International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Parametric Studies on Structural Behaviour of Retrofitted R C Beams Using GFRP

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Abstract - Fiber Reinforces Polymer (FRP) has been established as an effective retrofit material world wide. Several researches have been carried out to evaluate its behaviour as retrofit material on different structural components with varying configuration. In the present work, the use of FRP for retrofitting of structural elements was reviewed with special emphasis on reinforced concrete (RC) beams. An experimental study was carried out on twenty seven RC beams. The beams were strengthened with single, double and triple layers of externally bonded Glass Fiber Reinforced Polymer (GFRP) of varying fiber content measured in grams / square meter (GSM). The RC beams were tested up to failure using a four point static loading system. The efforts have been taken to investigate the effect of different amount and configuration of GFRP wrapping on ultimate load capacity, central deflection and failure modes of the beams.

Keywords: Fiber Reinforced Polymer, retrofitting, strengthening, service load, repaired beams.

I. INTRODUCTION

The changes in seismic zones have raised the concern among structural engineers about the serviceability of existing structures. In addition to this, the degradation of concrete and corrosion of reinforcement have always questioned the integrity of structures and their performance. To overcome these difficulties retrofit remains the only suitable option. Retrofitting using FRP has gained too much importance due to its advantages such as high strength to weight ratio, less space requirement, less labour, easy to handle and corrosion proof. Several research works have been carried out by using FRP as a retrofit material for different structural components. Some notable researches on retrofit of RC beams using FRP includes those of D. Kachlakev et al.[1], M. N. S. Hadi[2], Md. Ashraful Alam et al.[3], Tarek H. Almusallam[4], Bo Gaoet al.[5], Lijuan Li et al.[6], Yung-Chih Wang et al.[7], Baris Yalim et al.[8], A.H. Al-Saidy et al.[9], U. Shanmugam et al.[10], H. Tokgöz et al.[11], Hee Sun Kim et al.[12], Renata Kotynia[13] and Mariappan Mahalingam[14]. The FRP used for these researches were either Carbon Fiber Reinforced Polymer (CFRP) or GFRP. In this experimental work, GFRP was preferred against CFRP due to its low cost and availability. The strengthening methodology of external bonding by wet lay-up process was adopted. The main objective of this research was to investigate the effect of different amount of GFRP wrapping on load capacity, deflection and failure modes of the beams.

II. MATERIALS AND METHODS

A. Reinforced Concrete: The concrete used for casting of test specimens was prepared using Ordinary Portland Cement (53 grade), natural river sand and coarse aggregates. The concrete mix proportion of 1:2.08:3.34 with w/c ratio of 0.54 was used for casting of test specimens with 28 days cube strength of 33.63 MPa.

B. Fiber Reinforced Polymer: The GFRP fabrics used were all unidirectional with fibers mainly orientated along the length. Three different types of GFRP fabrics with 600, 900 and 1200 GSM were used for the strengthening scheme. The two part specialty epoxy system comprising of a primer part and a saturant part was used to prepare the laminates. Primer and saturant both comprised of a base and a curing agent. The properties of fiber as provided by manufacturer are diameter 10 µm, specific gravity 2.5 to 2.55, modulus of elasticity 73 GPa, tensile strength 2200 MPa, ultimate elongation 3 to 5 %, and coefficient of thermal expansion 5 x $10^{-6}/{}^{0}$C.

C. Test Specimens: The beams used for the experimentation program were of size 700 x 150 x 150 mm. All the specimens were reinforced with 2 bars of 8 mm diameter on the tension face and 2 bars of 8 mm diameter on compression face. Shear reinforcement in the form of 2 legged stirrups were provided by 6 mm diameter @ 70 mm c/c. The specimens were cured for 28 days. These beams were then air cured for a period of 7 days after which they were tested.

D. Preparation of Specimens: A total of twenty seven specimens were prepared and tested. Out of the twenty seven, three beams were control beams without any strengthening. Nine beams were strengthen with GFRP in single, double and triple layers as virgin beams. The remaining fifteen beams were first stressed up to service load and repaired with epoxy putty and then strengthen with GFRP in single, double and triple layers as repaired beams. The cracks that appeared in the beams loaded till service load were repaired using epoxy putty. The surface was rubbed off and irregularities were leveled with epoxy putty. After the surface preparation epoxy saturant matrix was applied to the soffit of specimens. The fabric was cut in strips of 700 mm length and 150 mm width and carefully placed on the soffit of the specimens. It was made sure that all the air bubbles were removed using a roller. After placing the fabric, a second of coat of epoxy matrix was applied. The same size of fabric sheet was again placed and the process was repeated till the required number of layers was placed. All the operations were carried out at room temperature. The beam specimens thus prepared were air cured for 7 days and then tested till failure.

III. EXPERIMENTATION

All twenty seven beams were tested under four point loading arrangement at uniform rate of loading using Universal Testing Machine (UTM) of 1000 kN capacity. The load was gradually increased up to the failure of the beam. The load and the corresponding central deflection were recorded throughout the test at a regular interval up to failure. The load at the first visible crack was considered as the crack load. The load corresponding to serviceability criterion of central deflection was considered as service load. The maximum load at which the specimen failed was considered as ultimate load. The test specimens were supported on roller bearings from bottom providing 50 mm projection from both the ends to avoid slipping of specimen. The loads were recorded from the UTM and deflections were recorded using a dial gauge having a least count of 0.01 mm.

IV. RESULT AND DISCUSSION

The test results for virgin beams and repaired beams are tabulated in **Table 1and 2**.

Table 1: Load and deflection data for control beam and virgin beam specimens

Beam Designation	P_{cr} kN	d_{cr} mm	P_s kN	d_s mm	P_u kN	d_u mm	Failure pattern
CB	21.20	0.50	49.52	1.85	82.55	5.35	Flexure
VB1G1	31.95	0.73	52.25	1.85	96.85	6.77	Shear failure of section with peeling
VB1G2	36.60	0.84	58.90	1.85	98.35	5.60	

VB1G3	39.10	0.79	65.00	1.85	99.60	5.27	of GFRP
VB2G1	37.10	0.68	71.20	1.85	100.00	4.50	
VB2G2	40.30	0.72	72.80	1.85	107.00	5.00	
VB2G3	44.10	0.75	75.50	1.85	106.00	4.20	
VB3G1	39.45	0.67	79.80	1.85	110.00	4.05	
VB3G2	49.80	0.56	93.55	1.85	125.00	4.20	
VB3G3	51.70	0.62	91.30	1.85	120.00	4.94	

Table 2: Load and deflection for control beam and repaired beam specimens

Beam Designation	Pcr kN	dcr mm	Ps kN	ds mm	Pu kN	du mm	Failure pattern
CB	21.20	0.50	49.52	1.85	82.55	5.35	Flexure
RB1G1	24.33	0.49	63.37	1.85	94.13	4.98	Shear failure of section with peeling of GFRP
RB1G2	31.55	0.58	67.25	1.85	97.73	5.35	
RB1G3	33.95	0.48	78.10	1.85	100.15	5.29	
RB2G1	31.45	0.51	77.50	1.85	105.50	4.91	
RB3G1	37.25	0.46	83.00	1.85	110.75	5.13	

P_{cr} - first crack load; d_{cr} - deflection at first crack load; P_s - service load; d_s - deflection at service load; P_u - ultimate load; d_u - deflection at ultimate load.

V. DISCUSSION ON TEST RESULTS

A. Comparisons of crack load, service load and ultimate load

The crack load registered for the control beams was 21.20 kN for the first visible crack on surface of the beams. The increase in the crack load for virgin beams were found to be 50.70, 72.64, 84.43, 75, 90.10, 108.02, 86.08, 134.91 and 143.87 % respectively, as compared to the average crack load for control beams. The service load for the control beams was 49.52 kN for the central deflection of 1.85 mm. For the same deflection, the increases in the service load for repaired beams were 27.97, 35.80, 57.71, 56.50 and 67.60 % respectively. Similarly, the increase of service load in virgin beams was 5.51, 18.95, 31.26, 43.78, 47.01, 52.46, 61.15, 88.91 and 84.37 % respectively. The ultimate load registered for the control beams was 82.55 kN with a central deflection of 5.35 mm. For the same deflection, ultimate load registered for repaired beams were 94.13, 97.73, 100.15, 105.50 and 110.75 kN respectively. The increase in ultimate load was 14.02, 18.38, 21.32, 27.80 and 34.16 % respectively. Similarly, the ultimate load value registered for virgin beams were 96.85, 98.35, 99.60, 100, 107, 106, 110, 125 and 120 kN respectively. The increases in the ultimate load for virgin beams were 17.32, 19.14, 20.65, 21.14, 29.62, 28.41, 33.25, 51.42 and 45.37 % respectively.

B. Load-displacement behaviour

The loads and their corresponding deflections were used to establish the load displacement behaviour of control, repaired and virgin beams. The load-deflection plots are shown in **Fig. 1**and **2**. From the load-deflection plots, it is observed that the deflection values corresponding to the ultimate load for repaired and virgin beam are lower as compared to that of control beams. It is also observed that for a certain value of load, the corresponding deflection obtained, is more when compared to the same corresponding values obtained from load deflection plots for repaired and virgin beams.

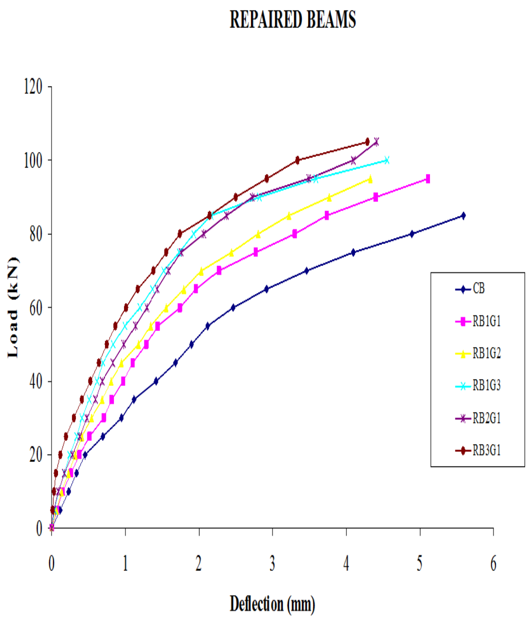

Fig. 1: Load – deflection plots for CB and RB specimens

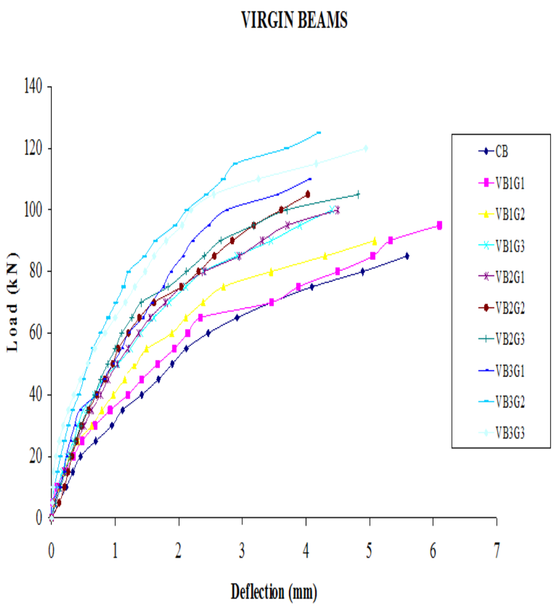

Fig. 2: Load – deflection plots for CB and VB specimens

C. Virgin Vs Repaired beams (at crack, service and ultimate load and deflection)

Single layer with 600 GSM: The corresponding values of load and central deflection for VB and RB specimens at first crack load were 39.95 kN (0.73 mm), 24.33 kN (0.49 mm); at service load were 52.25 kN (1.85 mm), 63.37 kN (1.85 mm); at ultimate load were 96.85 kN (6.77 mm), 94.13 kN (4.98 mm) respectively.

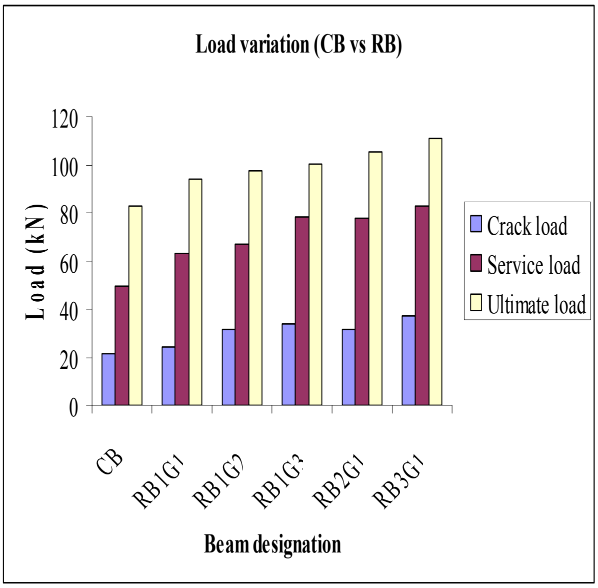

Fig. 3: Load variation for CB and RB specimens

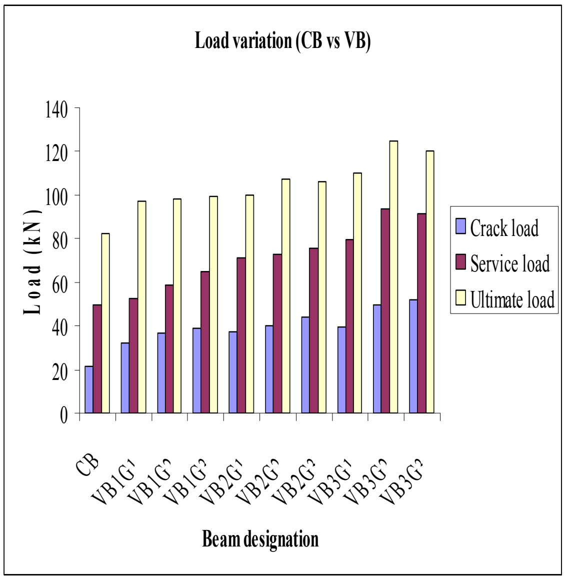

Fig. 4: Load variation for CB and VB specimens

Single layers with 900 GSM: The corresponding values of load and central deflection for VB and RB specimens at first crack load were 36.60 kN (0.84 mm), 31.55 kN (0.58 mm); at service load were 58.90 kN (1.85 mm), 67.25 kN (1.85 mm); at ultimate load were 98.35 kN (5.60 mm), 97.73 kN (5.35 mm) respectively.

Single layer with 1200 GSM: The corresponding values of load and central deflection for VB and RB specimens at first crack load were 39.10 kN (0.79 mm), 33.95 kN (0.48 mm); at service load were 65 kN (1.85 mm), 78.10 kN (1.85 mm); at ultimate load were 99.60 kN (5.27 mm), 100.15 kN (5.29 mm) respectively.

Double layer with (600 + 600) GSM: The corresponding values of load and central deflection for VB and RB specimens at first crack load were 37.10 kN (0.68 mm), 31.45 kN (0.51 mm); at service load were 71.20 kN (1.85 mm), 77.50 kN (1.85 mm); at ultimate load were 100 kN (4.50 mm), 105.50 kN (4.91 mm) respectively.

Triple layer with (600 + 600 +600) GSM: The corresponding values of load and central deflection for VB and RB specimens for first crack load were 39.45 kN (0.67 mm), 37.25 kN (0.46 mm); for service load were 79.80 kN (1.85 mm), 83.00 kN (1.85 mm); for ultimate load were 110 kN (4.05 mm), 110.75 kN (5.13 mm) respectively.

D. Failure Modes

The control beams exhibited flexure failure with major vertical cracks at mid span with appearance of shear cracks at the failure stage. For control beams, crushing of concrete was not observed. From all the other GFRP wrapped beams none of the beam showed the flexure failure. The beams failed with shear cracks propagating and leading to debonding of laminate just below the crack. The debonding was observed to propagate towards end supports. Certain specimen showed full end debonding of laminates beyond supports. The roller supports acted as anchoring system and prevented end debonding from propagating towards mid span. The failure patterns for control beam, repaired beam and virgin beams are shown in **Fig. 5.**

Fig. 5 – Failure patterns for beams

V. CONCLUSIONS

From the test results the following conclusions were drawn:

1. The ultimate load carrying capacity of all the strengthen beams were enhanced as compared to the control beams where as in all, the ultimate deflection for control beam was found to be more than repaired and virgin beams.

2. As the GSM of GFRP was increased, an increase in ultimate strength was observed. The maximum increase in ultimate strength was observed for the $VB3G_2$ specimen where as the ultimate strength of $VB3G_3$ specimen was observed to have less value than $VB3G_2$.
3. None of the beams except control beams showed flexure failure i.e. the beams showed increased strength in flexure. The failure pattern for strengthened beams was noticed in shear failure of the section along with delamination of GFRP below the crack towards support.
4. A single layer of GFRP registered increased value for first crack load and service as compared to double layer of GFRP with same GSM value but the difference was not so significant.
5. No significant variation was found in the ultimate strengths of virgin and repaired beam specimens with identical GFRP wrapping. That meant that pre-cracking did not significantly affect the ultimate strength enhancement of GFRP.
6. In test, the roller supports acted as anchoring system and prevented the end debonding. This shows the significance of anchoring system to be provided in actual retrofit procedure using FRP.

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