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The Effects of Filling the Rectangular Hollow Steel Tube Beam with Concrete: An Experimental Case Study

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Abstract

In order to understand further the influence of using the concrete-filled steel tube (CFST) composite beams in the modern structural projects, the flexural and energy absorption capacities of simply supported rectangular hollow steel tube (HST) beams filled with normal concrete was investigated in this study. Eight downscale specimens (HST and CFST beams) were tested experimentally under static four-point bending, where these beams have varied tube section classifications (Class 1 and 3) and lengths. Generally, the results confirmed that both of the moment and the energy absorption capacities of hollow steel tube beams were significantly improved when filled with concrete, specifically for those with section Class 3. However, this improvement ratio reduced gradually with increasing of tube's thickness (Class 1) and/or beam's length.

Keywords: CFST beam ;HST beam ;Flexural improvement ;Energy absorption;

1. Introduction

Recently, in the modern structural projects, fill the hollow steel tube (HST) member with normal concrete in order to improve its loading, ductility and energy absorption capacities are commonly used, where this composite system usually known as a concrete filled steel tube (CFST) member. To date, several studies are extensively investigated the compression behaviour of these composite members, where the researchers examined the performance of CFST members under pure axial and/or axial-bending loading, for example, such studies are presented in [1-6]. In general, studying the performance of CFST members under pure flexural loading still limited compared to those under axial loading [7-10]. In addition, some studies are examined the validity of using lightweight and/or

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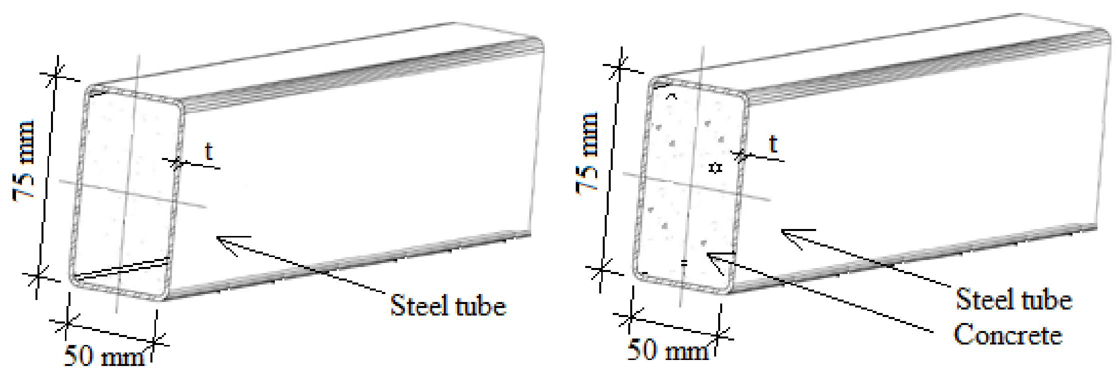
recycled concrete materials in the CFST beams [11-13]. For example, in 2002, Nakamura et al. [7] adopted the circular steel tube sections in-filled with light and normal concrete as a main girders in construction of the railway bridge in Japan. This in-filling steel tube with concrete technique significantly delayed the wall local buckling of the steel tube (that occurs in the high-compression zones). Logically, the I-beam girder is lighter than the CFST girder, but the conventional I-beams require additional welding works for their parts (webs, stiffeners and flanges). However, several parameters that expected majorly affected on the performance of the CFST beams are still needs further investigations, such as the effects of tube's cross-section shapes and classifications (thickness), the lengths of beam, and the loading types (cyclic, impact, thermal, etc.). Therefore, specifically the main objective in the current study is to investigate the effects of tube's sections classification and the beam's length on the behaviour of CFST beams. Eight rectangular HST specimens with two different sections' classifications (Class 1and 3, as per Eurocode 3-2002), four of these specimens were filled with low concrete strength. All specimens were tested experimentally under four-point bending in the structural laboratory of Universiti Kebangsaan Malaysia (UKM).

2. Experimental Program

2.1. General Description

Eight of simply supported rectangular HST specimens were tested under static four-point bending; including four specimens filled with normal concrete, as shown in Fig. 1. Four tubes with total length equal to 1,100 mm and another four with 800 mm in length. Steel tubes with depth (D) equal to 75 mm and width (W) of 50 mm were used, but with two different thicknesses (3.0 mm and 1.5 mm) which are classified as Class 1 and 3, respectively. Specifically, for each tube's length, two specimens were tested as a HST beams, and another two as CFST beams, those have varied section classification (Class 1 and 3), as presented in Table 1. The numbering system for the tested specimens indicated their type, tube's section class, and the CFRP layers. The letters 'HT' and 'FT' are represents the HST and CFST specimens, respectively, and the letters 'C1' and 'C3' are represents the tube's section of Class 1 and Class 3, respectively. The last letters '720' and '1020' are indicated the effective beam's length (support-to-support distance).



(a) HT specimen (b) FT specimen

Fig. 1 The HT and FT specimens cross-section

Table 1. Rectangular HT and FT specimens' designations, parameters and flexural capacities

No.	Specimens designation	Beam's type	Tube section classification	Effective length Le (mm)	Le/D	M_u (kN.m)	LIR	EA (kN.mm)
1	HT-C1-720	Hollow steel tube	Class1	720	9.6	4.3	-	113.7
2	FT-C1-720	Concrete-filled steel tube	Class1	720	9.6	5.7	1.34	166.1
3	HT-C3-720	Hollow steel tube	Class3	720	9.6	1.6	-	37.8
4	FT-C3-720	Concrete-filled steel tube	Class3	720	9.6	3.2	2.00	102.3
5	HT-C1-1020	Hollow steel tube	Class1	1020	13.6	3.5	-	103.6
6	FT-C1-1020	Concrete-filled steel tube	Class1	1020	13.6	4.0	1.14	117.5
7	HT-C3-1020	Hollow steel tube	Class3	1020	13.6	1.3	-	32.4
8	FT-C3-1020	Concrete-filled steel tube	Class3	1020	13.6	1.8	1.38	84.2

2.2. Specimens Preparations and Test Setup

Only 4 hollow steel tube specimens from the total 8 were placed upright to pour the concrete from top side, specifically 2 specimens with 800 mm length (Class 1 and 3), and another 2 specimens with 1100 mm length (Class 1 and 3), as shown in Fig. 2. The bottom side of each tube was covered temporarily with a plastic sheet to prevent the water of the concrete from leaking out during the casting time. The steel yielding strength and modulus of elasticity of the hollow steel tubes are equal to 352.3 MPa and 203.8 GPa, respectively, as per the test certificate given by the steel tubes supplier. Normal concrete with low strength was used in this study as a filler material for the CFST beams, where the mixing ratio was equal to 1:3:6 by weight and a 0.47 water/cement ratio. The average compressive strength was equal to 20.1 MPa that obtained from the results of three cubes tested at 28 days. In general, to achieve the four-point bending, a manual hydraulic jack with a capacity of 300 kN was used, where gradually increased the loads with average rate of about 4 kN/minutes. Three linear variable displacement transducers (LVDTs) were placed equally under the specimens to record the deflection values during the loading stages. Fig. 3 presents the test rig system. At each loading step of the tested specimens, the data obtained from the LVDTs and load cell was recorded in a computerised data acquisition system.

3. Test Results and Discussion

3.1. Failure Modes

The failure modes of CFST beams are different from the HST beams. Before the HST beams achieving their ultimate capacities, first the top flange was inward buckled (at the loading points), immediately after that their web was outward buckled. However, the infill concrete significantly delayed the inward local buckling of tubes at the compression zones, even for those with less tube's thickness (sections Class 3). Thus, using the same tube sections with concrete infill (FT-C1-720/1020 and FT-C3-720/1020 beams) shows limited outward buckling at the top flange and web once these beams reached their ultimate capacities, as shown in Fig. 4 for the beams

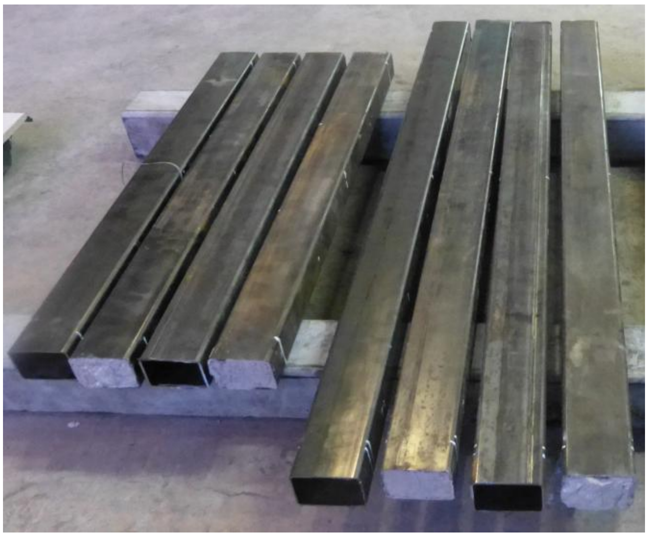


Fig. 2 Specimens before test

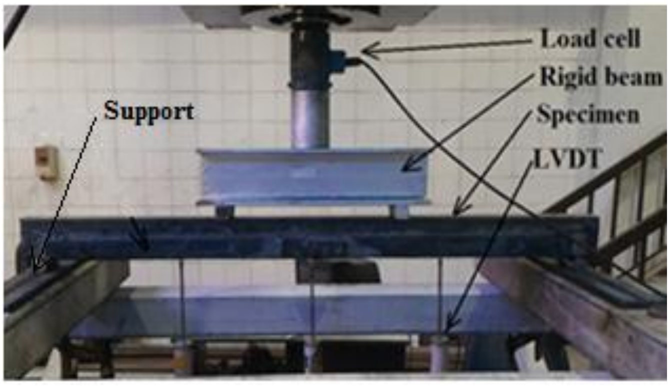


Fig. 3 Test setup of HST and CFST specimens

with Class 3 as example. Generally, the HST specimen with Class 3 (HT-C3-720/1020) showed more buckling failure than those with Class 1 (HT-C1-720/1020), and this is logic behaviour since it has thinner tube's thickness. Furthermore, unlike the HST specimens, ripple outward buckling at the top flange (between the two loading points) were observed for the filled specimen FT-C3-1020 (see Fig. 4, as example). No slip failure was recorded between the concrete and tube at the beams' ends during the loading stages.

3.2. Moment-Deflection Relationships

The relationships between the moment and mid-span deflection of the tested specimens are shown in Fig. 5. All tested beams shows an elastic behaviour at the initial loading stage, then at the inelastic stage their flexural stiffness decreased continuously until reached the moment capacity (M_u). In general, regardless the class level of steel tubes' sections (Class 1 or Class 3), the CFST specimens achieved higher moment capacities than the related HST beams. Figure 5 also show that, the loading curves of

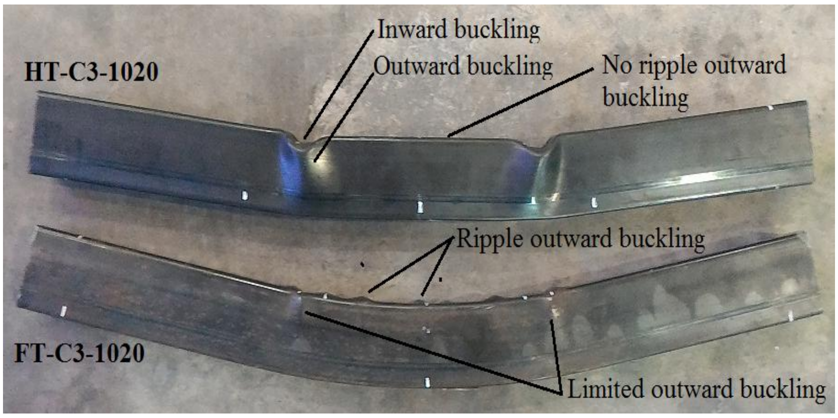


Fig. 4 Compression between the failure modes of HST and CFST specimens – Class 3

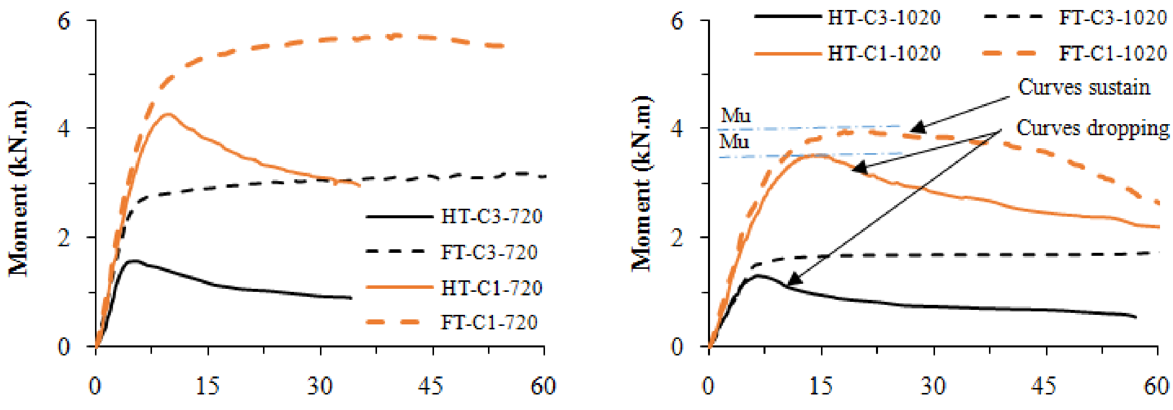
the HST beams are dropped immediately after passing their M_u values (at deflection limit slightly higher than that related to M_u value). Meanwhile the curves of CFST beams sustain almost constant for higher deflection limit even after passing their M_u values.This improvement in the loading curve's behaviour was occurred due to the effects of infill concrete, because of that, the CFST beams usually achieved higher ductility index than the related HST beams, specifically for tubes with Class 3 than those with Class 1 (thicker tube's section).

3.3. Moment Carrying Capacity

The ultimate movement capacity (M_u) of the tested specimens are presented in Fig. 6. In addition, Table 1 presents the load's improvement ratio (LIR), which measured from the ratio of M_u value of the filled beam (CFST)-to- M_u value of the related HST beam. In general, from this figure and table, obviously can see that the infill concrete improved the load's capacity of hollow steel tube beam, where the CFST beams with section Class 3 achieved higher LIR values than those with Class 1. However, this load's improvement value reduced gradually with increasing of beam's length. For example, the HST specimen with section Class 1 and effective length of 720 mm (HT-C1-720) achieved M_u value equal to 4.3 kN.m, this value increased of about +34% (LIR= 1.34) when filled with concrete material (5.7 kN.m for specimen FT-C1-720). This LIR value increase further to achieve 2.00 (+100%) for the same specimens' length but with section Class 3 (the ratio of M_u values of specimens HT-C3-720 –to- FT-C3-720). For the specimens with longer effective length (Le= 1020 mm), the specimen HT-C1-1020 achieved M_u value equal to 3.5 kN.m, which increased about +13% when filled with concrete (4.0 kN.m for specimen FT-C1-1020), again this load's improvement ratio increased further (1.38) for the thinner tube's thickness (section Class 3). In another words, to highlight the effects of beam's length, the specimen FT-C3-720 achieved LIR value equal to 2.00 (+100%) compared to the related hollow steel tube beam (HT-C3-720), this LIR value reduced to 1.38 (+38%) compared to the related hollow steel tube beam, when only the beam's length ratio (Le/D) increased from 9.6 to 13.6.

3.4. Energy Absorption

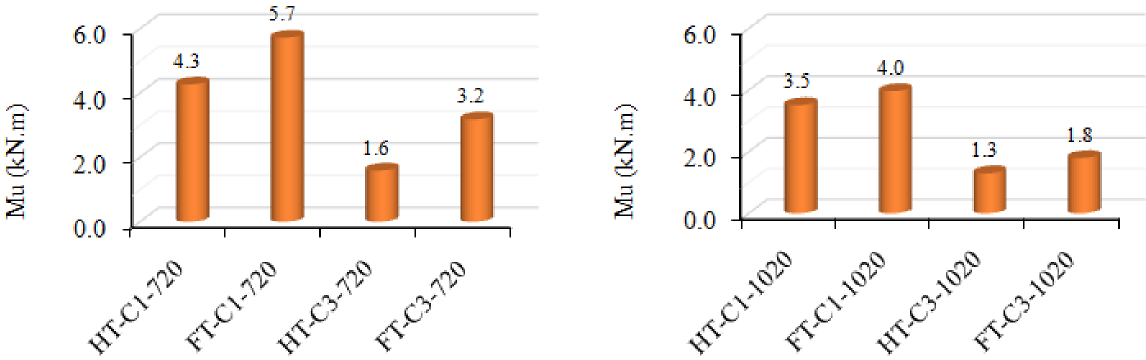
This section discussed the energy absorption (EA) capacity of the HST with/without infill concrete. The EA value estimated from the areas under the load-deflection curve, which estimated up to deflection limit equal to 35 mm. Table 1 and Fig. 7 are presents the values of EA capacities for the tested specimens. The infill concrete significantly improved the EA capacities of the hollow steel tube beams since it is increased their load's capacity and ductility behaviour (directly increase the area under the loading curves). Specifically, the EA capacity of the HST beam with section Class 3 improved much more



(a) Specimens with Le = 720 mm

(b) Specimens with Le =1020 mm

Fig. 5 Moment-deflection relationships of the tested specimens

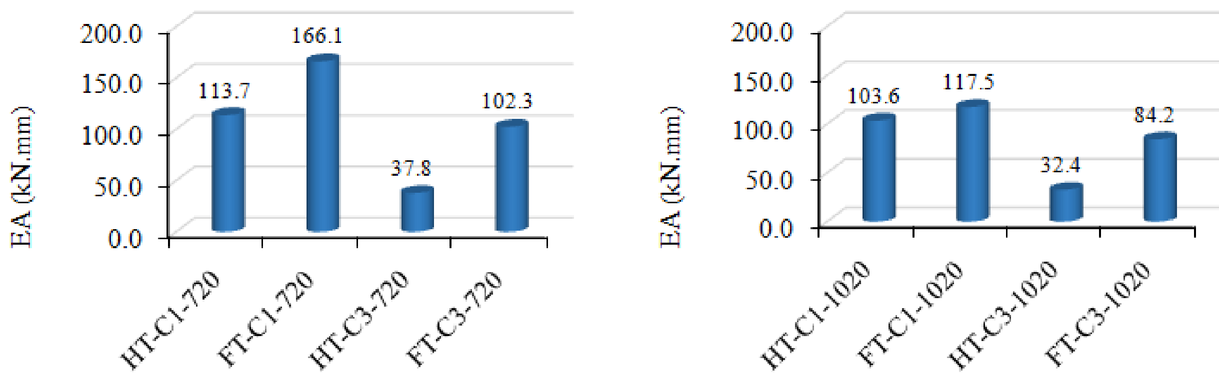


(a) Specimens with Le =720 mm

(b) Specimens with Le =1020 mm

Fig. 6. The M_u values of the tested specimens

than that with Class 1 when filled with normal concrete. However, again this capacity improvements reduced when the beam's length increase. For example, the specimen HT-C1-720 recorded an EA capacity equal to 113.7 kN.mm, this value increased of about 1.47 times when the same tube beam filled with concrete, which is 166.1 kN.mm for specimen FT-C1-720. For the same HST beams' length but with tube section Class 3, the EA capacity increased from 37.8 kN.mm to 102.3 kN.mm for specimens HT-C3-720 and FT-C3-720, respectively, achieving an improvement equal to 2.71. However, these EA improvement values (1.47 and 2.71) reduced to 1.13 and 2.6 times, respectively, when only the beam's effective length increased to 1020 mm.



(a) Specimens with 720 mm Le

(b) Specimens with 1020 mm Le

Fig. 7 Energy absorption (EA) capacity.

4. Conclusions

The conclusions of the study are summarised as follows:

- In general, the infill concrete significantly delayed the inward local buckling of hollow steel tube beams at the compression loading zones. Thus, the moment carrying capacity and the ductility behaviour of the HST beams improved obviously when filled with normal concrete, specifically for the tubes with sections Class 3 much more than those with section Class 1 (thicker thickness). However, this load's improvement ratio decreased gradually with increasing of beam's length. For example, the HST specimen with section Class 1 achieved load's improvement equal to 1.34 (+34%) when filled with concrete, this value increase up to 2.00 (+100%) for the same specimens but with section Class 3.
- The HST beams can absorb more energy when filled with concrete, but this improvement reduced with increasing of tube's thickness and/or length. For example, the energy absorption (EA) capacity of HST specimen with Class 1 increase of about 1.47 times when filled with concrete, this EA improvement increased up to 2.71 for the same specimen's length but with tube section Class 3. These improvement values (1.47 and 2.71) reduced to 1.13 and 2.6 times when the specimen's length ratio (Le/D) increased from 9.6 to 13.6, respectively.

References

[1] L.H. Han, G.H. Yao, X.L. Zhao, Behavior and calculation on concrete-filled steel CHS (circular hollow section) beam-columns, Steel and Composite Structures, 4 (2004) 169-188.

[2] D. Liu, Behaviour of eccentrically loaded high-strength rectangular concrete-filled steel tubular columns, Journal of Constructional Steel Research, 62 (2006) 839-846.

[3] A. Bahrami, W.H.W. Badaruzzaman, S.A. Osman, Structural Behaviour of Tapered Concrete-Filled Steel Composite (TCFSC) Columns Subjected to Eccentric Loading, COMPUTERS AND CONCRETE, 9 (2012) 403-426.

[4] A. Bahrami, W.H. Wan Badaruzzaman, S.A. Osman, Investigation of Concrete-Filled Steel Composite (CFSC) Stub Columns with Bar Stiffeners, Journal of Civil Engineering and Management, 19 (2013) 433-446.

[5] S.J. Hilo, W.W. Badaruzzaman, S. Osman, A.W. Al-Zand, Structural behavior of composite wall systems strengthened with embedded cold-formed steel tube, Thin-Walled Structures, 98 (2016) 607-616.

[6] K. Bagherinejad, E. Hosseinpour, S.H. Hosseini, Evaluation of Rectangular Concrete-Filled Steel-Hollow Section Beam-Columns, Journal of Asian Scientific Research, 5 (2015) 46.

[7] S.-i. Nakamura, Y. Momiyama, T. Hosaka, K. Homma, New technologies of steel/concrete composite bridges, Journal of Constructional Steel Research, 58 (2002) 99-130.

[8] L.-H. Han, Flexural Behaviour of Concrete-Filled Steel Tubes, Journal of Constructional Steel Research, 60 (2004) 313-337.

[9] L.-H. Han, H. Lu, G.-H. Yao, F.-Y. Liao, Further study on the flexural behaviour of concrete-filled steel tubes, Journal of Constructional Steel Research, 62 (2006) 554-565.

[10] J.-Y. Kang, E.-S. Choi, W.-J. Chin, J.-W. Lee, Flexural behavior of concrete-filled steel tube members and its application, International Journal of Steel Structures, 7 (2007) 319-324.

[11] Y.-F. Yang, G.-L. Ma, Experimental behaviour of recycled aggregate concrete filled stainless steel tube stub columns and beams, Thin-Walled Structures, 66 (2013) 62-75.

[12] J.F. Dong, Q.Y. Wang, Z.W. Guan, Structural Behaviour of Recycled Aggregate Concrete Filled Steel Tube Columns Strengthened by CFRP, Engineering Structures, 48 (2013) 532-542.

[13] Y.-F. Yang, Z.-C. Zhang, F. Fu, Experimental and numerical study on square RACFST members under lateral impact loading, Journal of Constructional Steel Research, 111 (2015) 43-56.