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Parametric Studies on Structural Behaviour of Strengthened Beams Using Glass Fiber Reinforced Plastic

Akshay D. Barkale[1*], Sunil B. Thakare[2]

[1] JSPM's Rajarshi Shahu College of Engineering, Tathwade, Pune, India
[2] ABMSP's Anantrao Pawar College of Engineering and Research, Pune, India
* Corresponding author's e-mail: akshaybarkale@gmail.com

ABSTRACT
Fiber reinforced polymer (FRP) has been established as an effective retrofit material world wide. Its behaviour as retrofit material has been evaluated by several research works. In this research work, the use of FRP for retrofitting of reinforced concrete (RC) beams was reviewed and the experimental study was carried out by casting twelve RC beams with nominal reinforcement. Except control beams all the beams were strengthened using single, double and triple layer of externally bonded glass fiber reinforced plastic (GFRP) of varying fiber content measured in grams per square meter (GSM) as the main parameter of difference. The RC beams were tested to failure and experimental data was obtained on load, deflection and failure modes of the beams. The efforts have been taken to investigate the effect of different amount of GFRP wrapping on load capacity, deflection and failure modes of the beams.

Keywords: fiber reinforced polymer, strengthening, flexural test, multilayer FRP.

INTRODUCTION

The recent 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 has been carried out by using FRP as the retrofit material for different structural components. Some notable researches on retrofit of RC beams using FRP are reviewed as follows. Kachlakev et al. [1] replicated bridge beams for experimentation where in the increased failure loads and ultimate deflection were observed. The performance comparison of glass fiber reinforced plastic (GFRP)and carbon fiber reinforced plastic (CFRP) was studied concluded with CFRP outperforming GFRP [2]. The available retrofitting techniques for beams were compared by Md. Ashraful Alam et al. [3] through experimentation where in plate debonding method with adhesive such as epoxy using steel plates and FRP proved to be efficient and preferable due to inherent advantages. Tarek H. Almusallam [4] examined the behavior of GFRP for flexure enhancement in different initial conditions and found no any significant effect. Bo Gao et al. [5] explained the failure modes of RC beams with FRP through available literature data as FRP rupture, Delamination and Cover separation. Lijuan Li et al. [6] checked performance of Fiber Reinforced Concrete beams with FRP strengthening and found improved strength and bending stiffness with thinner cracks. Yung-Chih Wang et al. [7] established the importance of anchorage for shear enhancement through flexure tests of RC beams with GFRP attachments. Baris Yalim et al. [8] established the profound effects on strength enhancement and failure mode due to surface voids and cracks of RC beams. Performance of CFRP strengthening on corroded RC beams showed restored structural integrity along with increased in ultimate strength by A.H. Al-Saidy et al. [9]. The effect of alternate layer of CFRP and GFRP showed lesser values of strength enhancement when compared to individual CFRP and GFRP layers by experimentation of U. Shanmugam et al. [10]. Study conducted by H. Tokgöz et al. [11] on Strengthening of RC beams with insufficient bending rigidity using GFRP and CFRP suggested use of glass fibers due to economy. Hee Sun Kim et al. [12] studied effect of different sequencing of GFRP and CFRP along preloading conditions showed GFRP before CFRP gave better results and non-preloaded specimens showed high increment than preloaded. Renata Kotynia [13] investigated bond behavior between Externally Bonded (EB) and Near Surface Mounted (NSM) FRP strengthened RC beams which showed both performing near about same. M. Mahalingam et al. [14] conducted an experimental investigation on Steel FRC beams with GFRP laminates which showed increased deflection ductility and decreased crack width. The FRP used for these researches were either CFRP or GFRP. In this experimental work GFRP was preferred to CFRP due to its low cost. The strengthening methodology of external bonding by wet lay up process was adopted. The main objective of this research was to to investigate the effect of different amount of GFRP wrapping in terms of mono and multi-layer application on load capacity, deflection and failure modes of the beams.

MATERIALS AND METHODS

The concrete mix proportion of 1:2.08:3.34 with w/c ratio of 0.54 was used for casting of beams with 28 days cube strength of 33.63 MPa. The details of beams are shown in Figure 1. The unidirectional glass fiber reinforced polymer fabrics used were obtained from SAERTEX India Private Limited. Three different types of GFRP fabrics with 600, 900 and 1200 grams per square meter (GSM) were used for the strengthening scheme. The properties of fibers as provided by manufacturer are given in Table 1. The two part specialty epoxy system comprising of a primer part and a saturant part was used to prepare the laminates.

Specimen preparation

Total twelve beams were prepared and tested. Out of twelve, three without strengthening were taken as control beams, nine strengthened with varying GFRP in single, double and triple layer as virgin beams. The beams were cured by keeping them submerged in the water tank over the period of 28 days. After the curing period those were air dried for a day following which the strengthening scheme was applied. FRP external bonding methodology by wet layup process was adopted as the strengthening scheme. The cracks appeared in the beams loaded till service load were repaired using epoxy putty. The surface to be repaired was rubbed off and leveled with epoxy putty. After which the epoxy saturant matrix was applied to the soffit of beams. The fabric was then carefully laid onto soffit of the beams by removing all the air bubbles using roller. After application of fabric, second coat of epoxy matrix was applied which was then followed by application of fabric sheet as second and third layer and epoxy coating was applied. All the operations were carried out at room temperature. The beams thus prepared were air cured for 7 days and then tested till failure.

Experimentation

All beams were tested under four point loading arrangement at uniform rate of loading using universal testing machine of capacity 1000 kN. 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; till the central deflection reaches to clear span / 325 value i.e. 1.85 mm was considered as service load. The maximum load at which the beam failed was considered as ultimate load.

RESULTS

The control beams were taken as the reference to investigate the structural behaviour of GFRP strengthened beams in unstressed condition. The load and corresponding deflection values observed at salient points are given in Table 2.

Crack, service and ultimate load comparison (CB, VB)

The percentage increment in the average values of crack load for virgin beams $VB1G_1$, $VB1G_2$, $VB1G_3$, $VB2G_1$, $VB2G_2$, $VB2G_3$, $VB3G_1$, $VB3G_2$ and $VB3G_3$ are thus 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 value for control beams.The percentage increment in the average values of service load for virgin beams $VB1G_1$, $VB1G_2$, $VB1G_3$, $VB2G_1$, $VB2G_2$, $VB2G_3$, $VB3G_1$, $VB3G_2$ and $VB3G_3$ are thus found to be 5.51, 18.95, 31.26, 43.78, 47.01, 52.46, 61.15, 88.91 and 84.37% respectively, as compared to the average service load value for control beams. The percentage increment in the average values of ultimate load for virgin beams $VB1G_1$, $VB1G_2$, $VB1G_3$, $VB2G_1$, $VB2G_2$, $VB2G_3$, $VB3G_1$, $VB3G_2$ and $VB3G_3$ are thus found to be 17.32, 19.14, 20.65, 21.14, 29.62, 28.41, 33.25, 51.42 and 45.37% respectively, as compared to the average ultimate load value for control beams.

Table 1. Properties of glass fibers

Typical diameter (μm)	10
Specific gravity	2.50-2.55
Modulus of elasticity (GPa)	73
Tensile strength (MPa)	2200
Ultimate elongation (%)	3-5
Coeff. of thermal expansion ($10^{-6}/^{0}C$)	5
Humidity absorption (%)	0–1

Load displacement behaviour

The loads and their corresponding deflections obtained during testing of test specimens were used to establish the load displacement behaviour of control and virgin beams as shown in Figure 2. From the load deflection plots it can easily be observed that the deflection values corresponding to the ultimate load for virgin beams had lesser values when compared to that of control beams. It is also observed that for a certain value of load, the corresponding deflection value obtained from load deflection plot of control beam is more when compared to the same corresponding values obtained from load deflection plots for virgin beams.

Single vs double layer comparison

1200 GSM vs 600+600 GSM (Virgin) (at crack, service and ultimate load)

The crack load values observed for the 1200 GSM and 600+600 GSM virgin beams were

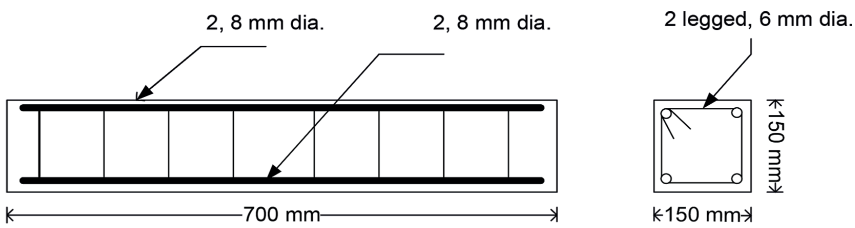

Fig. 1. Reinforcement detailing of beams

Table 2. Load – deflection data for control beam and virgin beams

Beam designation	P_{cr} in kN	d_{cr} in mm	P_s in kN	d_s in mm	P_u in kN	d_u in mm	Failure pattern
CB_{avg}	21.20	0.50	49.52	1.85	82.55	5.35	Flexure
$VB1G_1$	31.95	0.73	52.25	1.85	96.85	6.77	Shear failure of section with shear peeling of GFRP
$VB1G_2$	36.60	0.84	58.90	1.85	98.35	5.60	
$VB1G_3$	39.10	0.79	65.00	1.85	99.60	5.27	
$VB2G_1$	37.10	0.68	71.20	1.85	100.00	4.50	
$VB2G_2$	40.30	0.72	72.80	1.85	107.00	5.00	
$VB2G_3$	44.10	0.75	75.50	1.85	106.00	4.20	
$VB3G_1$	39.45	0.67	79.80	1.85	110.00	4.05	
$VB3G_2$	49.80	0.56	93.55	1.85	125.00	4.20	
$VB3G_3$	51.70	0.62	91.30	1.85	120.00	4.94	

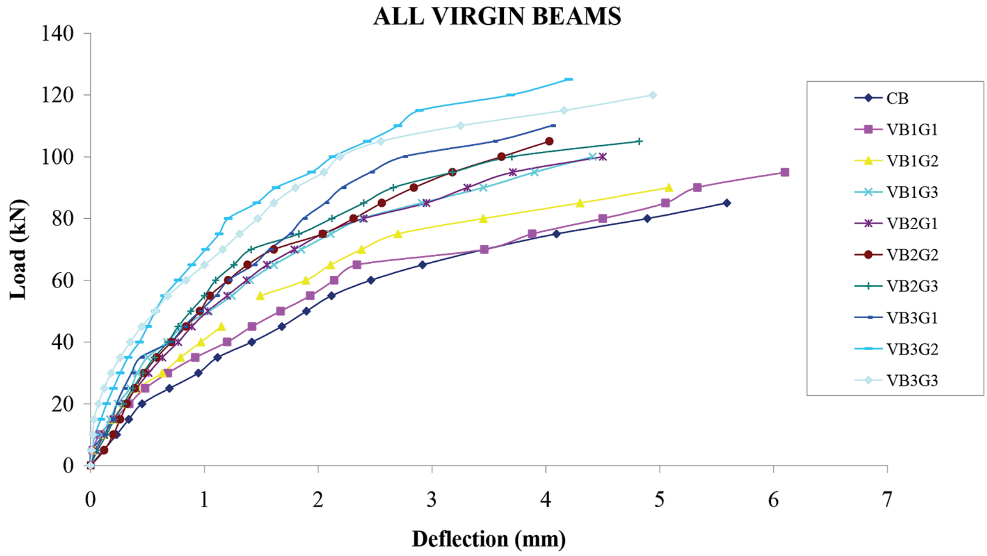

Figure 2. Load – deflection plots for CB and VB specimens

39.10 and 37.10 kN respectively and the deflection values observed for the corresponding crack load values were 0.79 mm and 0.68 mm respectively. The service load values observed for the 1200 GSM and 600+600 GSM virgin beams were 65 and 71.20 kN respectively for the deflection value of 1.85 mm. The ultimate load values observed for the 1200 GSM and 600+600 GSM virgin beams were 99.60 and 100 kN respectively and the deflection values observed for the corresponding ultimate load values were 5.27 mm and 4.50 mm respectively.

Fig. 3. Failure diagrams for beams

Double vs triple layer comparison

900+900 GSM vs 600+600+600 GSM virgin only

The crack load values observed for the 900+900 GSM and 600+600+600 GSM virgin beams were 40.30 and 39.45 kN respectively and the deflection values observed for the corresponding crack load values were 0.72 mm and 0.67 mm respectively. The service load values observed for the 900+900 GSM and 600+600+600 GSM virgin beams were 72.80 and 79.80 kN respectively for the deflection value of 1.85 mm. The ultimate load values observed for the 900+900 GSM and 600+600+600 GSM virgin beams were 107 and 110 kN respectively and the deflection values observed for the corresponding ultimate load values were 5 mm and 4.05 mm respectively.

Failure modes

The control beams exhibited the flexure failure with major vertical cracks in mid span with slight appearance of shear cracks at the failure stage. For control beams no any crushing of concrete was observed. From all the other GFRP wrapped beams none of the beam showed the flexure failure. The beams failed with shear crack propagation 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 diagrams for control beam and virgin beams are shown in Figure 3.

CONCLUSIONS

The ultimate load carrying capacity of all the strengthen beams was enhanced as compared to the control beams where as in all, the ultimate deflection for control beam was found to be more than virgin beams. 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 (900 + 900 + 900 GSM) where as the ultimate strength of $VB3G_3$ specimen (1200+1200+1200 GSM) was observed to have less value than $VB3G_2$. 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. A single layer of GFRP registered increased value for crack load and service as compared to double layer of GFRP with same GSM value but the difference was not so significant. In test, roller supports acted as anchoring system and prevented the end debonding. This shows the significance of anchoring system provision in actual retrofit procedure using FRP.

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