Thin-Walled Structures 123 (2018) 294–304

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Comparative study of stirrup-confined circular concrete-filled steel tubular stub columns under axial loading

Fa-xing Ding[a,d], Jiang Zhu[a], ShanShan Cheng[b,*], Xuemei Liu[c]

[a] School of Civil Engineering, Central South University, Changsha, Hunan Province 410075, PR China
[b] School of Engineering, University of Plymouth, Plymouth PL4 8AA, United Kingdom
[c] School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, QLD 4001, Australia
[d] National Engineering Laboratory for High Speed Railway Construction, Changsha 410075, PR China

ARTICLE INFO

Keywords:
Circular CFT stub columns
Stirrup-confinement
Comparative study
Composite action
Ultimate bearing capacity

ABSTRACT

This paper presents a comparative study of circular concrete-filled steel tubular stub columns with three different stirrup confinement types: bidirectional stirrups, loop stirrups and orthogonal stirrups. Axial compression tests have been carried out aiming at investigating the effects of the stirrup form and volume-stirrup ratio on the mechanical behavior of the stirrup-confined circular CFT stub columns, and ABAQUS was used to carry out the 3D numerical modelling. Radial stress of the core concrete and the composite action among the steel tube, stirrups and the core concrete have been investigated. It is found that the confinement provided by stirrups on core concrete strongly outperforms that provided by steel tube, steel sections or steel reinforcement. Furthermore, a simplified approach was developed to predict the ultimate bearing capacity of stirrup-confined circular CFT stub columns, which agreed well with the experimental and numerical results.

1. Introduction

Concrete-filled steel tubular (CFT) columns have been widely used in high-rise/super-high-rise buildings, urban bridges and large-span structures, thanks to their excellent static and earthquake-resistant capacities. Circular tube shows best confinement to the core concrete of CFT columns. However, the thickness of the steel tube is limited due to weldability and construction concerns for large-diameter CFT columns [1]. In order to improve the mechanical performance of CFT columns without increasing the wall thickness of the steel tube, various methods have been proposed. Regarding the existing concrete-filled steel tubular columns, FRP strengthening methods (by wrapping the steel tube with FRP materials) have been comprehensively studied in [2–5]. FRP could generally help resist local buckling and improve ultimate bearing capacity of columns significantly, but the ductility may be decreased due to FRP rupture and sudden deterioration at the ultimate state. On the other hand, for newly built CFT columns, the methods of adding steel inside the steel tube have been extensively used to improve the overall steel ratio and ultimate capacity of the CFT stub column. For example, Hassanein et al. [6,7] studied the mechanical behavior of double skin tubular short columns, and found that the ultimate axial load increased significantly by increasing the concrete compressive strength or by decreasing the hollow ratio. However, increasing the inner-to-outer thicknesses ratio or the yield strength of the inner steel tube did not significantly increase the ultimate axial load. Chang et al. [8] and Wang et al. [9] studied the strength and ductility of CFT columns with steel sections and concluded that those types of columns have very high ductility and energy absorption capacities due to the composite action among the steel tube, steel section, and the core concrete; however, their ultimate bearing capacities are approximately equivalent to the simple superpositions of steel sections and the CFT columns, with no additional confinement produced by steel sections. Chithira and Baskar [10] studied the strength behavior of CFT columns with and without shear connectors, who found that the shear connectors did not significantly increase the load capacities of CFT columns. Xiamuxi et al. [11,12] also proposed a reinforcing method by applying axial reinforcement inside the steel tube to improve its overall mechanical property; the results have shown that, although reinforced CFT has better performance than CFT, the axial reinforcement cannot deduce the buckling of CFT stub columns, and over arranged reinforcement may cause pre-failure of concrete.

Welding technology has been commonly used in steel structures. In practice, however, it is difficult to guarantee the quality of welding when the wall of large diameter CFT column is too thick (e.g. thickness larger than 800 mm). Therefore, using relatively thin steel tube combined with welded stirrups on the steel tube could be an alternative

* Corresponding author.
E-mail address: shanshan.cheng@plymouth.ac.uk (S. Cheng).

https://doi.org/10.1016/j.tws.2017.11.033
Received 21 June 2017; Received in revised form 11 November 2017; Accepted 16 November 2017

Nomenclature

A_c	Cross-sectional area of the core concrete
A_s	Cross-sectional area of the steel tube
A_{sso}	The converted cross-sectional area of the stirrup
A_{sc}	Total area of cross-section
d	Diameter of the stirrup
D	Diameter of the circular section
f_c	Uniaxial compressive strength of concrete
f_{cu}	Compressive cubic strength of concrete
f_s	Yield strength of the steel tube
f_{sv}	Yield strength of stirrups
f_{sc}	Ultimate strength of CFT column
k	Lateral pressure coefficient
L	Height of specimens
N_u	Axial ultimate bearing capacity of stirrup-confined circular CFT stub columns
$N_{u,3}$	Ultimate bearing capacity of stirrup-confined circular CFT stub columns
$N_{u,e}$	Ultimate bearing capacity of stirrup-confined circular CFT stub columns from test results
$N_{u,fe}$	Ultimate bearing capacity of stirrup-confined circular CFT stub columns from FE results
t	Wall thickness of the steel tube
σ	Axial stress of concrete
σ_i	Equivalent stress of steel tube
$\sigma_{L,s}$	Axial compressive stress of steel tube
$\sigma_{r,c}$	Radial concrete stress of the confined area
$\sigma_{r,cr}$	radial stress of core concrete caused by stirrups
$\sigma_{\theta,s}$	Tensile transverse stress of steel tube
ε	Axial strain of concrete
ε_c	Strain corresponding with the peak compressive stress of concrete
ε_L	Axial strain of columns
ε_i	Equivalent strain of steel tube
ε_y	Yield strain of the steel tube
ν_{sc}	Poisson's ratio of steel tube
ρ_s	Steel ratio of the steel tube
ρ_{sv}	Volume-stirrup ratio
ρ_{sa}	Equivalent stirrup ratio
ρ_{so}	Overall steel ratio

method. Ding [1] studied square stirrup-confined CFT stub columns with cross ties, spiral, and rhombus stirrups. The results showed that welding bidirectional stirrups to the inner surface of the steel tube is the most efficient way in reinforcing square CFT stub columns. This approach has been validated for track-shaped concrete-filled steel tubular stub columns [13] as well.

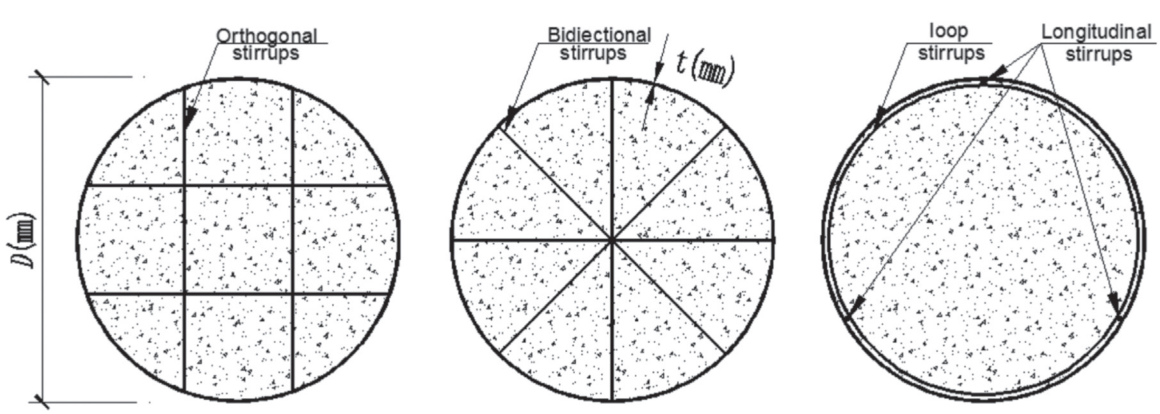
In this paper, the reinforcing methods using stirrups were studied for circular CFT columns, thanks to the promising improvement on the mechanical properties of other sectional shapes of CFT columns. The main objectives and research scopes of this study are: (1) circular CFT stub columns with bidirectional stirrups, loop stirrups or orthogonal stirrups with the same volume-stirrup ratio were tested to investigate the effect of different stirrups forms on the overall ultimate bearing capacities and ductility; (2) circular loop stirrup-confined CFT stub columns with different volume-stirrup ratios were tested to investigate the effect of different volume-stirrup ratios on their ultimate bearing capacities and ductility; (3) 3D finite element modelling was established using ABAQUS for carrying out parametric studies; the confinement effect on the core concrete between stirrups and the steel tube were compared; (4) a simplified approach was developed to predict the ultimate bearing capacity of a stirrup-confined circular CFT stub column.

2. Experimental investigation

2.1. Specimens and material

A total of 5 groups of test specimens were designed, and the cross-sections of specimens are shown in Fig. 1. Geometric properties and characteristics of specimens are shown in Table 1, where the first number in the specimen label represents the type of stirrups: 1 for orthogonal stirrups; 2 for bidirectional stirrups; and 3 for loop stirrups. The CFT represents concrete-filled steel tubular stub column. The second number in the specimen label stands for the volume-stirrup ratio. Each test is repeated twice (namely A and B), therefore ten specimens were tested in total. The nominal dimensions of each specimen were 500 (D) mm × 4 (t) mm × 6(8/10) (d) mm × 1200 (H) mm. D is the diameter of the circular section; t is the wall thickness of the steel tube; H is the height of the specimen; d is the stirrups diameter; s is the spacing of longitudinal stirrups; ρ_s is the cross-sectional steel ratio; f_{cu} is the cubic compressive strength of the core concrete; f_s is the yield strength of the steel tube; f_{sv} is the yield strength of stirrups; $N_{u,e}$ is the experimental ultimate load-bearing capacity of a stub column; $N_{u,c}$ is the FE numerical ultimate load-bearing capacity of a stub column; DI is the ductility index of a specimen; ρ_{sv} is the volume-stirrup ratio; ρ_{sa} is the equivalent stirrup ratio ($\rho_{sa} = \rho_{sv} \times f_{sv}/f_s$).

The volume-stirrup ratio of a circular CFT stub column with



(a) 1CFT (b) 2CFT (c) 3CFT

Fig. 1. Cross-sections of specimens.