Thin-Walled Structures 64 (2013) 83–93

Contents lists available at SciVerse ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Experimental study of rectangular CFST columns subjected to eccentric loading

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ARTICLE INFO

Article history:
Received 16 February 2012
Accepted 14 December 2012
Available online 22 January 2013

Keywords:
Biaxial bending
Concrete contribution ratio (CCR)
Concrete-filled steel tube (CFST)
Uniaxial bending

ABSTRACT

To study the behavior of rectangular CFST columns subjected to eccentric loading, a total of 17 rectangular CFST columns uniaxial and biaxial bending tests were carried out. Concrete compressive strength, steel strength, cross-sectional proportion and eccentricity were selected as the variables to be investigated. The relationship between the load and the lateral displacement at the mid-height of the columns in the directions of both the strong and weak axes and the relationships of load versus end shortening for each specimen were duly recorded. The influences of the constraining factor and eccentric ratio in relation to the strength and ductility indexes of the specimens were investigated. Moreover, in order to achieve the ultimate bearing capacity of the relative rectangular hollow sections with a load of the same eccentricity, the rectangular hollow section models were established by means of the FEM. The concrete contribution ratio necessary for the rectangular CFST columns to be able to resist the eccentric loading was obtained also through comparison of the simulated results and the test data. Finally, based on the definitions and conclusions obtained for the design strength of rectangular CFST columns relying on the "Technical specification for design of steel structure dwelling houses in Tianjin" code (DB 29-57-2003), a factor β was proposed to enhance the steel strength in order to take into account the concrete contribution to the resistance. The modified equation can subsequently provide improved understanding and a more accurate predictive ability or value.

1. Introduction

In the normal course of events the composite columns will necessarily be subjected to eccentric loads in practical engineering. In addition, the corner columns usually need to be subjected to a combination of both compression and biaxial bending.

The related information that refers to the bearing capacity of CFST columns under this combination of compression and bending are currently provided in the form of the design codes, such as EC4 [1], ACI318M-05 [2], GJB(4142-2000) [3]and AISC 2005 [4]. The thrust–moment (*P–M*) interaction curve is usually used in fact for predicting the bearing capacity of the reinforced concrete structure under eccentric loading. This method has also been found to be adopted in the design of composite structures too. The exact *P–M* interaction curves found in current design codes are based on a summary of test results or alternatively through the fiber analysis method. However, to make it more convenient for the purposes of design, some codes have adopted a simplified P-M interaction curve to predict the design resistance strength of composite columns. The current typical interaction curves are the AISC 2005 simplified bilinear interaction curve and the simplified 4-line interaction curve proposed by EC4. The AISC 2005 simplified bilinear curve was revised based on changes in approach provided by AISC 2001 [5]. On account of the AISC 2001 approach not suitably taking consideration of the contribution of the concrete; as a result the code does not realize the differences in behavior between pure steel members and composite members: in fact it usually provides an overly conservative estimation. To make it more accurate and safe for design, the revised version-AISC 2005 provides two new simplified interaction curves for composite structure. One of them is the rigid-plastic approach, which is similar with the EC4 simplified interaction curve. However, it is still different in relation to how it calculates the concrete stress value and, as well, as to how the concrete contributes in resisting the pure bending: this as well should be considered.

Some researchers have undertaken an investigation into the behavior of CFST columns subjected to eccentric loading [6–16]. Of all these experimental studies on CFST columns, greatest efforts were placed on research intending to determine the failure mode as well as the bearing capacity for the tested specimens. However, as to the concrete contribution to the columns ability to resist combined compression and bending, and especially to resist combined compression and biaxial bending: this type of research analysis is still lacking and in need of further research.

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http://dx.doi.org/10.1016/j.tws.2012.12.006

Nomenclature

A_c	cross-sectional area of concrete core;
A_s	cross-sectional area of steel tube;
B	width of the rectangular steel tube;
CFST	concrete-filled steel tube;
CHS	circular hollow section;
D	depth of the rectangular steel tube;
DI_x	ductility index about x-axis;
DI_y	ductility index about y-axis;
E_c	Young's modulus of concrete;
E_s	Young's modulus of rectangular steel tube;
f_{cu}	compressive cube strength of concrete;
f_y	yield strength of steel;
f_u	ultimate strength of steel;
L	length of the rectangular steel tube;
M_x	available flexural strength about x-axis;
M_y	available flexural strength about y-axis;
N_u	ultimate axial compression bearing capacity;
$N_{u,e}$	ultimate test resistance of concrete-filled rectangular specimens;
$N_{u,hollow}$	ultimate strength of the empty hollow steel member;
N_{Ex}	Euler's critical load about x-axis;
N_{Ey}	Euler's critical load about y-axis;
W_x	net section resistance moment about x-axis;
W_y	net section resistance moment about y-axis;
RHS	rectangular hollow section;
SI	strength index;
SHS	square hollow section;
t	wall thickness of the steel tube;
ξ	constraining factor;
δ	specimen end shortening;
$\delta_{85\%}$	axial deformation corresponding to the 85% of the ultimate strength of CFST columns measured after the ultimate strength was reached;
δ_u	axial deformation at the ultimate strength;
φ_x	stability factor for compression about x-axis;
φ_y	stability factor for compression about y-axis.

As distinct from square and circular CFST columns, the flexural strength of rectangular CFST columns is different along both of the two symmetry axes. The aim of this paper is to study the behavior of rectangular CFST columns subjected to combined compression and bending (including uniaxial and biaxial bending). Seventeen eccentrically loading tests were carried out on rectangular CFST columns. The results obtained from the testing, including the ultimate load, maximum lateral and vertical displacement and strain development of the steel tubes, were each, in turn, recorded and analyzed. Furthermore, the strength index, ductility index and concrete contribution ratio for the tested specimens were investigated. Finally, based on the analysis of these test results, as well as test data drawn from other literatures, a factor β was proposed to enhance the steel strength so as to take account of the concrete contribution to the resistance for the design strength for the rectangular CFST columns in the "Technical specification for design of steel structure dwelling houses in Tianjin" code (DB 29-57-2003).

2. Experimental study

2.1. General

A total of 17 RCFST stub columns tests were carried out at Tianjin University to investigate the behavior of rectangular CFST columns subjected to eccentric loads. All the test specimens were classified into two groups—Group PYA and Group PYB. Specimens in Group PYA were subjected to combined compression and uniaxial bending about the strong axis, whilst specimens in Group PYB were subjected to combined compression and biaxial bending. The investigated variables were selected accordingly: electricity, concrete compressive strength, steel strength grade and cross-sectional proportions. Table 1 provides details of the ranges of values covered. The section labeling convention is shown in Fig. 1.

2.2. Fabrication of specimens

All specimens of the same size of steel tube were cut from the same cold-formed rectangular steel tube. The concrete was vertically cast into the steel tube in layers. Each layer was compacted using a poker vibrator. All specimens were kept in an indoor environment to cure.

2.3. Material properties

The nominal tube thicknesses are 4 mm, 5 mm and 6 mm respectively. The basic stress–strain characteristics of the rectangular steel tubes were obtained by means of tensile coupon tests. Coupons were machined from the complete sections of the wider-width regions (see Fig. 1) and subsequently tested in accordance with Code (GB/T 228-2002) [17]. The key results from the coupon tests are summarized in Table 2.

Three different grades of commercial concrete strengths – C30, C40, and C50 – were used in the test. Nine cubes (100 mm) of each batch were cast for material testing [18], the concrete elastic modulus and the average cubic strength (f_{cu}) at the testing time are illustrated in Table 3.

2.4. Test set-up

All column tests were performed in a 5000 kN capacity testing machine (see Fig. 2). Since the standard accessories of the testing machine were unable to produce eccentric loading, knife edges and ball edges were constructed which allowed the load from the testing machine to be applied at given eccentricities to the specimen. More details about the bearing plates employed at both ends of the specimens are shown in Fig. 3. The knife edges and ball edges were employed at both the bottom and the top to enable each Group PYA specimen and Group PYB specimen respectively to simulate the required pin-pin boundary conditions.

For the specimens subjected to compression and uniaxial bending, the axial shortening was captured by means of two linear variable displacement transducers (LVDTs) positioned between the end platens of the testing machine. While the lateral displacements of specimens were measured by means of three LVDTs at the locations of L/4, L/2 and 3L/4 mm respectively for the specimens subjected to compression and biaxial bending, the axial shortening was captured by means of four linear variable displacement transducers (LVDTs) positioned at each corner between the end platens of the testing machine. Meanwhile the lateral displacements of the specimens on the two perpendicular sides were measured by means of two LVDTs at the locations of L/2 mm. All the relevant details as to the measurement arrangement are shown in Fig. 4.

Strain gauges were used to measure the axial longitudinal strains and transverse strains at the different locations along the