NUMERICAL AND ANALYTICAL MODELLING OF REINFORCED CONCRETE CIRCULAR COLUMNS SUBJECTED TO TORSION

Tarutal Ghosh Mondal[1] and S. Suriya Prakash[2]

[1]Graduate Student, Email: ce13m1023@iith.ac.in
[2]Corresponding Author, Assistant Professor, E-mail: suriyap@iith.ac.in
Dept. of Civil Engineering, Indian Institute of Technology Hyderabad, India.

Abstract: This paper compares the efficiency of tension stiffened softened truss model (TS-STM) and a nonlinear finite element (FE) model to predict the behaviour of reinforced concrete (RC) circular columns under torsional loading. Predictions of the models are calibrated with test data on two circular columns taken from literature. Overall torque – twist behaviour and average strain in the transverse reinforcements were parameters for comparison. It is observed that both the models predicted the overall torsional behaviour of the test specimens reasonably well. However, the peak twist and post peak behaviour were better captured by the TS-STM. Average strain in transverse reinforcements predicted by the TS-STM was also closer to the measured values compared to the FE predictions. On the whole, it can be concluded that, TS-STM performs better than nonlinear FE model in capturing the overall response of circular RC columns subjected to torsional loading.

Keywords: Circular RC columns; torsion; nonlinear finite element analysis; softened truss model.

INTRODUCTION

Reinforced concrete bridge columns are subjected to torsional loading during seismic vibration due to various reasons. Neglecting this torsional moment in the design process may lead to sudden catastrophic failure of the entire bridge structure. So, it is of primary importance to accurately predict the torsional strength of the bridge columns. However, very few studies in the past focused on the understanding of torsional behaviour of RC members from analytical or FE perspective. This study aims at filling this knowledge gap existing in this important area of research by presenting a comparative study on the efficiency of TS-STM and nonlinear FE approach in predicting the overall torsional response of circular RC columns. Predictions of the models were calibrated with experimental data on local as well as global behaviour of two circular columns tested in the University of Missouri under torsional loading. Overall torque – twist behaviour and strain in the transverse reinforcements predicted by the models were compared with experimental data. It is observed that both the models predicted the overall torsional behaviour of the test specimens reasonably well. However, the peak twist and post peak behaviour were better captured by the TS-STM. Average strain in transverse reinforcement predicted by the TS-STM was also closer to the measured values compared to the FE predictions. On the whole, it can be concluded that, TS-STM performs better than nonlinear FE model in capturing the overall response of circular RC columns subjected to torsional loading.

EXPERIMENTAL PROGRAM

Experimental data of two circular columns (H/D(3)-T/M(∞)-1.32% and H/D(6)-T/M(∞)-0.73%) (Fig. 1) tested at University of Missouri (Prakash, 2009) was used in this study for validation of the developed model. Cyclic torsional loading was generated in the tested specimen by controlling two horizontal servo-controlled hydraulic actuators. The axial compressive load was applied by a hydraulic jack on top of the load stubs.

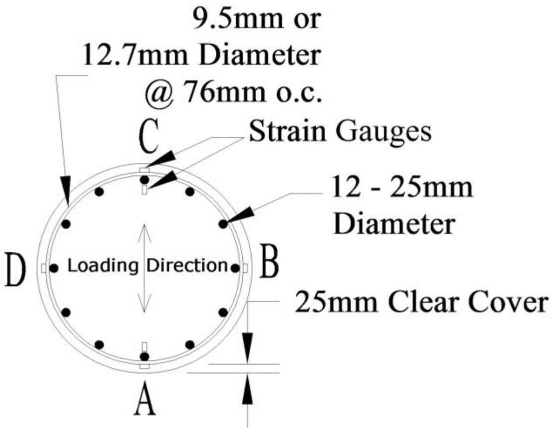


Fig. 1 Cross section of tested specimens

BRIEF DESCRIPTION OF TS-STM

Softened truss model (STM) was developed in the University of Huston (Hsu, 1968) in order to estimate the torsional response of reinforced concrete (RC) members. The model assumes that, an RC member under torsional loading behaves as a thin tube with an effective thickness (t_d) which is known as the thickness of shear flow zone. The thin tube is an assembly of membrane elements which are subjected to bi-directional state of stress. The STM is formulated based on three basics tenets of mechanics, i.e. equilibrium equations, compatibility equations and constitutive laws. Original STM was developed by ignoring the tensile capacity of concrete after cracking. However, Mondal and Prakash (2015) showed that tension stiffening significantly influence the behaviour of concrete under torsion and proposed tension stiffened (TS) STM. The same TS-STM is used in this study for analytical calculations. It adopts a displacement controlled iterative technique to calculate torque – twist behaviour of RC members.

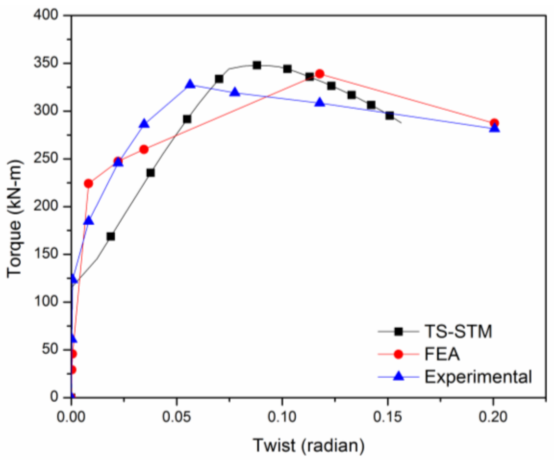
BRIEF DESCRIPTION OF THE FINITE ELEMENT MODEL

A full scale nonlinear finite element model was developed in this study using commercial finite element code ABAQUS. Damaged plasticity approach (Jankowiak and Lodygowski, 2005; SIMULIA, 2011) was used as a material model for concrete. Elastic – perfectly plastic material model for steel reinforcement. Perfect bonding was assumed in the steel – concrete interface. Bond behaviour (slip) was approximately modelled by specifying tension stiffening relationship of concrete. Explicit integration scheme was adopted owing to its numerical stability and robustness in convergence (Zimmermann, 2001). The bottom of the columns was fixed and a monotonic time dependent rotation was applied on the top in addition to a fixed axial compression. Concrete was modelled by three dimensional brick elements (C3D8R) and reinforcing bars were modelled by linear truss (T3D2) elements.

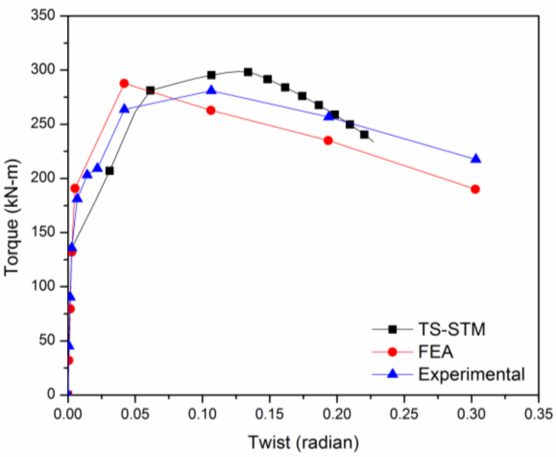
RESULTS AND DISCUSSION

Overall Torque – Twist Behaviour

Overall torque – twist behaviour of the tested columns were predicted by the developed FE model and TS-STM and were compared with experimental data as shown in Fig. 2. It can be observed that, predictions of both the models are more or less close to observed behaviour. However, Peak twist and post peak behaviour are more accurately captured by the TS-STM compared to the proposed FE model.



(a) H/D(3)-T/M(∞)-1.32%



(b) H/D(6)-T/M(∞)-0.73%)

Fig. 2 Overall torque - twist behavior

STRAIN IN REINFORCEMENT

Strain in the transverse reinforcement of specimen H/D(3)-T/M(∞)-1.32% measured during experiment is compared with predicted values as shown in Fig. 3. It was observed that, TS-STM predicted strain values are closer to the experimental data compared to FE predictions.

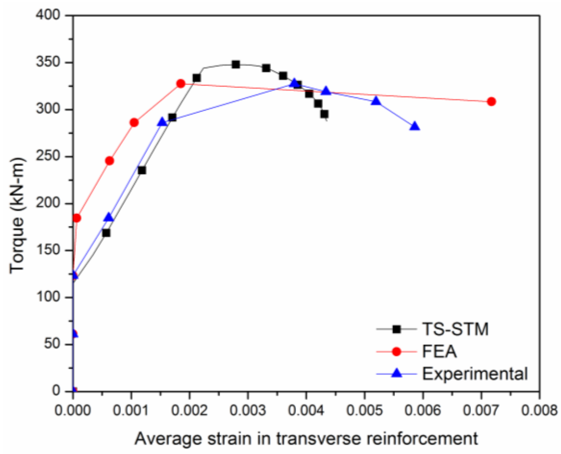


Fig. 3 Strain in transverse reinforcement

CONCLUSIONS

The FE model developed in this study efficiently predicts overall torsional response reinforced concrete circular columns including the strain in reinforcement. However, TS-STM was found to outperform the proposed FE model in regards to accuracy of prediction. Peak twist and post peak torsional response was better captured by the TS-STM. Besides, local behaviour like strain in transverse reinforcement predicted by TS-STM showed better correlation with measured values compared to FE predictions. On the whole, it may be inferred from this study that, TS-STM is relatively more accurate than the proposed FE model in predicting overall torsional response RC circular columns.

ACKNOWLEDGEMENTS

This analytical work is carried out as part of the project funded by SERB, Department of Science and Technology, India. Their financial support is gratefully acknowledged. Experimental data used in this study was carried out as a part of a project funded by NEES-NSF-NEESR, USA, the National University

Transportation Centre, and the Intelligent Systems Centre of Missouri S&T, USA. Their financial support during the PhD work of second author is also gratefully acknowledged.

REFERENCES

Abaqus Analysis User's Manual 6.11 Dassault Systèmes Simulia Corporation, Providence RI USA

Hsu T T C 1968 Torsion of Structural Concrete - Behavior of Reinforced Concrete Rectangular Members *Torsion of Structural Concrete SP-18 American Concrete Institute* Detroit MI.

Jankowiak T and Lodygowski T 2005 Identification of Parameters of Concrete Damage Plasticity Constitutive Model *Foundations of Civil and Environmental Engineering* No. 6

Mondal T G and Prakash S S 2015 Effect of Tension Stiffening on the Behavior of Reinforced Concrete Circular Columns under Torsion *Engineering Structures Journal Elsevier* 92 186-195

Prakash S S 2009 Seismic Behavior of RC Circular Columns under Combined Loading Including Torsion *PhD Thesis Department of Civil Engineering Missouri University of Science and Technology Missouri USA*

Zimmermann S 2001 Finite Elemente und ihre Anwendung auf physikalisch und geometrisch nichtlineare Probleme Report TUE-BCO 01.05. Technische Universitat Eindhoven Niederlande