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Experimental Validation of GFRP Smeared Analysis for Composite Concrete in Torsion

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Abstract: **This paper investigates the torsion behavior of reinforced concrete beams strengthened with glass fibre reinforced polymer (GFRP). The effect of GFRP wrapping on the torsion strength of the beam is examined. There are two group of beam. Group 1- Two of the beam was used as a control beam and Group 2- Four beams were strengthened using different configurations and different types of GFRP fabrics. Totally Six test beams are made with normal steel bars. Beams are made with 40 % replacement of fly ash in cement. All the beams were designed to fail in torsion. The study is restricted to continuously wrapped GFRP fabrics. The experimental study shows that the GFRP wrapping increase the torsion strength of the reinforced concrete beams. The beams will be numerically analysis using ANSYS Software. Load deflection relation as well as torsion twist angle relations were drawn and behavior comparison. In this Full Wrapping pattern gives a better result than the other beams.**

Keywords: **Torsion, Glass fibre, Wrapping and Fly ash.**

I. INTRODUCTION

Modern civilization relies upon the continuing performance of its civil engineering infrastructure ranging from industrial buildings to power stations and bridges Composite material made of fly ash is used in many ways and is subject to a variety of different loading conditions, and so different types of stress develop. On the other hand, since the behavior of concrete under torsion is similar to that of shear in most brittle elements even though bending has much ductility in beams, studying the influential factors on torsion is of great significance.

The structural retrofit problem has two options, repair/retrofit or demolition/ reconstruction. This problem needs development of successful structural retrofit technologies. Retrofitting of concrete structures with wrapping FRP sheets provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry.

A. Torsional strengthening of beam:

Structural members subjected to torsion are of different shapes such as T-Shape and box sections. These different configurations make the understand Reinforced concrete(RC) beams have been found to be deficient in torsional capacity and in need of strengthening. These deficiencies occur for several reasons, such as insufficient stirrups result in from construction errors or inadequate design, reduction in the effective steel area due to corrosion, or increased demand due to a change of torsion in RC members a complex task. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using FRP in strips.

II. LITERATURE REVIEW

Ameli et al.,(2007) experimentally reinforced concrete beams subjected to torsion that are strengthened with FRP wraps in a variety of configurations. Experimental results show that FRP wraps can increase the ultimate torque of fully wrapped beams considerably in addition to enhancing the ductility.

Al-Mahaidi and Hii(2006) focuses on the bond-behavior of externally bonded CFRP in an overall investigation of torsional strengthening of solid and box-section reinforced concrete beams. Significant levels of debonding prior to failure by CFRP rupture were measured in experiments with photogrammetry. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque twist behaviour, steel and CFRP reinforcement responses, and crack patterns was achieved. The addition of a bond-slip model between the CFRP reinforcement and concrete meant that the debonding mechanisms prior to and unique failure modes of all the specimens were modeled correctly as well. Numerical work was carried out using non-linear finite element (FE) modeling. Good agreement in terms of torque-twist behaviour, steel and CFRP reinforcement responses, and crack patterns was achieved.

Santhakumar et al. (2007) presented the numerical study on unretrofitted and retrofitted reinforced concrete beams subjected to combined bending and torsion. Different ratios between twisting moment and bending moment are considered. The finite elements adopted by ANSYS are used for this study. For the purpose of validation of the finite element model developed, the numerical study is first carried out on the un-retrofitted reinforced concrete beams that were experimentally tested and reported in the literature. Then the study has been extended for the same reinforced concrete beams retrofitted with carbon fiber reinforced plastic composites with ±45and 0/90o fiber orientations. The present study reveals that the CFRP composites with ±45 fiber orientations are more effective in retrofitting the RC beams subjected to combined bending and torsion for higher torque to moment ratios

III. MATERIALS AND METHODS

A. *Materials Used:*

Ordinary Portland cement of grade 53 conforming to IS12269-1987 was used to make the concrete mixtures. Low calcium class F fly ash, with a specific gravity of 2.3, was also used. The fine aggregate used was river sand conforming to IS383-1970, with a specific gravity of 2.64. The crushed granite, with a specific gravity of 2.55, was used as a coarse aggregate. Epoxy Resin is used to laminate glass fibre sheet on the beam for the final structure to be strong.

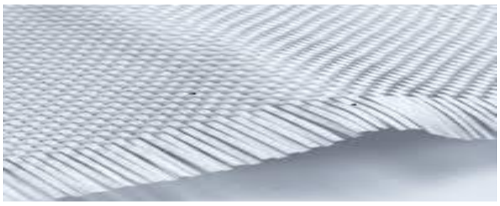

Fig. 1. Glass fibre reinforced polymer sheet

B. *Experimental Study:*

Two groups of beam designed to fail in torsion were cast, for investigation. The Group 1- Two of the beam was used as a control beam and one beam are made with 40 % replacement of fly ash in cement. In Group 2- Four beams were strengthened using different configurations and different types of GFRP fabrics. The beam was retrofitted with Fibre reinforced polymer bonded with Epoxy resin. Six test beams are made with normal steel bars. All the beams were designed to fail in torsion. The study is restricted to continuously wrapped GFRP fabrics. The reinforcement was used in the beam as mentioned in the Fig. 1. Wooden mould satisfying the above specimen size was used. Before casting, machine oil was smeared on the inner surfaces of moulds. Concrete was mixed using tilting type laboratory mixing machine and was poured into the moulds in layers. Each layer of concrete was compacted well. The specimens were removed from mould after 24 hours of casting and then cured using jute bags. All specimens were moist cured for 28 days.

TABLE I: MIX PROPORTION

Mix Id	Description	Cement	Fly ash	Sand	Aggregate	w/c
B1	Mix proportion by weight	1	-	1.5	3	0.4
B2,B3, B4,B5,B6	Mix proportion by weight	0.6	0.4	1.5	3	0.4

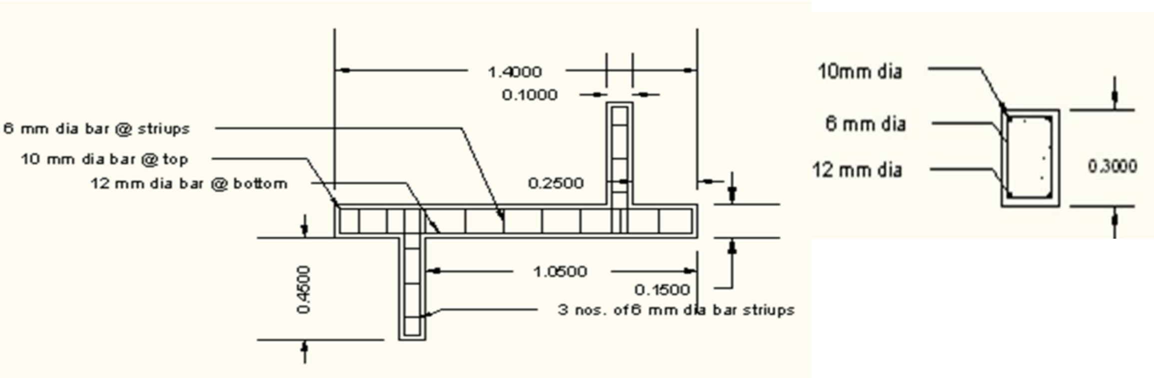

Fig.2 Reinforcement details of specimen

C. Wrapping of glass fibre:

For torsion test, in B3 GFRP was pasted along three sides of the beam, i.e. not in the bottom side of the beam.50mm strips of GFRP were used. Three type of spacing was followed to study the torsional effect of the reinforced concrete beam wrapped with GFRP. For B4, GFRP was pasted only at the centre position with width of 220 mm around all sides of the beam. In B5, GFRP was only placed at the sides projection beam and B6, GFRP was pasted at a distance of 1/3 position of the centre beam. The configuration of GFRP for torsion test is as shown in Fig.2

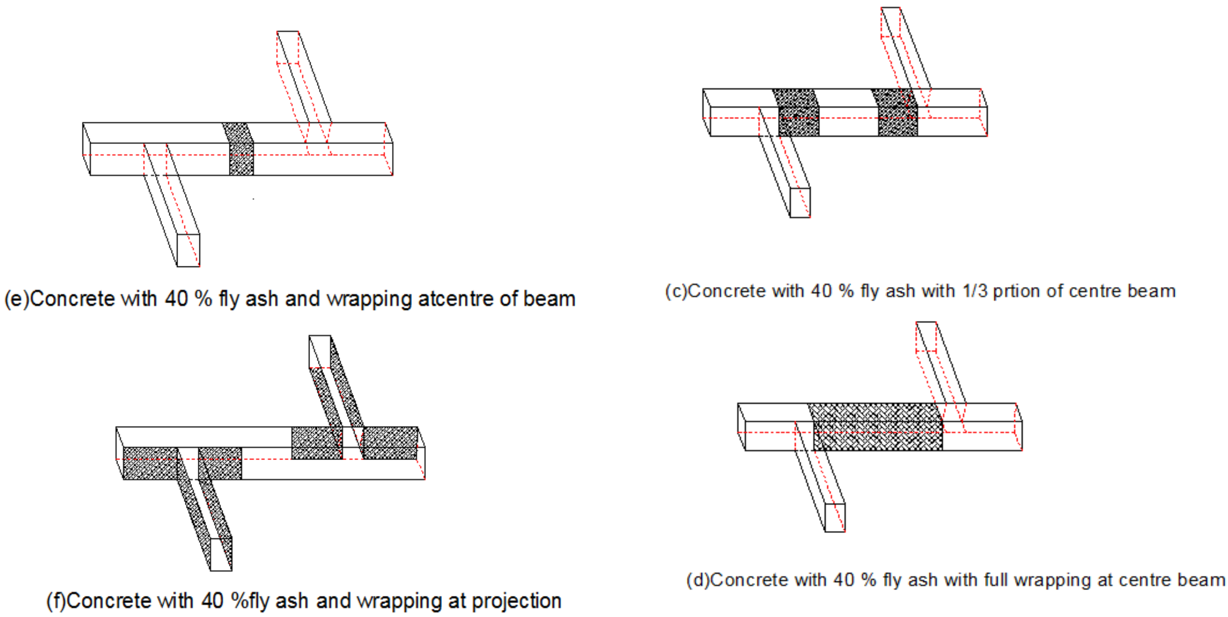

Fig.3 Wrapping patterns of beam

IV. EXPERIMENTAL SETUP

The beams were tested in the loading frame of "Structural Engineering" Laboratory. The testing procedure for the all the specimen is same. First the beams are cured for a period of 28 days then its surface is cleaned with the help of sand paper for clear visibility of cracks. The two-point loading arrangement was used for testing of beams. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. Two-point loading is conveniently provided by the arrangement shown in Figure. The load is transmitted through a load cell and spherical seating on to a spreader beam. The test member is supported on roller bearings acting on similar spreader plates. The specimen is placed over the two steel rollers bearing leaving 50 mm from the ends of the beam. The load is transmitted through a load cell via the square plates kept over the flange of the beam at a distance 300 mm from the end.

V. ULTIMATE TORSIONAL MOMENT CARRYING CAPACITY

The ultimate torsional moment carrying capacities of various beams are shown below. The GFRP wrapping increases the torsional moment carrying capacity of the reinforced concrete beams. The full GFRP wrapping shows 19 % increase when compared to control torsion beam where as wrapping on sides of projection should be preferred for torsional strengthening of reinforced concrete beam. The centre double wrapping of GFRP shows 7% and another 1/3 wrapping gives better result in increase in the torsional moment when compared to the control torsion beam

TABLE II: RELATIONBETWEEN ANGLE OF TWISTAND TORSIONAL MOMENT (CONTROL BEAM)

Torsional moment (kN /m)	Angle of twist (rad/m)	Remarks
0	0	
5.4	0.001	
7.8	0.002	
10.3	0.003	
13	0.004	
15.8	0.005	
18.2	0.006	
21	0.007	
23.7	0.008	First hairline crack appeared (65KN)
25	0.009	
25.5	0.010	
26.3	0.012	
27.8	0.015	
29	0.017	
33.4	0.019	
ULTIMATE LOAD		110KN

TABLE III: RELATIONBETWEEN ANGLE OF TWISTAND TORSIONAL MOMENT (BEAM 4)

Torsional moment (kN /m)	Angle of twist (rad/m) (sec 1)	Angle of twist (rad/m) (sec 1)	Remarks
0	0	0	
2.7	0.0006	0.00085	
5.4	0.00068	0.00095	
7.8	0.00074	0.00103	
16.1	0.00096	0.0013	
28	0.0015	0.00248	
35.1	0.002	0.00335	
40.4	0.00241	0.00427	First hairline crack appeared (90KN)
43	0.0026	0.00514	
45.8	0.00287	0.00621	
50	0.00421	0.00756	
54	0.00486	0.00813	
56.5	0.0057	0.00864	
ULTIMATE LOAD			230KN

VI. RESULT AND DISCUSSION

From the test result GFRP wrapping increases the torsional moment carrying capacity of reinforced concrete beams. Four

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types of configurations were studied out of which full wrapping shows 97KN/m increment in torsional moment then other and wrapping on sides of projection should be preferred for torsional strengthening of reinforced concrete beam.

TABLE IIV: SUMMARY OF RESULTS

Specimen	Configuration	Yield load moment	Ultimate load moment
Beam 1	Control beam	65	110
Beam 2	Control beam with 40%fly ash	58	100
Beam 3	Wrapped GFRP (1/3 position of the centre beam)	77	133
Beam 4	Wrapped GFRP (Full wrapping)	90	230
Beam 5	Wrapped GFRP (220 mm @centre)	81	150
Beam 6	Wrapped GFRP (side portion of the projection beam)	85	180

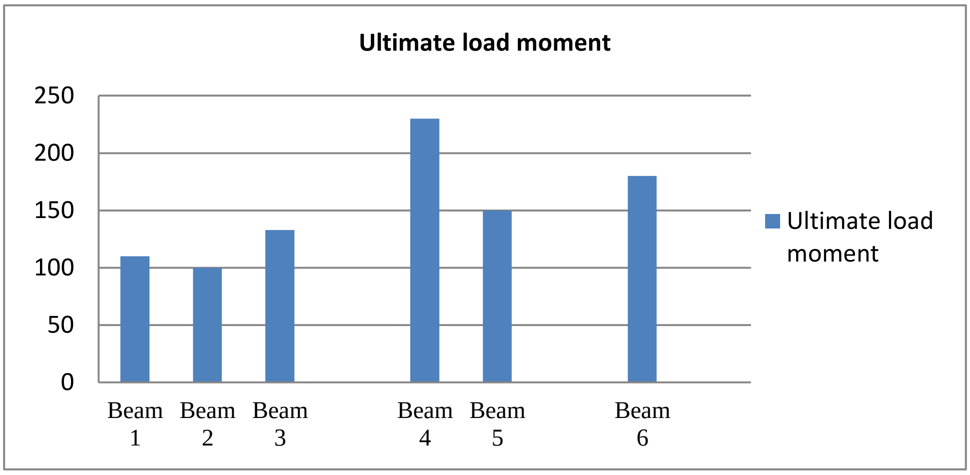
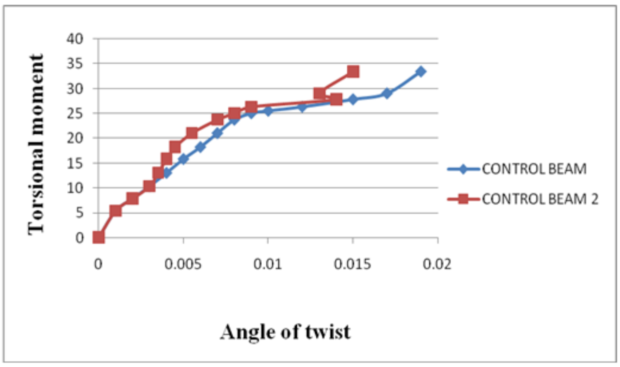


Fig.4 Torsional moment Vs Twist angle relationships

VII. MODE OF FAILURE

The entire beams tested in torsion test failed by parallel shear crack pattern. The conrol beam first cracked at 65 kNm, diagonal cracks developed and similar type of cracks formed along the length of the beam. The GFRP wrapped and control beams show the same mode of failure.



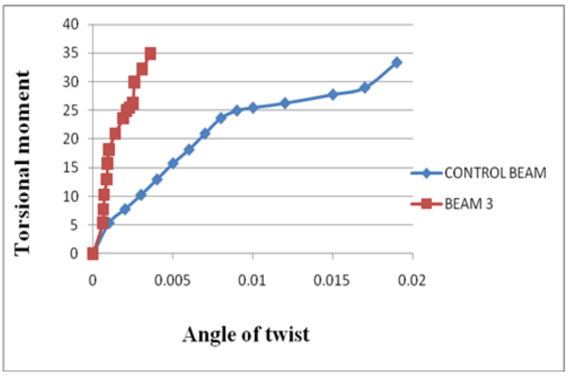


Fig.5Torsional moment Vs Angle of twist for beam 1 and beam 2 Fig.6 Torsional moment Vs Angle of twist for beam 1 and beam 3

In this control Beams, load was applied on the two moment arm of the beams which is 0.35m away from the main beam and at the each increment of the load, deflections are noted. Using this load and deflection data, the corresponding

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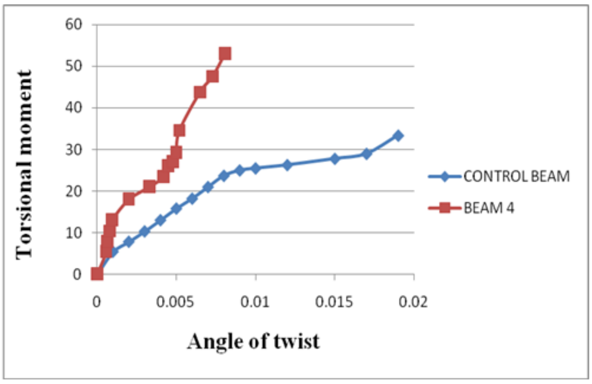
torsion moment and the twisting angle were calculated and the above graph was plotted. At the load of 65 KN initial hairline cracks appeared. Later with the increase in loading values the crack propagated further. The Beam1 failed completely in torsion at a load 110KN. It was observed those cracks were appeared.

In this above Fig.6 Beam-3wasstrengthenedbywrapping with two 220 mm GFRP strips at a distance 350 mm from each other over the beam under torsion. At the load of 77 KN cracking sound was heard. The Beam 3 failed completely in torsion at a load 133 KN. The increase strength of beam was 23% as compared to control beam. After the test is done the GFRP sheets were removed and the crack pattern was observed.

In this below Fig. 7 Beam 4 is compared with control beams which are weak in torsion. Beam-4 was strengthened by wrapping the full span of the beam between two projection beams under torsion with GFRP. At the load of 90KN cracking sound was heard. At the load of 90KN cracking sound was heard. The Beam 4 failed completely in torsion at a load 230KN. The increase strength of beam was 120% as compared to control beam. The increase strength of beam was 23% as compared to control beam.

In this below Fig.8 Beam-5 was strengthened by wrapping with two 220 mm GFRP strips at a distance 660 mm from each other over the beam under torsion. The GFRP strips with double layer. At the load of 81KN cracking sound was heard. The Beam 4 failed completely in torsion at a load 150KN. The increase strength of beam was 40% as compared to control beam.



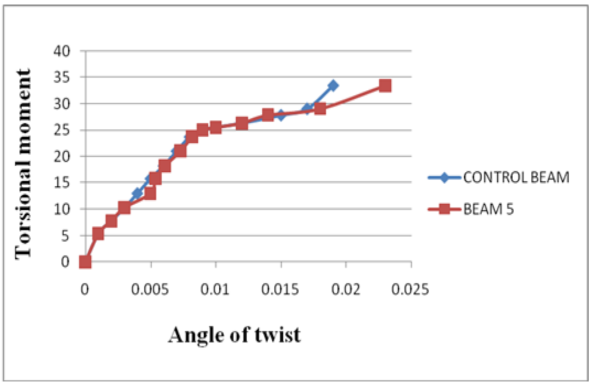
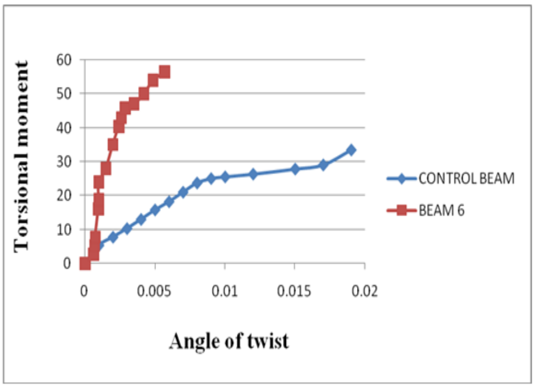


Fig.7 Torsional moment Vs Angle of twist for beam 1 and beam 4 Fig.8 Torsional moment Vs Angle of twist for beam 1 and beam 5

In this below Fig.9 In this Beam 6 is compared with control beam which is weak in torsion. Beam-6 was strengthened by wrapping the side span of the projection beam with GFRP under torsion. At the load of 85KN cracking sound was heard. The Beam 6 failed completely in torsion at aload180KN. The increase strength of beam was 70% as compared to control beam.

In this below Fig.10 Angle of twist of each beam is compared with the angle of twist of control beam. Also the torsional behaviour is compared between different wrapping schemes having the same reinforcement. Same type of load arrangement was done for all the beams.



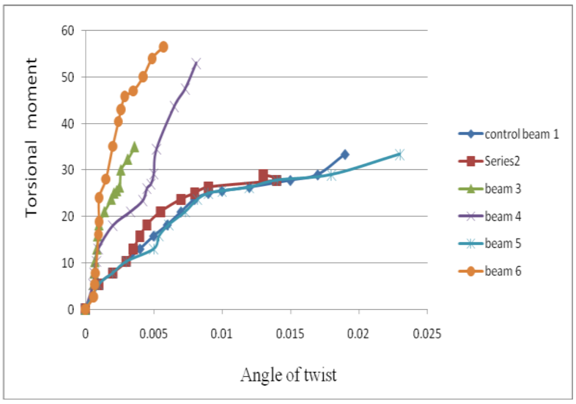


Fig.9Torsional moment Vs Angle of twist for beam 1 and beam 6Fig.10 Torsional moment Vs Angle of twist for all beams

VIII. NUMERICAL STUDY

Solid 65, a 3-D structural reinforced concrete solid element was used to model the concrete. This element is capable of cracking in tension and crushing in compression. It is defined by eight nodes having three translational degrees of freedom at each node. The All the reinforcements were modeled separately using Link 8, a 3-D spar element which is an uniaxial tension-compression element defined by two nodes with three translational degrees of freedom at each node. Important aspect of this element is the treatment of nonlinear material properties.

The bond between steel reinforcement and concrete was assumed to be perfect and no loss of bond between them was considered in this study. The Link 8, 3-D sparelement for the steel reinforcement was connected between nodes of each adjacent concrete Solid 65elements so that the two materials share the same nodes. The same approach was adopted for the CFRP composites to simulate the perfect bonding. The thickness of the Solid 46 element was modified due to geometric constraints from the other concrete elements in the model. However the equivalent overall stiffness of the Solid 46 element was maintained by making changes in the elastic and shear moduli Figures 2(a) and 2(b) show the finite element models of the control and retrofitted beams respectively.

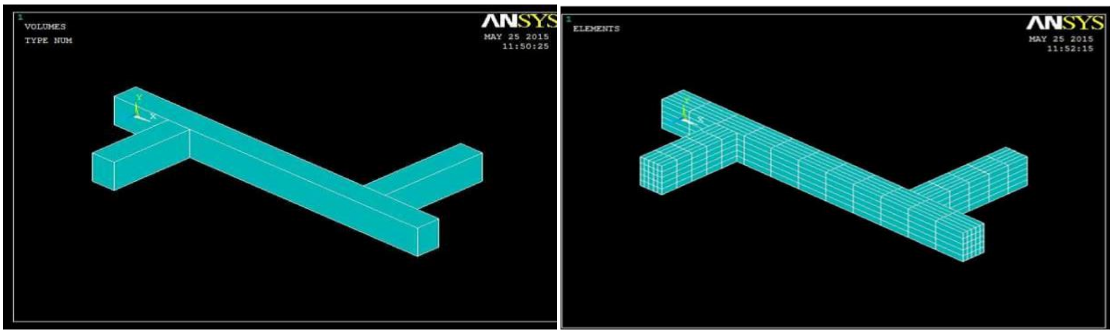


Fig.12 Modeling and Meshing of Beam

A. Non- linear solution and failure Criteria:

In this study the total load applied was divided in to a series of load increments (or) load steps. The automatic time stepping in the ANSYS program predicts and controls load step sizes for which the maximum and minimum load step sizes are required. After attempting many trials the number of load steps, minimum and maximum step sizes was determined. During concrete cracking, steel yielding and ultimate stage in which large numbers of cracks occur, the loads were applied gradually with smaller load increments. Failure for each model was identified when the solution for 0.0045 Kn(0.001 kips) load increment was not converging.

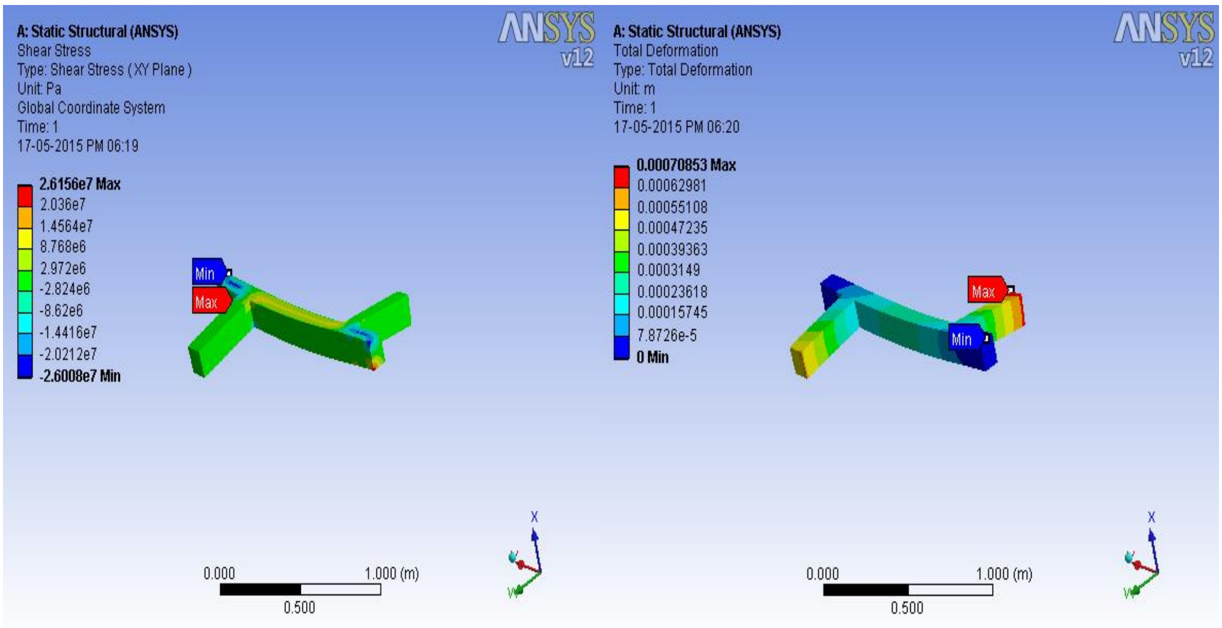


Fig.13 Deformation of beam

IX. CONCLUSION

An experimental program comprised testing six rectangular cross section reinforced concrete beams was conducted to evaluate the efficiency and feasibility of strengthening beams subjected tosion using GFRP wraps. Based on the obtained results, the following conclusions can be furnished:

- Strengthening reinforced concrete rectangular beams subjected to torional loads using GFRP wraps helped in improving the overall performance of strengthened beams.
- Strengthening beams with GFRP wraps helped in improving the torsional capacity of beams up to 230% of its non-strengthened value.
- Strengthening beams with GFRP wraps helped in increasing the torsional stiffness by decreasing the twist angle up to 100% of its non-strengthened value. There is no effect of GFRP wraps on beam torsional stiffness in loading stages before cracking and in early loading stages after cracking.

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