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Research Article

The enhancement of ultimate torsional resistance of under-reinforced fibrous, high strength concrete beams by the thickness of concrete cover

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Abstract: This research highlights the contribution of concrete cover to improve the torsional resistance of peak load of under-reinforced fibrous high-strength concrete beams. The thickness of concrete cover is the main variable which was varied from 17 mm to 53 mm in this research. To investigate the influence of thickness of concrete cover on the behavior of under-reinforced fibrous, high strength concrete beams subjected to pure torsional loading, four rectangular solid beams were cast and tested. The test results showed that the torsional resistances at peak load was improved up to 80.6%. Furthermore, all of the twisting angle, shear strain in concrete, strain in transverse reinforcement, and strain in longitudinal reinforcement were reduced at peak loads up to 70.2%, 90%, 50.6%, and 34.5%, respectively.

Keywords: Concrete cover, Fibrous high strength concrete, Steel fiber, and Spiral cracks.

INTRODUCTION

Fibrous high strength concrete is a high compressive strength concrete which is more than 41MPa with inclusion of steel fibre to enhance the ductility (C. 318. 2015). The value of brittleness index of fibrous high strength concrete is reduced due to inclusion of fibre (Rjoub, M. I., & Musmar, M. A. 2007).

In non-fibrous concrete beams, the torsional resistance at pre-cracking stage is provided by concrete. Meanwhile, the torsional resistance at post-cracking stage is provided by reinforcement only (Collins, M. P., & MP, C. 1980). In contrast, the fibrous high strength concrete beams behaved as fibrous normal strength concrete beams under pure torsional loading except higher principal tensile strength provided fibrous high strength concrete. In addition, the torsional resistance at post-cracking stage is provided by reinforcement and fibre (Fuad, O., & Sekan, E. 2012).

Even though the elements are contributed to resist torsion in non-fibrous and fibrous concrete differ only in inclusion of fibre, the thickness of concrete cover contributes to improve the torsional resistance at crack and peak loads (Karim, F. R. *et al.*, 2016). Meanwhile, the spall-off concrete cover during torsional loading is too small or non-occurrence at all in fibrous concrete in comparison with non-fibrous concrete (C. 318. 2015; & Namiq, F. 2012).

It was found that the contribution of steel reinforcement to resist torsion was reduced for under-reinforced fibrous normal strength concrete beams with large thickness of concrete cover. In fact, the contribution of fibre before and after cracking has increased (Karim, F. R. *et al.*, 2016). In contrast, for non-fibrous concrete beams, it has been found that the large concrete cover tend to spall off whereas the torsional resistance of concrete beams with small thickness of cover seems to be over-strengthened based on space truss analogy (Hsu, T. T. C., & Mo, Y. L. 1985).). Therefore, it is important to investigate the influence of concrete cover on the torsional resistance prior cracking and at post-cracking stage in under-reinforced high strength concrete beams. This paper highlights the contribution of concrete cover to resist torsion at crack and peak loads. The thickness of concrete cover in fibrous high strength concrete

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influenced directly on the strain in concrete at extreme fibre and in reinforcement. Therefore, the space truss model is not suitable to evaluate torsional resistance due to tension stiffening in reinforcement and converting the stress condition in extreme fibre of concrete from compression to tension.

MATERIALS AND METHODS

The under-reinforced fibrous high strength concrete beam (B-1-H) is the control beam. The other three beams are denoted as (C-1-H, C-2-H and C-3-H) with different thickness of cover. They were designed based on ACI-318 (C. 318. 2015). The experimental parameter is the thickness of concrete cover which was varied between 17 mm and 53 mm. Meanwhile, the span to depth ratio and aspect ratio of the section was kept constant at 5.72 and 1.22, respectively. The beam was loaded by pure torsional moment, which comes from two point loads acting at the end of the loading arms. The load was converted to pure torsional moment on the main beam. The following sections describe the materials and mix proportion used. After that, preparation of specimen before and after testing were explained.

Materials and mix proportion between ingredients

The materials were chosen based on the ACI recommendation for fibrous concrete (C. R-93. 1998; & C. R-98. 1998). Type I Portland cement (Tasek brand) was used. The quartz sand and crushed stone were used. Tap water, high range water reducer Sika VC 2199, retard-admixture Plastiment R with two size of micro steel fibre were used. The mix proportion of the ingredients used for production of fibrous high strength concrete is shown in Table 1.

Table 1. Mix proportion of UHPFRC

Materials	Quantity , kg/m^3
Cement (Type I)	511.1
Silica sand	680.55
Crushed stone	833.33
Water	207
Water reducing super-plasticizer VC2199	10.22
Retard-admixture (Plastiment-R)	2.55
Micro steel fibre A(21mmX 0.35mmΦ)	21.59
Micro steel fibre B(12mm X 0.20mmΦ)	64.76
Slump-flow, mm	190

Φ: diameter of fibre

Proportioning of Beam specimen

The dimensions of the beams were selected after designing using ACI 318 building code. The dimensions are tabulated in Table 2. The dimension of the stirrup in the main beam was kept constant with dimension of 166 mm wide and 216 mm deep. The spacing between stirrups was kept constant at 95 mm as shown in Figures 1 and 2. Reinforcement was used 4 bars 12 mm diameter as longitudinal reinforcement and rectangular stirrup with 135º standard hooks.

Table 2. Details of the beams designed based on ACI 318 [5]

Beam designation	Concrete cover, mm	Width, mm	Height, mm **	Span length, mm*
B-1-H	28	222	272	1584
C-1-H	17	206	256	1459
C-2-H	27	234	284	1599
C-3-H	53	278	328	1886

*: span to depth ratio is around 5.72 **: aspect ratio of the section is in the range of 1.22

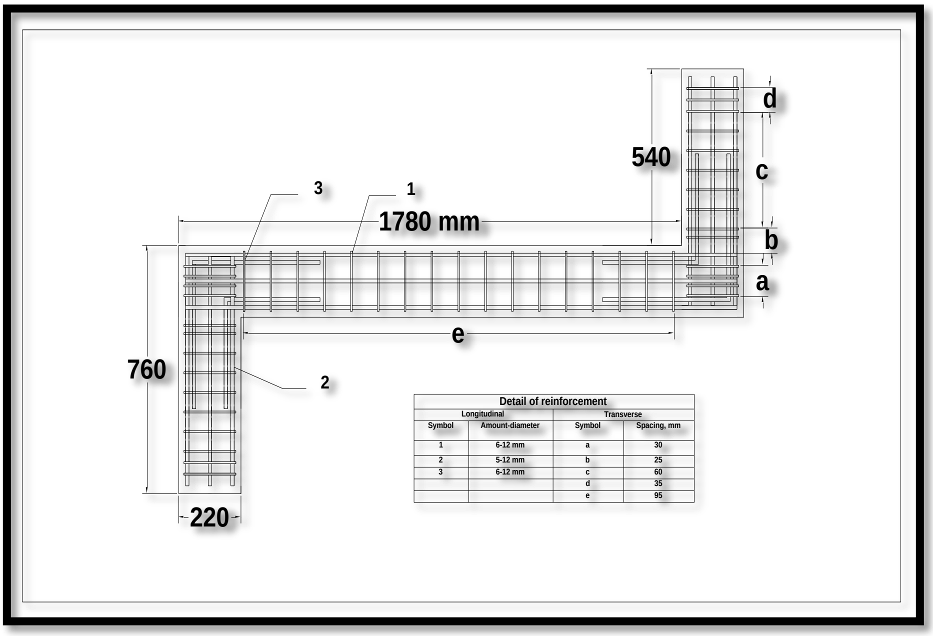

Figure 1. Detail of reinforcements in the beams

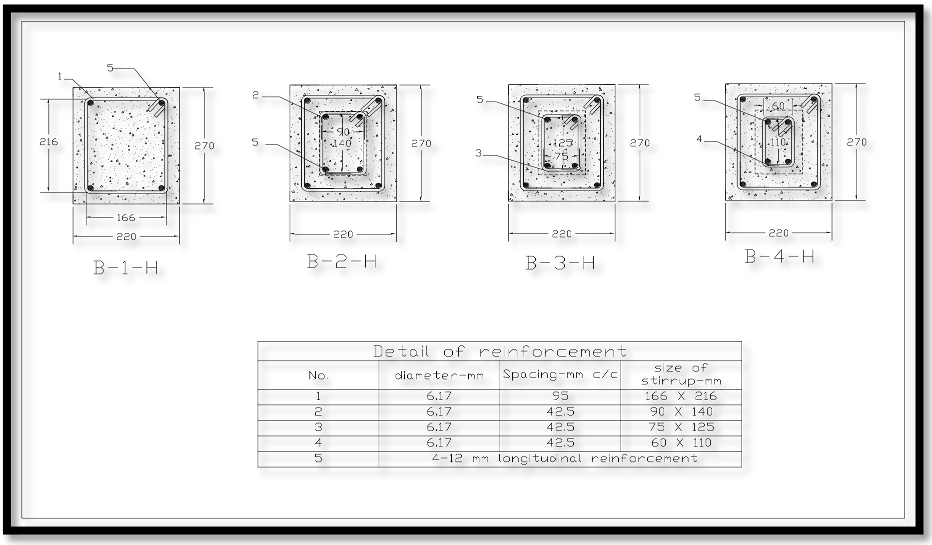

Figure 2. Details of reinforcement in the idealized core zone

Specimen preparation

For casting fibrous high strength concrete, two pan mixers 0.05 m^3 capacity were used. The sequence for adding materials in the mixer with elapse time to make uniform fibrous high strength concrete is shown in Figure 3. Fibrous high strength concrete beams were cast in the mould associated with 3 cylinders for compression test, 3 cylinders for split tension test, 3 prisms for flexural test and 6 cubes for bond test were cast together with 45 seconds vibration (ASTM-C39/C39M. 2010; ASTM-C496/C496M. 2004; ASTM-C1609/C1609M. 2010; & IS:2770. 2007).

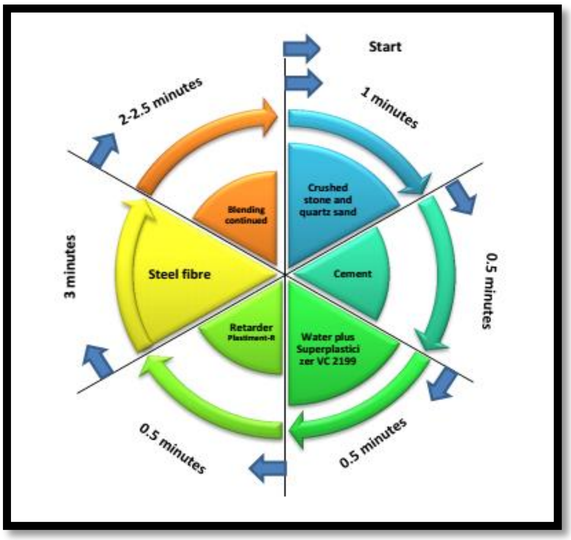

Figure 3. Schematic for mixing materials

Testing of beams

Fibrous high strength concrete beams were loaded by Universal Testing Machine of 50 tons capacity in the Heavy Structure laboratory, School of Civil Engineering in USM. The load was directly applied to the load spreader beam. The load acted at the end of loading arm producing bending moment in the joint between loading arms and the main beam was converted to the torsional moment to the main beam because of the free movement of saddle support in one direction. Thus, the main beams were tested under pure torsional moment. The set-up of loading arrangement is shown in Figures 4 and 5. The twisting angle was measured during loading at a distance 15 cm from the joint in the main beam by two LVDTs on the steel frame which was held on the body of the main beam as shown in Figure 6. The strain in the extreme fibre of concrete and the axial strain in the transverse and longitudinal reinforcements was measured by LVDTs and electrical strain gauges, respectively. The load was applied manually via hydraulic jack until the beam failed under pure torsion. The load was recorded using load cell.

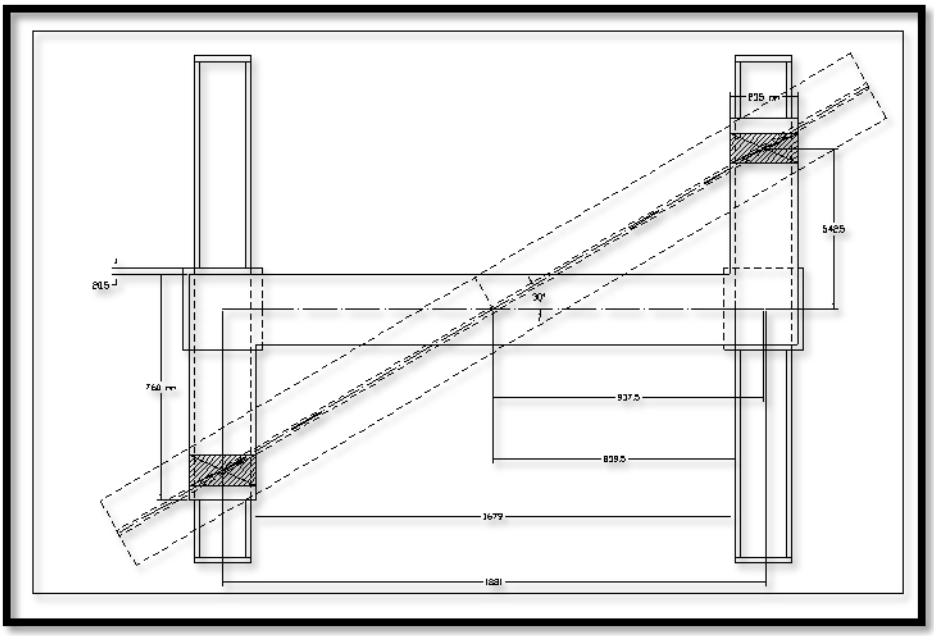

Figure 4. Schematic Test set-up

Figure 5. Experimental setup of the beam

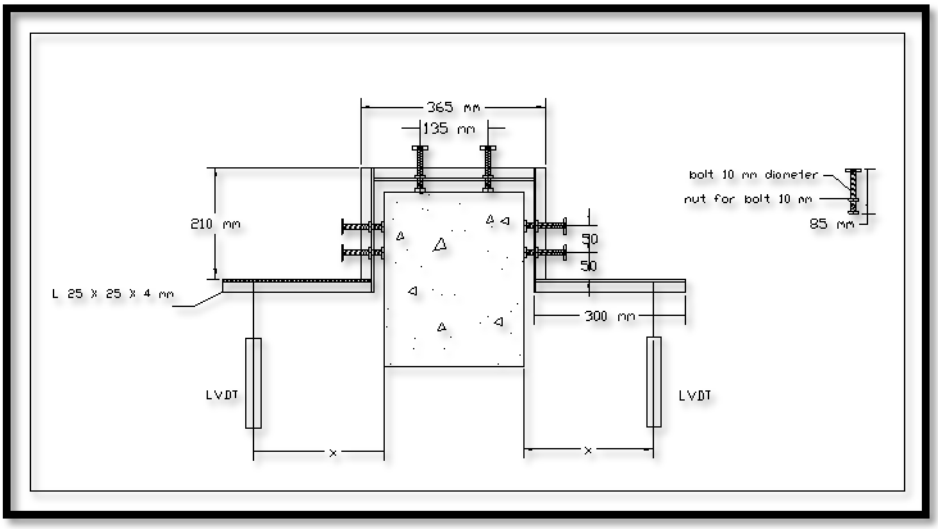

Figure 6. Schematic measuring of twisting angle

RESULTS AND DISCUSSION

The fibrous high strength concrete beams were tested under pure torsional loading. During testing, the torsional resistance and twisting angles were measured using load cell and LVDTs reading, respectively. Moreover, the angle of crack at failure was measured as shown in Table 3 and 4.

Table 3. Properties and details of the beams

Beam designation	Cylinder compressive strength, MPa	Split tensile strength, MPa	Flexural strength, MPa	Bond strength, MPa	
				Treansverse reinforcement	Longitudinal reinforcement
B-1-H	62.1	8.71	8.51	4.87	10.72
C-1-H	59.2	7.44	8.99	5.04	10.84
C-2-H	58.7	7.68	7.25	5.11	10.42
C-3-H	59.0	8.14	8.11	4.95	11.07

Table 4. Results of pure torsion test in UHPFRC beams

Beam	Torsional resistance at crack load, kN.m	Twisting angle at crack load, rad/m X 10^{-3}	Torsional resistance at peak load, kN.m	Twisting angle at peak load, rad/m X 10^{-3}
B-1-H	21.09	1.606	26.92	11.328
C-1-H	14.59	1.109	21.80	14.124
C-2-H	18.11	1.591	22.99	5.307
C-3-H	28.23	1.122	39.39	4.206

The influence of concrete cover thickness on the torsional resistance at crack and peak loads, torsional resistance provided by reinforcement and fibre, twisting angle, shear strain in concrete strut, strain in transverse and longitudinal reinforcements and details of spiral cracks is described in the following sections.

Torsional resistance before and after cracking

The torsional resistance at crack and peak loads were improved up to 93.4% and 80.6%, respectively, due to enlarge thickness of concrete cover from 28 mm to 53 mm. In contrast, the torsional resistance in crack load was marginally influenced by the compressive strength of fibrous, high strength concrete as shown in Figures 7 and 8. Meanwhile, the torsional resistance provided by reinforcement and fibres improved up to 54.9% due to enlarged thickness of concrete cover as shown in Figure 9.

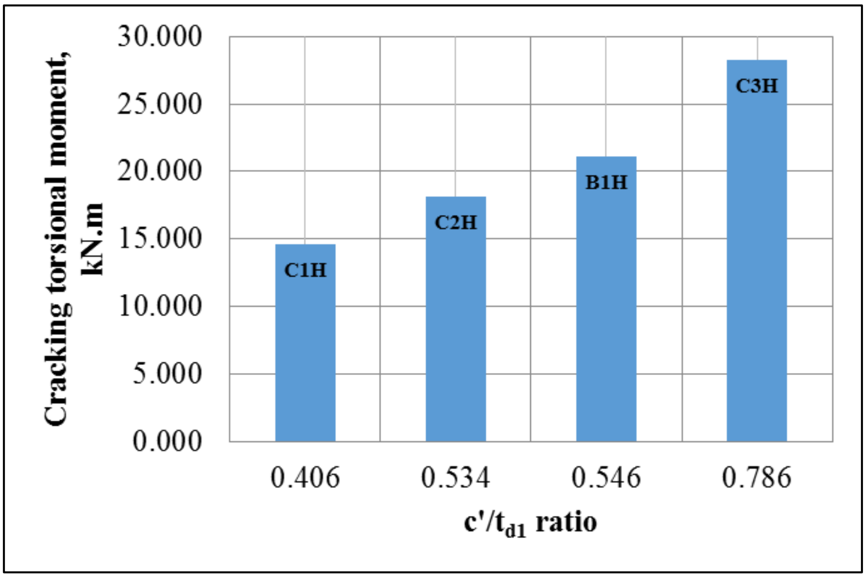

Figure 7. Effect of concrete cover on the cracking torsional resistance

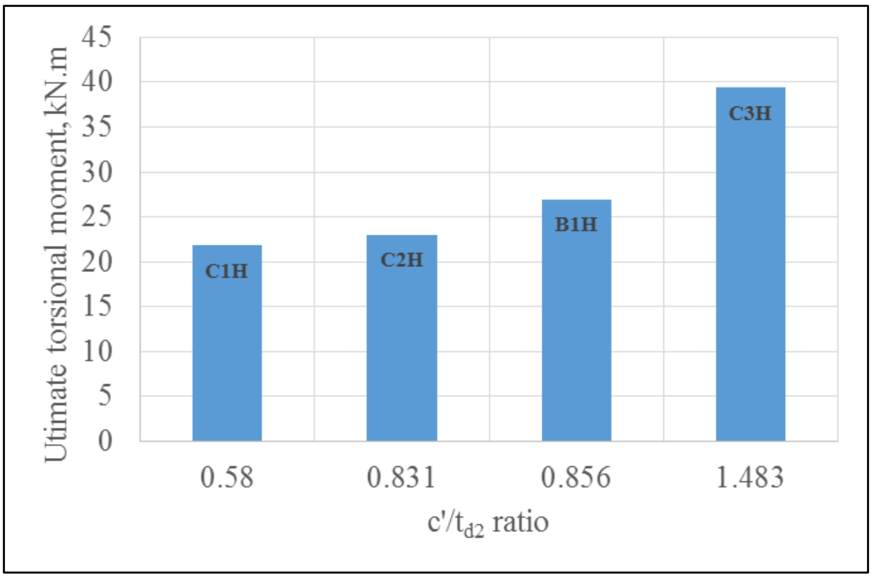

Figure 8. Effect of concrete cover on the cracking torsional resistance

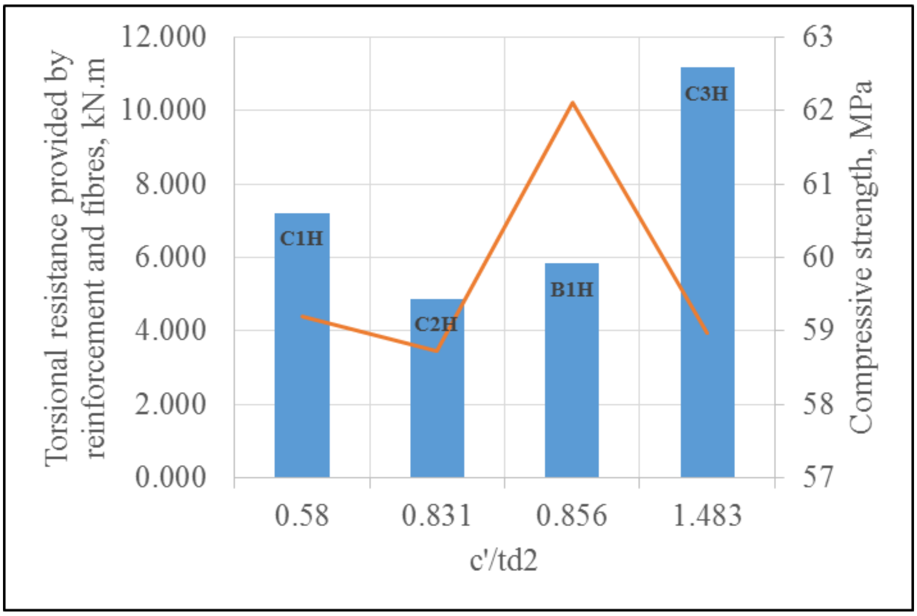

Figure 9. Effect of concrete cover on the torsional resistance provided by reinforcements and fibre

Torsional moment and twisting angle

The value of the twisting angle changed during the pure torsional test as shown in Figure 10. It was observed that the twisting angle is reduced up to 70.2% due to increase of concrete cover from 17 mm to 53 mm. In contrast, the value of twisting angle at crack load was only marginally changed even though the stiffness was improved up to 91.2% due to the factor of plasticity of the beams were kept constant at 0.5.

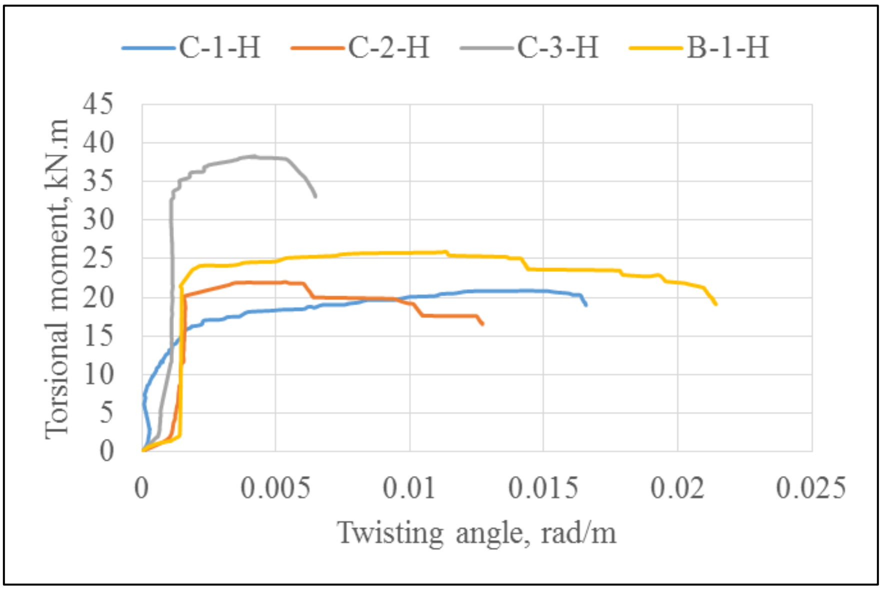

Figure 10. Torsional resistance versus twisting angle

Strain in concrete and reinforcements

The value of shear strain in concrete, strain in transverse reinforcement and strain in longitudinal reinforcement were reduced up to 90%, 50.6% and 34.5%, respectively. The change in strain of concrete and reinforcements are shown in Figures 11-13. These reduction in strains came from the effect of tension stiffening. Therefore, the contribution of reinforcement to resist torsion was reduced.

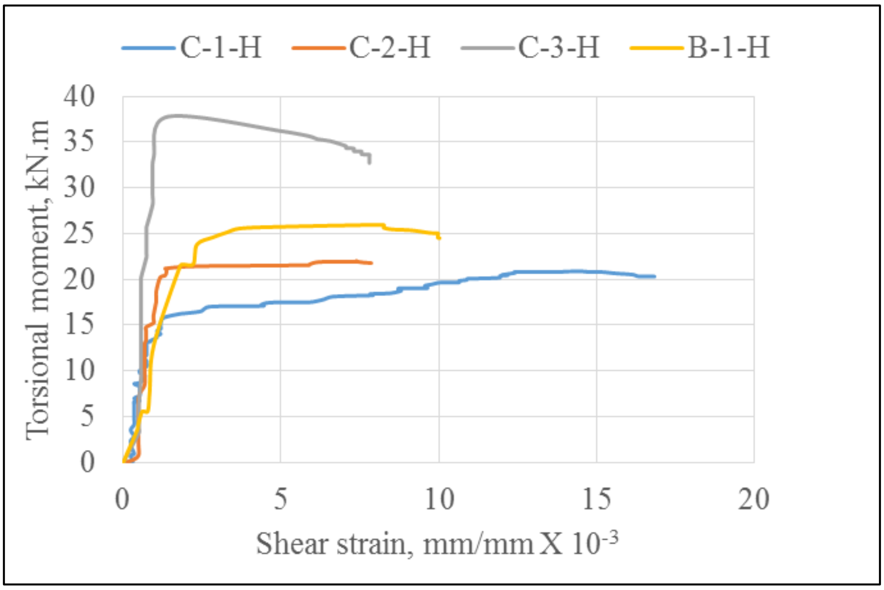

Figure 11. Torsional resistance versus shear strain in concrete

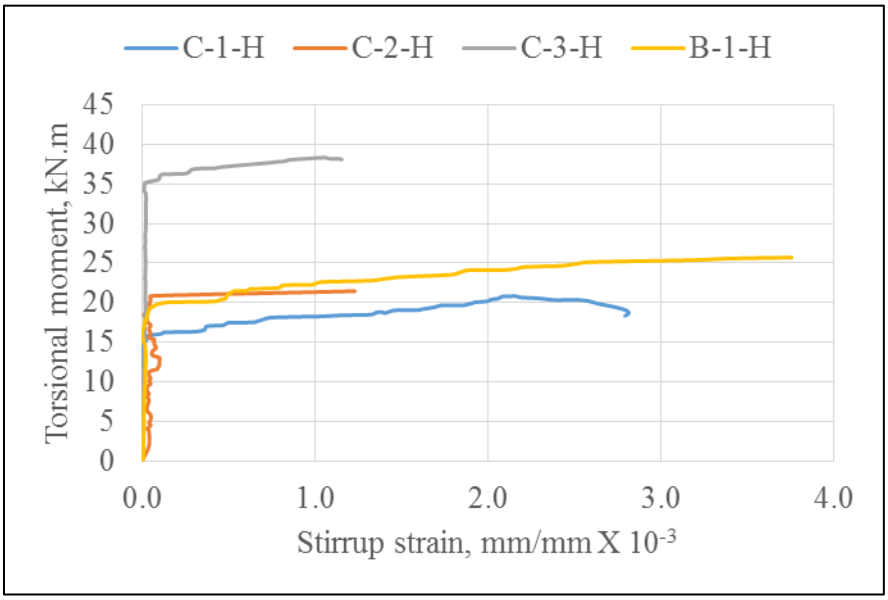

Figure 12. Torsional resistance versus strain in longitudinal reinforcement

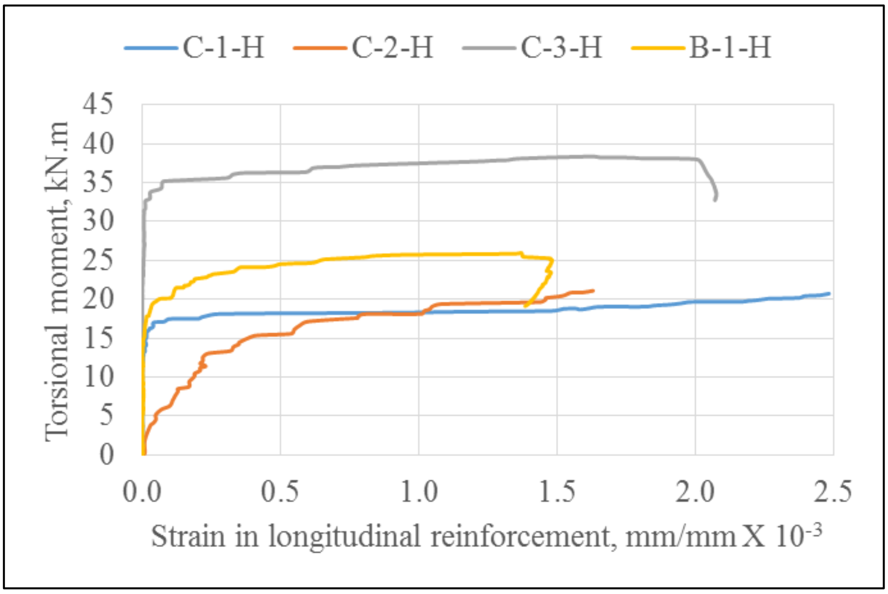

Figure 13. Torsional resistance versus strain in transverse reinforcement

The stress in the extreme fibre in concrete changed from compression to tension. Thus, the application of space truss analogy is not able to represent all of the section. The outermost part of the section worked as a hollow section under tension and the inner part was able to conduct space truss model on that part which was under compression (Karim, F. R. *et al.*, 2016).

Detail and crack patterns

The number of spiral cracks, average spacing between cracks and inclusion angle between cracks were influenced by thickness of concrete cover as shown in Table 5. It was observed that the spacing between spiral cracks increased due to widening of concrete cover. Thus, the number of cracks was reduced. The crack patterns were influenced by the thickness of concrete cover as shown in Figures 14-17. It can be seen from the figures that the thickening of concrete cover increased the possibility of producing continued spiral cracks.

Table 5. Detail of spiral cracks

Beam	No. of spiral cracks	Ɵ, degrees	Average spacing between spiral cracks, mm
B-1-H	7	46	178
C-1-H	6	49	229
C-2-H	3	47	363
C-3-H	4	43	488

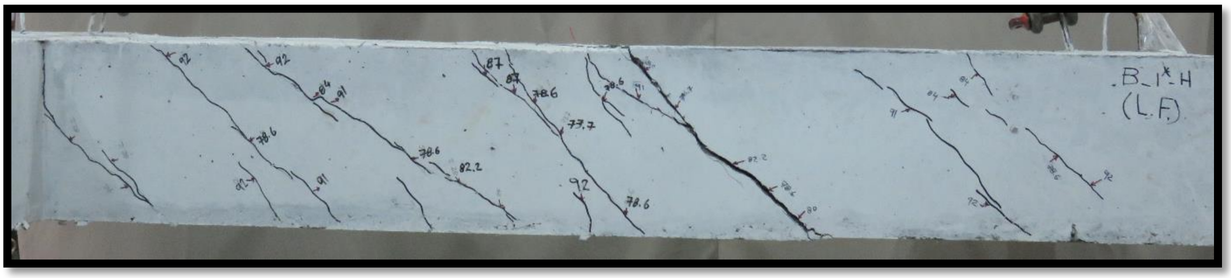

Figure 14. Crack patterns of beam B-1-H

Figure 15. Crack patterns of beam C-1-H

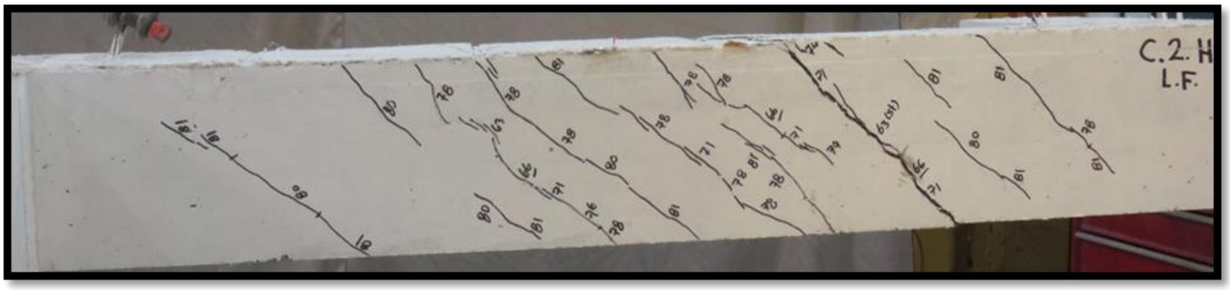

Figure 16. Crack patterns of beam C-2-H

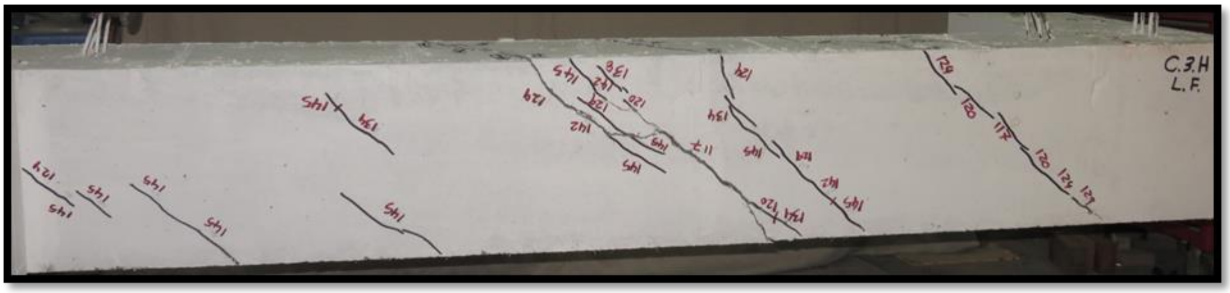

Figure 17. Crack patterns of beam C-3-H

CONCLUSION

The following points could be drawn from the results of torsional test on under-reinforced high strength fibrous concrete beams:

- The torsional resistance provided by reinforcements and fiber, and torsional resistance in crack load were improved up to 54.9% and 93.4% , respectively, due to increase thickness of concrete cover from 28 mm to 53 mm.
- The axial strain in the stirrup, axial strain in longitudinal reinforcement, shear strain in concrete and twisting angle at peak load were decreased up to 50.6%, 34.5%, 90% and 70.2%, respectively, due to the enlarged concrete cover thickness from 17 to 53 mm.
- The thick concrete cover increased the spacing between spiral cracks. Thus, it reduced the number of spiral cracks as a result.
- The larger thickness of concrete cover changed the condition of stress in the extreme fibre of concrete from compression to tension. Therefore, the space truss model is not suitable for the whole section of the beam.

Abbreviations

Symbol	Description
A_o	$=0.85*A_{oh}$
A_t	Area of one leg of stirrup, mm^2
A_L	Total area of the longitudinal reinforcement, mm^2
A_{cp}	Area of outside dimensions of cross-section, mm^2
A_{oh}	Area enclosed by stirrup dimensions, mm^2
c	Thickness of concrete cover, mm
c'	Concrete cover plus diameter of stirrup, mm
f_c'	Cylinder compressive strength, MPa
f_{ty}	Yield strength of transverse reinforcement in tension test, MPa
f_{Ly}	Yield strength of longitudinal reinforcement in tension test, MPa
P_{cp}	Perimeter of concrete cross section, mm
P_h	Perimeter of stirrup, mm
s	Spacing between stirrups, mm
V_f	Volume fraction of fibre
t_{d1}	Thickness of idealized shear flow zone prior to cracking based on European Standard , mm

$$t_{d1} = \frac{A_{cp}}{P_{cp}}$$

t_{d2}	Thickness of idealized shear flow zone after cracking based on ACI-318, mm $$t_{d2} = \frac{A_o}{P_h}$$
T_{cr}	Torsional resistance provided by concrete, kN.m
T_u	Torsional resistance at peak load, kN.m
T_{sf}	Torsional resistance provided by reinforcements and fibre, kN.m
ϴ	Inclination angle of crack at failure, degree
λ	Aspect ratio of fibre

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REFERENCES

1. C. 318. (2015). "Torsional strength," in *Building Code Requirements for Structural Concrete (ACI 318M-14) and Commentary (ACI 318RM-14)*, ed USA: American Concrete Institute, pp. 371-378.
2. Rjoub, M. I., & Musmar, M. A. (2007). "Toirsional strength of steel fiber reinforced concrete," *Journal of Engineering Sciences, Assiut University*, 35, pp. 1-7.
3. Collins, M. P., & MP, C. (1980)."Shear and Torsion Design of Prestressed and Non-Prestressed Concrete beams," *PCI Journal*, 25, pp. 32-100.
4. Fuad, O., & Sekan, E. (2012). "Torsional behavior of steel fiber reinforced concrete beams," *Construction and Building Materials Journal*, 28, pp. 269-275.
5. Karim, F. R., BH, A. B., Kok Keong, C., & Aziz, O. Q. (2016). Enhancement of torsional resistance in fibrous normal strength concrete beams. *International Journal of Research in Engineering and Technology*, 123-32.
6. Namiq, F. (2012). "Effect of steel fibre on the strength and behavior of non-circularsolid and hollow cross section beams under pure torsion," M.Sc., Civil Engineering Department, University of Salahaddin, Erbil, Iraq.
7. Hsu, T. T. C., & Mo, Y. L. (1985). "Softening of concrete in torsional members-design recommendations," *ACI Journal*, vol. 82, pp. 443-452.
8. C. R-93. (1998). "Guide for specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete," *American Concrete Institute*, 544.3R.
9. C. R-98. (1998). "Guide to Quality Control and Testing of High Strength Concrete," *American Concrete Institute*, 363.2R.
10. ASTM-C39/C39M. (2010). "Standard Test Method for Compressive Strength of Cylinderical Specimens," *Annual book of ASTM standard*, 4.02, pp. 23-29.
11. ASTM-C496/C496M. (2004). "Standard Test Method for Splitting Tensile Strength of Cylinderical Concrete Specimens," *Annual book of ASTM standard*, 4.02, pp. 299-303.
12. ASTM-C1609/C1609M. (2010). "Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading," *Annual book of ASTM standard*, vol. 4.02, pp. 846-854, 2010.
13. IS:2770. (2007). "Methods of Testing Bond in reinforced concrete: Pull-out test," *Bureau of Indian Standards*, vol. 2770, pp. 1-10.
14. Bridgman, W.P. (2012). *Dimensional Analysis*. London: Yale University press.
15. Palmer, C. (2008). *Dimensional Analysis and Intelligent Experimentation*. Singapore: Fuisland Offset Printing (S) Pte Ltd.
16. TD, G. R., & Warnitchai, P. (2010). Effect of Steel Fibers on the Behavior of Over-Reinforced Beams Subjected to Pure Torsion. *Civil Engineering Dimension*, *12*(1), 44-51.
17. Rao, T. G., & Seshu, D. R. (2005). Analytical model for the torsional response of steel fiber reinforced concrete members under pure torsion. *Cement and Concrete Composites*, *27*(4), 493-501.
18. Narayanan, R., & Kareem-Palanjian, A. S. (1986). Torsion in beams reinforced with bars and fibers. *Journal of Structural Engineering*, *112*(1), 53-66.