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Impact on Torsional Behavior of RCC Flanged Beams Strengthened With Glass FRP

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ABSTRACT
Environmental degradation, increased service loads, reduced capacity due to aging, degradation owing to poor construction materials and workmanships and conditional need for seismic retrofitting have demanded the necessity for repair and rehabilitation of existing structures. Fibre reinforced polymers has been used successfully in many such applications for reasons like low weight, high strength and durability. Many previous research works on torsional strengthening were focused on solid rectangular RC beams with different strip layouts and different types of fibers. Various analytical models were developed to predict torsional behavior of strengthened rectangular beams and successfully used for validation of the experimental works. But literature on torsional strengthening of RC T-beam is limited.

In the present work experimental study was conducted in order to have a better understanding the behavior of torsional strengthening of solid RC flanged T-beams. An RC T-beam is analyzed and designed for torsion like an RC rectangular beam; the effect of concrete on flange is neglected by codes. In the present study effect of flange part in resisting torsion is studied by changing flange width of controlled beams. The other parameters studied are strengthening configurations and fiber orientations.

The objective of present study is to evaluate the effectiveness of the use of epoxy-bonded GFRP fabrics as external transverse reinforced to reinforced concrete beams with flanged cross sections (T-beam) subjected to torsion. Torsional results from strengthened beams are compared with the experimental result of the control beams without FRP application. The study shows remarkable improvement in torsional behavior of all the GFRP strengthens beams.

INTRODUCTION

OVERVIEW

The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget. Structural strengthening may be required due to many different situations. Demolition or reconstruction means complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increasing financial burden if upgrading is a viable alternative.

- Additional strength may be needed to allow for higher loads to be placed on the structure.

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This is often required when the use of the structure changes and a higher load-carrying capacity is needed. This can also occur if additional mechanical equipment, filing systems, planters, or other items are being added to a structure.

- Strengthening may be needed to allow the structure to resist loads that were not anticipated in the original design. This may be encountered when structural strengthening isrequired for loads resulting from wind and seismic forces or to improve resistance to blast loading.
- Additional strength may be needed due to a deficiency in the structure's ability to carry the original design loads. Deficiencies may be the result of deterioration (e.g., corrosion of steel reinforcement and loss of concrete section), structural damage (e.g., vehicular impact, excessive wear, excessive loading, and fire), or errors in the original design or construction (e.g., misplaced or missing reinforcing steel and inadequate concrete strength).

TORSIONAL STRENGHTENING OF BEAMS

Only a few years ago, the construction market started to use FRP for structural reinforcement, generally in combination with other construction materials such as wood, steel, and concrete. FRPs exhibit several improved properties, such as high strength-weight ratio, high stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue strength, and ease of application. The use of FRP sheets or plates bonded to concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs, and walls. Because the FRP materials are non-corrosive, non-magnetic, and resistant to various types of chemicals, they are increasingly being used for external reinforcement of existing concrete structures. From the past studies conducted it has been shown that externally bonded glass fiber-reinforced polymers (GFRP) can be used to enhance the flexural, shear and torsional capacity of RC beams. Due to the flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness, the flexible glass fiber sheets are found to be highly effective for strengthening of RC beams.

ADVANTAGES AND DISADVANTAGES OF FRP

ADVANTAGES:

- Laps and joints are not required
- The material can take up irregularities in the shape of the concrete surface
- The material can follow a curved profile; steel plate would have to be pre-bent to the required radius
- The material can be readily installed behind existing service.
- Overlapping, required when strengthening in two directions, is not a problem because the material is thin.

DISADVANTAGES:

The main disadvantage of externally strengthening structures with fiber composite materials is the risk of fire, vandalism or accidental damage, unless the strengthening is protected. A particular concern for bridges over roads is the risk of soffit reinforcement being hit by over-height vehicles. However, strengthening using plates is generally provided to carry additional live load and the ability of the un- strengthened structure to carry its own self-weight is unimpaired. Damage to the plate strengthening material only reduces the overall factor of safety and is unlikely to lead to collapse.

Experience of the long-term durability of fiber composites is not yet available. This may be a disadvantage for structures for which a very long design life is required but can be overcome by appropriate monitoring.

A perceived disadvantage of using FRP for strengthening is the relatively high cost of the materials. However, comparisons should be made on the basis of the complete strengthening exercise; in certain cases the costs can be less than that of steel plate bonding.

A disadvantage in the eyes of many clients will be the lack of experience of the techniques and suitably qualified staff to carry out the work. Finally, a significant disadvantage is the lack of accepted design standards.

EXPERIMENTAL STUDY

To study the most influential strengthening variables on torsional behavior a total of eleven medium scale reinforced concrete beams of 1900 mm long were constructed for this work. T-shaped beams, which are sorted in three groups (T2, T3 and T4) and were tested under combined bending torsion. Three numbers of beams are without torsional reinforcement were the control specimens and eight specimens were strengthened using epoxy-bonded glass FRP fabrics as external transverse rein-forcemeat.

CASTING OF SPECIMENS

For conducting experiment, eleven reinforced concrete beam specimen of size as Shown in the fig (Length of main beam (L) = 1900mm, Breadth of main beam(bw) = 150mm, Depth of main beam(D) = 270mm, Length of cantilever parts = 400mm, Width of cantilever part= 200mm, Depth of cantilever part= 270mm, Distance of cantilever part from end of the beam= 350mm) and all having the same reinforcement detailing are cast. The mix proportion is 0.5: 1:1.67:3.3 for water, cement, fine aggregate and course aggregate is taken. The mixing is done by using concrete mixture. The beams were cured for 28 days. For each beam three cubes, two cylinders and two prisms were casted to determine the compressive strength of concrete for 28 days.

MATERIAL PROPERTIES

Concrete

For conducting experiment, the proportions in the concrete mix are tabulated in Table 3.1 as per IS:456-2000. The water cement ratio is fixed at 0.55. The mixing is done by using concrete mixture. The beams are cured for 28 days. For each beam six 150x150x150 mm concrete cube specimens and six 150x300 mm cylinder specimens were made at the time of casting and werekept for curing, to determine the compressive strength of concrete at the age of 7 days & 28 days are shown in table 3.2

Table 3.1 Design Mix Proportions of Concrete

Description	Cement	Sand (Fine Aggregate)	Coarse Aggregate	Water
Mix Proportion (by weight)	1	1.67	3.33	0.5

The compression tests on control and strengthened specimen of cubes are performed at 7 days and 28 days. The test results of cubes are presented in Table3.2.

Table 3.2 Test Result of Cubes after 28 days

Specimen Name	Average cube compressive strength(Mpa)	Average cylinder compressive strength(Mpa)
Group-A		
T2C	29.23	25.62
Group-B		
T3C	30.05	20.12
T3SU	28.62	22.15
T3SUA	29.12	23.56
T3SF	28.69	23.15
T3S45	28.12	22.12

Cement

Cement is a material, generally in powered form, which can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for an adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. The most widely used of the construction cements is Portland cement. It is bluish-gray powered obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. Portland Slag Cement (PSC) Konark Brandwas used for this investigation. It is having a specific gravity of 2.96.

Fine Aggregate

Fine aggregate is an accumulation of grains of mineral matter derived from disintegration of

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rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic material. Sand is used for making mortar and concrete and for polishing and sandblasting. Sands containing a little clay are used for making molds in foundries. Clear sands are employed for filtering water. Here, the fine aggregate/sand is passing through 4.75 mm sieve and having a specific gravity of 2.64. The grading zone of fine aggregate is zone-III as per Indian Standard specifications IS: 383-1970

Coarse Aggregate

Coarse aggregates are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone, and trap rock. The coarse aggregates of two grades are used one retained on 10 mm size sieve and another grade contained aggregates retained on 20 mm size sieve. The maximum size of coarse aggregate was 20 mm and is having specific gravity of 2.88 grading confirming to IS: 383-1970.

Water

Water fit for drinking is generally considered good for making the concrete. Water should be free from acids, alkalis, oils, vegetables or other organic impurities. Soft water produces weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement. Ordinary clean portable tap water is used for concrete mixing in all the mix.

Reinforcing Steel

High-Yield Strength Deformed (HYSD) bars confirming to IS 1786:1985. The longitudinal steel reinforcing bars were deformed, high-yield strength, with 20φ mm 10φ mm and 8mmφ diameter. The stirrups were made from deformed steel bars with 8 mm φ diameter.

Three coupons of steel bars were tested and yield strength of steel reinforcements used in this experimental program is determined under uni-axial tension accordance with ASTM specifications. The proof stress or yield strength of the specimens are averaged and shown inTable 3.3. The modulus of elasticity of steel bars was 2 × 105 MPa.

Table 3.3 Tensile Strength of reinforcing steel bars

Sl. no. of sample	Diameter of bar (mm)	0.2% Proof stress (N/mm2)	Avg. Proof Stress (N/mm2)
1	20	475	470
2	10	530	529
3	8	520	523

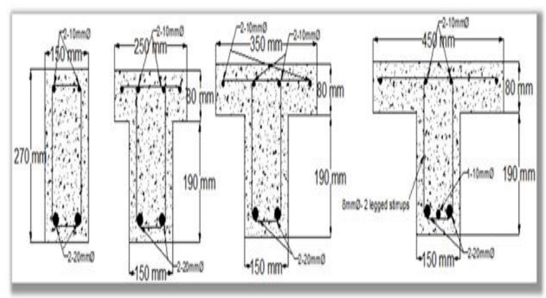

Figure 3-1. Detailing of Reinforcement

Mixing Of Concrete

Mixing of concrete is done thoroughly with the help of machine mixer so that a uniform quality of concrete was obtained.

Compaction

Compaction is done with the help of needle vibrator in all the specimens .And care is taken to avoid displacement of the reinforcement cage inside the form work. Then the surface of the concrete is levelled and smoothened by metal trowel and wooden float

Curing Of Concrete

Curing is done to prevent the loss of water which is essential for the process of hydration and hence for hardening. It also prevents the exposure of concrete to a hot atmosphere and to drying winds which may lead to quick drying out of moisture in the concrete and there by subject it to contraction stresses at a stage when the concrete would not be strong enough to resists them. Here curing is to be done by spraying water on the jute bags spread over the surface for a period of 7 days.

Fiber Reinforced Polymer (FRP)
Continuous fiber reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behavior up to failure. Normally, Glass and Carbon fibers are used as reinforcing material for FRP. Epoxy is used as the binding material between fiber layers.

Epoxy Resin
The success of the strengthening technique primarily depends on the performance of the epoxy resin used for bonding of FRP to concrete surface. Numerous types of epoxy resins with a wide range of mechanical properties are commercially available in the market. These epoxy resins are generally available in two parts, a resin and a hardener. The resin and hardener used in this study are Araldite LY 556 and hardener HY 951 respectively.

Casting of GFRP Plate for tensile strength
There are two basic processes for moulding, that is, hand lay-up and spray-up. The hand lay-up process is the oldest, simplest, and most labour intense fabrication method. This process is the most common in FRP marine construction. In hand lay-up method liquid resin is placed along with reinforcement (woven glass fiber) against finished surface of an open mould. Chemical reactions in the resin harden the material to a strong, light weight product. The resin serves as the matrix for the reinforcing glass fibers, much as concrete acts as the matrix for steel reinforcing rods. The percentage of fiber and matrix was 50:50 by weight.
The following constituent materials are used for fabricating the GFRP plate:

i. Glass FRP (GFRP)
ii. Epoxy as resin
iii. Hardener as diamine (catalyst)
iv. Polyvinyl alcohol as a releasing agent

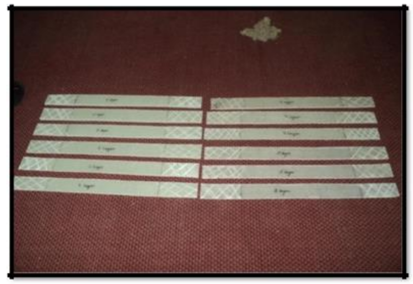

Figure 3-2. Specimens for tensile testing of woven Glass/Epoxy composite

Figure 3-3.Experimental setup of INSTRON universal testing Machine of 600 kN capacities

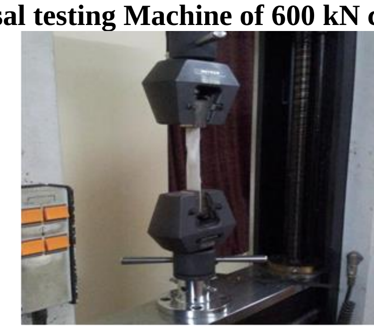

Figure 3-4. Specimen during testing

Table 3.4 Result of the Specimens

GFRP PLATE OF	Length of sample(mm)	Width of sample (mm)	Thickness of sample (mm)	Ultimate load (N)	Young's Modulus (Mpa)	Ultimate stress (Mpa)
1 layer	250	25	0.7	2760	5658	137.9
2 layers	250	25	1	4190	9493	167.7
4 layers	250	25	1.7	9400	10020	210.1
6 layers	250	25	2.1	13840	11000	276.8

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8 layers	250	25	3.1	1772 0	9253	228. 7

STRENGTHENING OF BEAMS

At the time of bonding of fiber, the concrete surface is made rough using a coarse sand paper textureand then cleaned with an air blower to remove all dirt and debris. After that the epoxy resin is mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of Araldite LY 556 to 10 parts by weight of Hardener HY 951). After their uniform mixing, the fabrics are cut according to the size then the epoxy resin is applied to the concrete surface. Then the GFRP sheet is placed on top of an epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or an epoxy / fabric interface are eliminated. During hardening of the epoxy, a constant uniform pressure is applied to the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation is carried out at room temperature. Concrete beams strengthened with glass fiber

Form Work

Fresh concrete being plastic in nature requires good form work to mold it to the required shape and size. So the form work should be rigid and strong to hold the weight of wet concrete without bulging anywhere. The joints of the form work are sealed to avoid leakage of cement slurry. Mobil oil was then applied to the inner faces of form work. The bottom rest over thick polythene sheet lead over the rigid floor. The reinforcement cage was then lowered, placed in position inside the side work carefully with a cover of 20mm on sides and bottom by placing concrete cover blocks.

IS Sieve	Percentage passing	Remarks
4.75 mm	100	Confirming to grading Zone III of Table 4 of IS:383-1970
2.36 mm	99	
1.18 mm	90	
600 microns	60	
300 microns	15	
150 microns	2	

TEST RESULTS AND DISCUSSIONS

Experimental Results

All the beams are tested till complete failure. Beams T2C, T3C and T4C are the control beams. It is observed that the control beam had less load carrying capacity and high deflection values compared to that of the FRP strengthened beams. Group A beam T2C has 250 mm wide flange beam is considered as control beam. In group-Band group-C, all beams are strengthened with 100mm wide ,four layered strips of GFRP fabrics with an clear spacing of 75 mm. The different patterns of wrapping adopted are 90 degree fully wrapped, 45º fully wrapped, U-wrapped, U-wrap with flange anchored with bolt.

Failure Modes:

Different failure modes have been observed in the experiments .These include torsional shear failure due to GFRP rupture and debonding .Rupture of the FRP strips is assumed to occur if the strain in the FRP reaches its design rupture strain before the concrete reaches its maximum usable strain. GFRP debonding can occur if the force in the FRP cannot be sustained by the substrate. Load was applied on the two moment arm of the beams which is 0.375m away from the main beam. At each increment of the load, deflections at L/3, L/2 and 2L/3 were observed and noted down with the help of six nos. of dial gauges. At each section two dial gauges werefixed to measure the displacement caused by twisting moment. The relative displacements divided by distance between dial gauges gives angle of twist. Section at L/3 was taken as sec-1, section at middle of beam as taken as sec-2, and section at 2L/3 was taken as section 3.The loading arrangement was same for all the beams.

Torsional Moment and Angle of Twist Analysis:

Torsional moment and Angle of twist Analysis of all Beams

Here the angle of twist of each beam is analyzed. Angle of twist of each beam is compared with the angle of twist of control beam. Also the torsional behaviors compared between different wrapping schemes having the same reinforcement. Same type of load arrangement was done for all the beams. All the beams were strengthened by application of GFRP in four layers over the beams. It was noted that the behavior of the beams strengthen with GFRP sheets are better than the control beams. The deflections are lower when beam was wrapped externally with GFRP strips. The use of GFRP strips had effect in delaying the growth of crack formation.

When all the wrapping schemes are considered it was found that the Beam with GFRP strips fully wrapped and 45º orientation over full a length of 0.8m in the middle part had a better resistant to torsional behavior as compared to the others strengthened beams with GFRP

Control Beam (R1C)

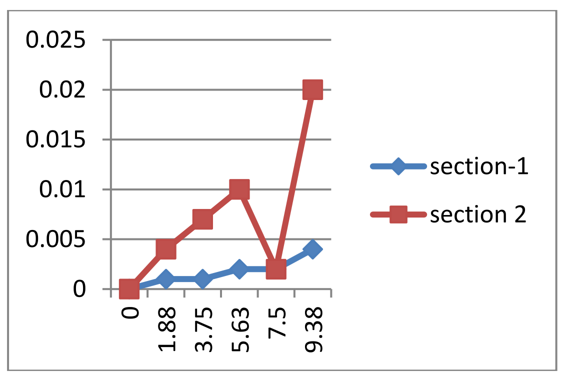
Fig.4.1b Crack pattern at face-1
Fig.4.1c crack pattern face-2

Table 4.1 Relation between angle of twist and Torsional moment (Control Beam)

Twisting moment T in kN-m	Angle of twist in section 1 (rad/m)	Angle of twist in section 2 (rad/m)	Remarks
0.00	0.000	0.000	
1.88	0.001	0.004	
3.75	0.001	0.007	
5.63	0.002	0.010	
7.50	0.002	0.014	
9.38	0.004	0.020	
11.25	0.007	0.027	First Hair line Crack appeared @80kN
12.75			Ultimate load @ 90kN

Beam R1C rectangular beam is unstrengthen beam and considered as the control beam .This beam was not a part of this study but had been taken from previous study. The details of data are given in Table 4.1. This beam has same reinforcement detail and dimensions. This is included into the present study to compare the effect of concrete in flange on torsional behavior of RC beams.

CONTROL BEAM RC1



ANGLE OF TWIST(rad/m)

Fig 4.2 Torsional moment Vs Angle of Twist for Beam R1C

BEAM (T2C)

Beam T2C is flanged RC beam with 250 mm wide flange. This beam was cast and tested to study effect of flange width on torsional behavior of T-Beam. In various design Codes a flange RC beam is designed like rectangular beam for torsion assuming that the shear flow takes place around the stirrups provided in the web portion only. The

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contribution of flange area in resisting torsional moment is neglected.

Fig. 4.2 Cracks Pattern in T2C

The first hair line inclined crack initiated at load of 80 kN and propagated spirally across the section along with various small inclined cracks. The beam failed at 102 kN load i.e. at 19.175 kNm torsional moment. It was observed those cracks were appeared making an angle 40º-50º with the main beam. The cracks were developed in a spiral pattern all over the main beam which later leads to the collapse of the beam in torsional shear.

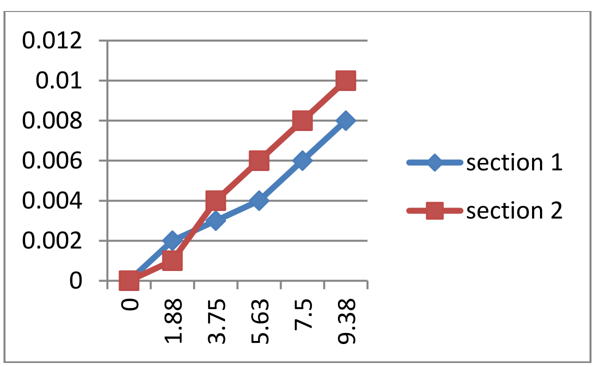
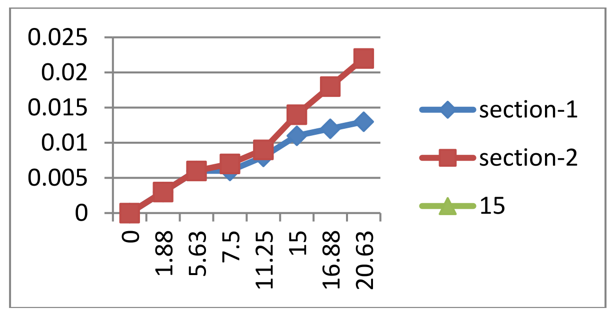


Fig 4.4 Torsional moment Vs Angle of Twist for Beam T2C

BEAM (T3C)

Beam T3C is RC T-beam with 350 mm wide flange. This beam was taken as control beam for series B. This beam is also considered to study the effect of flange area on torsional capacity of RC T-beam.

Fig. 4.3 Spiral crack in the beam



Angle of Twist (Rad/sec)

Fig 4.6 Torsional moment Vs Angle of Twist curve (T3C)

BEAM (T3SU)

The Beam T3SU was strengthened with four layers of bi-directional GFRP strips having U-warp for web and bottom of the flange. The strips were 100 mm wide and applied @ 175 mm center to center. At the load of 110 kN initial hairline diagonal cracks appeared on flange as shown in the Fig.4.7b. With the increase of load diagonal cracks appeared in the concrete between the FRP strips making approximately. This is because strips acted like external reinforcement .Further increasing the load FRP debonding takes place at the ultimate load 143 kN and torsional moment 26.81 kNm.T3SU resulted in a 23.27% increase in torsional capacity over the control beam. It was observed that cracks were appeared making an angle 55º-65 with the axis of main beam.The debonding of FRP were occurred and cracks were developed in a spiral pattern all over the main beam which later leads to the collapse of the beam in torsional shear.

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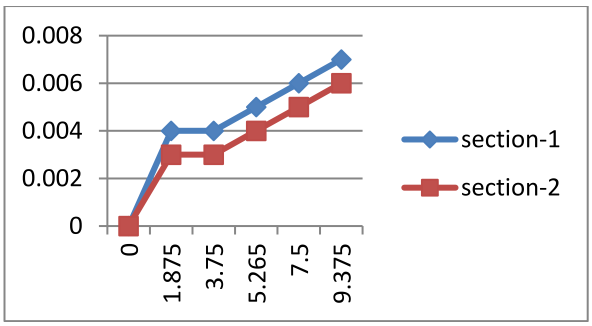
4.4(a) Initial hairline crack



Angle of Twist (Rad/sec)

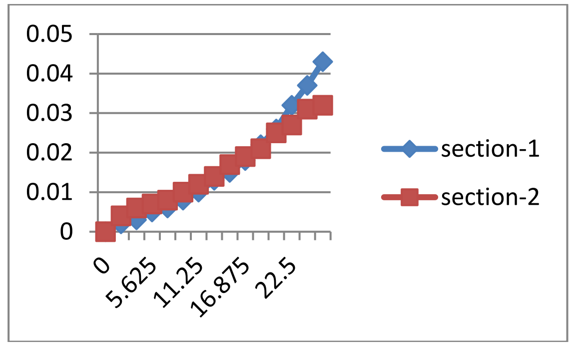
Fig 4.8 Torsional moment Vs Angle of Twist curve (T3SU)

BEAM (T3SUA)

The Beam T3SUA was strengthened with four layers of bi-directional GFRP strips of 100 mm width @ 175 mm c/c having U-warp for web and bottom of the flange, and top of the flange. The FRP were not applied on vertical sides of the flange. This causes discontinuity to the shear flow along FRP. One anchor bolt is used on each sides of the flange and on each strip of FRP .Anchor threaded bolts carry axial tension force as a part of the shear flow resisting mechanism developed to resist the applied torsion.

Fig 4.5(a) Closed view of Cracks

Fig 4.5(b) Cracks on Flange of Beam



Angle of Twist (Rad/sec)

Fig 4.10 Torsional moment Vs Angle of Twist curve (T3SUA)

BEAM (T3SF)

Beam fully wrapped with 100mm strips of GFRP making 90º with longitudinal axis of the beam. The spacing of strip was maintained as 175 mm c/c. This beam is also tested till complete failure. The cracking pattern were same as the privious beams.

Fig 4.6(a) Fully Wrapped beam after Cracking

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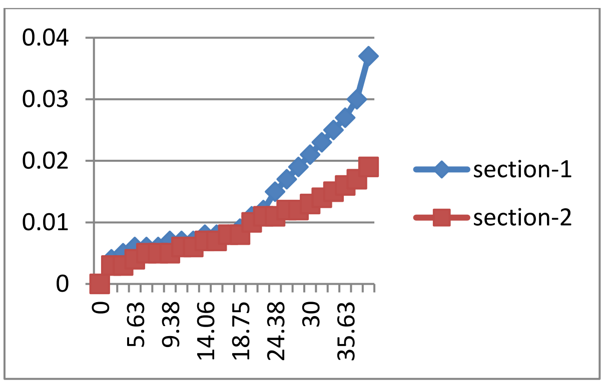
Fig 4.6(b) Cracks on Flange of Beam

Beam T3SF is taken as the strengthened beam for the series-B. In this Beam strengthening was done by full wrapping. At the load of 210 kN initial hairline cracks appeared. Later with the increase in loading values the crack propagated further. It has failed completely in torsion at a load 230kN and torsional moment 43.13 kNm. Increase strength of beam was 98.27% as the control beam. It was observed those cracks were initially generated in the web. And those cracks were appeared making an approximate angle 50° with the axis of main beam debonding was occurred when the beam reaches to ultimate load. The rupture of FRP was occurred and cracks were developed in a spiral pattern all over the main beam.



Angle of Twist (Rad/sec)
Fig 4.12 Torsional moment Vs Angle of Twist curve (T3SF)

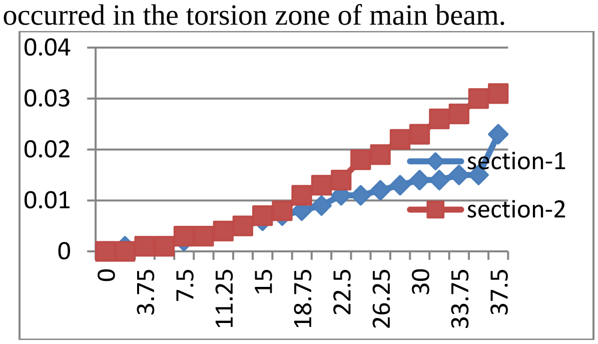
BEAM NO (T3S45)

Fig

Fig 4.7(a) Beam wrapped with 100mm Bi-directional GFRP (45°) after cracking.


Fig.4.7 (b)Closed view of cracksFig.4.7 (c) crack in the flange

Beam T3S45 was strengthened by wrapping with four layers of 100mm wide bidirectional GFRP strips at a clear spacing of 75mm. The GFRP strips were wrapped over the beam by making an angle 45° with the main beam. At the load of 190 kN first cracking sound was heard. The Beam T3S45 failed completely in torsion at a load 210KN and torsional moment 39.37 KNm. The increase strength of beam was 81.03% as compared to control beam. The cracks were appeared making an angle 55° with the main beam on the side faces and 40° at the top surface. The FRP rupture has occurred in the torsion zone of main beam.



Angle of Twist (rad/m)
Fig 4.8 Torsional moment Vs Angle of Twist curve (T3S45)

CONCLUSIONS

- Experimental results shows that the effect of flange width on torsional capacity of GFRP strengthened RC T-beams are significant.
- Torsional strength increases with increase in flange area irrespective of beam strengthening with GFRP following different configurations schemes.
- With 250 mm wide flange width increase in strength was 13%, with 350mm wide flange was 29% and for 450mm wide flange was found to be 69%. This is due to increase in area enclosed inside the critical shear path.
- The cracking and ultimate torque of all strengthen beams were greater than those of the control beams.
- The increase in magnitude depends on the FRP strengthening configurations.
- The maximum increase in torque was obtained for 90^0fully wrapped configurations.
  Beams fully wrapped with 450 resisting capacity. Increase oforiented GFRP stripes showed next highest torsional 111.11% to 91.667% in first cracking and 81.03% to 95.39% in ultimate torsion respectively.

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