TORSIONAL BEHAVIOUR OF RC BEAMS WRAPPED WITH FIBRE REINFORCED POLYMER (FRP)

THESIS SUBMITTED IN PARTIALFULLFILLMENT FOR THE DEGREE OF:

BACHELOR OF TECHNOLOGY IN CIVIL ENGINEERING

BY:

DEBADITYA CHAKRABORTY (107CE023)

AKASH MEHROLIA (107CE036)

UNDER THE GUIDANCE OF:

PROF. Mrs. ASHA PATEL

Department of Civil Engineering

National Institute of Technology Rourkela

Rourkela-769 008, Orissa, India

CERTIFICATE

CERTIFICATE

This is to certify that the thesis entitled **"*FULL TORSIONAL BEHAVIOUR OF RC BEAMS WRAPPED WITH FIBRE REINFORCED POLYMER (FRP)*"** submitted by **DEBADITYA CHAKRABORTY (107CE023) and AKASH MEHROLIA (107CE036),** in the partial fulfillment of the degree of **Bachelor of Technology** in **Civil Engineering**, National Institute of Technology, Rourkela, is an authentic work carried out by them under my supervision. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

Date:

PROF. Mrs. ASHA PATEL

Department of Civil Engineering
National Institute of Technology
Rourkela-769 008, Orissa, India

ACKNOWLEDGEMENT

We wish to express our sincere and heartfelt gratitude to our supervisor

Professor Mrs. ASHA PATEL, Department of Civil Engineering, National Institute of Rourkela, for her guidance, sympathy, inspiration and above all help throughout the duration of our project. We truly appreciate and value her esteemed guidance and encouragement throughout the year. Her knowledge and company at the time of crisis would be remembered throughout our life.

We would also take this opportunity to thank all our teachers, who provided us with a solid background for our project work.

Also we would like to thank the laboratory staff and administrative staff of this department for their timely help.

DEBADITYA CHAKRABORTY

AKASH MEHROLIA

TABLE OF CONTENTS

List of Figures:

List of Tables:

ABSTRACT

Many beams located at the perimeter of buildings carry loads from slabs, joists and beams from one side of the member only. This loading mechanism generates torsional forces that are transferred from the beams to the columns. Such beams are deficient in torsional shear capacity and are in need of strengthening.. Fibre Reinforced Polymer (FRP) as an external reinforcement is used extensively to address the strength requirements related to flexure and shear in structural systems, but the strengthening of beams subjected to torsion is yet to be explored. In this project, the behaviour and performance of reinforced concrete beams strengthened with externally bonded Glass FRP (GFRP) sheets subjected to pure torsion has been studied. Experimental result reveal that externally bonded GFRP sheets can significantly increase both the cracking and the ultimate torsion capacity. Concrete with mix proportion 1:1.8:3.6 was used during the casting of the specimens. Glass fibre sheets used was bi-directional woven roving mat. Polymer matrix Epoxy resin with 10 % hardener was used as the binder of GFRP sheets with the concrete surface. The obtained result shows that the load carrying capacity of the retrofitted beam is far more than the control beam. FRP based strengthening has better aesthetic appearance compared to other methods and is easier to implement and is light in weight.

INTRODUCTION

Structures deteriorate due to problems associated with reinforced concrete. Natural disasters like Earthquakes have repeatedly demonstrated the susceptibility of existing structures to seismic effect. Implements like retrofitting and rehabilitation of deteriorated structures are important in high seismic regions. Thus retrofitting and strengthening of existing reinforced concrete structures has become one of the most important challenges in civil engineering. Engineers often face problems associated with retrofitting and strength enhancement of existing structures. For the satisfactory performance of the existing structural system, the need for maintenance and strengthening is inevitable. Commonly encountered engineering challenges such as increase in service loads, changes in use of the structure, design and/or construction errors, degradation problems, changes in design code regulations, and seismic retrofits are some of the causes that lead to the need for rehabilitation & retrofittng of existing structures. Complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increased financial burden if upgrading is a viable alternative. In such occasions, repair and rehabilitation are most commonly used solutions. Reinforcement corrosion and structural deterioration in reinforced concrete (RC) structures are common and prompted many researchers to seek alternative materials and rehabilitation techniques. While many solutions have been investigated over the past decades, there is always a demand to search for use of new technologies and materials to upgrade the deficient structures. In this context, strengthening with Fibre Reinforced Polymers (FRP) composite materials in the form of external reinforcement is of great interest to the civil engineering community. The conventional strengthening methods of RC structures attempt to compensate the lost strength by adding more material around the existing sections.

Section enlargement, polymer modified concrete filling and polymer grouting are some strengthening methods. But there are drawbacks associated with section enlargement.

Damage to the structure may be caused due to the additional dead load, and cause unexpected consequences. Also it is unsuitable for seismic induced damages, the reason being, the inertia force generated during earthquakes are directly proportional to the mass of the structure.

Factors to be considered while adopting a suitable method for strengthening of structures:

- Magnitude of increase in the strength.
- Changes in relative member stiffness due to the strengthening process.
- Prevailing environmental conditions (eg. adhesives might be unsuitable for applications in humid, high-temperature environment, external steel methods may not be suitable in corrosive environments).
- Project size (methods involving special materials and methods may be less cost- effective on small projects).
- Dimensional/clearance constraints (section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space).
- Accessibility.
- Availability of materials, equipments, and qualified contractors.
- Cost of Construction, maintenance, and lifecycle.

Thus retrofitting and rehabilitation of structures can be concluded to be the best alternative. Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members. FRP composite materials are of great interest because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials. Also, the non-corrosive and nonmagnetic nature of the materials along with its resistance to chemicals makes FRP an excellent option for external reinforcement. The addition of externally bonded FRP sheets to improve the flexural and shear performance of RC beams has been actively pursued during the recent years.

Research reveals that strengthening using FRP provides a substantial increase in post-cracking stiffness and ultimate load carrying capacity of the members subjected to flexure and shear. The main objective of the study was to investigate the torsional behaviour of RC beams strengthened with externally bonded GFRP sheets.

LOCAL RETROFITTING TECHNIQUES

Structures have failed and some have been severely damaged in recent earthquakes. Such disasters have demonstrated the need for seismic retrofitting of seismically insufficient structures. These structures must be retrofitted, the reason being, the cost of replacement of engineered structures that do not have adequate earthquake resistance, is very high. Although these structures require overall strength and stiffness to resist the lateral load, it may not satisfy the performance objective due to inadequate strength, toughness, deformation capacity of the individual elements. Local retrofit strategies include strengthening of beams, columns, slabs, beam to column or slab to column joints, walls, foundations. Local retrofitting allows strengthening of elements to resist the strength demands predicted by the analysis, without significantly affecting the overall response of the structure.

FIBRE REINFORCED POLYMER

"*Fibre-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually fibreglass or carbon, while the polymer is usually an epoxy, vinyl-ester or polyester thermosetting plastic*". High strength-weight ratio, high stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue strength, and ease of application, these are some of the traits that FRP's possess. Glass-fibre sheets are found to be highly effective for strengthening of RC beams because of its flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness.

There are two techniques for strengthening of beams:-

1] Pasting FRP plates to the bottom (generally the tension face) of a beam, this increases the strength of beam, deflection capacity of beam and stiffness (load required to make unit deflection).

2] Wrapping FRP strips completely around the beam, which results in higher shear resistance. In our experiment we have adopted the 2^{nd} technique.

In our Experimental endeavour we have casted two beams, both weak in flexure. The first beam was used as the control beam, the second as the rehabilitated beam.

EXPERIMENTAL PROGRAMME

A] EXPERIMENTAL STUDY

Two beams designed to fail in torsion were cast, for investigation. The first was used as the control beam and the second was retrofitted with Fibre reinforced polymer bonded with Epoxy resin.

The dimensions of the beams are as follows:-

LENGTH OF MAIN BEAM :- 1650 mm

WIDTH OF MAIN BEAM:- 150 mm

DEPTH OF MAIN BEAM:- 250 mm

LENGTH OF CANTILIVER PART :- 300 mm

WIDTH OF CANTILIVER PART:- 150 mm

DEPTH OF CANTILIVER PART:-250 mm

DISTANCE OF CANTILIVER PART FROM END OF THE BEAM:-350 mm

Figure 1 shows the geometry of beams. Both the specimens were tested in horizontal position lying on roller supports on the ground. Both the beams were cured for 28 days after casting and were tested up to failure. Deflections were observed at a distance of 350 mm from the centre of the beam on both sides, as shown in **Figure 2**.

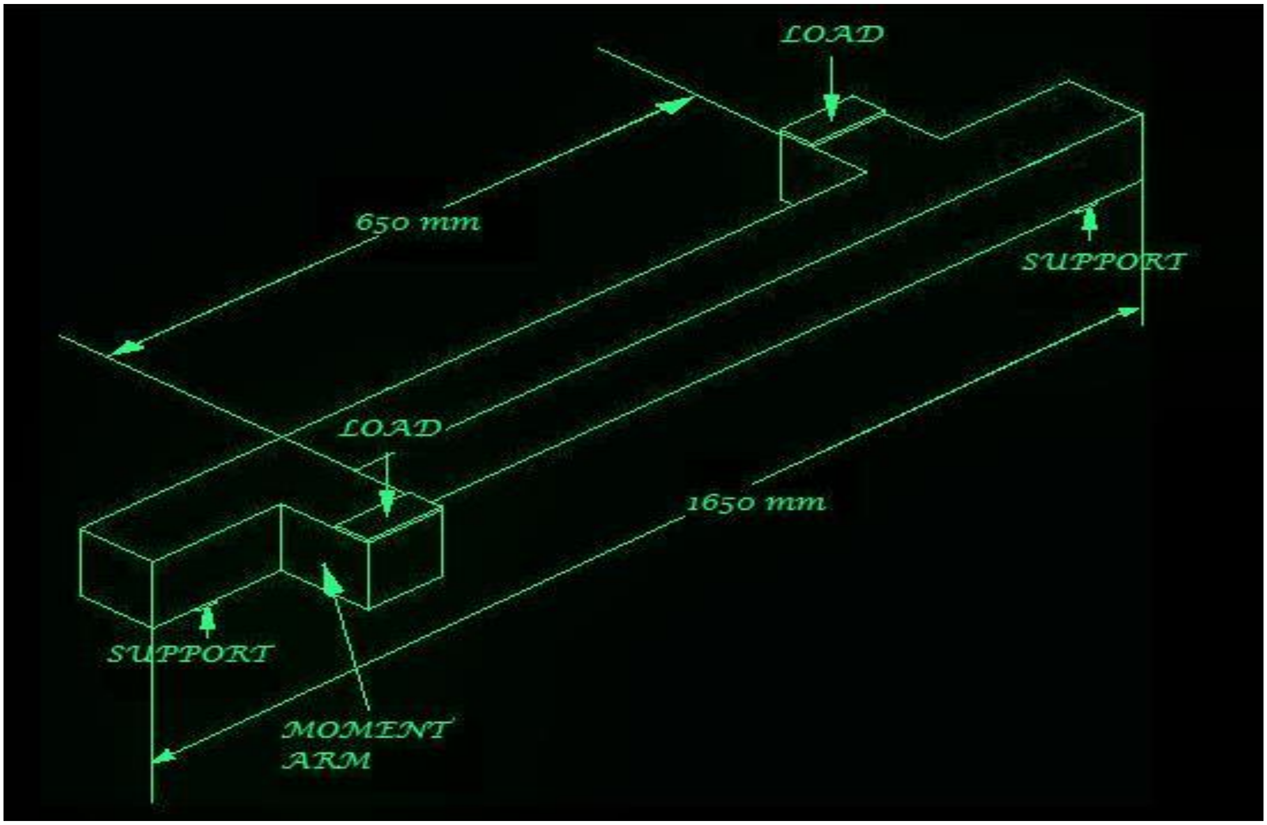


Fig. 1 Schematic diagram of a beam

Fig. 2 Beam 1

B] EXPERIMENTAL DESIGN

i] CONCRETE MIX:- **1:1.8:3.6 (M25 grade design mix)**

ii] REINFORCEMENT DETAILS:-

- MAIN REINFORCEMENT:- 2, 16mm ϕ bars (1.6 m long)
- ANCHORAGE BARS:- 2, 10 mm ϕ bars (1.6 m long)
- MAIN REINFORCEMENT IN THE CANTILIVER PART:- 3, 12 mm ϕ bars (1 m long)
- ANCHORAGE BARS IN THE CANTILIVER PART:- 2, 10 mm ϕ bars (0.410 m long)
- VERTICAL STIRRUPS:- 2 legged, 6 mm ϕ bars @ 180 mm c/c
- CLEAR COVER OF REINFORCEMENT PROVIDED:- 20 mm

* as shown in Figure 3 & 4

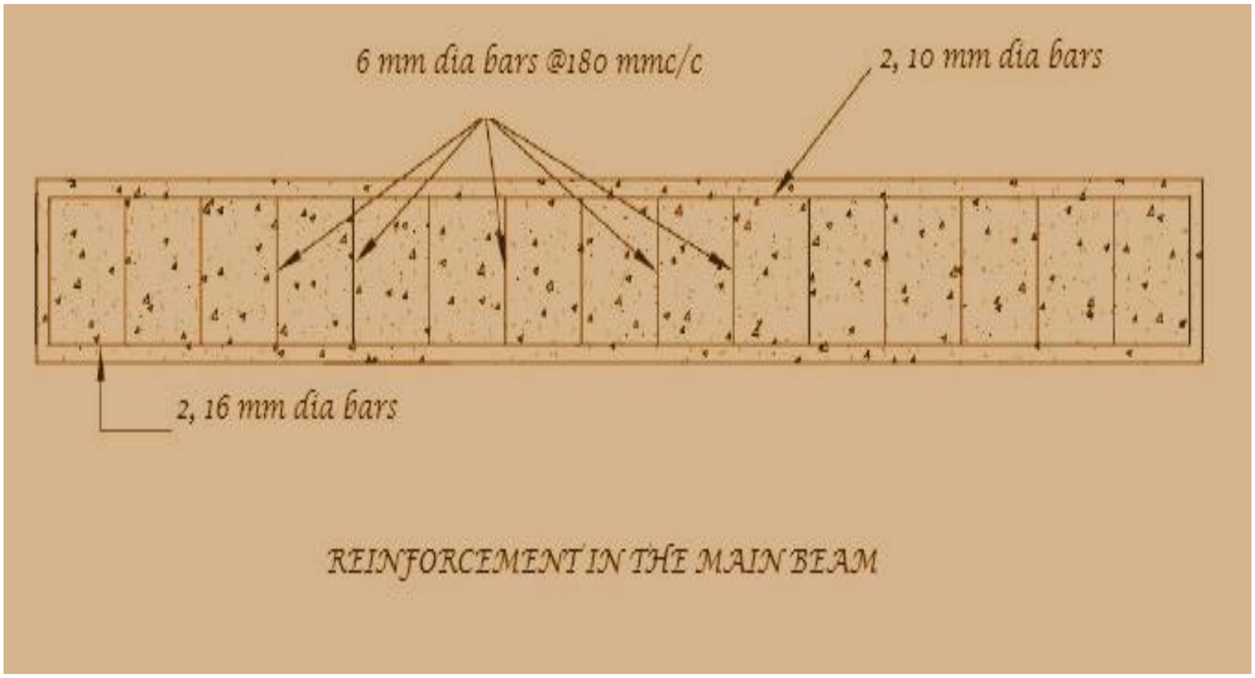


Fig. 3 Main reinforcement detailing

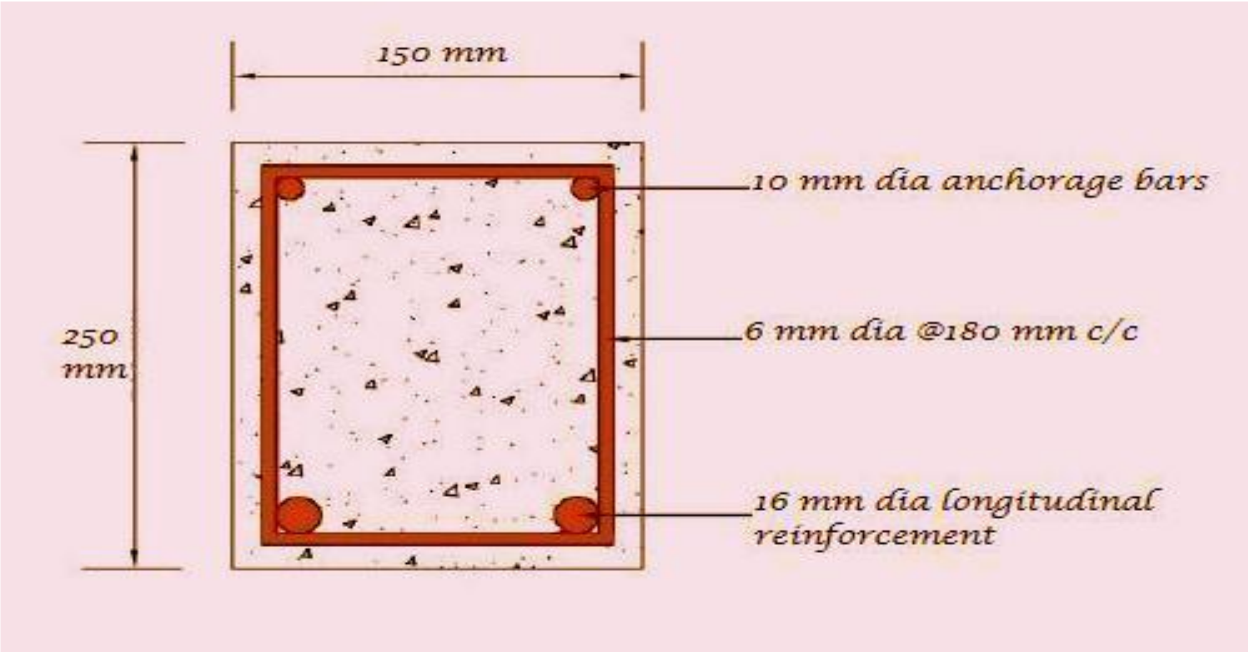


Fig. 4 Cross-sectional view

c] FORM WORK

Fresh concrete is plastic in nature and hence requires some kind of form work to mould into the required shape, and also to hold it, till it sets. Hence the form work needs to be suitably designed. It should be strong enough to take the dead load and live load, during construction, and also it must be rigid enough so as to prevent bulging, twisting or sagging due to the load. The form work was made out of wooden plates, in the Structural Engineering Laboratory of NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA. The prefabricated cage was then lowered carefully inside the formwork; proper cover (20 mm) was maintained. Concrete was then poured into the form work and compacted using needle vibrator.

Fig. 5 Formwork

d] MATERIALS

- ***CEMENT***

  KONARK Slag cement confirming to IS 455.

  Specific gravity -3.2

- ***FINE AGGREGATE***

  ZONE – III, according to IS – 383-1970.

  Specific Gravity – 2.5

  Water Absorption – 0.7%

- ***COURSE AGGREGATE***

  Size – 20 mm down.

  Specific Gravity – 2.79

  Water Absorption – 0.448%

- ***WATER***

  Ordinary tap water was used for concrete mix.

- ***REINFORCING STEEL***

  Fe 415 HYSD bars of 16 mm diameter were used as main reinforcement in the main Beam.

Fe 415 HYSD bars of 12 mm diameter were used as main reinforcement in the cantilever Part.

Fe 415 HYSD bars of 10 mm diameter were used as anchorage bars.

MILD STEEL Bars of 6 mm diameter were used as vertical reinforcement.

- ***GLASS FIBRE REINFORCED POLYMER SHEET***

Fibre sheet used was E-Glass, Bi-directional wove roving mat.

- ***RESIN***

Resin used was Epoxy and it was mixed with 10% hardener.

e] CASTING

The formwork was thoroughly cleaned and inner surface was properly oiled, and the joints and corners were sealed by using plaster of paris. The reinforcement cage was then inserted inside the formwork, and a clear cover of 20 mm was provided.

- ***COMPACTION***

Needle vibrator was used for proper compaction of concrete. Precaution were taken to avoid displacement of reinforcement cage inside the formwork. The surface of the concrete was finally levelled and finished by metal trowel and wooden float.

- ***CURING***

The specimens were taken out of the mould after 24 hours. They were kept under wet gunny bags for curing. Testing was done after a curing period of 28 days.

- ***WRAPPING WITH GFRP SHEETS***

  The surface of the second beam was smoothed using sand paper. The epoxy resin was mixed with 10% hardener by weight. The strips of GFRP sheet was then fixed to the surface of the beam in two layers using the resin.

f] TESTING:-

Both the beams were tested in the Structural Engineering Laboratory of " National Institute Of Technology , Rourkela". After 28 days of curing period, the beams were white washed for clear visibility of cracks. The specimen was placed over roller supports on the ground. Loading was done by Hydraulic Jack of capacity 100 Tones. Four Dial gauges were placed to find out the tilt, two in each side at a distance of 350mm from the centre.

Fig. 6 Load Testing Machine

Fig. 7 Arrangement of the beam under the hydraulic Jacks

SCHEME OF GFRP

- GFRP sheets were pasted on the concrete surface using Resin and rolled genteelly using roller. Strips make 90 degrees angle with the axis of the beam.
- GFRP sheets were pasted in strips of width 130 mm, and 130 mm edge to edge spacing. was provided between two consecutive GFRP sheets.
- Each strip has two layers of GFRP.

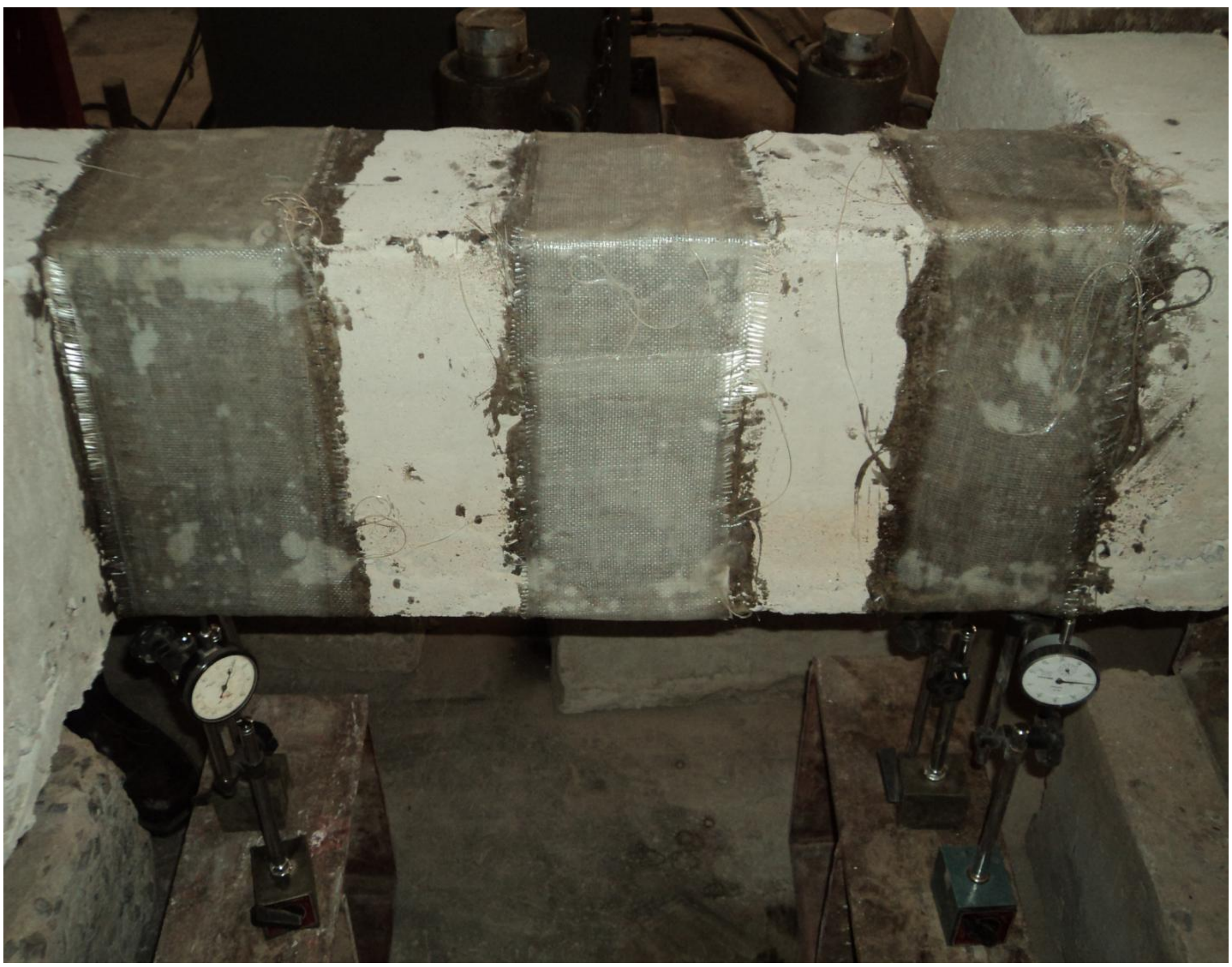


Fig. 8 FRP pasted over the beam, 130mm c/c

RESULTS AND DISCUSSION

Both the beams were tested under pure torsion. The torsion was applied through the projected cantilever on both sides of the beam as shown in figure 1.

The following data were obtained for Beam 1 (CONTROL BEAM).

Table 1. Relation between angle of twist and torsional moment (Beam1)

TORSIONAL MOMENT (KNm)	ANGLE OF TWIST (rad/m)
2	0.3
4	0.7
6	1.5
8	2
10	2.9
12	3.7
14	4.65
16	5.6
18.4 *	6.4
20	7.4
22	8.3
24	9.4
26	10.4
28	11.7
29.5 **	12.9

*** Torsional Moment when the 1st crack appeared is 18.4 KN-m.**

**** Torsional moment at complete failure is 29.5 KN-m**

Figure 9. Graph between angle of twist and torsional moment.

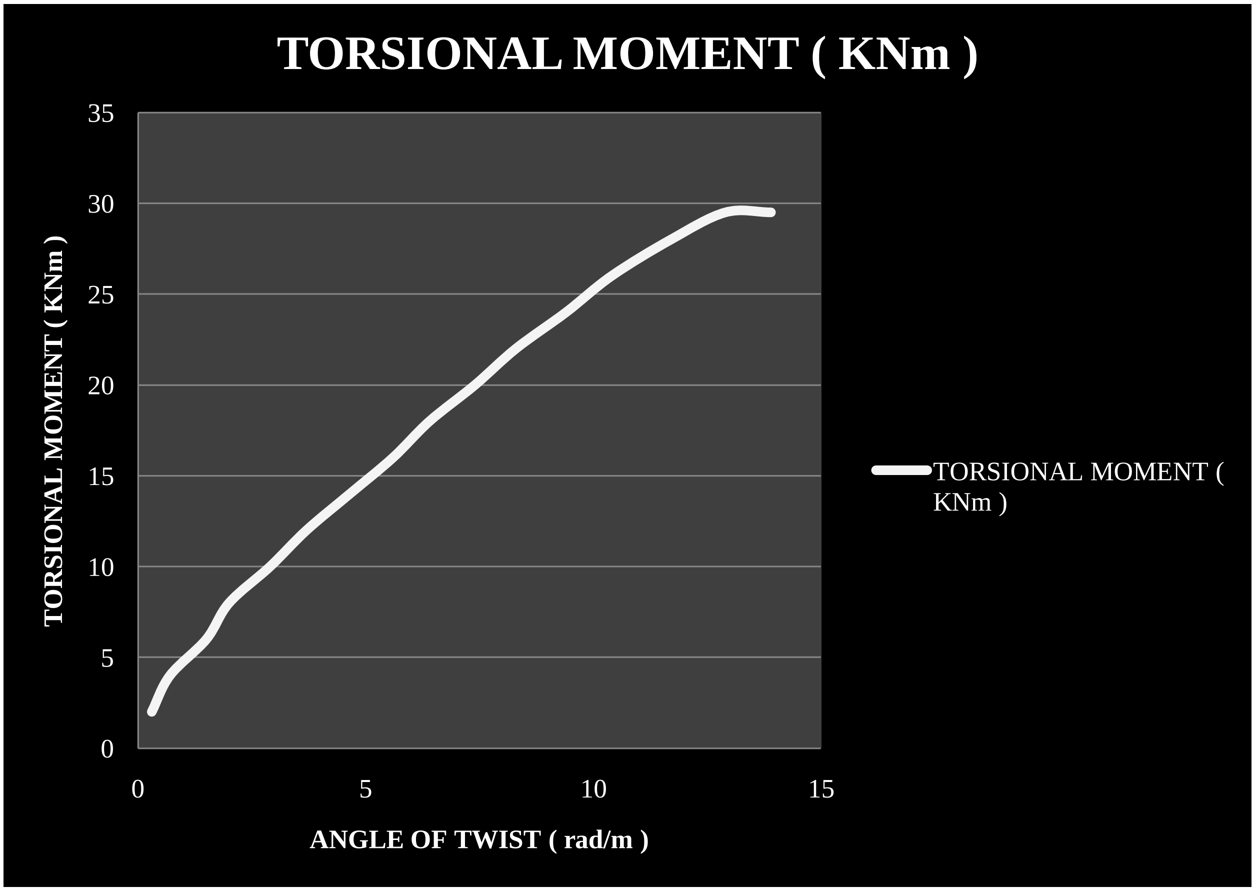


Fig. 9 Curve between Angle of twist and Torsional moment for beam 1

Figure 10 shows the failure of the control beam in torsion.

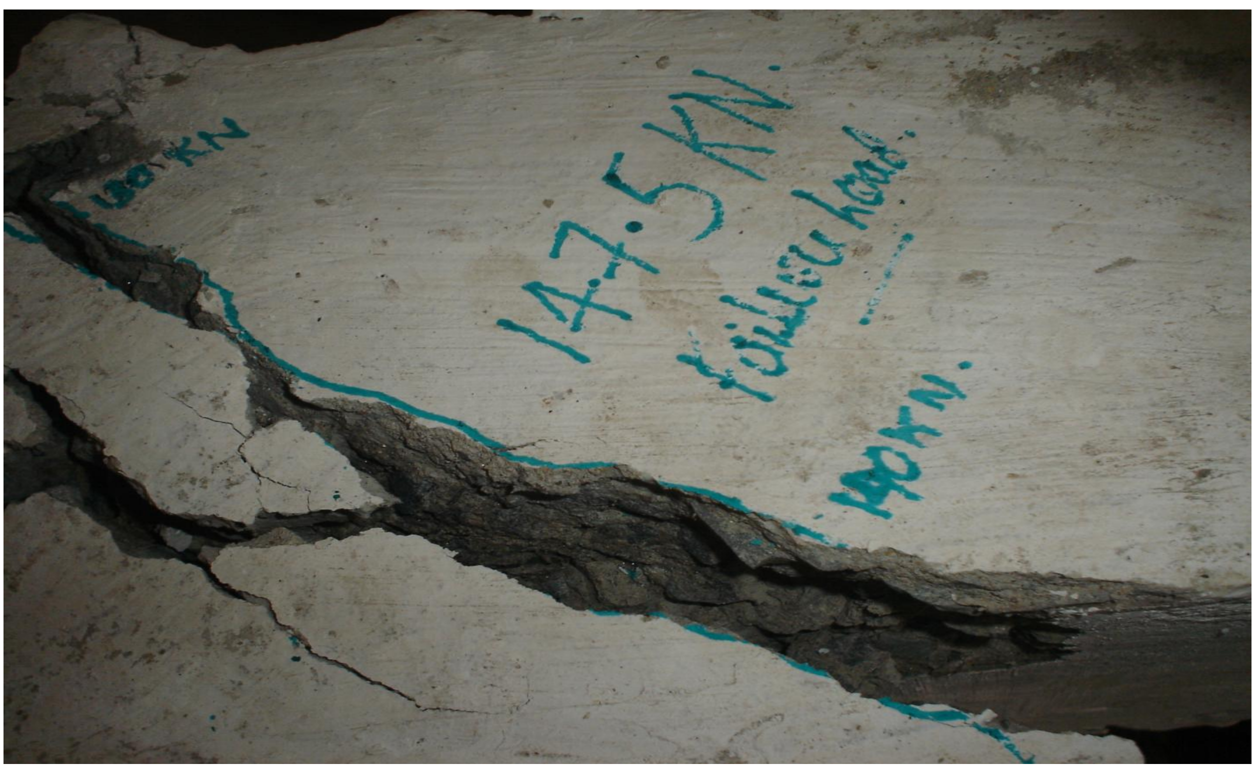


Fig. 11 Close view of the crack in Beam 1 after failure

The following data were obtained for Beam 2 (RETROFITED BEAM) :

Table 2. Relation between angle of twist and torsional moment (Beam 2)

TORSIONAL MOMENT (KNm)	ANGLE OF TWIST (rad/m)
2	0.1
4	0.7
6	1.3
8	1.7
10	2.3
12	2.9
14	3.4
16	3.9
18	4.5
20	5.1
22	5.7
24	6.4
26	7
28*	7.5
30	7.9
32	8.4
34	8.867
36	9.3
38	9.8
40	10.4
41.6**	11.1

*** Torsional Moment when 1st crack appeared is 28 KN-m.**

****Torsional Moment at complete failure is 41.6 KN-m.**

In **Figure 12** the curve represents, the angle of twist corresponding to torsional moment for beam 2 (Wrapped with FRP or RETROFITED BEAM)

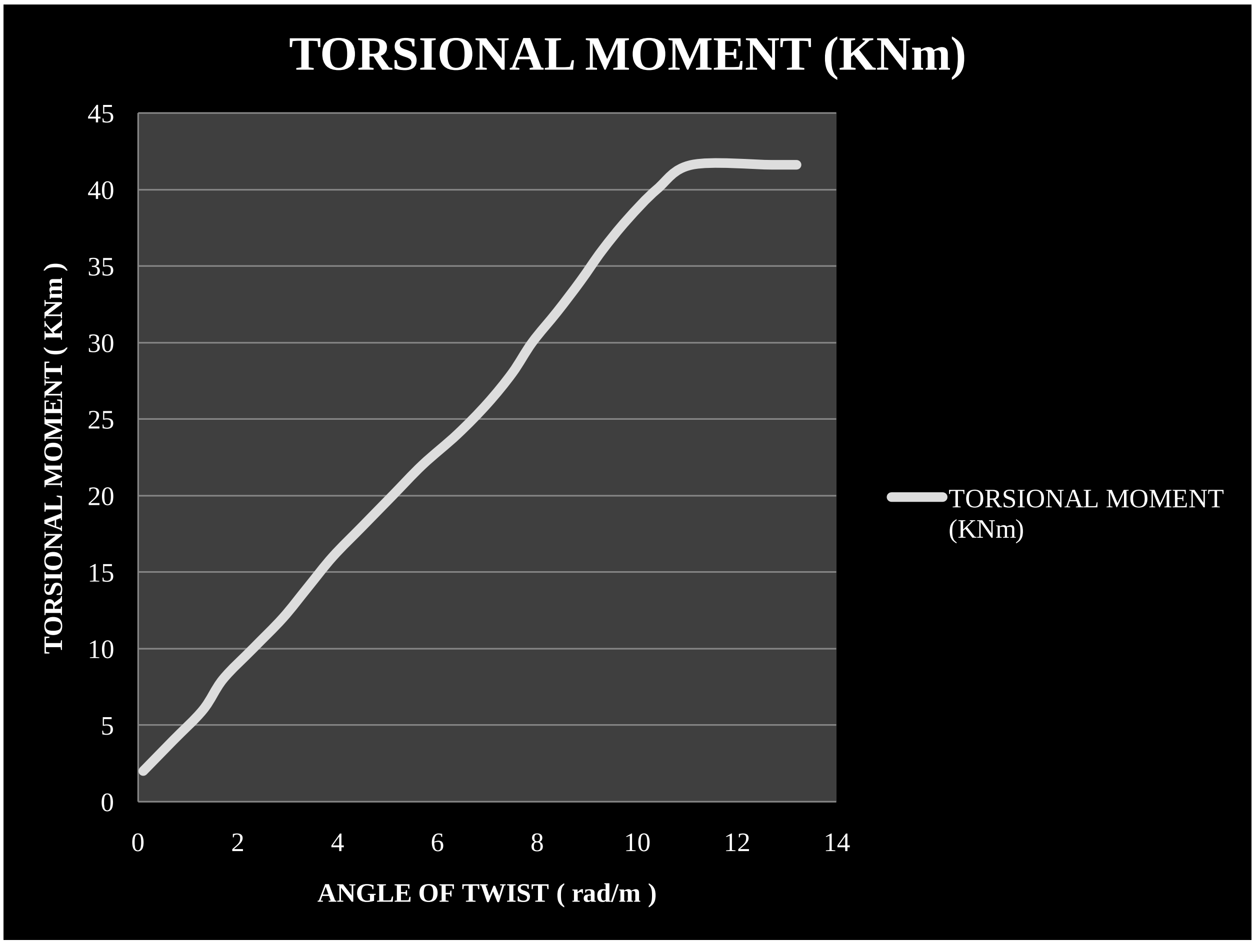
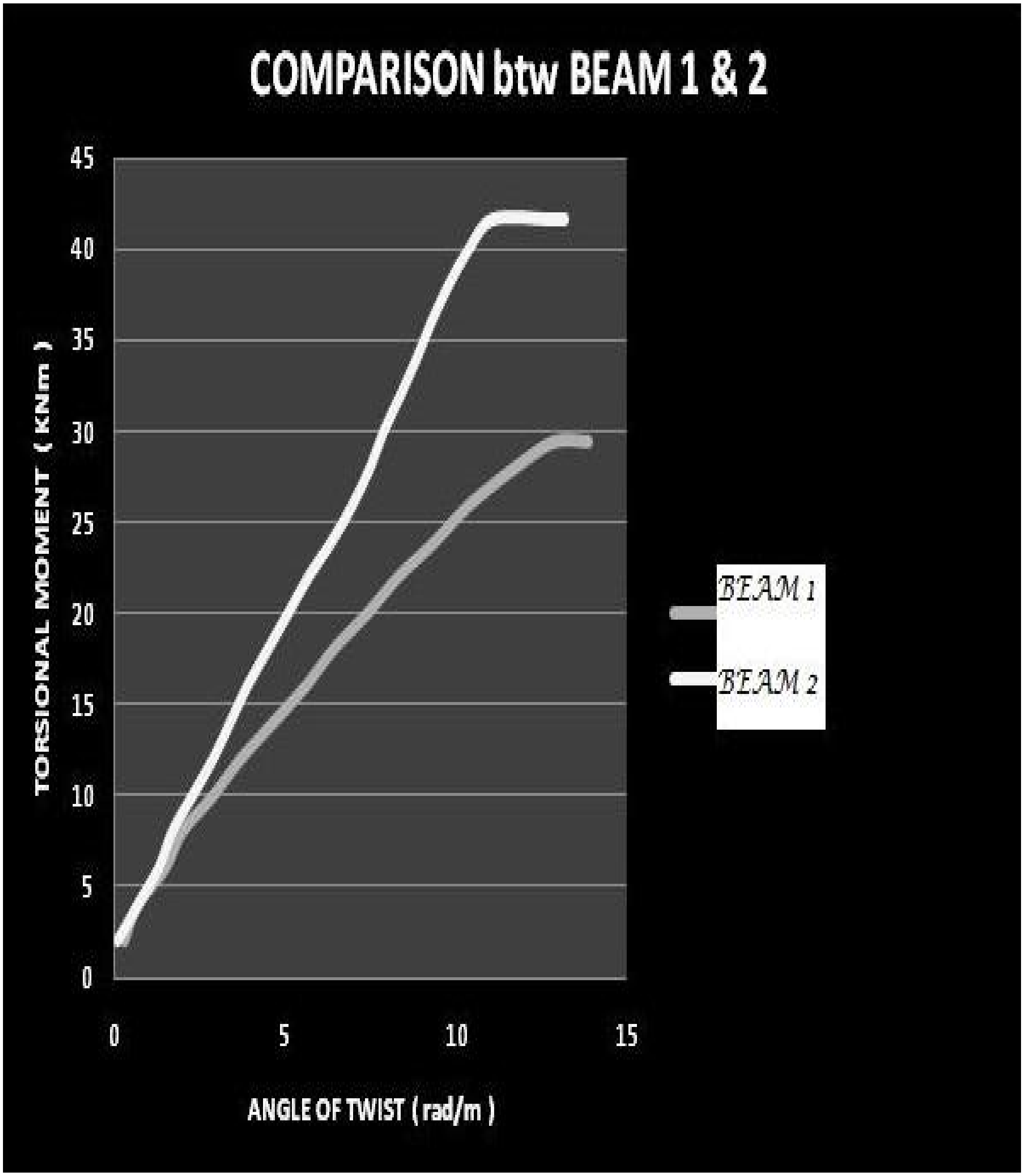


Figure 13 shows the failure of the retrofitted beam, when the GFRP sheet was still intact.

Figure 14 shows the failure pattern of the retrofitted beam, when the GFRP sheet was removed.

Figure 15 shows a graphical comparison between Beam 1 & 2.



CONCLUSION

The following conclusions are drawn from the experimental work:-

- The beam wrapped with GFRP sheets exhibited significant increase in the cracking strength.
- When the test results were compared, it was found that the cracking strength of the retrofitted beam (Beam 2) is **53%** more than that of the control beam (Beam 1).
- There was a significant increase in the Ultimate load carrying capacity of the retrofitted beam.
- The ultimate load carrying capacity of the retrofitted beam increased by **42 %**.
- The increase in strength was mainly due to confinement offered by the FRP sheets, which acts like closely looped shear reinforcement.
- It was observed that the retrofitted FRP sheet starts working only after sufficient cracking occurs in the concrete.
- FRP based strengthening has better aesthetic appearance compared to other methods, and is easier to implement and is light in weight.

REFERENCES

[1] A.Deifalla and Ghobarah, (2010) Full Torsional Behavior of RC Beams Wrapped with FRP: Analytical Model, Journal of composites for construction ASCE/ May/June 289-300.

[2] S. Panchacharam and A. Belarbi, “Torsional Behavior of Reinforced Concrete Beams Strengthened with FRP”

Composites,” First FIB Congress, Osaka, Japan, October 13-19,2002

[3] Meier, U. : Post-strengthening by continuous fiber sheets in Europe. Proceedings of Third International Symposium, Non-Metallic (FRP) Reinforcement for Concrete Structures, Vol. 1, Japan, Concrete Institute, Tokyo, pp. 41–56, 1997.

[4] Triantafillou, T.C. and Plevris, N. : Strengthening of RC Beams with Epoxy-Bonded Fibre-Composite Materials, Materials and Structures, Vol. 25, pp. 201-211, 1992.

[5] Chajes, M. J., Januska, T.F., Mertz, D.R., Thomson, T.A., and Finch, W.W. : Shear Strengthening of Reinforced Concrete Beams Using Externally Applied Composite Fabrics. Structural Journal of the American Concrete Institute, Vol. 92, No. 3, pp. 295-303, 1995.

[6] Behaviour of retrofitted reinforced concrete beams under combined bending and torsion : A numerical study

R.Santhakumar, Assistant Professor, National Institute of Technical Teachers Training and Research, Chennai.

R.Dhanaraj, Professor, Madras Institute of Technology, Chennai.

E.Chandrasekaran, Professor, Crescent Engineering College, Chennai.

[7] Nishikant Dash (2009) STRENGTHENING OF REINFORCED CONCRETE BEAMS USING GLASS FIBER REINFORCED POLYMER COMPOSITES.

[8] More Rajkumar Champatrao (2007) Experimental Investigation on Retrofitting and rehabilitation of reinforced concrete opening corners.

[8] http://www.scribd.com

[9]http://www.indiamart.com/nirmal-plastic/frp-moulding-products- manufacturers.html.