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Study on Torsional Behavior of RC T- 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. 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 aim of present work is to determine quantitatively the effectiveness of GFRP to be used as external lateral reinforcements to flanged T-beams subjected to torsion. Experimental results obtained from GFRP strengthen beams are compared with un-strengthen control beams. The study shows remarkable improvement in torsional behavior of all the GFRP strengthen T-beams. The experimentally obtained results are validated with analytical model presented by A. Deifalla and A. Ghobarah and found in good agreement.

Keywords: GFRP, reinforced concrete, T- beam, torsional strength, shear flow.

Introduction

Torsion is considered a secondary force in the design of RCC structures which generally accompanied with shear or flexure or combination of both. Behavior of an RCC beam subjected to various forces along with torsion is rather complicated . Hence lots of research works had been carried out to understand torsional behavior of RCC beams. In the present scenario boom in the construction industries with huge RCC structures with complicated planning etc may cause a complex system of forces acting on the members of the building. This complex forces generally consists of torsion along with other forces. Therefore understanding of behavior of RCC members subjected to torsion is required. Previous studies reveal that the behavior of concrete elements in torsion is primarily governed by the tensile response of the material, particularly its tensile cracking characteristics. Therefore to resist torsion mainly closed vertical stirrups are provided in the RCC beam.

Torsional stresses develop along the periphery of the section and form a close path called shear path . Provision of vertical stirrups take care of the torsional stresses in a rectangular beam. Similarly shear path followed by torsional stresses in a T-beam should go round the periphery of the section but codes neglects the flange area of T-beam and consider only web area while calculating torsional capacity hence rectangular stirrups are provided in the web portion only. This leads to interruption in the shear path and failure of flange occurs.

Natural calamities like Earthquake, Cyclone cause severe damage to RCC structures specially with un symmetrical plans and elevations. This un-symmetry give rise to torsion to many elements of the structure. Some times while designing these elements torsional effects are not considered hence necessitate retrofitting of the elements specially for torsion.The best solution in this regard if offered by FRP applications.In the past many research have been done to study the effect of FRP application on RCC elements mainly subjected to forces like shear and flexure. The number of researches on members subjected to torsion are limited.

Ghobarah et al.[1], chalioris et al.[2], Ameli et al.[3]etc conducted experimental works to determine the effectiveness of different types of FRP applications with different configurations and fiber orientations to improve torsional capacity of rectangular beams.

Deifalla and Ghobarah[4], Zojaji and Kabir[5] developed analytical models for the case of the RC beams strengthened in torsion. Al mahadi et.al.[6] conducted experimental tests on beams with CFRP strips oriented in 90^0 and 45^0 applied in various configurations and anchoring systems.

Methodology

Experimental program: For the experimental study total nine beams are cast. The concrete of M20 grade are designed with proportion 1:1.67:3.3 and water cement ratio of 0.5. HYSD bars of Fe415 grade are used. The beams are divided in three sets based on the flange width. Set T2 , T3 and T4 consist of flange width 250mm,350mm and 450 mm respectively. The sections details and reinforcement details are shown in the Fig.1

First set has one beam T2. The beam is un-strengthened and cast to study the effect of width of flange. Set T3 and T4 consists of four beams. T3C and T4C are un-strengthen beams treated as control beams. T3SF and T4SF are strengthen with fully wrapped GFRP strips oriented at 90^0, T3SU and T4SU are strengthen with U- wrapped GFRP strips oriented at 90^0 , T3S45 and T4S45 are strengthen with fully wrapped GFRP strips oriented at 45^0 . Bi-directional woven GFRP fiber are used for retrofitting the beams. The epoxy resin is used for bonding GFRP fibers to the concrete surface. The resin and hardener used in this study are Araldite LY 556 and hardener HY 951 respectively. Four layers of 100mm wide strips of GFRP are used for strengthening. Three types of strengthening schemes are adopted in the study. The details of strengthening schemes are given in Table 1. The edge to edge spacing betweenGFRP strips are 100 mm.

Experimental Setup: Three sets of T-beams of varying flange widths are cast. The cross sectional details and reinforcement arrangements are shown in the figure 1. The testing arrangement is shown in the figure 2.

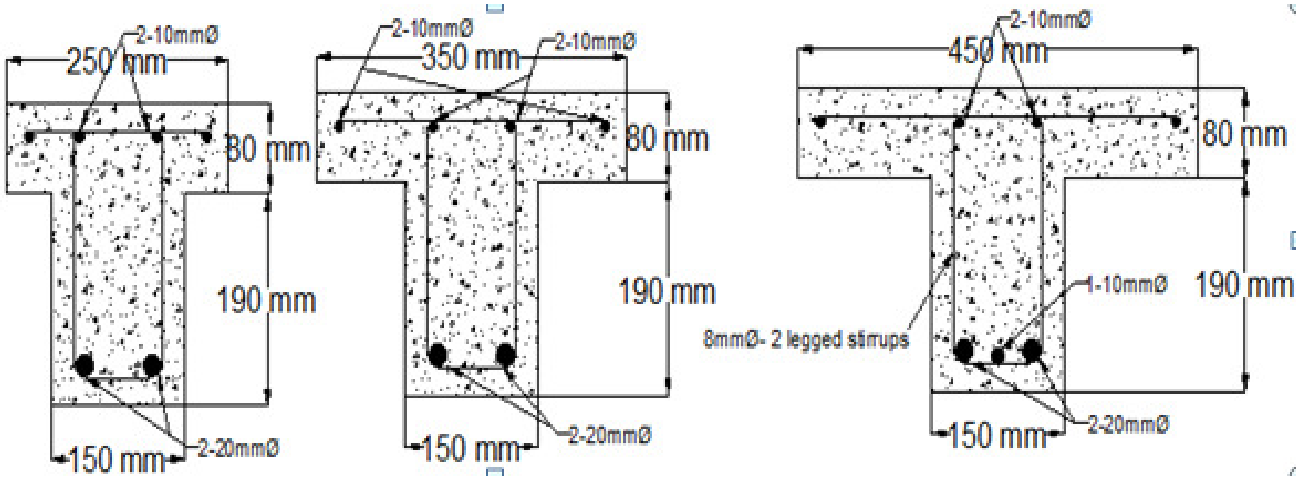


Figure-1
crossectionand reinforcement

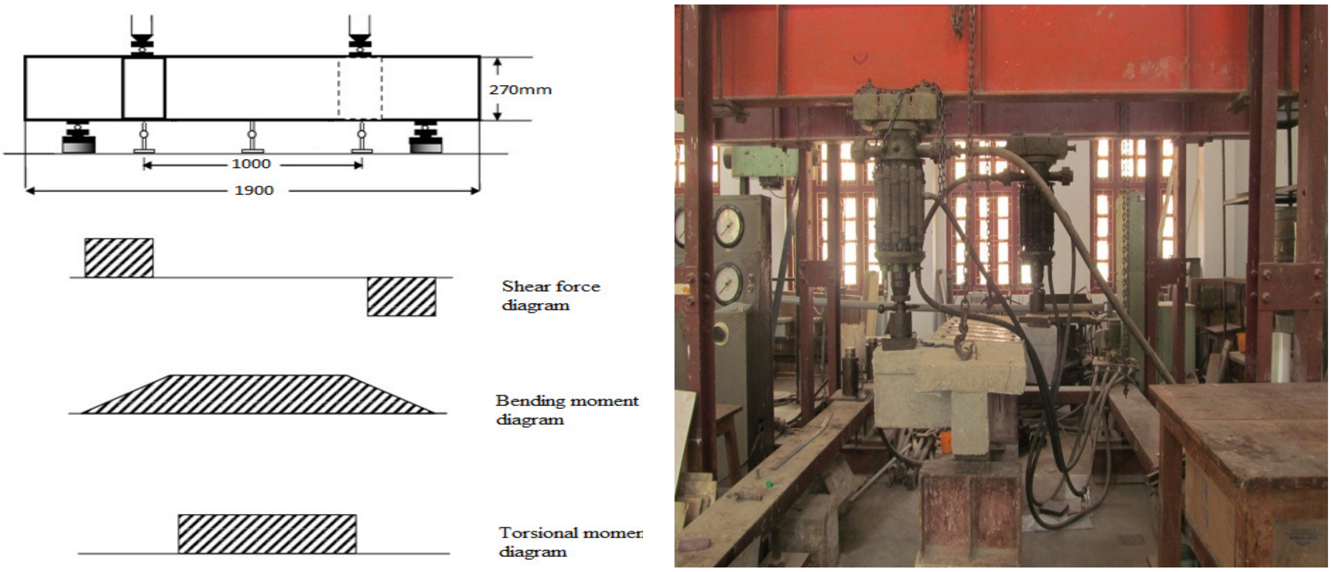


Figure-2
S.F and B.M Diagram for 2-Point Loading and Loading Setup

All beams are tested under monotonically increasing static loads on both projected arms simultaneously, this arrangement transfer torsion to the middle part of the beam of 0.8 m length. All beams are designed to fail in torsion hence no stirrups are provided except at each end to keep longitudinal reinforcements in positions. The beams are tested till failure in Structural Engineering Laboratory of National Institute of Technology, Rourkela . During testing loads are applied in increments and at each increment deflections were observed across the three sectionstocalculate twisting angles at different points on the beam.

During testing cracks formation and their propagation and inclinations are critically observed. For retrofitted beams crack patterns and failure pattern are observed after removing the GFRP from the beams. The details of results obtained through testing of beams are given in Table 2.

Results and Discussion

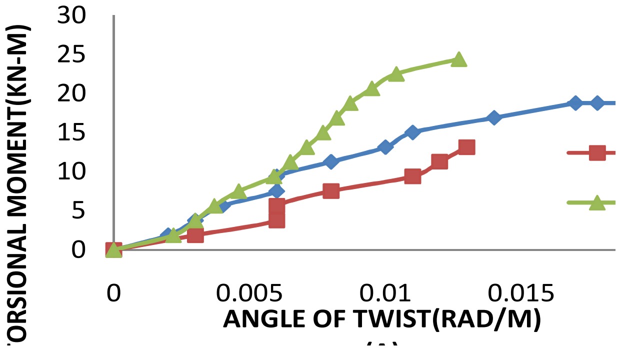
Effect of Flange width on Torsional Moment Capacity: Comparisons between control beams of varying flange width exhibit that torsional resisting capacity of increases with increase in flange width. Various codes neglect the flange area of T-beam and consider only web area while calculating torsional capacity unless stirrups are provided in the flange area. The present study showed that unreinforced flange also contributes to the torsional capacity hence conventions given in the codes are on conservative side.

Table-1
Description of Beams

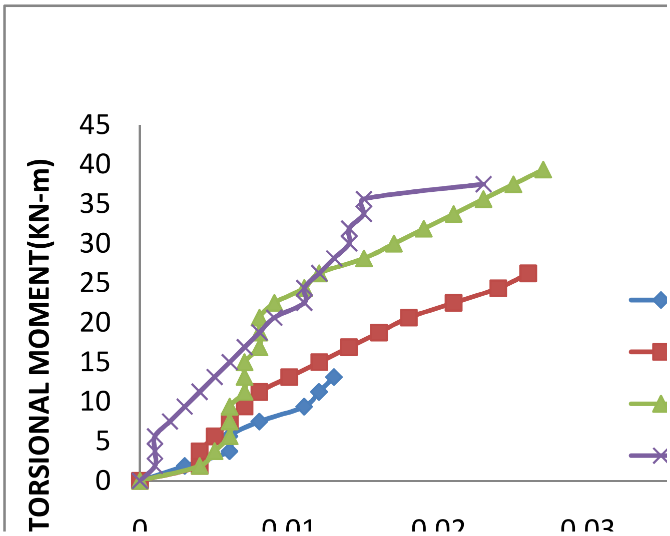
Beam	**Series I T2**	**Series II T3**	**Series III T4**	**Description**
	Flange width 250mm	**Flange width 350mm**	**Flange width 450mm**	
Beam Designation	T2C	T3C	T4C	Control Beam
	---------------	T3SU	T4SU	U wrapped with four layers of 100 mm wide strips of GFRP ,oriented 90^0 with horizontal.
	---------------	T3SF	T4SF	Fully wrapped with four layers of 100 mm wide strips of GFRP, oriented 90^0 with horizontal.
	---------------	T3S45	T4S45	Fully wrapped with four layers of 100 mm wide strips of GFRP ,oriented 45^0 with horizontal.

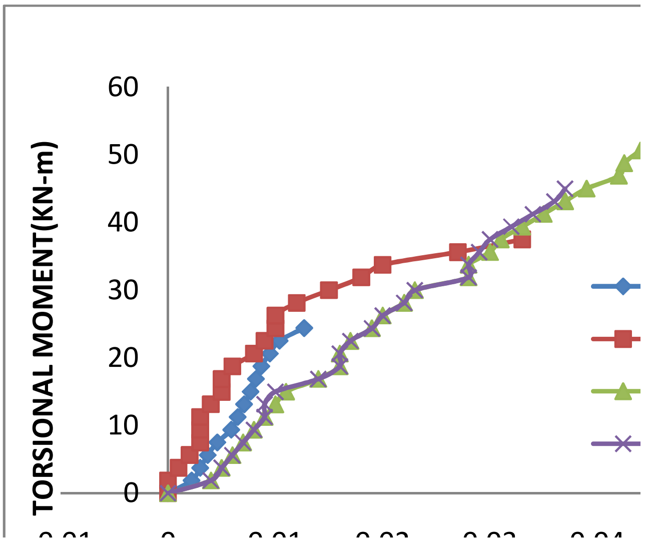
Table-2
Torsional capacity of Beams

Beam Description	**Beam Designation**	**Ultimate load InkN**	**Ultimate Torsional Moment in kN-m**	**Type of Failure**	**Remark**
Series T2	T2C	102	16.88	Debonding	First hair line crack appeared @80KN
Series T3	T3C	116	18.75	Debonding	First hair line crack appeared @90KN
	T3SU	143	26.81	Debonding	First hair line crack appeared @110KN
	T3SF	230	43.13	Debonding	First hair line crack appeared @210KN
	T3S45	210	39.375	Debonding	First hair line crack appeared @190KN
Series T4	T4C	152	28.50	Debonding	First hair line crack appeared @120KN
	T4SU	208	39.00	Debonding	First hair line crack appeared @160KN
	T4SF	315	58.13	Debonding	First hair line crack appeared @260KN
	T4S45	297	56.25	Debonding	First hair line crack appeared @230KN

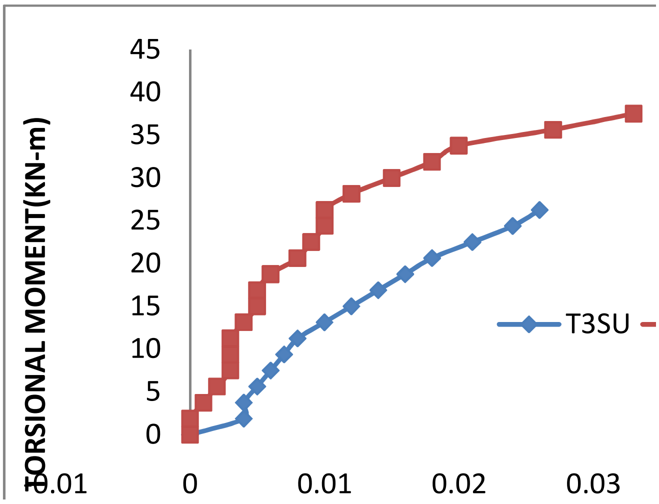


Effect of GFRP configuration Torsional Moment Capacity

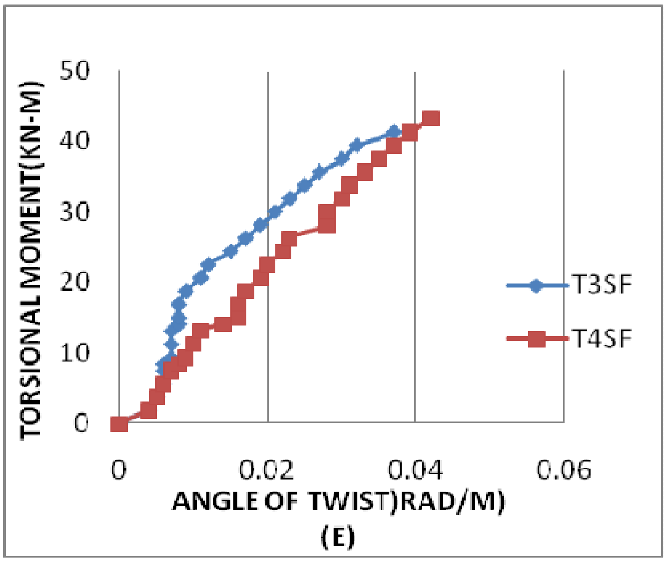




The maximum torsional strength is provided by fully wrapped configuration. 90^0 fiber orientations provide more torsional strength compared to 45^0 fiber orientation. Full wrapping scheme provide a close path for shear flow and an efficient confinement and in turn a significant increase in ultimate strength are observed. The increase in strength are 98.27% for T3SF and 107.23% for T4SF whereas for 45^0 orientations increase in strength are 81.03% for T3S45 and 95.39% for T4S45.



Beams U wrapped with 90^0 oriented GFRP stripes provide lower torsional strength. Since shear flow stresses take a close path during torsional loading, torsion would not be well resisted in case of U-jacketing strengthening. For U wrapped beams increase of 23.27% to 36.84% in ultimate torsion wereobserved for series T3 beams and series T4 beams respectively.



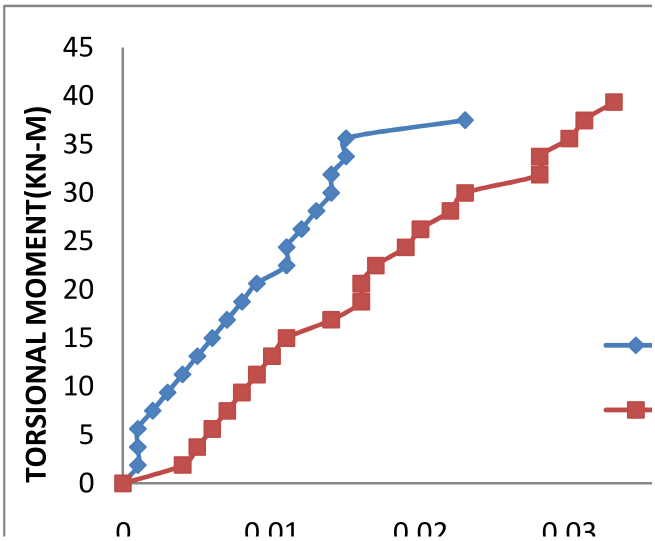


Figure-3
(A),(B),(C),(D),(E),(F) Are Curves Between Torsional Moment VS. Angle Of Twist

Analytical Validation: The model used for validation of the experimental results of present study are developed by A. Deifalla and A. Ghobarahis a simplified procedure to evaluate FRP contribution to torsional capacity of RC beams[4]. They proposed that FRP contribution to the total torsion capacity can be calculated by

$$T_f = \frac{2\ Ao\ ff\ Af\ [\cot \beta + \cot \theta]\sin \beta}{Sf}$$

Where; Ao =area enclosed inside the critical shear flow path due to strengthening includes area of flange, f_f = stress in the FRP sheet at failure, β =angle of orientation of the fiber direction to the longitudinal axis of the beam, S_f=spacing between the centerline of the FRP strips,
A_f = effective area of the FRP resisting torsion calculated by:
$A_f = t_f w_f$, w_f = width of FRP strips

Where n = number of FRP strips,
$f_f = E_f \mathcal{E}_{fe}$

Where Ɛfe = effective strain in fibres calculated by
$\mathcal{E}fe = \frac{0.33 w_f}{Lesf}$ for debonding failure of FRP

Where Le = effective bond length calculated by

$$Le = \sqrt{\frac{Eftf}{\sqrt{fc}}}$$

Where fc = compressive strength of concrete

Following the above equations and using material properties and specimen dimensions the torsional resistance provided by the FRP for beams are calculated and given in Table 3

GFRP properties E_f= 9493 N/mm^2 (determined by using INSTRON UTM at structural. Engg. Lab.)

Figure-4
Beams retrofitted with GFRP oriented at 45^0

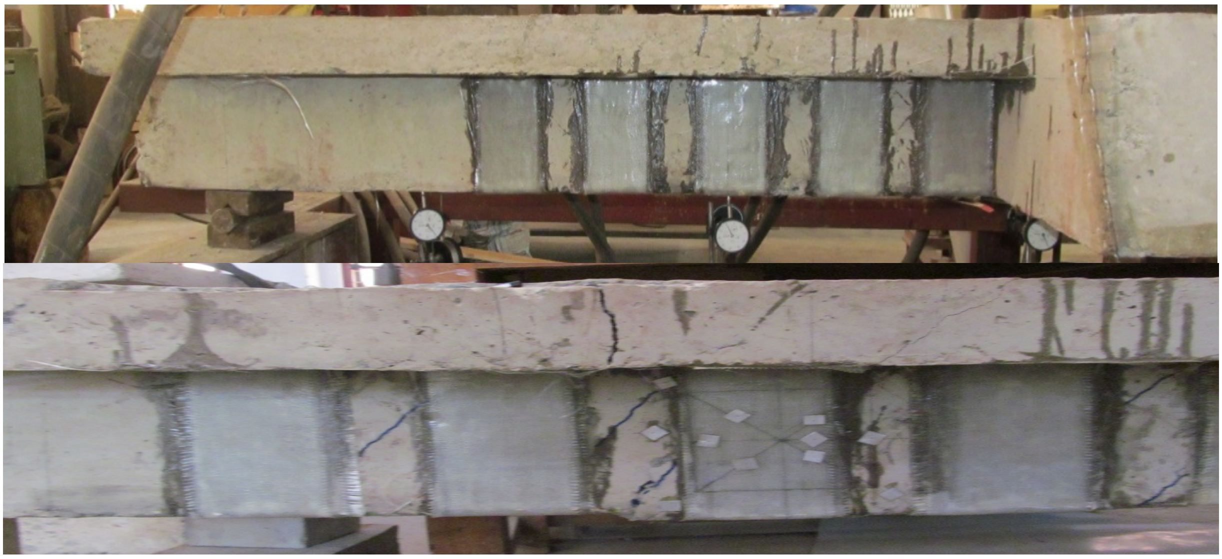


Figure-5
Beams retrofitted with U-wrapped GFRP oriented at 90^0

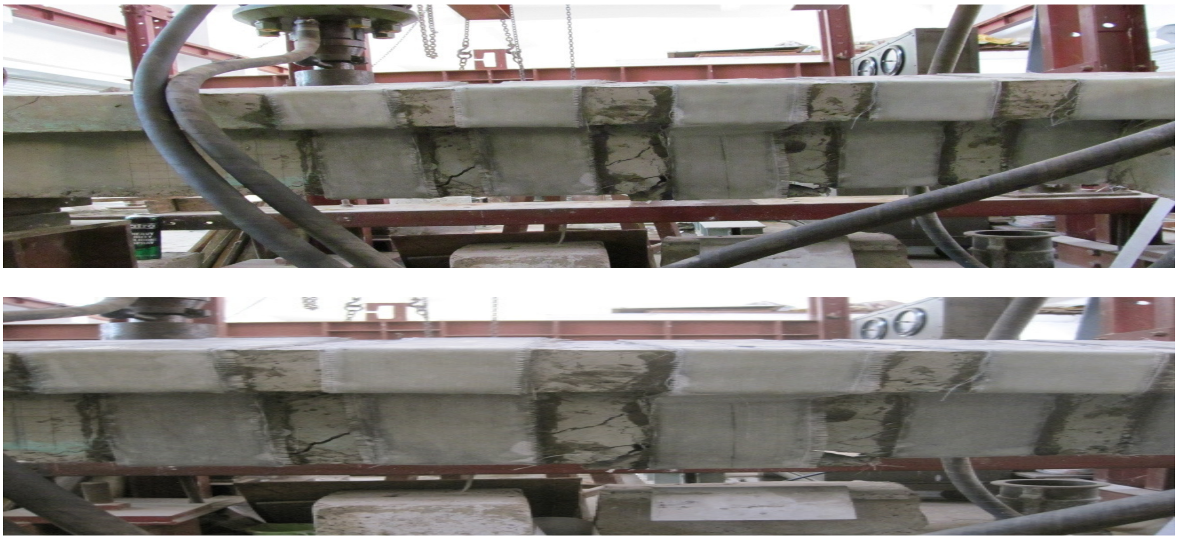


Figure-6
Beams retrofitted with Fully-wrapped GFRP oriented at 90^0

Table-3
Comparison of Analytical and Experimental Results

Beam Name		t_f (mm)	n	θ	B	f_c N/mm^2	$T_{f,cal}$ kN m	$T_{fexp=}$ Tult* - Tcont* kNm	$\frac{Tf, exp}{Tfcal}$
Series-A	T3SU	2.26	5	65º	90º	28.62	28.61	27	0.94
	T3SF	2.51	5	50º	90º	28.69	109.61	114	1.04
	T3S45	2.46	4	55º	45º	28.69	99.69	94	0.94
Series-B	T4SU	2.43	5	55º	90º	30.89	51.3	56	1.09
	T4SF	2.53	5	45º	90º	30.77	149.98	163	1.08
	T4S45	2.28	4	42º	45º	29.83	133.17	145	1.08

*T_{ult} - ultimate torsional moment of FRP strengthen beam, *Tcont - ultimate torsional moment of control beam. The calculated values compares well with the experimental values.

Conclusion

The present experimental program consisting of nine numbers of reinforced concrete T- beams with three different flange widths tested under torsion. The main objective is to examine the effectiveness of epoxy-bonded GFRP fabrics used as external transverse reinforcement to resist torsion. Based on presented experimental results and analytical predictions, the following conclusions are drawn. i. Experimental results show that the effect of flange width on torsional capacity of GFRP strengthened RC T-beams are significant. ii. Torsional strength increases with increase in flange area irrespective of beam strengthening with GFRP following different configurations schemes. iii. 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. iv. The cracking and ultimate torque of all strengthen beams were greater than those of the control beams. v. The maximum increase in torque was obtained for 90^0fully wrapped configurations. Increase of 133.33% to 116.67% in first cracking and 155.55% to 107.23% in ultimate torsion were recorded for series T3 beams and series T4 beams respectively. vi. Beams fully wrapped with 45^0 oriented GFRP stripes showed next highest torsional resisting capacity. Increase of 111.11% to 91.667% in first cracking and 81.03% to 95.39% in ultimate torsion were recorded for series T3 beams and series T4 beams respectively. vii. Beams U wrapped with 90^0 oriented GFRP stripes show lowest torsional resisting capacity. Since shear flow stresses take a close path during torsional loading ,torsion would not be well resisted in case of U-jacketing strengthening. viii. For U wrapped beams increase of 22.22% to 33.33% in first cracking and 23.27% to 36.84% in ultimate torsion were recorded for series T3 beams and series T4 beams respectively. ix. Strengthened beams using GFRP strips as the only transverse reinforcement exhibited better overall torsional performance than the non-strengthened control beams. x. Although the extended FRP U-jacket strengthening technique relatively less effective than the FRP full wrapping strengthening technique, it yielded promising results in terms of strength and ductility while being quite feasible for most strengthening practical situations. xi. The experimental results were validated with simplified model proposed by A. DeifallaandA.Ghobarah[4]. The model included the effect of different parameters studied in the present work like strengthening techniques, thickness and number of layers, spacing between FRP strips, FRP orientations, and angle of diagonal cracks. xii. Experimental results indicate that the estimation of the GFRP contribution to torsional strength using simplified model proposed by A. Deifalla and A.Ghobarah provided good accuracy for GFRP strengthen beams[4].

Acknowledgment

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