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Global buckling behaviour of welded Q460GJ steel box columns under axial compression

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ABSTRACT

This paper describes an experimental and numerical study on the global buckling behaviour of welded Q460GJ steel box columns. In the experimental programme, seven steel columns with different cross sections and wall thicknesses were tested under axial compression. The load capacity of steel columns was quantified. Comparisons were made between experimental results and design values calculated in accordance with national standards. Furthermore, numerical models were established in which initial geometric imperfections and residual stress distributions were considered. The model was validated against test data with reasonably good accuracy. A parametric study was conducted on the effects of initial geometric imperfections and normalised slenderness on the load capacity of box columns. Experimental and numerical results indicated that Q460GJ steel box columns could develop higher global buckling resistances than the values calculated from GB50017-2003 and Eurocode 3, but ANSI/AISC360-10 might not be safe for welded box columns with small width-thickness ratios. Therefore, the design approaches for conventional steel columns were modified so that the buckling behaviour of box columns fabricated of Q460GJ steel could be accurately evaluated.

1. Introduction

As a typical high-performance structural steel, GJ steel has been widely used for structural members in construction practices in China. Compared with high strength steel, it has relatively lower yield-to-ultimate strength ratio, better impact toughness, lamellar tearing resistances and weldability [1,2]. However, due to different processing techniques and metallurgical structures, the mechanical behaviour of GJ steel components may be different from those of high strength steel. To date, there is still a lack of test data on structural behaviour of GJ steel members under various loading conditions. Thus, experimental and numerical investigations are necessary in order to incorporate this type of steel in current design codes and guidelines.

Several experimental tests have been conducted on the buckling behaviour of high-strength steel members. As for columns, Ban et al. measured the residual stress distribution in 460 MPa high-strength steel columns [3] and studied the overall buckling of the columns through experimental tests [4]. It was concluded that the effects of initial geometric imperfections and residual stresses on buckling resistance became insignificant with increasing yield strength of steel. In the meantime, 960 MPa strength steel columns were also investigated by Ban et al. [5]. Experimental and numerical results indicated that current design approaches for conventional steel members provided rather conservative results when used for high-strength steel columns. Likewise, residual stresses in H and box sections fabricated of Q460 steel were reported and similar conclusions were drawn from the experimental and numerical studies on overall buckling of high-strength steel columns conducted by Wang et al. [6–8]. As for Q690 steel, design recommendations were provided based on experimental and numerical results [9,10]. Besides global buckling, Q460 high-strength steel column stubs were also tested to gain insight into local buckling behaviour [11]. Comparisons between numerical results and calculated values from current design methods suggested that the methods were fairly conservative for I-shaped columns but unsafe for box columns.

As another typical high-performance steel in China, GJ steel has similar material properties to its counterpart in the United States, Japan and Europe. Available experimental studies mainly focused on the lateral-torsional buckling resistance of steel beams. Yang et al. [12] investigated the lateral-torsional buckling behaviour of I-shaped GJ steel beams under a concentrated point load. Test results showed that the design methods in GB 50017-2003 [13] and ANSI/AISC360-10 [14] might not be conservative for global stability design of welded GJ steel beams. Furthermore, Yang et al. [15] tested the residual stress distribution in welded Q460GJ steel I-beams and the results were later used for numerical analyses on the lateral-torsional buckling of steel beams under a concentrated point load [16]. However, the global buckling resistance of GJ steel columns has not drawn sufficient attention.

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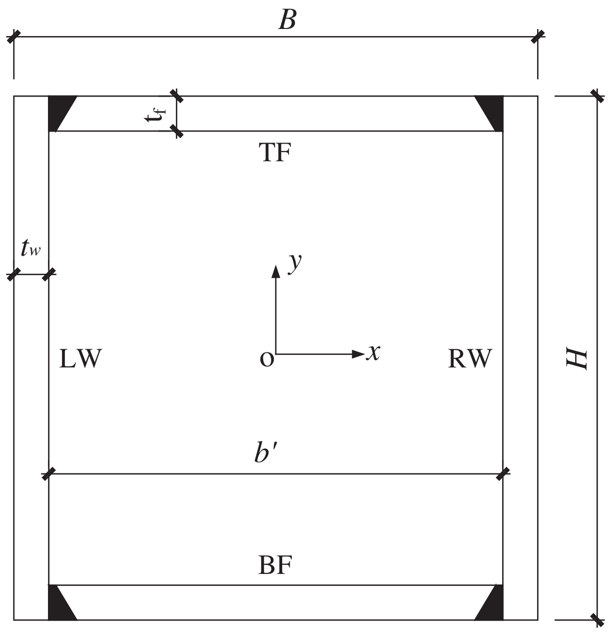

Fig. 1. Definition of symbols for a column section.

This paper presents an experimental and numerical study on the global buckling behaviour of Q460GJ steel box columns subject to axial compression. In the experimental programme, seven steel columns with various slendernesses and wall thicknesses were tested to buckling. Corresponding axial load and horizontal displacement were measured. Numerical models were developed and validated against experimental results. Based on the validated numerical model, parametric study was carried out to investigate the effects of normalised slenderness on buckling factor. Comparisons between numerical results and design curves suggest that design approaches in GB50017-2003 [13] and Eurocode 3 [17] are relatively conservative, whereas ANSI/AISC360-10 [14] may be inaccurate when used for box columns with relatively small width-thickness ratios. Finally, design recommendations were proposed for global stability design of Q460GJ steel box columns in accordance with experimental and numerical results.

2. Experimental programme

2.1. Specimen design

The load capacity of a compression member is determined by different column curves, in which the width-thickness ratio and slenderness play an important role. The width-thickness ratio mainly affects the residual stress distribution and buckling mode of steel plates. By varying the slenderness ratio, different buckling factors can be obtained. In the experimental programme, the effects of width-thickness ratio and normalised slenderness on buckling behaviour of box columns were taken into consideration. Seven box columns, fabricated of high-performance Q460GJ steel and with different width-thickness ratios and normalised slendernesses, were tested under axial compression. Fig. 1 shows the definition of symbols for a column section. Table 1 summarises the dimensions of steel columns. In the designation, "B" represents box columns; the first numeral denotes the nominal height of column sections, and the last is the nominal thickness of column web and flange. It is noteworthy that column B-120-20a, with nearly the same dimensions as B-120-12, was fabricated and tested to verify the reliability of test setup.

Steel plates with thicknesses of 12 and 25 mm were used for box columns. The width of columns with 12 mm thick plates ranged from 120 mm to 264 mm. The corresponding width-thickness ratio was in the range of 7.8 and 19.6. As for columns with 25 mm thick plates, the width-thickness ratio was from 4.8 to 7.9 due to the constraints of the testing machine. Steel columns with a wall thickness of 12 mm were fabricated by using carbon dioxide welding, whereas submerge arch welding was employed when the thickness was increased to 25 mm. The column height was adjusted so that the slenderness was in the range of 50 and 120. All steel columns were designed to fail in global buckling prior to local buckling by controlling the width-thickness ratio. The maximum width-thickness ratio of column walls was less than 20, and thus local buckling of steel columns was averted in accordance with GB 50017-2003 [13], as expressed in Eq. (1). It also satisfied the requirements in Eurocode 3 [17] and ANSI/AISC 360-10 [14]. All the columns were classified as "c" in GB 50017–2003 and Eurocode 3.

$$b^{'}/t \le 40\sqrt{\frac{235}{f_y}} \tag{1}$$

where $b^{'}$ and t are the net width and thickness of column walls, respectively, and f_y is the yield strength of steel plates.

2.2. Test setup and instrumentation

Fig. 2 shows the test set-up and instrumentation. To prevent premature failure, two strengthening plates with a thickness of 30 mm were welded to the ends of each column. Steel blocks with a groove were bolted to the column, as shown in Fig. 2(a). Besides, rigid arc supports were designed and placed in the grooves to provide pin supports. Thus, the column could rotate freely about the y-axis. A displacement-controlled hydraulic testing machine was employed in the tests. During testing, the vertical load applied to the column was measured by means of a load sensor. In addition, displacement transducers were utilised to measure horizontal and vertical displacements, as shown in Figs. 2(a and b). Transducer DH1 to DH5 was erected along the column height to measure its horizontal deflections. The axial deformation of the column was recorded by DV1 and DV2. Moreover, inclinometer Q1 was mounted at the testing machine to monitor its rotation. Another two inclinometers Q2 and Q3 were placed at both ends of the column to measure the angles of rotation. Besides axial and horizontal deformations, the strains of steel columns at the mid-height were also captured through strain gauges, as shown in Fig. 3.

Table 1
Measured dimensions of steel columns.

Specimen	H (mm)	t_w (mm)	B (mm)	t_f (mm)	$b^{'}/t$	i_y* (mm)	L (mm)	L_e (mm)	λ
B-120-12a	120.30	12.38	119.59	12.30	7.7	44.13	3114.00	3492.00	110
B-120-12	120.37	12.37	120.21	12.23	7.8	44.39	3115.00	3493.00	110
B-168-12	168.51	12.43	168.04	12.45	11.5	63.74	3733.50	4111.50	90
B-216-12	216.62	12.32	215.94	12.28	15.4	83.35	3801.50	4179.50	70
B-264-12	264.43	12.27	263.91	12.21	19.6	102.94	3306.00	3684.00	50
B-175-25	176.18	25.87	174.42	25.53	4.8	61.75	4945.60	5323.60	120
B-200-25	201.96	25.62	197.97	25.42	6.8	71.41	4776.50	5154.50	100

*: i_y denotes the radius of gyration about y-axis.