ASSESSING THE USE OF RECTANGULAR CONCRETE-FILLED STEEL TUBE BEAMS IN CONSTRUCTION FIELDS

[1]AHMED W. AL-ZAND, [2]WAN HAMIDON WAN BADARUZZAMAN, [3]AZRUL A. MUTALIB, [4]SALAM JASIM HILO

[1,2,3,4]Department of Civil and Structural Engineering Universiti Kebangsaan Malaysia (UKM) -Bangi, Selangor, Malaysia
E-mail: ahmedzand70@gmail.com

Abstract- Three important parameters of rectangular concrete-filled steel tube (CFST) beams, namely, weight, cost, and ultimate moment capacity, are investigated in this research to establish the validity of using this type of composite member in the modern construction projects. Finite element (FE) analysis with ABAQUS software was performed to implement the models of the CFST members. The validity of FE modeling was confirmed through a successful comparison with the experimental result for the CFST beam. The results confirmed that the in-filling of concrete delays the local buckling of hollow steel tube (HST) beams, which enhance their moment capacity approximately more than 70%, and the self-weight of these members increased approximately 2.5—4.0 times, whereas the cost increased by only 10%—15%. Moreover, the HST beams with high depth-to-thickness ratio and/or low yielding strength usually indicated better improvement of ultimate moment capacity when in-filled with concrete. Nonetheless, the use of high-compressive-strength of concrete does not significantly improve the capacity of the beams more than those in-filled with normal compressive strength.

Keywords- Concrete-Filledsteel Tube, CFST Beam, Composite Structure, Finite Element Analysis.

I. INTRODUCTION

The composite members of concrete-filled steel tubes (CFSTs) are widely used in construction fields recently. The CFST members usually display higher stiffness, capacity, and ductility performance than reinforced concrete and/or steel structural members (conventional members). The current study mainly focuses on the behaviors of CFST flexural members because engineers intend to adopt this type of composite member for modern steel structural projects. Several experimental studies have investigated the behaviors of CFST beams in the past 15 years, such as in [1-8]. In 2000, a railway bridge was constructed in Japan using circular steel tubes in-filled with light aggregate and normal concretes as main pipe girders. This technique (in-filling steel tubes with concrete) delays the local buckling of steel tubes, which is usually occurs in the high-compression zones of the girder[1]. The CFST girder is heavier than the I-beam girder, but it requires less welding than conventional steel girders do, where the conventional girders require additional welding for their parts (flanges, webs, and stiffeners). Atwelve specimens of a high-tensile, rectangular steel tube in-filled with concrete were tested by Gho and Liu (2004) up to the failure point under bending load [2]. The results of the ultimate moment capacities (Mu) according to the experimental tests were compared with the values calculated theoretically from the codes ACI, EC4, and AISC. The formulas of these codes significantly underestimated the flexural strengths of the specimens by 15%, 11%, and 18%. Yang and Ma (2013) [8] investigate around 14 square and circular specimens of stainless steel tubes subjected to flexural bending, where these tubes filled with varies percentage of recycle aggregate concrete (RAC). The stiffness and moment capacities conducted from the experimental tests were compared to the theoretical results of varies international cods. The experimental study confirmed that the RAC filled tube beams had the good deformation-resistant ability, and the performance of core RAC was largely improved due to the confinement of the outer stainless steel tube The main objective of the current study is to assess the validity of using rectangular CFST beams in construction fields by focusing on three major project parameters, namely, the weight, cost, and ultimate moment capacity. Finite element(FE) models were adopted to implement the simply supported CFST beams and also to investigate further the effects of various depth-to-thickness (D/t) ratios, steel yielding strengths, and concrete compressive strengths on these major parameters. The suggested FE models were validated according to the results of the sample that was experimentally tested in the laboratory of the structural department of UniversitiKebangsaan Malaysia.

II. FINITE ELEMENT ANALYSIS

A. Modeling of the CFST beams

Nonlinear 3D–FE models were prepared using ABAQUS software to determine the structural behavior of rectangular CFST beams. The loading scenario and boundary conditions adopted for all models are presented in Fig. 1. Each FE model was composed mainly of steel tube in-filled with concrete materials. All beams measured 1.85 m in effective length (Le) and were subject to two-point loads placed at a distance of 0.35Le from each support. The steel tubes were modeled with the shell element type S4R, whereas the element type C3D8RH was used to model the concrete material. A typical quarter FE mesh model was used to implement the rectangular CFST beamsthroughadopting the symmetry option which is

available in the ABAQUS software, as shown in Fig. 2. Support conditions were appropriately modeled by restraining the nodes that corresponded to the support points. A displacement load option was used inthis FE analysis. This displacement at the load points was gradually increased at a smooth rate until it satisfied the ultimate capacity of each FE model. The penalty friction option with a coefficient of 0.75 facilitated the surface interaction between the inner face of steel tube and the in-filled concrete elements.

The physical materials properties of the CFST beamwhich was tested experimentally in the laboratory are presented in Table I. The values represent the average results of tensile test for three random coupons obtained from the steel tube (RHS 175 x 125x 2.8mm), and three cylinder samples from concrete batch for compressive tests. The assumed uniaxial stress–strain curves that were adopted in the FE analysis for steel and concrete materials are shown in Fig. 3.

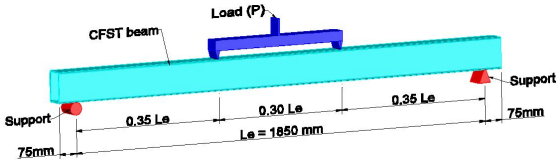

Fig. 1. Boundary Conditions of a CFST Beam

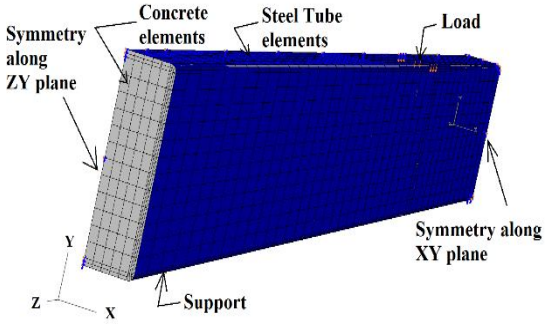

Fig. 2. Typical quarter CFST FE models

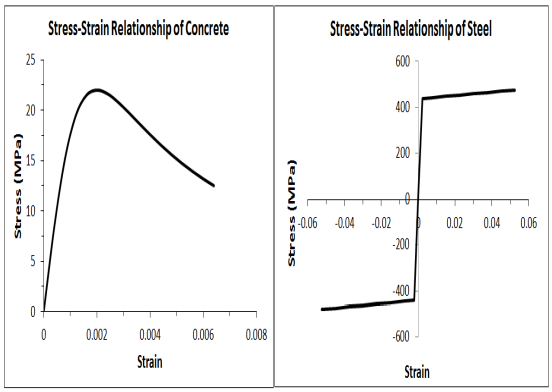

Fig. 3. Stress-strain relationships of steel tubes and concrete materials

TableI
Material propertiesof CFST specimen

Material	Poisson's Ratio	Elastic Modulus (GPa)	Yield Stress-Fy (MPa)	Compressive Strength-fc (MPa)	Ultimate Tensile Strength-Fu (MPa)
Steel Tube	0.29	206	440	-	476
Concrete	0.2	22.04	-	22	-

B. Verification of the Finite Element Model

One rectangular steel tube specimen was obtained with the following dimensions: 125 mm depth × 75 mm width × 2.8 mm thickness.

This specimenwas in-filled with normal concrete and tested up to the failure flexural load, as shown in Fig.4. The moment—midspan deflection curves obtained from the experimental test of rectangular specimen (RS1-EX) and from the FE analysis of equivalent model (RS1-FE)are presented in Fig.5. The Mu of (RS1–FE) was 46.1 kN.m, which was little higher than that of the (RS1–EX) at 42.9 kN.m. Hence, FE analysis overestimated this capacity of CFST specimen by +7.4% which is within the acceptable limit.

This verification study confirmed that the proposed FE modeling can implement the behavior and capacity of the rectangular CFST beam under ultimate flexural loads.

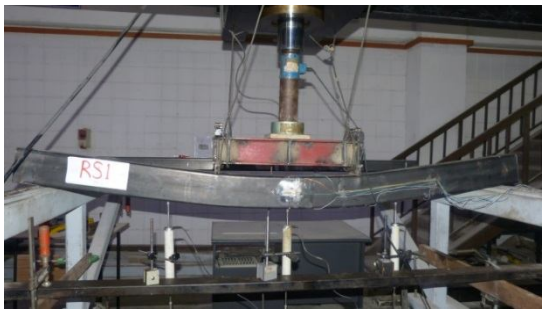

Fig. 4. Experimental test of CFST specimen (RS1-EX)

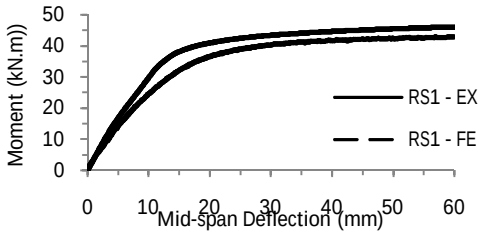

Fig. 5. Comparison of the moment-deflection curves between the experimental specimen and the equivalent FE model

III. NUMERICAL ANALYSIS OF CFST BEAMS

The accuracy of the proposed FE model was confirmed through a valid comparison with the results of the experimental test. Therefore, the method was used to determine the subsequent behaviors/capacities of FE CFST models with various D/t ratios, steel yielding strengths, and concrete compressive strengths, as listed in Table II. The rectangular FE model (RS1-FE) considered as a control model(RS1-CFST) in the following study in order to investigate the effects of the suggested parameters with reference to this model. However, the models started with letters RS2 and RS3 are representing those with higher and lower D/t ratios than the control model, respectively. The RS4 and RS5 are for models with steel yielding strength lower than the control model, whereasthe RS6 and RS7 are for models with higher concrete compressive strengths. The RS8 referred to the last hollow tube model which was suggested with specific dimensions to satisfy bending capacity equivalent to that for control model (RS1-CFST).The second part of numbering system of FE models (HST / CFST) isreferring to the hollow steel tube /concrete-filled steel tube models, respectively. The weight, cost, and bending capacities of these CFST models were compared with those for their HST models (tubes before in-filled with concrete). The Mu value of each HST model was calculated in accordance with fundamental theory of flexural beam capacity (plastic section modulus multiplied by the ultimate strength of steel tube without applying the design factors). Meanwhile, the Mu values of CFST models were all derived from the FE analysis.

TableII
The propertiesof hollow steel tube and CFST models

Steel Tube (HST) models	CFST models	Tube size (DxBxt mm)	D/t	Fy (MPa)	Fu (MPa)	fc (MPa)
RS1-HST	RS1-CFST	125x75x2.8	44.6	440.0	476.0	22.0
RS2-HST	RS2-CFST	125x75x2.1	59.5	440.0	476.0	22.0
RS3-HST	RS3-CFST	125x75x4.0	31.3	440.0	476.0	22.0
RS4-HST	RS4-CFST	125x75x2.8	44.6	340.0	380.0	22.0
RS5-HST	RS5-CFST	125x75x2.8	44.6	240.0	280.0	22.0
RS6-HST	RS6-CFST	125x75x2.8	44.6	440.0	476.0	40.0
RS7-HST	RS7-CFST	125x75x2.8	44.6	440.0	476.0	60.0
RS8-HST	-	150x75x4.7	31.9	440.0	476.0	-

IV. RESULTS AND DISCUSSION

The results for the CFST models obtained from the FE analysis arediscussed as follows:

A. The effects of in-filled concrete on the tube buckling

This result is attributed to the fact that the in-filled material can delay inward/outward local buckling, which usually occurs on the walls of tubes at high-compression zones (supports and/or load points), as indicated in Figs. 6&7.Therefore, this action of in-filling the tube beams with normal concrete led to improve theirductility and capacity clearly as shown in Fig. 8.

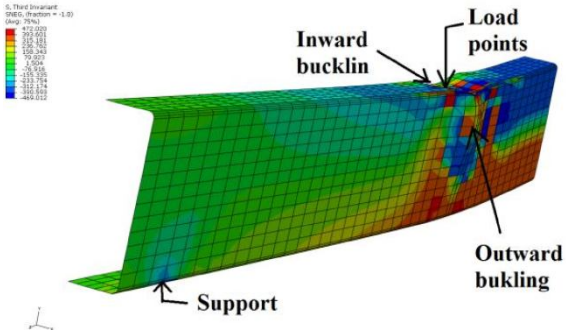

Fig. 6. Local buckling at load point of steel tube FE model (RS1-HST)

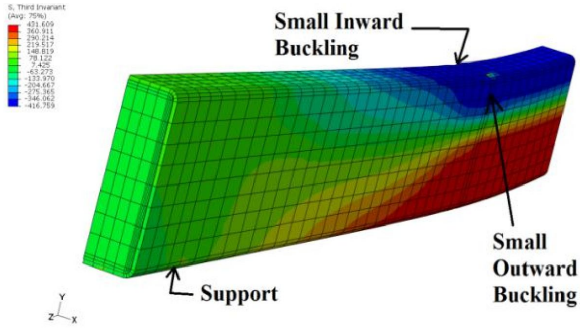

Fig. 7. Local buckling at load point of CFST FE model – (RS1-CFST)

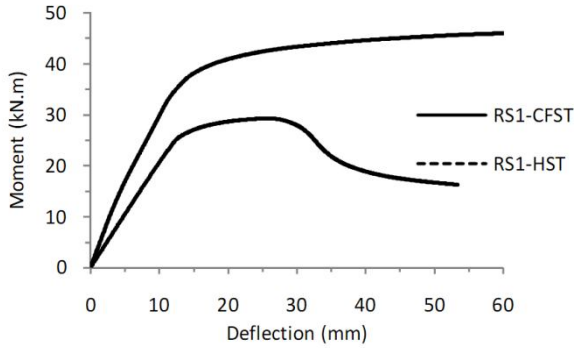

Fig. 8. Moment-midspan deflection curves of CFST model (RS1-CFST) and their HST model (RS1-ST)

B. The effects of weight, cost and ultimate moment

The technique of in-filling HST members with concrete (CFST members) modified the parameters of weight, cost, and ultimate capacity which are highly

important in the design stage any project. Table III presents the increasing ratios of weight and cost for each steel tube model after in-filling with concrete material, in addition to displaying the improvement ratios of their Mu values. The weight ratio (weight of CFST-to-HST) of each beam model increased gradually with the increasingof D/t ratio of their tubes. For example, the weight of the CFST model with a D/t ratio of 59.5 (RS2-CFST) was approximately 4.16 times higher than that of theirHST member (RS2-HST), whereas the weight of the model with a D/t of 31.3 (RS3-CFST) was only 2.56 times higher than that of RS3-HST. The cost of CFST models also depended completely on the parameter of the D/t ratio as well. Where the cost of the HST models with low D/t ratio (31.3) increased by approximately 7% when in-filling by concrete,whereas, this percentage increased up to 15% for modelswith higher a D/t ratio (59.5), as summarized in Fig. 9. This is because of the tubes with higher D/t ratio logically has larger hollow (void space) which it will be in-filled by large amount of concrete, then these two parameters (weight and cost) will increase accordingly.

Consequently, the Mu values of all CFST models were higher than those of the HSTs. The improvement Mu ratio(Mu of CFST-to-HST) gradually increased with the increasingofthe D/t ratio as well as with the decreasing of the steel yielding strength. For example, the Mu of the control model (RS1-CFST) was improved approximately78% higher than that for their HST beam (RS1-HST) at a D/t ratio = 44.6, Fy = 440 MPa, and fc= 22 MPa. This Mu improvement ratio decreased up to 68% when the D/t ratio alone reducedup to 31.3. Similarly, the Mu ratio increased up to 88% when using steel tube with lower yielding strength (240 MPa). Slightly improvement ratio of Mu has been observed when using high concrete compressive strength (60 MPa) which was increased around only 84% compared to the 78% for same model but with fc=22 MPa.

The RS8-HST model has ultimate moment capacityequal to that for control CFST model (RS1-CFST) which is equal to 46.1kN.m. However, the weight of this model (RS8-HST)was less than that of control CFST model definitely, but the overall cost of RS1-CFST model was around 40% less than the RS8-HST model, as shown in Fig. 10 and Table III.

Table III
Increment ratios of weight, cost and ultimate moment capacity

Steel Tube (HST) models	CFST models	Weight ratio CFST/HST	Costratio CFST/HST	Mu ratio CFST/HST
RS1-HST	RS1-CFST	3.32	1.11	1.78
RS2-HST	RS2-CFST	4.16	1.15	1.81
RS3-HST	RS3-CFST	2.56	1.07	1.68
RS4-HST	RS4-CFST	3.32	1.11	1.87
RS5-HST	RS5-CFST	3.32	1.11	1.88
RS6-HST	RS6-CFST	3.32	1.11	1.80
RS7-HST	RS7-CFST	3.32	1.11	1.84
RS8-HST	RS1-CFST	1.81	0.61	1.00

Note: a- Steel density (7850kg/m3) and concrete density (2350 kg/m3)
b- Cost of steel (950 USD/ton) and cost of concrete (45 USD/ton)

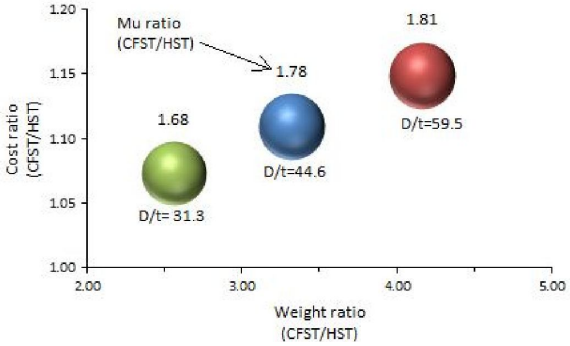

Fig. 9. The effects of steel tubes D/t ratio on the weight, Cost and ultimate moment ratios when in-filled with concrete

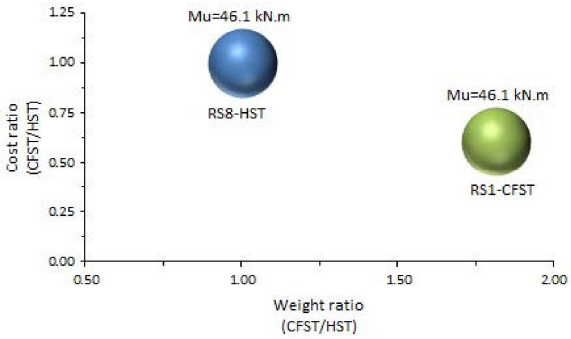

Fig. 10. Comparison of weight and cost ratios between two models have same moment capacity (RS1-CFST and RS8-HST)

CONCLUSION

The conclusions drawn from the results obtained through the FE analysis are summarized as follows:

- The successful comparison between the model of FE analysis and experimental specimenconfirm that, the proposed FE modeling is sufficient to implement the behaviors of the CFST beams.
- The in-filled concrete material delays the inward and outward local buckling of tubes wall which is usually occurred at the zones with high compression stresses (support and/or load points).

- The moment capacity tube beams improved more than 70% when in-filled with normal concrete material, and their weights increased by approximately 2.5—4.0times as well. Meanwhile, the cost of the same beams increases by only 7%—15%.
- The tubeswith high D/t ratio usually have higher weight and cost of beams when in-filled with concrete, as well as it will increase the ultimate capacity of beams more than those with lower D/t ratios.

Further studies are required toinvestigate the effects of beams length-to-depth ratio on the behaviors of steel tube beamswhen in-filled with normal concrete. The tubes with other shapessuch as circular and/or oval are needs to investigate as well since its high recommended architecturally in the modern projects.

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