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Experimental study on column buckling of 420 MPa high strength steel welded circular tubes

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ABSTRACT

This paper investigates the column buckling performance of welded circular tubes made of 420 MPa high strength steel (HSS). 24 axial compression column tests on specimens with a nominal diameter of 273 mm and thickness of 6 mm were conducted. Initial geometric imperfections including out-of-straightness and loading eccentricity were measured. Experimental results in terms of buckling modes and load-carrying capacities are presented and discussed in detail. Non-linear finite element (FE) models were developed which captured the experimental observations satisfactorily. Based on the validated FE models, further parametric analyses incorporating 60 HSS numerically generated welded circular tubular columns with various section sizes were carried out. The resulting FE and experimental results were compared with the existing column design curves in Chinese, European and American codes. Numerical results showed that the design resistances calculated based on design curve a in both GB50017-2003 and Eurocode 3 and the design formula in the ANSI/AISC 360-10 could be adopted. In addition, to further improve the design efficiency, a column design curve based on Eurocode 3 formulation with a new imperfection factor of 0.17 was proposed for the design of such HSS welded tubular columns.

1. Introduction

The application of high strength steel (HSS) has been widely adopted in building structures worldwide [1–6]. In the 2008 Beijing Olympic Games in China, the national stadium (also known as the Bird's Nest) was made by steel with the nominal yield strength of 460 MPa. This corresponds to the steel grade of Q460 in Chinese standard. The steel structure of the National Aquatic Centre (also known as Water Cube) in Beijing adopted Q420C HSS with the nominal yield strength of 420 MPa. In Berlin, Germany, the Sony Center utilised S460 (with the nominal yield strength of 460 MPa) and S690 (with the nominal yield strength of 690 MPa) HSS. In Sydney, Australia's Star City hotel and Latitude building adopted steel structural products with the yield strength of 690 MPa. The definition of HSS in this paper is related to the steel with the nominal yield strength greater than or equal to 420 MPa.

Structural steel members with tubular cross section have been used for decades in civil engineering practice. According to the section sizes, tubular structures can be divided into three categories: (1) Structural steel tubes, (2) Pipe and (3) Large diameter fabricated steel tubes [7]. Fabricated tubular steel columns were early used in offshore structures. In the 1970s, an extensive experimental programme on tubular members was conducted under the CIDECT research programme, and some other researchers [8–11] had conducted experimental research and analyses of the fabricated tubular columns which inherited more complicated imperfections than their hot-rolled counterparts. Wagner et al. [8] and Chen and Ross [9] proposed two different residual stress distributions of the welded tubular columns which provided references for the research of longitudinal residual stress distribution for welded tubular section columns. Recent tubular research also extends to the new form of tubular cross sections – elliptical hollow sections [12–14].

Welded circular tubes made of HSS in particular favour engineering application in truss structures, grid structures, latticed shell structures and transmission towers, in which the uniform strength in multi-direction of circular steel tube can be fully utilised. However, the knowledge on welded circular steel tubes made of HSS still requires further investigations to date, especially on the residual stress distribution, the local slenderness limit (or diameter-to-thickness ratio) and on the column buckling response.

Aligning with their application in the steel transmission towers as vertical compressive members, this paper presents an experimental

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Table 1
Nominal and measured dimensions of specimens.

Specification	Group number	Specimen label	Outer diameter D (mm)	Plate thickness T (mm)	Length L_0 (mm)	Length L (mm)
420 MPa Φ273 × 6 SAW un-galvanized	1	D420-20-1	274	6.01	1890	2362
		D420-20-2	275	6.01	1889	2361
		D420-20-3	274	5.87	1890	2362
	2	D420-30-1	273	5.85	2833	3305
		D420-30-2	273	5.95	2835	3307
		D420-30-3	273	5.91	2834	3306
	3	D420-40-1	275	5.89	3776	4248
		D420-40-2	276	5.83	3777	4249
		D420-40-3	271	5.91	3776	4248
	4	D420-50-1	274	5.87	4721	5193
		D420-50-2	273	5.88	4721	5192
		D420-50-3	273	5.88	4721	5193
	5	D420-60-1	273	5.85	5662	6134
		D420-60-2	273	5.95	5664	6136
		D420-60-3	272	5.91	5665	6137
420 MPa Φ273 × 6 SAW galvanized	6	D420-20-4	274	6.01	1890	2362
		D420-20-5	274	6.01	1890	2362
		D420-20-6	274	5.87	1890	2362
	7	D420-40-4	273	5.94	3776	4248
		D420-40-5	276	6.11	3777	4249
		D420-40-6	269	6.15	3776	4248
	8	D420-60-4	272	5.99	5662	6134
		D420-60-5	275	6.00	5662	6134
		D420-60-6	272	5.81	5663	6135

investigation which included 24 welded tubular section columns with the nominal yield strength of 420 MPa to clarify the flexural buckling behaviour. A finite element model is established and validated against experimental results. 60 HSS welded circular columns with various section sizes for parametric analyses are conducted. The experimental and FEA results are then compared with the existing column design curves in Chinese code [15], European code [16,17] and American code [18]. The design methods for such HSS tubular section columns are then proposed.

2. Experimental programme

2.1. Test specimen

Submerged-Arc Welded (SAW) circular tubes fabricated from HSS plates with the nominal yield strength of 420 MPa were examined in this test programme. Table 1 summarises the geometric properties of test specimens whilst Fig. 1 defines the symbols of geometric properties. A total of 24 specimens with the nominal section

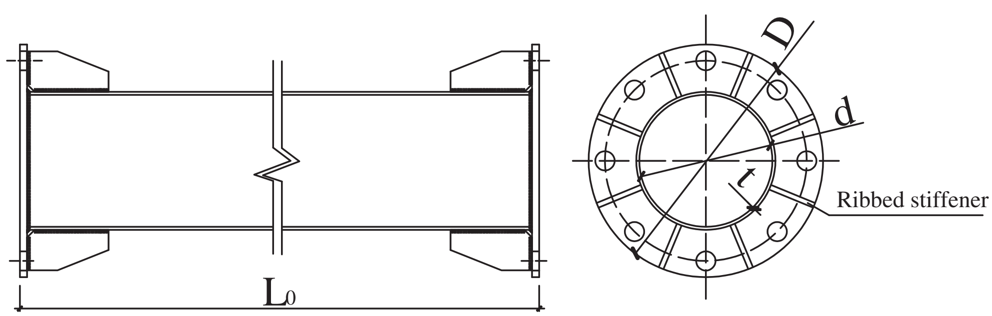

Fig. 1. Definition of symbols for section geometric.

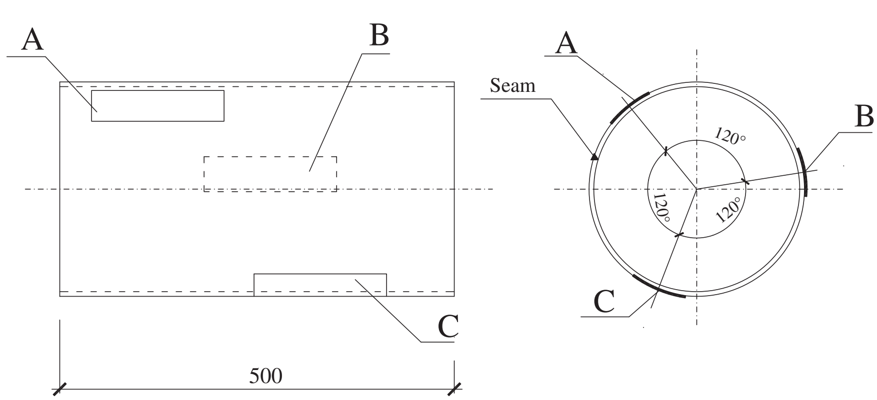

Fig. 2. Location of specimens for tensile coupon test.