EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF CONCRETE BEAM REINFORCED WITH HYBRID BARS (STEEL AND GFRP)

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Abstract: *In this paper, the results of experimental and analytical investigation of flexural behaviors of concrete beams reinforced with glass-reinforced-polymer (GFRP) bars were studied. The GFRP rebar having the tensile strength of 902 MPa and Young's modulus of 46 GPa. The beams were 1800 mm long with a rectangular cross section of 150 mm in width and 200 mm in depth. Totally Four beams were tested. One beam was reinforced with glass-FRP bars, two beams were reinforced with both glass-FRP bars and steel and one was reinforced with steel, serving as a control specimen. The beams were tested to failure in four-point bending over a clear span of 1600 mm. The test results were reported in terms of ultimate load carrying capacity, deflection and cracks. The experimental results were used to predict the load vs. deflection of Concrete beams reinforced with hybrid bars. The measured load vs. deflections was analyzed and compared with the predicted FEM model using ABAQUS. The results indicate that the reaction forces and deflections obtained from the finite element model (FEM) were well matched with the experimental results.*

Key words: **GFRP, ABAQUS, finite element, fiber reinforced polymer, reinforced concrete beam.**

1. INTRODUCTION

The durability of concrete structures has been a great concern. Most common problems are arising in durability relating to the corrosion of steel reinforcement in concrete structures. Coastal structures, chemical industries, ports and bridges are the examples of structure subjected to corrosion of steel reinforcement. Corrosion doesn't begin simultaneously in all steel bars in concrete. Corrosion starts in the corner areas of the structure, for the following reasons (Qu and Zhang 2001): (1) a high carbonation rate; (2) easy entry of oxygen and water content; and (3) lower resistance to spalling than in other parts of the cross section. Corrosion starts to spall the concrete around the corner area first, and following accelerates the corrosion of inner steel reinforcements. The resistance of reinforced concrete (RC) to corrosion can be enhanced by improving the concrete quality, increasing the concrete cover, and replacing the steel bars located in the corner areas of the cross section by non-corrodible materials such as fiber-reinforced polymer bars.

FRP bars are considered as an alternative to the steel reinforcements in concrete structures, especially in aggressive environments, because of their high strength to weight ratio and non-corrodible nature. The performances of concrete beams reinforced with FRP bars have been studied in many countries and have issued design codes or guides for FRP-reinforced concrete structures [Japan Society of Civil Engineers (JSCE) 1997; Canadian Standard Association (CSA) 2002; American Concrete Institute (ACI) 2006; (CSA) 2006].

In this paper, we investigated the load vs. deformation of hybrid GFRP/steel-reinforced concrete beams both analytically and experimentally. Our analytical model is done by using ABAQUS to predict the load vs. deflection relationship of the beams. Design models for predicting flexural strength, and deflection are presented. We tested beams with different reinforcement ratios of GFRP to steel, and compared the experimental results with the analytical predictions.

1.1 GFRP Rebar

Glass Fiber Reinforced Polymers are a proven and successful alternative that have numerous advantages over traditional reinforcement methods, giving structures a longer service life. The GFRP rebar is a structural ribbed reinforcing bar made of high strength and corrosion resistant glass fibers that are impregnated and bound by an extremely durable polymeric epoxy resin. This combination equals an engineered material system resulting in unique attributes that replace and supersede typical materials such as galvanized, epoxy coated and stainless steel rebar. Its characteristic properties are ideal for any harsh and corrosive environments. GFRP is permanently resistant to chemical acids and alkaline bases, therefore extra concrete cover, anti-shrink additives, and even cathodic protection are not required. GFRP significantly improves the longevity of engineering structures where corrosion is a major factor.

GFRP will not rust, even in the harshest environments. It does not react to salt ions, chemicals or the alkaline present in concrete. GFRP rebar offers a tensile strength up to 3 times that of steel. GFRP is highly efficient to resisting heat transfer applications and does not create a thermal bridge within structures. GFRP rebar does not contain any metal; it will not cause any interference in contact with strong magnetic fields or when operating sensitive electronic instruments such as MRI units and rooms, Communications, Airports, Transformers, Aluminum and Copper Smelting Plants, Tele-Communications towers, Airport control towers, Hospitals and Rail roads. GFRP rebar is 9 times lighter in weight than the equivalent strength of Steel rebar. It is much easier to handle, and in most cases, only one truck load will be sufficient to supply the rebar even for an entire project.

Fig - 1 GFRP Rebar

1.2. FINITE ELEMENT ANALYSIS USING ABAQUS

Reinforced concrete is a complicated material to be modeled within finite element packages. A proper material model in the finite element model should be capable of representing both the elastic and plastic behavior of concrete in compression and tension. The complete compressive behavior should include both elastic and inelastic behavior of concrete. The development of a finite element model (FEM) may need intensive material testing to incorporate into the material model in any of the finite element (FE) packages available (Sinaei et al., 2011.In this paper, the ABAQUS program is used to model the behavior of Concrete beams reinforced with hybrid bars. The finite element model uses the concrete damaged plasticity approach; this model can help to confirm the laboratory investigation behavior. For validation, a reinforced concrete beam was modeled which had been experimentally tested. This is followed by a comparison of the finite element results with experimental results on RC beam elements in the following study.

2. EXPERIMENTAL PROGRAM

2.1. Test specimen and materials

The summary of the experimental work conducted in the present investigation to study the loads vs. deflection with different reinforcement ratios. Totally four beams were tested. One beam was reinforced with glass-FRP bars, two beams were reinforced with both glass-FRP bars and steel and one was reinforced with steel, serving as control specimen. While the steel properties were determined according to Indian codes, the material properties of the GFRP bars used in the project were taken as provided by the manufacturer.

The beams had a load span of 1,800 mm and a rectangular cross section of 150 mm wide and 200 mm high. Two steel bars of 8-mm diameter were used as reinforcement at the compression side of the beam as hanger bar. Steel stirrups with 8-mm diameter and 100-mm spacing were used as shear reinforcement. More details of the test beams are shown in Figure 3, and Table 1. Cubic concrete specimens of 150 mm high were cast at the same time as the beams. The average cube strength in compression (f_{cu}) was evaluated by tests on four cubic specimens. Sand-coated GFRP bars used for the tests were manufactured by CSK Technology, Hyderabad. The bar was 16mm in diameter. The tensile strengths and elastic moduli of the GFRP bars are reported in Table 2.

Table - 1 : Details of Tested Beams

Description	Beam	f_{ck} (MPa)	E (GPa)	ρ_s	ρ_f	ρ_f / ρ_s
Steel	SRC	30	27386	0	1.34	
GFRP	GFRP	30	27386	0	1.34	
GFRP and Steel	GS - 1	30	27386	0.67	1.34	0.5
GFRP and Steel	GS - 2	30	27386	1.34	1.34	1

SRC - Beam reinforced with steel rod only
GFRP - Beam reinforced with GFRP rod only
GS – 1 - Beam reinforced with steel (As) and GFRP (Af) rod for 0.5 Af/As ratio.
GS – 2 - Beam reinforced with steel (As) and GFRP (Af) rod for 1.0 Af/As ratio.

Table - 2 : Mechanical Properties of GFRP Bars

Rebar Diameter (mm)	Tensile Strength (MPa)	Elastic Modulus (GPa)
16	**902**	**45**

Mix design of M_{30}

This study follows the concrete mix design of IS 10262-2006 for the design of M30 grade concrete. The mix proportion of M30 grade was shown in Table 3 and the mix ratio was 1: 1.85: 1.72: 0.45

Table-3 : Mix proportion of M30 Grade

Material	Weight	Unit
Cement content	476.10	Kg/m^3
Water content	214.30	Kg/m^3
Fine aggregate content	882.03	Kg/m^3
Coarse aggregate content	820.50	Kg/m^3

2.2 Test Setup and Test Procedure

A four-point flexural test was carried out as shown in Figure 2. Linear variable differential transducers (LVDT) were placed at mid-span and at middle third of supports to measure the deflections. Loads were gradually applied with a hydraulic jack and measured with a load cell. Crack initiation and propagation were examined at each load level. Beam deflection and load values were recorded simultaneously.

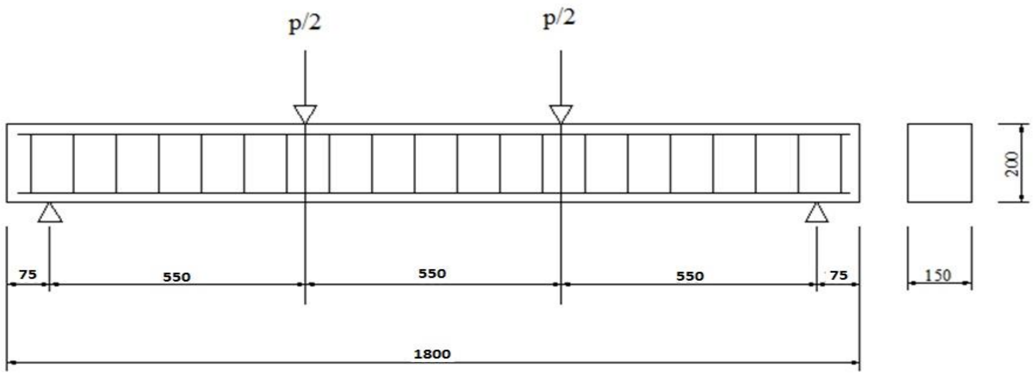

Fig - 2 : Tested beams description—instrument and setup

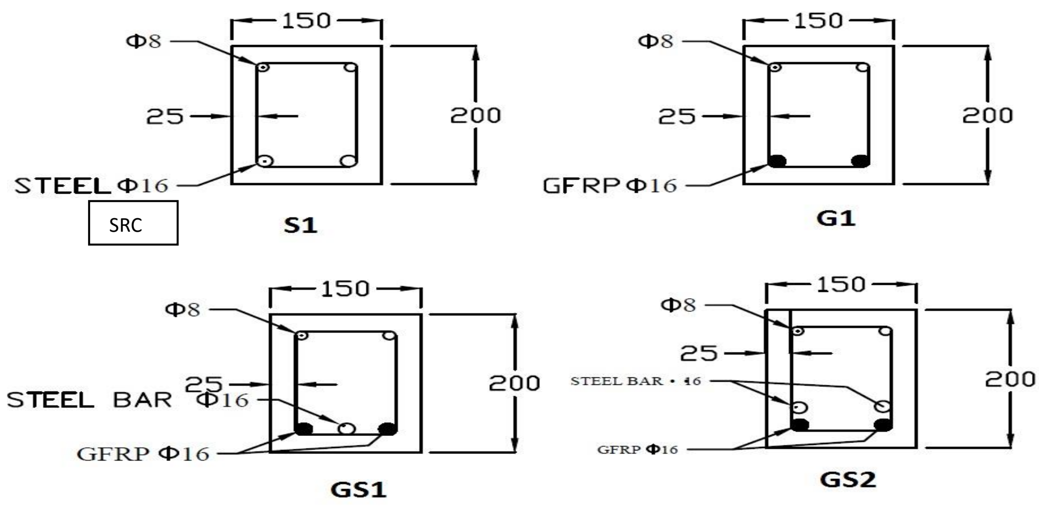

Fig - 3 : Description of beams cross section

Fig – 4 : Experimental setup.

Fig - 5 : Reinforcement cage

3 Finite Element Model in ABAQUS

3.1 Material properties

3.1.1 Steel reinforcing bar

An elastic, perfectly plastic material was used for the steel bar with an equal behavior in tension and compression (Li et al., 2006). The steel bar was treated as a uniaxial material throughout the element section. We can define the rebars as one-dimensional strain elements that can be embedded in the concrete. Their behavior is same as an elastic-plastic material. The rebars and concrete cracking behavior were considered independently. The steel bars used in the reinforced concrete beam were assumed to have the yielding stress:

σ_y = 415 MPa

While it's elastic modulus was assumed to be:

E = 200 GPa

The steel reinforcement was assigned with a Poisson's ratio of 0.3, and full bond contact between the steel reinforcement and concrete was presumed. The embedded element option was used for connecting the reinforcement element to the concrete element, steel reinforcement was used as the embedded element and the concrete was designated as the host element.

3.1.2 Concrete

The uniaxial compressive strength of concrete selected as:

f_{ck} = 30 MPa

The Poisson ratio of concrete (V) is taken as 0.2

The Stress – Strain graph of M30 grade concrete for to calculate the young's modulus as shown in Figure 6.

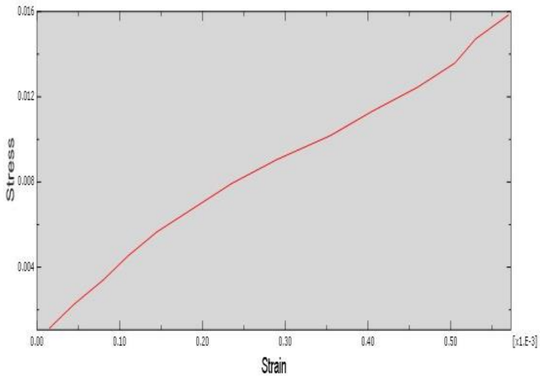

Fig – 6 : Stress – Strain graph of M30 Grade

3.1.3 GFRP Rebar

The GFRP bars used in the reinforced concrete beam were assumed to have the yielding stress (σ_y) of 920 MPa.

The Poisson ratio of concrete (V) is taken as 0.25.The elastic modulus was assumed to be 45GPa.

3.2 The finite element mesh

In order to obtain accurate results from the FE model, all the elements in the model were purposely assigned the mesh size of 10mm to ensure that each two different materials share the same node. The type of mesh selected in the model is structured. The mesh element for concrete is 3D solid which is called C3D8R and for the rebar it is 2D truss which is called T3D2 (Figure 8).

3.3 Boundary conditions

The first boundary condition was assumed as the bottom of the end Plates under the beam was fixed in X, Y and Z – Directions and second boundary condition was as the middle third plates were restrained in X and Z – Directions and Gives displacement in Y – Dir..

The boundary conditions in ABAQUS model were shown in Figure 10.

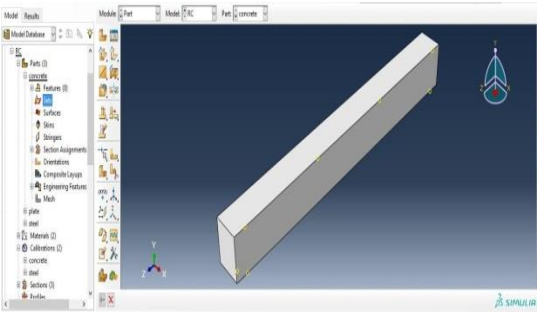

Fig - 7 : Beam modeling in ABAQUS

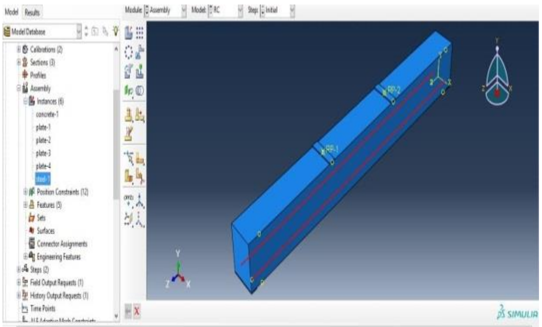

Fig - 8 : Meshing of beam in ABAQUS

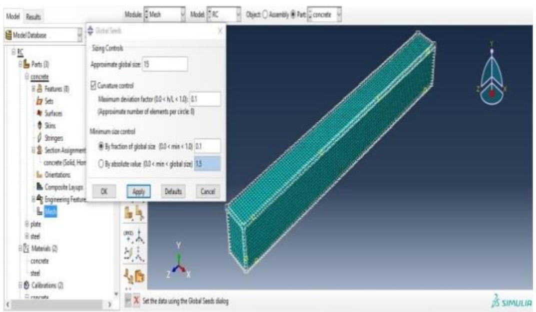

Fig - 9 : Assemblage in ABAQUS

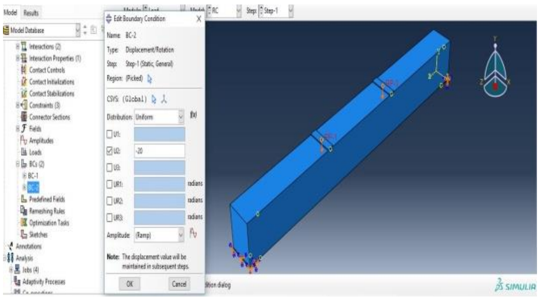

Fig - 10 : Boundary conditions in ABAQUS

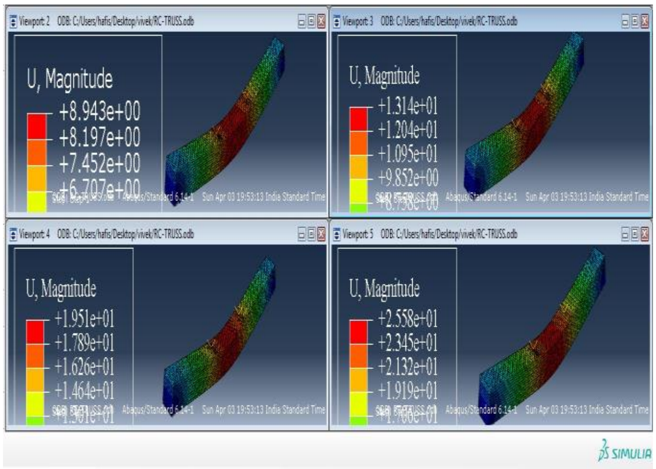

Fig - 11 : ABAQUS Results.

4 Test results and comparisons

This chapter describes the analytical and experimental results of all the 4 beam specimens. Out of 4 beams one beam was controlled beam. One beam was reinforced with GFRP and two beams were reinforced with different reinforcement ratio of Af/As.

4.1 Flexural Capacity

The Ultimate load carrying capacity of the tested beams are shown in Table 4.The flexural capacity of the hybrid GFRP/steel-reinforced concrete beams increased as the reinforcement ratio increased. From the graphs 11(a,b,c and d), the analytical models have good agreement with experiment results. The comparisons of Ultimate load capacity of beams are shown in Table 4. The ultimate load carrying capacity of GFRP reinforced beam is almost nearer to the steel reinforced beam. The load carrying capacity is increased about 15% with the decrease of Af/As ratio.

Table-4 : Comparison of Ultimate load capacity of beams

Specimens	Theoretical Load (kN)	Experimental Load (kN)
SRC	132.55	119
GFRP	124.34	121
GS – 1	131.22	128
GS - 2	138.89	135

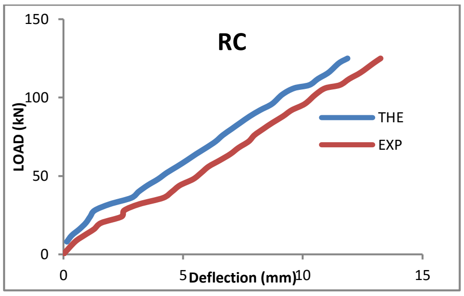

Fig-12(a) :SRC beam

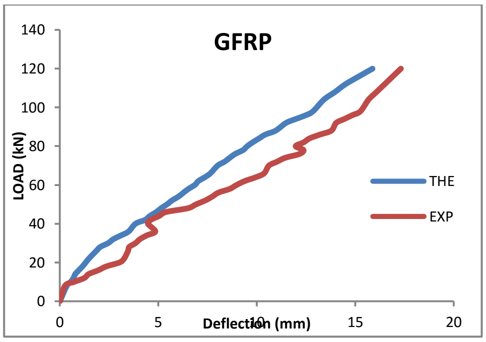

Fig - 12(b) : GFRP beam

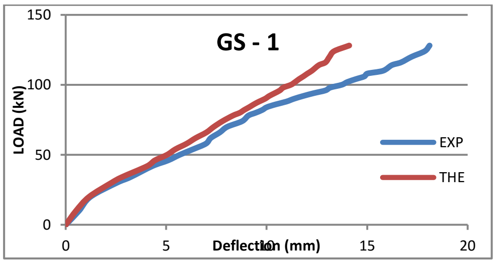

Fig - 12(c) : GS - 1 beam

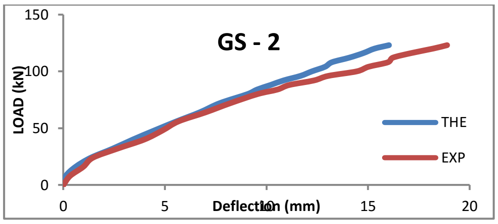

Fig -12(d) : GS - 2 beam

Figure.12 Plot of comparison of experimental and analytical values

4.2 Loads vs. Deflection

The Load vs. Deflection curve is shown in Figure 12. From the graph, for the same load, the deflection of GFRP beam is maximum, the deflection of SRC beam is minimum and the deflections of different reinforcement ratios are in between them. The deflection of Hybrid RC beams decreases with the decrease of A_f/A_s.The GFRP reinforced beam is more ductile than steel reinforced beam but decreased with the decrease of Af/As.

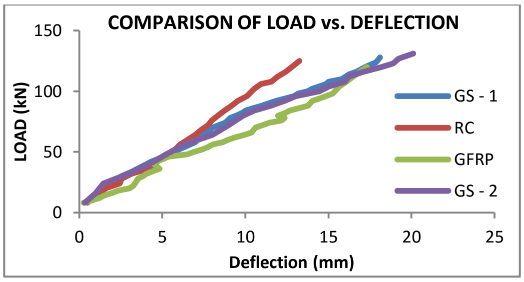

Figure.13 Plot of comparison of load vs. deflection

4.3 Cracks

The first crack developed in SRC, GS – 1 and GS – 2 at 30 kN, 21 kN, 24 kN and 28 kN respectively. In SRC beam, GS - 1 and GS – 2, the first crack was developed nearer to the center of the beam. In GFRP beam, the first crack was occurred just below the loading point. The cracks patterns developed in concrete beams are shown in (Figure 11). The average crack spacing of RC beams was minimal, the average crack spacing of GFRP beams was maximal, and the average crack spacing of hybrid RC beams was somewhere in the middle. The average crack spacing decreases with the decrease of Af/As.

Fig - 14(a) : SRC beam

Fig - 14(b) : GFRP beam

Fig - 14(c) : GS - 1 beam

Fig - 14(d) : GS - 2 beam

5. CONCLUSIONS

Based on the experimental results and predicted models, have drawn the following conclusions:

1. A Glass-FRP-reinforced beam behaved linearly until cracking and almost behaves linearly between cracking and failure, with a greatly reduced slope. At failure, the beam was largely deflected.
2. The ultimate load carrying capacity of GFRP reinforced beam is almost nearer to the steel reinforced beam. The load carrying capacity is increased about 15% with the decrease of Af/As ratio.
3. For the same load, the deflection of GFRP beam is maximal, the deflection of SRC beam is minimal and the deflections of GFRP-Steel reinforced beams are between them. The deflection of GFRP-Steel reinforced beams decreases with the decrease of A_f/A_s.
4. The predicted load vs. deflection behavior from ABAQUS was in good agreement with the experimental results.

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