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Experimental behaviour of reinforced concrete-filled steel tubes under eccentric tension

Ju Chen[a], Jun Wang[a], Wei Li[b,*]

[a] Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China
[b] Department of Civil Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

This paper presents research on the reinforced concrete-filled steel tubular (CFST) members subjected to eccentric tension, where the embedded components are the reinforcing bars or steel angles. A total of 8 full-scale specimens were designed and tested with main parameters of specimen types and load eccentricities. In particular, there was no direct connection between the outer tube and embedded components. Therefore the tensile load was transferred from the outer steel tube to the reinforcing bars or angles through the filled concrete. The failure mode, the load versus deformation relationships and the strain responses were recorded and analysed. The simplified design equations were also proposed for the elastic tensile stiffness and tension versus moment interaction relationships of reinforced CFSTs under eccentric tension.

1. Introduction

It is well known that the concrete-filled steel tube (CFST) has excellent structural performance owing to the composite action between the concrete and steel tube. Various researchers have conducted investigations of the CFST behaviour under compression, bending, tension and combined loadings [1–8]. It was found that the core concrete was confined by the steel tube and the buckling mode of steel tube was altered by the concrete. Therefore several codes of practice have been published and the CFST has been widely used all over the world [9–12].

Sometimes CFST members may be subjected to combined tension and bending, such as the ones in latticed electricity transmission towers, as shown in Fig. 1. The previous research found that the CFSTs had higher tensile strength than the bare steel tubular counterparts. Pan and Zhong [13] conducted experimental and theoretical investigations, which found that the tensile strength of CFST was 1.1 times higher than that of the hollow steel tube, attributing to the hoop stress developed in the outer tube. Han et al. [14] studied the influence of interface conditions on CFST tensile members. The results showed that the perfectly bonded and debonded interfaces had limited effect on the tensile strength of CFST using normal concrete. Li et al. [15–17] conducted a series of investigations on the CFST and the concrete-filled double skin steel tubes (CFDST) under tension. It was found that the filled concrete changed the stress status of steel tubes and enhanced the capacities of members under concentric or eccentric tension. For the eccentrically loaded CFSTs, the in-filled concrete worked well with the outer steel tube, and a large deformation capacity was observed for all members, for the final end rotation exceeded 0.1 rad [17].

In order to enhance the ultimate strength of CFSTs, the most effective way is to increase the cross-sectional area of steel. However, the steel tube with large thickness may increase difficulties in manufacturing and installation. When comparing with embedding a steel tube inside, embedding the reinforcing bars or steel angles could be an easier solution for the tensile CFSTs as the convenience of pouring the concrete. Chen et al. [18] has conducted experimental research on the CFSTs with embedded reinforcing bars and angles under concentric tension. It was found that the embedded components could effectively increase the ultimate strength of concentrically loaded tensile member owing to the increase of cross-sectional area of steel. It is also noted that the strength of embedded components could be fully developed through certain bonding length. However, there is still a lack of studies for the behaviour of CFSTs with reinforcing bars or angles under eccentric tension. The contribution of these reinforcing components may be underestimated, which may result in an over-conservative design of CFST tensile members.

This paper is a companion one with the CFSTs with reinforcing bars or angles under concentric tension [18]. The experimental investigation on 8 full-scale specimens is conducted. The test parameters include the types of the reinforcing components and the load eccentricities applied. The fail modes, load and deformation relationships and strain responses are recorded and analysed. The load carrying capacities of the CFSTs

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* Corresponding author.
E-mail address: iliwei@tsinghua.edu.cn (W. Li).

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Nomenclature

A_c	cross-sectional area of concrete
A_s	cross-sectional area of steel tube
A_{sa}	cross-sectional area of angle
A_{sr}	cross-sectional area of reinforcing bar
D	outside diameter of steel tube
d	diameter of reinforcing bar
E	elastic modulus of steel
E_c	elastic modulus of concrete
E_s	elastic modulus of steel tube
E_{sa}	elastic modulus of angle
E_{sr}	elastic modulus of reinforcing bar
$(EA)'_{T}$	elastic tensile stiffness under eccentric tension
$(EA)'_{T\text{-test}}$	elastic tensile stiffness under eccentric tension obtained from the experimental load-axial elongation curve
$(EA)'_{T\text{-cal}}$	elastic tensile stiffness under eccentric tension predicted using the proposed equation
f_{cu}	compressive strength of concrete of 150 × 150 × 150 mm cube
f_{ck}	characteristic compressive strength of concrete, $f_{ck} = 0.67f_{cu}$
f_t	tensile strength of concrete
f_u	ultimate tensile strength of steel
f_y	yield stress of steel
f_{ysa}	yield stress of angle
f_{ysr}	yield stress of reinforcing bar
L	length of test specimen
l	length of angle
M	moment
M_u	flexural strength of CFST
M_{ur}	flexural strength of CFST with reinforcing bars or angles
T	tension
t	thickness of steel tube
T_u	tensile strength of eccentrically loaded CFST
T_{ur}	tensile strength of eccentrically loaded CFST with reinforcing bars or angles
$T_{u\text{-Eq3}}$	tensile strength predicted using Eq. (3)
$T_{u\text{-Eq4}}$	tensile strength predicted using Eq. (4)
$T_{u\text{-Test}}$	tensile strength of test specimen
t_a	thickness of angle
α	steel ratio ($= A_s/A_c$)
δ	percentage elongation after fracture
ξ	confinement factor

with reinforcing bars or angles subjected to eccentric tension are also assessed. The main objectives of this research are as follows.

1) to provide a new series of test data for CFSTs with angles and reinforcing bars under eccentric tension;
2) to evaluate the contribution of embedded angles and reinforcing bars for the overall behaviour of eccentrically loaded CFSTs; and
3) to propose simplified design equations which could reasonably predict the stiffness and tension versus moment relationships of CFSTs with embedded components under eccentric tension.

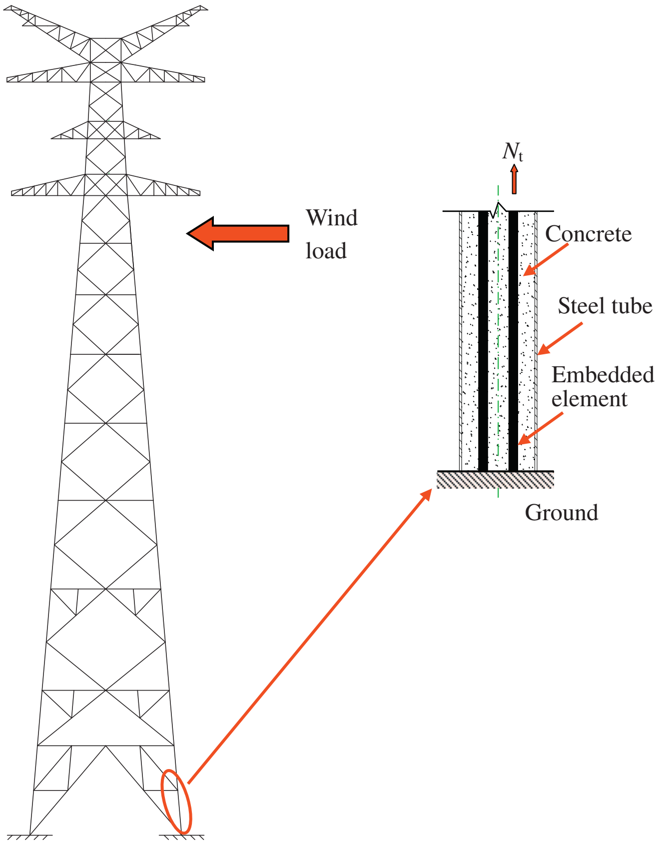

Fig. 1. Member in composite transmission tower under eccentric tension.

2. Experimental investigation

2.1. General description

A total of 8 full-scale specimens were designed for the eccentric tension test. The main parameters are the type of the cross section, the tensile load eccentricity and the connection pattern. Two kinds of embedded components, i.e., the angle with connecting plate and the reinforcing bars were used in the tests. These embedded components were originally designed as construction details and the strength contribution was not considered tentatively. The load eccentricity ratios (λ) of 0.1 and 0.2 were designated, where λ is obtained by dividing the load eccentricity (e) with the radius of steel tube ($D/2$) for specimens with circular cross section. Two specimens were designed to evaluate the effectiveness of the flange connection for column segments.

The nominal diameters of the longitudinal reinforcing bars and the stirrup were 16 mm and 8 mm, respectively. The distance between two stirrup layers was 200 mm. The cross-sectional profile of the steel angle was L-56 × 5 mm, and battens of 156 × 50 × 4 mm were used to connect four steel angles together. The nominal length of each specimen was 4000 mm, while the nominal outer diameter of the steel tube was approximately 400 mm. The schematic view of CFST specimens with reinforcing bars and angles are shown in Fig. 2(a) and (b), respectively.

The labels of the specimens are listed in Table 1, where the characters 'AG', 'E', 'FC' and 'RB' represent the angle, eccentricity, flange connection and reinforcing bars, respectively. Two load eccentricities, i.e., 20 mm and 40 mm were used in the test, and the corresponding labels are E20 and E40, respectively. The last character 'A' or 'B' represents the test specimen with the same parameters. Table 1 also lists the measured cross-sectional dimensions and the specimen length for each specimen.

2.2. Specimen end and connection

Two 30-mm-thick steel end-plates were welded to both ends to ensure full contact between the specimen and the bearings. There are

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