QUEEN'S UNIVERSITY BELFAST

International Institute for FRP in Construction

FRPRCS-14, Belfast - June 2019

Effect of concrete strength and FRP confinement on the compressive behaviour of FRP-HSC-steel double-skin columns

Chen, G.M.[1], Lan, Z.H.[2], Ozbakkaloglu, T.[3], Chen J.F.[4]

[1] *School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510641, China*

[2] *School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou 510006, China*

[3] *Ingram School of Engineering, Texas State University, San Marcos, TX, USA.*

[4] *School of Natural and Built Environment, David Keir Building, Queen's University Belfast, Belfast BT9 5AG, UK*

Abstract

An experimental study was carried to investigate the effects of concrete strength and FRP confinement on the compressive behaviour of FRP-concrete-steel double-skin tubular columns (DSTC). For comparison, concrete-filled FRP tubular (CFFT) columns, double-tube concrete columns (DTCC), and concrete-filled steel tubular (CFST) columns were also tested. The tests included a total of 27 columns: 12 normal-strength concrete (NSC) and 15 high-strength concrete (HSC) specimens. The test results show that the concrete strength and FRP confinement have a significant effect on the failure mode and load-strain response of the columns. All of the DTSC columns failed by FRP rupture near the mid-height. In DSTC specimens with NSC, inward buckling of the steel tube was observed, while in DSTCs with HSC, inward buckling appeared only when the FRP confining stiffness was sufficiently high. Filling the DSTC with concrete (i.e., DTCC) effectively prevented the inward buckling of the inner steel tube. For DSTC, DTCC and CFFT specimens with NSC, the load-strain curves are usually two-stage bilinear, with a first linear elastic stage and second hardening stage. For DSTC and CFFT specimens with HSC, the load-strain curves may have either a hardening or softening branch, depending on the FRP confinement stiffness.

Keywords: FRP-concrete-steel double-skin tubular column (DSTC), hybrid double-tube concrete column (DTCC), concrete-filled FRP tube (CFFT), concrete-filled steel tube (CFST), high-strength concrete (HSC), compressive behaviour, local buckling

Corresponding author's email: j.chen@qub.ac.uk

Introduction

A fibre reinforced polymer (FRP)-concrete-steel double-skin tubular column (DSTC) is a new type of FRP-steel-concrete hybrid member invented by Teng et al. [1] which makes the optimal use of three materials, i.e., steel, concrete and FRP. According to Teng [2], DSTC columns have at least three advantages: 1) a more ductile response of concrete due to the FRP confinement; 2) no need for corrosion protection for the inner steel tube; 3) ease of construction. As a result, there have been an increasing number of studies on DSTC members around the world [1-7]. However, most of the existing research has been focused on DSTC columns made of normal strength concrete (NSC) [1-4], although a number of studies have been reported on FRP-HSC-steel DSTCs (e.g. [5, 6]). Considering the significant potentials offered by this structural system, additional studies investigating different aspects of these members are required. Furthermore, previous studies [5, 6] have revealed that the behaviour of DSTC columns with HSC can be quite different from that of DSTC column with NSC. For example, in a DSTC column with HSC under concentric compression, a descending branch in the load-strain curve is a common phenomenon.

To further investigate the compressive behaviour of HSC-DSTC columns under concentric compression, a total of 27 columns, including DSTC columns, concrete-filled FRP tubular (CFFT) columns, double-tube concrete columns (DTCC, namely DSTC with inner steel tube filled with concrete), and concrete-filled steel tubular (CFST) columns were tested; the testing of the CFFT, CFST and DTCC columns is mainly for comparison purpose. The main objective of the experimental study was to investigate the effects of concrete strength (NSC vs. HSC) and FRP confinement stiffness on the compressive behaviour of DSTC columns with and without concrete filling. Due to space limitation, only the failure modes and load-strain responses are briefly reported herein.

Test Programme

As mentioned above, a total of 27 specimens were tested in this study. They can be grouped into 12 NSC specimens and 15 HSC specimens. In each group, one plain concrete column, two CFFT columns, two CFST columns and five DTCC columns were tested in addition to the DSTC columns. All the specimens had a diameter of 200 mm and a height of 400 mm. The steel tubes used in the DSTC, DTCC and CFST specimens had the same dimensions ($D \times t$ = 133 mm × 4 mm), yield strength (315.1 MPa) and elastic modulus (205.4 GPa). The concrete cylinder strength of NSC and HSC was 48.21 MPa and 112.18 MPa respectively. Two types of filament-wound GFRP tubes with 4-layer and 8-layer of fibre respectively were used in this study. The fibres were oriented mainly in the hoop direction. It should be noted that in most of the existing studies (e.g. [2-4, 6]), hand-made GFRP tubes were used.

All the specimens were tested using a compression machine with a load capacity of 5000 kN. The loading procedure followed what was reported in [5]. LVDTs and strain gauges were used to measure strains in the axial and hoop direction respectively. Axial strain gauges were also deployed at the middle height for cross-checking (in the initial loading stage) to ensure concentric loading.

Failure mode

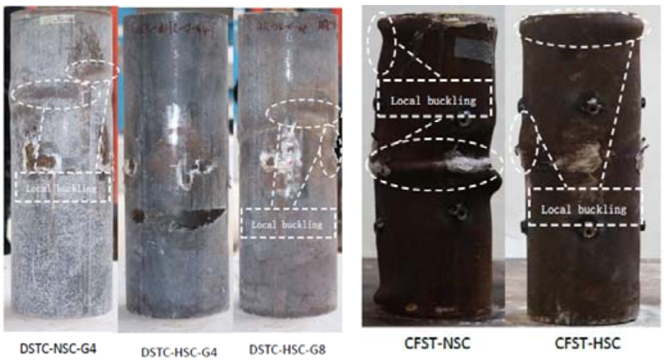
Both DSTC and DTCC columns failed by GFRP rupture at or near the mid-height of the column, which was very similar in all of these specimens, as shown in Fig. 1. This failure was independent of the GFRP thickness, except that a louder sound was heard for thicker

GFRP tubes when rupture of the GFRP fibre occurred. Significant differences were found for the steel tubes in the DSTC and DTCC columns. Local bucking of the steel tubes was usually observed in the DSTC columns with NSC after removing the GFRP and concrete (Fig. 2(a)). The failure of steel tubes in the DSTC columns with HSC was more complex: for those with a 4-layer fibre GFRP tube, no local buckling was observed in the steel tubes, while for those with a 8-layer of fibre GFRP tube, local bucking of steel tubes was usually observed (Fig. 2(a)). These phenomena suggest that the concrete strength and FRP confinement have a significant effect on the failure mode of steel tubes in DSTC columns, which is an issue requiring further research.

For the DTCC specimens, no local buckling was observed in the steel tubes as the concrete filling in the steel tube prevented it from inward local buckling. For CFST columns (Fig. 2b), local outward bucking of the steel tube was a typical failure mode. The local deformation associate with the outward buckling (Fig. 2b) was more significant than that associated with the inward local buckling in the DSTC specimens. Furthermore, local bucking of steel tubes occurred in CFST columns with both NSC and HSC, but it was less evident in the latter. These results confirm that in DSTC columns, the FRP confinement can effectively prevent the local outward buckling of the steel tube [2].

(a) DSTC (b) DTCC

Figure 1: Failure modes of DSTC and DTCC

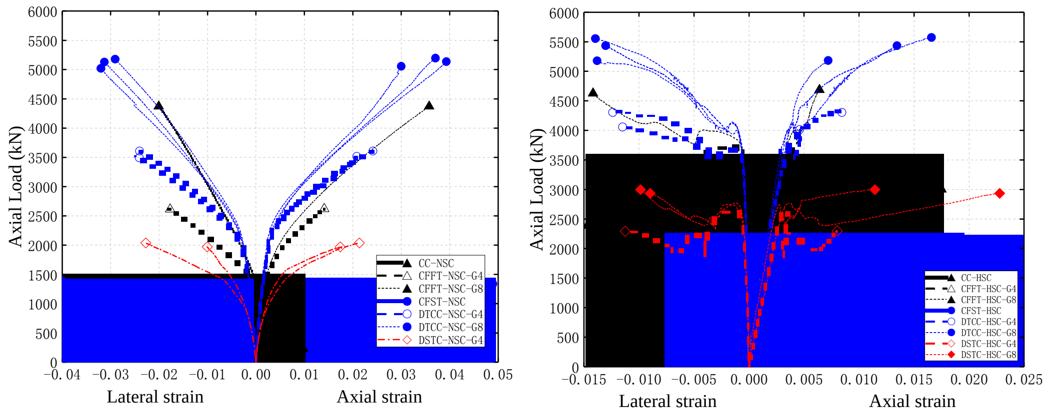


(a) Steel tube in DSTC (b) CFST

Figure 2: Failure modes of steel tubes: DSTC versus CFST

Load-strain response

Typical load-axial responses of the NSC and HSC specimens are shown in Fig. 3(a) and 3(b) respectively. For specimens with NSC, the load-strain curves of DSTC, DTCC and CFFT usually appear as two-stage bilinear curves, with a linear elastic first stage and a hardening second stage; the load-carrying capacity and the deformation capacity increase with an increase of the FRP confinement. For those with HSC, the load-strain curves of DSTC and CFFT may have a descending branch, which can be transformed into a hardening segment with or without a small softening portion if the FRP confinement is large enough (e.g. 8-layer fibre GFRP tube). Filling the DSTC specimen with concrete (i.e. DTCC) further reduces the length of the softening branch.



(a) NSC (b) HSC

Figure 3: Load-displacement curves: NSC versus HSC

Conclusions

This paper has presented an experimental study on the behaviour of DSTC. It has been found that the concrete strength and FRP confinement have significant effects on the failure mode and the load-strain responses of DSTC. Consequently, specimens with HSC has different compressive behaviour from specimens with NSC; filling the DSTC with concrete (DTCC) increases its load-carrying capacity and deformation capacity.

References

[1] Teng, J.G., Yu, T., and Wong. Y.L., 2004, "Behaviour of hybrid FRP-concrete-steel double-skin tubular columns," Balkema AA (editor). The 2nd International Conference on FRP Composites in Civil Engineering. Rotterdam, Netherlands. pp811-818.

[2] Teng, J.G., Yu, T., Wong, Y.L. and Dong, S.L., 2007, "Hybrid FRP-concrete-steel tubular columns: Concept and behaviour," Constr Build Mater. 2007(21), pp846-54.

[3] Yu, T., Teng, J.G. and Wong, Y.L. 2010, "Stress-Strain Behavior of Concrete in Hybrid FRP-Concrete-Steel Double-Skin Tubular Columns," J Struct Eng, 2010(136), pp379-89.

[4] Yu, T. and Teng, J.G., 2013, "Behavior of Hybrid FRP-Concrete-Steel Double-Skin Tubular Columns with a Square Outer Tube and a Circular Inner Tube Subjected to Axial Compression," J Compos Constr. 2013(17), pp271-279.

[5] Zhang, B., Teng, J.G. and Yu, T. 2017, "Compressive Behavior of Double-Skin Tubular Columns with High-Strength Concrete and a Filament-Wound FRP Tube," J Compos Constr., 2017(21), 04017029.

[6] Ozbakkaloglu, T. and Idris, Y., 2014, "Seismic Behavior of FRP-High-Strength Concrete-Steel Double-Skin Tubular Columns," J Struct. Eng., 2014(140), 04014019.