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Tests of cold-formed and welded stainless steel beam-columns

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ABSTRACT

This paper describes a test program on austenitic stainless steel beam-columns. Two types of section were investigated: cold-formed square hollow section and welded H section. Twelve material tensile coupon tests and four stub column tests were conducted to provide the material properties of the specimens. The overall initial geometric imperfections were measured. Ten beam-columns were tested between pin-ended conditions with sideway supports. Results from the tests, including the strengths, the load-deformation responses, and the failure modes were presented. The test strengths and the strengths of all the previous available test specimens were compared with the design strengths predicted using Eurocode (EN 1993-1-4:2006) and American code (SEI/ASCE 8-02). It is shown that the design strengths predicted by these two design codes are generally conservative, and the performance of the American code is better than that of the Eurocode. A modified design rule based on the American code was proposed. Comparison of the predicted strengths with the tests strengths shows that the proposed method offers improved accuracy and reduced scatter.

1. Introduction

The use of stainless steel for load bearing structural members has been under growing interest in recent years due to its esthetic appearance, superior corrosion resistance, and ease of maintenance. Stainless steel has low proportional limit, no yield plateau, and an extensive strain hardening range. These characters make the behavior and the design of stainless steel members different from those of low carbon steel members.

Investigations on stainless steel members under pure axial compression and pure bending have been reported by many researchers. Modifications on the traditional design methods [1,2] and new design methods, such as DSM [3–5] method and CSM [6,7] method, were proposed for stainless steel beams and columns. In the real structures, most of the members are subjected to combined compression and bending. The design formula for beam-columns involves the strengths of beams and the strengths of columns. Therefore, beam-column test is an important type of test to check the column design method and the beam design method. To date, few tests and theoretical studies on the stainless steel beam-columns have been presented.

Hyttinen [8] performed beam-column tests of cold-formed stainless steel square hollow sections (SHS), loaded with concentric axial compression force and with transverse forces. Talja and Salmi [9], Huang and Young [10], Liu and Young [11] conducted tests on stainless steel beam-columns with cold-formed square hollow sections (SHS) subjected to eccentric compression force. Rhodes and Macdonald [12, 13] and Fan and Liu [14] conducted beam-column tests with cold-formed lipped channel sections including bending about the major axis and the minor axis. Burgan and Baddoo [15] reported tests on stainless steel beam-columns with welded H sections and with circular hollow sections. All the available previous test data are listed in Table 1. More test data of stainless steel beam-columns are required.

Greiner and Kettler [16] conducted numerical study on the stainless steel beam-columns, mainly focused on the interaction factor. A set of interaction factors for stainless steel beam-columns was proposed for different sections. Gardner and Nethercot [17] developed a consistent approach to modeling of cold formed stainless steel structures including the nonlinear material properties, corner enhancement, initial imperfection and residual stresses. Ashraf and Gardner [7] developed a new design method based on the deformation capacity of members (CSM method). In addition to the resistant capacity of the beams and the columns calculated by CSM formula, a new interaction factor for stainless steel beam-columns was proposed based on test data.

There are several specifications available for the design of stainless steel beam-columns, including the Eurocode (EN 1993-1-4:2006) [18] for the cold-formed and welded members, the American code (SEI/ASCE 8-02) [19], and the Australian/New Zealand standard (AS/NZS 4673-2001) [20] for cold-formed members. Most of the design methods in these specifications are the same as those in their corresponding low carbon steel design specifications. Previous experimental researches have shown that these codes provided conservative predictions for stainless steel beam-columns.

The objective of this paper is to study the behavior of the stainless steel beam-columns. Two types of section, cold-formed square hollow

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Table 1
Tests conducted on stainless steel beam-columns.

Date	Author	Material	Section	Num. of specimens	Type of test
1994	Hyttinen	1.4301 (304)	SHS	9	Transverse load + concentric compression
		1.4512 (409)	SHS	6	
		1.4003	SHS	6	
1995	Talja	304	SHS	4	Eccentric compression
			RHS	8	
2000	Burgan	1.4541 (312)	CHS	4	Eccentric compression
		1.4435 (316L)	CHS	4	
		1.4301 (304)	Welded H	8	Eccentric compression Major axis
2000	Rhodes	304	Lipped channel	22	Eccentric compression Minor axis (lip in tension)
2007	Macdonald	304	Lipped channel	20	Eccentric compression Minor axis (lip in compression)
2014	Fan	304	Lipped channel	38	Eccentric compression Major axis
2014	Huang	1.4162	SHS	37	Eccentric compression
2014	Liu	2205	SHS	20	Eccentric compression
2014	This paper	304	SHS	5	Eccentric compression
			Welded H	5	Major axis
Sum				196	

section and welded H section were tested, including material tests, stub column tests, and beam-column tests. Furthermore, the strengths of the specimens were compared with the predictions of the Eurocode and the American code for stainless steel structures. Lastly, a modified formula based on the American code was proposed and compared with test results.

2. Test program

2.1. Test specimens

The tests were performed on cold-formed square hollow section (SHS) and welded H section of austenitic 304 stainless steel. The SHS specimens were cold-drawn from annealed stainless steel bar. For the welded H specimens, the virgin plates of the specimens were cut from annealed stainless steel plate by laser cutting machine. TIG welding (tungsten inert gas welding) was used to fabricate the welded H specimens. After welding, the specimens were put into a reforming machine to reduce the imperfections caused by the welding process. The nominal size of SHS section was 80 × 3 mm, and the welded H section was 80 × 80 × 6 × 6 mm. The length of the stub column was 400 mm. The lengths of the beam-column specimens varied from 1500 mm to 3500 mm at intervals of 500 mm. Tables 2 and 3 show the measured cross-section dimensions of the specimens using the nomenclature defined in Fig. 1. In Table 2, the imperfections e_1 and e_2 are the overall imperfections about the major axis and the minor axis of the welded H specimens at the mid-length, respectively. In Table 3, the e_1 and e_2 are the overall imperfections in the web plane and the flange plane of the SHS specimens at the mid-length, respectively.

2.2. Tensile coupon tests

Tensile coupons were cut from the cross-section using spark cutting machine. Neither the heat nor the cold working was introduced into the coupon during the cutting process. For the SHS specimens, coupons were cut from both the flat faces and the corners. For the welded H section, coupons were cut from both the web and the flanges. The locations of the coupons on the cross-section and the shape of the coupons are shown in Fig. 1. The coupon dimensions conformed to the Chinese Standard GB/T 228.1-2010 [21] for the tensile testing of metals using 12.5 mm wide coupon and a gauge length of 50 mm. A total of twelve coupons were tested, three coupons for each location.

Coupons were tested in a 100 kN capacity MTS-SANS displacement controlled testing machine with friction grips. The load rate was 1 mm/min controlled by the machine automatically. For flat coupons, two linear strain gauges were attached to each coupon at the center of each face. Strain was recorded until the strain gauge peeled off from the coupon. Usually, the strain gauge peels off from coupons when the strain is approximately equal to 0.020. After that, tests continued until the fracture of the coupon to provide the ultimate stress σ_u and the percentage elongation δ. Corner coupons were tested in pairs, gripped symmetrically at the end around a copper bar that had the same radius as the internal corner radius of the test specimens. Each pair of corner specimens was removed from the same corner of the cross-section. Two strain gauges were pasted on each edge of the corner specimens. Fig. 2 shows the tensile coupon test arrangements. Fig. 3 shows the typical material test results for coupons HW-1, T-1, and C-1.

Test results were processed according to Eq. (1) [22]. In this equation, σ and ε are the engineering stress and strain, respectively, E_0 is the initial Young's modulus, $\sigma_{0.2}$ is the 0.2% proof stress (also called

Table 2
Measured dimensions and imperfections for welded H specimens.

Specimen	Dimension (mm)					Imperfection (mm)	
	h	b	t_f	t_w	L	e_1	e_2
H-S-1	80.00	80.00	6.01	6.01	400	–	–
H-S-2	80.00	80.00	6.01	6.01	400	–	–
80H1500	79.89	80.07	5.88	5.82	1499	1	0.5
80H2000	79.81	79.98	5.81	5.82	2000	0	1.5
80H2500	80.31	80.13	6.22	6.08	2499	0.5	0.5
80H3000	79.73	79.95	5.81	5.85	3000	0.5	0.5
80H3500	79.82	79.69	5.78	5.98	3496	0.25	1.58

Table 3
Measured dimensions and imperfections for SHS specimens.

Specimen	Dimension (mm)					Imperfection (mm)	
	h	b	t	R	L	e_1	e_2
S-S-1	80.00	80.00	2.85	3.5	400	–	–
S-S-2	80.00	80.00	2.85	3.5	400	–	–
SHS1500	80.18	80.16	3.1	3.5	1500	0.5	0
SHS2000	80.15	80.05	3.25	3.5	2000	0.75	0.75
SHS2500	80.03	80.07	3	3.5	2499	0.75	0.5
SHS3000	80.21	80.17	3.09	3.5	3000	1.25	0.5
SHS3500	80.11	80.24	3.12	3.5	3500	1.0	0.25