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Composite action of hexagonal concrete-filled steel tubular stub columns under axial loading

Fa-xing Ding [a], Zhe Li [a], Shanshan Cheng [b,*], Zhi-wu Yu [c]

[a] School of Civil Engineering, Central South University, Changsha 410075, PR China
[b] Department of Civil and Structural Engineering, University of Sheffield, United Kingdom
[c] National Engineering Laboratory for High Speed Railway Construction, Changsha 410075, PR China

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ABSTRACT

Four groups of axial compression tests on hexagonal CFT stub columns have been carried out aiming to investigate the effects of the concrete strength and steel ratio on the behaviour of hexagonal CFT stub columns. Studies on parametric analysis and composite action between core concrete and steel tube have been carried out using FE modelling which had been benchmarked using the test data. Based on the essential data obtained in this paper, the ratio of axial stress-yield strength of steel tube was determined at the ultimate state. The stress contour of core concrete was simplified to an unconfined area without constraint and a confined area with uniform constraint imposed by hexagonal steel tube. Eventually, a practical design equation of the ultimate bearing capacity of hexagonal CFT stub columns was proposed based on the superposition principle. An excellent agreement between the proposed equation and the experimental results was observed, with an average ratio of predicted to measured capacity of 1.08 and a standard deviation of 0.05.

1. Introduction

A concrete-filled steel tube (CFT) column is a composite member formed by a steel tube filled with concrete. The concrete core adds stiffness to the steel tube and prevents the occurrence of inward local buckling, while the steel tube confines the concrete core and acts as longitudinal and lateral reinforcement. Due to the benefit of composite action of the two materials, the CFT columns provide excellent structural properties such as high strength, high ductility and large energy absorption capacity. Since 1970s, CFT has been widely used in high-rise, long-span structures [1,2], not only due to the favourable structural properties, but also the rapid construction without removing any formwork.

Extensive research on effects of cross-sectional profiles of CFT columns has been conducted in literature. Experimental and numerical studies of circular [3–11], elliptical [12–14], octagonal [15], and square [16–20] CFT columns have been carried out in studying the axial load bearing capacity of CFT columns. A unified formula for CFT columns circular and polygonal cross-sectional profiles subjected to axial compression has been obtained by Yu et al. [21]. However, available studies on hexagonal CFT stub columns are rather few in literature, although hexagonal cross-sections are commonly demanded in architectural design. Ketema and Taye [23] studied the moment-axial load interaction for hexagonal and octagonal CFT columns subjected to uniaxial bending, and a unified approach has been presented for designing purpose. Circular, hexagonal, rectangular and square cross-sections have been tested by Evirgen et al. [24] recently with the focus on the effects of width-thickness ratio (b/t), the compressive strength of concrete and geometrical shape of cross section parameters on ultimate loads, axial stress, ductility and buckling behaviour.

The effects of the concrete strength and steel ratios on the mechanical behaviour of hexagonal CFT stub columns were investigated in this paper. Eight axial compression specimens of hexagonal CFT stub columns have been conducted at the Central South University in China. The nonlinear finite element analysis of hexagonal CFT stub columns throughout loading history has been carried out using ABAQUS. Based on the essential experimental and numerical data, practical formulas for the ultimate bearing capacity of hexagonal CFT stub columns have been proposed by using superposition principle at the ultimate state, which follows the same research idea as Ding et al. [22]. Details of the studies have been explained in the following sections of this paper.

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* Corresponding author.
E-mail address: shanshan.cheng@sheffield.ac.uk (S. Cheng).

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Nomenclature

A_c	Cross-sectional area of core concrete
A_{c1}	Non-constrained area of core concrete
A_{c2}	Constrained area of core concrete
A_s	Area of steel tube
A_{sc}	Total area of cross-section
B	Edge length of the hexagonal section
b	Edge length of core concrete
DI	Ductility index
E_s	Elastic modulus of steel tube
f_{b0}	Initial equibiaxial compressive yield stress of concrete
f_c	Uniaxial compressive strength of concrete
f_{c0}	Initial uniaxial compressive yield stress of concrete
f_{cu}	Compressive cubic strength of concrete
f_{sc}	Ultimate strength of CFT column
f_u	Ultimate strength of steel tube
f_y	Yield strength of steel tube
k	Ratio of initial tangent modulus to secant modulus at peak stress
L	Height of specimens
N	Axial load
N_u	Axial ultimate bearing capacity
$N_{u,c}$	Ultimate bearing capacity of hexagonal CFT stub columns from calculated results
$N_{u,\ Eq.14}$	Ultimate bearing capacity of hexagonal CFT stub columns from Eq. (14).
$N_{u,\ Exp}$	Ultimate bearing capacity of hexagonal CFT stub columns from experimental results
$N_{u,\ FE}$	Ultimate bearing capacity of hexagonal CFT stub columns from FE results
p	Lateral pressure coefficient
t	Wall thickness of steel tube
σ	Axial stress of concrete
σ_i	Equivalent stress of steel tube
$\sigma_{L,c}$	Axial compressive stress of core concrete
$\sigma_{L,s}$	Axial compressive stress of steel tube
$\sigma_{r,c}$	Radial concrete stress of the confined area
$\sigma_{\theta,s}$	Tensile transverse stress of steel tube
$\varepsilon_{0.75}$	Axial strain when the load attains of 75% the ultimate load in the pre-peak stage
$\varepsilon_{0.85}$	Strain when experimental bearing capacity is decreased to 85% of ultimate value
ε	Axial strain of concrete
ε_c	Strain corresponding with the peak compressive stress of concrete
ε_L	Axial strain of columns
ε_i	Equivalent strain of steel tube
ε_y	Yield strain of steel tube
ε_{st}	Hardening strain of steel tube
ε_u	Ultimate strain of steel tube
ν_{sc}	Strain ratio of steel tube
θ	Dilation angle of concrete
ρ	Steel ratio of columns

2. Experimental investigation

2.1. Test set-up

In total 8 specimens of hexagonal CFT were designed in this study. The nominal dimension of each specimen is 200 (B) mm × 4 (6) (t) mm × 1200 (L) mm, where B is the outer edge length of the hexagonal section, t is the wall thickness of the steel tube and L is the height of the specimen. Detailed cross-sectional dimensions and material properties are shown in Fig. 1 and in Table 1 respectively. Two identical specimens (namely A and B) were made for each group and there were eight specimens in total.

The hexagonal steel tubes were moulded by bending Q235 steel plates into grooves and then welding the two edges at the corner. The position at which the butt welds were made was

Table 1
Properties of tested specimens.

Specimens number	$B\times t$	L	f_{cu}	f_y	$N_{u,\ Exp}$	Steel ratio (ρ)	DI
	mm × mm	mm	MPa	MPa	kN	–	–
HST1-A	196 × 3.73	1200	39.3	311	4947	0.044	3.781
HST1-B	198 × 3.71				4618	0.043	3.288
HST2-A	196 × 5.78			321	6001	0.067	7.174
HST2-B	198 × 5.96				6041	0.068	7.569
HST3-A	197 × 3.72		57.4	311	6827	0.043	3.241
HST3-B	198 × 3.76				6803	0.043	3.294
HST4-A	199 × 5.89			321	7079	0.067	5.817
HST4-B	196 × 5.81				7289	0.067	6.387

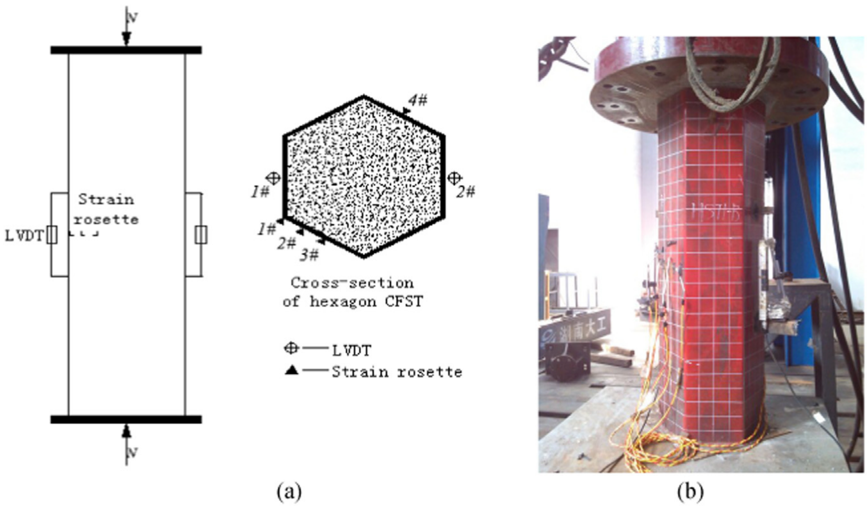

Fig. 1. Experimental instrumentation for all specimens.