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Behaviour of concrete-filled cold-formed elliptical hollow sections with varying aspect ratios

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ABSTRACT

This paper presents the experimental and numerical studies of concrete-filled cold-formed elliptical hollow sections with varying aspect ratios subjected to axial compression load. Twenty one stub columns were tested to investigate the fundamental behaviours of these elliptical concrete-filled steel tubular (CFST) columns. The axial load versus displacement curves, longitudinal and transverse strains in steel tube and failure modes were obtained and discussed. A constitutive model for concrete in the elliptical CFST columns was proposed. Finite element (FE) models were developed and validated against the test results. Parametric studies were carried out to identify the influence of key parameters on the load-bearing capacity. Key parameters included aspect ratio, steel tube to concrete area ratio, yield strength of steel and compressive strength of concrete. Finally, the applicability of relevant design methods to elliptical CFST columns was assessed on the basis of the test and the FE results of this research and other related studies. Results indicated that the design method recommended in the Chinese Standard (GB50936-2014), and the design method for circular CFST columns in EC4 were found to generate accurate predictions.

1. Introduction

Elliptical hollow section has gained much attention, recently, from engineers due to its aesthetical appearance and structural efficiency [1]. Concrete-filled elliptical hollow sections further enhance the load-bearing capacity, ductility and seismic performance [2]. These enhancements are attributed to the composite action of steel tube and concrete, of which the steel tube provides confinement to the concrete, and in turn the concrete delays or prevents the local buckling of steel tube. The degree of the confinement offered by an elliptical cross-section to the concrete infill lies between that offered by a circular cross-section (with uniform confinement) and that offered by a rectangular hollow sections (with limited confinement) which further depends on the aspect ratio of the elliptical cross-section.

To date, extensive investigations have been conducted on the behaviours of the elliptical CFST columns. Yang et al. [2], Zhao and Packer [3], Uenaka [4] and Chan et al. [5] tested the axially loaded elliptical CFST stub columns. Sheehan et al. [6] investigated the eccentrically loaded elliptical CFST stub columns experimentally and numerically. Jamaluddin et al. [7] tested the axially loaded elliptical CFST stub and slender columns. Dai et al. [8,9] numerically studied the axially loaded elliptical CFST stub columns and slender columns. Espinos et al. [10] conducted experiments on ambient and fire behaviours of eccentrically loaded elliptical CFST columns, filled with plain and reinforced concrete. Ren et al. [11] tested elliptical CFST beams and eccentrically loaded elliptical CFST slender columns. McCann et al. [12] carried out experiments on axially and eccentrically loaded elliptical CFST slender columns, filled with plain and reinforced concrete.

However, most of the above studies used hot-rolled elliptical hollow sections, and the steel tube to concrete area ratio was between 17–69%, which was higher than the common range of steel tube to concrete area ratio for CFST columns (4–20% [13]). Meanwhile, the aspect ratio (a/b) of all the commercially available hot-rolled elliptical hollow sections is 2.0, and the available dimensions of the hot-rolled section are limited, which may hinder a wider use of elliptical CFST columns in practice. Therefore, cold-formed elliptical hollow sections can be used to provide a wider range of sections for construction use. In this paper, the fundamental behaviour of cold-formed elliptical CFST columns with an aspect ratio ranging from 1.0 to 2.5 is investigated.

A series of tests was conducted to study the influence of aspect ratio and steel tube to concrete area ratio on the behaviour of elliptical CFST stub columns. After that, a finite element (FE) model was developed, using the program ABAQUS, to simulate the behaviour of the elliptical

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Nomenclature

a	major axis outer radius	f_u	ultimate tensile strength of steel
b	minor axis outer radius	H	height of column
A_c	cross-sectional area of concrete core	N_y	yield load of composite column
A_s	cross-sectional area of steel tube	N_u	cross-sectional capacity of composite column
D_e	equivalent diameter	t_s	wall thickness of the steel tube
E_c	Young's modulus of concrete	α_s	steel tube to concrete area ratio, α_s=A_s/A_c
E_s	Young's modulus of steel	ε	strain
f_{ck}	characteristic concrete strength, f_{ck}=0.67 f_{cu}	ε_f	percentage elongation at fracture of steel
f_{cu}	concrete cube strength	$\mu_\triangle$	ductility index
$f_{cu,28}$	concrete cube strength at 28 days	ν_s	Poisson's ratio of structural steel
$f_{cu,\ test}$	concrete cube strength at the test day of specimens	σ	stress
f_c'	concrete cylinder strength	$\triangle_y$	displacement at yield load
f_y	yield strength of steel	$\triangle_u$	displacement at ultimate load
		$\triangle_{0.85}$	displacement at 0.85Nu after peak load

CFST columns. A uniaxial compressive stress-strain relationship for concrete was proposed, which can account for the changes of the confinement effect of steel tube to concrete caused by the change in aspect ratio. Parametric studies were performed to identify the influence of key parameters on the load-bearing capacity of elliptical CFST columns. Finally, the test and FE results in this research, together with the test results of related studies, were compared with predictions of current codes and related design methods. The design method for elliptical CFST columns in Chinese code GB50936-2014 and the method for circular CFST columns in EC4 were found to yield good predictions for the concrete-filled cold-formed elliptical hollow sections.

2. Experimental program

2.1. General

Experiments were conducted to investigate the fundamental behaviours of the axially loaded elliptical CFST stub columns. Tests on elliptical hollow sections were also performed for comparison.

A total of 21 specimens, including 3 axially loaded elliptical hollow sections and 18 axially loaded elliptical CFST columns were tested. The key parameters were: aspect ratio a/b 1.0–2.5) and steel tube to concrete area ratio α_s (5–12%). The columns were labelled by the above-mentioned parameters. Taking the specimen *C20-5-a* for example, *C* denotes column; *20* represents the aspect ratio of 2.0; 5 refers to the steel tube to concrete area ratio of 5% while the finial letter identifies the different column in a group with the same parameters. In addition, group *CH20* corresponds to the elliptical hollow tubes. Detailed parameters of the specimens are given in Table 1, where a is the major axis outer radius, b is the minor axis outer radius, t_s is the thickness of the steel tube, H is the height of the column, α_s is the steel tube to concrete area ratio defined as A_s/A_c. A typical cross-section of the elliptical CFST column is shown in Fig. 1. The height of all specimens was taken as 4a to ensure short column behaviour.

The elliptical steel tubes were cold-formed from steel sheets and seam welded. A steel sheet, with a nominal thickness of 2.75 mm, was used in the test. The steel tube to concrete area ratio was kept constant while aspect ratio varied from 1.0 to 2.5, whereas the cross-sectional area varied to fulfil the variation of steel tube to concrete area ratio. The properties of the parent steel sheets were determined by performing tensile coupon tests according to the Chinese Standard GB/T 228–2010 [14] and were summarised in Table 2, in which E_s is the elastic modulus, f_y is the yield strength, f_u is the ultimate tensile strength, ν_s is

Table 1
Detailed parameters of the specimens.

Column No.	2a (mm)		2b (mm)		t_s (mm)		Designed H (mm)	a/b	Nominal α_s (%)
	Designed	Measured	Designed	Measured	Nominal	Measured			
CH20-a	203.3	200.0	101.6	100.5	2.75	2.60	407	2.0	–
CH20-b	203.3	201.0	101.6	101.5	2.75	2.60	407	2.0	–
CH20-c	203.3	201.2	101.6	101.7	2.75	2.61	407	2.0	–
C10–8-a	135.3	136.5	135.3	136.5	2.75	2.63	271	1.0	8.0
C10–8-b	135.3	137.0	135.3	137.0	2.75	2.61	271	1.0	8.0
C10–8-c	135.3	137.8	135.3	137.8	2.75	2.64	271	1.0	8.0
C15–8-a	169.2	170.0	112.8	112.0	2.75	2.62	338	1.5	8.0
C15–8-b	169.2	169.6	112.8	111.0	2.75	2.61	338	1.5	8.0
C15–8-c	169.2	168.0	112.8	112.5	2.75	2.60	338	1.5	8.0
C20–8-a	203.3	202.0	101.6	99.0	2.75	2.60	407	2.0	8.0
C20–8-b	203.3	199.8	101.6	100.8	2.75	2.60	407	2.0	8.0
C20–8-c	203.3	201.5	101.6	100.4	2.75	2.59	407	2.0	8.0
C25–8-a	237.5	236.0	95.0	95.8	2.75	2.62	475	2.5	8.0
C25–8-b	237.5	237.5	95.0	96.0	2.75	2.58	475	2.5	8.0
C25–8-c	237.5	236.0	95.0	96.5	2.75	2.61	475	2.5	8.0
C20–5-a	318.0	318.0	159.0	155.0	2.75	2.59	636	2.0	5.0
C20–5-b	318.0	318.5	159.0	151.5	2.75	2.60	636	2.0	5.0
C20–5-c	318.0	317.0	159.0	153.5	2.75	2.60	636	2.0	5.0
C20–12-a	139.6	139.0	69.8	68.0	2.75	2.59	279	2.0	12.0
C20–12-b	139.6	138.0	69.8	68.2	2.75	2.61	279	2.0	12.0
C20–12-c	139.6	137.5	69.8	68.0	2.75	2.58	279	2.0	12.0