Journal of Constructional Steel Research 140 (2018) 74–81

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental study on axially compressed circular CFST columns with improved confinement effect

Liusheng He [a,*], Yangang Zhao [b], Siqi Lin [b]

[a] Research Institute of Structural Engineering and Disaster Reduction, Tongji Univ., Shanghai 200092, China
[b] Department of Architecture, Kanagawa Univ., Kanagawa 2218686, Japan

ARTICLE INFO

Article history:
Received 19 June 2017
Received in revised form 17 October 2017
Accepted 19 October 2017
Available online xxxx

Keywords:
Concrete-filled-steel-tube
Confinement
Compressive
Strength
Corrugation
Lubricated

ABSTRACT

The concrete-filled-steel-tube (CFST) column has been widely used in construction due to the benefit of composite action between inner concrete and exterior steel tube. Under axial compression, the steel tube is subjected to biaxial stress state in the hoop and axial direction, and the hoop stress component provides confinement for the inner concrete. However, the existence of axial stress component accelerates the buckling of steel tube, which hinders its confinement effect to inner concrete and accordingly column's axial compressive strength and ductility. This paper aims to enhance the axial compressive strength and ductility of CFST stub columns by improving its confinement effect provided by the steel tube. CFST stub columns axially loaded/unloaded were experimentally studied for different cases: a) varying concrete strength, b) lubrication on the contact between steel tube and concrete and c) corrugations in the steel tube that are introduced to intentionally weaken the tube vertically. It was found that axial compressive strength of CFST stub columns was effectively enhanced by reducing the axial stress in the steel tube. The introduction of corrugations in the steel tube led to largely concentrated axial deformation which reduced axial stress in other portions of the steel tube and consequently resulted in "tighter" hoop confinement to the inner concrete; both axial compressive strength and ductility were enhanced.

1. Introduction

CFST columns are being widely used in engineering practice, such as high-rise buildings, bridges and subways, owning to their excellent seismic performance including high axial compressive strength, stiffness and ductility. In CFST columns, steel tube confines the inner concrete, which effectively enhances the axial load bearing capacity of concrete; inner concrete provides partial support for steel tube and thus prevents or at least delays the local buckling of steel tube. Moreover, the steel tube functions as the permanent formwork in casting the inner concrete, which saves material cost and construction time. Of interest in this study are the CFST stub columns using circular steel tubes, which are considered more effective in offering post-yield strength and stiffness than those with square or rectangular cross sections [1]. There are extensive experimental studies available on circular CFST columns, with primary research focuses on tube diameter-to-thickness ratio [2–6], concrete strength [7–9] or bond behavior between steel tube and concrete [10–13].

The composite action between steel tube and inner concrete is the key factor in compressive behavior of CFST columns. However, at the initial elastic stage under compression, there is no composite action due to the different dilation of steel tube and concrete. To be more specific, the steel tube expands faster in the radial direction than the concrete core because the Poisson's ratio for steel is larger than that for concrete. With the increase of axial compression, the compressed concrete starts to plasticize, the lateral expansion of the concrete catch up with that of the tube and confinement effect initiates [14]. After micro cracks in the concrete propagate and the steel tube enters into the inelastic outward buckling, the efficiency of composite action degrades. To improve the composite action, various types of external confinement were proposed, such as installment of steel rings [15], ties [16], spirals [17], jackets [18], or FRP wraps [19–23]. With all these added external confinements, the composite action was improved to varying extent. However, it is worth mentioning that the improved composite action was provided by the added strips/layers, not by the steel tube itself. Under axial compression, the steel tube can be assumed to be in biaxial plane stress state, in axial and hoop stress state, where the hoop stress component provides the confinement to the inner concrete. The overall axial capacity of CFST columns may be enhanced if the confinement provided by hoop stress in the steel tube itself can be increased somehow, even without needing external confinement. To the best knowledge of the authors, there is no literature available yet regarding enhancing axial capacity of CFST columns through increasing the confinement provided by the steel tube itself.

* Corresponding author.
E-mail address: hls@tongji.edu.cn (L. He).

https://doi.org/10.1016/j.jcsr.2017.10.025
0143-974X/

This paper focuses on improving the confinement effect in CFST columns by two methods: a) eliminating contact by lubrication and b) introducing corrugations. The influence of the axial stress in the steel tube on column's axial compressive strength and ductility and effectiveness of using corrugations to achieve larger confinement effect were investigated through a series of experimental tests.

2. Mechanical behavior of stub CFST columns

The stress state of steel tube and concrete in CFST columns is schematically shown in Fig. 1. Under axial compression, the steel tube undertakes part of the axial strength N by the axial stress component σ_{sz}; the hoop stress component $\sigma_{s\theta}$ produces the lateral confining pressure σ_r, which confines the inner concrete (Fig. 1a and b). With lateral confinement provided by the steel tube, the inner concrete is subjected to triaxial compressive stress state and its axial compressive strength capacity is greatly enhanced. The compressive strength of the confined concrete, f_{cc}, can be obtained by [24]

$$f_{cc} = f_c + k\sigma_r \tag{1}$$

where f_c is the unconfined compressive strength of concrete; k is a coefficient; and σ_r is the lateral confining pressure. Richart et al. [25] found that the average value of k was 4.1, which is commonly adopted by many researchers. Eq. (1) suggests that an increase of the lateral confining pressure provided by the steel tube would result in a higher axial compressive strength.

According to Fig. 1c, the equilibrium of σ_r and $\sigma_{s\theta}$ gives

$$(D-2t)\sigma_r = -2t\sigma_{s\theta} \tag{2}$$

where D is the external diameter of the steel tube, t is its plate thickness, and the minus sign (−) stands for compressive stress.

Rewriting Eq. (2) gives

$$\sigma_r = \frac{-2t}{D-2t}\sigma_{s\theta} \tag{3}$$

Substituting Eq. (3) into Eq. (1) gives

$$f_{cc} = f_c - k\frac{2t}{D-2t}\sigma_{s\theta} \tag{4}$$

For the thin-walled steel tube in stub CFST columns, it is reasonable to ignore the relatively small radial stress of the steel tube. Thus, the steel tube can be assumed to be in biaxial plane stress state and Von Mises yield criterion can be applied.

$$\sigma_{s\theta}^2 - \sigma_{s\theta}\sigma_{sz} + \sigma_{sz}^2 = f_s^2 \tag{5}$$

where f_s is steel tube yield strength.

Eq. (4) reveals that, for a certain concrete mix, its confined compressive strength can be enhanced if the hoop stress component $\sigma_{s\theta}$ in steel tube can be somehow increased. As shown in Fig. 1c, the hoop stress component $\sigma_{s\theta}$ is tensile (+) and axial stress component σ_{sz} is compressive (−). Taking into consideration of the signs, the hoop stress component $\sigma_{s\theta}$ will increase if the axial stress component σ_{sz} can be reduced when the steel tube yields according to Eq. (5).

3. Test preparation

3.1. Test specimens

A length-to-diameter ratio of 3 was selected to ensure stub column behavior [26]. Table 1 summarizes a total of 11 specimens designed. The concrete was commercial ready-mixed concrete with normal mixing and curing techniques. Four grades of concrete, with cylinder (with a diameter of 100 mm and height of 200 mm) strengths of 29.5, 43.5, 58.0 and 81.6 N/mm^2 respectively, were used for specimens in both Groups 1 and 2. The concrete cylinder strength of specimens in Group 3 was 52.3 N/mm^2. All steel tubes were cold-formed carbon steel and seam welded by machine welding, and they had the same diameter of 165.2 mm and thickness of 3.7 mm.

The specimens were clarified into three groups: Group 1 belongs to the reference common CFST columns with both concrete and steel tube compressed; Group 2 actually consists of tubed concrete columns with only the inner concrete core directly compressed; corrugation is introduced to the steel tubes in Group 3. The inside surface of steel tubes in Group 2 was lubricated with grease prior to the casting of the inner concrete, to eliminate the friction between steel tube and inner concrete. Details of the corrugation in Group 3 will be described later. Three coupons were randomly cut from the steel tube and were tested according to standard procedures [27]. The yield strengths of the steel tube were found to be 366.0 MPa for Groups 1 and 2, and 372.6 MPa for Group 3,

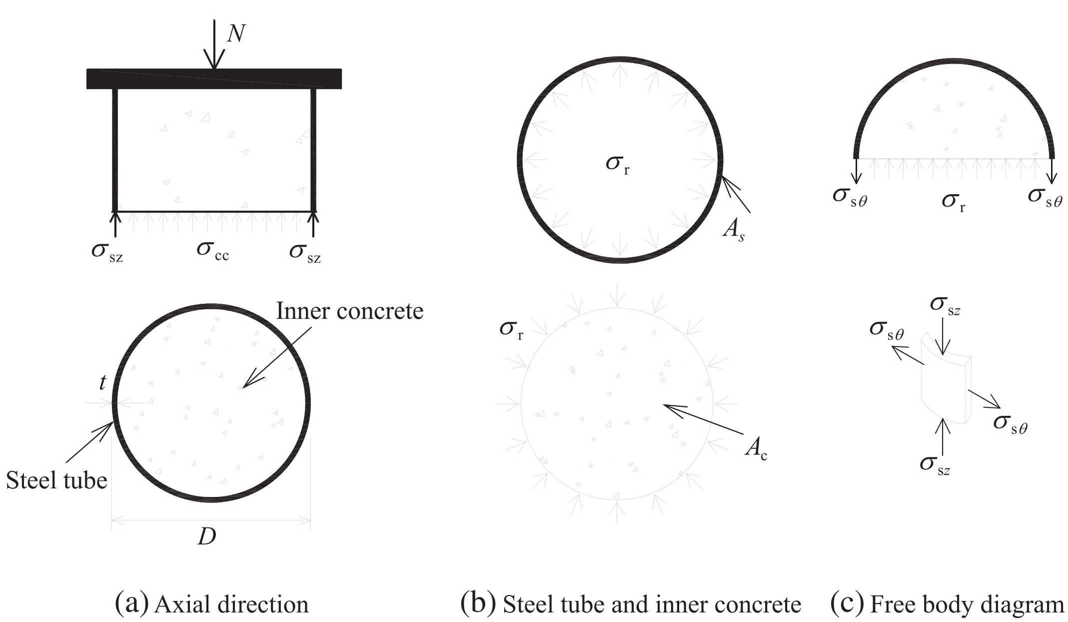

Fig. 1. Stress state of a circular CFST column in a limited state.