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Experimental investigation on lightweight concrete-filled cold-formed elliptical hollow section stub columns

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ABSTRACT

This paper presents an experimental investigation on lightweight concrete-filled circular and elliptical hollow sections under axial compression at cross-section level. The elliptical hollow section (EHS) was cold-formed from the hot-rolled circular hollow section (CHS). Experimental findings, including failure mode, load-deformation history and load carrying capacity, from the 24 stub column tests were compared and reported. Comparisons in particular between the parent hot-rolled CHS and cold-formed EHS were made and stub column results have indicated the cold-forming process decreases both the load carrying capacity and the ductility. Design rules based on European standards were also assessed and assessments have shown that the existing rules can be adopted for the design of lightweight concrete-filled hot-rolled CHS while a simple superposition model can be used for the design of lightweight concrete-filled cold-formed EHS.

1. Introduction

Concrete-filled steel tubular columns have been widely used in construction industry [1,2]. Due to the closed shape nature of the outer steel tube, it can confine the concrete in-fill. In return, the concrete in-fill restrains the steel tube from buckling locally inwards. As a result, concrete-filled members provide higher stiffness, ductility as well as higher compressive strength when compared with the plain steel and concrete counterparts. To date, circular, rectangular and square hollow sections are the common tubular shape. In the last decade, elliptical hollow section (EHS) has joined this tubular family to offer an alternate for designers in various applications [3,4]. Previous research under axial compression targeted the response from hot-finished elliptical hollow sections [5] in which the elliptical hollow section was heat-treated at the final stage of the manufacturing process. Design guides based on Eurocode methodology has also been proposed [6]. Concrete-filled stub columns primarily related to the normal weight concrete have also been investigated by researchers around the globe [7–12].

Gardner et al. [13] conducted an experimental investigation to compare the performance of hot-rolled and cold-formed rectangular hollow sections and assessed the applicability of using the same codified system in the design of these two types of members. Effect of material properties on hot-finished and cold-formed hollow sections was also discussed by Packer et al. [14]. Puthli and Packer [15] discussed the performance of cold-formed and hot-finished structural tubular section. In this paper, the elliptical hollow section was cold-formed from the parent hot-rolled circular hollow sections. Their structural performance was compared directly.

To further promote the use of concrete-filled tubular members, one will target to minimize the self-weight. There have been numerous research in using lightweight concrete in tubular members [16,17]. Ghannam et al. [16] compared the structural performance of concrete-filled steel tubular columns with circular, square and rectangular cross sections between normal and lightweight aggregate concrete. Results indicated better ductility was observed with lightweight aggregate concrete specimens. Mouli and Khelafi [17] conducted experimental investigation on short lightweight concrete-filled tubular columns. Results indicated that lightweight aggregate concrete offered higher bond strength than the normal concrete in the composite action. In this paper, lightweight concrete was used in the composite stub columns.

In general, the aims of this paper are (1) to compare directly the structural performance between the parent hot-rolled CHS and the corresponding cold-formed EHS; (2) to assess the structural performance of the light-weight concrete filled CHS and EHS and (3) to assess the codified values from European codes of practice. A comprehensive experimental investigation will be discussed in the next sections while results on material property, failure mode, ductility, load bearing capacity and stress–strain relationship will also be presented.

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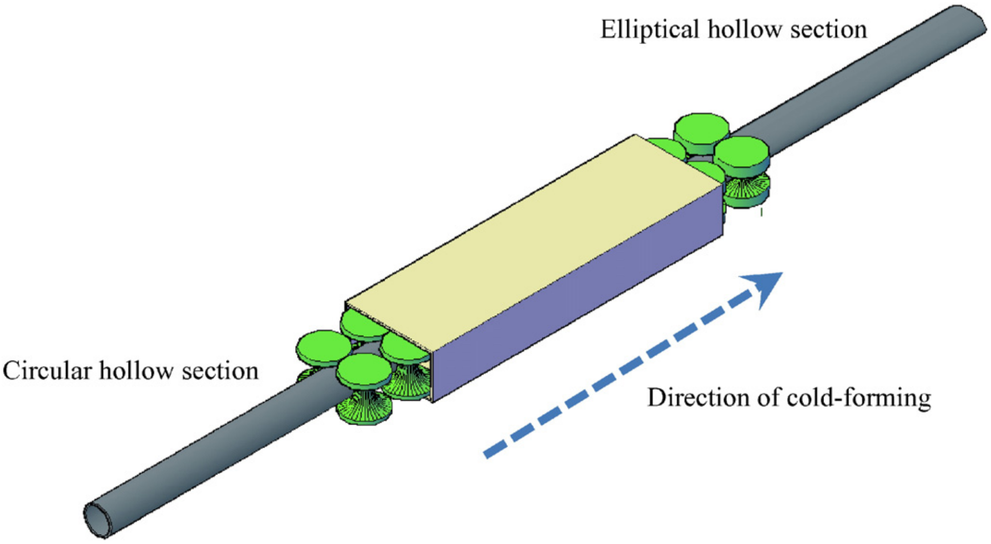

Fig. 1. Schematic cold-forming process.

2. Experimental investigation

2.1. Specimens

A total of 24 hollow and concrete-filled stub columns was tested at Tongji University, China to investigate the cross-section response. The specimen length, L, of 250 mm was carefully chosen with reference to Ziemian [18] and observations from Chan and Gardner [5] such that local buckling would be the dominant mode of failure. This arrangement also provided equal geometric conditions for the direct comparison between the parent hot-rolled CHS and the cold-formed EHS. As suggested earlier, the EHS specimens were cold formed from the parent hot-rolled CHS. The key manufacturing process involves passing the hot-rolled CHS through a series of rollers to form the EHS at ambient temperature. A schematic illustration is showed in Fig. 1. The parent hot-rolled CHS was designated as grade

Table 1
Nominal and measured geometric properties for circular hollow section specimens.

Specimen ID	Nominal dimension (mm)			Average measured dimension (mm)		Area (mm^2)		Maximum local imperfection (mm)	
	d	t	L	d	t	A_s	A_c	Inward	Outward
CH-A-SC1	95	5	250	95.5	5.3	1502	–	0.19	0.18
CH-A-SC2	95	5	250	95.5	5.3	1502	–	0.23	0.15
CH-A-SC3	95	5	250	95.5	5.4	1529	–	0.19	0.10
CH-B-SC1	95	7	250	95.6	7.5	2076	–	0.18	0.17
CH-B-SC2	95	7	250	95.6	7.4	2050	–	0.17	0.14
CH-B-SC3	95	7	250	95.6	7.4	2050	–	0.07	0.07
CF-A-SC1	95	5	250	95.4	5.4	1527	5621	0.39	0.35
CF-A-SC2	95	5	250	95.3	5.5	1552	5581	0.27	0.28
CF-A-SC3	95	5	250	95.4	5.5	1553	5595	0.14	0.30
CF-B-SC1	95	7	250	95.6	7.2	2000	5178	0.09	0.12
CF-B-SC2	95	7	250	95.6	7.6	2101	5077	0.20	0.18
CF-B-SC3	95	7	250	95.4	7.1	1970	5178	0.12	0.11

Table 2
Nominal and measured geometric properties for elliptical hollow section specimens.

Specimen ID	Nominal dimension (mm)				Average measured dimension (mm)			Area (mm^2)		Maximum imperfection (mm)	
	h	b	t	L	h	b	t	A_s	A_c	inward	outward
EH-A-SC1	120	60	5	250	120.4	60.0	5.4	1439	–	1.11	0.57
EH-A-SC2	120	60	5	250	120.2	59.5	5.2	1383	–	0.91	0.43
EH-A-SC3	120	60	5	250	120.1	59.7	5.3	1409	–	0.78	0.41
EH-C-SC1	120	60	8	250	120.2	58.1	9.0	2266	–	0.51	0.33
EH-C-SC2	120	60	8	250	120.3	57.5	8.9	2237	–	0.56	0.33
EH-C-SC3	120	60	8	250	120.3	57.5	8.9	2237	–	0.51	0.23
EF-A-SC1	120	60	5	250	119.6	59.8	5.4	1430	4187	0.91	1.02
EF-A-SC2	120	60	5	250	119.5	60.1	5.4	1432	4209	0.40	0.80
EF-A-SC3	120	60	5	250	119.5	60.8	5.4	1438	4269	0.41	1.10
EF-C-SC1	120	60	8	250	119.9	57.9	8.7	2192	3260	0.22	0.50
EF-C-SC2	120	60	8	250	119.8	58.0	8.9	2237	3220	0.31	0.80
EF-C-SC3	120	60	8	250	119.9	57.9	8.8	2214	3238	0.40	0.56