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Experimental investigation of concrete-filled steel tubular longitudinal gusset plate connections

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ABSTRACT

A series of tests on the concrete-filled tubular gusset plate T–connections is presented in this paper. Three different loading conditions, including axial tension, eccentric tension and in-plane bending, were applied to the brace. The chord wall slenderness ratio (D/t) of the test specimens ranged from 48 to 75. The material properties of the steel and concrete used in the test specimens were measured. Each connection was tested to failure, and the behavior under loading was recorded. Punching shear failure of the chord member was the main failure mode observed during the tests. The test results were compared with the current AISC-360 and CIDECT DG1 design predictions, which only concern hollow section steel tubular connections. It is shown that the design strengths predicted by the current design rules are quite conservative for all the test specimens examined in this study. It is recommended that the contribution of concrete be considered in the design because it could effectively restrain the deformation of the chord wall that was observed in the test. The proposed design equations predict the ultimate strengths of the concrete-filled tubular gusset plate T–connections generally well.

1. Introduction

The use of concrete-filled steel tubes in truss structures for buildings, bridge structures, marine engineering and electronic transmission engineering has become increasingly popular because of their excellent performance in compression. This is due to the efficiency of the inner concrete, which significantly enhances the local buckling resistance capacity of the thin-walled steel tubes, especially for members with a large diameter to thickness ratio [1–3]. The maximum permitted width-to-thickness ratio (D/t) for round Hollow structural steel section (HSS) compression steel elements in composite members subjected to axial compression specified in the AISC-360 standard [4] is $0.31E/F_y$. However, the maximum permitted chord wall slenderness ratio (D/t) for circular hollow section steel (CHS) connections is 50, as specified in the AISC-360 standard, which is much smaller than the $0.31E/F_y$ for normal strength carbon steel. There is a lack of information regarding concrete-filled steel tubular connections.

Concrete-filled steel tubular gusset plate connections are a traditional and convenient connecting method to directly weld plates to the faces of columns, especially those with a small load on the branch members. For steel tubular gusset plate connections, special precautions [5–7], for example stiffening method, are always taken during design because the connecting face of an HSS chord is flexible. Some research has been undertaken for plate-to-HSS connections [5–10]. From these studies, it has been confirmed that for longitudinal plate connections, the chord members always failed upon reaching the limit state for chord face yielding. This failure mode may not occur for connections having a concrete-filled steel tubular chord. Unfortunately, few studies have focused on the behavior and strength of concrete-filled steel tubular gusset plate connections, though filling concrete in the chord member is another effective way of stiffening the flexible chord face. Additionally, no design rules have been proposed for concrete-filled tubular gusset plate joints.

Extensive investigations have been conducted on concrete-filled steel tube CHS connections and indicate that filling the HSS chord member with concrete could effectively improve the strength of the connections under compressive or tensile load from the brace [11–15]. Sakai et al. [16] also concluded from static test results of concrete-filled CHS tubular K connections that the ultimate load resistance of the concrete-filled specimen was roughly twice that of non-concrete-filled specimens. Xu et al. [17] reported that the ultimate tensile strengths of concrete-filled tubular CHS connections were governed by the limit state of punching shear instead of deformation limit state, which could be different from those non-concrete-filled connections in the same configurations. These test results demonstrated that the ultimate strength of the tubular CHS connections could be significantly improved when the chord members of the connections were concrete-filled. Currently, the existing design guidelines [4,18] for plate-to-HSS connections are only for non-concrete-filled HSS connections. There is a lack of design methods for concrete-filled steel tubular gusset plate connections.

This paper focuses on the behavior of concrete-filled steel tubular longitudinal gusset plate *T*-type connections. The following three types

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of loading conditions were considered: axial tension, eccentric tension and in-plane bending. In the tests, the ratios of chord slenderness ranged from 48 to 75. The chord wall deformation, ultimate strength and observed failure modes of the test specimens were reported. The suitability of the current AISC-360 design standard [4] and the CIDECT DG1 recommendations [18] for concrete-filled gusset plate tubular connections were evaluated. In addition, design methods for concrete-filled tubular gusset plate connections were proposed based on the test results.

2. Experimental program

2.1. Test Specimens

In total, three series of 11 specimens were tested, as follows: three (3) specimens were subjected to axial tension, two (2) specimens were subjected to eccentric tension and six (6) specimens were subjected to in-plane bending. The chord members of all the test specimens were fabricated from circular hollow section steel tubes and filled with self-compacting concrete over the entire length. The nominal length of the chord members were 1400 mm and 2000 mm for tensile/eccentric and in-plane bending specimens respectively. A 12 mm thick gusset plate was welded to the chord member. Plate thickness, height and the connection area between the plate and chord member were kept constant for all test specimens. The nominal thickness of the bolt plate for all the test specimens is 12 mm and the nominal lengths are 200 mm and 400 mm for the tension and bending test specimens, respectively. The measured dimensions for all test specimens are provided in Table 1 using the labels described in Fig. 1. The cross section of brace is the same for all connections. The nominal outer diameter and thickness of the brace are 133 mm and 6 mm, respectively.

The mechanical properties of the steel used for the specimens were determined from tensile coupons taken from the same batch of material. The results are shown in Table 2. A calibrated extensometer of 50 mm gauge length was used to measure the longitudinal strain. A data acquisition system was used to record the load and the readings of strain at regular intervals during the tests. The concrete mix was designed for compressive cube strength (f_{cu}) of approximately 50 MPa at 28 days. Concrete were taken out from the specimens belonging to the same batched as the connection test specimens. The compressive strength (f_{cu}) and elastic modulus (E_c) obtained from test results at 28 days were 47.6 MPa and 30,120 MPa, respectively. The weld profile and specimen preparation were carried out in accordance with the AWS specification [19]. The specimens were then checked using ultrasonic inspection. The ultrasonic test results deemed the quality of the welds to be acceptable. Two 20 mm thick end plates were welded at the chord ends, whereas one 20 mm thick steel plate with stiffened plates

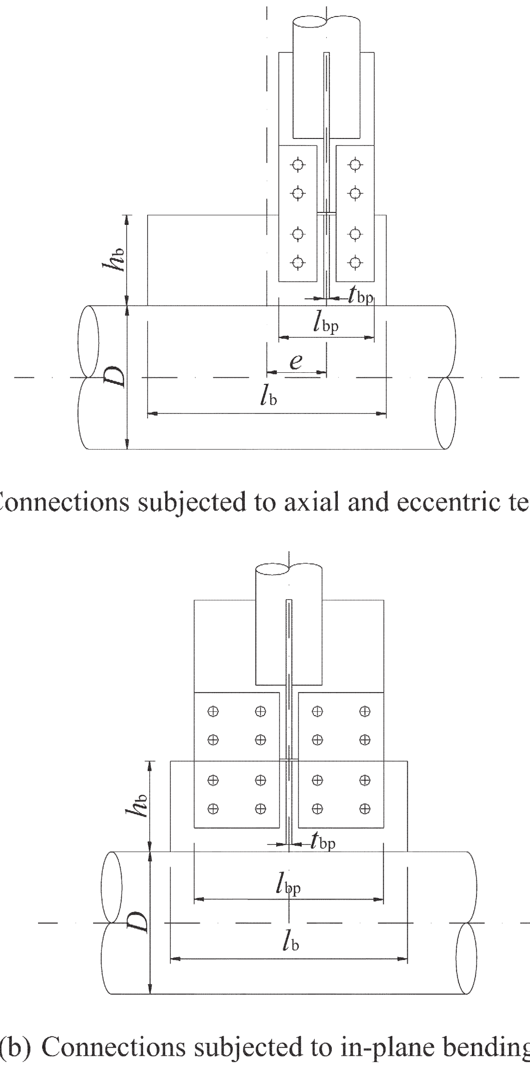

Fig. 1. Dimension details of test specimens. (a) Connections subjected to axial and eccentric tension (b) Connections subjected to in-plane bending.

was welded to the top end of each brace of the specimen to facilitate installation and load application.

The test specimens were labelled so that the type of connection, the outer diameter of the chord, the thickness of the chord and the load condition could be identified from the label. For example, the labels "*T*-300-

Table 1
Measured configurations, ultimate strengths and failure modes of the test specimens.

Specimens	Chord			Gusset plate			e (mm)	P_{Exp} (kN)	M_{Exp} (kN·m)	Failure mode
	L (mm)	D (mm)	t (mm)	l_b (mm)	t_b (mm)	h_b (mm)				
T-300-4-AX	1394.7	300.9	3.95	498.3	11.86	191.6	0	843.7	–	CPS
T-300-4-AXR	1395.1	300.5	3.94	497.5	11.98	191.9	0	766.3	–	CPS
T-300-6-AX	1397.2	299.4	6.02	498.4	11.78	188.8	0	>980.0	–	BY
T-300-4-E50	1397.8	299.8	3.94	497.8	11.89	189.0	50	652.1	–	CPS
T-300-4-E125	1395.1	300.1	4.05	498.2	11.79	190.1	125	464.4	–	CPS
T-300-4-IB	1994.9	300.6	3.98	498.8	11.88	191.5	–	–	165.27	CPS
T-300-5-IB	1995.7	300.4	4.91	498.3	11.92	191.2	–	–	203.82	CPS
T-300-5-IBR	1997.1	300.7	4.92	497.5	11.77	189.1	–	–	186.12	CPS
T-240-4-IB	1996.9	240.5	4.02	498.9	11.79	190.9	–	–	185.33	CPS
T-240-4-IBR	1996.0	240.9	3.91	499.0	11.89	189.1	–	–	195.76	CPS
T-240-5-IB	1994.7	240.3	4.95	498.2	11.92	191.2	–	–	212.40	CPS

Note: D: Outer diameter of the chord, t: Wall thickness of the chord, L: Length of the chord member, l_b: Length of the branch gusset plate, t_b: Gusset plate thickness, h_b: Gusset plate height, CPS: Chord punching shear and BY: Brace yielding.