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Concrete filled elliptical steel tubular members with large diameter-to-thickness ratio subjected to bending

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ABSTRACT

Concrete filled elliptical steel tubes, hereafter called CFESTs, are elliptical steel tube members filled in with concrete. The CFEST belongs to a family of concrete filled steel tubes, the so-called CFT, having good deformability and large seismic strength due to confined effect between the tube and in-filled concrete. The present study aims to investigate experimentally the characteristics of the CFEST members under pure bending. The selected testing parameters are diameter-to-thickness ratio of elliptical steel tube and loading directions, namely, the minor and major axes directions. From the test results, both local buckling and cracking of the steel tube can be observed in compressive and tensile regions, respectively. Obtained pure bending strength of the CFEST is strongly affected by diameter-to-thickness ratio. Pure bending capacity of the CFEST is also compared to that of the circular CFT. Methods to predict pure bending strength of the CFEST based on concrete strength, yielding and fracture points of the steel tube and confinement effect are described. Moreover, pure bending strength of the CFEST members is mainly discussed in comparison to that of ordinary CFT members. Additionally, biaxial stress behavior of the steel tube induced by in-filled concrete is also mentioned.

1. Introduction

Concrete filled elliptical steel tubes, hereafter called CFEST, consist of elliptical steel tube members filled in with concrete as shown in Fig. 1. CFEST members belong to the concrete filled steel tube, CFT [1,2] family, holding good deformability and large seismic strength. When a CFEST member is applied to a steel–concrete composite bridge pier located at a river, reduction of the bottom scouring due to the water flow can be expected.

Reviewing the past studies on elliptical hollow sections, EHS or CFEST (in-filled EHS), we can first find that elliptical steel tube and in-filled or un-filled concrete stub column tests [3,4,5]. Second, minor and major axes bending-shear tests of EHS beam were performed by Chan [6] and Gardner [7]. Then, flexural behavior of stainless steel oval hollow section (OHS) was investigated by Theofanous et al. [8]. Third, elastic buckling behavior and cross-section classification of EHS/OHS were discussed by Ruiz-Teran and Gardner [9] and Gardner and Chan [10]. Willibald et al. [11] and Sauced [12] investigated new applications of the EHS gusset plate connections which are regularly used in steel frames. Next, Episons et al. [13] conducted analytical studies on the fire resistance behavior of concrete filled EHS under compression. Last, studies on concrete filled EHS stub columns under eccentric compression were carried out experimentally by Sheehan et al. [14], and Insausti [15] carried out numerical studies applying a model of plastic collapse of EHS.

Under the above-described background, the authors have conducted 21 axially loading tests on CFEST stub columns with large diameter-to-thickness ratio ($2a/t$) and aspect ratios (a/b), which ranged from 69.6 to 160.0 and 1.5 to 2.5, respectively [16]. From the results of the stub column tests, it can be found that confinement effect between in-filled concrete and steel tubes did not change when diameter-to-thickness ratio ($2a/t$) became larger. In order to apply CFEST in practical use, it is necessary to investigate the mechanical behavior of CFEST members.

The present study aims to investigate experimentally the pure bending characteristics of the CFEST beams with large diameter-to-thickness ratio ($2a/t$) ranging from 69.6 to 160.0 through the symmetric four-point loading testing method. Two testing parameters were selected: diameter-to-thickness ratio of elliptical steel tubes and loading directions, namely, minor and major axes. Moreover, pure bending behavior of CFEST member is compared with that of an ordinary CFT member, whose diameter-to-thickness ratio ($2a/t$) ranges from 34.8 to 160.0. A method to predict the pure bending capacity of CFEST beam is mainly discussed and biaxial stress behavior of the elliptical steel tubes is provided. A part of this study has been previously reported [17,18].

2. Experimental testing

2.1. Test specimens

Figs. 2 and 3 and Table 1 show the details of the test specimens. The length (larger diameter) and aspect ratio of elliptical steel tubes were

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Nomenclature

a and b	larger and smaller radii of the elliptical steel tubes
t	tube's thickness of elliptical steel section
f_c'	concrete strength
f_y	yielding point of the steel tube
f_u	fracture point of the steel tube
ν	Poisson's ratio of steel tube
M	applied bending moment
ϕ	curvature of CFEST
M_{exp}	experimental bending strength
M_{est}	estimation of ultimate bending moment based upon yielding point
N_{est}	estimation of ultimate axial load based upon yielding point
$M_{est\text{-}u}$	estimation of ultimate bending moment based upon fracture point
$N_{est\text{-}u}$	estimation of ultimate axial load based upon fracture point
α	angle between bottom of compressive area and neutral axis
$M_{est\text{-}aij}$	estimated bending strength based on CFT in AIJ
$N_{est\text{-}aij}$	estimated axial force based on CFT in AIJ
${}_c\sigma_{cB}$	concrete strength induced by confined effect
σ_r	confined stress induced by external tube proposed by AIJ
ε_z and ε_θ	axial and circumferential strains of the tube
σ_z and σ_θ	axial and circumferential stresses of the tube

160 mm and 2.0, respectively. Concrete filled circular steel tubes (CFT) having diameters of 80 mm and 160 mm were prepared to be compared with the CFEST members. The thicknesses of the elliptical/circular steel tubes were 1.0, 1.6 and 2.3 mm. Thus, the larger diameter-to-thickness ratio ($2a/t$) ranged from 66.9 to 160.0. Elliptical/circular tubes having two welded plates at both ends were connected to rigid lateral beams through ten high-tension bolts.

Fig. 4 illustrates the testing apparatus. Pure bending moment ($M = Pl_1/2$, where P: Applied load) without shear force was applied to the specimens through the symmetric four-point loading testing method using the 500 kN universal testing machine located at Kobe City College of Technology(KCCT) as shown in Fig. 5.

2.2. Measurements

Fig. 2 shows the arrangement of the strain gages. Four biaxial strain gages were attached on the external surface of the steel tube to obtain stress condition of elliptical and circular steel tubes. Three displacement transducers were placed under the specimens to obtain bending deformabilities of the CFEST beam as illustrated in Fig. 4. The experimental test was terminated when the fatal failure of the specimen was observed.

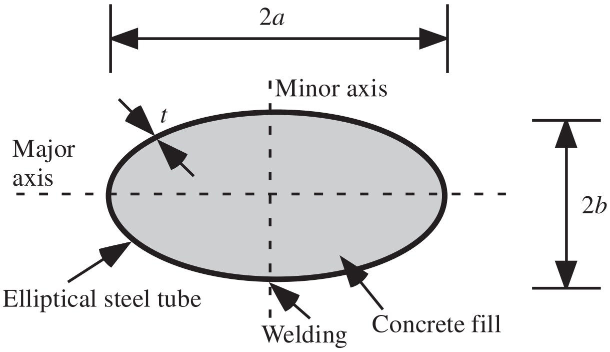

Fig. 1. Cross sectional area of the CFEST.

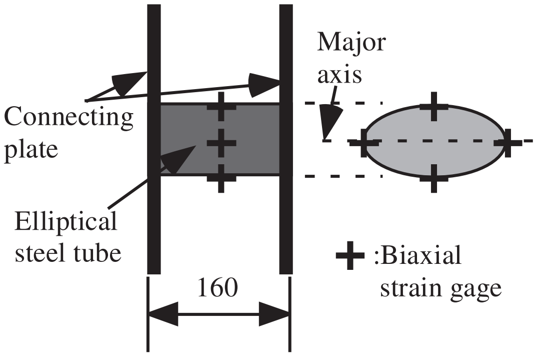

Fig. 2. Detail of the specimens and position of strain gages (minor axis test).

3. Results and discussion

3.1. Failure modes

Observed failure modes are shown in Fig. 6. Fig. 6(a) and (b) shows the ultimate states of the CFEST specimens after major and minor axes tests, respectively. In all the specimens, tensile failure in the tensile region occurred after local buckling of the tubes in the compressive region. No effect of diameter-to-thickness ratio ($2a/t$) on the failure modes could be found. Furthermore, Fig. 6(c) and (d) shows failure modes of CFT specimens with $D = 80$ and 160 mm. Failure modes of the CFEST member coincided with those of the CFT. No cracking of welding of two connecting plates can be found. Therefore, pure bending moment can be correctly applied to the specimens.

3.2. Bending deformability

The applied bending moment (M) plotted against central displacement is shown in Fig. 7, where panels (a) and (c) are the CFEST and panels (b) and (d) are the CFT specimens, respectively. In all test results, bending deformability increased as the larger diameter-to-thickness ratio ($2a/t$) decreased. Furthermore, displacement of CFT specimen having $D = 160$ mm with $t = 1.6$ and 1.0 mm decreased drastically to

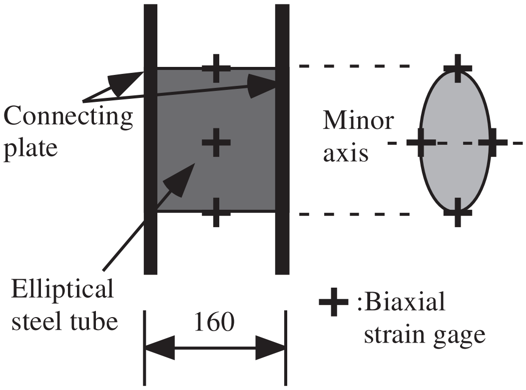

Fig. 3. Detail of the specimens and position of stain gages (major axis test).