Experiment on Torsional Behaviour of Reinforced Concrete Beams

A. Prabaghar, G. Kumaran

Abstract*—Structural beams in construction are subjected to significant torsional moment which affects the design of structures.Eight beams were produced with two distinct grade of concrete with two ratios of longitudinal as well as transverse reinforcements.An experiment for evaluation of torsional strength of reinforced concrete beams is presented in this paper.The main objective of this study is to access the role of varying percentage of transverse and longitudinal reinforcements on torsional strength of beams.Concrete grades of M 20 and M 30 beams were cast with 0.56% and 0.85% of longitudinal reinforcement as well as 50 mm and 75 mm spacing of stirrups.The experimental results are presented.The reported results include the behavioural curves and the values of torsional moment and angle of twist for entire 8 beams.

***Index Terms*— Torsional moment – Angle of twist – Concrete grade – Reinforcement ratio – behavioural curves.**

I. INTRODUCTION

Generally all the structural members will experience torsion, when the external loads acts away from the plane of bending along with shear and bending moment [1]. Due to this torsion, the shear stresses will occur resulting in diagonal cracks. The design of structural elements should also consider the effect of torsion to counteract the twisting effects. The structures with L shape, T shape, double T shape and box sections are generally experience torsion force. The members which are curved in plan, eccentrically loaded beams and spiral staircase are also have torsion force. Early studies were mostly concentrate only on flexure, shear and bending moments since they believe that the members fails due tension and shear force but actually it accompanied by tension force also[2]. Now the scope of research is becoming wider and now in addition the studies are focusing on the behaviour of members due to pure torsion [3] is encouraged. This is because the torsion force can cause severe damage than other forces. The design of reinforced concrete beams should be provide sufficient reinforcement to accommodate the effects due to torsion. If there is no adequate reinforcement for torsion force, the member will subjected to sudden brittle failure. The main aim of this study is to determine the behaviour of reinforced concrete beam with different percentage of longitudinal and transverse reinforcements under torsion force.

II. PROPERTIES OF MATERIALS

Concrete

Ordinary Portland Cement is used to produce M 20 and M 30 grade concrete and used to cast the concrete beams. The sizes of fine and coarse aggregates are 0 - 4.75 mm and 20 mm respectively. Natural curing for about 28 days of all specimens and are tested. The uni-axial compressive strength of concrete is determined from standard test cubes of size 150 mm as per IS 516 - 1959. Cylindrical specimens of 150 mm dia. and 300 mm length were cast and the elasticity modulus of concrete was found by testing it in a compression testing machine. The mix designs were carried out as per Indian Standards IS: 10262-1982. The mix ratios and the compressive strength of concrete are shown in Table 1.

Table 1 Design ratios and Average compressive strength of concrete.

<table>
<tr><th>Materials (m^3)</th><th>Grade of concrete M20</th><th>Mix Design Ratio</th><th>Grade of concrete M30</th><th>Mix Design Ratio</th></tr>
<tr><td>Cement</td><td>348.32kg</td><td rowspan="5">1:1.64:3.48</td><td>476.92 kg</td><td rowspan="5">1:1.09:2.42</td></tr>
<tr><td>Fine aggregate</td><td>572.93 kg</td><td>520.14 kg</td></tr>
<tr><td>Coarse aggregate</td><td>1213.75 kg</td><td>1156.4 kg</td></tr>
<tr><td>W/ C ratio</td><td>0.55</td><td>0.50</td></tr>
<tr><td>Avg. compressive strength of concrete cubes</td><td>32.25 (MPa)</td><td>44.14 (MPa)</td></tr>
</table>

Reinforcement

Table 2 summarizes the average values of the mechanical properties of steel reinforcements

Table 2 Tensile properties of reinforcements

Properties	Steel Specimen (Fe 415 rod)
Tensile strength (MPa)	475
Longitudinal modulus (GPa)	215
Strain (ε)	0.002
Poisson's ratio (μ)	0.25 – 0.3

All beams are provided with equal eccentric arms on either side to induce pure torque along the span.The

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eccentric load was applied using the wedge and plate assembly.The theoretical span*l* of the tested beamsis equal to 3000mm. Each specimens were positioned in between the saddle supports on torsion testing equipment with two eccentric arms cast with wedges to hold on both sides of the specimen with identical eccentricity of *e*= 350mm to ensure, as far as possible pure torque along the span.The ends of the beams are provided with a wedge to hold the wedge plate attached to the torsion testing machine. Also wedge plates are provided at the ends of the beams to ensure uniform torque transmitted to the beam cross section.All beams are reinforced with 12 mm diameter as longitudinal reinforcement and 8mm diameter as transverse reinforcements as shown in Fig.1. The c/c spacing of the transverse reinforcements are equally spaced along the span.The longitudinal steel ratios are 0.56 and 0.86. The cover of 20 mm (d_c) was provided for the specimens. All the specimens were cast and normal moist curing is done. After curing, grid points are marked using paint on the surface of the beams. Typical cast specimens for torsional test are shown in Fig.2.

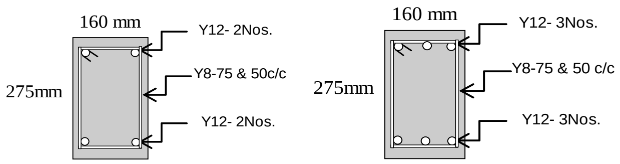

Fig. 1 Reinforcement details of the specimens (Section)

Fig. 2Cast specimen for torsional test

The experimental investigation consists of totally eight beam specimens with same parameters. The specimens with properties, loading conditions and the test related parameters are listed below.The test specimens are concrete beams of rectangular cross sections of size 160×275 mm as shown in Figure 1and 2. The parameters and design descriptions are given in Table 3.

Table 3 Parameters and design descriptions

Parameters	Description	Designation
Reinforcements kind	Steel rods	*Fe*
Grade of Concrete	f_{cu} average cube strength	m_1& m_2
Dimension of Specimen	160 x 275 mm	*B*
Percentage of steel	1. 0.56% (2 nos. of 12 mm dia. bars top & Bottom) 2. 0.85% (3 nos. of 12 mm dia bars top & Bottom)	p_1&p_2
Spacing of stirrups	75 mm and 50 mm	s_1&s_2

The grades of concrete used in this study are M20 and M30. The span of the specimens were influenced by the length of torsion testing equipment. The effective span between the saddle supports is 3000 mm (L).In this series, totally eight numbers of specimens were prepared and are designated are as follows:

***Bp*$_1$*m*$_1$*S*$_1$*Fe*;; *Bp*$_1$*m*$_2$*S*$_1$*Fe*; *Bp*$_2$*m*$_1$*S*$_1$*Fe*; *Bp*$_2$*m*$_2$ *S*$_1$*Fe*; *Bp*$_1$*m*$_1$*S*$_2$*Fe*; *Bp*$_1$*m*$_2$*S*$_2$*Fe*; *Bp*$_2$*m*$_1$*S*$_2$*Fe*; *Bp*$_2$*m*$_2$*S*$_2$*Fe*;**

III. TEST SETUP

Arrangements for each specimens were made to measure their complete twist and axial deformations using dial gaugesand LVDTs.The geometry and reinforcement details of test specimens are shown in Figs. 4 to 7.

Static Loading

Torsion testing frame of capacity 10 tonnes is used for testing the rectangular solid beam specimens. The static monotonically increasing loads are applied at the ends by using a 100 kN capacity hydraulic jacks manually and are monitored by pressure gauges.This frame is provided with two plungers along with loading wedges at both the ends in order to induce uniform torque.Torque is induced by applying eccentric loads along the axis of the beam with an eccentricity of 350mm.The deflections or deformations of the beamsare measured by dial gauges andLinear Variable Displacement Transducers (LVDT).The schematic diagrams of the torsional beam supported on saddle supports are shown in figs. 4 - 7. A typical experimental test setup is shown in fig. 7.

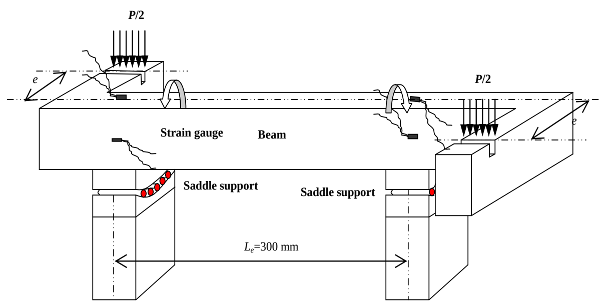

Fig. 4 Schematic diagram of beam supported on saddle support

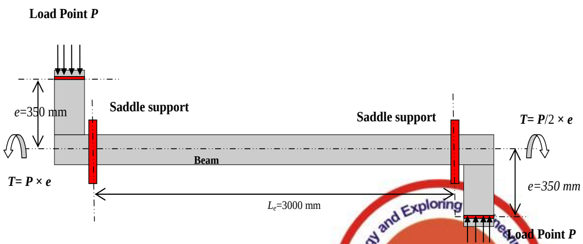

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Fig. 5 Schematic diagram of test specimens with load positions

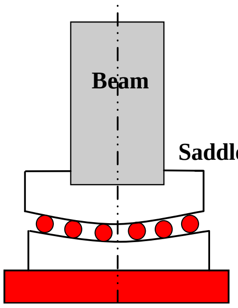


Fig. 6 Schematic diagram of saddle support and specimen

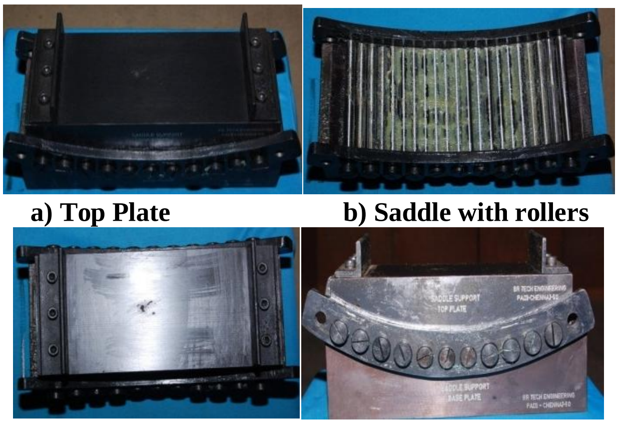
Fig. 7 Experimental setup

Instrumentations

Strain gauges were fixed on the all specimens both internally and externally to determine the deformations of the beams. Internal strain gauges are fixed on the steel/GFRP reinforcementsat the time of casting the specimens with due precaution. External strain gauges are glued on the beam specimens near the support at the middle depth (vertically and horizontally) on both ends of the beam. Strains aremeasured using strain gauges.The twist induced is then calculated on the basis of the measured deformations.The axial extensionsare also measured with the help of dial gaugeswith a least count of 0.01 mm attached on magnetic base stands at the end of beam specimens at both the ends.The signals from the LVDT and the electrical strain gauges were measured using a data acquisition system with a sampling rate of fifty samples. These electrical signals are converted into strains and are processed with the help of computers. The load is gradually applied with an increment of 1 kN up to the failure of the beams.

Saddle Point

These saddle supports are useful for inducing twisting moments along the beam length with an assumption that both the ends are provided with uniform torque thereby pure torque is applied.The magnitudes of the twisting moments are entirely determinable from statics alone.The entire saddle support unit consists of top plate, rollers and bottom plate. The top and bottom plates are kept in between rollers which may permit rotationalong the path of application of loading. The fig. 8 shows the components of saddle supports. The figs. 9 and 10 shows the failure of conventional concrete specimens with steel reinforcement due yielding of reinforcements and crushing of concrete.

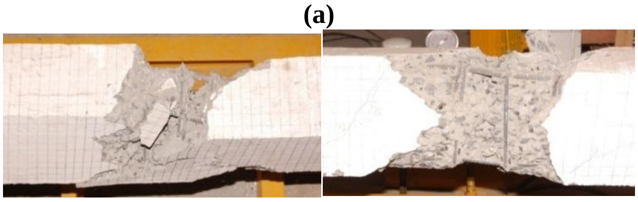


a) Top Plate **b) Saddle with rollers**

c) Base Plate **d) Entire Unit**

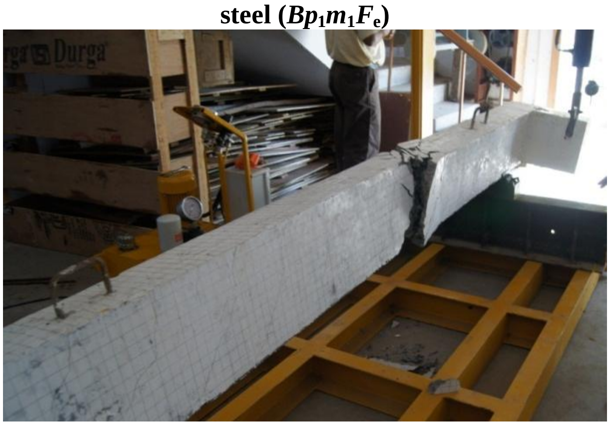
Fig. 8 Saddle support with other accessories

(a)

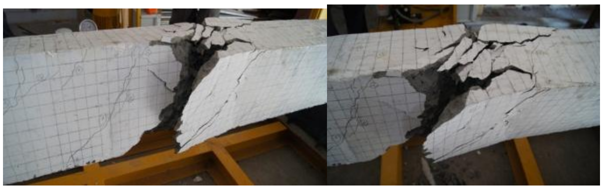


(b) **(c)**

Fig. 9 (a,b,c) Failure of conventional steel reinforced beams due to yielding of longitudinal and transverse steel ($Bp_1m_1F_e$)



(a)



(b) (c)

Fig. 10 (a,b,c) Failure of conventional steel reinforced beams due to concrete crushing ($Bp_2m_2F_e$)

IV. RESULTS AND DISCUSSIONS

The reinforced concrete beams was tested for torsional load and the results are represented.Figures 11 – 17 shows the relation between torque and twist.The strength of the specimens are mainly depends upon the type of reinforcement available in them when the specimen is starts to crack under increased load. During the cracking of beam the torsional stiffness is completely reducing resulting in increased twist with constant torque. The experimental investigations shows that the failure of conventional steel reinforced beams are failed due to yielding of reinforcements and crushing of concrete. It is also observed from the present study that for beams reinforced with conventional steel reinforcements having a reinforcement ratio lesser than 1% (ie.0.56%) are failed by yielding of longitudinal and transverse reinforcements before crushing of concrete in compression but beams with approximately closer to 1% (ie.0.86%) of steel reinforcement ratio are failed by crushing of concrete in compression before yielding of longitudinal or transverse reinforcements.

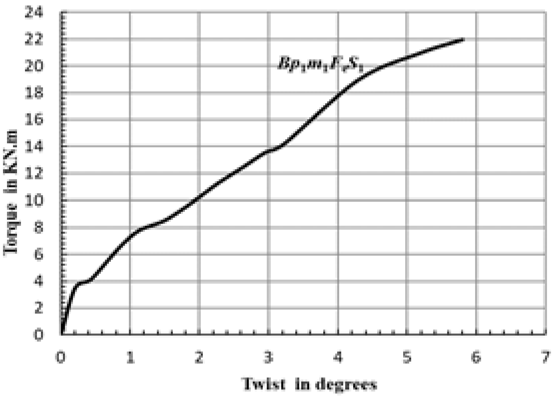


Fig. 11 Torque verses twist curve for the specimen $Bp_1m_1F_eS_1$

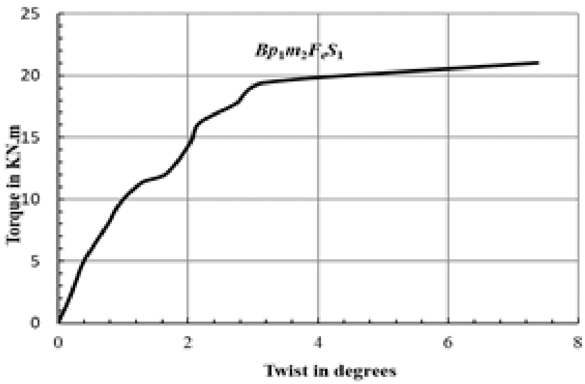


Fig. 12 Torque verses twist curve for the specimen $Bp_1m_2F_eS_1$

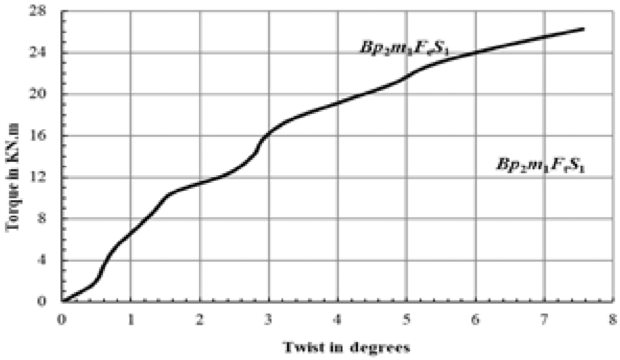


Fig.Torque verses twist curve for the specimen$Bp_2m_1F_eS_1$

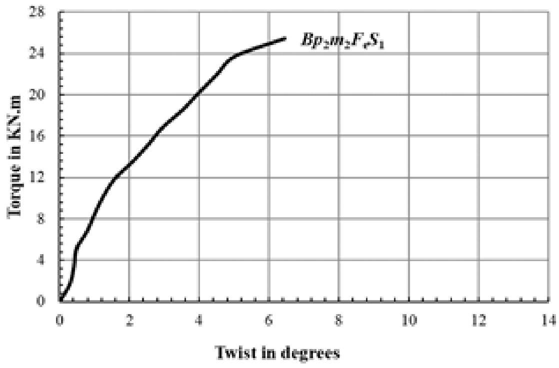


Fig. 13 Torque verses twist curve for the specimen$Bp_2m_2F_eS_1$

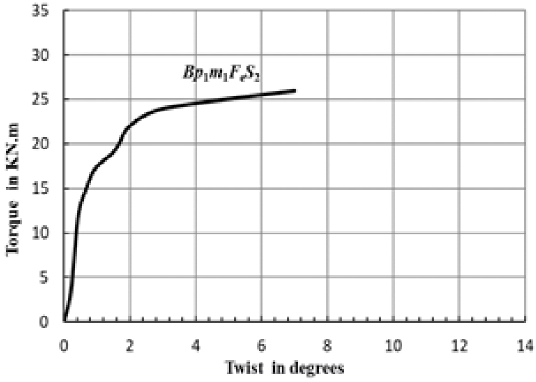


Fig. 14 Torque verses twist curve for the specimen$Bp_1m_1F_eS_2$

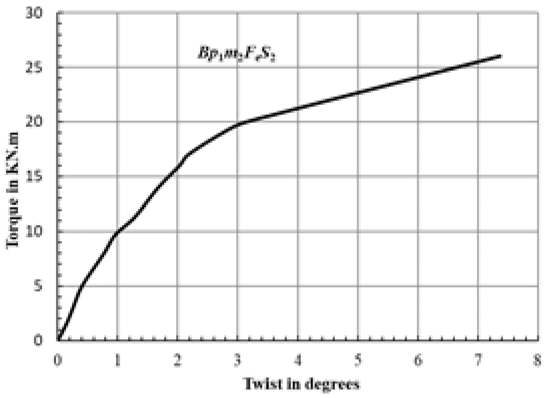


Fig. 15 Torque verses twist curve for the specimen$Bp_1m_2F_eS_2$

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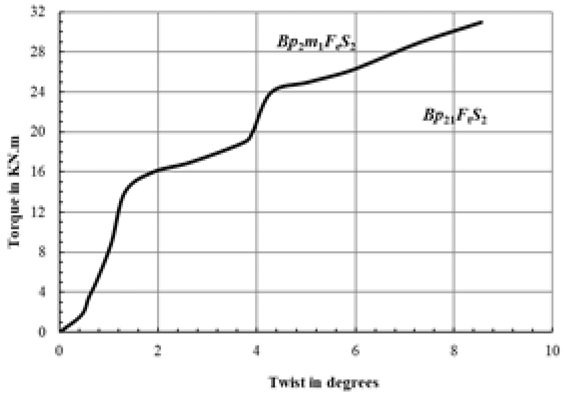

Fig. 16 Torque verses twist curve for the specimen$Bp_2m_1F_eS_2$

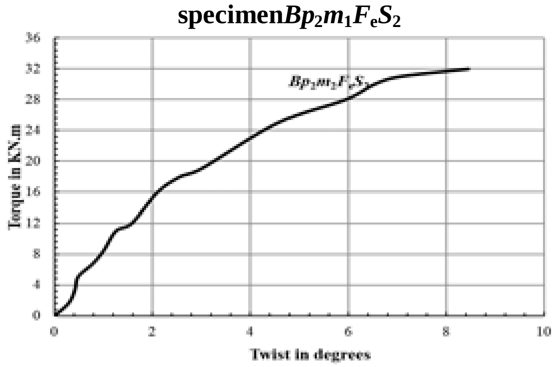

Fig. 17 Torque verses twist curve for the specimen $Bp_2m_2F_eS_2$

V. CONCLUSION

From the experimental investigations, the following conclusions are conveyed for reinforced concrete beam subjected to eccentrically loading conditions.

1. The specimens of M 30 grade exhibits lesser value oftorque as compared to M 20 grade specimens invariablyfor all the specimens.
2. The specimens of M 30 grade exhibits higher twist value oftorque as compared to M 20 grade specimens invariablyfor all the specimens.
3. The specimens having the spacing of stirrups 50mm showidentical values of torque and twist value in the ultimateload capacity in spite of the concrete grade and thereinforcement ratios.
4. The increased percentages of (0.86%) reinforcements showbetter performance in the load carrying capacity. The samekind of variation has been noticed for the specimens havingthe spacing of stirrups 50mm.
5. With the increase in concrete grade and steel percentage,there is an increase in angle of twist and torsional strength.
6. A rapid increase in the twist of specimen and torque is found when the grade of concrete and percentage of steel is increased.

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BIOGRAPHY

Dr. A. Prabhagar was born in India in 1967.He received his, B.E., M.E., and Ph.D. degrees from Annamalai University,Tamilnadu, India in 1988, 1990 and 2014 respectively.He joined as lecturer in Annamalai University, Tamilnadu, India, in 1990 and presently he is an Associate Professor, Department of Structural Engineering –DDE Wing of Annamalai University. His main area of research interest are the behaviour of concrete elements subjected to torsion and he has published seven scientific papers in the field of torsional behaviour of beams.

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