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Tensile behaviour of concrete-filled double-skin steel tubular members

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ABSTRACT

Concrete-filled double-skin steel tube (CFDST) a type of steel–concrete composite section which has two concentrically placed steel tubes and concrete filled in between. The CFDST members inherit the advantages of traditional concrete-filled steel tubes and are relatively lighter. They have been used in electric poles and have great potential in other types of structures. This paper in particular presents an experimental study on the concentrically and eccentrically loaded CFDST tensile members. The test parameters include the load eccentricity, the hollow ratio and the nominal steel ratio of the cross section. It is found that the filled concrete works efficiently with the double steel tubes, and provides additional support to the steel tubes under tension. All eccentrically loaded CFDST tensile members exhibit ductile behaviour with end rotation exceeding 0.1 rad. Design calculations are also assessed. The results indicate that the existing design proposal for CFDST tensile member has to be improved.

1. Introduction

Concrete-filled double skin steel tubular (CFDST) member consists of inner and outer steel tubes with concrete in-filled in the sandwiched cavity [1]. It inherits advantages of the common concrete-filled steel tube, such as high resistance, high stiffness and good constructability. It also has some other characteristics, such as lighter self-weight and better fire performance. It is found that the inner tube can provide a sufficient support to the sandwiched concrete, and the steel–concrete–steel interfaces can work together effectively under various loading conditions. The concrete-filled double skin steel tubes may provide a better design option when designing members of large cross-sectional profile. Recently, they have been used as main structural components for electric poles in China [2] (Fig. 1). It has lighter self-weight than the fully filled concrete-filled steel tubular (CFST) poles and occupies less land area than ordinary steel lattice towers. When compared to the pure steel tubular structures, the CFST member can avoid the use of thick steel plates.

Many researchers [3–5] have carried out experimental investigations on the compressive, bending and cyclic performance of CFDST members. It was found that, the sandwiched concrete infill restrained the local inward buckling of the outer tube and the local outward buckling of the inner tube, therefore the plastic strength of the CFDST member was fully developed relative to the hollow tube counterparts. In addition, no sign of slip was observed on the interfaces of steel tubes and concrete, and the tubes and concrete worked compositely to support the loads and provide the stiffness. For the CFDST members under monotonic compressive loading, the outward buckling of the outer tube was occurred, and the inner tube exhibited a diamond-like buckling mode. The sandwiched concrete was crushed where the tubes buckled. For the CFDST members under bending, experimental results showed that the outer tube behaved in a same way with the concrete-filled steel tube, whereas the inner tube behaved like an empty compact tube [6]. For CFDST members under cyclic loading, the test results showed that the CFDST beam-column demonstrated favourable ductility and energy dissipative performance even when the member was subjected to a high axial load. Besides the common CFDST members with uniform cross section, tapered CFDST members have also been used in constructions. The compressive performance of the tapered CFDST members was studied experimentally by the authors [2,7]. It was found that the steel tubes and concrete could work well despite the tapered angle, and the failure mode of the tapered member was similar to that of the straight counterparts.

Apart from the experimental investigations, numerical investigations on CFDST members were also conducted. Han et al. [8] proposed a fibre-based numerical model, and Huang et al. [9] proposed comprehensive numerical models for predicting the structural response. Materials and geometrical nonlinearities were incorporated in the numerical models and were verified against the experimental results. Design formulas have been proposed for the calculation of compressive strength of CFDST members.

The CFDST members may be subjected to tensile loading when being used in structures. For instance, the CFDST members may sustain concentric tension when being used as chord members in the latticed structures. They may be subjected to combine tension and bending moment when being used as columns in high-rise buildings in some seismic-prone zones. However, to date, no test data was found in literature on the tensile behaviour of CFDST members. There is also no clear guidance for designing CFDST members under tension, which hinders further application

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Notations

A_c	Cross-sectional area of the sandwiched concrete, given by $\pi((D-2t_o)^2-d^2)/4$ for CFDST member with circular inner and outer tubes
A_{ce}	Nominal inner cross-sectional area, given by $\pi(D-2t_o)^2/4$ for circular cross section
A_{si}	Cross-sectional area of inner steel tube
A_{so}	Cross-sectional area of outer steel tube
D	Diameter of outer circular steel tube
d	Diameter of inner circular steel tube
e	Load eccentricity
f_{cu}	Concrete cube strength
f_c	Compressive strength of concrete
f_i	Yield strength of inner steel tube
f_o	Yield strength of outer steel tube
M	Moment
M_a	Average of the measured ultimate flexural strength
M_y	Yield moment
M_u	Ultimate flexural strength
r	Radius of outer tube
T	Tensile load
T_{cal}	Calculated ultimate tensile strength
T_y	Yield tensile strength
T_u	Ultimate tensile strength
t_o	Wall thickness of outer steel tube
t_i	Wall thickness of inner steel tube
α	Steel ratio of the cross section, $\alpha = A_{so}/A_c$
α_n	Nominal steel ratio of the cross section, $\alpha_n = A_{so}/A_{ce}$
Δ	Elongation of the specimen
Δ_y	Elongation corresponding to yield tensile strength
Δ_u	Elongation corresponding to ultimate tensile strength
ε	Strain
θ	End rotation of the specimen
θ_y	End rotation corresponding to yield moment
θ_u	End rotation corresponding to ultimate flexural strength
ξ	Nominal confinement factor $= \xi = \alpha_n f_o/f_c$
χ	Hollow ratio of the cross section $= d/(D-2t_o)$

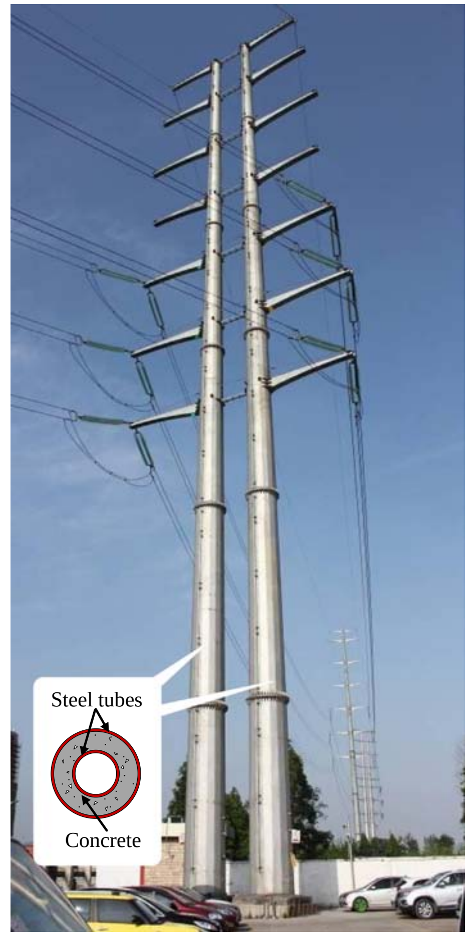

Fig. 1. CFDST electric poles in Hangzhou, China.

of CFDST members. This paper thus presents an experimental investigation on the tensile behaviour of CFDST members. Experiments are conducted for CFDST members under concentric and eccentric tension. The main parameters are the eccentricity, the hollow ratio and the nominal steel ratio. The failure modes of the outer tube, the inner tube and the sandwiched concrete are also presented. The load-deformation and the moment–curvature relationships of specimens together with the composite effect are discussed. A companion numerical study for CFDST tensile members is presented in another paper [10]. The main aims of this experimental study are:

(1) to provide a set of test data on the tensile behaviour of CFDST members;
(2) to study the composite effect between steel and concrete for CFDST tensile members; and
(3) to assess the feasibility of current design formulas for tensile strength of CFDST members.

2. Experimental programme

2.1. General description

There were 18 specimens in total, including 2 double skin hollow steel tubes without concrete. The most important parameters for the tensile test include the loading and geometric parameters. The load eccentricity (e), the hollow ratio (χ) and the nominal steel ratio of the cross section (α_n) were selected to be the experimental parameters for the CFDST specimen.

The load eccentricity (e) for the specimens ranges from 0 to 140 mm, therefore the e/r ratio ranges from 0 to 2, where r is the radius of the outer tube. The load eccentricity assigned for the specimens covers most application conditions.

The CFDST member consists of inner and outer steel tubes, the diameter of the inner tube changes for the specimens. A hollow ratio (χ) is tentatively used to represent the proportion of the inner tube, as defined in Han et al. [8]:

$$\chi = \frac{d}{D-2t_o} \tag{1}$$

where d is the diameter of the inner tube; D and t_o are the diameter and the wall thickness of the outer tube, respectively. It can be seen that the hollow ratio increases with the increase of diameter of inner tube. According to engineering practice, it ranges from 0.2 to 0.9. The hollow ratio used in this study ranges from 0.441 to 0.567.

In the previous study on CFDST members, it was found that the inner tube provided sufficient support to the sandwiched concrete and behaved like a hollow steel tube. Furthermore, although the CFDST member had two steel tubes, only the outer steel tube provided confinement to the sandwiched concrete. Therefore a nominal steel ratio of the cross