Thin-Walled Structures 130 (2018) 550–563

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Structural behavior of UHPC filled steel tube columns under axial loading

Shiming Chen[a,*], Rui Zhang[a], Liang-Jiu Jia[a], Jun-Yan Wang[b], Ping Gu[a]

[a] College of Civil Engineering, Tongji University, Shanghai 200092, China
[b] Key Laboratory of Advanced Civil Engineering Materials, Tongji University, Ministry of Education, Shanghai 201804, China

ARTICLE INFO

Keywords:
Concrete filled steel tubes (CFST)
Ultra-high performance concrete (UHPC)
Compressive behavior
Diameter (width)-to-thickness ratio
Calculation model

ABSTRACT

Steel tube filled with ultra-high performance concrete (UHPCFST) is an innovative and efficient structural form. To promote its application, a comprehensive experimental program was conducted to investigate the structural behavior of UHPCFST columns subjected to axial compression. The key issue is to clarify the differences in mechanical behavior between UHPCFSTs and CFSTs, and to evaluate whether the current design guidelines related to CFSTs are applicable to UHPCFSTs. To address this, the compression characteristics of UHPCFSTs were analyzed, including failure mode, load versus deformation relationship, axial compressive strength and strain development. The test results showed that the steel tube and UHPC worked well together, but the enhancement effect of the steel tube on the core UHPC strength was not as significant as that of ordinary concrete. Moreover, an experimental database of UHPCFSTs including this study was established, and the experimental results were compared with the predictions by various design codes. Based on the regression analysis of the database results, a simplified model for predicting the ultimate strength of UHPCFSTs was developed. It was concluded that the proposed model could accurately predict the axial compressive strength of UHPCFSTs with circular and square cross-sections, and was also applicable to UHPCFSTs with high-strength steel (HSS).

1. Introduction

Concrete-filled steel tube (CFST) columns have been widely used in high-rise or even super high-rise buildings and long-span bridges as structural members [1–4]. The successful application of CFST structures is due to their mechanical and constructional advantages such as high bearing capacity, favorable ductility and easy installation. The excellent mechanical performance of CFSTs is obtained by the composite action between the outer steel tube and the core concrete. The outer steel tube provides lateral confinement to the core concrete, while the core concrete delays the local buckling of the steel tube. A large number of investigations have been carried out on the structural behaviors of CFSTs, with a comparatively comprehensive and profound understanding [5–8]. In order to improve the structural efficiency of CFST, a variety of new composite cross-sectional forms were put forward, including concrete filled double skin steel tube (CFDST), concrete filled stainless steel tube (CFSST), concrete filled bimetallic tubes (CFBT), and concrete encased CFST, and the related researches were conducted [9–14].

High-strength concrete (HSC) has gradually become an attractive alternative to the ordinary concrete in order to increase the bearing capacity and reduce the self-weight of CFST structure. However, HSC is characterized by autogenous shrinkage property and brittle failure under axial compression in comparison with the ordinary concrete. This is unfavorable to the load transfer between the steel tube and the core concrete, which weakens the composite effect of the cross section, resulting in a sharp drop in axial load after the peak strength [15,16]. To obtain a ductile behavior, improving the performance of core concrete by adding steel fibers is an efficient and economic method. The behavior of CFSTs employing fiber reinforced concrete (FRC) has been investigated [17,18]. The addition of steel fibers was found to be effective in not only enhancing the strength but also providing higher stiffness, which delays the increase of lateral deflection and therefore improves the ductility and energy dissipation of CFSTs [19].

In recent years, with the development of concrete technology and engineering application of various materials such as silica fume and superplasticizer, the production of ultra-high performance concrete (UHPC) with compressive strength greater than 120 MPa has been possible [20–23]. However, the application of UHPC in structural engineering has not yet been popularized due to concerns on its compressive brittleness and complexity of its preparation and construction techniques [24–26]. In order to improve the compressive brittleness of UHPC, it may be an efficient and reasonable method to fill the UHPC into the steel tube (UHPCFST).

Compared with ordinary CFST, UHPCFST shows potentially advantages in the following aspects: (1) the composition of UHPC is finer

---

[*] Corresponding author.
E-mail address: chensm@tongji.edu.cn (S. Chen).

https://doi.org/10.1016/j.tws.2018.06.016
Received 25 March 2018; Received in revised form 24 May 2018; Accepted 12 June 2018

Table 1
Mix proportions of concrete.

Label	Mix proportions (to the weight of cement)								
	Cement	Slag powder	Mineral powder	Silica fume	Water	Fine aggregate	Coarse aggregate	SP	SF
C60	1	0.19	–	0.24	0.41	1.88	2.59	0.02	–
UHPC-120	1	–	0.30	0.25	0.28	1.47	–	0.04	0.22
UHPC-150	1	–	0.30	0.25	0.28	1.47	–	0.05	0.05

Note: "SP" superplasticizer; "SF" steel fiber.

Table 2
Properties of steel fiber.

Label	Length (mm)	Diameter (mm)	Aspect ratio (l_f /d_f)	Density (kg/m^3)	Tensile strength (MPa)	Elastic modulus (GPa)
UHPC-120	13	0.2	65	7800	2750	200
UHPC-150	13	0.13	100	7800	2750	200

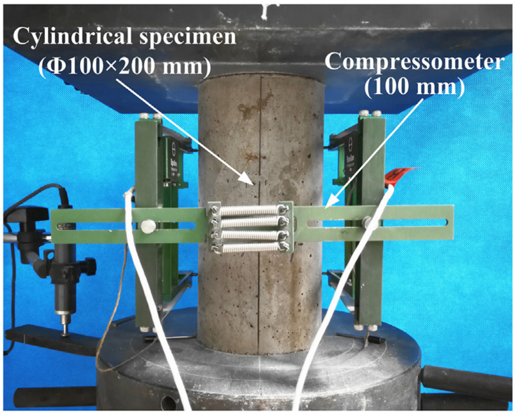


Fig. 1. Compressive strength test setup.

than that of ordinary concrete and is therefore more suitable for the filling of CFSTs, resulting in a more uniform and dense internal structure; (2) UHPCFST column presents extremely high bearing capacity, which can effectively reduce the section size and shows great application prospects in super high-rise buildings and long-span bridges; (3) the use of high-performance materials can reduce energy and resource consumption, which is conducive to sustainable development.

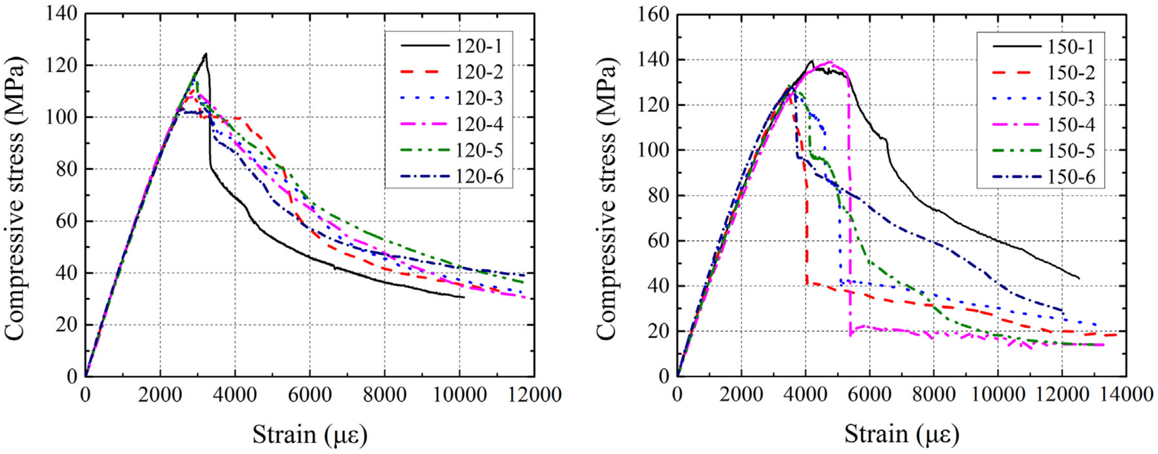
Table 3
Material properties of concrete.

Label	f_{cu} (MPa)	f_c (MPa)	E_c (GPa)	ε_c (με)
C60	70.86	59.03	45.80	2000
UHPC-120	–	113.2	45.83	3028
UHPC-150	–	130.8	45.61	3832

Note: "f_{cu}" cube compressive strength; "f_c" cylinder compressive strength; "E_c" elastic modulus; "εc" strain at the peak load.

However, the current design guidelines related to CFST structures are only applicable to normal strength and high strength concrete [27–30]. To the author's knowledge, there is relatively little research on the structural behavior of UHPCFST members [31–35]. Guler et al. [31] and Xiong et al. [32,33] conducted experimental study on the composite behavior of CFST columns employing ultra-high strength concrete. Steel tube with Class 1 section was recommended to use considering the ductility performance of UHPCFSTs. An and Fehling [34,35] evaluated the axial stress-strain model of UHPC confined by circular steel tube and developed a new axial stress-strain model for confined UHPC. In summary, the differences in mechanical behavior between UHPCFSTs and ordinary CFSTs, especially whether the current design guidelines related to CFSTs are applicable to UHPCFSTs, are still to be clarified. Therefore, systematic study on UHPCFSTs should be carried out to extend the current design guidelines and promote the application of this new type of composite member in structural construction.

Thus, the purpose of this paper includes the following four parts: (1) to provide initial test data pertaining to the axial compressive behavior of UHPCFSTs; (2) to observe and analysis the differences in mechanical behavior between UHPCFSTs and ordinary CFSTs; (3) to study the influence of different parameters on the compressive behavior of UHPCFSTs; and (4) to propose a model for predicting the axial compressive strength of UHPCFSTs with circular and square cross-sections.



(a) UHPC-120
(b) UHPC-150

Fig. 2. Compressive stress-strain curves of UHPC.