Non-linear Finite Element analysis of concrete beams reinforced with GFRP bars

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***Abstract* - The non-linear flexural behaviour of concrete beams reinforced in the GFRP bars has been studied in this paper. This paper consist of numerical investigation of TMT and GFRP reinforced concrete beams. Finite Element analysis has been carried out using ABAQUS software. The parameters used for studying the flexural behaviour are the reinforcement ratio. The load response of the FE model was found to be much stiffer than the experimental results. Analytical load deflection response was compared with the experimental results using ACI 440 1R-06 and it was found that the Barnson's model proposed in ACI code was less stiffer and conservative than the experimental results.**

Keywords – non-linear, GFRP, CDP,ABAQUS,Analytical

1 INTRODUCTION

Steel reinforcement corrodes rapidly under aggressive marine environment, chemical plants, waste water treatment plants and bridges. Corrosion is an electrochemical process in which the reinforcement acts both as anode and cathode. The presence of salt water which has chlorine ions acts as the electrolyte, thus accelerating the electrochemical reaction. Glass Fibre Reinforced Polymer (GFRP) bars are very much resistant to corrosion since there is no Fe ions present in it.

Thus replacing normal steel reinforcement with GFRP bars is an effective method to prevent corrosion. These bars has greater application in the adverse environment. It also has higher strength to weight ratio. The GFRP bars are manufactured using pultrusion process. The pultrusion process of GFRP bars involves impregnating the liquid resin mixture (resin, filter and additives) in the fibre rovings and pulling it through the die. Fibre rovings, resins hardens by heating and producing into a cured profile. The GFRP bars have high tensile strength but low Young's modulus and is non-ductile unlike steel bars.

Experimental investigations have been crried out earlier a CSIR-SERC on twelve number of concrete beams reinforced with GFRP and TMT bars. In the six beams reinforced with TMT bars, three beams were reinforced with 10 mm TMT and 3 were reinforced with 12 mm TMT bars as main reinforcement. Same way 6 beams reinforced with GFRP has 3 beams reinforced with 10 mm GFRP bars and another 3 beams reinforced with 13 mm GFRP bars. Stirrups were 8 mm TMT bars in all the specimens. The objectives of the present study are,

- Development of Finite Element (FE) model for Reinforced Concrete (RC) beams reinforced with TMT and GFRP bars.
- Non-linear FE analysis of concrete model.
- Validation and comparison of the FE result with the available experimental results.
- Comparison of experimental result with the analytical expression available in the ACI 440 1R-06.

2 EXPERIMENT

2.1Test specimen

The beam specimen used for the experimental study were of size 100×200×1500 mm. M40 grade concrete and Fe415 steel were used. The Young's modulus and Poisson's ratio of GFRP bars were found to be 50 GPa and 0.2 respectively. The ultimate tensile strength of GFRP bars is 640 MPa. The stress-strain behaviour of TMT and GFRP bars are shown figure 1 & 2 respectively.

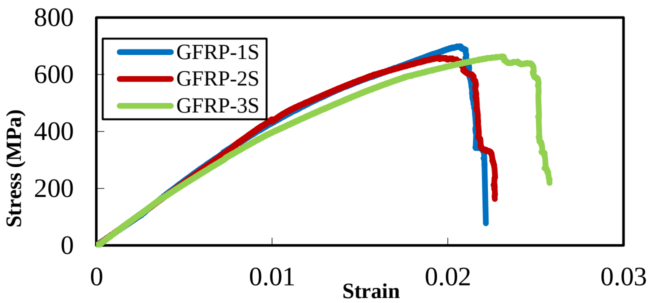

Fig. 1 Stress-strain curve of 13 mm diameter bars

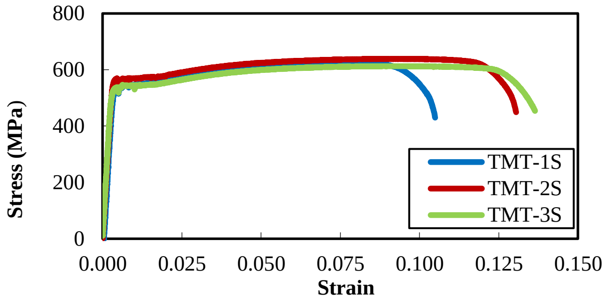

Fig. 2 Stress-strain curve of 12 mm diameter bars

The Young's modulus and Poisson's ratio of TMT bars are 200 GPa and 0.3 respectively. The reinforcement ratio for 10 mm TMT and GFRP are 1.79% , 2.58% for 12mm TMT bars and 3.03% for 13mm GFRP bars.

2.2 *Test Program*

Four point bending was applied on the beam at a distance of 450 mm from the centre of the support on either side of beam. Load was applied through a servo hydraulic actuator of ±100kN capacity. The various data acquired during the test include the maximum load, deflection and strain at mid span. The test setup and the reinforcement detailing of the beams are shown in the figure 3.

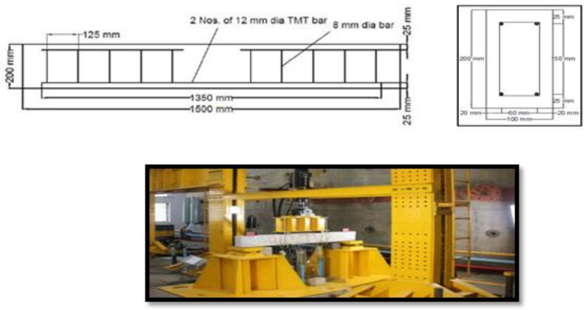

Fig. 3 Test setup and the reinforcement detailing

3 FINITE ELEMENT STUDY

The general purpose FE software – ABAQUS is used for numerically simulating the structural response of the concrete beams reinforced with TMT and GFRP bars. The general models are validated with the experimental results.

3.1 *Constitutive Models*

3.1.1 Concrete model: The Concrete Damaged Plasticity (CDP) model available in the ABAQUS was used to model the non-linear behaviour of concrete. The values for eccentricity, ratio of initial biaxial compressive yield stress to initial uni-axial compressive yield stress, f_{b0}/f_{c0} , ratio of the second stress invariant on the tensile meridian to compressive meridian at initial yield are taken as 0.1, 1.16 and 2/3 respectively. The dilation angle was taken as 36^{O} as suggested by Yusuf Sumer et al (2015). Appropriate inputs were provided for CDP model. Viscosity was assumed as 0.2.The compression and tension values of concrete, damage parameters were given. The compression and tension values were obtained from HSU model and tension stiffening model respectively.

CONCRETE COMPRESSION BEHAVIOUR	
yield stress(MPa)	inelastic strain
22.33581	0
26.75134	0.0000625
36.3784	0.000255
42.19756	0.000521
44.5189	0.00094
44.27531	0.001448
42.46598	0.002012
34.09702	0.003805
21.04289	0.007263
16.00131	0.009439
damage parameter	inelastic strain
0	0
0.0464275	0.000783
0.067109	0.001
0.099312	0.0015
0.146453	0.002
0.205555	0.0025
0.272292	0.003
0.342128	0.0035
0.56832	0.005
0.776919	0.008
0.855452	0.01

CONCRETE TENSION BEHAVIOUR	
Tensile stress (MPa)	Fracture energy (N/mm)
2.5	0.2
Damage parameter	Inelastic strain
0	0
0.9	0.01

3.1.2 Reinforcement model: The rebars were modelled as elastic, isotropic one dimensional material. Young's modulus and Poisson's ratio are given as an elastic material property input for both TMT and GFRP bars. To include the non-linearity in the model stress vs plastic strain values were given as input from experimental results. The values are given below are the average of the three specimens tested. As shown in the fig 1, all the three specimens show non-linearity from 200 MPa. So, the plastic strain was considered from that point onwards. The values given are the average of the three specimens tested.

3.1.3 Solid element: The solid element in ABAQUS can be used for linear and non-linear analysis. A 3D solid continuum element having 8 nodes with linear interpolation was used and was modelled in 3D space. They are designated as C3D8. The Degree Of Freedom (DOF) for solid element is 3(X,Y & Z translations).

3.1.4 Beam Element: The wire feature which embeds in the 2D planar space was choosen for modelling reinforcement. In ABAQUS, beam element is a 1D line element. The beam element deformations include axial stretch and bending. Hence the DOF is 2. They are designated as B2D2.

3.2 Constraints

To simulate the experimental program in the model, there must be proper constraints defined in the model. Rigid, tie and embedded constraints were applied to simulate the physical behaviour of the beam.

3.3 Meshing

Meshing was done by using solid and beam element. The sizes of the meshes for the concrete beam and the load plate was choosen in such a manner that there is compatability between the nodes. The reinforcement was also meshed.

3.4 Boundary Condition

In the experimental setup, the supports were at a distance of 200 mm from the end of the either side of the beam. Similarly in the model, the supports were provided at a distance of 200 mm from the either side of the beam. In the hinged support the translations in the y and z directions are restrained and in the roller support the translations in y direction is restrained.

3.5 Loading

To capture the non-linear behaviour of the model, the loading must be given in terms of deflection. The deflection corresponding to the peak load was taken and was applied.

3.6 Numerical Analysis

Non-linear analysis is an iterative process and for performing this iteration there needs to be increase in load and deflection for every iteration taking the non-linear property of the materials into account. This is performed by static, Riks analysis available in the ABAQUS.

4. RESULTS AND DISCUSSIONS

The load vs deflection curve for the concrete beams reinforced with TMT and GFRP bars from the FE model was compared with the experimental results. The load deflection response curve of the concrete beams reinforced with TMT bars from the FE model is similar to the experimental results. Fig 4 shows the load deflection curve for RC beams reinforced with TMT bars.

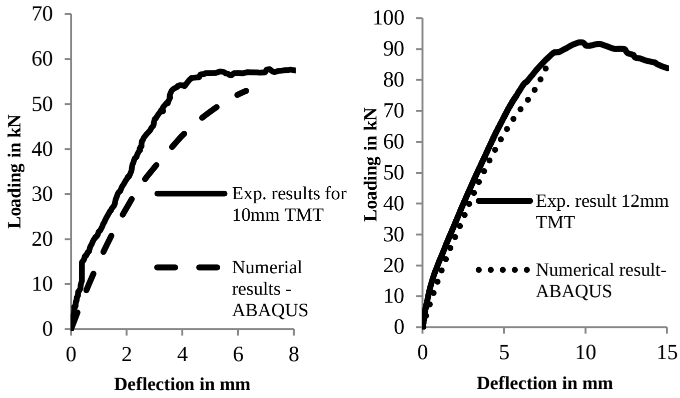

Fig.4 load response curve of 10mm & 12mm TMT bars RC beams

But for the GFRP bars RC beams, the load response curve obtained from the FE model was stiffer compared to the experimental results. Fig 5 shows the load deflection curve of RC beams reinforced with GFRP bars.

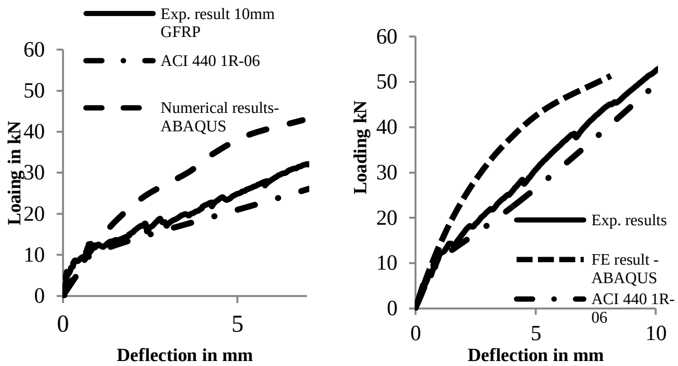

Fig.5 load response curve of 10mm & 13mm GFRP bars RC beams

5. ANALYTICL MODEL

Barson's approach represents the expression for effective moment of inertia I_e.

$$I_e = I_g(\frac{M_{cr}}{M_a})^3 + I_{cr}(1 - (\frac{M_{cr}}{M_a})^3)$$

was used to calculate the deflection of the GFRP reinforced concrete beams according to ACI 440 1R-06.

Load vs Deflection was plotted by sing the expressions available in ACI 440 1R-06 and the corresponding plots are shown in fig 5. From fig , it can be noted that the load-deflection response obtained by using the codal provisions of ACI and the experimental results match well with eachother compared to the FEA response.

6. SUMMARY

Non-linear FE analysis was carried out with RC beams reinforced with GFRP and TMT bars. The available experimental results were taken as reference and used for validation. The widely used model CDP, was employed to represent the non-linear behavior of concrete. Appropriate material input, boundary conditions and loading were given as input for the FE model to simulate as close to as experimental conditions. Static non-linear analysis was carried out to predict the behavior of specimens with increase of load. The load deflection response is also obtained by using the expressions available in ACI. From the analysis it was foud that the load-deflection response was found to reasonably agree with the corresponding experimental observations.

7. ACKNOWLEDGEMENT

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