

Mechanical performances of concrete-filled steel tubular stub columns with round ends under axial loading



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ABSTRACT

An experimental study of 22 concrete-filled round-ended steel tubular (CFRT) stub columns under axial compression is conducted compared with 4 circular concrete-filled steel tubular (CFT) stub columns. The influences of width–thickness ratio, concrete strength, steel yield strength and wall-thickness of steel tube on the ultimate bearing capacity of the CFRT columns are discussed. The 3D finite element (FE) model is also developed to analyze the behavior of the CFRT columns under axial compression. From the results, local buckling of the round-ended steel tube associated with shear failure of in-filled concrete could be observed. With the increasing width–thickness ratio, the corresponding load–strain curves have a shorter elastic–plastic stage. The parametric studies indicate that the concrete strength, tube thickness and width–thickness ratio of the steel tube also have a great effect on the ultimate bearing capacity. The numerical results also show that the confinement effect of the stub columns decreases with the increasing width–thickness ratio. A practical calculation formula for the bearing capacity of the CFRT stub columns is proposed, which is well in agreement with the experimental results.

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1. Introduction

Concrete-filled steel tube (CFT) columns have been increasingly used in the construction of bridges, high-rise building, transmission tower and warehouses etc. It is well known that CFT columns have been frequently used in numerous engineering structures owing to their excellent structural behavior in terms of high strength, high ductility, high stiffness and full usage of construction materials. In the past, many studies on CFT columns have been conducted, such as Schneide [1], Hassanein et al. [2–4], Chang et al. [5–8], Ellobody [9], Yu et al. [10], Thayalan et al. [11], Mohamed [12], Tu et al. [13], Uenaka [14], Ren et al. [15], Ding et al. [16], Han [17], Tao et al. [18], Lam and Williams [19], Sakino et al. [20] etc.

With the development of heavy haul railway and highway bridges, requirements for the bearing capacity and ductility of the pier become higher. In order to meet the requirement of capacity and ductility, the concrete-filled round-ended steel tubular (CFRT) bridge pier column is proposed and has been applied in actual engineering [21,22]. Fig. 1 shows the cross-section of the CFRT column, where B is the sectional width, D is the sectional

thickness of the column and t is the wall-thickness of steel tube. According to [23], the CFRT column has not only high bearing capacity, plastic toughness, convenient construction, and low cost advantages but also has the following advantages:

(1) The CFRT column has a good external model, and can meet the requirement of architectural esthetics.

(2) The CFRT column has strong axis and the weak axis, and the strong axis has strong stability.

(3) The circular arc section of the CFRT column is more smooth than any other section of the form of concrete-filled steel tube, which can effectively resist running water of other liquid impact. For example in the river bridge across the river, it can reduce the impact of water load and prolong the service life of the pier.

Thanks to the excellent features of CFRT columns, therefore, CFRT columns have a good application prospect in bridge structure. In recent years, there is also some research reported on CFRT stub columns. Wang et al. [23] reported that the experimental research of concrete-filled round-end steel tubular stub columns under axial compression was carried out with different sectional aspect ratio, steel ratios and the structural measures. It can be found from experiments that core concrete can be confined by the steel tube. Xie et al. [24] studied the behavior of round-ended concrete-filled steel tube (CFST) coupled column. Han [25] investigated the behavior of round-end stainless steel-concrete-carbon steel double-skin tubular stub columns; the test results showed this type of hybrid column with high bearing capacity and

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Nomenclature

A_c	cross-sectional area of core concrete
A_s	cross-sectional area of steel tube
A_{c1}	the constrained concrete area
A_{s1}	the constrained steel tube area
A_{c2}	the unconstrained concrete area
A_{s2}	the unconstrained steel tube area
B	sectional width of CFRT stub column
D	sectional thickness of CFRT stub column
DI	ductility index
E_c	elastic modulus of concrete
E_s	elastic modulus of steel
f_c	uniaxial compressive strength of concrete
f_{cu}	cubic compressive strength of concrete
f_s	yielding strength of steel
K	coefficient of confinement effect
L	height of specimen
N	axial load
N_u	axial ultimate bearing capacity
$N_{u,1}$	ultimate bearing capacity of CFRT stub columns from FE results
$N_{u,2}$	ultimate bearing capacity of CFRT stub columns from Eq. (11)

$N_{u,0}$	ultimate bearing capacity of CFRT stub columns from experimental results
t	wall thickness of steel tube
σ	axial stress
$\sigma_{L,c}$	axial stress of concrete
$\sigma_{L,c1}$	the axial compressive stress of constrained concrete
$\sigma_{L,c2}$	the axial compressive stress of unconstrained concrete
$\sigma_{r,c1}$	radial constrained concrete stress caused by steel tube
$\sigma_{L,s}$	axial stress of steel tube
$\sigma_{L,s1}$	the round-ended steel tube's axial compressive stress
$\sigma_{L,s2}$	the rectangular steel tube's axial compressive stress
$\sigma_{r,c2}$	unconstrained concrete stress
$\sigma_{\theta,st}$	tensile transverse stress of steel tube
$\sigma_{\theta,s1}$	constrained transverse stress of the steel tube
$\sigma_{\theta,s2}$	unconstrained transverse stress of the steel tube
ϵ_L	axial strain
$\epsilon_{\theta,s}$	tensile transverse strain of steel tube
ϵ_I	equivalent strain of steel
ϵ_y	yielding strain of steel
ϵ_{st}	strengthening strain of steel
ϵ_u	ultimate strain of steel
Φ	confinement index
ρ	steel ratio

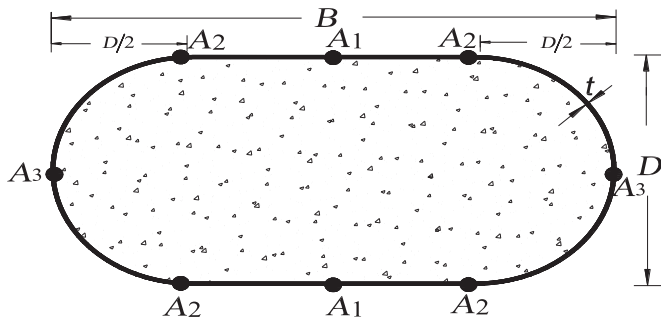


Fig. 1. Section of the CFRT stub column.

good ductility. However, more attention has been paid to the smaller width–thickness ratio ($1 < B/D < 3$), the round-end stainless steel–concrete–carbon steel double-skin tubular stub column and round-ended CFST coupled column. In addition, Wang et al. [23] then calculated the bearing capacity of the CFRT stub column based on a practical calculation formula for the bearing capacity of the concrete-filled rectangular steel tube columns. However, any formula concerning the capacity of CFRT stub column is still in absence.

In this paper, in order to comprehensively study the mechanical behavior of CFRT stub columns and the confining effect of width–thickness ratios on core concrete. Compressive tests are conducted on 22 CFRT stub columns, with various width–thickness ratios (from 1 to 4), concrete strengths, the steel thicknesses and steel yield strengths. The effects of such parameters on the load–strain curves, load-bearing capacities and column ductility are discussed

in detail. Especially, when width–thickness ratio (B/D) equals to 1, the hybrid column is reduced to the circular concrete-filled steel tubular (CFT) stub column. Further, 4 circular CFT ($B/D = 1$) stub columns are also examined for comparison. As an attempt to give a further insight on the performances of the proposed columns, a numerical analysis based on the ABAQUS/standard is also carried out. A practical calculation formula for the bearing capacity of CFRT stub columns is also proposed.

2. Experimental program

2.1. Specimens and materials

Three types of steel are adopted in the test. For each type of steel, three tension coupons are cut with dimensions in accordance with the Chinese Standard GB2975 [26] to determine the steel material properties. The average yield strengths are found to be 327.7 MPa, 311 MPa and 299.5 MPa. The cube strength and elastic modulus of concrete are measured in accordance with the Chinese standard GBJ81-85 [27]. Four types of concretes are used and their cube strengths are 39.3 MPa, 40.4 MPa, 50.4 MPa and 57.4 MPa. The fine aggregate used is silica based sand; the coarse aggregate is carbonate stone and the mix ratio is summarized in Table 1.

2.2. Test specimens

A total of 26 specimens are designed for this study and the details are shown in Table 2, where t is the wall thickness of steel

Table 1
Concrete mix proportions.

Concrete strength level	Mix ratio	Water (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Aggregates (kg/m ³)	water reducer (kg/m ³)
C30	0.38	175	420	512	1252	4.10
C40	0.34	168	432	320	1201	4.32
C50	0.38	164	461	686	1118	5.11

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