Journal of Constructional Steel Research 118 (2016) 120–134

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental and numerical investigation of concrete-filled stainless steel columns exposed to fire

Zhong Tao [a,*], Mohamed Ghannam [a], Tian-Yi Song [a], Lin-Hai Han [b]

[a] Institute for Infrastructure Engineering, Western Sydney University, Penrith, NSW 2751, Australia
[b] Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form 20 October 2015
Accepted 8 November 2015
Available online 6 December 2015

Keywords:
Concrete-filled steel tubes
Stainless steel
Fire resistance
Post-fire
FE analysis

ABSTRACT

This paper presents an investigation on concrete-filled stainless steel tubular (CFSST) columns in fire and after fire exposure. A total of 12 specimens were tested, including 6 CFSST columns exposed to fire and another 6 CFSST columns subjected to sequential ambient temperature loading, fire exposure with constant applied load and post-fire loading phases. A photogrammetric method was employed during the test to capture the initial imperfections of the CFSST columns and strain developments of the stainless steel tubes in fire. The main variables explored in the test program include: (a) cross-section type (circular, square); (b) axial load level (0.28–0.48); and (c) presence of reinforcement or not. A three-dimensional finite eõlement (FE) model was developed by introducing the measured initial imperfections and load eccentricities. The comparison of the FE predictions and the tests performed showed a reasonable agreement. To further simplify the FE analysis, the initial geometric imperfection of a column may be simulated in the model as the first buckling mode shape of the column multiplied by an amplification factor. The simplified model was verified by comparison with test results.

1. Introduction

Concrete-filled steel tubular (CFST) columns using carbon steel material have been studied and applied in engineering practice for over one century. Compared to traditional carbon steel, stainless steel is extremely durable and easily maintained; it also has greater corrosion resistance, ductility and improved fire resistance. Therefore, by replacing carbon steel with stainless steel, concrete-filled stainless steel tubular (CFSST) columns can provide a viable alternative to engineers and architects; thus this type of column has great potential for structural applications.

Existing studies have mainly focused on the behaviour of CFSST columns at ambient temperature. Experimental and numerical studies have been conducted on CFSST stub columns under axial compression [1–4] and CFSST columns subjected to combined axial compression and bending [4]. In general, CFSST columns showed improved structural performance over conventional CFST columns. By comparing with the test results, it was found that the existing design codes in America, Australia, China and Europe for CFST columns are somewhat conservative in predicting the load-carrying capacities of both stub and slender CFSST columns. Yousuf et al. [5] recently investigated the impact performance of CFSST columns, and they found that CFSST columns had higher strength and ductility compared with the CFST counterparts.

Fire is recognised as a significant hazard during the service life of a structure, and it is a regulatory requirement of any building design to maintain structural integrity during fire attack. Although extensive studies have been conducted on fire performance of traditional CFST columns, little research has been devoted to investigating the fire resistance of CFSST columns. Han et al. [6] tested five axially-loaded CFSST columns in fire, where austenitic stainless steel was used for the steel tubes. The test parameters included section type (circular or square), load level (0.15–0.45) and section size (300–630 mm). A finite element (FE) model was developed to simulate the test results, and a parametric analysis was conducted to investigate the important factors affecting the fire resistance of CFSST columns. Two design tables were then proposed to predict the fire resistance of CFSST columns under standard fire conditions, in which the effects of the section type, section size, slenderness ratio and load level were considered. Tao and Ghannam [7] developed numerical models to investigate the heat transfer in CFST and CFSST columns. A comparison between the two types of columns indicated that lower temperature development was found in the CFSST columns due to the smaller thermal conductivity and emissivity coefficient for stainless steel.

In reality, fire performance of slender columns under axial compression is very sensitive to initial geometric imperfections and accidental load eccentricities. However, they were not measured by Han et al. [6] for their test specimens. Meanwhile, the specimens in Han et al. [6] were fabricated without any internal reinforcement. In contrast, internal reinforcement is often used in engineering practice to improve the fire resistance of composite columns. Furthermore, composite columns

* Corresponding author.
E-mail address: z.tao@westernsydney.edu.au (Z. Tao).

http://dx.doi.org/10.1016/j.jcsr.2015.11.003

have a good chance to survive a fire compared with pure steel columns. Therefore, there is a need to study the post-fire performance of CFSST columns for repairing purposes; but no research has been conducted in this area.

This paper presents new test data concerning CFSST columns in fire and after fire exposure. A photogrammetric method was adopted to measure the initial imperfections of the test specimens and strain developments of the steel tubes in fire. A FE model was then developed to simulate the behaviour of the tested columns. To consider the initial geometric imperfection of a CFSST column, the paper also recommends an amplification factor when the first buckling mode shape is used.

2. Experimental program

2.1. Specimen preparation

A total of 12 CFSST columns with circular or square cross-section were fabricated and tested. For the circular specimens, cold-formed austenitic stainless steel tubes were used. For the square specimens, two U-shaped austenitic stainless steel channels were cold-formed first and then welded together to form the square tube. The inner radius of the square tube at corners was 7.5 mm. The grade of the austenitic stainless steel was type 304, which is approximately equivalent to EN 1.4031. The nominal section sizes ($D \times t_s$) for the circular and square tubes were 200 × 3 mm and 200 × 4 mm, respectively, where D is the overall diameter of the circular section or width of the square section; t_s is the thickness of the steel tube. All specimens had a same length (L) of 1870 mm including two carbon steel endplates with a thickness of 20 mm. Fig. 1 shows the detailed dimensions of the test specimens. A total of 14 reference points, as shown in Fig. 1, were marked on the outer surface of the steel tube by inserting 2 mm diameter ceramic rods into pre-drilled holes. These reference points were used in the photogrammetry process for monitoring the deformation of the steel tube in fire. Two vent holes with a diameter of 10 mm were drilled in the steel tube wall to release the water vapour in the core concrete during the fire exposure. Three thermocouples were used for each specimen to monitor the temperature development, and the locations of the thermocouples in the cross-section are shown in Fig. 1.

The effects of the following parameters were investigated in the test:

(1) Cross-section type: circular section and square section;
(2) load level (n_f): 0.28–0.48. n_f is defined as N_o/N_u, where N_o is the axial compression load applied to the column; and N_u is the ultimate load-bearing capacity of the column at ambient temperature, which was calculated in accordance with Eurocode 4 Part 1.1 [8];
(3) presence of steel reinforcement: Four circular specimens were longitudinally reinforced with four 12 mm diameter deformed reinforcement and 10 mm diameter plain transverse reinforcement spaced at 200 mm centres. The clear cover to the longitudinal reinforcement was 39 mm; and
(4) test type: Fire resistance test and post-fire test with initial load.

The measured cross-sectional dimensions ($D \times t_s$) of the CFSST column specimens, the applied axial compression load (N_o) and the load level (n_f) corresponding to each specimen are shown in Table 1, where "CT" and "ST" in the specimen labels denote circular and square columns, respectively.

2.2. Material properties

The material properties of the stainless steel tubes and longitudinal bars were determined by tensile tests at ambient temperature. Four tensile coupons for each type of steel were tested. The stainless steel coupons were extracted from the tubes in the longitudinal direction. The

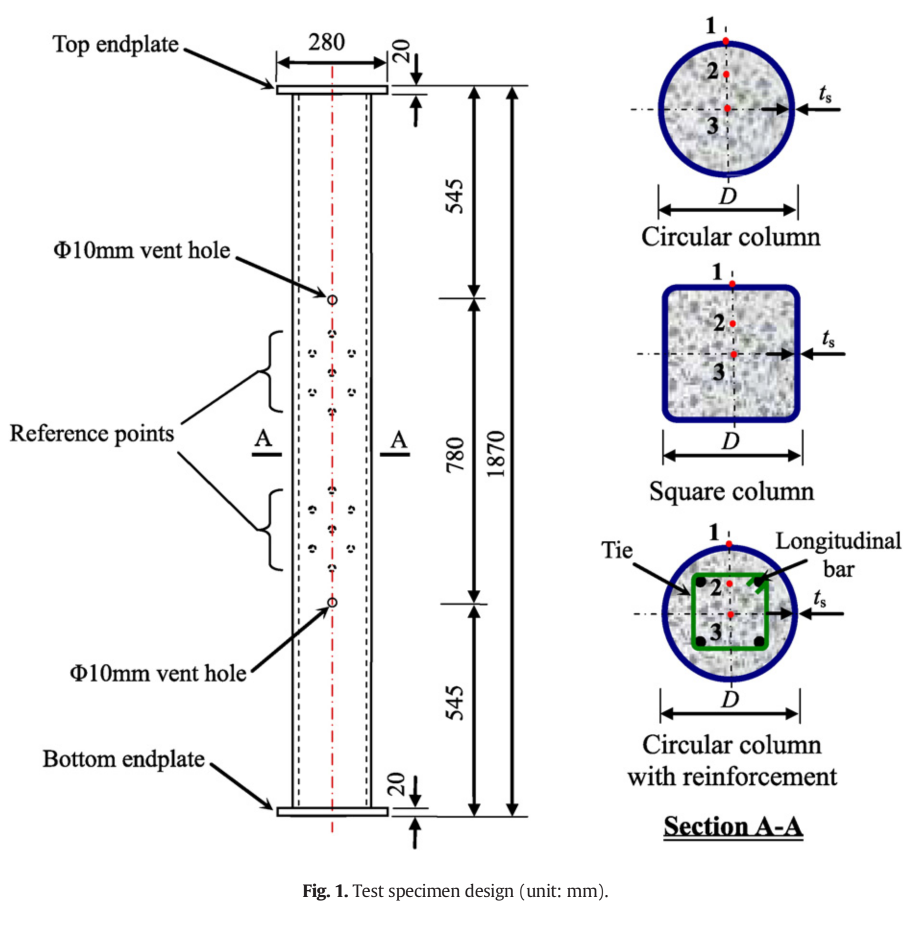

Fig. 1. Test specimen design (unit: mm).