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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 2, Issue 9, September 2017

Shear Strength of Beam U-wrapped with Symmetrical Angle Ply

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Abstract: **U-wrapped externally bonded Glass Fiber Reinforced Polymer (GFRP) provides a valuable alternative for strengthening of shear deficient beams. The effect of GFRP laminates up to three laminas for strengthening the beams in shear has been studied. The GFRP laminate (00/450/450/00) was wrapped in U-fashion on the beams, to ascertain its suitability for strengthening the beams. Beams, U-wrapped with GFRP all along the span, were tested by four-point loading. The results of the experimental program were validated using the software ANSYS. It has been found that considerable enhancement of shear strength can be achieved for shear deficient beams wrapped with GFRP laminates.**

***Key Words*— GFRP, Symmetric angle ply, Strength.**

I. INTRODUCTION

Retrofitting and strengthening has become an economically viable solution for the distressed structural elements. The use of FRP to repair and rehabilitate damaged steel and concrete structures has become increasingly attractive due to the well-known good mechanical properties of this material, with particular reference to its very high strength to density ratio [1]. The strengthening is the most intuitive strategy to improve the response of the building, and it is largely used currently. It can be easily applied to whole or parts of buildings to correct a weakness or not-homogeneous distribution of strength [2].

90° FRP alignments was found to be most effective for the strength gain while 0° alignment only helped in controlling the propagation of shear cracks to some extent [3]. U-wrapped and bottom wrapped FRPs prove to be good for improving shear strength and reducing deflection of RC members as compared to both sides wrapped FRPs[4].

In this paper, the study was carried out using a series of shear deficient beams that had been experimentally tested for shear strength and the results were validated using ANSYS software.

II. EXPERIMENTAL WORK

A summary of the specimens used for testing of shear deficient beams is given in Table 1. The beams are divided in two distinct categories designated as RB, and B. Here, RB denotes the reference beams, whereas B series describes the beam strengthened with symmetric angle ply (00/450/450/00). The subscript in the last shows specimen number in the series. Sets of five beams each were designed in both categories. The design was done as per the code IS: 456-2000. Specimen beams were 300-mm deep, 150-mm wide, and 2000-mm long. The longitudinal reinforcement consisted of two 12 mm dia for tension and two 10 mm dia for compression. All the beams were designed shear deficient by keeping the spacing of two legged stirrups at a distance of 315 mm. Ordinary Portland Cement of 43 Grade conforming to IS 8112:1989 was used. Standard sand conforming to IS 650: 1991 was used as fine aggregate. M 20 Grade of concrete was used for casting of beams from each batch of which standard cubes of 150 mm side were cast and compressive strength was determined in accordance to IS 516: 1959. The strength after 28 days of curing was found to be 23.67 MPa. Reinforcing steel bars used were of Grade Fe 500. Steel bars were tested under uniaxial tension and average yield stress of the bars was 511 MPa. Tensile strength value of symmetric angle-ply), was found to be 112 N/mm2.

III. EXPERIMENTAL OBSERVATIONS

The beams were subjected to four point loading. Reference Beams were loaded up to the failure in increments of 1kN load. Mid-span deflections were recorded at each load increment. Other beams were U-wrapped with symmetric angle-ply GFRP laminates and mid-span deflections were recorded.

The test results of the beams are presented in this section. Behaviour of the beams, throughout the test, up to failure is described on the basis of the recorded data, observed crack patterns, and failure mode of the reference beams and U-wrapped beams.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 2, Issue 9, September 2017

Reference beams without any external wrapping were tested up to failure. These were loaded in increments. New flexure cracks kept on developing and old flexure cracks between supports enlarged up to a load of 32 kN. After this load, shear cracks appeared at supports. With further increase in the load, the already developed shear cracks enlarged. Beams failed in shear at support at a load of 73 kN. Figure 1 shows the failure mode of the reference beam. Figure 2 shows load-deflection behaviour of the shear deficient reference beams. The load-deflection curves of all the beams show almost linear variation.

Fig. 1 Failure mode of shear deficient RC reference beam

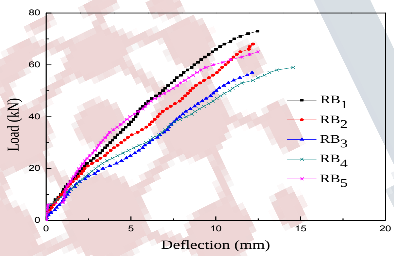

Fig. 2 Load-deflection behaviour of reference beam

Set of five specimens of U-wrapped beams were tested up to failure load. Incremental loads were applied and mid-span deflections were observed. Since the beams were U-wrapped, it was not possible to observe the crack pattern. Loading was discontinued after debonding of GFRP laminates. In case of U-wrapped shear deficient beams, debonding took place from sides of the beams.

Fig. 3 depicts that failure took place due to delamination of GFRP with crushing of concrete in RC beams U-wrapped with symmetric angle-ply (B-SAP) laminate. Load-deflection curves for shear deficient U-wrapped beams are shown in Figs. 4. A linear behavior is observed in almost all the cases.

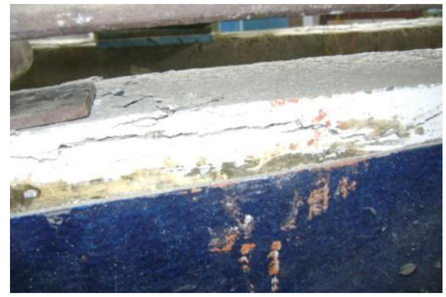

Fig. 3 Failure mode of U-wrapped beams with symmetric angle-ply laminate

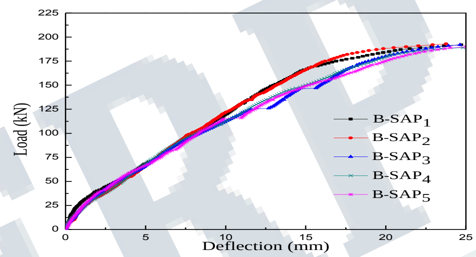

Fig. 4 Load-deflection behaviour of U-wrapped beams with symmetric angle-ply laminate

To validate the experimental results, finite element analysis of full scale reference beam as well as U-wrapped beam were carried out using finite element (FE) software ANSYS. Three dimensional full scale prototypes were developed. Concrete was represented by the SOLID65, 3-D reinforced concrete solid element. The reinforcing steel bars and stirrups were depicted by LINK8, 3-D spar element. GFRP materials were represented by SOLID46, 3-D layered structural solid element [5]. Finite element model was made more efficient and the model complexity, run-time, and memory requirements were reduced by affecting suitable modifications. The finite element mesh, boundary conditions and loading regions of all the beams are shown in Fig 5.

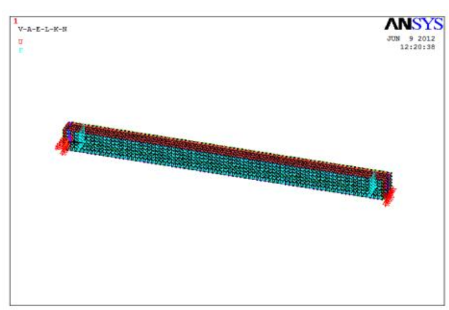

Fig. 5 Boundary conditions of U-wrapped beam

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Table 1 Characteristics of shear deficient reference beams

Name	Serviceability load (kN)	Ultimate load (kN)	Final deflection (mm)
RB_1	56	73	12.47
RB_2	47	68	12.2
RB_3	41	57	12.15
RB_4	39	59	14.56
RB_5	53	65	12.48
$B\text{-}SAP_1$	99	192	24.71
$B\text{-}SAP_2$	101	193	23.76
$B\text{-}SAP_3$	96	192	24.64
$B\text{-}SAP_4$	99	189	24.82
$B\text{-}SAP_5$	96	190	25.00

A comparison of the results of the shear deficient U-wrapped beams with laminates is shown in Figs.6. It can be seen that numerical results are in agreement with the experimentally found values. Beyond a load of 75 kN, however, beam model could not be analysed due to the limitations of the computing system.

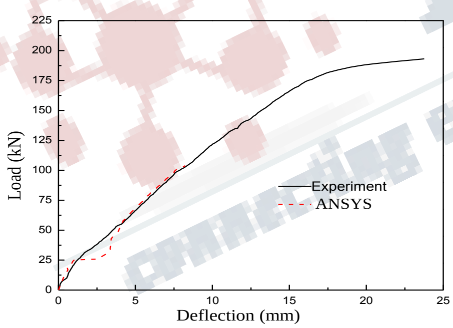

Fig. 6 Comparison of load-deflection behaviour of beam U-wrapped with symmetric angle-ply laminate

IV. DISCUSSIONS AND CONCLUSION

The point where the deflection of the beam is equal to span/250 is defined as the serviceability limit (IS: 456-2000). In the present case the limiting deflection corresponding to serviceability limit is 8 mm. It is observed that at serviceability stage as well as at ultimate stage, the U-wrapped beams showed enhanced load carrying capacity. However, at serviceability stage the percentage increase in load carrying capacity of beams U-wrapped with symmetric angle-ply (B-SAP) as compared to that of reference beam is less than that at failure stage. Table 2 shows a comparison of results obtained for U-wrapped beams GFRP laminates. At debonding stage, load carrying capacity of U-wrapped beams increased by 197% compared to reference beam.

Table 2 Comparison of Loads at different stages

Beam detail	Serviceability stage		Failure stage	
	Load(kN)	Increase in load (%)	Load(kN)	Increase in load (%)
RB	47.2	0.0	64.4	0.00
B-SAP	98.2	108.5	191.2	196.89

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