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RC Beam Strengthening by Glass Fibre Reinforced Polymer

Er. Rahul 1 , Mrs. Monika 2

(M.Tech Student, Department of Civil Engineering,MRIEM, ROHTAK, HARYANA)

(Assistant Professor, Department of Civil Engineering, MRIEM College, Rohtak, Haryana (India)

ABSTRACT

The present study is based on the experimental investigation of glass fibre reinforced polymer (GFRP) strengthened reinforced concrete beams. The behaviour of control and GFRP strengthened beams under static loading is studied. The experimental method of investigation helps in evaluating the performance of RC beam with GFRP composites with various patterns. To investigate the efficiency of a shear reinforcement of RC beam using GFRP composites externally with epoxy resin adhesive and compare for the better performance. .It determines the increase shear strength, stiffness, load carrying capacity and ductility by the application of GFRP composites. The strengthening scheme should be cost-effective.The validated experimental methods are then used for studying the efficacy and effectiveness of various strengthening schemes using epoxy impregnated GFRP fabric where the number of layers, orientation and distribution of fibres are considered as parameters.In all GFRP strengthened beams, mode of failure changed from shear to flexural failure and showed great improvement in the ductile behaviour.It was observed that the beam strengthened with GFRP shows increase in shear strength, stiffness, load carrying capacity and ductility by 38.41 % and 13.47% respectively in compare to control beam. Based on the experimental studies, the schemes which provide anoptimum improvement in performance for thestrengthening of the beams are identified.

Keywords—RCC beam,Strengthening, GFRP, Flexural Strength

INTRODUCTION

Glass fibre reinforced polymer (GFRP) sheets/plates are widely used to strengthen deficient reinforced concrete (RC) structures. Over the past few decades, the adoption of adhesively-bonded composites to strengthen existing concrete structures has steadily increased. Bond behaviour between GFRP reinforcement and concrete has been widely studied and some studies have been adopted by the design guidelines for concrete structures strengthened with externally applied GFRP. In recent years, alot of research was focused on thestrengthening of under-designed and deficient RC structures. Khalifa and Nanni [1]. GFRP significantly increases the flexural strength of masonry wall [2, 3]. Failure of a civil structure refers to the loss of structural integrity due to loss of the load-carrying capacity. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure for any kind of loading. Parretti and Nanni [4] presented a design overview on thestrengthening of RC members using near-surface mounted (NSM) FRP composites. Suleiman et al. [5] conducted experimental and numerical investigations to study the applicability of CFRP sheets for thecyclic strengthening of RC beams. They developed finite element model by incorporating cracking of concrete, thebond between concrete and steel reinforcement, and thebond between concrete and CFRP sheets. Dias and Barros [6] evaluated the effectiveness of shear strengthening provided by externally bonded reinforcement (EBR) and NSM CFRP. The influence of percentage and inclination of laminates in terms of the NSM shear strengthening performance was investigated. Shear failure of reinforced concrete (RC) beams occurs suddenly without pre-alarming indicators and could lead to catastrophic Results [7-11]. RC beams could reach a point of shear deficiency due to several reasons such as design faults, corrosion of shear reinforcement (stirrups), and/or increase in the live loads acting on the structure. Effective bond length, theorientation of the GFRP sheets, etc. On the contrary, limited researches addressed theresponse of continuous RC beams strengthened in shear

EXPERIMENTAL PROGRAMME

This experimental program investigates the efficiency and effectiveness of GFRP strengthening technique to improve the flexural performance of controlled beam. Twelve RC beam were tested for centre point loading. Different strengthening configurations have been used. Properties of constituents of RC beam were determined experimentally. For casting of concrete beams, the design compressive strength is 40 Mpa.Tests were carried out on rectangular reinforced concrete beams with different patterns and types of GFRP sheets. All beams have the same overall cross-sectional dimensions, internal longitudinal reinforcement and stirrup arrangements. The overall length of beam is 1050mm, the width of the beam is 150mm and the cross-section of the beam is 100mm.The length of main bar is 10mm.the value of shear reinforcement is 6mm.The total number of shear bars are used is 6 with 150mm spacing. The parameters influence the overall deformation of the specimens and included different: 1) stirrup strength; 2) shear reinforcement ratio; 3) type of flexural reinforcement, and 4) type of GFRP.

Fibre Reinforced Polymer (FRP) is a good reinforcing material. Use of FRPs has been vastly applied in the research programmes. FRPs consist of high strength fibres fixed in a resin matrix. The fibres are stronger than steel in the longitudinal direction and generally weak lateral direction. Generally, FRP shows no ductile behaviour, hence, the stress-strain behaviour can be considered as a linear elastic up-to failure. GFRP (Glass Fibre Reinforced Polymer) are used in the panels. GFRP has a very high strength to weight ratio. GFRP is unaffected by acid rain, salts, and most chemicals. GFRP is an engineered material composed of a polyester or epoxy resin, reinforced with glass fibres. In previous researches, retrofit of FRP was able to reduce the inherent variability of URM. In this study, one specimen was kept unreinforced and six specimens were strengthened, with different strengthening configurations, by one layer of GFRP using Epoxy Resin with a mixture of hardener 1:10 by volume. The materials property of GFRP and Epoxy Resin are given in Table 1 and Table 2. Figure 1 shows the strengthening of RC beam. For each pattern, three specimens were strengthened in with GFRP.

Table1. Material properties of GFRP

Material	**Tensile strength (MPa)**	**Young's modulus (GPa)**	**Tensile modulus (GPa)**	**Bending strength (MPa)**	**Bending modulus (GPa)**	**Compressive strength (MPa)**	**Ultimate Elongation (%)**
GFRP	2400	70	7800	204	6770	900	2

Table2. Material properties of Epoxy

Material	**Tensile Strength (MPa)**	**Tensile shear bond strength (MPa)**	**Compressive Strength (MPa)**	**Compressive shear bond strength (MPa)**	**Compressive elasticity modulus (MPa)**
Epoxy	20	9.6	50	21	1.5

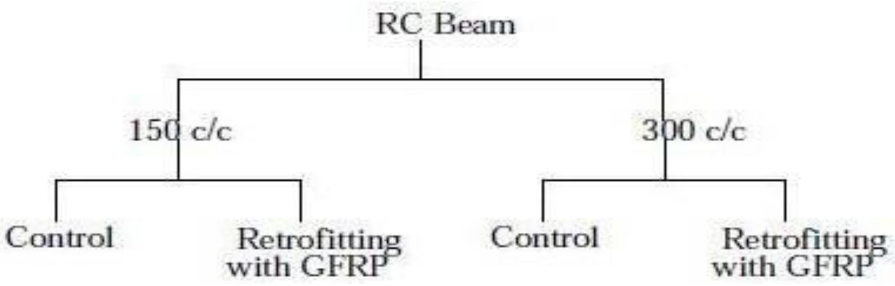

Fig1: Labelling details with respect to strengthening pattern

Twelve panels were tested at the Digital Dynamic Actuator Laboratory in Civil Engineering Department, National Institute of Technology, Durgapur (NITD). Forces and displacements were monitored and measured using the provided devices included in the Dynamic Actuator during the tests. Data collected from these tests permit evaluation of performance parameters of the specimens at different loading conditions. The actuator is manufactured by HEICO and has a maximum load capacity of 100 kN. The dynamic actuator is a highly advanced system with the fully computer-controlled operation and also suitable for static loading applications. An inline coaxially mounted LVDT is fitted in the actuator to measure the displacement of the actuator and also run the system in displacement control mode. The servo valve is fixed to the actuator. Hydraulic power supplies are compact in design and are suitable for the supply of required flow and pressure for the actuation of the actuator to carry out various tests as per different standard for dynamic/static tests. It has an oil tank of adequate capacity, a pump powered by a three-phase motor. It includes all the accessories like return line filter, oil level, relief valve, pressure gauge, Bye pass valve in case of clogging of the filter etc. Anti-vibration mountings are provided as standard along with the HPS. The load was applied to all specimens at a constant rate of 0.005mm/sec under displacement control mode.Figure 2 shows the schematic diagram of LoadingPattern.

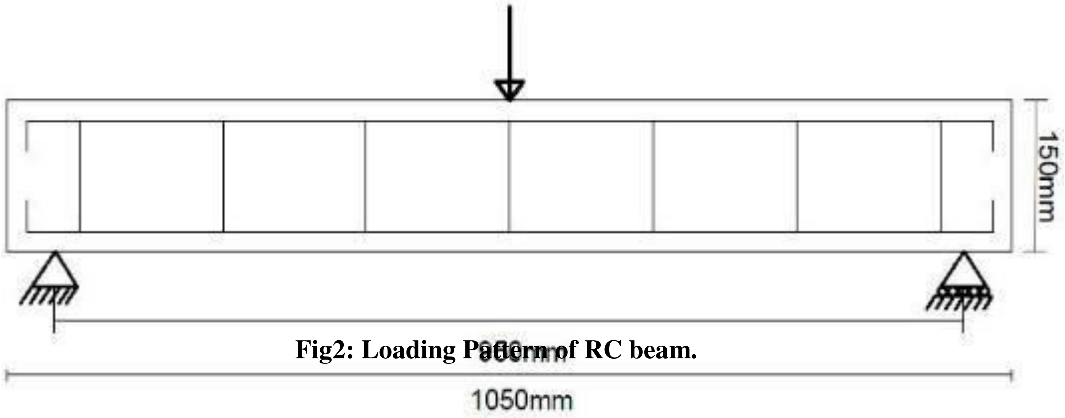

Fig2: Loading Pattern of RC beam.

OBSERVATION AND RESULTS

The summary of the behaviour, crack pattern and failure mode, theshear strength of the test panels subjected to centre point loading tests is given in this section. The control 150specimens (CC_{150}) was failed by shear as shown in Fig.3 (a).

Table3. Crushing load and failure modes of the specimen

Pattern	Specimen	Average Crushing Load (kN)	Average Displacement at Crushing Load (mm)	Failure mode
CC$_{150}$	Control 150 c/c	50.5	9.2	Shear
CC$_{150GFRP}$	strengthening of Control 150 c/c with GFRP	69	10.3	Shear
CC$_{300}$	Control 150 c/c	41.4	8.4	Flexural
CC$_{300GFRP}$	strengthening of Control 150 c/c with GFRP	57.3	8.7	Flexural

(a) CC$_{150}$ (b) CC$_{150GFRP}$

(c) CC$_{300}$ (d) CC$_{300GFRP}$

Fig3. Failure modes of tested specimen

Maximum crushing load, used as a reference value for comparison with the rest strengthenedspecimen results, is 50.5 kN. For $CC_{150GFRP}$(Fig.3 b), the crack is shear. In CC_{300} (Fig.3 c), crack initiated due to flexural. In $CC_{300GFRP}$ (Fig.3 c), crack is also initiated due to flexural. The Failure mode of each panel is shown in Fig.3 and the maximum crushing load and displacement are given in Table 3.

The experimental results of the test specimens are discussed and compared in this section. Performance parameters of specimens are evaluated and compared to investigate the best strengthening pattern and tabulated in table 4. To observe the global behaviour of the specimens, load versus displacement are plotted from experimental test results of control and strengthened pattern in Fig.4. It was observed that failure load is increased from 41.4 kN (CC_{300})to 69 kN ($CC_{150GFRP}$). GFRP has increased the peak strength of CC_{300} from

41.4 kN to 69 kN when strengthened with 150 c/c. Similarly, the stiffness is increased from $CC_{300}$to highest for $CC_{150GFRP}$.

According to ASTM C293 [12], the flexural strength of RC beam are calculated as follows:

$$R=\frac{3P}{2\ d^2} \tag{2}$$

Where, R = modulus of rupture, in MPa, P = Crushing load in N. L = span length, in., or mm, b = average width of thespecimen, at the fracture, in., or mm, and d = average depth of specimen, at the fracture, in., or mm.

Table4. Performance parameter of the investigated RC beam

Pattern	Flexural Strength(MPa)
CC_{150}	35.35
$CC_{150GFRP}$	48.3
CC_{300}	28.98
$CC_{300GFRP}$	40.11

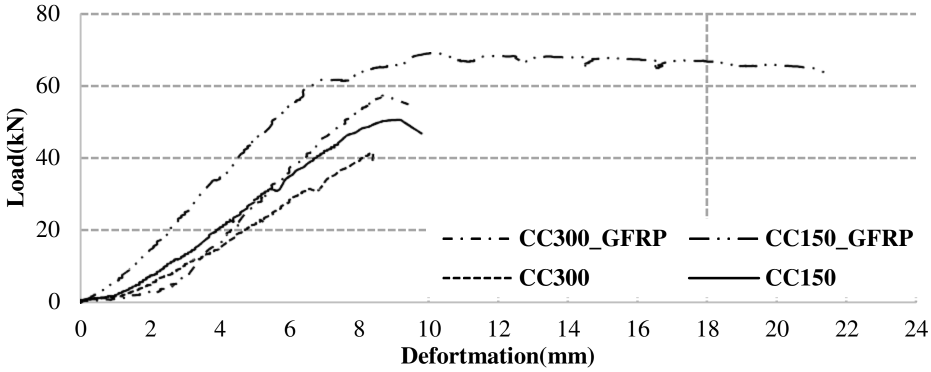

Fig 4. Comparision of tested beam

From the post-peak characteristic graphs, ductility factor(µ), which is the ratio of the ultimate displacement and the yield displacement can be estimated. Table. 5 shows the ductility factor for thespecimen. It was observed that ductility factor for GFRP strengthened panels were substantially increased with maximum (20% approximately) for$CC_{300GFRP}$.

Table 5. Ductility factor of the beam [13]

RC Beam	Ductility Factor(µ)
CC_{150}	1.05
$CC_{150GFRP}$	1.15
CC_{300}	1.01
$CC_{300GFRP}$	2.06

CONCLUSION

The flexural performances of RC beam with different strengthening patterns using GFRP have been studied under centre point loading test. The panels were strengthenedwith two patterns. This experimental study demonstrates the effectiveness of glass fibre reinforced polymers (GFRPs) as new strengthening technology for unreinforced brick structures. The RC beam brittle behaviour whereas strengthening increased its deformation capacity. The strengthened specimens increased the failure load from 41.4 kN (CC_{300}) to 69.5 kN. Further, it also observed GFRP has increased displacement capacity from 8.4 mm (CC_{300}) to 10.3 mm. It was observed that the flexural strength of the strengthened patterns increased from 28.93 to 48.3%. Further, it also observed that the beam with $CC_{150GFRP}$strengthening showed more efficiency in terms of flexural strength, stiffness and deformation capacity. The flexural strength of $CC_{150gfrp}$ is increased by 36.63%as compared to the CC_{150}. As transverse reinforcement has been reduced in CC_{300} the flexural strength is decreased by 18.019% as compare to the CC_{150}but it is observed from the experimental result that the flexural strength of $CC_{300gfrp}$ further increased by 38.41 % and 13.47% as compared to the CC_{300} and CC_{150} respectively. Hence it can be concluded that stirrups can be replaced by externally applied GFRP.

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