Journal of Constructional Steel Research 150 (2018) 99–114

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Performance and design of eccentrically-loaded concrete-filled round-ended elliptical hollow section stub columns

Qihan Shen [a], Jingfeng Wang [a,b,*], Wanqian Wang [a], Zhibin Wang [c]

[a] School of Civil Engineering, Hefei University of Technology, Anhui Province 230009, China
[b] Anhui Civil Engineering Structures and Materials Laboratory, Anhui Province 230009, China
[c] College of Civil Engineering, Fuzhou University, Fuzhou, Fujian Province 350108, China

ARTICLE INFO

Article history:
Received 10 May 2018
Received in revised form 28 June 2018
Accepted 22 July 2018
Available online xxxx

Keywords:
Concrete-filled round-ended elliptical hollow section (CFREHS) column
Eccentric compressive behaviour
Numerical modelling
Mechanical performance
Simplified empirical formulae

ABSTRACT

Concrete-filled round-ended elliptical hollow section (CFREHS) columns are gradually coming into use as piers and arches in engineering practice, owing to their unique properties concerning aesthetic perception and low flow resistance coefficients. However, there has been a paucity of studies focusing on the structural behaviour and design methods for CFREHS columns. The present study has involved investigating the behaviour of eccentrically-loaded CFREHS stub columns. A nonlinear numerical model that adopts an equivalent stress-strain model for the novel type of confined core concrete was established, and verified via experimental data. Subsequently, the effects of various parameters on the eccentric compressive response of CFREHS stub columns were analysed, including the diameter-to-thickness ratio, load eccentricity ratio, and the cross-section slenderness. Eccentric compressive capacities, failure patterns, strength indexes, stress–strain responses, contact stress, typical force-displacement curves, and *M*–*N* curves of eccentrically pressured CFREHS stub columns were also evaluated. The findings of the numerical analysis indicated that the eccentric load bearing capacity of CFREHS stub columns evidently increased for increases in the cross-section area, steel strength, and concrete strength, while the opposite was observed for increases in the load eccentricity ratio and diameter-to-thickness ratio. Finally, simplified empirical formulae were presented to predict the eccentric load bearing capacities of CFREHS stub columns. The results of the study are expected to provide a reliable reference for application to the proposed CFREHS columns in concrete-filled steel tube (CFST) structures.

1. Introduction

In recent decades, reinforced concrete (RC) columns with round ends have commonly been employed in bridge engineering, given the various demands for transverse and longitudinal stiffness. However, some disadvantages of RC columns include difficulties in construction, deterioration in durability, and a reduction in impact resistance. In addition, an increased demand for the construction of heavy-haul railways, large-scale bridges, and advanced expressways in earthquake-prone areas, with requirements for high bearing capacities and superior ductility, has emerged as an unavoidable consequence of economic development. In order to withstand high traffic flows and the increasing weights of high-rise buildings, concrete-filled steel hollow section columns are commonly employed and favoured by several engineers and scholars, including Wang et al. [1], Li et al. [2], Hassanein et al. [3], Liu et al. [4, 5], Petrus et al. [6], Ren et al. [7, 8], Wang et al. [9], Wang and Zhang [10], Ding et al. [11], Thayalan et al. [12], Huo et al. [13], Aslani et al. [14, 15], and Liao et al. [16, 17]. In view of the superior properties of round-ended concrete columns and normal concrete-filled steel tube (CFST) members, a type of hybrid supporting member termed a concrete-filled round-ended elliptical hollow section (CFREHS) column has been conceived and examined by several researchers [18, 19], owing to its combined advantages.

The CFREHS column comprises a round-ended hollow steel section and a concrete infill (shown in Fig. 1). This novel composite column exhibits all the superiorities of normal CFST columns, including high strength, easy construction, good ductility, and high earthquake and impact resistant behaviour. Furthermore, the CFREHS column also achieves superior aesthetic perception, a low fluid resistance factor, and high structural efficiency, owing to the reasonable distribution of its cross-section slenderness. Therefore, some engineers and architects have been increasingly inclined to employ this type of column in large-scale bridge projects. For example, the Houhu cable-stayed bridge in China employed this type of column for piers, as shown in Fig. 2.

In recent years, a few studies have focused on the experimental behaviour of CFREHS columns, with attention concentrated entirely on their engineering applications and axial compressive performance. For example, Ding et al. [18] carried out an experimental study that

* Corresponding author at: School of Civil Engineering, Hefei University of Technology, Anhui Province 230009, China.
E-mail address: jfwang008@163.com (J. Wang).

https://doi.org/10.1016/j.jcsr.2018.07.025
0143-974X/© 2018 Elsevier Ltd. All rights reserved.

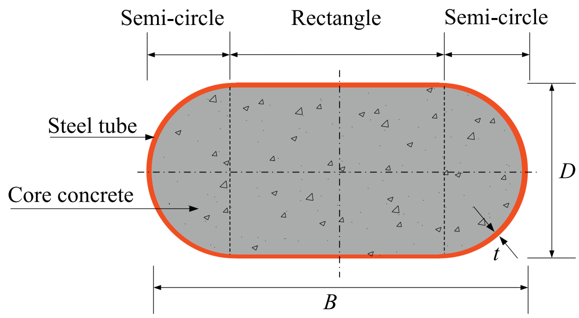

Fig. 1. Detail of CFREHS cross-section.Note: "*B*" and "*D*" represent the major and minor axis length of CFREHScolumn, respectively; "*t*" represents the thickness of steel tube.

explored the axial compressive behaviour of CFREHS stub columns with a varied cross-section slenderness ranging from 1 to 4. Wang et al. [19] examined the performance of stiffened and thin-walled CFREHS stub columns under axial pressure. Hassanein and Patel [20] adopted a numerical analysis approach to investigate the performance of axially-loaded CFREHS stub columns. Han et al. [21] conducted an experiment to predict the axial compressive response of concrete-filled round-ended double-skin steel hollow section columns. Xie et al. [22] investigated the behaviour of coupled CFREHS tower columns in the construction of a long-span cable-stayed bridge. All of the test results revealed that this novel type of CFST column displayed high strength, good ductility, and convenient construction properties. Although eccentric compressive members, such as side and corner columns, commonly exist in buildings, there exists a paucity of studies concerning the behaviour of CFREHS columns under eccentric pressure. Therefore, it is highly important to investigate this type of eccentrically-loaded composite column. Conversely, with development of the finite element (FE) simulation method, a numerical analysis approach that explores the behaviour of CFREHS columns provides an effective method for reducing the time spent by researchers on further studies. However, it is difficult to simulate CFREHS columns, owing to the insufficiency in cognizing an actual stress-strain model for confined concrete that has a round-ended elliptical feature. Hence, in order to efficiently explore the static behaviour of CFREHS columns, a demand is emerging to conduct a discussion on the stress–strain relationship and establish an FE model of the CFREHS stub column.

The present study attempted to explore the mechanical performance of CFREHS stub columns subjected to eccentric loading. An FE model of a CFREHS stub column under eccentric loading was developed by introducing an equivalent stress-strain model for confined core concrete with round ends. After the respective analytical models were verified via the test data, a parametric analysis was performed to investigate the effects of the load eccentricity ratio, cross-section slenderness, and diameter-to-thickness ratio on the eccentric load bearing capacity of this type of column. Analytical FE results including failure modes, strength indexes, stress–strain responses, contact stress, typical force (N)-longitudinal shortening (δ) curves, and uniaxial bending moment (M)-eccentric compressive load (N) curves of the CFREHS stub columns were also obtained. Finally, simplified empirical formulae to calculate the eccentric load bearing capacity of the CFREHS stub column were proposed, in compliance with the unified theory method and simple superposition principle. The research results are expected to provide a reliable reference for applying this novel type of composite column in practical engineering.

2. Finite element modelling

Presently, there has been a paucity of studies conducting numerical analyses on CFREHS stub columns. Despite the existing studies [18, 19] mentioned above, numerical simulations of the eccentric compressive behaviour of CFREHS columns present some difficulties, owing to the deficiency in the actual stress–strain model for this novel type of confined concrete infill. Furthermore, the contact interaction between the concrete infill outside surface and the steel tube inside surface is ambiguous, because of the limited research on CFREHS columns. For effectively assessing the eccentric compressive performance of CFREHS stub columns, FE analytical models considering the aforementioned problems have been established using the ABAQUS/Standard solver. The material models and other modelling details are discussed below.

2.1. Steel properties

In general, commercially available steel hollow sections (SHS) and steel plates are typically employed as steel tubes and loading plates in experiments. Hence, the stress–strain (σ)-(ε) model, as recommended by Han [23], was employed to simulate the actual conditions of the test specimens (seen in Fig. 3). The σ–ε model is expressed as follows:

$$\sigma=\begin{cases} E_s\varepsilon & \varepsilon\le\varepsilon_e \\ -A\varepsilon^2+B\varepsilon+C & \varepsilon_e<\varepsilon\le\varepsilon_{e1} \\ f_y & \varepsilon_{e1}<\varepsilon\le\varepsilon_{e2} \\ f_y\left[1+0.6\dfrac{\varepsilon-\varepsilon_{e2}}{\varepsilon_{e3}-\varepsilon_{e2}}\right] & \varepsilon_{e2}<\varepsilon\le\varepsilon_{e3} \\ 1.6f_y & \varepsilon>\varepsilon_{e3} \end{cases} \tag{1}$$

where $A=0.2f_y/(\varepsilon_{e1}-\varepsilon_e)^2$, $B=0.2A\varepsilon_{el}$, $C=0.8f_y+A{\varepsilon_e}^2-B\varepsilon_e$, E_s

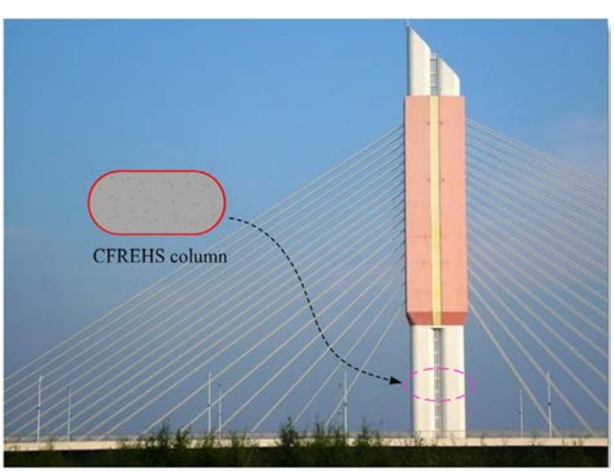

Fig. 2. CFREHS tower column in engineering practice.

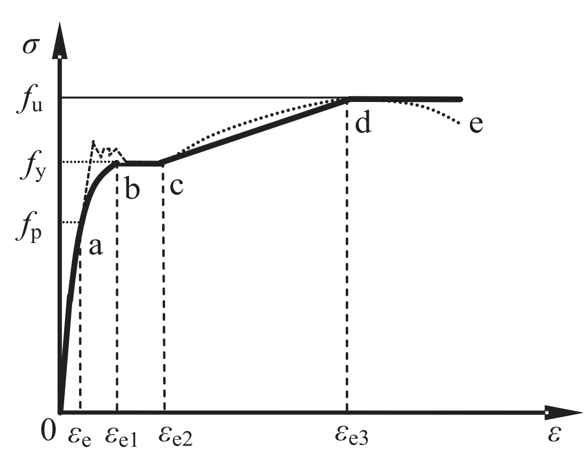

Fig. 3. Stress (σ) - strain (ε) curve of steel.