Available online at www.sciencedirect.com

ScienceDirect

Thin-Walled Structures 45 (2007) 961–973

THIN-WALLED STRUCTURES

www.elsevier.com/locate/tws

Behavior of square hollow steel tubes and steel tubes filled with concrete

Lanhui Guo[a,*], Sumei Zhang[a], Wha-Jung Kim[b], Gianluca Ranzi[c]

[a]*School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, PR China*
[b]*School of Architecture, Kyungpook National University, Daegu, South Korea*
[c]*School of Civil Engineering, The University of Sydney, Sydney, Australia*

Received 13 April 2007; received in revised form 18 July 2007; accepted 19 July 2007
Available online 4 October 2007

Abstract

This paper investigates the occurrence of local buckling in bare steel and concrete-filled tubes to study how different depth-to-thickness ratios affect the response of the steel component. The experimental set-up and results of 24 tests are presented in this paper. Specimens with values of depth-to-thickness ratios in the range of 50–125 have been considered. The presence of the concrete has been observed to affect the exhibited buckling mode and to significantly increase the buckling bearing capacity of the concrete-filled steel tubes. A numerical model has been developed using the commercial software ABAQUS and has been validated against the experimental results of this study. From a design viewpoint, it has been observed that local buckling needs to be included in the calculation of the contribution of the steel component to the bearing capacity of a concrete-filled tube when its depth-to-thickness ratio is over 50. For a slender plate, i.e., with a depth-to-thickness ratio over 120, its post-buckling behavior could be included in the calculation of the steel contribution as it evidently increases its bearing capacity. Finally, an equation for the calculation of the bearing capacity of composite sections with both stocky and slender steel elements has been proposed and validated against extensive experimental results available in the literature.

Keywords: Square hollow section (SHS); Concrete-filled; Local buckling; Post-local buckling

---

1. Introduction

Concrete-filled steel tubular (CFST) columns possess excellent earthquake-resistant properties such as high strength, high ductility, and large energy absorption capacity. In the last decades, they have gained increasing popularity in buildings, bridges and other structural applications [1]. It is common practice to utilize the steel frame to resist construction loads while considering final design loads to be carried by the composite behavior. This approach is economical and significantly speeds up erection. For concrete-filled tubes, inward local buckling, commonly observed in bare steel columns, is effectively prevented and, therefore, the exhibited buckling mode is modified. This change results in a higher carrying capacity for a steel hollow section utilized in a composite fashion rather than in isolation [2]. This enhancement is produced by the fact that local buckling instabilities of concrete-filled steel tubes occur for depth-to-thickness ratios higher than those observed for bare steel members. In this context, it is very important for the design of composite columns to accurately evaluate the maximum depth-to-thickness ratio for which local buckling can be ignored and to determine the actual bearing capacities of slender columns (i.e., with higher depth-to-thickness ratios) which are influenced by local instabilities.

Guidelines for the design of rectangular composite columns are provided in EC4 [3], LFRD [4], AIJ [5] and CECS [6] codes. Based on these design guidelines, limits of depth-to-thickness ratios below which local buckling can be ignored in design are defined as

$$\frac{D}{t} \leqslant 52\sqrt{\frac{235}{f_y}} \quad \text{(EC4 guidelines)}, \tag{1}$$

---

[*] Corresponding author. Present address: PO Box 2551, 202 Haihe Road, Nan'gang District, Harbin Institute of Technology (Campus 2), Harbin, 150090, PR China. Tel.: +86 451 86282083; fax: +86 451 86282083.

E-mail address: guolanhui@hit.edu.cn (L. Guo).

0263-8231/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tws.2007.07.009

$$\frac{D}{t} \leqslant \sqrt{\frac{3E_s}{f_y}} \quad \text{(LRFD guidelines)}, \tag{2}$$

$$\frac{D}{t} \leqslant 1.5\frac{74}{\sqrt{0.0102 f_y}} \quad \text{(AIJ guidelines)}, \tag{3}$$

$$\frac{D}{t} \leqslant 60\sqrt{\frac{235}{f_y}} \quad \text{(CECS guidelines)}. \tag{4}$$

For example, considering a steel tube with a steel yield strength f_y of 235 MPa and an elastic modulus E_s of 200,000 MPa, the maximum depth-to-thickness ratios are equal to 52, 50.5, 71.6 and 60 according to EC4, LRFD, AIJ and CECS, respectively. Due to the variation between these limiting values, further work is required to better identify the maximum depth-to-thickness ratio below which local buckling can be ignored in design.

Numerical solutions have been developed to investigate the occurrence of local buckling and most of available work has relied on the use of the finite strip method. In 1995, Wright [7] studied the occurrence of elastic and inelastic local buckling of plates in contact with concrete based on an energy method. In 1996, Uy and Bradford [8] utilized the finite strip method to analyze the elastic local buckling of thin steel plates in composite members. Russell and O'Shea [2] investigated the behavior of steel tube considering the two limiting cases with and without internal restraints. As part of their study, they compared experimental results against design capacities calculated using available design specifications. Based on this work, they proposed improved design recommendations. In 1998, Uy [9] tested five square hollow section steel tubes filled with concrete where only the steel tube was subjected to axial load. In this study the depth-to-thickness ratios varied from 40 to 100. The experimental results highlighted how the concrete infill can lead to enhanced bearing capacities. The design expression utilized for the calculation of the bearing capacity with large depth-to-thickness ratio relied on the effective width method. Uy [10,11] used the finite strip element method to analyze the local buckling of square composite columns. In 2002, Vrcelj and Uy [12] presented a cross-sectional analysis to incorporate local and global buckling of concrete-filled steel tubes.

This paper presents new experimental data to provide a further insight into the occurrence of local buckling in bare steel hollow sections and concrete-filled tubes. As part of this study, a finite element model has been developed to evaluate the post-buckling behavior and to investigate the effects of both residual stresses and initial deformations on the overall response. Finally, an equation for calculating the bearing capacity of steel plates with different depth-to-thickness values used in composite applications is proposed and its validity is verified against published experimental results.

2. Experimental program

2.1. Experimental specimens and set-up

The experimental work carried out as part of this study includes the testing of bare steel specimens and of concrete-filled steel tubes as shown in Fig. 1. The composite specimens are loaded on the steel only. The main parameter investigated in this study consists of the depth-to-thickness ratio which varied between 50 and 125. The labeling and details of all specimens is given in Table 1. In particular, the adopted specimen's naming system includes the series number (each test series refers to a column size), the column width, the presence of the concrete and the specimen numbering within each test series with and without concrete, respectively. For example, specimen "S3-160-C-2" represents a column of test series 3 (i.e., "S3"), with a column width of 160 mm and filled with concrete (i.e., "C" defines the presence of concrete while "S" represents the case of bare steel), while the last digit depicts that it is the second test of the concrete-filled tubes (see Table 1).

All tubes were manufactured from mild steel sheet with two *L*-shaped plates (Fig. 2). During fabrication, these plates were welded into a square shape applying a single bevel butt weld at their tips. All produced steel columns had a length-to-depth ratio of 3.0 to avoid any influence on the experimental results from end effect and column slenderness. All end plates have a thickness of 8 mm. Stiffeners were welded at the ends of the composite columns and designed in accordance with the Chinese code for the design of steel structures GB50017 (2003) [13]. Two stiffeners were welded at both ends for specimens with a cross-section depth of 80 or 110 mm, while four stiffeners were welded for 160 or 200 mm deep cross-sections.

Standard tests were carried out on steel coupons in accordance with Chinese standard GBJ2975 (1982) [14]. Measured average yield strengths (f_y) are reported in Table 1. During casting, the steel tubes were kept in a vertical position and progressive vibration was employed to eliminate air voids present in the concrete and to produce a homogeneous mix. In order to be able to load

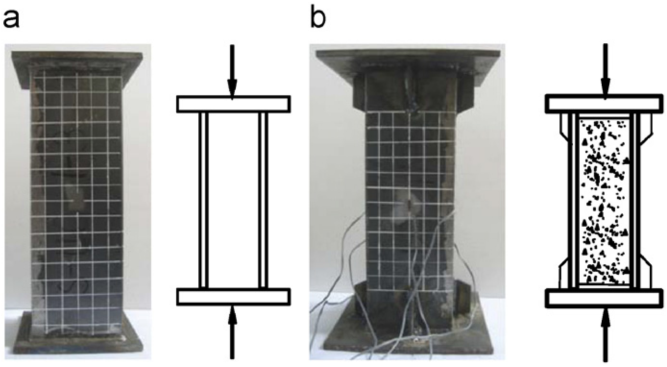

Fig. 1. Proposed experimental series.