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Compressive strength of circular concrete-filled double skin tubular short columns

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ABSTRACT

This paper focuses on the compressive strength of the concrete-filled double skin steel tubular (CFDST) short columns. Columns with external and internal circular carbon steel tubes are merely considered. First, this paper summarises previously developed formulas for predicting the compressive strength of the CFDST columns, along with the formula recently suggested by Yu et al. (2013) for solid and hollow circular concrete-filled tubular (CFST) columns. The various formulas for predicting compressive strength are then compared with test results. Test results are then organised and evaluated according to the relevant test specimen parameter; the diameter-to-thickness ratio (D/t_e). It is found that the available tests do not cover the full range of the D/t_e ratio. Hence, numerical nonlinear simulations, based on the finite element (FE) method using the software package ABAQUS/Standard, are constructed to compensate for the shortage in the available results. Through comparison with test and FE results, a new design formula is suggested. Such formula is shown to be more accurate than available formulas for estimating the compressive strength of the CFDST short columns. This recommended design model requires relatively less calculation efforts, and provides less scattered predictions than those using the current design rules. At the end, an illustrative example for the calculation of the compressive strength of the CFDST columns using the currently proposed formula is provided.

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1. Introduction

Because of the local and global stability concerns preventing bare steel tubes from developing their full yielding strengths, composite columns were initially suggested. There is a wide variety of composite column types of varying cross-section, but the most commonly used and studied are encased I-section, concrete-filled steel tubes and more recently the double skin columns. A concrete-filled steel tubular (CFST) column is formed by filling a steel tube with concrete, while the concrete-filled double skin steel tubular (CFDST) column is formed by pouring concrete in between two steel elements (external and internal tubes); see Fig. 1. Application of the CFDST columns was found to reduce the own weight of the structure due to their hollow sections. The CFDST columns have also been recognised to have a series of advantages, such as high strength, bending stiffness and fire performance along with favourable construction ability. Additionally, they were found to be advantageous to seismic resistant structures such as high raise bridge pier owing to mitigate seismic force against foundation. Recently, the behaviour of the CFDST columns become of great interest to design engineers, infrastructure owners and researchers. Accordingly, different factors affecting the strength and behaviour of the CFDST columns were effectively discussed [1–8].

This paper focuses on the compressive strength of the CFDST short columns (Fig. 1(b)). The compressive strength of the CFDST columns has been studied extensively. For example, Uenaka et al. [4] presented test results for the compressive strength of the CFDST columns. Consequently, they suggested an equation to estimate their ultimate strengths based upon the yielding strengths (f_{sy}) of the tubes and the filled concrete cylinder strength (f'_c). Han et al. [5] investigated the behaviour of the CFDST columns and developed a formula for predicting their nominal compressive strength. Han et al. [7] presented experimental results for the CFDST columns loaded predominantly in compression with external stainless steel tubes. More recently, it was found by Hassanein et al. [8] that the existing design guidance of the ACI code [9] for the CFST columns provides overly conservative results for the circular CFDST columns. However, Hassanein et al. [8] suggested a design model to estimate the compressive strength of the CFDST columns based upon the results of 48 virtual tests. However, the diameter-to-thickness ratio of internal steel tube (d/t_i) was found to have no effect on the strength of the CFDST short columns [6,8]. This is because the internal steel tube contributes comparatively little to the column

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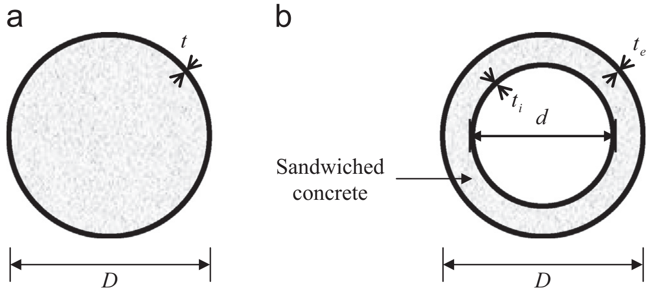

Fig. 1. Types of circular concrete-filled tubular short columns. (a) CFST (b) CFDST.

strength. On the other hand, it was found that the axial capacities of the CFDST short columns depend on the confinement effect of the external tube rather than that of the internal tube. Hence, the most important parameter affecting the strength of the CFDST short columns is the diameter-to-thickness ratio of the external tubes (D/t_e) [4–8].

This paper summarises previously developed formulas for predicting the compressive strength of the CFDST short columns [4,5,8], along with the formula recently suggested by Yu et al. [10] for solid and hollow circular concrete-filled tubular (CFST) columns. These various formulas were then compared with test results from previous research on the CFDST columns with circular external and internal steel tubes [4,11–13]. The test results were next organised and evaluated according to the relevant test specimen parameter (D/t_e). The verified finite element (FE) models, found in detail in Ref. [8] for the same authors, were after that conducted to add new results to literature. A new formula is finally developed. From the comparison with test and FE results, the new formula is shown to be more accurate than previous formulas for estimating the compressive strength of the CFDST short columns.

2. Goals and objectives

The objective of this paper is to provide data to engineers on the strength of the CFDST short columns under axial compressive loads. As a result, the following new points are added to literature for the first time:

1. The paper expands the available design strengths for the CFDST columns. This was made by utilising a *modified* version from the unified axial load bearing capacity for the solid and hollow circular CFST columns recently proposed by Yu et al. [10],
2. the paper provides a wider D/t_e range for the CFDST columns compared to that available in the literature. This was made by generating FE modelling results ($D/t_e \le 47$ and $D/t_e > 150$) which substitute the lack in the current D/t_e range,
3. the paper divides the D/t_e range of the CFDST columns into three parts; $D/t_e \le 47$, $47 < D/t_e \le 150$ and $D/t_e > 150$). Then, it identifies *the design model* that best fits the strengths of the CFDST columns of each D/t_e range, and
4. finally, the paper suggests a new design model that provides weight savings compared to the other available models.

3. Formulas for compressive strength

This section reports recent advances in the design methods relevant to the compressive strengths of the CFDST columns; Uenaka et al. [4], Han et al. [5,7] and Hassanein et al. [8]. It should be noted that other suggested methods required in the coming comparisons are also included.

3.1. ACI code

The ACI code [9] ignores the concrete confinement effect. The ACI equation for the ultimate axial strength ($P_{u,ACI}$) of a concrete-filled circular column incorporating the contribution of the internal tube is given as

$$P_{u,ACI} = f_{sye}A_{se} + 0.85f'_cA_{sc} + f_{syi}A_{si} \tag{1}$$

where A_{se} is the cross-sectional area of the external steel tube, A_{sc} is the cross-sectional area of the concrete infill between both tubes, f'_c is the unconfined cylindrical concrete strength, and A_{si} is the cross-sectional area of the internal steel tube. f_{sye} and f_{syi} are the yield strengths of the external and internal steel tubes, respectively.

3.2. Design strength by Uenaka et al.

An axial ultimate load for the CFDST columns was proposed by Uenaka et al. [4]. They estimated the capacity of the CFDST columns via introducing an experimental confined coefficient. In their proposed strength, the experimental confined coefficient $(2.86-2.59(d/D))$ is to be multiplied to the contribution of the external tube as follows:

$$P_{u,Uenaka} = \left(2.86-2.59\frac{d}{D}\right)f_{sye}A_{se} + f_{syi}A_{si} + A_{sc}f'_c \quad \text{with } 0.2 < \frac{d}{D} < 0.7 \tag{2}$$

3.3. Design strength by Han et al.

This is a kind of superposition model [5,7] which is used to determine the capacity of the CFDST short columns ($P_{u,Han}$) as follows:

$$P_{u,Han} = N_{osc,u} + N_{i,u} \tag{3}$$

where $N_{osc,u}$ is the compressive capacity of the external tube with the sandwiched concrete and $N_{i,u}$ is the compressive capacity of the internal tube computed as $\left(A_{si}f_{syi}\right)$.

The determination of the compressive capacity of the external steel tube with the sandwiched concrete $N_{osc,u}$ is given as follows:

$$N_{osc,u} = f_{scy}A_{sco} \quad \text{with } A_{sco} = A_{se} + A_{sc} \tag{4}$$

where A_{sc} is the cross-sectional area of concrete and A_{se} is the cross-sectional area of the external steel tube.

$$f_{scy} = C_1\chi^2\sigma_{0.2} + C_2(1.14+1.02\zeta)f_{ck} \quad (f_{scy} \text{ and } f_{ck}\ [\text{N/mm}^2]) \tag{5}$$

where $C_1 = \alpha/(1+\alpha)$ and $C_2 = (1+\alpha_n)/(1+\alpha)$.

α and α_n are the steel ratio and nominal steel ratio, respectively, calculated as

$$\alpha = \frac{A_{se}}{A_{sc}}$$

$$\alpha_n = \frac{A_{se}}{A_{c,no\min al}}$$

$A_{c,no\min al}$ is the nominal cross section area of concrete given by $\pi(D-2t_e)^2/4$, f_{ck} is the characteristic concrete strength ($0.67f_{cu}$), f_{cu} is the characteristic cube strength of concrete, χ is the hollow section ratio given by $d/(D-2t_e)$ and ζ is the confinement factor ($A_{se}f_{sye}/A_{c,no\min al}f_{ck}$).

3.4. Design strength for the unified solid and hollow CFST columns [10]

A unified axial load bearing capacity for the solid and hollow circular CFST columns was recently proposed by Yu et al. [10],

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