Construction and Building Materials 177 (2018) 366–377

Contents lists available at ScienceDirect

Construction and Building Materials

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

Axial stress-strain behavior of high-strength concrete confined by circular thin-walled steel tubes

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HIGHLIGHTS

- 18 steel tube confined concrete columns were tested by monotonic or cyclic axial compression.
- The interaction behavior between the concrete and the steel tube was studied.
- The average transverse stress along the tube height was adopted for the estimation of confinement effect.
- The stress-strain model proposed by Mander et al. was modified for steel tube confined concrete.

ARTICLE INFO

Article history:
Received 25 December 2017
Received in revised form 1 May 2018
Accepted 4 May 2018

Keywords:
Steel tube confined concrete (STCC)
Axial stress-strain relationship
High-strength concrete (HSC)
Equivalent lateral confining stress

ABSTRACT

The axial stress-strain behavior of high-strength concrete confined by circular thin-walled steel tube was experimentally investigated. Specifically, 18 column specimens with the key parameters of concrete compressive strength and diameter-to-thickness ratio of steel tube were tested by monotonic or cyclic axial compression. The failure mode, load versus axial displacement curves, strain and stress states of the steel tube, interaction behavior between the steel tube and the concrete core, and stress-stain characteristics of steel tube confined concrete were described and discussed in detail. The loading path affects little on the strength and stiffness of the confined concrete. As the concrete grade increases from C40 to C80, the specimens show higher brittleness with a ratio of yield to peak loads changing from 0.6 to 0.9. Due to the accumulation of frictional stresses between the steel tube and the concrete, the stress state of steel tube varies along the tube height. The equivalent confinement of steel tube was estimated by the average transverse stress which was based on the observed stress distribution. The stress-strain model proposed by Mander et al. was modified and the predicted stress-strain curves for steel tube confined concrete are in good agreement with test results.

1. Introduction

In the past two decades, high-strength concrete (HSC) has gained popularity in the construction industry due to its advantages of high strength, good durability, and high resistance to deformation. The concern of the brittleness of HSC may be eased by providing a sufficient lateral confinement to improve the stress-strain behavior including higher strength, higher critical strain, and better ductility [1–4]. The hollow structural steel section on a concrete member provides the confinement and protection to the concrete effectively. For example, the concrete-filled steel tube (CFST) possesses many advantages and have gained wide acceptance as column members [5]. Another form of composite construction known as “steel tube confined concrete (STCC)” was proposed by Tomii et al. [6], where the steel tube is disconnected at the beam-column joint and primarily used as the lateral confinement for the concrete core. In practice, to enhance the stiffness and bending strength, the concrete core in a STCC column generally needs to be reinforced by steel bars or structural steel sections. The main difference between CFST and STCC columns lies in the end condition. As shown in Fig. 1, the axial load of a CFST column is carried by both the concrete and the steel tube, while in a STCC column, the axial load is only applied to the concrete core at the column end with the steel casing sustaining no direct loads. As a result, virtually no elastic local buckling occurs on the steel tube

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https://doi.org/10.1016/j.conbuildmat.2018.05.021
0950-0618/

Notation

A	Area of cross-section	δ_s	Elongation of steel tube
D	Diameter of cross-section	ε_c	Strain of concrete
E_c	Elastic modulus of concrete	ε_{cl}	Average axial strain of concrete
E_s	Elastic modulus of steel tube	ε_{cc}	Peak strain of confined concrete
f	Frictional stress	ε_{pl}	Plastic strain when unloaded to zero stress
f_c	Average axial compressive strength of concrete	ε_{sl}	Longitudinal strain of steel tube
f_{cc}	Compressive strength of confined concrete	ε_{st}	Transverse strain of steel tube
f_{el}	Effective lateral confining stress	μ	Frictional coefficient
f_l	Confining stress	σ_c	Stress of concrete
f_y	Yield strength of steel tube	σ_{sl}	Longitudinal stress of steel tube
f_u	Ultimate tensile strength of steel tube	σ_{st}	Transverse stress of steel tube
h_t	Height of steel tube between two adjacent gaps	σ_{se}	Equivalent stress of steel tube
L	Height of specimen	σ_{sl_p}	Longitudinal stress of steel tube corresponding to peak load
l_0	Gauge length of displacement measurement	σ_{st_p}	Transverse stress of steel tube corresponding to peak load
N	Axial load	σ_{st_pa}	Average transverse stress of steel tube along the tube height corresponding to peak load
N_y	Yield load of specimen		
t	Wall-thickness of steel tube		
γ_s	Poisson's ratio of steel tube		
δ	Axial displacement		

occurs despite of the thin wall of the tube [7,8]. It is also noted that the confinement effect of this composite column is more effective compared to CFST columns, which is delayed until the lateral dilation of concrete overcomes that of the directly loaded steel tube [9].

Prior to the introduction of STCC concept, such composite member had been investigated by Gardner et al. (1967) [10] as a contrasting CFST column specimen where only the concrete core was loaded. Some similar investigations were carried out by Prion [11], Johansson [12], Fam [13], Xiong [14] et al. and their studies indicated that the end loading condition had little influence on the axial strength of CFST columns due to the friction between the concrete and the steel tube. However, the development of stresses in the steel tube was quite different. To further enhance the tube confinement to the concrete core, Orito (1987) [15], Lahlou (1999) [16], O'shear (2000) [17], Peter (2004) [18] et al. focused on the behavior of unbonded STCC columns where antifriction material was applied to the inner surface of the steel tube to maximize the confinement effect. In 1985, Tomii et al. [6] were the first researchers introducing the STCC into the traditional reinforced concrete field to improve the shear strength for the edge columns of shear walls and the short columns restrained by spandrel walls. Since then, their research group conducted a series of investigations on the behavior of STCC structures. Sun et al. [19] conducted both theoretical and experimental investigations on the earthquake-resisting performance of square tubed reinforced concrete (TRC) columns, in which the influences of axial load ratio, wall thickness of steel tube, and shear span ratio were discussed.

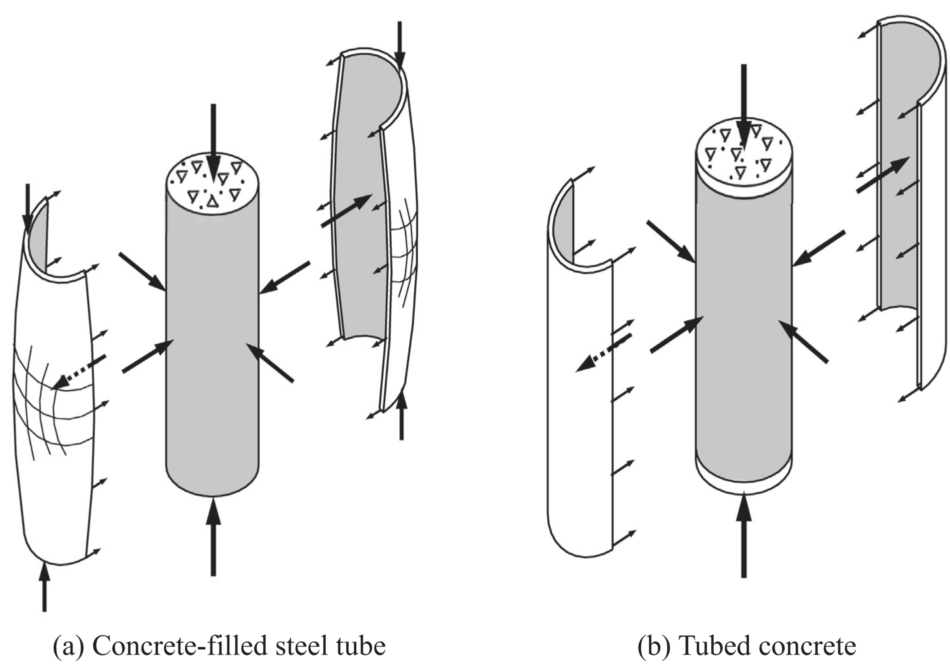

Fig. 1. Comparison between concrete-filled steel tube and tubed concrete members.