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Behaviour of circular concrete filled double skin tubes subjected to local bearing force

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ABSTRACT

This paper presents the behaviour of circular concrete filled double skin tubes (CFDST) subjected to local bearing forces. This is an extension of a previous work on concrete filled steel tubes (CFST). A series of tests were conducted where some key parameters were varied, including loading angle, hollow ratio, chord wall thickness, as well as brace to chord diameter ratio. A finite element analysis (FEA) modelling was established and verified by the test data. Comparative analysis was conducted between the full-range behaviour of CFDST and CFST under local bearing. It was found that the performance of CFDST is considerably affected by the interaction of the outer tube, inner tube and the sandwiched concrete, whilst its bearing capacity depends on the hollow ratio. Finally, based on the load-transfer mechanism analysis, simplified formulae for predicting the strength of CFDST under local bearing forces are presented. Reasonable agreement between the predicted and measured values is achieved.

1. Introduction

It is well known that one important application of concrete filled steel tubes (CFST) is chord member in trusses, towers and bridges (Han et al., 2014) [1], as filling the hollow sectional chord member with concrete has been proved to be an effective method to improve the strength and stiffness, and even fatigue life (Mashiri and Zhao, 2010) [2] of truss connections. However, some modern infrastructures can be substantially large in dimension and the corresponding high self-weight of concrete filled components thus becomes a problem, since it could result in disadvantages in the seismic resistance of the structure.

Fig. 1 shows a typical CFST transmission tower in China with a height of 370 m when it is under construction. Filling the total cross-section of chord with concrete provides high strength and high rigidity for the tower, whilst causing the structural self-weight to increase sharply. In such occasions, in order to reduce the self-weight while maintaining the favourable structural performance of CFST members, there is a potential to use concrete filled double skin steel tubes as the chord member (Zhao and Han, 2006) [3]. In such application as illustrated in Fig. 1, CFDST chord components may be subjected to local bearing forces since concentrated loads are transferred from the braces. The performance of CFDST under local bearing forces needs to be addressed to ensure the capacity of the connections as well as the safety of the structures.

In the past, investigations have been conducted both experimentally and theoretically on the behaviour of CFDST members under different loading conditions such as static loading, cyclic loading, preloading, fire, and so on (Wei, 1995; Tao et al., 2004; Huang et al., 2010, 2013; Li et al., 2012; Han et al., 2014) [4–8,1]. Furthermore, Yang et al. (2012) [9] carried out experimental studies on the behaviour of CFDST stub columns subjected to partial axial compression when used as bridge piers, load-introduction members, or bottom bearing members. Packer and Fear (1991), Zhao (1999), Feng and Young (2008, 2009, 2010) [10–14] conducted studies on rectangular CFST members under transverse compression forces. Meanwhile, the authors (Hou et al., 2013, 2014) [15,16] presented both experimental and theoretical investigations on circular CFST, unfilled circular hollow section (CHS) steel tube, as well as plain concrete members under local bearing forces transferred though bearing plates and CHS braces. However, there is a lack of understanding of CFDST members subjected to local bearing forces.

Based on their unique sectional profiles, it is expected that the mechanism of CFDST under local bearing forces is different from that of the corresponding CFST members, e.g. (1) As local bearing condition is a material-nonlinear issue for the composite members, it could be deduced that the bearing capacity of CFDST should be considerably affected by the interaction of the outer tube, inner

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Nomenclature

A_1	bearing area over which local bearing force is applied
A_2	dispersed bearing area
A_c	cross-sectional area of the sandwiched concrete in CFST member
A_{ce}	cross-sectional area of the sandwiched concrete in CFDST member
d_i	diameter of the inner steel tube
d_o	diameter of the outer steel tube
d_w	diameter of the brace tube
E_c	elastic modulus of concrete
E_s	elastic modulus of steel
f_{cu}	cube strength of concrete
f_c'	crushing strength of concrete by cylinder tests ($=0.8f_{cu}$)
f_u	tensile strength of steel
f_y	yield strength of steel
L	length of specimen
N	local bearing force
$N_{3\%do}$	local bearing force at the flange indentation of $3\%d_o$
N_{max}	maximum test load of the specimen
N_{ua}	analyzed ultimate strength of specimen under local bearing forces
N_{uc}	predicted ultimate strength of specimen under local bearing forces
N_{ue}	tested ultimate strength of specimen under local bearing forces
t_i	wall thickness of the inner steel tube
t_o	wall thickness of the outer steel tube
t_w	Wall thickness of the brace tube
ε	strain
ε_{ue}	strain corresponding to the ultimate strength
ε_y	yield strain of the steel
Δ	flange indentation of the chord
β	brace to chord diameter ratio ($=d_w/d_o$)
υ	side deformation of the chord
χ	hollow ratio of CFDST [$=d_i/(d_o-2t_o)$]
θ	angle between the brace and chord

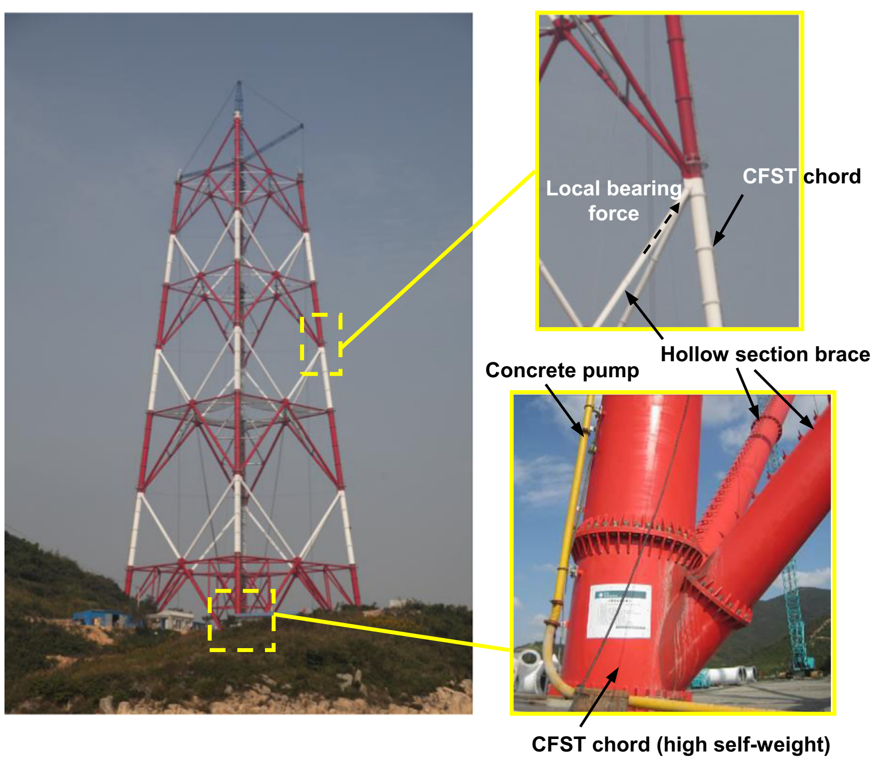

Fig. 1. A CFST transmission tower in China (when under construction).

tube and the sandwiched concrete. (2) The hollow part of CFDST member changes the stiffness of the composite section. The behaviour of CFDST members under local bearing may depend on the hollow ratio (χ), as defined in the following equation:

$$\chi=\frac{d_i}{d_o-2t_o} \tag{1}$$

where d_o and d_i are the diameter of the outer and inner steel tube, respectively; t_o is the steel wall thickness of the outer tube. Due to the reasons stated above, there is a need to investigate and to gain a rational understanding of the load transfer mechanism and full-range behaviour of circular CFDST subjected to local bearing forces, also to ensure the reliable and ductile connections for the potential CFDST construction.

This paper presents both experimental and analytical study on the behaviour of circular CFDST under local bearing forces. The objectives of this paper are thus threefold: (1) to report a series of tests on circular CFDST specimens under local bearing forces. The results are compared with those of the reference CHS and CFST. (2) To present a finite element analysis (FEA) modelling on circular CFDST members under local bearing forces, which is verified using the test results. (3) To conduct analysis on the full-range behaviour and load transfer mechanism of circular CFDST members subjected to local bearing forces, based on which simplified methods for the prediction of strength are proposed.