading. Four beams were strengthened by changing the levels of CFRP laminates whereas the last one was not strengthened with FRP and considered as a control beam. Test results showed that the addition of CFRP sheets to the tension surface of the beams significantly improved the stiffness and ultimate capacity of beams. It was observed that tension side bonding of CFRP sheets with U-shaped end anchorages was very efficient in flexural strengthening. Maghsoudi and Bengar (2011) investigated the serviceability and ultimate behaviour of four RC continuous beams strengthened with carbon FRP (CFRP) sheets, in flexure along their sagging and hogging regions. The results showed that by strengthening the beams, lower rate of transition of flexural rigidity from the un-cracked to the fully cracked section occurred. Petkova et al. (2014) studied the behaviour of CFRP strengthened flexural elements on the effect of elevated temperatures after heating and cooling. The behaviour of RC beams retrofitted using carbon fiber reinforced plastic laminates under actual loading was discussed.

EXPERIMENTAL

In the experimental programme, tests are conducted on reinforced concrete beams with external bonding of CFRP sheets in the flexural and shear zone. The beams are tested under single point loading to investigate their structural behaviour. The objective of this experimental investigation is to determine the

- Flexural and Shear strength of RC beam;
- Failure pattern of RC beams and
- Flexural and Shear strengthening of RC beams using CFRP (carbon fibre reinforced polymer) sheets.

Five rectangular RC beams are casted and tested under single point loading. Out of five beams, one is a control beam and another one is a retrofitted beam. The CFRP epoxy bonded specimens are Semi wrapped beam (ASW-F), U-wrapped beam (AUW-U) and beam wrapped in the flexure zone (AFW-D).

Beam dimension details

Size: 150 x 200 x 1800 mm

Grade of concrete: M20,

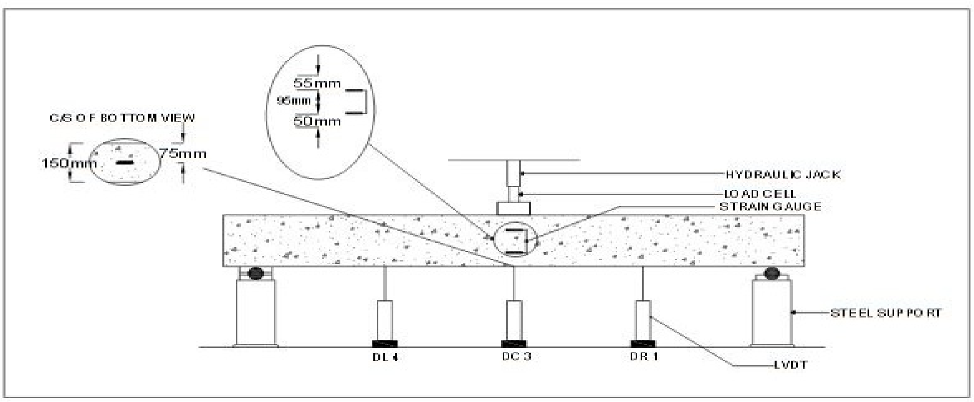

Fig. 1: Shows the position of strain gauges

Type of material

Sheet: Carbon fibre reinforced plastic glue for bonding: Nitowrap 40 (Base), Nitowrap 40 (Hardener).

Fig. 1 shows the position of strain gauges in the beams tested. Fig. 2 shows the test setup of the control beam. Table 1 shows the details of specimens and reinforcement.

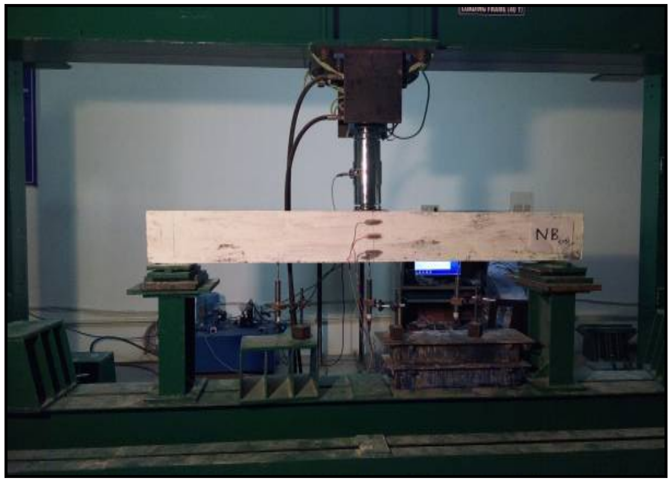

Fig. 2: Test setup of the control beam

Table 1: Details of the specimen and reinforcement

Details of beam	Types of beam	Testing of beam (days)	Reinforcement in beam	
			Longitudinal	Stirrups
Control beam	C B	28	2-8# @ top and 4-10# @ bottom	6 mm # stirrups @ 150 mm C/C
Retrofitted beam	R B			
Semi wrapped beam	ASW-F			
U-wrapped beam	AUW-U			
Beam wrapped in the flexural zone	AFW-D			

Material properties

The concrete used in the experimental program is M_{20} and steel with nominal yield strength of 415 N/mm^2 are used as the longitudinal reinforcement.

Properties of Nitowrap

Table 2 and 3 show the properties of Nitowrap CFP 50, Nitowrap 40 (Base), Nitowrap 40 (Hardener), respectively.

Table 2: Nitowrap CFP 50

Nitowrap CFP 50	CFP 50
Nominal thickness	1.2 mm
Nominal width	50 mm
C/S area	60 mm^2
Young's modulus	>165000N/mm^2
Tensile strength	>2800 N/mm^2
Elongation at break	1.7%

Table 3: Nitowrap 40

Compressive strength	40 N/mm^2 at 1 day 75 N/mm^2 at 7 day
Shear strength	13 N/mm^2
Pot life	30 min. @ 40^{o}C
Open time	60 min. @ 40^{o}C
Curing time	7 days

Surface preparation

It is ensured that concrete surfaces are free from oil residues, demoulding agents, curing compounds, grout holes and protrusions. Structural damages are repaired by using epoxy grouting appropriate mortar from the Renderoc range. All depressions, imperfections etc. shall be repaired by using Nitocote VF/Nitomortar FC, epoxy putty.

RESULTS AND DISCUSSION

Five rectangular RC beams are casted and tested under single point loading. Out of five beams, one is a control beam and another one is a retrofitted beam. The CFRP epoxy bonded specimens are Semi wrapped beam (ASW-F), U-wrapped beam (AUW-U), and beam wrapped in the flexure zone (AFW-D). Table 4 shows the comparison of ultimate load and maximum deflection of the beams.

Table 4: Comparison of ultimate load and maximum deflection

S. No.	Specimen	First crack load (kN)	Ultimate load (kN)	Maximum deflection (mm)
1	C B	23.5	83.5	15.3
2	RB	25.6	91.1	13.5
3	AUW-U	27.5	85.1	10
4	ASW- F	27.1	89.8	12.5
5	AFW-D	23.5	82.8	10.8

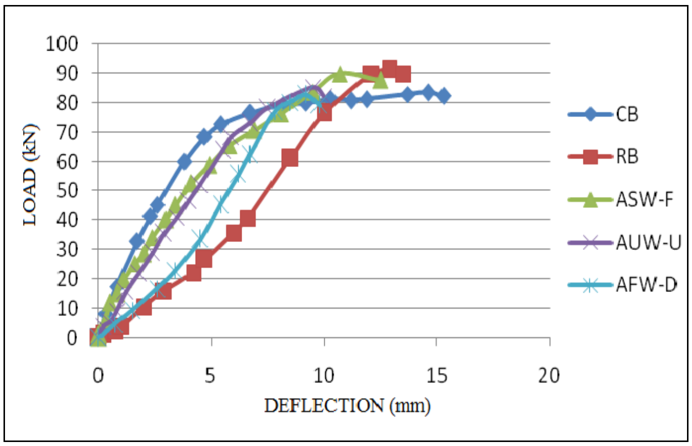

Fig. 3: Load vs deflection behaviour of a all beam specimens

From the load-deflection behaviour, it can be seen that the load carrying capacity is maximum for Retrofitted beam but brittle failure occurs. In AUW-U beam, the initial crack occurs at 27.5 kN which is 10% higher than that of the control beam. The ductility ratio is also more in AUW-U beam which is desirable in earthquake prone areas.

Failure pattern

The cracking patterns of the control beam, Retrofitted beam, U-wrapped beam, Semi wrapped beam and beam wrapped in the flexural zone are shown in Figs. 4 to 8, respectively.

Debonding of CFRP wraps occurred after the initial crack appeared. Fig. 9 to Fig. 11 shows the debonding of CFRP. Sudden failure of AUW-U beam occurred at ultimate load.

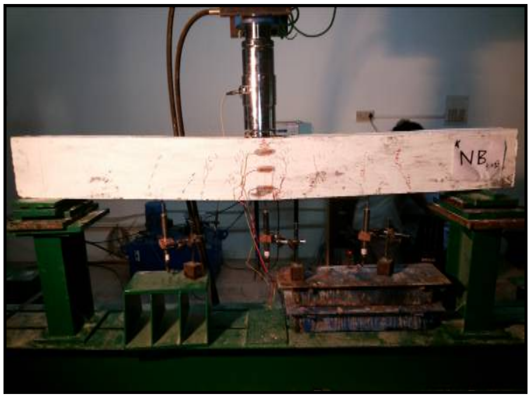

Fig. 4: Cracking pattern of control beam

Fig. 5: Cracking pattern of RB specimen

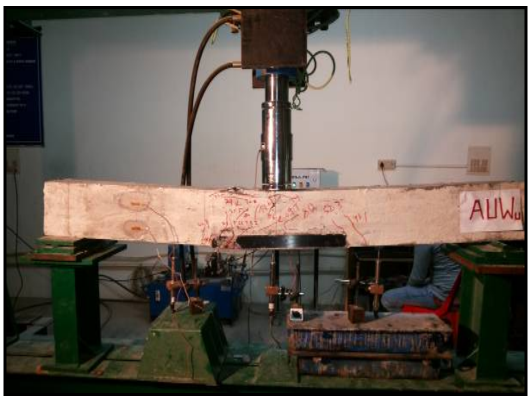

Fig. 6: Cracking pattern of AUW-U specimen

Fig. 7: Cracking pattern of ASW-F specimen

Fig. 8: Cracking pattern of AFW-D specimen

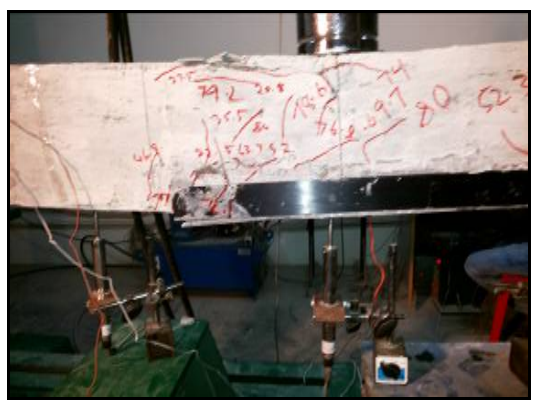

Fig. 9: Debonding of AUW-U specimen

Fig. 10: Debonding of ASW-F specimen

Fig. 11: Debonding of AFW-D specimen

CONCLUSION

Five rectangular RC beams are casted and tested under single point loading. Out of five beams, one is a control beam and another one is a retrofitted beam. The CFRP epoxy bonded specimens are Semi wrapped beam (ASW-F), U-wrapped beam (AUW-U), and beam wrapped in the flexure zone (AFW-D).

Based on the test results the following conclusions are drawn.

(i) Compared to all other specimens, deflection of AUW-U specimen is less and the load bearing capacity is more. However brittle failure occurs.

(ii) In ASW-F beam, the initial crack occurs at 27.1 kN, which is 10% higher than that of the control beam. The ductility ratio is also more in ASW-F beam which is desirable in earthquake prone areas.

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