EXPERIMENTAL STUDY ON THE EFFECT OF WEB OPENING LOCATION ON THE BEHAVIOR OF REINFORCED CONCRETE HYBRID DEEP T-BEAM SUBJECTED TO PURE TORSION – VARIOUS LOCATION IN VERTICAL DIRECTION

Ade Lisantono[1], M. Sahari Besari[2], Ridwan Suhud[3], Biemo W. Soemardi[4]

ABSTRACT

Three reinforced concrete hybrid deep T-beams with circular web openings were tested under pure torsion. The beams were cast of normal weight concrete (NWC) webs and light weight concrete (LWC) flanges. The opening was placed at beam mid span. The main parameter considered in this study was the location of web opening in vertical direction.

The results show that generally all beams give no significant difference in torque strength, twist capability and torsional stiffness.

Keywords : Reinforced Concrete Hybrid Deep T-Beam, Web Opening Location, Crack Pattern, Cracking Torque, Torque Strength, Twist capability and Torsional Stiffness.

INTRODUCTION

In high-rise buildings, it is often required to provide openings at different positions in a beam for ducting services. This transverse web opening may considerably weaken the torsional capacity of the beams depending on their dimensions and the opening location. The torsional capacity of such beams needs to be experimentally investigated, since data on such cases is still scarcely available. Special attention shall be directed towards phenomena taking place in the area around the openings.

Several researchers have reported their investigations on torsional deep beams. Akhtaruzzaman and Hasnat (1989) investigated the effect of torsion on rectangular normal weight plain concrete deep beams with and without opening, while Samman (1995), Samman, Radain and Al-Harbi [illegible] without opening. Although several researches have been carried out on deep beams subjected to torsion, however none has been reported on the subject of hybrid deep T-beams with openings. Moreover, the current code such as the ACI Building Code as well as the CEB Model Code have provisions for the design of deep beams subjected to flexure and shear only. No recommendation have been made for deep beams subjected to torsion.

Preliminary investigation on the effect of light weight concrete (LWC) flanges and web opening on the torsional capacity of reinforced concrete deep T-beams was reported by Lisantono et al in 2001. This research did not investigate the effect of the location of the web opening. Therefore, to obtain a clear understanding of the effect of web opening location on the torsional capacity of reinforced concrete hybrid deep T-beams, experimental investigations were recently carried out in the Laboratory of Structures and Materials of ITB.

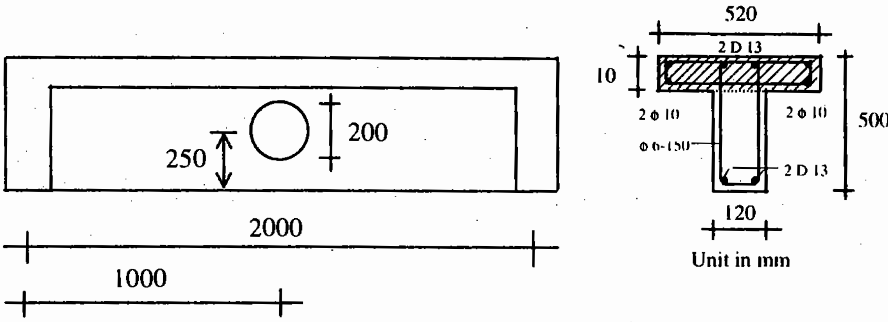
EXPERIMENTAL PROGRAM

Specimen Details

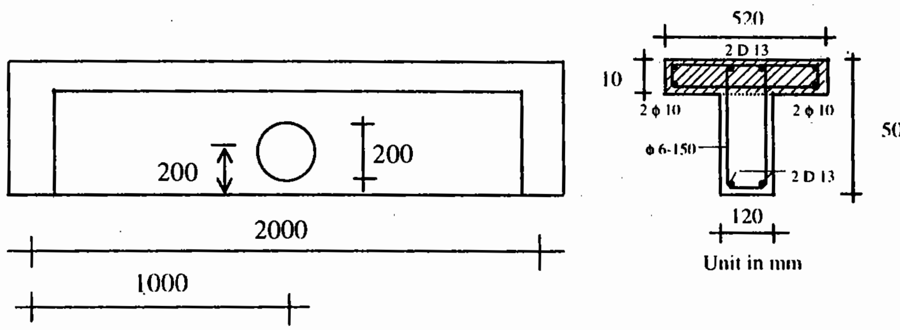
[illegible] opening of 200 mm diameter located at mid span and mid depth of the beam. The second beam, B4HOL1, and the third beam, B4HOL2, were hybrid T-beams with an opening of 200 mm diameter located at mid span with vertical eccentricities of 50 mm down and up respectively. The details of the beams are shown in Figure 1.

---

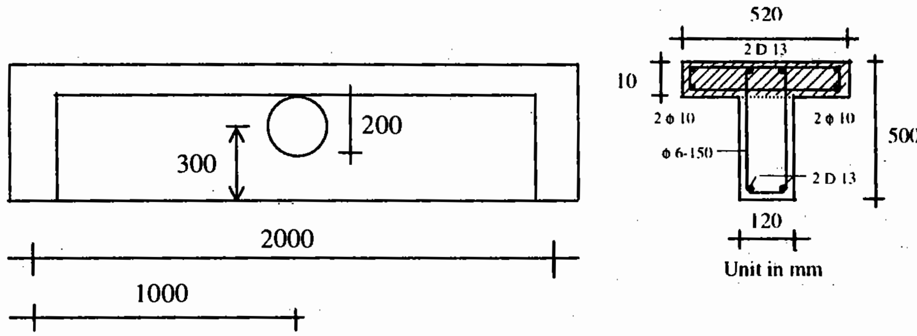
[1] Ir. Ade Lisantono, M.Eng., Research Student, Civil Engineering Dept., ITB, Bandung.
[2] Prof. Ir. M. Sahari Besari, M.Sc., Ph.D., Lecturer, Civil Engineering Dept., ITB, Bandung.
[3] Prof. DR. Ir. Ridwan Suhud, Lecturer, Civil Engineering Dept., ITB, Bandung.
[4] Ir. Biemo W. Soemardi, MSE., Ph.D., Lecturer, Civil Engineering Dept., ITB, Bandung.



(a) Specimen B4HO



(b) Specimen B4HOL1



(c) Specimen B4HOL2

Figure 1. Details of the beams

Longitudinal and transverse reinforcements were kept constant for all beams. To force failure to occur in the test zone of the beam, heavy reinforcement was provided at the end of the beams (see Figure 2).

Material Properties

The reinforcement of the beam were 4 D 13 mm and 4 ϕ 10 mm longitudinal bars having an average yield strength of 350 MPa, and ϕ 6 mm closed stirrups having an average yield strength of 260 MPa. Spacing of stirrups was 150 mm. The tested beams were cast of two kinds of concrete material. The beams had light weight concrete (LWC) flanges and normal weight concrete (NWC) webs. Locally available crushed aggregates with maximum size of 19 mm were used for NWC, while pelletized expanded clay aggregates were utilized for LWC. The first beam (B4HO), was cast out of batches different from those for the second (B4HOL1) and the third beam (B4HOL2). The properties of concretes used can be seen in the Table 1.

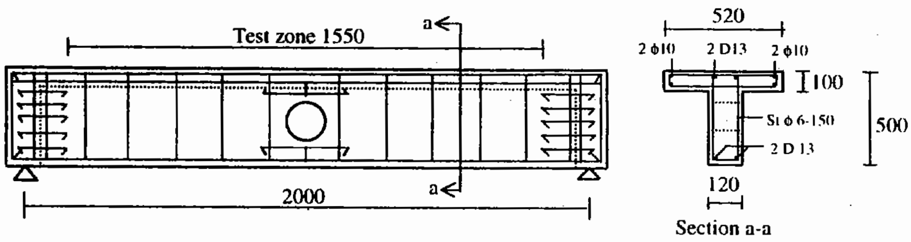


Figure 2. Test zone and reinforcement arrangement of the beam (in mm)

Table 1. The properties of concretes

Specimen	B4HO		B4HOL1 & B4HOL2	
Concrete	NWC	LWC	NWC	LWC
Density (kg/m^3)	2356.96	1721.98	2374.20	1780.65
f_c' (MPa)	35.40	40.74	35.68	40.03
f_{sp} (MPa)	3.32	2.79	3.41	2.76
E_c (GPa)	25.15	14.70	26.04	15.57
μ	0.18-0.22	0.18-0.26	0.19-0.26	0.19-0.23

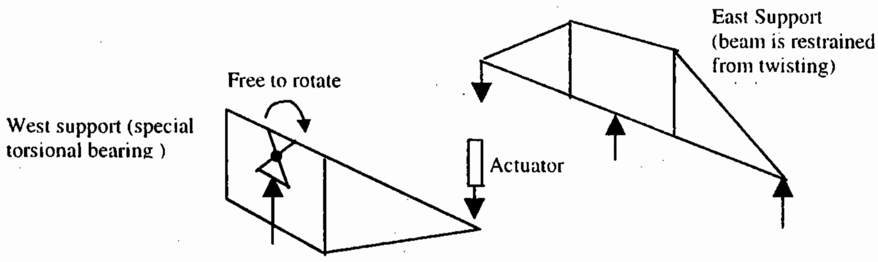
Test Setup and Instrumentation

The loading arrangement and test setup are illustrated schematically in Figure 3 (a) and (b). A 120 kN hydraulic actuator was used to apply the load at the West support. The load had an 850 mm arm from the centroidal axis of the beam. A reaction arm was used at the East support to balance the applied load by attaching the arm to the laboratory floor. The East support was restrained from twisting, while the West support was free to rotate to provide the required applied torque force. The West support was designed to properly provide the necessary twist with respect to the centroidal axis of the beam.

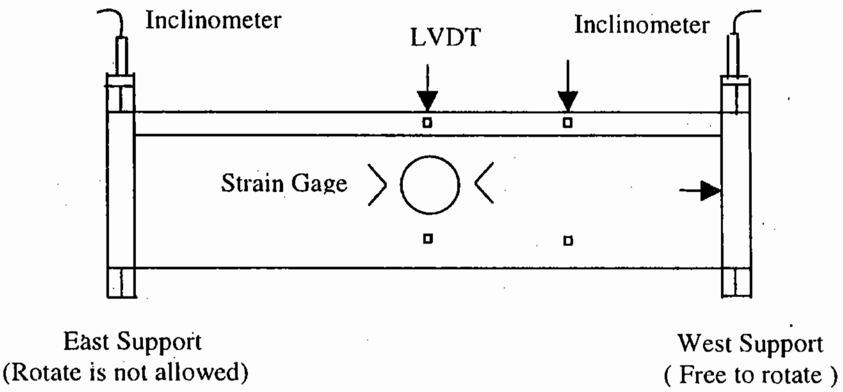
The specimens were instrumented for measurements of prevailing deflections and rotations. The deflection and rotation due to the torque force were measured using Linear Variable Differential Transformers (LVDT) and inclinometers respectively. Electrical resistance strain gages were used to measure strains in reinforcement and concrete.

Test procedure

The beams were first whitewashed and then square grid of 50 mm were drawn for easy identification of crack patterns. All beams were tested under monotonic loading, using displacement control loading at a rate of 0.02 mm/sec up to the ultimate torque, after which the rate was increased up to 0.05 mm/sec until failure. Measured data of load, deformations and strains were read through a computer driven data acquisition system. The crack propagation was marked to obtain the crack pattern of the beams.



(a) Loading arrangement



(b) Test setup of the specimen

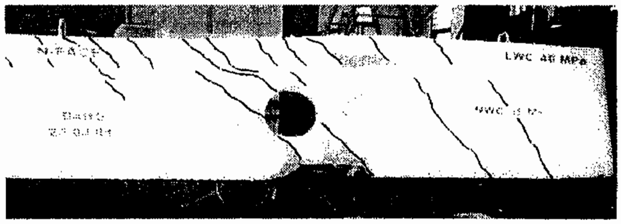
Figure 3 : Loading arrangement and test setup of the specimen

TESTS RESULTS AND DISCUSSIONS

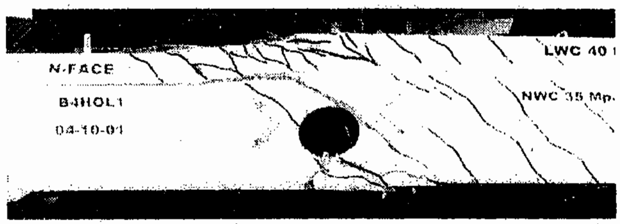
Crack Pattern

The first cracks of all specimens appeared on the North and South face, initiated at the lower right hand corner of the opening and continued with the crack to the upper left hand corner of the opening. This crack propagated upward and downward as the applied torque increased, at an angle of inclination approximately 50 deg with respect to the beam axis. The crack propagated to the flanges and continued a short distance of about 100-150 mm along the corner line of web-flange interface. More cracks parallel to the initial crack subsequently appeared as the applied torque force increased, and eventually made complete spirals of cracks until the maximum twist was reached.

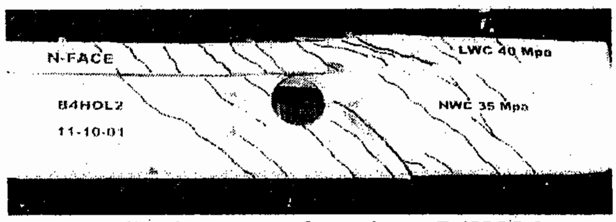
The crack patterns viewed from the sides of the tested specimens were similar in configuration as shown in Figure 4. (a), (b) & (c).



(a) Crack pattern of specimen B4HO



(b) Crack pattern of specimen B4HOL1



(c) Crack pattern of specimen B4HOL2

Figure 4 : The crack pattern of the tested specimens

Torque-twist curves

The torque-twist curves of the tested specimens are shown in Figure 5. It can be seen that the torque-twist curves are linear up to the cracking torque. After cracking, preceded by a small drop in load, the curves increased non-linearly with increasing twists up to their ultimate torque. It was observed that a small drop of load also occurred when the crack propagated a short distance along the corner line of the web-flange interface. After the ultimate torque was reached, the curve decreased non-linearly with increasing twists, and proceeded with a section of an approximately horizontal plateau, indicating a state of yielding prior to collapse.

It was also observed that in the non-linear regime, the number of cracks parallel to the initial crack increased as the twist increases, forming complete spirals of cracks until the maximum twist was reached. This phenomenon indicates that there was a redistribution of internal stresses to form a truss action where reinforcement acted as tension links and concrete acted as compression diagonals.

Torque strengths and twists

The experimental results of torque strength as well as twist at cracking and ultimate stage can be seen in Table 2. Comparing of the ultimate torque of specimen B4HO to those of specimens B4HOL1 and B4HOL2 gives ratio values of 0.94 and 1.01 respectively, while between specimen B4HOL1 and B4HOL2 gives the value of 1.07. In the same manner for twist capability until ultimate gives the value of 1.04; 1.02 and 0.98 respectively. The differences of the ultimate torque and twist capability among the specimens are small, less than 8 percent, indicating that the location of web opening in vertical direction does not significantly affect the ultimate torque and twist capability of the beams.

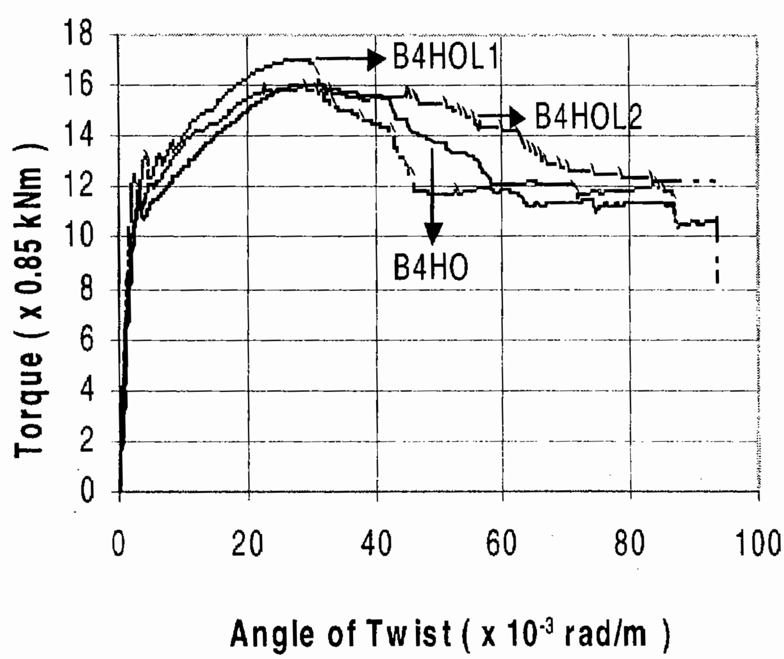


Figure 5 : The torque-twist curves of the specimen

Table 2. Experimental results

Beam	At Cracking		At Ultimate	
	Torque (x 0.85 kNm)	Twist ($x10^{-3}$rad/m)	Torque (x 0.85 kNm)	Twist ($x10^{-3}$rad/m)
B4HO	10.14	2.147	16.07	29.226
B4HOL1	11.89	2.493	17.11	27.988
B4HOL2	9.97	2.119	15.97	28.673

Torsional stiffness

The torsional stiffness can be defined as torque per unit angle of twist. By using the torque-twist curves of the tested beams, each torsional stiffness can be derived from the slope of the corresponding curve up to cracking or linear range. The torsional stiffness of specimens B4HO, B4HOL1 and B4HOL2 are 4014.44 ; 4053.95 and 3999.29 respectively (unit kNm^2/rad). It can be observed that the differences among them are less than 2 percent. This indicates also that the location of web opening in vertical direction does not affect the torsional stiffness of the beams.

Reinforcement strains

Figure 6 and figure 7 show strain of web stirrup and longitudinal bar respectively at section 850 mm from East support. The figure indicates that the reinforcement bars seem to have no effect on the torsional capacity of the beam before first cracking of concrete, so it can be said that at the linear regime the torque was mainly resisted by the concrete. This is obvious since significant strain in reinforcement bars only start immediately after the cracking of concrete. These strains continue to grow well into the yield regime of the bars together with the growth of crack widths.

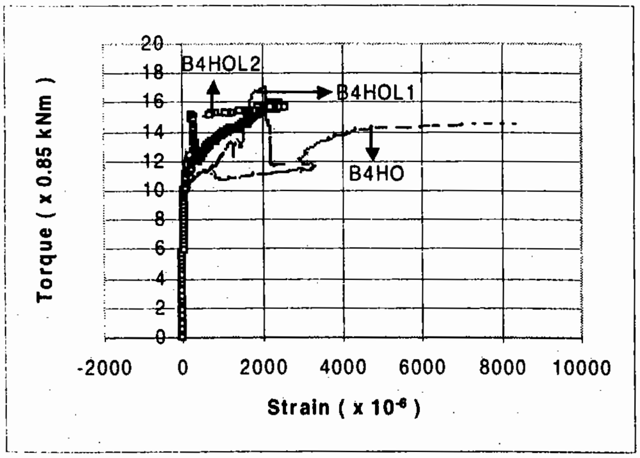


Figure 6 : Stirrup strain of the specimens

Concrete surface strain

The surface compression strains of concrete at section 850 mm from East support are shown in Figure 8. The curves indicates that the compressive stresses in concrete were initiated at low torque loads, then continued to increase beyond the cracking torque. These concrete compressive strains together with the large reinforcement tensile strains contributed to the large ductilities of the beams.

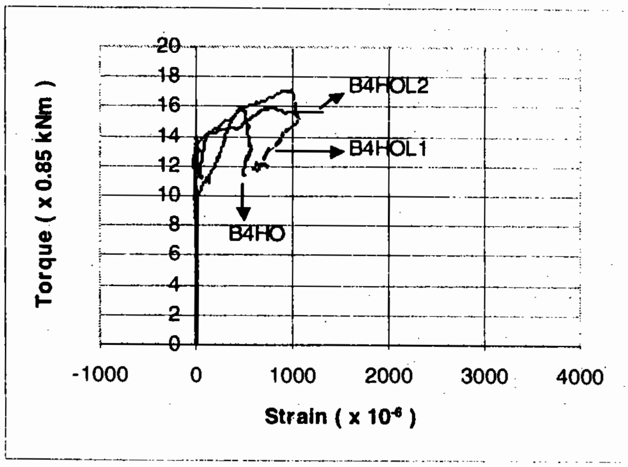


Figure 7 : Longitudinal strain of the specimens

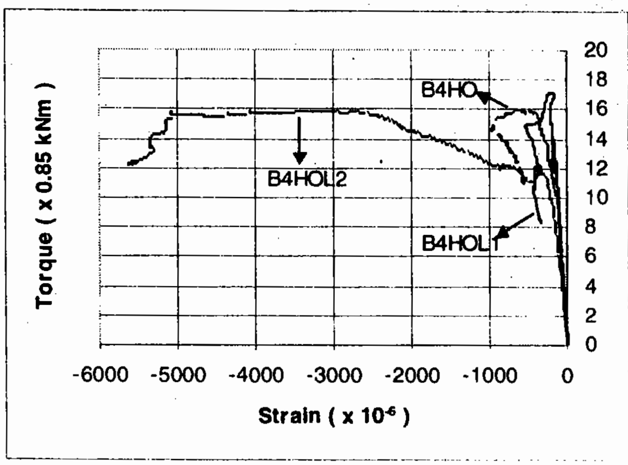


Figure 8 : Concrete surface strain of the specimens

CONCLUSIONS

Based on the obtained experimental results, the following conclusions can be drawn :

1. The crack pattern of the tested specimens have the same configuration and the crack angle of inclinations were approximately 50 degrees.
2. At lower values, the torque in hybrid T-beams with web opening was essentially linear with increasing twist up to the cracking torque, after which the torque increased non-linearly with increasing twists. Upon reaching their ultimate strengths the torque in the beams decreased non-linearly and concluded with a yield condition prior to collapse.
3. Generally the location of web opening in vertical direction does not significantly affect the torque strength, twist capability and torsional stiffness of the beams

ACKNOWLEDGMENT

The research work reported herein was made possible due to fund of Competitive Research Grant of the Directorate General of Higher Education under contract No. 096/LIT/BPPK-SDM/IV/2002. The authors gratefully acknowledge of this support. The authors also thanks to the Laboratory of Structures and Materials, Civil Engineering Department of ITB, and the Laboratory of Structural Mechanics of the Inter University Research Center of ITB for the use of their research facilities.

REFERENCES

Akhtaruzzaman, A.A., Hasnat, A. (1989). Torsion in Concrete Deep Beams with an Opening. *ACI Structural Journal.* January-February, pp. 20-25.

ACI Committee 318 (1999). Building Code Requirements for Structural Concrete and Commentary.

CEB Comite Euro-International Du Beton (1993). CEB-FIP Model Code 1990. Bulletin D'Information. 213/214.

Lisantono, A., Besari, M.S., Suhud, R., and Soemardi, B.W. (2001). The Effect of LWC Flanges and Web Opening on the Torsional Capacity of Reinforced Concrete Deep T-Beams. *Proceeding of EASEC-8*, NTU, Singapore, 5-7 December 2001. Paper No. 1349.

Samman. T.A. (1995). High-Strength Plain Concrete Deep Beams under Torsion. *Structural Engineering Review*. Vol. 7, No.2, pp. 93-105.

Samman, T.A., Radain, T.A., and Al-Harbi, M.N. (1996). Torsional Behavior of High Strength Concrete Deep Beams. *Proceeding of Fourth International Symposium on the Utilization of High Strength/High Performance Concrete*. Paris, France, pp. 1003-1008.