Flexural and Shear Strengthening of RC Beams with FRP –An Experimental Study

Gannarapu Vijay[1] ,Vallepu Vishnu Vardhan[2]
Roll number: 14tq1d2013[1]
Associate professor[2]
Siddhartha institute of technology and sciences (tq)[12]
Department of civil engineering[12]

Abstract: **This study deals with experimental investigation for enhancing the flexural and shear capacity of RC beams using Glass fiber reinforced polymers (GFRP) and Carbon fiber reinforced polymers (CFRP). Fifteen concrete beam specimens with dimensions of 110mm width, 200mm height and 1300mm length were fabricated in the laboratory. As per practical consideration of pre-stressed bridge girders, one 30mm diameter longitudinal hole was provided below the neutral axis in the tension zone in all the beams for future strengthening, service lines and other consideration. The geometry of all beams was kept constant, while steel reinforcement varied as per initial design. Out of 15 beams four were control beams. One beam was made without any steel reinforcement strengthened with two layers of GFRP fabrics U- jacketed over the full span. Five beams were weak in flexure, strengthened using GFRP fabrics with varying configurations in higher flexural zone. Four beams were weak in shear, (tied with two 6-Ø stirrups in each support, one 6-Ø stirrup at mid span to keep the grill intact for concreting) strengthened using GFRP fabrics with varying configurations in higher shear zones near both supports. One beam was made weak in shear, strengthened with CFRP fabrics in higher shear zones near both supports. All the beams were simply supported at both ends with 1000mm effective span, 150mm bearings, loaded under more realistic loading conditions, i.e. uniformly distributed loaded (UDL) and tested up to failure by gradually increasing super imposed load. The preparation of concrete surface was done with great care and showed no bond failure in all U-jacketed and inclined stripped beams. One beam bonded with GFRP fabric in the soffit bottom only failed due to debonding.The flexural and shear capacities of the beams are compared with the theoretical prediction using codal provisions. The experimental deflection of beams are also compared with the theoretical predictions. The beams weak in flexure after strengthening showed remarkable flexural strength with 33% to 83% increase in cracking load capacity with respect to the control beam depending on the configuration of GFRP. The four beams weak in shear after strengthening showed 25% to 81% increase in cracking load capacity with respect to the control beam depending on the configuration of GFRP. One beam shear strengthened with CFRP showed remarkable increase of 131% in cracking load capacity and rigidity with respect to the control beam which is highest in the series of tested beams. There was increase in the stiffness of all strengthened beams compared to the control beams.**

I. INTRODUCTION

There are many existing bridge and building structures throughout the world, which do not fulfil specified design requirements. This may be due to upgrading of the design standards, increased loading due to change of use, ageing, corrosion of the reinforcement bars, marginal design, construction errors and poor construction, use of inferior material, and accidents such as fires and earthquakes, which renders the structure incapable of resisting the applied service loads. Thus the structure needs complete replacement or strengthening. The solution in such cases is complete dismantling and new construction or increasing the load carrying capacity through strengthening of the effected structures in various ways. Because of the prohibitive cost of replacing large number of deteriorated structures throughout the world, research efforts have focused on many methods of strengthening of structures. The strengthening and retrofitting of concrete structures represents one of the most challenging problems faced by engineers today. Historically, steel has been the primary material used to strengthen concrete bridges and buildings. Bonded steel plates or stirrups have been applied externally to successfully strengthen and repair concrete girders that are deficient in flexure or in shear. However, using steel as a strengthening element adds additional dead load to the structure and normally requires corrosion protection. These methods suffer from inherent disadvantages ranging from difficult application procedure to lack of durability. In recent years, the bonding of fiber reinforced polymer (FRP) fabrics, plates or sheets has become a very popular method for strengthening of RC beams. In fact, the application of FRPs to the strengthening of structures was first researched in the middle of 1980s for the flexural strengthening of RC beams using CFRP plates at the Swiss Federal Laboratory for Materials Testing and Research (Meier *et al.* 1993). In recent years, there is extensive research on the use of FRP fabrics, plates or sheets to replace steel plates in plate bonding. FRPs are used widely for beam and column strengthening by external wrapping. At present there are numerous research teams all over the world undertaking research in this area. The main advantages of FRP fabrics, sheets or plates are their high strength-to -weight ratio and high corrosion resistance. The former property leads to great ease in site handling, reducing.

II. LIMIT STATE METHOD OF DESIGN (IS 456 - 2000)

Considering partial factor of safety = 1

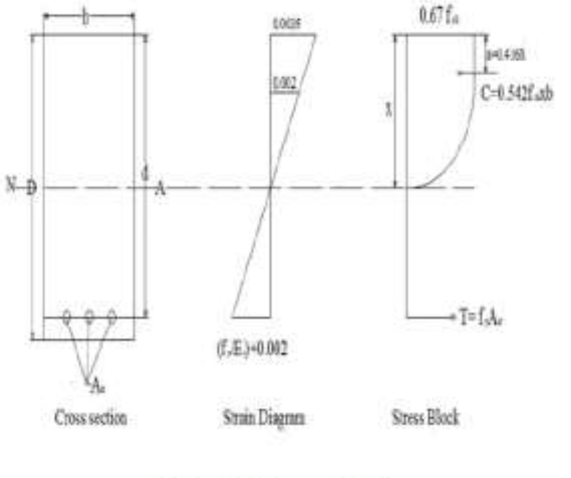


Fig.1 Stress Block Parameters for LSM

2.1 Ultimate Load Method of Design

There are many theories in practice, out of which Whitney's theory (37) has been the most popular and applied to calculate moment of resistance and initial cracking load.

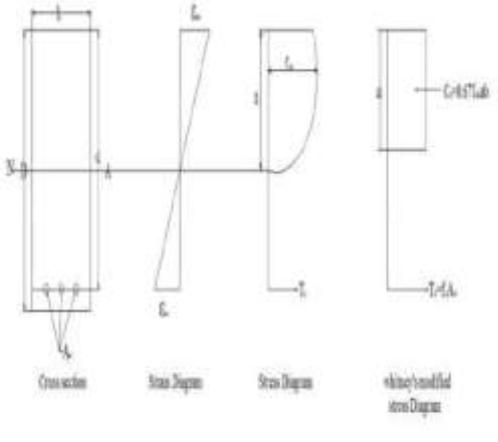


Fig.2 Stress block parameters for ULM

III. DETERMINATION OF YIELD STRESS AND YOUNG'S MODULUS OF FRP

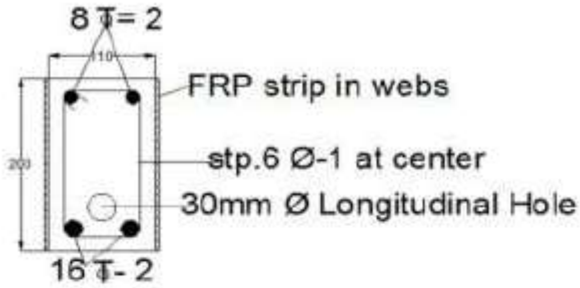
The yield stress (at 0.2% strain) and Young's Modulus are obtained experimentally by performing unidirectional tensile tests on specimens cut in longitudinal and transverse directions as prescribed in ASTM:D3039M-08 from the FRP plates fabricated earlier having constant rectangular size 250 mm length × 25mm width. The specimens are cut from the plates by a diamond cutter or by mechanically operated hex saw. After cutting, the sides are polished by sand paper. Three or more sample specimens are prepared from each plate of 2 PLY GFRP, 3 PLY GFRP and 2 PLY CFRP in this experiment, details shown in Table 5.2, 5.3 and 5.4 respectively. The specimens are tested in INSTRON 1195 universal testing machine. Each specimen is fixed in the upper jaw first, and gripped in the movable lower jaw having a gauge length of 150 mm. Gripping of specimen should as much as possible to prevent slippage. The load and extension are recorded digitally with the help of a load cell and an extensometer respectively. The specimen gradually loaded up to failure which is abrupt and sudden as the FRP material is brittle in nature. The INSTRON 1195 machine shown in Fig. 5.3 directly indicated the yield stress, Young's Modulus, ultimate strength and plotted the load-deflection curve shown in Fig. 4.The test results of 2 PLY CFRP, 2PLY GFRP and 3 PLY GFRP fabrics . . All the 15 beams are tested up to failure. Prior to testing of beams, the tensile test results of reinforcing steel as per IS 1786- 1985 and test results corresponding to tensile test of FRP laminates as per ASTM: D3039M-08 are presented. The compressive strength of controlled concrete cubes are also presented along with the flexural and shear strength of test beams. Their behavior throughout the test up to failure are described with respect to initial and ultimate load carrying capacity, deflection behaviour, rigidity, ductility, crack pattern and mode of failure.

3.1 Testing of Beams, Crack Pattern and Failure Mode

All the 15 beams are tested one by one in the loading frame. Three dial gauges are fixed below the beam each one at quarter span, mid span and three-fourth span. The load is gradually increased up to failure. The deflections are recorded up to initial cracking load. After the needles in the dial gauge rotated rapidly indicating approach of imminent failure, the dial gauges are removed to save from damage during failure of beams.

IV. SHEAR STRENGTH OF FRP STRENGTHENED BEAMS (RS1)

Beam RS1 The cross section of the beam RS1 is shown in Fig



Strengthened with 2 layers of GFRP in webs near supports for a length of 300mm

$V_s = 0$

$V_{frp} = \Phi_{frp} A_{frp} f_{frp} \left(\quad \right) d$

$\Phi_{frp} = 0.80$, d = effective depth of beam = 164mm

$A_{frp} = t_{frp} \times w_{frp}$, t_{frp} = thickness of FRP = 1mm, w_{frp} = width of FRP = 300mm

$f_{frp} = 241\ N/mm^2$, Angle β = (oriented 90^0 to the horizontal) = 90^0

$V_{frp} = \quad \times \times \quad \times \quad \times 164 = 63.24$ KN

$V_n = 79+0+63.24=142.24$

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