EXPERIMENTAL INVESTIGATIONS OF RC BEAMS STRENGHTENED WITH 4-LAYERD SYMMETRIC CROSS-PLY (SCP) GFRP LAMINATES

S. T. Rushad[1], S.K. Duggal[2], K. K. Shukla[3]

[1] Assistant Professor, Department of Civil Engineering, Birla Institute of Technology, Mesra (Patna campus), Patna-800014, , India
[2]Professor,Department of Civil Engineering MNNIT, Allahabad- 211004, India
[3]Professor,Department of Applied MechanicsMNNIT, Allahabad- 211004, India
*[1]Corresponding author **tabinrushad@gmail.com***

Abstract

To increase the flexural capacity of reinforced concrete beams (RCC) beams, use of fiber reinforced composites bonded to the surface of RC members, started in the mid-1980s, has gained momentum due to limitations of plate bonding technique. Experiments were conducted to study the effect of 4-layerd symmetric cross-ply (SCP) GFRP laminates on the flexural behavior of simple RCC beams. It is observed that beam strengthened with the symmetric cross-ply laminate is suitable for enhancement of strength and stiffness of structural elements for restoration and retrofitting. The experimental results are also validated by the finite element based results using ANSYS.

Key Words: Laminates, Debonding, ANSYS, Strength

---***---

1. INTRODUCTION

The plate bonding technique is now established as a simple and convenient repair method for enhancing the flexural performance of concrete structures . The advantages of this technique are that the work can be carried out while the structure is still in use and it is economical compared to other methods. The earliest reported examples of plate bonding were those carried out in South Africa and France [1]. Problems, associated with the steel plate as external reinforcement for existing concrete structures, like careful surface preparation adhesive bond durability and potential corrosion at the steel/adhesive interface, etc have led towards Fiber reinforced plastic materials (FRP). More recently noncorrosive, high strength but lightweight fiber-reinforced polymer composites (FRPs), which were initially developed for use in high-performance aerospace structures, are becoming popular in retrofitting reinforced concrete (RC) structures. The use of fiber reinforced composites bonded to the surface of RC members, started in the mid-1980s, has gained momentum and since then investigations about post-strengthening of RC members by externally bonding FRP is being carried out across the world.

Fathelbab et al. [2] observed that in case of flexure strengthening, increase in number of CFRP plies enhances ultimate bearing capacity and ductility of the beam significantly. In case of shear strengthened beams, increase in ductility was significant but ultimate capacity was affected. Sawant et al.[3] observed that U-Shape wrap and bottom wrap was good for improving shear strength as well as for reducing deflection of RC members as compared to both side wrap. U-wrapped RC beams with symmetrical cross ply GFRP laminates can be used to increase shear capacity of RC beams significantly [4]. Chiew et al.[5] showed the effectiveness of glass fiber-reinforced polymer (GFRP) in strengthening undamaged concrete beams instead of repairing or rehabilitating old structures in terms of improving flexural strength and stiffness of reinforced concrete beams by such a bonding technique. Hosany et al.[6] studied the performance of RC beams strengthened by hybrid FRP laminates consisting of carbon fiber reinforced polymer (CFRP) and GFRP laminates. They concluded that combination of GFRP and CFRP laminates is an effective method to enhance the ductility of strengthened beams. Lenwari and Thepchatri [7] investigated the effects of carbon and glass fiber sheets on flexure behavior of RC beams and observed that the stiffness and ultimate load of the beams enhanced with increase in number of layers.

Santhakumar et al. [8] presented a numerical study to simulate the behavior of RC shear beams strengthened with cross-ply and angle-ply CFRP composites. No significant change in behaviour between the uncracked and precracked retrofitted beams at ultimate stage was observed. Hu et al. [9] used ABAQUS finite element programme to predict the ultimate load capacity of RC beam strengthened with FRPs. They concluded that use of FRPs significantly increases the stiffness of the RC beams.

However, there is a need to investigate the behavior of RC members strengthened with different types of FRP laminates for better understanding. The present work focuses on the experimental investigation of flexural behavior of RC beam strengthened with four layered symmetric cross-ply GFRP laminates.

2. EXPERIMENTAL PROGRAM

A summary of the specimens, as shown in Fig.1, used for testing of RC beams is given in Table 1. The beams were divided in two different categories designated as V, and S. Here, V denotes the reference beam, S designates the strengthened beam The letters after hyphen refer the type of strengthening scheme. The subscript in the last shows specimen number in the series. The letters after hyphen refer the type of strengthening scheme. The subscript in the last shows specimen number in the series

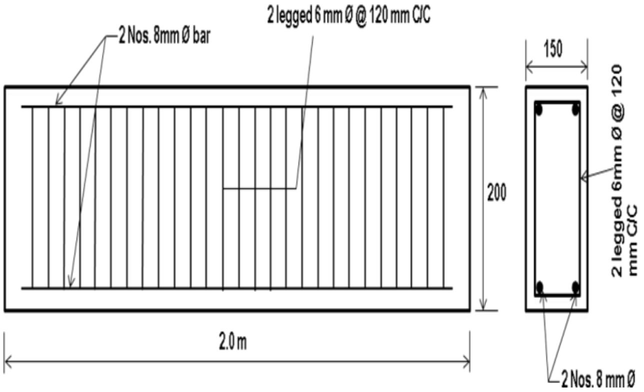

Fig. 1. Details of beam specimen designed for flexure failure

Table 1. Summary of test specimens for flexure deficient beams

Specimen Designation	Type of specimen	Type of GFRP laminate
V_1 to V_5	**Reference**	—
S-SC_1 to S-SC_5	**Strengthened**	Symmetric cross-ply [0/90/90/0]

Reinforced concrete beams were designed and cast using materials complying following specifications:

3. MATERIALS USED

[1]. **Concrete:** Standard cubes of 150 mm sides were cast from each batch of concrete used for making beams and 28 days average cube strength was 27.5 MPa.

[2]. Steel: Three samples of the steel rebars were tested under uniaxial tension. The average yield stresses of the bars are found to be 506 N/mm^2.

[3]. GFRP laminates were tested under uniaxial tension. The specimens exhibited linear-elastic behavior up to failure. Tensile strength values of respective GFRP laminates 148 MPa.

[4]. **Epoxy:** Araldite GY 257 and Aradur 140 were mixed in the ratio of 2:1 and used for bonding the GFRP sheets over the RC beams.

4. EXPERIMENTAL PROCEDURE

A line diagram of test arrangement for the beam specimens under four-point loading is shown in Fig. 2. The test beams have simply supported span of 2000 mm. Equal concentrated loads acting downwards were applied at 500 mm from each support at I-girder beams placed centrally over two rollers which in turn were placed over the test beam at a distance of 500 mm from each end support. Deflection gauges were placed under applied load-points as well as at mid-point of the beam. The test programme consisted of testing the beams of series V and S one by one, under incremental loading till failure.

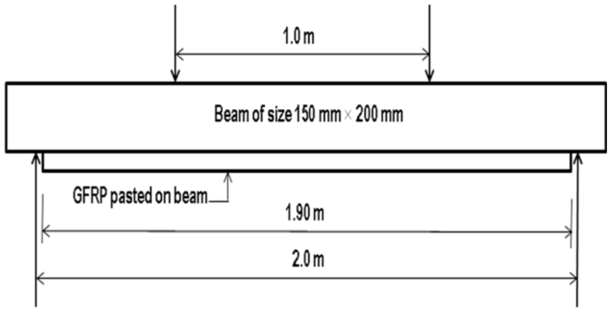

Fig. 2. Line diagram for the test set-up for flexure deficient beams

5. REFERENCE BEAM

In the first phase of testing, five beams of series V marked as V_1, V_2, V_3, V_4 and V_5 were loaded up to the failure in increments of 1kN. Mid-deflections were recorded at each load increment. Crack patterns were also observed.

6. STRENGTHENED BEAM

In the second phase, five beams, strengthened with GFRP laminates on their tension sides were tested. Deflections at mid- span and quarter-span were recorded and crack patterns observed.

The tension face of beam was smoothened. Epoxy resin in the ratio of 2:1 (Hardener: Resin) by weight was applied on the tension face of the beam as well as on the surface of the GFRP laminate. To have good bonding between the beam and the laminate, the outer face of the GFRP laminate was pressed with thick wooden plank against the beam as shown in Fig. 3. After drying for forty eight hours the beams were ready for testing. The beams prepared in the manner described above were subjected to incremental load.

Fig. 3. GFRP laminates pasted at tension side of RC beams

7. EXPERIMENTAL OBSERVATIONS

The test results of the flexure deficient beams are presented in this section.

8. REFERENCE BEAMS

The beams were tested to compare the results of GFRP strengthened and retrofitted beams and hereafter will be known as reference beams. Five beams namely V_1, V_2, V_3, V_4 and V_5 were tested. Cracks were visible in the reference beams at load of about 14 kN. The beams were loaded further in the same manner up to the failure. After appearance of the first crack, small cracks started to develop vertically in the mid-span region. They were similar in width, but displayed no specific spacing pattern. All cracks continued to grow in both width and length in the direction towards the top. With increase in load, larger cracks travelled up to depth of the beam. This trend continued till at an average load of about 35 kN approximately. Failure mode of the beam is shown Fig. 4.

Summary of the experimental observation of the reference beam is tabulated in Table 2.

Fig. 4. Failure mode of reference beam

Table 2. Experimental observations of each specimen of reference beams

S. No.	Specimen Detail	First crack load (kN)	Deflection (mm) corresponding to first crack	Failure load (kN)	Final deflection (mm)	Failure Mode
1.	V_1	13	1.9	35	11.96	Flexure
2.	V_2	17	2.32	37	8.75	Flexure
3.	V_3	12	1.35	37	11.56	Flexure
4.	V_4	14	1.9	35	11.98	Flexure
5.	V_5	15	1.6	35	11.86	Flexure

9. STRENGTHENED BEAM

RC Beams strengthened with GFRP laminates on its tension side are referred as strengthened beams. Five beams were strengthened with symmetric cross-ply laminates and were tested as discussed previously. Crack patterns and possible failure modes were investigated.The first crack in the strengthened beam was observed at 21.5 kN. Unlike the reference beam, the cracks were smaller in width and length. Small, flexural cracks began to form in the mid-section region. They continued to travel up to the depth of the beam with increase in load. Failure of the beams occurred with knocking sound due to debonding of GFRP laminates; debonding started from one end. Failure mode of beam is shown in Fig.5.Summary of the experimental observations of the strengthened beams is tabulated in Table 3.

Fig. 5. Failure mode of beam strengthened with symmetric cross-ply laminate

Table 3. Experimental observations of each specimen of strengthened beams

S. No.	Specimen Detail	First crack load (kN)	Deflection (mm) corresponding to first crack	Failure load (kN)	Final deflection (mm)	Failure Mode
1.	$S\text{-}SC_1$	24	2.72	64	23.17	Debonding
2.	$S\text{-}SC_2$	20	1.18	72	23.67	Debonding
3.	$S\text{-}SC_3$	20	2.10	66	24.67	Debonding
4.	$S\text{-}SC_4$	22	1.6	66	23.6	Debonding
5.	$S\text{-}SC_5$	23	2.2	67	22.1	Debonding

10. ANSYS MODELING

Strengthened beams are analysed with ANSYS software. Graph drawn from values found through software were compared with that of experiments. The Solid65 element, Solid46 element and Link8 element are used for concrete material, GFRP laminates, and steel reinforcement, respectively [10].The full-size beam model having dimension 2000 mm × 200 mm ×150 mm was created. Model of longitudinal and shear reinforcements are shown in Fig. 6.

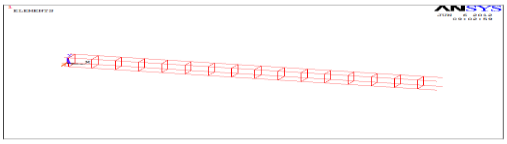

Fig. 6: Model of reinforcement in RC beamTo have the perfect bond, the link element for steel reinforcement is connected between nodes of each adjacent concrete solid element, so that the two materials share the same nodes [11].Nodes of the GFRP layered solid elements are connected to those of adjacent concrete solid elements in order to satisfy the perfect bond. The model of RC strengthened beam with load and boundary condition is shown in Fig. 7. Finally the solution is obtained.

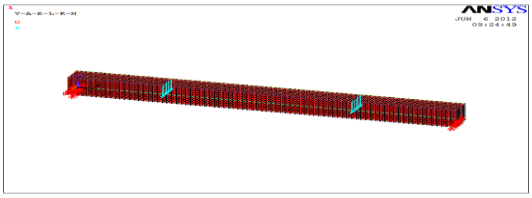

Fig. 7: Boundary conditions of strengthened beam in ANSYS

11. DISCUSSION

Average values of increase in load carrying capacity of the beams failure stage of each series of the beams are calculated based on experimental observation. It is observed that all the strengthened beams show increased load carrying capacity with respect to reference beam. The ultimate load carrying capacity of all the strengthened beam increased by more than 75%.

The influence of the external strengthening on the development of the cracks is also significant. From the comparison of the crack patterns of the strengthened and reference beams, the crack propagation is found to reduce due to GFRP laminates. Number of cracks in strengthened specimens just prior to failure was not reduced when compared to that of the reference beam before failure. It was also observed that cracks were much wider on the reference beams at different load stages in comparison to strengthened beams.

ANSYS analysis predicts the beam to be stronger. Debonding failure of beams, which was observed in the laboratory, is not observed in ANSYS because of the perfect bond model.

CONCLUSIONS

From the detailed experimental programme on strengthening of RC beams major conclusion can be drawn as:

- Strengthening the beams with symmetrical cross ply GFRP laminates are found to be effective in flexure and can be used as an alternative for enhancing the capacity of RC beams or for restoring the original strength.
- The symmetric ply composite is found to be suitable one for enhancing strength with less deflection.
- Strengthening retards the progress of cracks.

REFERENCES

[1]. Fleming, C. J., and King, G. E. M. "The development of structural adhesives for three original uses in South Africa". RILEM Int.Symp. on Synthetic Resins in Build. Constr., 1967;RILEM, Paris, 75–92.

[2]. Fathelbab, F.A., Ramadan, M.S., and Al-Tantawy, A. "Finite element modelling of strengthened simple meams using FRP techniques: A parametric study." Concrete Research Letters., 2011;2(2),228-240.

[3]. Sawant, S.G., Sawant, A.B., and Kumthekar, M.B. 2013. "Strengthening of RCC beam- using different glass fiber." International Journal of Inventive Engineering and Sciences**.,** 2013**;**1(2), 1-8.

[4]. Syed, T. R., Duggal,S. K., and Shukla, K.K. "Experimental Investigation of RC Beam U-Wrapped with Symmetrical Cross-Ply GFRP." Proceedings of 3rd International Conference on Recent Trends in Engineering & Technology (ICRTET'2014),2014; Nasik, 243-246

[5]. Chiew, S.P., Qin, S. and Yi, Y.. "Flexural strength of RC beams with GFRP laminates." J. Comp for Const, 2007;Vol. 11 No. 5, pp. 497-506.

[6]. Hosny, A., Shaheen, H., Abdelrahman, A. and Elafandy, T. "Performance of reinforced concrete beams strengthened by hybrid FRP laminates." Cement and Concrete Composites.,2006; 28 (10), 906-913.

[7]. Lenwari, A. & Thepchatri, T. " Experimental study on RC beams Strengthened with Carbon and Glass Fibre Sheets." Engineering Journal, 2009; Vol.13, No. 2, pp 09-18.

[8]. Santhakumar, R., Chandrasekaran, E., and Dhanaraj, R. "Analysis of retrofitted reinforced concrete shear beams using carbon fiber composites." Electronic Journal of Structural Engineering, 2004; 4, 66-74.

[9]. Hu, H.T., Lin, F.M., and Jan ,Y.Y. "Nonlinear finite element analysis of reinforced concrete beams strengthened by fiber-reinforced plastics." Composite Structures, 2004;63 (3-4), 271–281.

[10]. Potisuk, T. Finite Element Modeling of reinforced concrete beams externally strengthened by FRP Composites, MS Thesis ,2000; Oregon State University. Corvallis.

[11]. Wolanski, A.J."Flexural behavior of reinforced and pre-Stressed concrete beams using finite element analysis." *MS Thesis*,2004; Milwaukee, Wisconsin.