Imperial Journal of Interdisciplinary Research (IJIR)
Vol-3, Issue-3, 2017 (Special Issue) , ISSN: 2454-1362, http://www.onlinejournal.in
Proceedings of 4th International Conference on Current Trends in Engineering, Science Technology and Management

Torsional Behaviour of Plain and Reinforced Normal Strength Concrete Beams

M. R. Prakash[1] Chinmayee[2] , Vikram Kumar[3] & R Prabhakara[4]
[1]Department of Civil Engineering, Acharya Institute of Technology, Bangalore - 107, India.
[2]Department of Civil Engineering,, UVCE, Bangalore - 01 , India.
[3]Department of Civil Engineering, Acharya Institute of Technology, Bangalore -107, India.
[4]Department of Civil Engineering, M S Ramaiah Institute of Technology, Bangalore - 54, India.

Abstract : *Concrete as building material has a complex behavior phenomenon at micro structure in transferring of stresses between the ingredients, Changes in the mechanical properties, change the cracking and failure behavior and is not clearly understood the behavior of beams, in the case of mechanism of pure torsion, torsion with bending, torsion with shear and the formulas developed for the calculation is wholly or partly empirical. To understand the behavior, an experimental investigation was carried out to study the Torsional behavior of the reinforced Normal Strength Concrete (NSC) beams with the mix proportion of* ***1:1.57:2.48:0.44*** *concrete grade M40. Twelve NSC beams with constant width (100 mm), depth (100 mm), effective span 800mm without steel as plain beam, with varying longitudinal reinforcement and* ***nine*** *beams with varying longitudinal and transverse reinforcement ratio were tested under the standard testing procedures. The parameters studied in this investigation are ductility behavior, cracking torsional strength, ultimate torsional strength, failure pattern, Torque-rotation behavior, torsional stiffness, strains and comparison of torque resistance with plain and reinforced beams. The ratio of the experimental to that of the predicted torsional moment by different theories and codes were calculated. The mean, standard deviation and the coefficient of variation was obtained. Based on these observations, conclusions were drawn.*

Key Words: *NSC, Crack, Failure, Ductility, Torsion, Strength*

1. INTRODUCTION

Reinforced concrete members in a structure may be subjected to axial forces, shear forces, bending moments, torsion, or a combination of these effects. For most design situations, bending moments and shear forces are considered primary effect, whereas torsion is regarded secondary. For this reason the torsional behavior of reinforced concrete beams is not studied as much in depth as the behavior under bending and shear stresses. Torsion becomes a primary effect, however, for situations as in, where beams curved in plan, staircases, balcony beams, eccentrically loaded beams, curved bridges, beams supporting a secondary beam and beams in supporting sunshades and canopies are used. These structures are often required to resist torsion and should be designed or at least be checked for torsion. Therefore, the analysis and design of torsion are getting more important for structural engineers.

The mechanism of torsional failure is as yet not clearly understood and all formulas developed for the calculation of the torsional strength of the reinforced concrete beams are either wholly or partly empirical. This is due to the lack of rationality in our approach to the problem of torsion. The behaviour of members under the effect of torsion is still a subject of extensive research. As on date, there is no prescribed equation to use the longitudinal reinforcement in to consideration to calculate the Torsional strength. Moreover, in almost all of the reported investigations the percentage of reinforcement has not been considered as a variable. As it is a well known fact that the behavior of the structures, especially in the Torsional moment -twist response and ductility index, is strictly dependent on the percentage of steel, in the present study an attempt has been done to take into account the effect of the steel ratio.

2. TORSION THEORIES & CODES FOR PLAIN CONCRETE MEMBER

There are various theories available for the analysis of reinforced concrete member subjected to torsion. The basic theories are

a) Skew bending theory based on: i) Compressive strength ii) Modulus of Rupture
b) Elastic theory c) Plastic theory d) ACI CODE.

2.3 FORMULATION

All the formulae given by different theories and codes were used for calculation of torsional moment and are illustrated below in the sub-sections.

2.3.1 Elastic theory

The behavior of a torsional member is described by St. Venant's elastic theory. Torsional failure of a plain concrete member is assumed to occur when the maximum principal tensile stress σ_{max} becomes equal to the tensile strength of concrete f_t. The elastic failure torque T_e can be expressed as

$$T_e = \alpha x^2 y f_t \qquad (01)$$

The elastic theory consistently underestimates the failure strength of plain normal strength concrete beams with the test results being about 50 percent greater than the predicted values.

2.3.2 Plastic theory

Since the elastic theory consistently underestimates thetorsional strength, the extra strength may be attributed to the plastic behavior of concrete. As in the elastic theory, failure is assumed to occur when the maximum principal tensile stress reaches the tensile strength of concrete f_t. The plastic failure torque T_p is expressed as

$$T_p = \alpha_p x^2 y f_t \qquad (02)$$

2.3.3 Skew-bending theory

The skew-bending theory has been proposed to predict the ultimate torsional strength of plain concrete members. According to the skew-bending theory, the torsional strength can be expressed as

$$T_{np} = \frac{x^2 y}{3}\left(0.85 f_r\right) \qquad (03)$$

3. ANALYSIS OF THE TEST DATA BY DIFFERENT CODES

The ultimate Torsional strength of plain and longitudinally reinforced concrete beams were calculated using different theories. The cracking torsional moment is the main parameter which decides the safe Torsional moment the beam can withstand, hence it satisfies serviceability requirements given in many structural codes. In the flexure and shear behavior, the reserve strength is available after the first crack. The compression zone has the ability to carry the redistributed loads and moments after the propagation of cracks in tension zone. The beam failure takes place when the compression zone also fails to take further load due to the cracks or steel yields. But it's not true for the Torsional behavior, as the cracks propagate the member fails due to twisting. When the beam is subjected to torsional moment, the formation of the crack is not limited to the one face; it propagates on all the faces which lead to the failure of section without further increase in the Torsional strength. The principle parameter which influences the Torsional strength was concrete compressive strength, however size of the beam, percentage of longitudinal and transverse reinforcement does not have much influence on the strength but their contribution towards post ductility of the beam is significant.

Table 3.1 Analysis of Experimental data

BEAM	$T_{u(expt)}$ KN-m	$T_{u(expt)}$/Bd MPa	$T_{u\ (theory)}$ in KN-m				
			SKEW BENDING THEORY-1	SKEW BENDING THEORY-2	ELASTIC THEORY	PLASTIC THEORY	ACI
NSC-B1-0	**0.72**	0.082	2.153	2.05	0.369	0.872	0.524
NSC-B2-0	**0.72**	0.082	2.153	2.05	0.369	0.872	0.524
NSC-B3-0	**0.84**	0.096	2.153	2.05	0.369	0.872	0.524
NSC-B4-2	**0.87**	0.099	3.678	1.024	0.9252	1.045	1.667
NSC-B5-2	**0.90**	0.103	3.678	1.024	0.9252	1.045	1.667
NSC-B6-2	**0.96**	0.109	3.678	1.024	0.9252	1.045	1.667
NSC-B7-3	**1.81**	0.207	3.678	1.024	0.9252	1.045	1.667
NSC-B8-3	**1.87**	0.214	3.678	1.024	0.9252	1.045	1.667
NSC-B9-3	**1.90**	0.217	3.678	1.024	0.9252	1.045	1.667
NSC-B10-4	**1.99**	0.227	3.678	1.024	0.9252	1.045	1.667
NSC-B11-4	**1.93**	0.221	3.678	1.024	0.9252	1.045	1.667
NSC-B12-4	**1.93**	0.221	3.678	1.024	0.9252	1.045	1.667

Table 3.2 Ratio of Experimental to Theoretical Torsional Moment Strength

BEAM	SKEW BENDING THEORY-1	SKEW BENDING THEORY-2	ELASTIC THEORY	PLASTIC THEORY	ACI
NSC-B1-0	0.334	0.703	1.946	0.826	1.373
NSC-B2-0	0.333	0.703	1.946	0.826	1.373
NSC-B3-0	0.390	0.821	2.271	0.963	1.602
NSC-B4-2	0.237	0.849	0.940	0.833	0.522
NSC-B5-2	0.245	0.879	0.973	0.861	0.540
NSC-B6-2	0.261	0.938	1.038	0.919	0.576
NSC-B7-3	0.492	1.768	1.956	1.732	1.086
NSC-B8-3	0.508	1.827	2.021	1.789	1.122
NSC-B9-3	0.517	1.856	2.053	1.818	1.140
NSC-B10-4	0.541	1.944	2.151	1.904	1.194
NSC-B11-4	0.525	1.886	2.086	1.847	1.158
NSC-B12-4	0.525	1.886	2.086	1.847	1.158

3.2 DISCUSSION ON THE ANALYSIS OF EXPERIMENTAL AND THEORETICAL DATA

In order to investigate the accuracy of standards' provisions for torsion, they are compared with the experimental results in this section. Ratios of ultimate torsional moment obtained by experimental results to that obtained by different theories are calculated and recorded in Table 3.2. In order to make the comparison more convenient, statistical approach is used by calculating mean, standard deviation and coefficient of variation as shown in Table 3.3.

Table 3.3 Comparisons of Values between Experimental results and Different Code / Theories for Plain Beams

THEORIES/ CODE	SKEW BENDING THEORY-1	SKEW BENDING THEORY-2	ELASTIC THEORY	PLASTIC THEORY	ACI
MEAN	0.353	0.742	2.054	0.872	1.449
SD	0.032	0.068	0.187	0.079	0.132
CV	0.0912	0.0912	0.0912	0.0912	0.0912

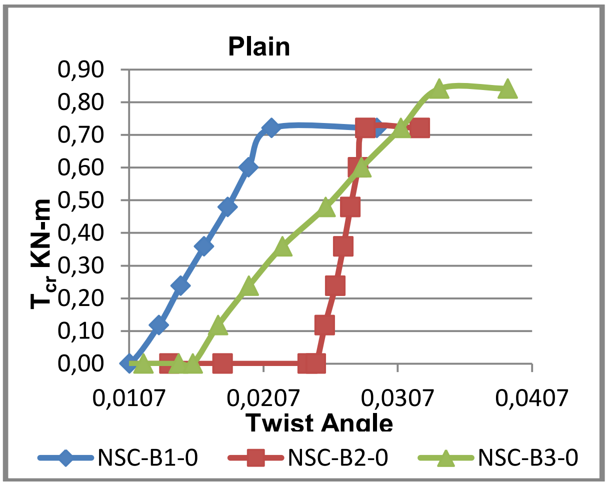
From table 3.3, it can be seen that for plain beams all the codes and theories are predicting values greater than 1, which in case for plain beams is a higher value. Thus here SBT-2 & Plastic Theory is predicting better values for torsional strength compared to other theories and codes, whereas SBT-1 is predicting comparatively lower value then other theories.

Table 3.4 Comparisons of Values between Experimental results and Different Code / Theories for Longitudinally Reinforced Beam

THEORIES/ CODE	SKEW BENDING THEORY-1	SKEW BENDING THEORY-2	ELASTIC THEORY	PLASTIC THEORY	ACI
MEAN	0.428	1.537	1.700	1.506	0.944
SD	0.136	0.489	0.541	0.479	0.300
CV	0.32	0.32	0.32	0.32	0.32

From Table 3.4, it can be observed that mean values of the Torsional Strength ratios for all standards are greater than one except for ACI codes and skew bending theory based on strength. This indicates that except for ACI codes & SBT-1 all other standards have predicted the torsional capacities conservatively.

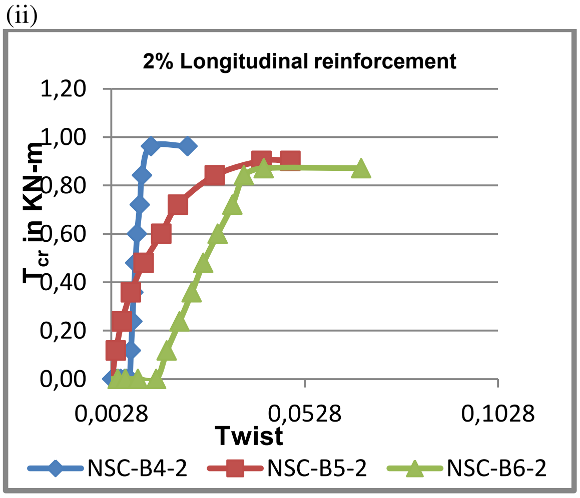
3.4.1 TORSIONAL MOMENT Vs TWIST CURVES



3.4.1 Curves for each beam

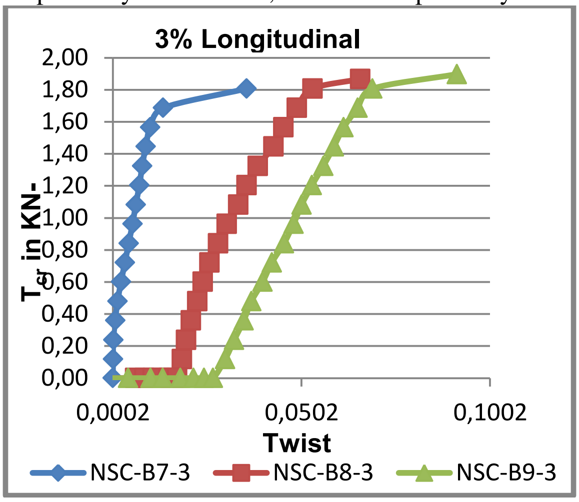
(i) **Plain Concrete Beam:** The graph was plotted for torsional moment v/s angle of twist for all the three plain beams. It was found that there was not much variation in the behavior. Beams B2 & B3 showed less stiffness initially and twisting after taking some amount of torsion compared to that of Beam B1. The value of twist angle 'θ' increased with the increase in the value of torque and after achieving the ultimate torsional strength with no further increase in torsion, the beams failed suddenly with formation of first crack.

(ii)

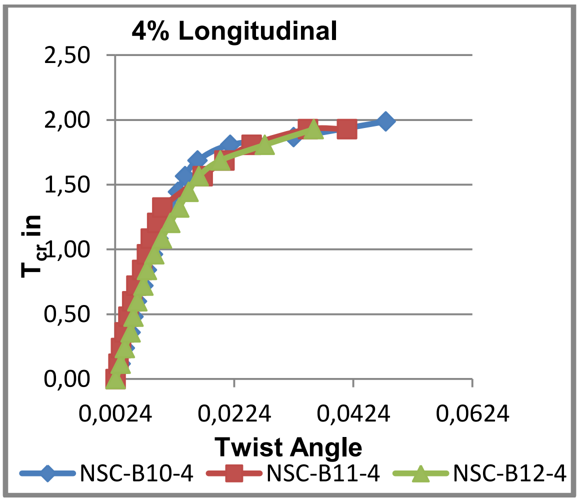


(ii) 2% Longitudinally Reinforced Beam

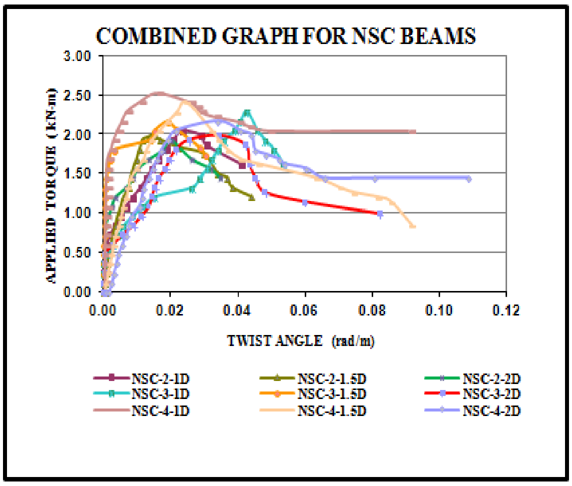
The beams with longitudinal reinforcement gave higher torsional carrying capacity than that of plain beams. The graph was linear up to a certain torque value, which after the first crack formation at constant torque, the crack widened. The ultimate crack did not increase beyond 1KN-m. The angle of twist increased with the increasing torque. The torque value obtained was 0.96, 0.90 & 0.87 KN-m respectively for NSC B4, B5 & B6 respectively.



iii) 3% longitudinally reinforced beams showed increase in the torsional capacity with the increase in % reinforcement. The torque values so obtained are 1.81, 1.87 & 1.90 for beam B7, B8 & B9 respectively, with much higher than that for beams with 2% longitudinal reinforcement. The graph was found to be more linear.



iv) 4% longitudinally reinforced beams showed highest torsion carrying capacity. The beams had the least variation compared in resistant to torque and angle of twist. The beams when attained the first crack kept widening with the increase in the torsional moment, till it reached ultimate moment. There was a more amount of twist as compared to 2% and 3%.



3.5 Torsional moment v/s Twist curves Combined for all NSC beams

The beams tested with % variation of longitudinal and spacing of transverse steel, it was observed that, the torsional moment v/s twist curves are linear up to cracking and after that the non-linear behavior of curves takes place. The curves for all NSC beams are compared with plain beams and only longitudinally reinforced beams.

3.6 COMPARISON WITH 2% LONGITUDINAL REINFORCEMENT

Comparison of torsional resistant of beams with the plain beams was done when reinforced with both in longitudinal steel and transverse steel separately. The torsional resistance of beams compared had with the 1D spacing of stirrups, was found that the concrete alone resisted to about 37% of the total torsional value, the longitudinal bars alone could resist about 7.4%. The torsion capacity was found to be resisted more with re-distribution of load, when stirrups were spaced with 49.6% incremental in 2D spacing. As the area of stirrups was increased with close spacing to 1.5D and 1D, in 1.5 D it resisted 3% of the torsional value and with 1D spacing of stirrups, there was a further 3% increment in torsional strength.

3.7 COMPARISON WITH 3% LONGITUDINAL REINFORCEMENT

The beams compared with 3% of longitudinal reinforcement and 1D spacing of stirrups showed that the plain beam alone can take torsion up to 33%, which with the introduction of longitudinal steel, showed a large elapse in the total torsion resisting capacity by about 81% of the torsional value. The elapse was found to be about 48%, which certainly suggest that the longitudinal bar for 3% reinforcement plays a vital role in resting the torque. With the introduction of stirrups, with 2D spacing this value was found to be about 6%, with a decrease in the spacing by 1.5D & 1D the torsion resisting capacity increased by 8% and 5% respectively.

3.8 COMPARISON WITH 4% LONGITUDINAL REINFORCEMENT

The beams tested with longitudinal and transverse steel, the concrete alone was found to resist about 30% of the torsion value, which with reinforcement of 4% resisted about 47% of its torsional capacity, with the involvement stirrups of spacing as 2D, had an increment of torsion by 9% in its total capacity and with close spacing of 1.5D & 1D, the torsional valve increased by 4.5% and 9.5% respectively.

4. CONCLUSIONS

1. Mix proportion of 1:1.57:2.48:0.44 for NSC (M40) was obtained without using mineral admixture and the average 28 day strength was found to be 39.58MPa.
2. NSC Plain beams tested in the present investigations showed ultimate failure whereas the Reinforced beams showed moderate ductile type of failure at the ultimate Torsional moments.
3. Most of the beams failed suddenly with single crack leading to several cracks at an inclination of 45º.
4. It has been found that as the percentage of longitudinal reinforcement increases, the ultimate Torsional shear stress of all the beams increased.
5. The cracking torsional moment was equal to the ultimate Torsional moment observed in the experiment.
6. As the concrete attain its full compressive strength, the reinforcement takes care of further torsional moment applied across the section, it undergoes twisting effect to certain limit and it also loses its ductility.
7. The contribution of concrete in resisting torsion for 2%, 3% and 4% respectively was found to be 37%, 33% and 30%.
8. In 2% longitudinal steel, the torsional resistance was more in the stirrups to about 49.6% of total torsional capacity.
9. The torsional resistance by 3% longitudinal steel was about 48%, whereas stirrups capacity was comparatively lower.
10. Similarly torsional resistance of 47% was found to be taken by 4% longitudinal steel.
11. As the quantity of steel was increased, transverse reinforcement from 2D spacing to 1.5D & 1D, a very minimal increase in torsional resistance was found.
12. In the case of 3% longitudinal steel, spacing of stirrups had incremental of torsional resistance

of 6% , 8% and 5% respectively for 2D, 1.5D & 1D.

13. Whereas in the case of 4% longitudinal steel, spacing of stirrups had incremental of torsional resistance of 9%, 4.5% & 9.5% respectively for 2D, 1.5D & 1D.
14. It has been observed that the Plastic Theory for plain beams predicts the value of Torsional strength much better than the other theories for the experimental beams.
15. For longitudinal Reinforced beam, it was observed that ACI code predicts the value of Torsional strength much better than the other theories and codes.

References

[1] ZDENEK P BAZANT, SIDDIK SENER, PERE C. PRAT, "*Size effect tests of torsional failure of plain and reinforced concrete beams*," Materials and Structures, V. 21, pp. 425-430.
[2] ATEF H. BAKHSH, FAISAL F WAFA, and ALI A. AKHTARUZZAMAN (Sept-Oct 1990), "*Torsional Behavior of Plain High-Strength Concrete Beams*," ACI Structural Journal, V. 87, No. 5, 1988, pp. 583-588.
[3] METIN HUSEM, ERTEKIN OZTEKIN, SELIM PUL, "*A calculation method of cracking moment for the high strength concrete beams under pure torsion",* Sadhana Vol. 36, Part 1, Volume 36, Issue 1, February 2011, pp. 1-15.
[4] I-KUANG FANG and JYH-KUN SHIAU, *"Torsional Behavior of Normal- and High-Strength Concrete Beams"* Structural Journal, 2004,volume-101, Issue-3 pp.-304-313.
[4] MOHAMMAD NAJIM MAHMOOD, "*ACI Code provisions for Torsion Design of Reinforced concrete Beams", A need for Revision,* Journal of applied science Asian Network for scientific Information vol. 7(9), 2007 pp. 1293-1298.
[5] THOMAS T C, HSU, Fellow, *Shear flow zone in torsion of reinforced concrete,* Journal of Structural Engineering vol. 116, No. 11, January 27,1988, pp. 3206-3220.
[6] SAMMAN TAMIM A., *"Effect Of Aspect Ratio On Torsional Capacity Of High-Strength Plain Concrete Deep Beams",* Engineering Journal of Qatar University, 1993, Vol. 6, Pages 115-134.