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Behaviours of concrete-filled cold-formed elliptical hollow section beam-columns with varying aspect ratios

Hua Yang[a,b], Faqi Liu[a,b,*], Tak-ming Chan[c], Wei Wang[a,b]

[a] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China

[b] Key Lab of Smart Prevention and Mitigation of Civil Engineering Disasters of the Ministry of Industry and Information Technology, Harbin Institute of Technology, Harbin 150090, China

[c] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Experimental and numerical studies were conducted to investigate the behaviours of the concrete-filled cold-formed elliptical hollow section beam-columns. A total of 11 specimens were tested to evaluate the failure modes, load-deformation histories and strains development in the steel tube. Complementary finite element (FE) models were developed and validated against experimental results. Validated FE methodology was then used to study the influence of key parameters, including aspect ratio, slenderness ratio, load eccentricity ratio, yield strength of steel, compressive strength of concrete and steel tube to concrete area ratio, on the load carrying capacity. As a result, the design method for elliptical concrete-filled steel tubular (CFST) columns in Chinese code - GB50936-2014 and the design method for circular CFST columns in EC4 were assessed to confirm their applicability for cold-formed elliptical CFST columns with aspect ratio ranging from 1.0 to 2.5.

1. Introduction

Concrete-filled steel tubular (CFST) column is well known for its high load-carrying capacity and good ductility due to the complementary characteristics between outer steel tube and inner concrete: the steel tube provides confinement to the concrete, thereby enhancing the strength and ductility of concrete, while the inner concrete on the other hand delays or even prevents local buckling of the steel tube, which increases the efficiency of the steel tube. The cross-section shape of the CFST column is generally circular, square or rectangular. In recent years, elliptical shape has been introduced into structural engineering because of its aesthetic appearance and structural efficiency [1]. To date, Yang et al. [2], Zhao and Packer [3], Dai and Lam [4], Jamaluddin et al. [5] have studied the cross-section behaviour of the elliptical CFST columns. Sheehan et al. [6] investigated the behaviours of eccentrically loaded elliptical CFST stub columns. Dai et al. [7], McCann et al. [8], Mahgub et al. [9] and Qiu et al. [10] studied the axially and eccentrically loaded slender elliptical CFST columns. Ali et al. studied the behaviour of elliptical CFST columns exposed to hydrocarbon fire [11,12].

All the above studies used hot-finished elliptical hollow sections, and the steel tube to concrete area ratio ranges from 13.2% to 38.9%, most of which exceeds the common range of steel tube to concrete area ratio of CFST column (4% to 20% [13]). And all these sections have a constant aspect ratio of 2.0. However, aspect ratio is an essential parameter which will affect the structural performance. If the aspect ratio approximates to 1.0, its performance resembles to a circular section while with an increase in the aspect ratio, the behaviour would tend to be similar to a rectangular section [14]. The confinement effect of steel tube to concrete also varies correspondingly with the varying aspect ratio, which further affects the load-carrying capacity and ductility. The varying aspect ratio can be achieved by cold-forming the elliptical shape.

Recently, a few studies have been conducted on the concrete-filled cold-formed elliptical hollow sections. Uenaka [15] and Chan et al. [16] investigated the behaviour of concrete-filled cold-formed elliptical hollow section stub columns. Ren et al. [17] tested the behaviours of concrete-filled cold-formed elliptical hollow section beams and columns. Uenaka and Tsunokake tested the concrete-filled cold-formed elliptical hollow section columns under pure bending [18] and combined bending and shear [19]. Espinos et al. [20] tested the ambient and fire behaviours of eccentrically loaded concrete-filled cold-formed elliptical hollow section slender columns.

Table 1 summarizes the previous studies on the elliptical CFST columns, in which a is the major axis outer radius, b is the minor axis outer radius, t_s is the steel wall thickness, α_s is the area ratio of steel

* Corresponding author at: Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China.
E-mail address: fqliu@hit.edu.cn (F. Liu).

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Nomenclature

a	major axis outer radius	f_c	concrete cylinder strength
b	minor axis outer radius	f_y	yield strength of steel
A_c	cross-sectional area of concrete core	L	length of column
A_s	cross-sectional area of steel tube	L_e	effective length of column
D_e	equivalent diameter	M	bending moment
e	Load eccentricity	N	axial force
E_c	Young's modulus of concrete	t_s	wall thickness of the steel tube
E_s	Young's modulus of steel	α_s	steel tube to concrete area ratio, $\alpha_s = A_s/A_c$
		λ	slenderness ratio
		χ	buckling reduction factor

tube to concrete $= A_s/A_c$ (in which A_s and A_c is the cross-section area of steel tube and cross-section area of concrete, respectively), L is the column length and e is the load eccentricity.

To date, no study has been reported on the cold-formed elliptical CFST beam-columns with varying aspect ratios. The authors have been carrying research on the behaviours of cold-formed elliptical CFST columns with varying aspect ratios. The first phase of the research focuses on the cross-section behaviours of cold-formed elliptical CFST stub columns under axial compression with an aspect ratio ranging from 1.0 to 2.5. Findings have been summarised in [21]. This paper expands the studies to the cross-section and member behaviours of cold-formed elliptical CFST beam-columns with varying aspect ratios.

A total of 11 specimens were tested to illustrate the fundamental behaviours of the axially loaded and eccentrically loaded slender

Table 1
Ranges of parameters from previous studies.

Fabrication method	Member	Reference	$2a$ (mm)	$2b$ (mm)	a/b	t_s (mm)	α_s (%)	L (mm)	e (mm)	Buckling axis	Number of specimens
Hot-finished	Stub column	Yang et al. [2]	150	75	2.0	4, 5, 6.3	18.2, 23.6, 31.2	300	0	-	21
		Zhao and Packer [3]	150	75	2.0	4, 5, 6.3	18.2, 23.6, 31.2	500	0	-	12
			200	100	2.0	5, 6.3, 8, 10	17.0, 22.1 29.4, 38.9	600			
			220	110	2.0	6	18.7	698			
			320	160		8	17.0	-			
		Jamaluddin et al. [5]	150	75	2.0	4.0	18.2	$4a$	0	-	6
			200	100		5.0	17.0				
	Slender column	Jamaluddin et al. [5]	150	75	2.0	4.0	18.2	λ = 16-143	0	Minor	18
			200	100		5.0	17.0				
		Mahgub et al. [9]	150	75	2.0	6.3	31.2	1500, 2000, 2500	0	Minor	8
			250	125			17.1	2000			
	Slender column (fire)	Ali et al. [11]	200	100	2.0	8	29.4	1800	0	Minor	3
		Ali et al. [12]	200	100	2.0	8	29.4	1800	0	Minor	9
			300	150			18.2				
			400	200			13.2				
	Beam-column	Sheehan et al. [6]	150	75	2.0	6.6, 4.8	33.2, 22.8	300	25, 75, 100	Minor & Major	8
		McCann et al. [8]	150	75	2.0	6.3	31.2	1154, 2154, 3154, 300 (stub)	0-2a 0-1.33b	Minor & Major	27
Cold-formed	Stub column	Uenaka [15]	160	107	1.5	1.0	3.2-10.9	160, 200, 250	0	-	21
				80	2.0	1.6					
				64	2.5	2.3					
		Chan et al. [16]	120	60	2.0	5, 8	30.9, 57.3	250	0	-	6
		Liu et al. [21]	135.3	135.3	1.0	2.75	8.0	$4a$	0	-	18
			169.2	112.8	1.5		5.0				
			203.3	101.6	2.0		12.0				
			237.5	95	2.5						
			318	159							
			139.6	69.8							
	Beam-column	Ren et al. [17]	192	124	1.5	3.8	11.0	λ = 38, 56, 75	0, 48, 144	Major	14
	Beam-column (fire)	Espinos et al. [20]	220	110	2.0	12	43.6	2135	0, 20, 50	Minor	6
	Beam	Ren et al. [17]	192	124	1.5	3.8	11.0	-	-	Major	6
		Uenaka and Tsunokake [18]	160	80	2.0	1.0	3.9	-	-	Minor & Major	6
						1.6	6.3				
						2.3	9.2				
		Uenaka and Tsunokake [19]	160	80	2.0	1.0	3.9	-	-	Minor & Major	6
						1.6	6.3				
						2.3	9.2				