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Performance of concrete filled steel tube reinforced concrete columns subjected to cyclic bending

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ABSTRACT

This paper reports nine test results of concrete filled steel tube reinforced concrete (CFSTRC) columns, which were tested under constant axial load and cyclically increasing flexural loading. The main parameters varied in the experiments were axial load level and cross-sectional type. The influence of these parameters on strength, ductility, stiffness and energy dissipation was investigated. It was found that, in general, CFSTRC columns exhibit favourable energy dissipation and ductility, even when the columns were subjected to high axial loads. This type of composite column is adoptable in practical engineering, particularly in regions of high seismicity.

1. Introduction

In China, an innovative type of composite column, named as concrete filled steel tube reinforced concrete (CFSTRC) column in this paper, has been utilised in some high-rise buildings recently. This new composite technology has attracted more and more research interest. Fig. 1 gives a schematic view of three typical cross-sections.

For innovative composite columns, the following advantages over conventional concrete filled steel tubular (CFST) columns are expected:

(1) Higher stiffness.
(2) The beam-column joints of the CFSTRC column system can be designed according to the well established knowledge of conventional reinforced concrete (RC) beam-column joints.
(3) Higher fire resistance due to the protection of the inner steel tubes provided by the concrete.
(4) Corrosion of the steel tubes can be prevented due to protection from the outer concrete.
(5) The possibility of "outward" buckling of the steel tubes is virtually prohibited due to the restraint of the outer concrete.

Compared with conventional RC columns, the following advantages are expected:

(1) Higher ductility owing to the existence of the inner CFST.
(2) Faster construction speed is expected. In practice, the inner CFSTs can be built first to bear the construction load alone, and the outer concrete can be poured later.

Some previous research has been carried out on CFSTRC columns [1,2], which demonstrates the fact that this type of composite column generally has good performance. However, there is still a lack of information on the composite members under cyclic loading. It indicates a need for further research in this area.

This paper thus tested nine CFSTRC columns under constant axial load and cyclically increasing flexural loading. The main objectives of this research were twofold: first, to report a series of new tests on CFSTRC columns. And second, to investigate influence of some parameters, including axial load level and cross-sectional type, on the seismic behaviour of CFSTRC columns.

2. Experimental programme

2.1. General

Nine CFSTRC specimens were tested. Test parameters were the section type and the axial load level (n). Three kinds of cross-section were selected as shown in Fig. 1 (a), (b) and (c), respectively, i.e., square RC column reinforced with square CFST, square RC column reinforced with circular CFST, and circular RC column reinforced with circular CFST. The axial load level (n) in this paper is defined as follows, i.e.,

$$n = \frac{N_o}{N_u} \tag{1}$$

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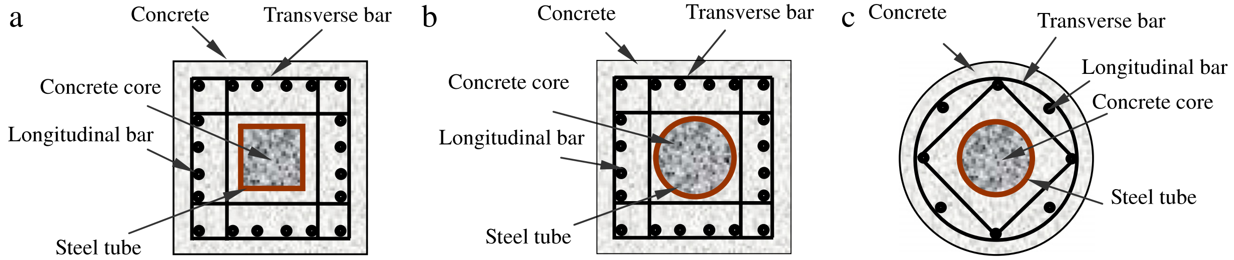

Fig. 1. Typical concrete filled steel tube reinforced concrete (CFSTRC) column cross-sections.

Table 1
Summary of specimen information.

Test series	Outer section type	Inner steel tube type	Specimen label	Dimension of inner steel tube (mm)	Axial load N_o (kN)	Axial load level n	P_{ue} (kN)	K_{ie} (kN m^2)	K_{se} (kN m^2)	Ductility ratio μ	Dissipated energy E_{total} (kN · m)
I	Square	Square	SS1	50 × 50 × 2.7	0	0	49.5	675	585	4.02	28.0
		Square	SS2	50 × 50 × 2.7	287	0.3	62.6	1404	1169	3.91	18.5
		Square	SS3	50 × 50 × 2.7	574	0.6	61.8	1824	1616	3.18	10.6
II	Square	Circular	SC1	60 × 2.0	0	0	42.6	707	616	4.15	34.3
		Circular	SC2	60 × 2.0	282	0.3	55.8	1402	1218	3.89	16.2
		Circular	SC3	60 × 2.0	564	0.6	61.8	1778	1611	2.36	7.8
III	Circular	Circular	CC1	60 × 2.0	0	0	29.2	475	305	4.18	40.8
		Circular	CC2	60 × 2.0	219	0.3	31.0	799	449	3.71	12.7
		Circular	CC3	60 × 2.0	438	0.6	30.2	1104	813	3.33	7.0

Notation

A_s	Steel cross-sectional area
A_c	Concrete cross-sectional area
D	Sectional dimension
E_c	Concrete modulus of elasticity
E_s	Steel modulus of elasticity
f_y	Yield strength of steel
$f_c{}'$	Concrete cylinder strength
f_{cu}	Concrete cube strength
L	Effective buckling length of column in the plane of bending
M	Moment
M_u	Moment capacity
n	Axial load level ($= N_o/N_u$)
N_o	Axial compressive load
N_u	Compressive capacity of the composite column
P	Lateral load
P_{ue}	Ultimate lateral load capacity
Δ	Lateral displacement
ε	Strain
ϕ	Curvature
μ	Ductility coefficient

where N_o is the axial load applied to the composite specimens; N_u is the axially compressive capacity of the composite columns. The value of N_u was determined by using the mechanics model described by Han et al. [3]. Concrete strength measured at the time of tests was used in the calculations.

The details of each column are presented in Table 1, where the specimens with "SS", "SC" and "CC" in the specimen labels refer to columns with cross-sections as shown in Fig. 1 (a), (b) and (c), respectively. For clarity, they were designated as test series I, II and III respectively in this paper.

Owing to the loading limitation of the test machine and the high axial load level (n), the overall sectional dimension (D) for all specimens was designed as 150 mm. This dimension was expected to be similar to some low rise buildings, such as some workshop structures. However, the column dimension is smaller than that of columns used in some engineering practice, such as high rise buildings and long span bridges. Thus, there is still potential research need to clarify the size effect on the column behaviour.

All specimens were longitudinally reinforced with four 10 mm diameter deformed reinforcements and 6 mm diameter plain transverse reinforcements spaced at 100 mm centres. The clear cover to the stirrups was 15 mm.

2.2. *Material properties*

Tension tests were carried out to determine the material properties of the steel tubes and rebars. Table 2 lists the measured average yield strength (f_y), tensile strength (f_u) and modulus of elasticity (E_s).

The concrete mix was designed for a compressive cube strength (f_{cu}) at 28 days of approximately 40 N/mm^2. The mix proportions were as follows:

- Cement: 538 kg/m^3
- Water: 205 kg/m^3
- Sand: 598 kg/m^3
- Coarse aggregate: 1109 kg/m^3.

In all the concrete mixes, the fine aggregate used was silica-based sand, the coarse aggregate was carbonate stone. For each batch of concrete mixture, three 150 mm cubes were also cast and cured in conditions similar to the related specimens. The average cube strengths (f_{cu}) of the concrete used to fabricate specimens in series I and II at 28 days and the time of tests were 33.6 N/mm^2 and 52.4 N/mm^2 respectively, whilst those for the specimens in series III were 32.2 N/mm^2 and 45.0 N/mm^2 respectively.

2.3. *Specimens preparation*

The steel tubes for all inner CFSTs were made of cold-formed steel. The measured inner corner radius (r_i) for the square tubes was 3 mm. The ends of the steel tube sections were cut and machined to the required length. The insides of the tubes were wire