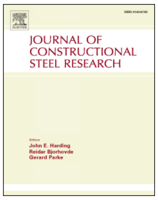
Journal of Constructional Steel Research 145 (2018) 573–590

Contents lists available at ScienceDirect

Journal of Constructional Steel Research



Performance of L-shaped columns comprising concrete-filled steel tubes under axial compression

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ARTICLE INFO

Article history:
Received 29 August 2017
Received in revised form 4 March 2018
Accepted 7 March 2018
Available online xxxx

Keywords:
LCFST-D columns
Axial-compressive test
Finite-element analysis
Slenderness ratio
Calculation of bearing capacity

ABSTRACT

This study examines the performance of a new type of composite column: L-shaped columns comprising concrete-filled steel tubes connected by double-vertical steel plates (LCFST-D). The fundamental structural behaviour of the LCFST-D columns is discussed. Seven LCFST-D columns were tested under axial compression. In the experiments, the variables were the height and the width of the vertical steel plates. The experimental results were used to assess the load-deformation relationship, strain distribution, and strength index. The tests demonstrated that the axial-compressive performance of the LCFST-D columns was favourable and showed that the mono-columns worked more cooperatively in the LCFST-D column structural form. Next, 3D nonlinear element models were used to analyse the mechanical properties and axial compressive behaviour of the LCFST-D columns. The results of the finite-element analysis were in good agreement with the experimental results. Based on the finite-element model, parametric studies were conducted to investigate the effects of the thickness and width of the vertical steel plates; the slenderness ratio, size and thickness of the steel tube; and the steel and concrete strengths. A method is proposed to calculate the slenderness ratio. This method considers the material properties of the steel and concrete and the sectional shape. Based on the confined effects of the concrete-filled steel tube, a method is proposed to calculate the axial-compressive bearing capacity of an LCFST-D column. The calculation results are in good agreement with the finite-element and experimental results, and the error is <10%.

1. Introduction

Special-shaped columns can be embedded into walls and thus help avoid column protrusion, making them beneficial from an architectural design viewpoint. L-, T-, cross- and Z-shaped reinforced concrete columns have frequently been employed in residential structures. However, such columns fail to meet the requirements of high-rise buildings with respect to heavy loads such as might occur during strong earthquakes [1]. These problems have restricted the development of special-shaped columns, and addressing them requires further research. A concrete-filled steel tubular (CFST) structure offers numerous structural benefits, including high strength and fire resistance, favourable ductility and high energy-absorption capacity. Moreover, shuttering is not required during the concrete construction, which reducing the construction cost and time. These advantages have been widely exploited and have led to the extensive use of concrete-filled tubular structures in civil engineering [2–11]. To further the development of CFST columns and to promote the application of CFST columns in building structures, many scholars have proposed special-shaped CFST columns, such as special-shaped concrete-filled steel tube columns with different structures [12–14] (Fig. 1), multiple-cell special-shaped CFST columns [15–16] (Fig. 2), and special-shaped columns fabricated using concrete-filled steel tubes [17] (Fig. 3).

Studies have shown that the constraining effect of special-shaped CFST columns is largely concentrated at their corners and this effect decreases rapidly outside the corner. Because the constraining effect of the steel plate in the middle section of the column on the core concrete is negligible, the material strengths of the steel and concrete are not used to their full advantage in the column. To address this issue, many scholars have attempted to optimize various special-shaped CFST columns. Lin and Shen [18] proposed using a welding longitudinal stiffener in the middle section or the weak area of a special-shaped CFST column (Fig. 1 (c) and (d)). The use of longitudinal stiffeners can help improve the bond between the steel and concrete. This approach can enhance the overall coordinating deformation of the special-shaped column. In addition, internal filling with concrete can effectively delay the local

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https://doi.org/10.1016/j.jcsr.2018.03.007

Nomenclature

f_y	Yield strength of steel
f_u	Ultimate strength of steel
f_c	Compressive strength of concrete
E_s	Elastic modulus of steel
E_c	Elastic modulus of concrete
ε_y	Yield strain
d_y	Yield displacement
N_m	Peak load
d_m	Maximum displacement
N_y	Yield load
N_u	Ultimate load
d_u	Ultimate displacement
U_m	Lateral deflection
μ	Ductility ratio
A_s	Sectional area of the steel tube
A_c	Sectional area of the concrete in the steel tube
A_{ps}	Sectional area of the vertical steel plates
A_{pc}	Sectional area of the concrete in the vertical steel plates
A_{sc}	Sectional area of the solid CFST components, which is equal to the sum of the sectional area of the steel tube and the internal concrete section
A_{sc}	Sectional area sum of the vertical steel plates and the internal concrete
f_{ps}	Yield strength of the vertical steel plates
f_{pc}	Comprehensive strength of the concrete in the vertical steel plates
f_{sc}	Designed concrete compression strength of the solid steel tube
f_{sc}'	Designed compressive strengths of the vertical steel plates and the filled concrete (the calculation method is the same as that of f_{sc})
φ	Coefficient of axial compressive load stability
I	Second moment of area
λ	Slenderness ratio
λ_x	Slenderness ratio of specimens around the X axis
λ_y	Slenderness ratio of specimens around the Y axis
$\lambda_{x'x'}$	Slenderness ratio of specimens around the sectional symmetric axis (X'-X' axis)
$\lambda_{y'y'}$	Slenderness ratio of specimens around the sectional symmetric axis (Y′-Y′ axis)
λ_w	Equivalent slenderness ratio of flexural-torsional buckling
G_s	Shear modulus of steel
G	Shear modulus of the specimens
N_u	Bearing capacity of the LCFST-D columns
λ_0	Relative slenderness ratio of the axial compression members
$\overline{\lambda}_{sc}$	Slenderness ratio

buckling of the steel plate and better transfer the internal force. As a result, the overall performance of the specimen is strengthened because the strength of the material is used fully. Yang and Wang [19–21] employed the angle steels in a special-shaped CFST column (Fig. 1 (e) and (f)). Their approach helped delay the local buckling of the steel tube wall and significantly improved the bearing capacity and ductility. Zuo and Cai [22–25] improved the mechanical properties of a special-shaped CFST column by setting binding bars (Fig. 1 (g) and (h)). This approach helped improve the confinement around the core concrete and enhance the bearing capacity and ductility. However, many holes on the column were observed, which decrease the integrity of the column. Tu [26–27] proposed a multi-cell composite special-shaped concrete-filled steel tubular (MS-CFST) column (Fig. 2). The column was formed by welding three steel tubes together, then vertically pouring concrete into the steel tube. These columns improved the confinement around the core concrete, but the quality of the vertical weld between the steel tubes could not be ensured. Additionally, two parallel steel plates were installed between the two longitudinal welds, so the material strength could not be fully utilized. Chen [28–29] also proposed a new variety of special-shaped CFST columns with satisfactory mechanical properties and seismic behaviours. The columns were formed by connecting mono-rectangular columns with lacing bars or steel plates. The connecting patterns developed from the early weld-lacing bars [30] (Fig. 3 (a)) to the connecting vertical steel plates with or without circular holes [31–35] (Fig. 3 (b) and (c)).

It has been shown that special-shaped columns comprising CFSTs connected by single vertical steel plates (SCFST columns, Fig. 4) cannot meet the requirements of high-rise steel housing construction in terms of the bearing capacity and welding transverse stiffeners, complicating their application in rapid industrial construction processes. In this study, special-shaped columns comprising CFSTs connected by double steel plates (SCFST-D columns, Fig. 5) are proposed. This pattern not only helps improve the confinement of the core concrete but also helps increase the bearing capacity and flexural rigidity.

In this study, an axial compression test is conducted on L-shaped columns comprising concrete-filled steel tubes connected by double-vertical steel plates (LCFST-D columns). 3D nonlinear element modelling is used to analyse the mechanical properties and axial compressive behaviours of the LCFST-D columns, and the finite-element results are compared to the experimental results. Based on the finite-element model, parametric studies are conducted to investigate the effect of the thickness and width of the vertical steel plates, the slenderness ratio, size and thickness of the steel tube; and the steel and concrete strengths. Based on the stress mechanism of the LCFST-D columns and the confinement of the core concrete, a method is proposed to calculate the axial-compressive bearing capacity of the LCFST-D columns.

2. Experimental programme

2.1. Specimen design

The sectional dimensions of the mono-steel tubes are 100 × 100 × 5.75 mm for the columns. Parametric studies were conducted to investigate the effects of the column height and the width of the vertical steel plates. Seven LCFST-D columns were tested under axial compression. Fig. 6 and Table 1 present the geometric and sectional dimensions of the specimens.

2.2. Mechanical properties of materials

Table 2 lists the tensile test results of the standard steel specimens, where f_y is the yield strength, f_u is the tensile strength, E_s is the elastic modulus of steel, and ε_y is the yield strain of the steel. Concrete cube and cylinder tests [36] were used to determine the compressive strength and elastic modulus. The Young's modulus of concrete is 3×10^4 N/mm^2 and the fracture strain is 2.3×10^{-4}. The average axial compressive strength of concrete (f_c) is listed in Table 2.

2.3. Test setup and loading procedure

Fig. 7 shows the general arrangement of the test setup. A 1000 kN universal testing machine was used to conduct the axial test. The top loading plate of the instrument was fixed, while the bottom loading plate could be rotated to create a spherical hinge. The axial loads pass through the centroid of the LCFST-D column.

Pre-loading was conducted prior to formal testing. The pre-loading value was 15% of the predicted axial-compressive bearing capacity. Formal loading was accomplished by grading loading. The load of each