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Design and optimization of 420 MPa large-section HSSY columns

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ABSTRACT

A new type of large-section high strength steel Y-shaped (HSSY) column was presented. 24 specimens in total were designed and subject to experiment in order to investigate the overall buckling behavior. The columns including two commonly-used slenderness ratios of 35 and 40 were divided into two groups for axial and eccentric compression, respectively. Prior to the buckling test, the material properties, initial geometric imperfections and longitudinal residual stresses were measured. The buckling deformations and ultimate strengths were obtained by test and compared with numerical results, which were based on validated finite element models taking the real initial imperfections and boundary conditions into account. A good agreement was reached between the test and numerical approaches. Buckling factors and column curves of axial compression specimens were obtained and compared with existing code design curves. To accurately predict the overall buckling strengths of HSSY columns, recommended column curves and their formulae corresponding to different codes were proposed through nonlinear regression method. In addition, the influence of loading eccentricity on ultimate buckling capacity was analyzed. Furthermore, the cross section efficiency was formulated and criteria for section optimal selection were concluded for making the best use of the column. Finally, a variety of large-section and medium-section columns with potentially high utilization ratios were recommended for engineering application.

1. Introduction

Due to its superiority over normal strength steel (NSS) in material saving, structural safety and economic benefits, high strength steel (HSS) has been increasingly used in transmission towers in recent years. During the design of steel members, simple cross section (i.e. steel angles or circular tube) and built-up cross section (i.e. cruciform angle or quad angle section connected with fill plates) [1–3] were developed and applied in high-rise structures. On the one hand, latticed transmission towers with multi-circuit, high voltage, light weight and super height are developing rapidly in China for the huge demands for electric power; on the other hand, main members do not satisfy the requirement of sufficient bearing capacity if designed with simple cross section, nor economic and reasonable with conventional built-up section due to its drawbacks of connective material consuming, non-uniform stress distribution and relatively low section utilization. Under these circumstances, a new type of Y-section column featuring better stress performance, fabrication simplicity and material saving was invented and has been safely used in practical latticed transmission towers, which had been subject to full-scale field test by us as shown in Fig. 1. The test result showed that one diagonal bracing member at front tilt slope was buckled firstly, which caused the final collapse of the whole tower. For those HSSY main members, they did not fail until the external load reached 130% of the designed value, at which moment the maximum compressive stress of main members reached 115% of the designed full stress. Therefore, the HSSY column was considerably reliable and safe to be used as the main member in transmission tower. Meanwhile, the full-scale test of an individual HSSY column was essential as well to investigate its overall buckling behavior, because no provisions at present were stipulated in current design codes regarding to such a novel column [3–11].

Research on diversified bucking curves of different cross-sectional columns is an important objective. Some studies have been focusing on curves acquisition and pertinent formulae derivation through experimental and numerical approaches. Deterministic and probabilistic solutions to developing a total of 112 maximum strength column curves were elaborated in detail by Bjorhovde et al. [12,13]. It was concluded that the probabilistic multiple curves represented a scientifically sound solution and was regarded as more adequate than those obtained by the deterministic approach, which provided theoretical evidence for the American column curves. For HSSY columns, the mono-symmetric cross section shares similar geometric and mechanical properties to equal-leg angle section column or tee section column. 66 and 90 columns both fabricated from 420 MPa HSS equal-leg angles were subject to axial compression tests by Ban et al. [14] and Cao et al. [15], respectively. Cardoso and Rasmussen [16] investigated the buckling behavior of concentrically loaded T-section steel columns with measured yield strength of 300 MPa, which concluded that the Australian standard AS4100 provided the most accurate predictions for the buckling

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(a) (b)

Fig. 1. Field test of full-scale latticed transmission tower with HSSY main members: (a) Tower member assembly field; (b) full-scale tower test.

strength, but Eurocode 3 and ANSI/AISC 360-10 were more conservative and modifications for improving the design strength predictions were recommended.

The assessment of initial imperfections (i.e. initial out-of-straightness and residual stresses) of HSS columns is another research issue. Some studies [17–21] highlighted that the influence of initial bending and residual stresses on overall buckling capacities was less significant when compared with NSS columns. The overall buckling behavior of HSS columns was investigated by experiments [22–24], and it revealed that the buckling curves specified in the selected codes (GB 50017-2003, Eurocode 3 and ANSI/AISC 360-10) were conservative to predict the buckling strengths of these HSS columns. Eccentric and concentric axial loading tests of 13 box- and I-section HSS columns with nominal yield strength of 690 MPa were carried out by Rasmussen and Hancock [17]. The residual stresses in three box columns and three welded flame-cut H-section columns fabricated from Q460 steel plates were measured and assessed by Wang et al. [25,26]. The result showed that the residual stresses ratios of HSS welded box sections and H-sections tended to be less detrimental to the buckling strength than the ordinary steel sections. Similar measurements of residual stresses in three box- and H-sections fabricated from Q690 steel plates were conducted by Li

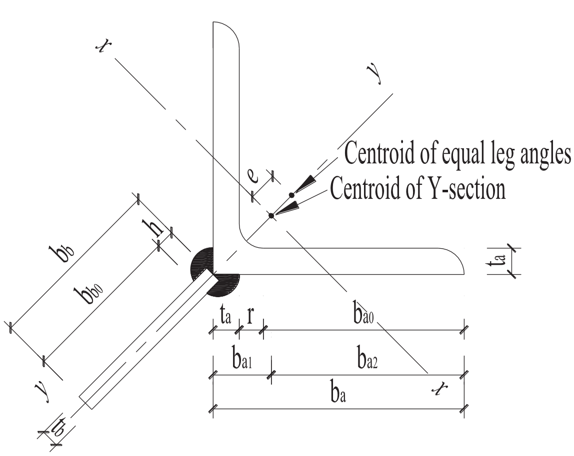

Fig. 2. Geometric parameter definition of Y-section.

et al. [27] and lower ratios of residual compressive stress were obtained when compared with that of Q460 test specimens by Wang et al. [25, 26]. Summary can be concluded from the aforementioned studies that the buckling strengths corresponding to code design curves were underestimated and the influence of initial imperfections on buckling strengths were overestimated. However, it remains to be testified to determine whether these conclusions are equally applicable to the HSSY column or not in view of the differences of manufacturing process and residual stress distribution between a new and conventional section. In addition, material properties and boundary conditions are also important factors influencing the overall buckling capacities of steel columns, which were carefully studied in [19,28–30].

The present study focused on the test and numerical investigations of 420 MPa large-section HSSY columns subject to axial and eccentric compression with 12 specimens for each. It aimed to explore the overall buckling behavior of a new-style column. Before the buckling tests, initial geometric imperfections, longitudinal residual stresses and material properties were measured and described in detail. The buckling deformations and buckling capacities were obtained from the tests and compared with numerical results. The finite element (FE) models of all specimens were established and validated by test results. Sensitivity of buckling capacities to loading eccentricities was evaluated regarding to eccentrically compressed specimens. Based on extended numerical data and various code formulae, corresponding column curves derived through parametric analyses were recommended to predict the ultimate buckling capacities of the columns. Finally, criteria for section optimal selection and potentially high efficient sections were proposed for experimental and practical uses.

2. Test program

2.1. Test specimen details

The test specimens comprised a total of 24 large-section HSSY columns with different sectional width-to-thickness ratios (for steel angles: 7.8 and 9.1; for steel plate: 7.9 and 9.1). 12 columns were designed for axial compression and the other 12 columns were subject to eccentric loadings. The equal-leg steel angles of all columns were fabricated from hot-rolled Q420 steel and the steel plates were flame cut also from Q420 steel. The steel angles were welded at the limb back