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Engineering Structures 28 (2006) 1698–1714
ENGINEERING STRUCTURES
www.elsevier.com/locate/engstruct

Concrete-filled double skin steel tubular (CFDST) beam–columns subjected to cyclic bending

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Received 2 August 2005; received in revised form 24 February 2006; accepted 6 March 2006
Available online 3 May 2006

Abstract

In recent years, it was proposed by several researchers that concrete filled double skin steel tubes (CFDST) be studied for their strength as a column or a beam. Advantages of CFDST over fully concrete filled steel tubes (CFST) include: increase in section modulus; enhancement in stability; lighter weight; better damping characteristics and better cyclic performance. It is thus expected that concrete filled double skin steel tubes (CFDST) have the potential of being used in building structures. This paper provides new test data pertaining to the seismic behavior of CFDST beam–columns. The test parameters included the section types (circular and square), the core concrete strength (f_{cu}), and the axial load level (n). Twenty-eight CFDST column specimens, including 16 specimens with SHS (square hollow section) outer and CHS (circular hollow section) inner, 12 specimens with CHS (circular hollow section) outer and CHS (circular hollow section) inner were tested under constant axial load and cyclically increasing flexural loading. The CFDST beam–columns were found to have significant increase in strength, ductility, and dissipated energy over the outer jackets. In general, the ductility and energy dissipation ability of specimens with circular sections are higher than those of the specimens with square sections. The mechanics model which was developed by the authors for concrete filled steel tubular (CFST) beam–columns subjected to constant axial load and cyclically increasing flexural loading, is used to analyze the behavior of CFDST beam–columns. It is found that the predicted cyclic responses for the composite beam–columns are generally in reasonable agreement with test results. Finally, comparisons are made with predicted beam–column flexural stiffness using the existing codes.

Keywords: Composite beam–columns; Concrete; Seismic design; Cyclic load; Ductility; Strength; Hollow sections; Double-skin; Mechanics model

1. Introduction

The use of fully concrete filled steel tubes (CFST) has become widespread in the past few decades [3]. They have better structural performance than those of bare steel or bare reinforced concrete. The steel hollow section acts as formwork as well as reinforcement for the concrete. Concrete eliminates or delays the local buckling of steel hollow section, and increases significantly the ductility of the section. CFST construction has proven to be economic in material as well as providing for rapid construction and thus additional cost savings.

In recent years, it was proposed by several researchers that concrete filled double skin steel tubes (CFDST) be studied for their strength as a column or a beam. Advantages of CFDST over CFST include: increase in section modulus; enhancement in stability; lighter weight; good damping characteristics and better cyclic performance. It is expected that the CFDST columns can obtain a higher fire resistance period than the CFST columns, due to the inner tubes of the composite columns being protected by the sandwiched concrete during fire. It is thus expected that concrete filled double skin steel tubes (CFDST) have a potential of being used in building structures.

In the past, a large number of research studies were carried out on CFST columns, and some literature reviews had been

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0141-0296/$ - see front matter
doi:10.1016/j.engstruct.2006.03.004

Nomenclature

CFDST	Concrete filled double skin steel tube
CFST	Concrete filled steel tube
CHS	Circular hollow section
d	Outer diameter of the inner steel tube
D	Outer dimension of the outer steel tube
E_c	Concrete modulus of elasticity
E_s	Steel modulus of elasticity
f_{syo}	Yield strength of the outer steel tube
f_{syi}	Yield strength of the inner steel tube
f_{cu}	Characteristic 28-day concrete cube strength
f'_c	Concrete cylinder strength
I_c	Moment of inertia for the gross concrete section
I_{si}	Moment of inertia for the inner steel tube
I_{so}	Moment of inertia for the outer steel tube
K_i	Initial section flexural stiffness
K_{ic}	Calculated value of initial section flexural stiffness
K_{ie}	Tested value of initial section flexural stiffness
$K_{i,e}$	Flexural stiffness of inner tube
K_{osce}	Flexural stiffness of outer tube and concrete
K_s	Serviceability-level section flexural stiffness
K_{sc}	Calculated value of serviceability-level section flexural stiffness
K_{se}	Tested value of serviceability-level section flexural stiffness
M_u	Ultimate strength of CFDST beams
n	Axial load level ($=N_o/N_u$)
N_u	Ultimate strength of the composite columns
N_{uc}	Predicted ultimate strength
N_{ue}	Experimental ultimate strength
N_o	Axially compressive load
P	Lateral load
P_u	Ultimate lateral strength
P_{uc}	Predicted lateral strength
P_{ue}	Experimental lateral strength
SHS	Square hollow section
t_{so}	Wall thickness of the outer steel tube
t_{si}	Wall thickness of the inner steel tube
χ	Hollow ratio, given by $d/(D - 2 \cdot t_{so})$
Δ	Lateral displacement
Δ_y	Yielding displacement
Δ_u	Displacement when the axial load falls to 85% of the ultimate strength (P_u)
ϕ	Curvature
μ	Ductility coefficient

done by Schneider [17] and Han [10]. Several state of the art reports and papers were published recently on concrete-filled steel tubular structures, such as [9,16,18,19].

In recent years, concrete filled double skin steel tubes (CFDST) were studied as columns or beams, such as [6,11,14,15,20,21,23–29]. The literature on CFDST has been generally reviewed by [11]. A summary of research conducted on CFDST is presented in Table 1.

The behavior of CFDST columns under cyclic loading has been experimentally investigated and the results are presented in this paper. The differences of this test program compared with the similar studies carried out by other researchers mentioned above are as follows:

(1) CFDST columns with both circular and square sections were tested; CFDST columns with square sections under cyclic loads were seldom reported before.
(2) Axial load level (n) ranges from 0 to 0.65 (in the previous studies, the axial load level generally ranges from 0 to 0.4). The lack of information on cyclic behavior of CFDST columns under high axial load level indicates a need for further research in this area.

The main objectives of this paper were thus threefold: first, to report a series of cyclic tests on CFDST columns. The test parameters included the section types (circular and square), the core concrete strength (f_{cu}), and the axial load level (n). Twenty-eight CFDST column specimens, including 16 specimens with SHS (square hollow section) outer and CHS (circular hollow section) inner, and 12 specimens with CHS (circular hollow section) outer and CHS (circular hollow section) inner were tested under constant axial loading and cyclically increasing flexural loading. Second, to predict the response of CFDST columns subjected to constant axial loading and cyclically increasing flexural loading theoretically. And finally, to compare the predicted flexural stiffness using the existing codes, such as AIJ [2], BS5400 [5], EC4 [8] and LRFD-AISC [1].

2. Experimental program

2.1. Specimen preparation

Twenty-eight CFDST beam–column specimens, including 16 specimens with SHS outer and CHS inner, and 12 specimens with CHS outer and CHS inner were tested. Fig. 1(a) and (b) show the sectional details and dimensions of the specimens with circular and square sections respectively. Test design parameters were the section types, the axial load level (n) from 0 to 0.6, and the hollow section ratio (χ) from 0 to 0.77. Three square hollow steel specimens were also tested at the same time, with the axial load level (n) from 0 to 0.6.

The axial load level (n) in this paper is defined as follows, i.e.,

$$n = \frac{N_o}{N_u} \quad (1)$$

where N_o is the axial load applied on the composite specimens; N_u is the axially compressive capacity of the composite columns. The value of N_u can be determined by using a mechanics model or the simplified formulas described in [11] for specimens with SHS outer and CHS inner, and [20] for specimens with CHS outer and CHS inner, respectively. Concrete strength at the time of test was used in the calculations.

The real axial load level (n) of the tested specimens is listed in Table 1.