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Structural behaviour of slender columns of high strength S690 steel welded H-sections under compression

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ABSTRACT

This paper presents an experimental investigation into structural behaviour of slender columns of high strength S690 steel welded H-sections under axial compression. A total of seven slender columns with four sections of different cross-sectional dimensions and two different effective lengths were tested successfully. As expected, all of these columns failed in overall buckling about minor axes of their cross-sections, similar to those of conventional steel welded H-sections. Hence, these tests may be regarded to be confirmatory tests to structural behaviour of slender columns of high strength S690 steel welded H-sections under axial compression. No welding failure was observed after close inspection to all the columns after tests.

It should be noted that the measured failure loads of these slender columns were directly compared with predicted resistances of corresponding sections based on their measured geometrical and materials properties according to current design rules given in European, Chinese, and American Steel Codes, namely, EN 1993-1-1, GB 50017-2003, and ANSI/AISC 360-16 respectively. As effects of residual stresses in S690 steel welded H-sections were considered to be proportionally less pronounced when compared with those in S355 steel welded H-sections, their buckling resistances should be significantly increased when compared with those S355 welded H-sections. It was found that the current design rules given in both EN 1993-1-1 and GB 50017-2003 underestimated buckling resistances of slender columns of S690 steel welded H-sections significantly, and use of a different buckling curve with an increased structural efficiency was suggested. However, the predicted resistances of these slender columns to the current design rules given in ANSI/AISC 360-16 were found to be close to the measured failure loads. Hence, they were considered to be applicable to design slender columns of S690 steel welded H-sections.

1. Introduction

With advancement of steel production technology in the past two decades, structural steel materials with high yield strengths and ductility have been available to construction. Those steel materials with yield strengths higher than 460 N/mm^2 are currently referred as high strength steel materials. High strength steel materials are widely considered to be able to give efficient structural solutions in heavily load members, such as columns in high-rise buildings and beam-column frames with long spanning beams [1–4]. Compared with conventional steel materials, high strength steel materials possess excellent strength to self-weight ratios, reduced tensile to yield strength ratios, and reduced elongations at fracture. These characteristics will influence behaviour of structural steel members made of high strength steel materials. Effects of both material and geometrical initial imperfections onto structural stability of S690 steel sections should be quantified.

Initial material imperfection in the form of residual stresses is generally considered to be one of the major factors affecting structural stability of slender columns of S690 steel welded H-sections. According to previous studies on residual stresses in various welded sections made of high strength steel plates [5–14], it was found that the magnitudes of welding induced residual stresses were generally independent from the yield strengths of the steel plates. Thus, the ratios of maximum residual stresses to yield strengths of high strength steel plates were significantly smaller than those of welded sections made of conventional steel materials. Consequently, it is expected that members made of high strength steel plates will give higher buckling resistances than those made of conventional steel plates on a proportional basis.

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Structural behaviour of welded sections made of high strength steel plates has been investigated by many researchers in the past two decades. Rasmussen and Hancock [5] measured compressive resistances of stocky columns made of S690 steel plates, and concluded that the plate slenderness limits obtained from welded sections of conventional steel plates were applicable to those welded sections made of high strength steel plates. However, Yuan [15] compared deformation capacities of stocky columns made of steel materials with different steel grades. However, he considered that the classification limits obtained from sections of conventional steel plates could not guarantee sufficient deformation capacities to be mobilized in sections made up of high strength steel plates.

Axial buckling behaviour of welded sections made of high strength steel plates was also examined by Rasmussen and Hancock [6], Li et al. [16], and Ban et al. [17], and it should be noted that these H-sections buckled about minor axes of their cross-sections. With the use of substantial restraining beams and bracings, a series of high strength S690 steel welded H-sections were conducted by Shi et al. [18]. In these tests, all the columns were restrained with beams at both ends while out-of-plane and torsional deformations of the columns were restrained with braces. All of these columns were found to buckle about major axes of their cross-sections, and failed at buckling resistances significantly larger than those design values [6,16–18]. Such improvement was attributed to reduced effects from both residual stresses and initial geometrical out-of-straightness. It should be noted that for those sections made of S460 steel materials, improvement on axial buckling resistances of these sections was found to be not as significant as those made of S690 and S960 steel materials [19–22].

Currently, EN 1993-1-1 [23] provides a design method for columns of S235 to S460 steel welded H-sections. To extend the design method to welded H-sections of high strength steels, EN 1993-1-12 [24] gives supplementary rules for up to S700 steel sections. Moreover, ANSI/AISC 360-16 [25] covers up to S690 steel sections (ASTM A514 and A709 steel sections) while GB 50017-2003 [26] is only applicable to S235 to S420 steel sections. As development of these design codes was based on experimental results conducted with conventional steel materials, there is a concern on applicability of these codes in designing high strength steel sections [6,16–18].

1.1. Objectives and the scope of work

In order to promote an effective use of high strength steel sections in building construction, a comprehensive research programme was undertaken to investigate structural behaviour of beams and columns made of S690 steel welded H-sections, and to establish supplementary design rules through calibration against test results. As effects of residual stresses in S690 steel welded H-sections were considered to be proportionally less pronounced when compared with those in S355 steel welded H-sections, their buckling resistances should be significantly increased, when compared with those S355 steel welded H-sections.

This paper presents an experimental investigation into structural behaviour of slender columns of high strength S690 steel welded H-sections under axial compression. A total of seven slender columns with four sections of different cross-sectional dimensions and two different effective lengths were tested under axial compression. All of them were designed to undergo overall flexural buckling about minor axes of their cross-sections. Standard tensile tests were also carried out on coupons cut from S690 steel plates of various thickness to establish their mechanical properties. After testing, the measured failure loads of these slender columns would be directly compared with predicted resistances of corresponding sections based on their measured geometrical and material properties according to various design rules given in European, Chinese and American Steel Codes.

It should be noted that these high strength S690 steel welded H-sections are expected to behave in various ways similar to those of welded H-sections made of conventional steel materials. Hence, these tests may be regarded to be confirmatory tests to structural behaviour of S690 steel welded H-sections under axial compression. It is highly desirable to establish applicability of current design rules given in various codes for high strength S690 steel welded H-sections under axial compression through calibration against test results.

Furthermore, there was a complementary experimental investigation into structural behaviour of high strength S690 steel welded H-sections under combined compression and bending [27]. A total of eight slender columns with four sections of different cross-sectional dimensions and two different effective lengths were tested successfully under eccentric loads. Applicability of current design rules given in various codes has also been established with properly selected parameters through calibration against test results.

2. Experimental investigation

2.1. Overview of test programme

A total of seven slender columns of S690 steel welded H-sections were tested under axial compression. These columns were made from S690 high strength steel plates in quenched and tempered condition with nominal thicknesses of 6, 10 and 16 mm. Four sections of different cross-sectional dimensions, namely, Sections H1, H2, H3 and H4 were adopted, and their nominal cross-sectional dimensions are shown in Fig. 1.

It should be noted that:

(a) For Section H1, only a column with a length of 1610 mm was tested.
(b) For each of Sections H2, H3 and H4, a column with a length of 1610 mm and a column with a length of 2410 mm were tested.

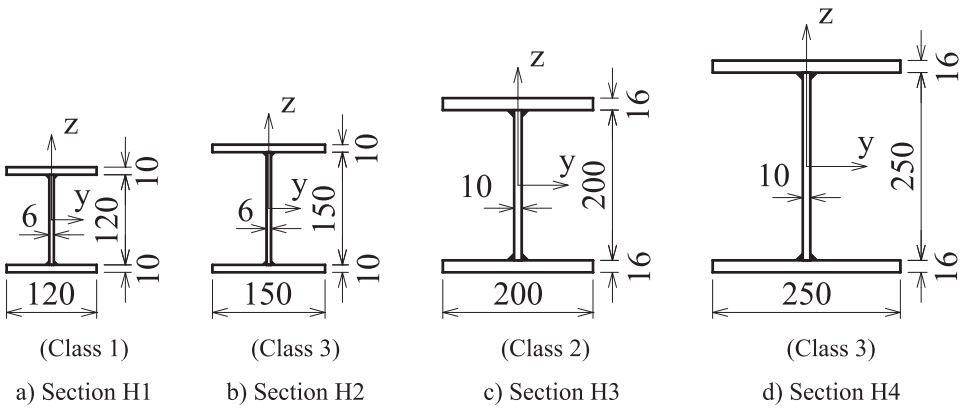

Fig. 1. Nominal sectional dimensions of slender columns.