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Experimental study on concrete filled elliptical/oval steel tubular stub columns under compression

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A B S T R A C T

A concrete filled elliptical/oval steel tubular (CFEST) member consists of elliptical/oval steel tube and in-filled concrete. The CFEST member is a new type of steel–concrete composite member and is part of a family of concrete filled steel tubular members known as CFT. The present study aims to investigate, experimentally, the characteristics of CFEST stub columns under centric loading. The main test parameters selected are diameter-to-thickness and diameters ratios of elliptical/oval steel tube. From the results, local buckling of the elliptical/oval steel tube associated with shear failure of in-filled concrete could be observed. Axial loading capacity decreased as diameter-to-thickness ratio increased. Whereas, those capacities normalized by the summation of the individual strengths, namely the elliptical/oval steel tube and in-filled concrete strengths, are regulated in case the diameter-to-thickness ratio becomes larger. Finally, a method to predict the axial loading capacity induced by confinement effects of the in-filled concrete is proposed.

1. Introduction

Concrete filled elliptical/oval steel tubular (CFEST) members consist of elliptical/oval steel tube and in-filled concrete, as shown in Fig. 1. The CFEST is a new steel–concrete composite column structural member and is part of a family of concrete filled steel tubular members, the so-called CFT [1], which have good deformability and large toughness due to the effects of the confinement stresses between the steel tube and the in-filled concrete. Furthermore, when CFEST member is applied to a steel–concrete composite bridge pier located in a river, reduction of the river scouring can be expected owing to the smooth flow of the water in the riverbed.

Tracing the history of the studies on elliptical/oval hollow steel tubes with or without in-filled concrete, various mechanical investigations of CFEST, elliptical hollow steel tubes (EHS) and oval hollow steel tubes (OHS), in which the diameter-to-thickness ratio ranges from 28 to 40, can be found. First, CFEST and EHS stub column tests under centric compressive loading were performed and their design equations were discussed by Yang [2], Chan [3] and Zhao [4]. Secondly, Chan [5], Gardner [6] and Theofanous [7] carried out bending-shear tests on elliptical or oval steel/stainless beams through symmetrically three- or four-point loading tests. Thirdly, Ruiz [8] and Gardner [9] investigated the buckling behavior of the EHS long column. Next, aiming the application of gusset plate connection to the ends of the EHS, tensile test on three types of the EHS connections were also examined by Willbald [10] and Sauced [11]. Moreover, analytical study on the fire resistance of CFEST based upon non-liner FEM analysis was conducted by Episons [12]. Last, eccentric structural response of CFEST stub column under the combination of axial force and bending moment was investigated by Sheehan [13].

Under the above-described background, the present study aims to investigate, experimentally, the axial loading capacities of CFEST stub columns with large diameter-to-thickness ratio, which ranges from 69 to 160, and are to be applied to steel concrete bridge piers located in rivers. The three selected parameters are diameter-to-thickness ratio ($2a/t$ and $2b/t$), diameters ratio (a/b) and specimen's height (H), respectively. Discussion on confinement intensity effects induced by the elliptical/oval steel tubes is provided. Additionally, a method to predict the axial loading capacitiy of CFEST stub columns induced by the confinement strength of the in-filled concrete is also provided. Part of this study have been previously reported in Japan [14].

2. Experimental testing

2.1. Test specimens

The details of the specimens are summarized in Table 1. Test specimens dimensions are combinations of different tube

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thicknesses (t), diameter ratios (a/b) and specimen heights (H). Thin steel plates ($t=1.0$, 1.6 and 2.3 mm) are bent into elliptical/oval shape, then both ends of the plate are welded to each other.

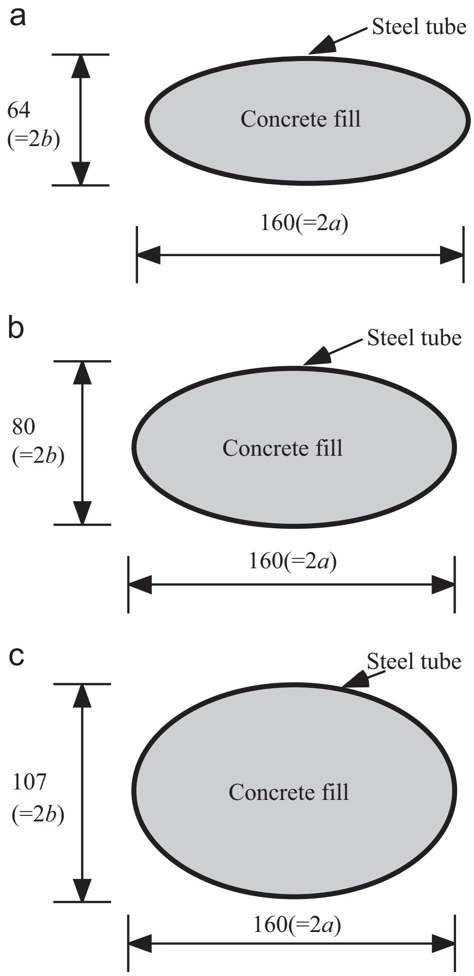

Fig. 1. Cross sections of CFEST. (a) $a/b=2.5$. (b) $a/b=2.0$. (c) $a/b=1.5$.

The larger diameter $2a$, common to all cross sections, is 160 mm and the smaller diameter $2b$ are 64, 80 or 107 mm, respectively; what provides diameter ratios a/b equal to 1.5, 2.0 or 2.5. Whereas, the diameter-to-thickness ratios of major axis ($2a/t$) range from 69 to 160, which are greater than the ratios of previous studies that varied from 28 to 40. Additionally, the diameter-to-thickness ratios of minor axis varies from 27 to 107. Specimens' heights (H) are 160, 200 ($a/b=2.0$) and 250 mm.

In order to obtain a flat loading surface on the concrete filling, the top of the specimen was capped by cement paste with water-cement ratio of 30%. Centric load was applied to the specimens by 2 MN universal tester at Kobe City College of Technology (KCCT) as shown in Fig. 2.

2.2. Test measurements

Four biaxial strain gages were attached on eastern–western (larger diameter) and northern–southern (smaller diameter) directions at central height and external side of the elliptical/oval steel tubes to measure axial and circumferential strain distributions as shown in Fig. 3. Two displacement transducers were placed to obtain the axial deformation of the stub column.

3. Test results

3.1. Failure modes

Figs. 4–6 show the typical failure modes of the specimens, in which a/b are 1.5, 2.0 and 2.5, respectively. As it can be seen from these figures, local buckling of the elliptical/oval tubes in the smaller diameter direction is associated with the shear failure of the in-filled concrete, which appeared from the top to the lower parts of the specimens. The observed failure mode is identical to the results obtained for ordinary CFT stub column test under centric compressive loading.

Table 1
List of the specimens

No.	Specimen label	Elliptical steel tube							Conc strength	
		$2a$ (mm)	$2b$ (mm)	t (mm)	H (mm)	a/b	$2a/t$	$2b/t$	f_y (MPa)	$f_{c'}$ (MPa)
1	e10-15-160	160.0	107.8	1.0	160	1.48	160.0	107.8	207	27.3
2	e16-15-160	159.4	106.5	1.6		1.50	99.6	66.5	296	
3	e23-15-160	159.7	107.4	2.3		1.49	69.4	46.7	341	
4	e10-15-250	159.9	105.5	1.0	250	1.51	159.9	105.5	207	
5	e16-15-250	160.1	105.5	1.6		1.52	100.1	65.9	296	
6	e23-15-250	160.8	107.0	2.3		1.50	69.9	46.5	341	
7	e10-20-160	160.4	77.3	1.0	160	2.08	160.4	77.3	211	25.0
8	e16-20-160	159.4	80.5	1.6		1.98	99.6	50.3	279	
9	e23-20-160	158.8	80.7	2.3		1.97	69.0	35.1	201	
10	e10-20-250	160.8	74.9	1.0	250	2.15	160.8	74.9	211	
11	e16-20-250	159.3	79.8	1.6		2.00	99.6	49.9	279	
12	e23-20-250	158.3	82.0	2.3		1.93	68.8	35.7	201	
13	e10-25-160	159.2	63.2	1.0	160	2.52	159.2	63.2	207	27.3
14	e16-25-160	159.6	63.3	1.6		2.52	99.8	39.6	296	
15	e23-25-160	159.5	64.2	2.3		2.48	69.4	27.9	341	
16	e10-25-250	158.5	64.5	1.0	250	2.46	158.5	64.5	207	
17	e16-25-250	159.3	63.1	1.6		2.52	99.5	39.5	296	
18	e23-25-250	158.8	63.2	2.3		2.51	69.1	27.5	341	
19	e10-20-200	158.6	79.7	1.0	200	1.99	158.6	79.7	207	27.3
20	e16-20-200	158.0	80.6	1.6		1.96	98.7	50.4	296	
21	e23-20-200	159.2	82.1	2.3		1.94	69.2	35.7	341	