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Axial behaviour of circular steel tubed concrete stub columns confined by CFRP materials

Jie-Peng Liu [a,b], Tian-Xiang Xu [a,b], Yu-Hang Wang [a,b,*], Ying Guo [a,b]

[a] School of Civil Engineering, Chongqing University, Chongqing 400045, China
[b] Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China

HIGHLIGHTS

- The static axial behavior of CFRP-steel composite tubed concrete columns was studied.
- The typical failure modes of CFRP-steel composite tubed concrete columns could be found.
- The calculation methods for the axial ultimate capacity were compared and advised.

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ABSTRACT

Carbon fibre reinforced polymer material has many advantages, including high strength, light weight and good durability, resulting in good performance when it is used in concrete structures; however, the construction procedures of concrete columns confined by a CFRP tube are very complicated, leading to a relatively high cost. Therefore, CFRP-steel composite tubed concrete columns are suitable for application in concrete structures because of their excellent mechanical properties and convenient construction. In this paper, the axial static mechanical behaviour of circular CFRP-steel composite tubed concrete stub columns was investigated, including an experimental study and a theoretical analysis. Based on investigation of the strain efficiency of CFRP material, the calculation methods for the axial ultimate loading capacity of circular CFRP-steel composite tubed concrete stub columns were compared, and recommendations for practical design were provided.

1. Introduction

Carbon fibre reinforced polymer (CFRP) materials, consisting of continuous fibres and a resin base, have many advantages, such as light weight, high strength, good durability and fatigue resistance [1–4]. Consequently, CFRP material is being widely used in strengthening existing concrete columns because of its effective confinement of concrete materials. Various research literatures have demonstrated that the ultimate loading capacity of concrete columns could be obviously improved with FRP materials [2,4–10]. Meanwhile, the related analytical model and calculation method for predicting the ultimate loading capacity and stress-strain relationships of confined concrete in FRP tubes have been established [1,10–19].

However, in newly built structures, the construction procedures of concrete columns confined by a CFRP tube are very complicated, resulting in a relatively high cost. FRP can be conveniently twined around arbitrarily shaped steel tubes. Therefore, the CFRP material and steel tube can be used together in concrete columns. Steel tubed concrete columns are fabricated by pouring concrete into vertically discontinuous steel tubes that do not bear any direct vertical loads and mainly provide lateral confinement to the core concrete [20–23], which can also significantly simplify the construction of joints. However, the confinement of steel tubes is limited, and many measures should be taken to prevent the corrosion problem of the steel tube. In CFRP-steel composite tubed concrete columns, the CFRP belts are twined around the steel tubed concrete columns so that the in-filled concrete is strongly confined by both CFRP belts and the steel tube, and the strength and ductility can be effectively improved. Furthermore, the corrosion-resistant capacity of CFRP material is very strong, therefore, this type of column can be widely used in offshore structures including drilling

* Corresponding author at: School of Civil Engineering, Chongqing University, Chongqing 400045, China.
E-mail address: wangyuhang@cqu.edu.cn (Y.-H. Wang).

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Nomenclature

Notions

A_c	cross-sectional area of concrete
D	diameter of the steel tube
E_c	elastic modulus of the concrete
E_{cf}	elastic modulus of CFRP
E_s	elastic modulus of the steel tube
f_{co}	unconfined concrete strength
f_{cu}	cubic compressive strength of the concrete
f_l	confining stress
$f_{l,s}$	confining stress of the steel tube
$f_{l,cf}$	confining stress of CFRP
f_y	yielding strength of the steel tube
f_u	ultimate strength of the steel tube
f_{cf}	ultimate strength of CFRP
L	length of the columns
n_0	number of the CFRP layers
N	longitudinal load
N_u	tested axial peak load of specimens with CFRP
N_u^0	tested axial peak load of specimens without CFRP
t_{cf}	thickness of the CFRP sheets
t_s	thickness of the steel tube
U	longitudinal displacement
U_p	tested axial peak deformation of specimens with CFRP
U_p^0	tested axial peak deformation of specimens without CFRP
α	angle between the failure surface and the horizontal plane
ε_s	ultimate strain of the steel tube
ε_{cf}	ultimate strain of CFRP
φ	internal friction angle of the concrete
f_{cc}	axial stress of the concrete
σ_h	transverse stress in the steel tube
σ_v	longitudinal stress in the steel tube
σ_z	equivalent stress in the steel tube

platforms and wharf piles, bridge structure piers and frame columns with huge sections in high-rise building structures.

A host of research work has been conducted on the behaviour of FRP confined CFST columns. Xiao [24] proposed a new concept of confined concrete-filled steel tubular (CCFT) columns, in which additional confinement (FRP or steel segments) was applied to the potential plastic hinge regions of CFT columns. Wang et al. [25] and Gu et al. [26] put forward a presumption on the utilisation of both CFRP and steel tube to confine concrete, and discussed the axial performance of CFRP-steel tubular short columns using experimental tests respectively. Following their initial work, a number of studies has been conducted to explore the axial behaviour of FRP confined concrete-filled steel tubes, and the shape of steel tube [27], concrete strength [28,29], diameter-to-thickness ratio of the steel tube [30–33], and FRP layers [27–31,34] were the main parameters. Models on the bearing capacity of CCFTs with FRP under axial compression have been proposed [27–30,32]. And analytical stress-strain models of FRP confined CFST columns have been proposed by Choi and Xiao [35], Teng et al. [36] and Dong et al. [37], respectively. On the other hand, Yu et al. [38] developed a cyclic stress-strain model for confined concrete in CCFTs under cyclic axial compression, which could be applied to the modelling of CCFTs under seismic loadings. Xiao et al. [34] showed that the seismic behaviour could be significantly improved by the application of additional confinement, and Yu et al. [39] also found that FRP jackets could significantly improve the behaviour of a cantilevered CFT column subjected to combined constant axial compression and cyclic lateral loading.

The foresaid studies have demonstrated that the combination of FRP and steel tube could significantly improve the load bearing capacity and ductility of core concrete. However, in most research work, the diameter-to-thickness ratio of steel tube was lower than 100, except for the experimental study conducted by Hu et al. [31], in which only GFRP was adopted. In addition, to the best knowledge of the authors, few research results are available regarding the mechanical behaviour of CFRP-steel composite tubed concrete columns, in which no direct axial load was applied on the steel tube. For the initial study on CFRP-steel composite tubed concrete columns, the static axial behaviour of this type of composite column is investigated in this paper. And the calculation methods for the bearing capacity of circular CFRP-steel composite tubed concrete stub columns are compared and recommended.

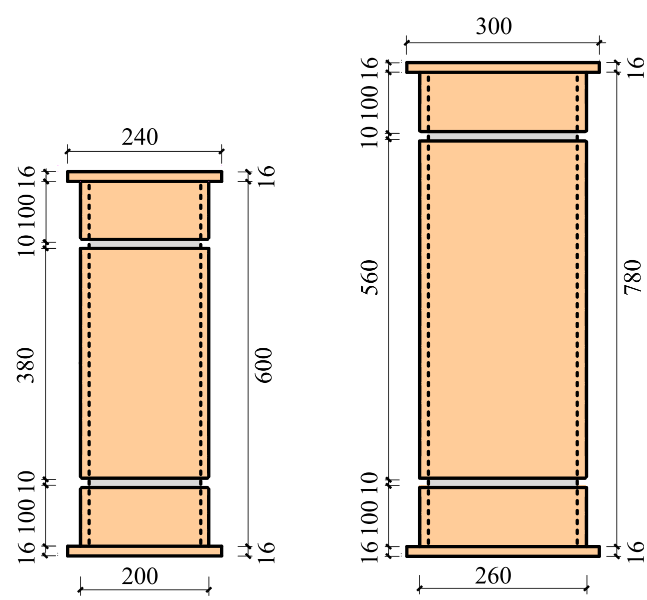

Fig. 1. Detailed geometrical size of specimens.

2. Experimental program

2.1. Specimen design

In total, 16 circular CFRP-steel composite tubed concrete stub columns were designed to investigate the confining effect provided by CFRP, and 4 circular steel tubed concrete stub columns were also designed for comparison. The geometrical details of specimens are shown in Fig. 1. A length-to-diameter ratio of 3 was selected for all columns in order to ensure short column behaviour. The diameter-to-thickness ratio of steel tubes (i.e. D/t_s = 100 and 130, in which D and t_s is the diameter and thickness of the steel tubes respectively), concrete compressive strength (i.e. f_{cu} = 57.1 MPa and 66.8 MPa) and number of CFRP layers (i.e. n_0 = 0, 2 and 4) were the main parameters, as shown in Table 1. The parameters of specimens were illustrated in their names. For example, the diameter of the steel tube and the designed concrete compressive strength level in the specimen D200-40-4-S1 were 200 mm and 40 MPa, respectively, and this specimen had four CFRP layers around the