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Effect of Width Variation of GFRPC Laminates on Flexural Strength of RC Beams

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Abstract—*Now-a-days most of the reinforced concrete (RC) structures get damaged during earthquakes and they need replacements. Presently several studies have been conducted to investigate the flexural strengths of reinforced concrete members with fiber reinforced composites. This paper presents the experimental studies on the Flexural strengthening of reinforced concrete beams by the external bonding of high-strength, light-weight glass fiber reinforced polymer composite (GFRPC) laminates to the tension face of the beam. A total of 12 beams were casted, 9 with different amounts of GFRPC reinforcement by changing the width of GFRPC laminate, and 3 without GFRPC were tested in 3-point bending over a span of 600 mm. The tests were carried out under displacement control loading. The increase in strength provided by the bonded laminate was assessed by varying the width of laminate. The results indicate that the flexural strength of beams were significantly increased as the width of laminate increased. Test results of the beams indicated that the ultimate strength of GFRPC reinforced specimens were increased by 20-30% of the control specimens.*

1. INTRODUCTION

Concrete structures can become deficient in carrying load they were designed for, due to deterioration of infrastructures. Concrete is the most widely used construction material which has several properties like good compressive strength, stiffness and durability under normal environmental factors. But concrete is found to be brittle and weak in tension. It is well known that concrete mixed with other material was applied for resistance purpose. Steel rebar has historically been used as an effective and cost efficient concrete reinforcement. Many buildings and structural elements require rehabilitation and repair. Effect of environment, increase in service load, traffic and design of older structures, which may have been adequate compared with old codes but are not adequate with current codes, are all factors that contribute to infrastructure becoming either structurally deficient or functionally obsolete. Since replacement of deficient structures requires huge investments, strengthening has become the suitable way for improving their load carrying capacity and prolonging their service life. While complete replacement of a deficient/deteriorated structure is a desirable option, strengthening/repair is often the more economical one.

There is currently a range of techniques available for extending the useful life of structurally deficient and functionally obsolete structures. Nowadays, fiber reinforced polymer (FRP) systems are used in several applications to strengthen existing RC structures instead of the traditional systems using steel. FRPs may be attached on a beam or a slab tension surface to provide additional flexural strength, on the sides of a beam to provide additional shear strength, or wrapped around columns to provide confinement and additional ductility. Application of FRPC to strengthen the concrete beams has already received attention from researchers.

Beams with FRPC have already been analyzed and investigated in their strength increasing aspect. Saadatmanesh and Ehsani [1], Meier and Kaiser [3], Ritchie et al [2] had justified using FRPC as the external reinforcement.

Experiments conducted so far used both glass fiber and carbon fiber laminates. The works reported by Meier and Kaiser [3], Meier et al. [4], Shahawy et al. [5,6], Takada et al. [7] used carbon fiber laminates. Ritchie et al. [2] studied the effectiveness of strengthening using different types of FRPC laminates. Glass, carbon and aramid fiber laminates have been used and the increase in ultimate strength is found to be ranging from 28 to 97% of that of unstrengthen beams for different types of laminates. Faza and Ganga Rao [8] reported an increase of 200% in strength when CFRPC laminates are wrapped around beams. Ross et al. [9] verified the results of CFRPC strengthened reinforced concrete beams with those obtained from inelastic analysis as well as finite element analysis. Spadea et al. [10] studied the improvement in ductility when end anchorages for laminate are used.

The purpose of this paper is mainly to contribute to the experimental database. Beams are strengthened with different levels of GFRPC reinforcement by varying the width of laminate. The flexural behavior is studied in terms of ultimate load and deflections.

2. EXPERIMENTAL STUDY

Twelve (12) under-reinforced RC beams of grade M20 were casted and reinforced externally in tension face by 2 layered GFRPC laminates of width 60, 80 and 120 mm in a set of 3 beams each. Then these beams were tested under three point bending. The beams were instrumented to record their response history until failure.

2.1. Test materials

Concrete and mild steel bars were used in preparation of beam specimens. Bidirectional 2 layer GFRPC laminates were used with an epoxy adhesive (resin-hardener combination) for strengthening.

Table 1: Concrete mix details

Aggregate-cement ratio	4.28
Coarse aggregate to fine	
Aggregate ratio	1.85
Water cement ratio (adjusted by experience)	0.43

2.1.1. Concrete

Concrete having average compressive strength of 20 MPa is specified for all the concrete beams. Pozzolana Portland cement, locally available sand and crushed basalt rock were used for making concrete. The maximum size of coarse aggregate used was 20 mm. Tests for both fine and coarse aggregates to get specific gravity, water content were conducted preliminarily.

12 concrete cubes of standard 150x150x150 mm^3 sizes were casted to check compressive strength which on average comes out to be 22.76 MPa.

Fig. 1. Concrete cubes

2.1.2. Steel

Mild steel bars of 8.0 mm diameter were used. Reinforcement was tested for their tensile strength and Young's modulus. The Young's modulus, yield strength and percentage of elongation at failure were found to be 2.15 x 10^{15} MPa, 513.6 MPa and 33.98%, respectively.

2.1.3. GFRPC laminates and epoxy adhesive

Glass Fiber cloth of 600 GSM was used. Polyester based Epoxy was used in which resin and hardener were used in 100:50 ratio. Ratio of fiber cloth to epoxy was 1:1.

Fig. 2: Resin-hardener (left) and glass fiber cloth (right)

The GFRPC laminate samples were tested for their tensile strength, Young's modulus and for percentage of elongation at failure. The 20% difference in tensile strength of GFRPC laminate may be attributed to difference in the test environmental conditions like temperature.

Table 2: GFRPC laminate properties

Tensile strength	41.432*
Tensile modulus (MPa)	364.5*
Elongation at ultimate (%)	3.7989*

*Found in the laboratory.

2.2. Test beams

2.2.1. Design

Design of the concrete beam was carried out using Indian code IS:456-2000 code [12]. The steel reinforcement was chosen to approach the lower limit of an under-reinforced beam. Under Reinforced section ensures the early transfer of bending tensile forces to composite laminate. The dimensions of the beam were 150 mm wide, 150 mm deep and 700 mm length (Fig. 1). The span of the beam (600 mm) was limited by the maximum span that can be tested in the universal testing machine. 2 – 8 mm dia. Fe 500 bars were used as longitudinal reinforcement, while 2 – 8 mm bars were used as hanger bars. Shear reinforcement consisted of two-legged stirrups of the same steel used as longitudinal steel.

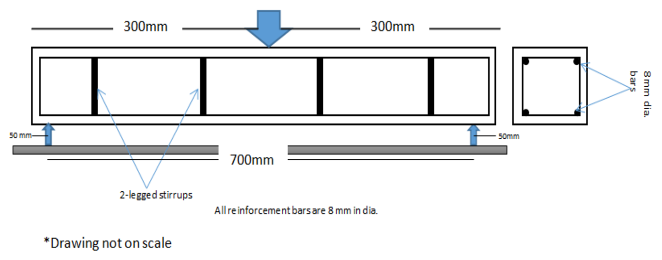

Fig. 3: Details of the test beam

2.2.2. Casting of beams

For dimensionally accurate beams of size 150 x 150 x 700 mm^3, six mild steel moulds were made as per IS:516-1959 specifications [13]. These beam moulds were cleaned and oiled before casting of the beams. Before commencement of casting of concrete beams, a set of rich cement mortar cover blocks were made and cured sufficiently in water. These cover blocks were useful for maintaining uniform cover of concrete throughout the length of beam. A total of 12 beams (3 in each batch) were cast in 2 batches. The same concrete mix was used for all batches.

Fig. 4: Casting of beams

2.2.3. Bonding of the GFRPC laminates

All loose and flaky particles of concrete surface at the tension face of the beam were chiseled out by using a chisel. Then the surface was roughened with wire brush and emery paper before cleaning it with air blower and dust cloth to remove all dust particles. Also it was ensured that no moisture was visible on the surface. After preparation of surface, the two component structural epoxy (1:1 by volume) paste was applied to fill all voids and uneven areas. It was ensured that the surface was free from dust, defects and unevenness. These ridges and uneven areas were removed using a trowel and the structural epoxy paste. Once the voids were filled, the composite laminate was attached starting at one end and applying enough pressure to press out any excess epoxy from the sides of the laminate. Excess epoxy was removed from sides of the laminate. Epoxy thickness was not specifically controlled, but excess epoxy was squeezed out all along the edges of the laminate which ensured complete epoxy coverage. The epoxy was then allowed to cure for a minimum of 3 to 5 days before testing.

Fig. 5: Application of Glass FRP

2.3. Strengthening

Three types of beams were strengthened to different levels by changing the width of GFRPC laminate. Three different widths, 60, 80 and 120 mm were used to obtain the above three types of beams.

3. TEST PROCEDURE

The beam surfaces at the supports and under point load were cleaned with sand-paper to have smooth surface to avoid any eccentricity in loading. The beams were tested under three-point static loading over a span of 600 mm. The loads was applied at the center of the beam by universal testing machine (UTM) with displacement control at the rate of 5 mm/min. Load cell of UTM was connected to data acquisition system. All beams were white washed to mark crack patterns while loading. Load at first crack appearance was noted down. Subsequent crack patterns were marked on the beam surfaces as they develop during testing. A total 12 beams were tested under three-point bending to investigate effect of laminate width variation.

4. RESULTS

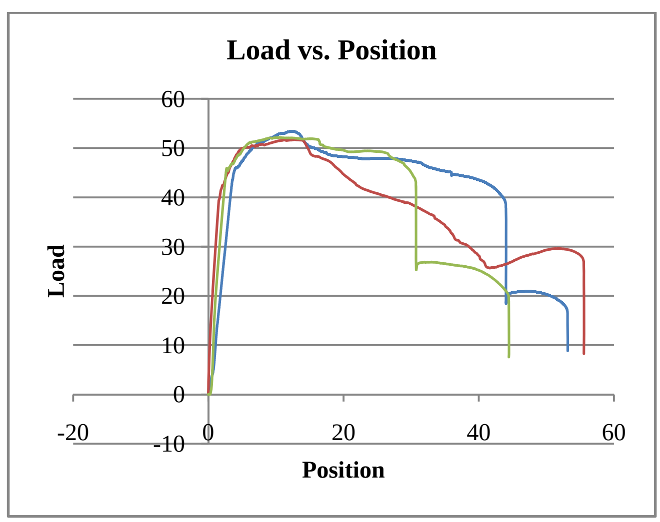

Fig. 7: Load vs. position graph of 3 control beams

Observed first cracking load and ultimate loads are presented in Table 3, 4, 5, 6. The percentage increase in these loads compared to control beam are shown in Fig. 7, 8, 9, 10. The increase in first crack load of strengthened beams can be attributed to laminate restraining effect. The cracking and ultimate load increased monotonically with increased strengthening.

All beams failed by typical peeling of the laminate due to flexural-shear crack. The continuous increase in ultimate load of these beams is due to increase in shear capacity because of external strengthening.

Table 3: Loads, position and energy values of control beams

Sample	Peak load (kN)	Peak position (mm)	Peak energy
CB 01	53.438	53.1754	2187.82
CB 02	51.731	55.5712	2124.068
CB 03	52.152	44.4875	1806.396

Fig. 6: Typical three point bending setup

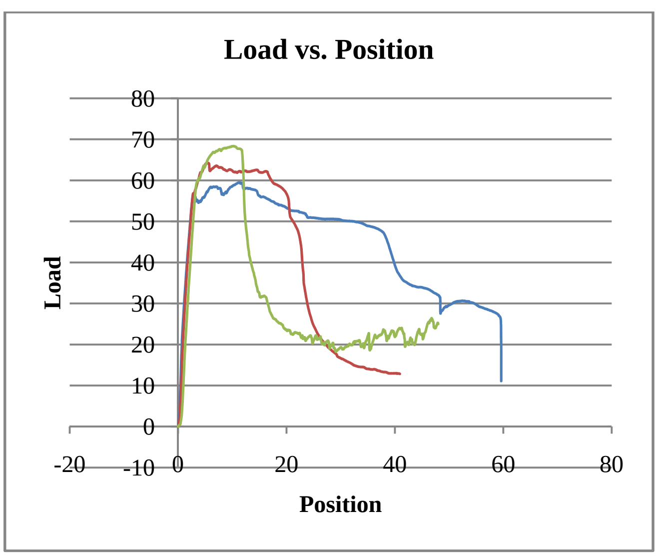

Fig. 8: Load vs. position graph of 3 beams strengthened with 60 mm width laminates

Table 4: Loads, position and energy values of beams strengthened with 60 mm width laminate.

Sample	Peak load (kN)	Peak position (mm)	Peak energy (Joules)
VB06 i	59.48	59.6164	2679.053
VB06 ii	64.309	40.9218	1607.988
VB06 iii	68.362	48.0049	1530.93

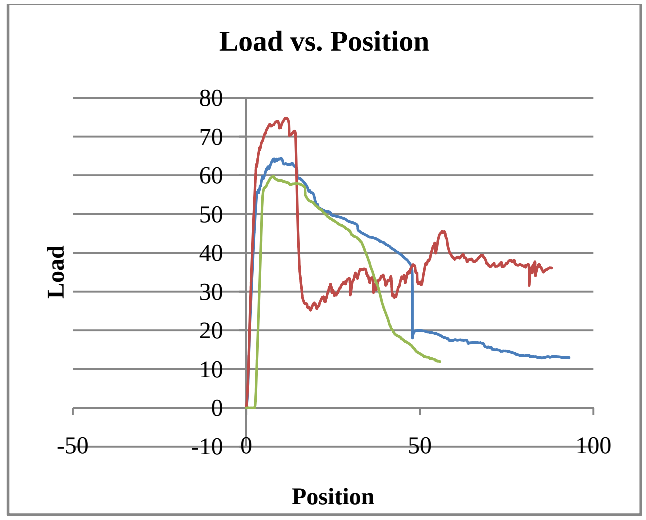

Fig. 9: Load vs. position graph of 3 beams strengthened with 80 mm width laminates.

Table 5: Loads, position and energy values of beams strengthened with 80 mm width laminate.

Sample	Peak load (kN)	Peak position (mm)	Peak energy (Joules)
VB08 i	64.379	92.9744	3091.03
VB08 ii	74.804	87.9386	3497.5
VB08 iii	59.802	55.7874	2049.624

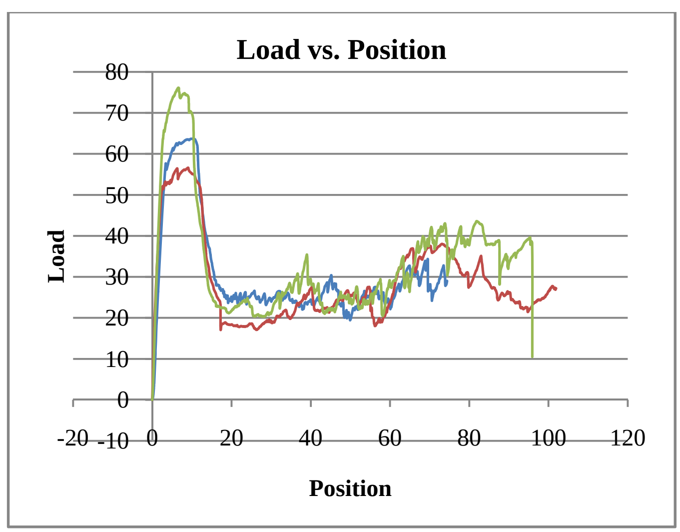

Fig. 10: Load vs. position graph of 3 beams strengthened with 120 mm width laminates

Table 6: Loads, position and energy values of beams strengthened with 120 mm width laminate.

Sample	Peak load (kN)	Peak position (mm)	Peak energy (Joules)
VB12 i	63.688	74.3779	2292.291
VB12 ii	66.596	101.9077	2939.926
VB12 iii	76.11	95.9195	3249.625

4.1 Crack patterns and failure modes

The crack patterns at collapse for the tested beams are shown in Fig. 9. The virgin beam exhibited widely spaced and lesser number of cracks compared to strengthened beams. The strengthened beams have also shown cracks at relatively close spacing. This shows the enhanced concrete confinement due to the GFRPC laminates.

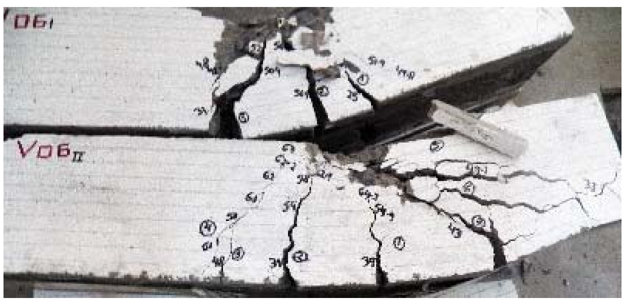

Fig. 11: Crack patterns marked according to loading.

This composite action has resulted in shifting of failure mode from flexural failure (steel yielding) in case of virgin beam to peeling of GFRPC laminate in case of strengthened beams. A crack normally initiates in the vertical direction and as the load increases it moves in inclined direction due to the combined effect of shear and flexure. If the load is increased further, cracks propagate to top and the beam splits. This type of failure is called flexure-shear failure.

5. CONCLUSIONS

The ultimate load carrying capacity of the strengthened beams is significantly higher than that of control beam indicating the reinforcing effect of the GFRPC laminate. The maximum increase in ultimate load is about 22%in 60 mm laminate, 27% in 80 mm laminate and 30% in 120 mm laminate, with respect to the control beams.

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