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Experimental study of the cyclic behavior of concrete-filled double skin steel tube columns subjected to pure torsion

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ABSTRACT

Based on a quasi-static test on six concrete-filled double skin steel tube columns subject to cyclic pure torsion, the torsion behavior of concrete-filled double skin steel tube columns with various section types, hollow ratios and steel ratios was studied. The failure modes, torsion-rotation angle hysteretic curves and strain distribution law of concrete-filled double skin steel tube columns under reversed cyclic loading are obtained. The test results show that the hysteretic curves of concrete-filled double skin steel tube columns under pure torsion are plump. The unloading stiffness was close to the initial elastic stiffness. The good energy dissipation capacity of concrete-filled double skin steel tube columns can be observed. Under a cyclic torsion moment, the torsion-resistance capacity of circular concrete-filled double skin steel tube columns was better than that of square and rectangular concrete-filled double skin steel tube columns. With the same thickness of the inner steel tube and the same section size and shape, the hollow ratio of concrete-filled double skin steel tube columns has little effect on the cyclic torsion behavior.

1. Introduction

A concrete-filled double skin steel tube column (CFDST) is a composite member formed by pouring concrete between two concentric steel tubes. Compared with traditional solid concrete-filled steel tube columns (CFSTs), concrete-filled double skin steel tube columns have a wider section and larger bending stiffness using the same amount of materials. Concrete-filled double skin steel tube columns can be used in engineering areas such as piers, water-resistant casing pipes of offshore oil drilling platforms, and piles with large diameters in long-span electric power pylons and high-rise buildings. The major section types of concrete-filled double skin steel tubes are circular nested circular, circular nested square, square nested circular, square nested square, and rectangular nested rectangular [1].

Many studies have conducted experimental and theoretical analysis of the static behavior and seismic performance of concrete-filled double skin steel tube columns under bending moments and axial force (e.g., [2–8]), and the results have shown that concrete-filled double skin steel tube columns not only have large axial stiffness and flexural capacity but also possess satisfactory seismic performance. Taking the diameter-to-thickness ratio, hollow ratio, slenderness ratio and eccentricity ratio of tubes as the main parameters, Han [9,10] proposed practical calculation methods for the ultimate bearing capacity of concrete-filled double skin steel tube columns under axial loading and eccentric loading by conducting an axial compression and eccentric compression experiment on concrete-filled double skin steel tube columns. Taking the steel ratio and hollow ratio as the main parameters, Huang [11] carried out an experimental study and finite element analysis on the mechanical behavior of CFDSTs under monotonic pure torsion and proposed design formulas for the calculation of the torsional capacity of CFDSTs.

In various practical engineering applications, CFDST members may be subjected to cyclic torsional loading, such as piers of a curved girder bridge and corner columns of a high-rise building under an earthquake or transmission towers that cross a river or sea under wind loading or an earthquake. Therefore, it is necessary to investigate the behavior of CFDST members under cyclic pure torsion. Compared with concrete-filled steel tube columns, CFDST columns can make full use of the mechanical properties of materials. Reference [12] shows that concrete-filled steel tube columns have perfect seismic performance. The torsion moment versus rotation angle hysteresis loops of CFST columns under cyclic torsion were plump. Torsion moment versus rotation angle skeleton curves have no obvious descending branch. Stiffness degradation and strength degradation of concrete-filled steel tube columns were not

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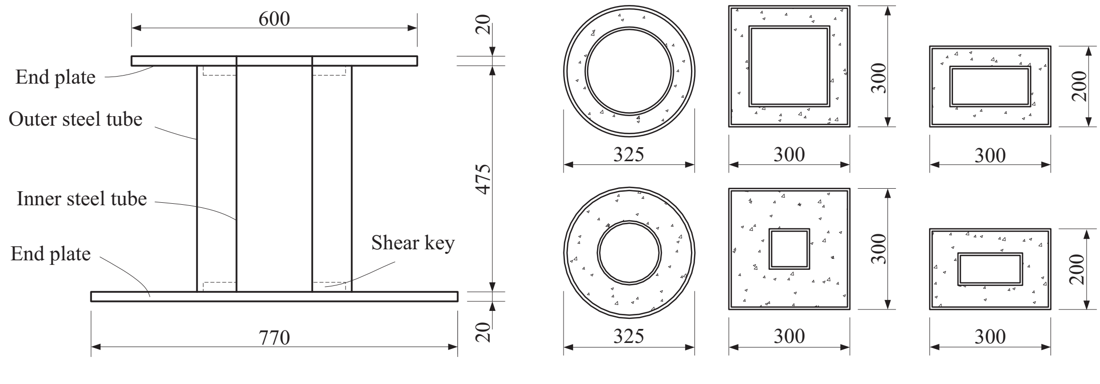
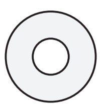
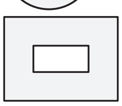
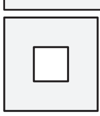


(a) Elevation view (b) Section form of specimens

Fig. 1. Geometric dimensions of the specimens.

Table 1
Details of the specimens.

Section type	Specimen label	Dimensions of the outer steel tube $D(H \times B) \times t_o$ (mm)	Dimensions of the inner steel tube $d(h \times b) \times t_i$ (mm)	ψ
	CC-T1 CC-T2	ϕ325 × 8.15 ϕ325 × 8.15	ϕ159 × 4.34 ϕ219 × 6.30	0.21 0.40
	RR-T1 RR-T2	300 × 200 × 4.60 300 × 200 × 4.60	160 × 80 × 3.80 200 × 100 × 3.88	0.18 0.29
	SS-T1 SS-T2	300 × 300 × 5.34 300 × 300 × 5.34	100 × 100 × 3.54 200 × 200 × 3.54	0.09 0.41

obvious. However, there is still a lack of research on the mechanical properties of concrete-filled double skin tube columns under cyclic pure torsion loading. This paper focuses on the failure modes and hysteretic behavior of concrete-filled double skin steel tube columns under cyclic pure torsion by carrying out pseudo-static testing and analysis.

2. Experimental program

2.1. Design and manufacturing of specimens

In this paper, six specimens of concrete-filled double skin tube columns were designed, including 2 CFDST members with circular hollow sections (CHSs) as the inner tube and outer tube, 2 CFDST members with square hollow sections (SHSs) as the inner tube and outer tube and 2 CFDST members with rectangular hollow sections (RHSs) as the inner tube and outer tube. The information of these specimens is shown in Fig. 1 and Table 1, where D (d) is the outside diameter of the outer (inner) circular steel tube, H (h) and B (b) are the outside diameters of the outer (inner) square and rectangular steel tube, and t_o (t_i) is the wall thickness of the outer (inner) steel tube. The main variable parameters in the tests are the tube shape (circular, square or rectangular) and the hollow ratio ψ. The hollow ratio ψ is given by $\psi = A_h/A_{sc}$. A_h is the hollow section area, which is given by $A_h = \pi(d\text{-}t_i)^2/4$ for a circular section, and $A_h = (h\text{-}t_i)(b\text{-}t_i)$ for a square or rectangular section. A_{sc} is the cross-sectional area of the CFDST ($= A_{so}+A_c+A_{si}+A_h$). A_{so} is the cross-sectional area of the outer steel tube. A_c is the cross-sectional area of the sandwiched concrete. A_{si} is the cross-sectional area of the inner steel tube. In references [11,12], welded steel tubes are used to create specimens, and the welding of steel tubes cracked in the experimentation. In this test, the seamless steel tubes are used for specimens to avoid the breakage of welding on steel tubes. The end plate and end region of the steel tubes are connected by a fillet weld. The surfaces of the upper and lower end plates between the double steel cylinders should be respectively welded with four shear connectors not only to ensure that the steel tubes and concrete can bear loading together but also to make sure that the torsion moment in the end region of the specimens can be transferred to steel tubes and concrete equably. The concrete between double skin steel tubes is poured through the holes reserved in the upper end plates.

2.2. Material properties

The strength grade of the concrete is C40. When the concrete is poured into the double skin steel tubes, the concrete test cubes, which are 150 mm on each edge, should be made for the material strength test, and both the specimens and concrete cubes should be naturally maintained under the same conditions. After 28 days, the compressive strength of those concrete test tubes was measured by standard testing methods, and the average value of the concrete compressive cube strength was 42.1 MPa. The property test data of 9 steel tubes is shown in Table 2 and Fig. 2, where f_y is the yield strength of the steel tube, f_u is the ultimate strength of the steel tube, and E_s is the Young's modulus of the steel tube. From the material test, it can been seen that expect steel tubes numbered as 6, 8 and 9 shown in Fig. 2, the stress-strain curves of the coupons taken from other steel tubes have a visible yielding plateau. Thus, the stress corresponding to the plastic strain of 0.2% is adopted as the yield strength for steel tubes numbered as 6, 8 and 9 based on the method proposed by reference [13].

Table 2
Steel material properties.

No.	Dimensions of the steel tube (mm)	f_y (MPa)	f_u (MPa)	E_s ($\times$ 10^5 MPa)	No.	Dimensions of the steel tube (mm)	f_y (MPa)	f_u (MPa)	E_s ($\times$ 10^5 MPa)
1	ϕ325 × 8.15	317.07	506.41	2.10	6	100 × 100 × 3.54	310.67	371.67	1.91
2	ϕ219 × 6.30	361.27	481.87	2.08	7	300 × 200 × 4.60	232.71	388.78	2.05
3	ϕ159 × 4.34	329.02	475.46	2.33	8	200 × 100 × 3.88	406.33	479.33	2.39
4	300 × 300 × 5.34	352.00	508.57	1.97	9	160 × 80 × 3.80	353.33	430.33	1.87
5	200 × 200 × 3.54	283.00	403.67	2.17					