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Load Deflection Characteristics of HSC Beam with Non-Metallic Reinforcement

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Abstract: Corrosion of steel reinforcement in concrete structures is caused principally by carbon-dioxide, de-icing salts and seawater and is a multi-billion pound problem worldwide. A radically new method which has recently been evolved out is the use of Fiber Reinforced Polymer (FRP) re-bar as a substitute for conventional steel reinforcement. FRP re-bar are typically made up of either with aramid, glass or carbon fibers embedded in resin such as vinyl ester, polyester or epoxy. Since, the constituents of FRP re-bar are non-metallic, corrosion problem does not arise. Use of FRP re-bar as reinforcement has gained numerous advantages compared to the conventional reinforcement. Hence, an attempt has been made to study the effect of high strength flexural member reinforced with Glass Fiber Reinforce Polymer (GFRP) re-bar. In the present research, two high strength concrete beams of size 125×200×2100 mm have been considered. The concrete grade used is M 40. One beam is reinforced with GFRP re-bar and the other is with steel. Two point loading test was carried out and the failure characteristics were studied. The plots showing load-deflection curves at different sections of the beams and the moment carrying capacity were also developed. Thus, the study provides a clear picture of the performance of flexural member reinforced with GFRP re-bar and also provides a clear comparison with steel reinforced beam.

Key words: Load-deflection, high strength concrete, beam, GFRP re-bar, two point loading, FRP

INTRODUCTION

The corrosion of steel reinforcement is the most common cause of failure of concrete structures. This fact is attributed in structures such as bridges and parking garages and to the use of de-icing salts in cold climate regions. Poor quality concrete also contributes to corrosion. Inadequate specifications and construction practices produce concrete with high permeability and undesirable cracking which enables the ingress of corrosion-inducing agents to the reinforcing steel, thus accelerating the corrosion process. It shows that in some old bridge structures, concrete is beginning to crack; some parts of the steel bars have been exposed. It is very dangerous to the whole structure and it will cost a lot to repair. Concrete has been the most widely used construction material for decades and will continue for years to come because of its very low cost, mouldability, good mechanical properties and availability throughout the world. Therefore, engineers are searching for solutions to the corrosion problems in concrete structures. Recently, Fibre Reinforced Plastic (FRP) re-bar has emerged as a promising material to enhance the corrosion resistance of RC structures. These bars have helical depressions and sand particle coatings. Fibre reinforced composite materials consists of fibres of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In general, fibres are the principal load-carrying members while the surrounding matrix keeps them in the desired locations and orientation. The matrix also acts as a load transfer medium between the fibres and protects them from environmental damages due to rubbing and humidity. Many fibre-reinforced composite materials offer a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. Because of low specific gravities, the high strength to weight ratios and high modulus/weight ratios of these composite materials, they are markedly superior to those of metallic materials. For these reasons, fibre reinforced composites have emerged as a major class of structural material and are either used or being considered as substitutions for metals in many weight-critical components in aerospace, automotive and other industries.

MATERIALS AND METHODS

Review of literature: Nanni (1993) has stated that FRP should become the reinforcement of choice in special non-prestressed applications where durability or magnetic permeability is the controlling parameters. Benmokrane *et al.* (1996) has done an experiment and theoretical comparison between flexural behaviour of concrete beams reinforced with fibre reinforced plastic reinforcing bars and identically conventionally reinforced

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ones are investigated. Toutanji and Saafi (2000) investigated that concrete members reinforced with GFRP exhibit large deflections and crack width compared with concrete members reinforced with steel. Alsayed and Alhozaimy (1999) provided a modified method for beams reinforced with steel fibers and FRP re-bars based on the considerations of ACI code. Li and Wang (2002) have studied 16 GFRP beams with various shear span depth ratio and concluded that ECC beams exhibit significant increase in flexural performance in terms of ductility load carrying capacity and damage tolerance.

Material properties: Ordinary Portland Cement of 43 grade was used for the study. Clean river sand falling in zone II was used as fine aggregate and broken granite stone jelly of 12 mm size was used as coarse aggregate. The materials used for the study exhibit the following properties. The properties of constituents of the concrete are obtained by conducting test on the materials and are shown in Table 1. The GFRP re-bar utilised for the study were supplied from Uniglass. Industries, Bangalore and its properties supplied by them are shown in Table 1.

Experimental programme: The GFRP bars used in this project were manufactured by pultrusion using e-glass fibres and a thermoplastic resin. The chemical admixture, silica fume used for the study was supplied from M/s Elkem India Pvt. Ltd., Navi Mumbai. The mix design required for the study was carried out by IS code method. The proportion of the concrete is 1:0.61:2.33.0.31 (C:FA: CA:w/c). The cement was replaced by 8, 10, 12 and 14% micro silica and a proper dosage of melamine based super plasticizer was also added. The slump was maintained between 50 and 75 mm. The optimum mix that gave the highest strength at 28 days of curing was found out and this optimum mix was used for the casting of the beams. Fibre glass of low alkali e-glass and polyester resins are used for the fabrication of GFRP reinforced beams. The average compressive strength of concrete with 12% replacement of silica fume is 48.89 N mm^{-2}. Fe 415 grade conforming to IS 1786-1990 were used as internal reinforcement in one of the beams. Two RC beams of 2.1 m in length were fabricated and tested for this research. The beams were designed as under-reinforced beams and were 125 mm wide ×200 mm deep ×2100 mm long. In the 1st beam, the tension reinforcement was provided by two 10 mm diameter bars of Fe 415 grade steel and two 8 mm diameter round bars of Fe 415 grade steel was used at the top as hangar bars. Shear reinforcement was provided by means of 8 mm diameter round bars of Fe 415 grade steel placed at 150 mm centre to centre. In the 2nd beam, the tension reinforcement was provided by two 12 mm diameter GFRP re-bars and two 8 mm diameter round GFRP re-bars were used at the top as hangar bars. Shear reinforcement was provided by means of 8 mm diameter round bars of Fe 415 grade steel placed at 150 mm centre to centre. The materials were mixed in a rotating tilting drum mixer. First coarse aggregate, fine aggregate and silica fume were mixed thoroughly in a dry condition and then cement, water and plasticizer are added to get a fresh concrete mix. The steel mould was placed in correct position on an even surface. All the interior faces and sides were coated with oil to prevent sticking of concrete to the mould. The reinforcement was placed inside the mould in position allowing enough cover spacing at the bottom and sides of the mould. Concrete was poured into the mould using a trowel. Needle vibrator was used for compaction. The mould is striped after 24 h. The test beams were cured for 21 days in a curing tank. After 21 days of wet during, the specimens were air cured for 7 days under laboratory conditions. The soffits of the beam are sand blasted to ensure complete removal of loose particles, grease, oil, moisture and corrosion inducing materials. Electrical strain gauges were pasted on GFRP re-bar.

Table 1: Material properties

Description	Cement	Fine aggregate	Coarse aggregate
Specific gravity	3.14	2.65	2.70
Fineness modulus	-	2.90	6.55

Test set-up, instrumentation and testing: Four-point flexural tests were carried out on the two beams using a loading of capacity 500 kN fixed frame on to a heavy test floor of the structural engineering laboratory. The beams were white washed and lines were marked. The load points and the reaction points were marked on the beams. The beam to be tested was placed on the loading frame and aligned exactly with the plumb bob. Both the beams were tested on a two point loading. The loading frame is of self-straining unit used for testing all types of beams. The load was applied by means of 500 kN hydraulic jack powered by a hand-operated pump. A proving ring placed below the jack directly measured the load applied by hydraulic jack. Finally, the applied load was read from the corresponding calibration chart. A steel I-section was used to apply the required two points over the beam; a single concentrated load was applied by the hydraulic jack over the centre of the steel girder to its reactions supports spaced symmetrically towards the centre. The reaction supports of the girders are placed on a small rod

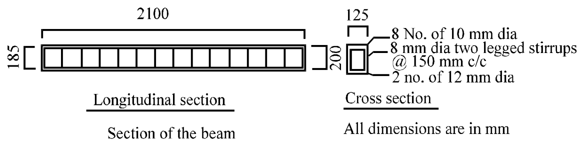

Fig. 1: Sectional details of the beam

and plate to transfer the load to the main beam. Figure 1 shows the longitudinal and cross sectional details of the beam. A dial gauge was fixed at the centre and at loading points of the beam to measure the deflection of the beam for various loading stages. All the instruments were completely checked before loading, initial readings of the deflectometer and the proving ring. Hydraulic jack was operated and the load was applied gradually. The proving ring reading and deflectometer reading were observed and recorded at different stages of loading up to ultimate load. During testing, formation and growth of cracks were marked on the surface of the beams by drawing lines on the cracks. While taking readings, extreme care was taken not to touch any of the testing and measuring equipment.

RESULTS AND DISCUSSION

Cylinders of size 150 mm in diameter and 300 mm height were cast to plot the stress strain curve of concrete. The load deformation characteristic of the steel reinforced beam was observed and shown in Fig. 2. Similarly, the load deformation characteristics of the GFRP reinforced beam are observed and are plotted as Fig. 3. The deformation of the reinforcing bars was measured by mechanical strain gauges at the top and bottom exactly where the reinforcements were placed. The variation of strain along the depth of the beam at ultimate load is shown in Table 2.

The variation of load carrying capacity in GFRP reinforced and a steel reinforced beam is shown in Fig. 4. The cracks for the GFRP reinforced beam developed at the left quarter span of the beam first and then at the centre of the beam in the tension zone. The cracks then propagated towards the compression zone. The maximum crack width noticed was 0.2 mm in the steel as well as the GFRP re-bar reinforced beams.

Figure 5 shows the failure pattern of the GFRP reinforced beam. Following points on results are; there is not much difference between the ultimate strength of both the beams. The reason may be due to insufficient ductility prevailing in the GFRP re-bar. Ultimate load obtained for the GFRP re-bar reinforced beam is almost equal to steel reinforced beam. It may be due to the reason that moment of resistance for the steel reinforced beam is kept constant and the area of GFRP re-bar reinforcement is reduced.

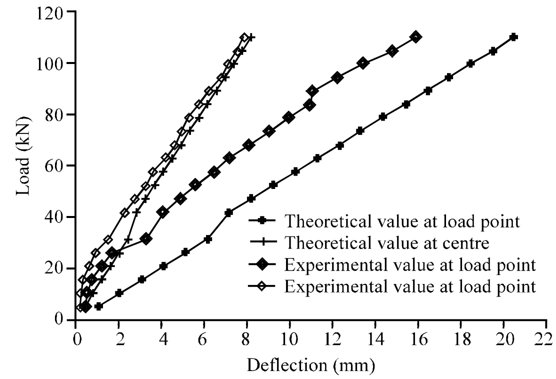

Fig. 2: Load deflection curve for steel reinforced beam

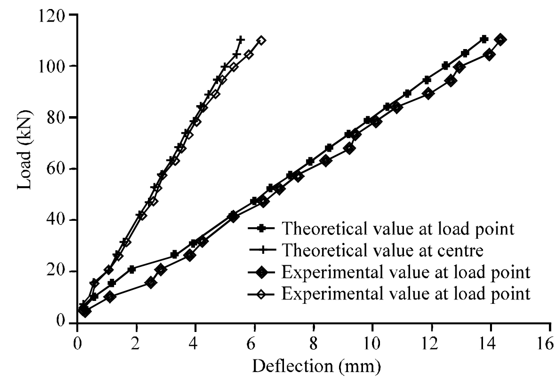

Fig. 3: Load deflection curve for GFRP reinforced beam

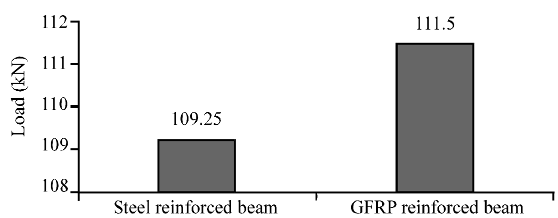

Fig. 4: Load carrying capacity of the beams

Fig. 5: Failure pattern of the GFRP beam

Table 2: Strain readings at the top and bottom of the reinforcement

Specimen	Strain at top reinforcement	Strain at bottom reinforcement
Steel beam	0.00687	0.00745
FRP beam	0.00642	0.00791

CONCLUSION

The feasibility of using Glass Fibre Reinforced Plastics (GFRP) re-bar as reinforcing elements in concrete beams was investigated in this study. The deflections were calculated theoretically and verified with experimental results.

Two beams reinforced with steel and GFRP re-bar of dimensions 125×200×2100 mm were tested under two point loading conditions. The deflections, strains and crack pattern were monitored to evaluate the structural behaviour of the beams. It is observed that the load carrying capacity of GFRP reinforced beam is >2% the steel reinforced beam and can be used for aggressive environment, since it is of non metallic and anti corrosive in nature.

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