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Behaviour of GFRP Reinforced Concrete Column Under Axial Load

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Abstract. Fiber-Reinforced Polymer (FRP) reinforcing bars as the main reinforcement for concrete structures in harsh environments is becoming a widely accepted solution to overcome the problem of steel corrosion. Due to the relatively lower cost of glass FRP (GFRP) bars compared to the other commercially available FRP bars, the use of GFRP bars in reinforced concrete (RC) structures has been widely investigated. The project deals with the study of GFRP bar as main reinforcement for a short column under axial compression. A concrete column reinforced with steel bars and GFRP bars of cross section 450 mm * 450 having length 3000 mm is chosen for the study as prototype. The prototype has been modelled with a Scale Ratio of 3:1.A steel reinforced concrete model short column with cross section 150 mm * 150 mm and height 1000mm with end condition of both the ends of the column are pinned is taken to the study. The model column reinforced with 8 mm dia steel bars as main reinforcement and 8 mm dia bars as lateral ties having spacing 100 mm c/c. A clear cover of 20 mm used for severe exposure condition. The loading condition is concentric with minimum eccentricity.

INTRODUCTION

Conventional concrete structures are reinforced with non prestressed and prestressed steel. The steel is initially protected against corrosion by the alkalinity of concrete, usually resulting in durable and serviceable construction. For many structures subjected to aggressive environments, such as marine structures, bridges, and parking garages exposed to deicing salts, combinations of moisture, temperature, and chlorides reduce the alkalinity of the concrete and result in the corrosion of reinforcing steel. The corrosion process ultimately causes concrete deterioration and loss of serviceability. To address corrosion problems, professionals have started using alternatives to bare steel bars, such as epoxy coated steel bars and specialty concrete admixtures. While effective in some situations, such remedies may not be able to completely eliminate the problems of steel corrosion in reinforced concrete structures. Recently, composite materials made of fibers embedded in a polymeric resin, also known as FRPs, have become an alternative to steel reinforcement for concrete structures. Because FRP materials are nonmagnetic and noncorrosive, the problems of both electromagnetic interference and steel corrosion can be avoided with FRP reinforcement. Additionally, FRP materials exhibit several desirable properties, such as high tensile strength, that make them suitable for use as structural reinforcement.

Manufacturing of FRP

A manufacturing process called Pultrusion is the most common technique used for manufacturing continuous lengths of FRP bars that are of constant or nearly constant in profile below shows this manufacturing technique. Continuous strands of reinforcing material are drawn from roving bobbins. A veil is introduced and they pass through a resin tank, where they are saturated with resin followed by a number of wiper rings to remove excess resin. The strands are then led to a pre-former and then formed to their final shape and cured by the heated die. The speed of pulling through the die is predetermined by the curing time needed. To ensure a good bond with concrete, the surface of the bars is usually coated with sand and then cut to length. The application of the sand coating is an additional process, a layer of resin is applied (but not under heated conditions) and then the bar is coated with a thin layer of sand

Coefficient of Thermal Expansion

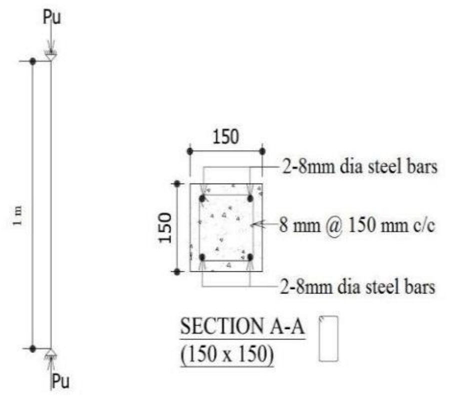
The coefficients of thermal expansion of FRP bars vary in the longitudinal and transverse directions depending on the types of fiber, resin, and volume fraction of fiber. The longitudinal coefficient of thermal expansion is dominated by the properties of the fibers, while the transverse coefficient is dominated by the resin. Coefficients of thermal expansion for typical FRP and steel bars. Note that a negative coefficient of thermal expansion indicates that the material contracts with increased temperature and expands with decreased temperature. For reference, concrete has a coefficient of thermal expansion that varies from 4×10^{-6} to 6×10^{-6}/°F (7.2×10^{-6} to 10.8×10^{-6}/°C) and is usually assumed to be isotropic.

OBJECTIVE OF THE PROJECT

To study the axial compressive behaviour of concrete columns reinforced with GFRP alone. Further, to study the feasibility of providing GFRP roving and GFRP mats as lateral ties/confinement.

Specimen Design

A concrete column reinforced with steel bars and GFRP bars of cross section 450 mm x 450 mm having length 3000 mm is chosen for the study as prototype. The prototype has been modelled with a Scale Ratio of 3:1. The detailing of a steel reinforced concrete model short column with cross section 150 mm x 150 mm and height 1000mm with end condition of both the ends of the column are pinned is given in the Fig 4.1. The model column reinforced with 8 mm dia steel bars as main reinforcement and 8 mm dia bars as lateral ties having spacing 100 mm c/c. A clear cover of 20 mm used. The loading condition is concentric with minimum eccentricity. A Demec Gauge is fixed in the mid height of the column and a Dial Gauge is fixed at the top of the column. The detailing of steel reinforced concrete column is shown in Fig. 1.



FIGIRE 1 Section of Steel Reinforced Column

The detailing of a GFRP reinforced concrete model short column with cross section 150 mm * 150 mm and height 1000mm with end condition of both the ends of the column are pinned is given in the Fig 4.3. The model column reinforced with 8 mm dia GFRP bars as main reinforcement and GFRP winding as lateral confinement. A clear cover of 20mm used. The loading condition is concentric with minimum eccentricity..

GFRP PROCEDURE

A 1000 kN testing machine (UTM) was used to conduct all tensile testing. The machine is equipped with hydraulic grips and a stroke capacity of 75 mm in either direction. Specimens were mounted into the hydraulic grips and a confining grip pressure of 2500 psi was applied by the hydraulic grips for specimens using the standard epoxy coupler, 1250 psi was applied to specimens using the Rock Frac coupler. Testing was done at a set strain rate of 0.02 mm/ second up to a load of 80 kN. Beyond that value the rate was increased to 0.05 mm /second. The slower initial loading rate was used to provide better resolution of the strains in the region used to determine the modulus of elasticity. The testing specimen mounted on the UTM and the failures of the specimen are shown in the following figures. The results of all tensile tests are summarized. The main properties of interest from these tests are the ultimate tensile strength, modulus of elasticity and elongation at failure. The Stress vs Strain graph for HYSD bar and GFRP bar were shown in the Fig.2 and Fig. 3 respectively.

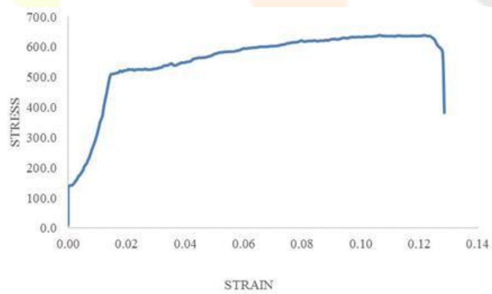


FIGURE 2. Stress – Strain curve for steel bar

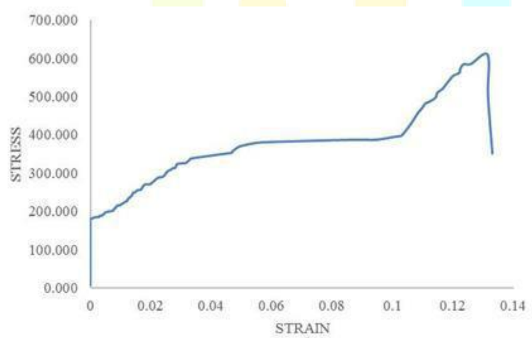


FIGURE3 Stress – Strain curve for GFRP bar

The young's modulus for the Steel and GFRP are 2.08 and 6.47 N/mm2 respectively. Generally, the tensile properties show a perfectly elastic behaviour until tensile failure occurred. This is the typical brittle behaviour of FRP rebar with unidirectional fibers. GFRP rebar's had brittle failures when compared to Steel. Visual observations indicated that the tensile failures of the GFRP rebar specimens were accompanied by delamination of the fibers, even if the failure was always brittle. It is seen that the GFRP rod are carrying a higher load when compared to steel. Steel was more ductile in nature compared to fibers, so their yielding is more and yielding at a point of 496.55 N/mm2.But in the specimens like GFRP attained a rupture failure. In GFRP, glass is a brittle material so it fails immediately at a maximum yielding stress of 542.63N/mm2. It is observed from the experimental investigations that the tensile strength of GFRP bars are 16% higher than Steel rods.

Test Setup

Long Column Compression Testing Machine with a capacity of 2000 kN available in Strength of materials Laboratory was used for testing of the columns. The bottom end of the machine moves on load application whereas the top end is stationary. The column specimens were placed in the column testing machine vertically between the end plates. Load was applied by hydraulic mechanism. The load was read using a proving ring. The strains in steel and GFRP were measured using strain gauges and data acquisition system. Axial deformation was measured using dial gauge. Strain in concrete was measured using Demec gauge

RESULT AND DISCUSSION

Specimen A

Specimen A was a cement concrete column reinforced with steel bars. The ultimate load carrying capacity and strain in concrete were found. The strains in concrete were found with the help of Demec Gauge. Demec Gauge readings corresponding to the applied loads were tabulated. Figure shows the crack pattern and the failure of Specimen A. Crack developed near the loading edge and propagated longitudinally through the column. Few diagonal cracks were also observed at mid height.. The graph shows that strain increases along with the applied load, but at a 120 kN the strain is reversed and is approximately a straight line as shown in figure.

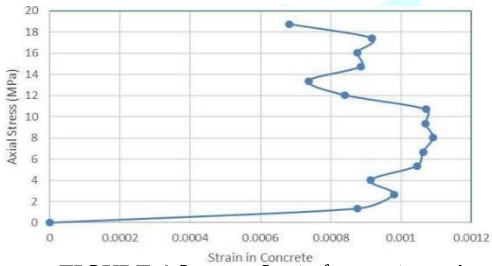


FIGURE.4 Stress – Strain for specimen A

Specimen B

Specimen B was made up of cement concrete reinforced with GFRP bars. The ultimate load carrying capacity, strain in concrete and strain in GFRP bars were found. The strain in GFRP bars were found with the help of Strain Gauge mounted in GFRP bars. Demec Gauge readings and strain in GFRP bar obtained from Data Acquisition System corresponding to the applied loads were tabulated. The Figure shows the crack pattern and the failure of Specimen B. Crack pattern of specimen reinforced with GFRP rods and GFRP ties is similar to that of column reinforced with steel. Figure show the strain pattern in concrete and GFRP respectively.

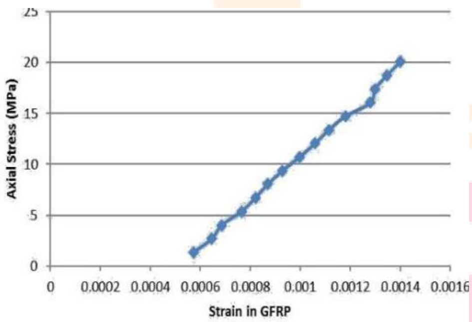


FIGURE. 5 Stress-strain for GFRP bar

Specimen C

Specimen C was made up of cement concrete reinforced with GFRP bars. It was tested under long column compression testing machine. The ultimate load carrying capacity and strain in GFRP bars were found. The strain in GFRP bars were found with the help of Strain Gauge mounted in GFRP bars. Strain in GFRP bar obtained from Data Acquisition System corresponding to the applied loads was tabulated. Figure shows the specimen at failure. The specimen failed by cracks near the loading edge and spalling of concrete. The strain behaviour of GFRP rods as shown in figure.

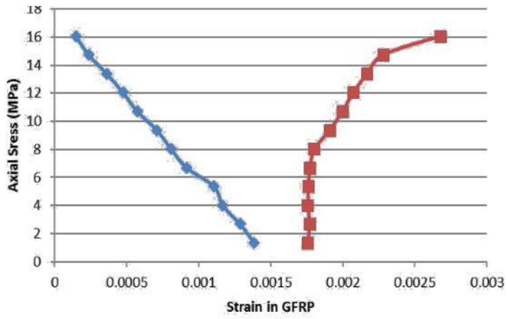


FIGURE 6 Stress-strain for GFRP bar

CONCLUSION

In this study an attempt was made to find the feasibility of the use of GFRP reinforced cement concrete columns. Three types of column specimens were cast, one with steel reinforcement, second with GFRP rods and ties and the third with GFRP rods, ties and GFRP wrap. All specimens were tested under axial compression upto failure.

i. Based on tensile test results, GFRP rods failed at 595 MPa and steel rods at 497 MPa. It is observed that the tensile strength of GFRP bars are 16% higher than Steel rods. But GFRP exhibited brittle failure when compared to steel rods.

ii. Column with steel reinforcement failed at 452 kN, Column with GFRP reinforcement failed at 452 kN, Column specimen with GFRP rods and GFRP wrap failed at a load of 520 kN.

iii. The load carrying capacities of GFRP reinforced concrete column without is same as that of steel reinforced concrete column. But GFRP reinforced concrete column wrapped with GFRP woven roving mat shows 20% decrease in strength due to defect in concrete during compaction. However in general GFRP reinforced concrete column wrapping gives higher strength compared to steel reinforced column and without wrapping.

iv. There was no sudden failure of GFRP bars or GFRP ties. Columns with GFRP showed similar pattern of cracks.

v. From the experimental study, it can be concluded that concrete columns reinforced with GFRP alone (both as longitudinal reinforcement and as lateral ties) performs similar to column reinforced with steel and hence, can be used as a viable alternative in situations where steel bars are prone to corrosion.

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