International Journal of Multidisciplinary Research and Modern Education (IJMRME)
ISSN (Online): 2454 - 6119
(www.rdmodernresearch.org) Volume I, Issue I, April, 2015

TORSIONAL BEHAVIOUR OF CONCRETE BEAMS REINFORCED INTERNALLY WITH GLASS FIBRE REINFORCED POLYMER REINFORCEMENTS

A. Prabaghar* & G. Kumaran**

* Associate Professor, Structural Engineering Division, Engineering Wing - DDE, Annamalai University, Annamalainagar, Chidambaram, Tamilnadu

** Professor, Department of Civil & Structural Engineering, Annamalai University, Annamalainagar, Chidambaram, Tamilnadu

Abstract:

This study briefly covers the experimental study on the behaviour of rectangular concrete beams reinforced internally with Glass Fibre Reinforced Polymer (GFRP) reinforcements under pure torsion for beam with different longitudinal reinforcement ratio. The basic strength properties of concrete, steel and GFRP reinforcements are determined experimentally. In this study, the experimental investigation consists of eight specimens with identical dimensions, geometry and different reinforcing arrangement. Torsional strength and angle of twist increase with the increase percentage of longitudinal and transverse reinforcements. The GFRP reinforced concrete beams showed higher angle of twist than the conventional reinforcements.

Key Words: Pure Torsion, Beam, GFRP Reinforcements, Steel

Introduction:

Glass Fibre Reinforced Polymer (GFRP) reinforcements are being used as internal reinforcements in the place of conventional steel reinforcements and are becoming a vital alternative which can improve the life span of concrete structures (ACI 440R, 1996 and Benmokrane, 1995). GFRP reinforcements are made of two components namely, the fibres and the matrix. The matrix is usually a thermo set resin such as vinyl ester or epoxy, while the fibres are carbon, aramid or glass fibres. Considerable research has also been carried out mainly on the use of internal reinforcements for concrete beams and slabs under flexural conditions (Benmokrane, 1995). Studies reported that different theories are developed for beams with conventional steel reinforcements, but no such study is carried out for beams reinforced internally with GFRP reinforcements under pure torsion (Chyuan, 2010 and Collins, 1972). Therefore the present study discusses mainly the experimental behaviour of concrete beams reinforced internally with Glass Fibre Reinforced Polymer (GFRP) reinforcements under pure torsion. In this study, the experimental investigation consists of eight specimens with identical dimensions, geometry and different reinforcing arrangement. The entire concrete beam is supported on saddle supports which can allow rotation in the direction of application of torsion. The torque twist relationships are derived for various parametric conditions and are plotted. Finally, the results of the analytical methods are compared with experimental results.

Materials:

Concrete:

Normal Strength Concrete (NSC) of grades M 20 is used to cast the concrete columns. The mix proportions are done as per Indian Standards and the average compressive strengths are obtained from laboratory tests (Fasa *et al.*1992, Hsu, 1968 & 1984, Vasanth, 2010, and Balaji Ponraj et al., 2011) and are depicted in Table 1.

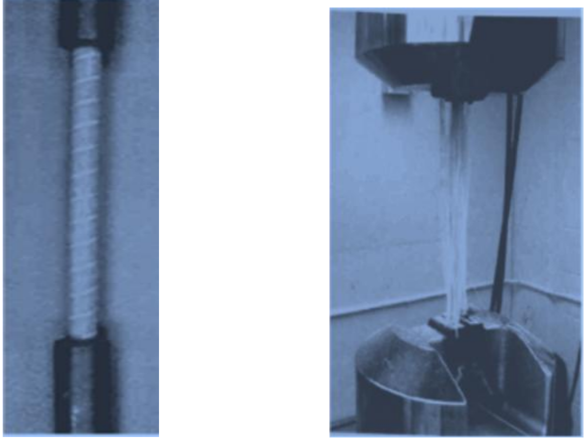
Table 1: Properties of Concrete

Description	M 20 grade (m_1)
Ratio	1:1.75:3.75

W/C Ratio	0.53
Average Compressive Strength of cubes	32.25 MPa

Reinforcements:

The tensile strength of GFRP reinforcements as per ASTM Standards (Benmokrane, 1995) and steel specimens as per Indian standards are obtained from laboratory tests and the results are tabulated in table 2. The stress strain curves of steel / GFRP reinforcements are shown in figure 2. The tensile strength of steel reinforcements (F_e) used in this study, conforming to IS 1786: 1985, and having an average value of the yield strength of steel is considered for this study.



(a) (b)

Figure 1: (a) GFRP reinforcements with end anchorages for tensile tests (b) Failure of GFRP reinforcements under tension

GFRP reinforcements used in this study are manufactured by pultrusion process with the E-glass fibre volume approximately 60% and these fibres are reinforced with epoxy resins (Liang *et al*, 2000). Threaded type of GFRP reinforcements are used in the present study. In this study, GFRP stirrups are manufactured by Vacuum Assisted Resin Transfer Moulding process, using glass fibres reinforced with Epoxy resin. Based on the experimental study, it is observed that the strength of GFRP bent bars/stirrups at the bend location (bend strength) is as low as 50 % of the strength parallel to the fibres. However, the stirrup strength in straight portion is comparable to the yield strength of conventional steel stirrups. Other related tests such as shear tests, thermal coefficient expansion, creep, fatigue and other durability tests are conducted and reported in the references (Fasa *et al.,* 1992, Hsu, 1968 and Hsu, 1984 Sivagama Sundari *et al.*, 2009; Deiveegan *et al.*, 2010; Saravanan *et al.*, 2011).

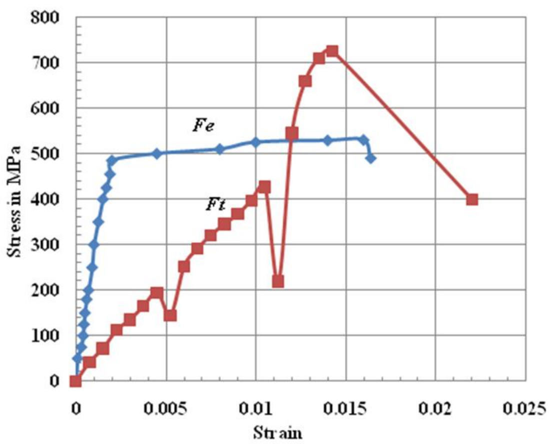


Figure 2: Stress-Strain curve for all the reinforcements involved in the present study

Table 2: Properties of reinforcements

Properties	Threaded GFRP (F_t)	Steel Fe 415 (S)
Tensile strength (MPa)	580	475
Longitudinal modulus (GPa)	59.5	200
Strain	0.012	0.002
Poisson's ratio	0.22	0.25 – 0.3

Test Set Up and Instrumentation:

Totally sixteen of rectangular cross sections of size 160×275 mm with different concrete grade and reinforcing arrangement are cast. The designations of the specimens are tabulated in Table 3. All beams are provided with equal eccentric arms on either side to induce pure torque along the span supported on the saddle supports.

Table 3: Various Parameters involved

Parameters	Description	Designation
Types of Reinforcements	Threaded GFRP	*Ft*
	Conventional	*Fe*
Concrete Grade	M 20	m_1
Beam Size	160 x 275 mm	*B*
Reinforcement Ratios	0.56% (2-12 mm bars top & bottom) 0.85% (3-12 mm bars top & bottom) 1.4 % (5-12 mm bars top & bottom)	p_1, p_2 & p_3

Torsion testing machine has two eccentric arms with equal eccentricity of *e* to ensure, as far as possible pure torque along the span. All beams are reinforced with 12 mm diameter as longitudinal reinforcement and 8mm diameter as transverse reinforcements. The centre-to-centre spacing of the transverse reinforcements (stirrups) is 75 mm c/c uniformly spaced (spacing is decided based on the Indian standards specifications).

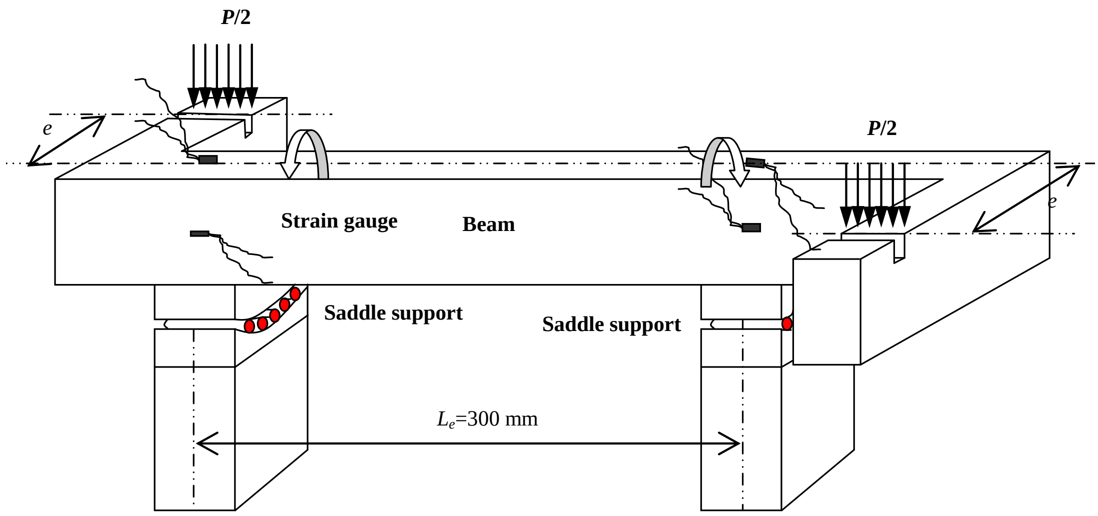


Figure 3: Experimental set up with instrumentation

The thickness of the concrete cover of longitudinal bars, measured from the bar centre to the surface, d_c = 20 mm. GFRP reinforcements are tied with stirrups with the help of Nylon zip ties. All the beam end portions are cast with additional reinforcements in order to avoid premature failure near the ends. Normal moist curing is done for all beams. After curing, grid points are marked. The test specimens are kept in the torsion testing frame of capacity 10 tonnes and the load is applied with the help of hydraulic jacks manually and is monitored by pressure gauges. The deflections of the beams are measured by dial gauges and Linear Variable Displacement Transducer

(LVDT). The twist induced is then calculated on the basis of the measured deformations. A data acquisition system is used to record all LVDT and electrical strain gauge signals. The experimental set up is shown in figures 3 to 5.

Figure 4: Saddle support

Figure 5: Arial view of the Test specimen with all accessories

Parameters Considered in this Study:

B = 160 mm; D = 275 mm; b_1 = 102 mm; d_1 = 217 mm; E_s = 212500 N/mm^2; $E_c = 5000\sqrt{f_{ck}}$; m_1 = 28.14 MPa; $m = E_s/E_c$; A_l = 113× 4= 452 mm^2 (2 Nos. of top and bottom); A_l = 113× 6= 678 mm^2 (3 Nos. of top and bottom); A_l = 113× 10= 1,130 mm^2 (5 Nos. of top and bottom); A_t = 2× 50.3 = 100.6 mm^2; f_y = 475 MPa; s = 75 mm; f_{GFRP-l} = 525 MPa ; f_{GFRP-t} = 150 MPa.

Experimental Observations:

The experimental results in the form of torque verses twist diagrams are shown in figure 6 to figure 8 and the results are compared with the reference beams.

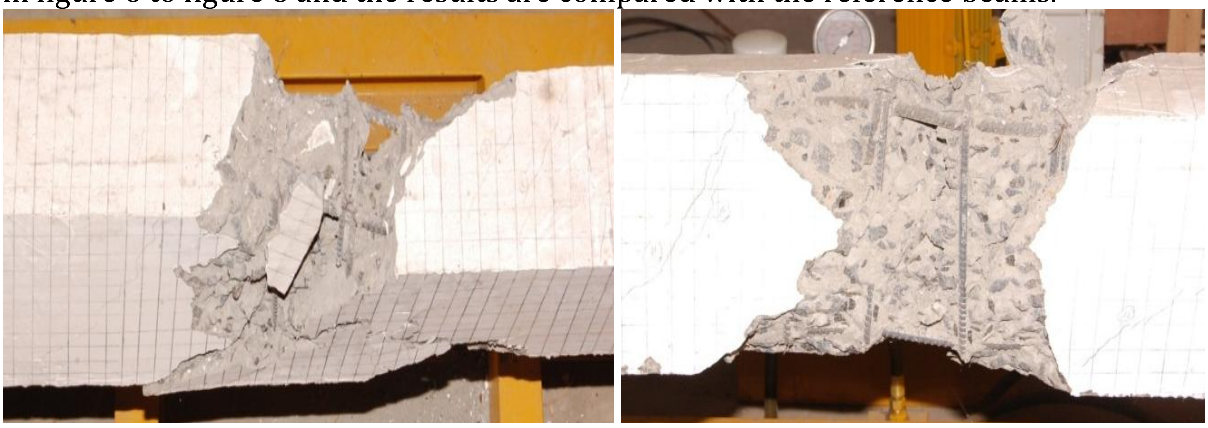


Figure 6: Failure of conventional steel reinforced beams due to yielding of longitudinal and transverse steel ($Bp_1m_1F_e$)

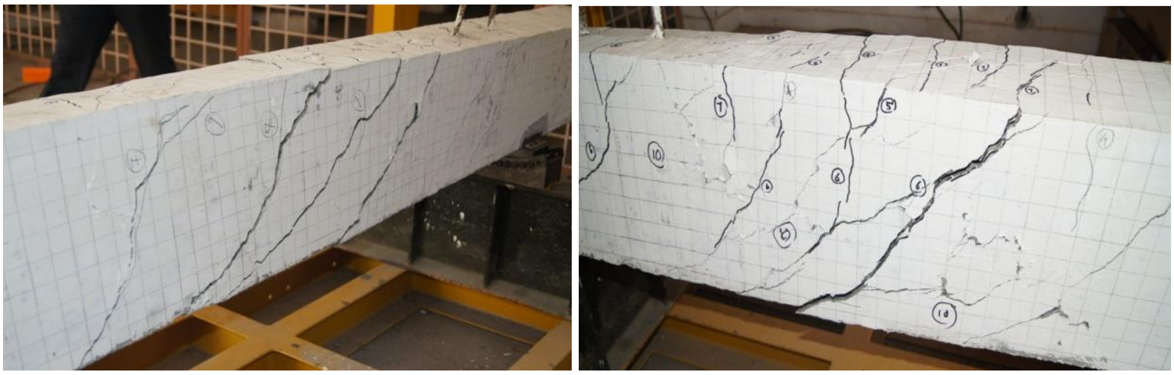


Figure 7: Larger diagonal cracks in GFRP reinforced beams

Figure 8: Failure of GFRP reinforced rectangular beam due to excessive spalling of cover followed by concrete crushing ($Bp_1m_1F_t$)

- Diagonal cracks (approximately 45° to the longitudinal axis of the beam) appeared approximately in the mid depth of the section first, subsequently at the middle of the width of the beam and finally these cracks continued spirally in all four faces of the beam. When the torque increased further small number of diagonal cracks appeared in larger number for GFRP reinforced concrete beams.
- It is observed from the experimental study that the beams reinforced with conventional steel reinforcements having a reinforcement ratio less than 1% (0.56%) failed by yielding to longitudinal and transverse reinforcements before crushing of concrete in compression, but beams with approximately closer to 1% (0.86%) of steel reinforcement ratio failed by crushing of concrete in compression before yielding to longitudinal or transverse reinforcements.
- GFRP reinforced concrete beams failed due to crushing of concrete followed by rupture of GFRP stirrups when the reinforcement ratio was 0.56% and was less than 1%. It is probably due to the fact that the ultimate tensile strains of GFRP stirrups are slightly higher than the ultimate compressive strains of concrete.

Such mode of failure is invariably observed for all GFRP reinforced beams with a reinforcement ratio less than 1% and approximately closer to 1 %. . But none of the beams failed due to rupture of GRFP reinforcements prior to concrete strain reached ultimate. It is probably due to the fact that the ultimate tensile strains of GFRP reinforcements are greater than the ultimate compressive strains of concrete.

- Torsional strength and angle of twist increase with the increase percentage of longitudinal and transverse reinforcements. But GFRP reinforced concrete beams showed higher angle of twist than the conventional reinforcements. This fact is primarily due to higher tensile strain values for GFRP reinforcements than the steel reinforcements.
- During test all specimens exhibited satisfactory ultimate torsional behaviour; however the post-peak behaviour differs for GFRP reinforced beam but not for conventionally reinforced beams.

Experimental and Theoretical Results:

The experimental and theoretical results in the form of torque verses twist diagrams are shown in figures 9 and 10 and the results are compared with the reference beams.

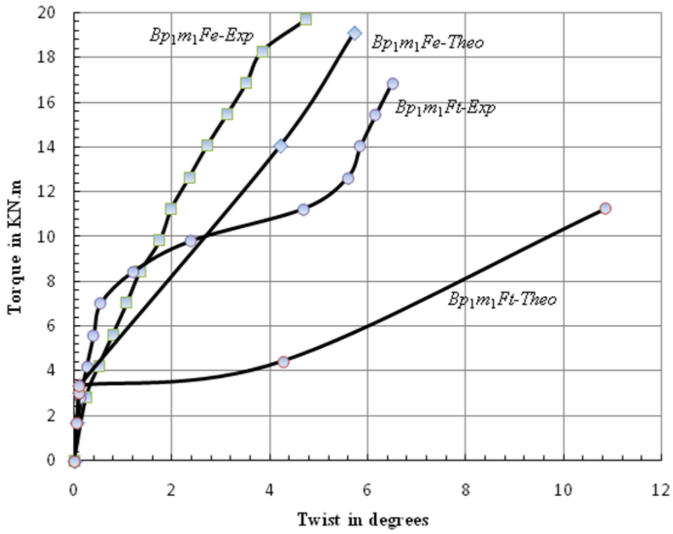


Figure 9: Torque verses twist for rectangular beam (m_1= 32.25 MPa; p_1=0.56%)

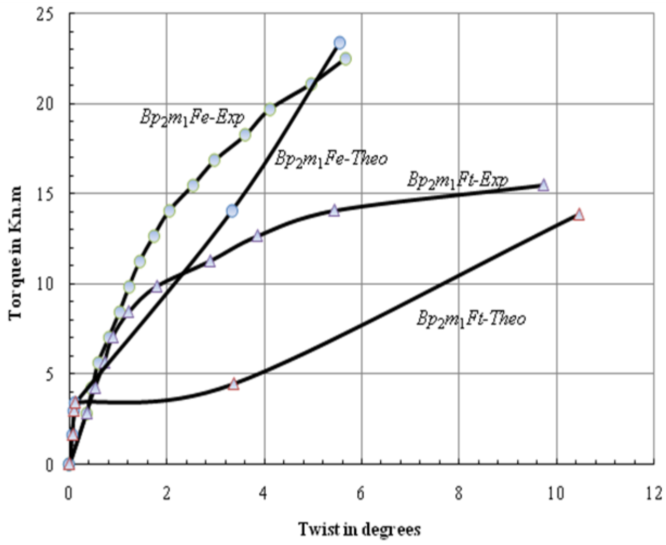


Figure 10: Torque verses twist for rectangular beam (m_1= 32.25 MPa; p_1=0.85%)

- The existing theoretical torque-twist relationship based on space truss analogy for various parametric beams under pure torque condition is utilized for GFRP reinforced concrete beams.
- The predicted variations of angle of twist with the applied torque for steel/GFRP reinforced beams show a closer and almost similar trend when compared to the experimental trend. Therefore the existing theories using space truss analogy are more reliable to predict the torsional behaviour.
- Torsional strength and angle of twist increase with the increase in the grade of concrete and percentage of longitudinal and transverse reinforcements. But GFRP reinforced concrete beams showed higher angle of twist than the conventional reinforcements. This fact is primarily due to higher tensile strain values for GFRP reinforcements than the steel reinforcements.
- It is also noted that the replacing of main and transverse steel reinforcements by an equal percentage of GFRP reinforcements , reduced their torsional capacities by 30% for lower grade concrete but their increase was reduced by 20 % for higher grade concrete and higher percentage of steel.
- The ultimate values of torsional strength of beams have greater influence on the spacing of stirrups. The minimum spacing of stirrups is arrived at based on the Indian Standards. An examination of the curves reveals that the slope of the curves at the initial stages of loading is mild for GFRP reinforced columns, whereas for conventional columns it is steeper. This is primarily due to lower elastic modulus than conventional steel reinforcements.
- It is also observed that for steel reinforced concrete beam, the yielding of reinforcement leads to a larger increase in twist with little change in torque, whereas GFRP reinforced beams show no yielding of reinforcements and the twist continues to increase with the increase in torque, thereby exhibiting some ductility despite the brittle nature of GFRP rebars.
- In higher grade of concrete and higher percentage of steel, the torque–twist diagrams show an increase in torque together with a rapid increase of beam twist. The failures are characterized by the crushing of the concrete at the compressive face, followed by the yielding of steel stirrups and rupture of GFRP stirrups. This qualitative behaviour is observed in GFRP/steel beams; consequently the overall behavior of the GFRP beam is similar to the behavior of conventionally reinforced concrete beams except the failure of GFRP stirrups even after concrete crushing.

Conclusions:

GFRP reinforcements do not have definite yield point, and its stress-strain response shows linear-elastic response up to failure; therefore, no GFRP reinforced beams exhibit a failure point before concrete fibre reaches its limiting strain 0.0035. None of the beams (lower and higher than 1%) failed by rupture of GFRP reinforcements either by brittle tension or premature compression. It is primarily due to higher strain values of GFRP reinforcements in tensile and compression than the bending strain of concrete. Therefore concrete crushing failure is more desirable for concrete beams reinforced with GFRP bars. Therefore, the use of partial safety factors for longitudinal reinforcement may not be essential for the torsional design of GFRP reinforced beams.

Acknowledgement:

The authors wish to thank the University Grants Commission (UGC) of India for the valuable financial support rend from the UGC Major Research Scheme.

References:

1. ACI 440R-96, "State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures", Reported by ACI Committee 440.
2. Asghar. M Bhatti and Anan Almughrabi, "Refined Model to Estimate Torsional Strength of Reinforced Concrete Beams, "ACI Structural Journal, Vol. 95, No.5 pp. 614622, 1996.
3. Balaji Ponraj. G, "Experimental Study on the Behaviour of Concrete Beams Reinforced Internally With GFRP Reinforcements under Pure Torsion", M.E Thesis, Department of Civil and Structural Engineering, Annamalai University, 2011.
4. Benmokrane. B, Chaallal.O and Masmoudi. R (1995), Flexural Response of concrete Beams Reinforced with FRP Reinforcing Bars, ACI Materials Journal, 91 Vol. (2), 46-55.
5. Bernardo. F.A et at., (1995), "Behaviour of Concrete Beams Under Torsion: NSC Plain and hollow beams", Journal of Material and Structures , Vol.41, 1143-1167, 2008
6. Chyuan-Hwan Jeng, "Simple Rational Formulas for cracking Torque and twist of Reinforced Concrete Members", ACI Structural Journal, Vol.107, No.2, PP-189-197, 2010.
7. Collins, M.P., The Torque-Twist Characteristics of Reinforced Concrete Beams, Inelasticity and Nonlinearity in Structural Concrete, SM Study No. 8, University of Waterloo Press, Waterloo, 1972, pp 211–232.
8. Deiveegan. A and Kumaran. G, "Reliability Study of Concrete Columns internally reinforced with Non-metallic Reinforcements", International Journal of Civil and Structural Engineering, Vol.1 (2), pp. 270-287, 2010.
9. Faza. S. S, and Ganga Rao. H.V.S, (1992), Bending and bond behavior of concrete beams reinforced with fibre reinforced plastic rebars, WVDOH-RP-83 phase 1 report, west Virginia University, Morgantown, 128-173.
10. Hsu, T.T.C., Behaviour of Reinforced Concrete Rectangular Members, ACI Publication SP – 18, 'Torsion of Structural Concrete' American Concrete Institute, Detroit, 1968, pp 261–306.
11. Hsu, T.T.C., Ultimate Torque of Reinforced Rectangular Beams, ASCE Journal of Structural Engineering, Vol. 94, No.1., pp 485–510, 1968.
12. Hsu T.T.C, Torsion of Reinforced Concrete, Van Nostrand Reinhold Publishing Company, Inc, New York, 1984.
13. Hsu T.T.C, Mo YL (1985) Softening of concrete in torsional members—Design recommendations, Journal of American Concrete Institute Proceedings, Vol. 82 (4), PP 443–452, 1985.
14. IS: 10262 (1982), Guide lines for concrete mix design, Bureau of Indian Standards, New Delhi.
15. IS: 516 (1959), Code of practice-Methods of test for strength of concrete, Bureau of Indian standards, New Delhi.
16. Khaldoun.N et al., "Simple Model for Predicting Torsional Strength of Reinforced and Prestressed Concrete Sections", ACI Structural Journal, Vol.93, No.6, PP. 658-666, 1996.
17. Liang Jenq Leu and Yu Shu Lee, " Torsion Design Charts for Reinforced Concrete Rectangular Members, Journal of Structural Engineering, V126, No.2, pp 210-218, 2000.
18. Luís F. A. Bernardo and Sérgio M. R. Lopes, "Behaviour of concrete beams

under torsion", Journal of Materials and Structures, V(2), pp35-49, 2008.
19. Mac Gregor. J. G and Ghoneim. M. G., "Design for Torsion", ACI Structural Journal, V-92, No.2, pp.211-18, 1995.
20. Mattock, A.H., "How to Design for Torsion", ACI Publication SP – 18, 'Torsion of Structural Concrete', American Concrete Institute, March 1968.
21. Mohammad Najim Mahmood, "Nonlinear Analysis of Reinforced Concrete Beams Under Pure Torsion", Journal of Applied Sciences, 7(22), pp: 3524-3529, 2007.
22. Nanni, A., "Flexural Behaviour and Design of RC Members using FRP Reinforcement", Journal of the structural Engineering, ASCE, Vol. 119, No.11, pp. 3344-3359, 1993.
23. Niema. EI, "Fiber Reinforced concrete Beams under Torsion", ACI Structural Journal, V. 90, No. 5, 1993.
24. Rahal K.N and Collins. MP, "Analysis of sections subjected to combined shesr and torsion-A theoretical model", ACI Structural Journal, V.92, No.4, PP.459-469, 1995.
25. Saravanan. J and Kumaran. G, "Joint shear strength of FRP reinforced concrete beam-column joints", Central European Journal of Engineering, Vol.1 (1), pp. 89-102, 2011.
26. Sivagamasundari, R., "Analytical and experimental study of one way slabs reinforced with glass fibre polymer reinforcements", Ph.D. Thesis, Department of Civil and Structural Engineering, Annamalai University, 2008
27. Trahait. N.S, "Nonlinear Nonuniform Torsion", ASCE Journal of Structural Engineering, Vol.131, No.7, PP.1135-1142, 2005.
28. Unnikrishna Pillai and Devdas Menon, "Reinforced Concrete Design", Tata Mc Graw-Hill Publishing Company Limited, New Delhi, 2003.