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xperimental and numerical investigation on cold-formed steel semi-oval hollow section compression members

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ABSTRACT

A comprehensive experimental and numerical investigation on cold-formed steel semi-oval hollow section pin-ended columns was performed and is presented herein. The semi-oval hollow sections investigated in this study are composed of one semi-circular flange, one flat flange and two flat web plates. Four cross-section sizes were included and a total of 19 tests was conducted under concentric loading with different specimen lengths in the test program. A finite element model was developed and validated against the test results. The numerical model is capable to replicate the test results. Upon the validation of finite element model, an extensive parametric study was performed consisting of 200 numerical data cases, which cover a wide range of cross-section geometries and column slenderness. The results obtained from experimental program and numerical study were compared with the predicted strengths by the existing and modified Direct Strength Method. Reliability analysis was conducted to assess the reliability of the design methods. The comparison results show that the existing Direct Strength Method generally provides conservative predictions, but the predictions are scattered for slender sections. Modification was proposed to address this issue. The modified Direct Strength Method provides accurate and less scattered predictions in a reliable manner. The modified Direct Strength Method is suitable for cold-formed steel semi-oval hollow section columns, especially for short column members and columns with slender sections.

1. Introduction

The semi-oval hollow section (SOHS) investigated in this study is a novel tubular section type, which is composed of one semi-circular flange, one flat flange and two flat web plates. Unlike the circular and square hollow sections, the possession of different geometric properties about the two principal axes allows the SOHS to be oriented to achieve better loading resistance. Compared with the rectangular hollow section, the SOHS has a semi-circular portion, which offers the aesthetic appearance and is able to provide larger local buckling resistance than the flat plate [1,2]. The complementary qualities of aesthetically pleasing appearance and the superior structural efficiency of SOHS offer an interesting alternative to engineers and architects especially for exposed steelwork. The SOHS has been adopted to decorate the façade supporting members as shown in Fig. 1, which manifests its attractiveness in architectural perspective. Nevertheless, even though the SOHS has prominent advantages in both structural and aesthetical aspects, there is scarce investigation and a lack of design information available for this newly developed section type.

Previously, Chen and Young [3] have conducted experimental and numerical investigation on the cross-sectional behavior of cold-formed steel semi-oval hollow section stub columns compressed between fixed ends and proposed design rules for SOHS stub columns. However, the structural behavior of cold-formed steel SOHS pin-ended column members remains unexplored.

The aim of this paper is to investigate the structural behavior of cold-formed steel semi-oval hollow section pin-ended column members in both experimental and numerical manners. In the test program, a total of 19 column tests was conducted between pinned ends. The specimen length of test specimens was designed to vary from 200 mm to 1500 mm in order to cover a range of column length. In addition, a non-linear finite element (FE) model was developed and validated against the test results. An extensive parametric study comprising 200 column specimens was performed based on the validated FE model to expand the range of cross-section geometries and column slenderness of cold-formed steel SOHS column members.

The current design specifications for steel structures [4–7] do not cover the cross-section classification and the effective width calculation for cold-formed steel SOHS investigated in this study. Unlike traditional design methods, the Direct Strength Method (DSM) as detailed in the AISI S100-16 [5] can be used to calculate the design strength of column member with arbitrary cross-section profile. However, the DSM design

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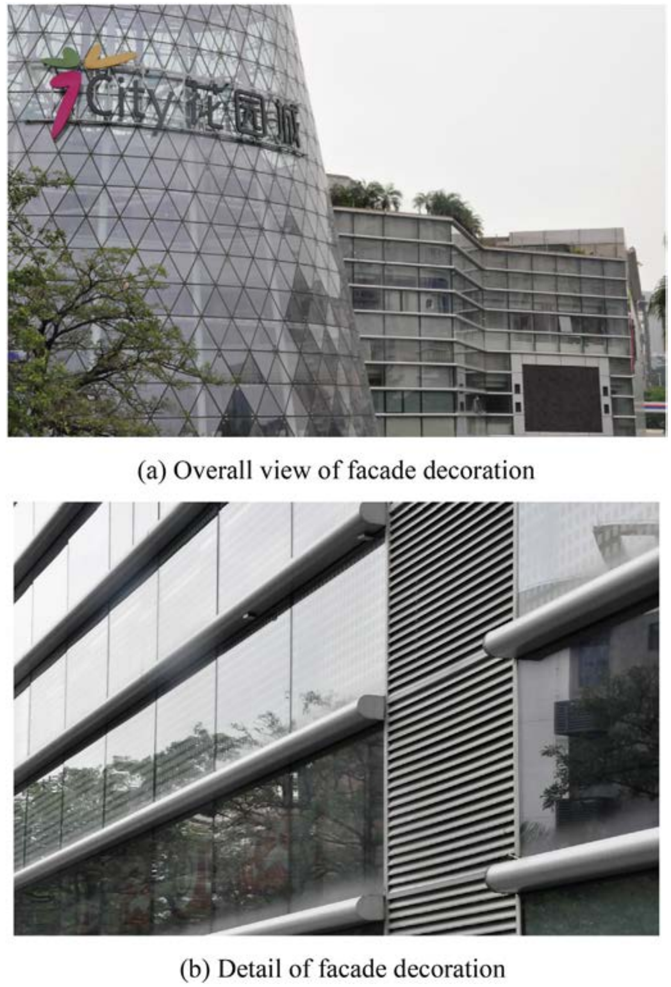

Fig. 1. Decoration of facade supporting system of Garden City in Shenzhen, China. (a) Overall view of facade decoration, (b) Detail of facade decoration.

equations were originally calibrated by open sections with plate elements, the applicability and reliability of the DSM for the column strength predictions of the cold-formed steel SOHS members are questionable and were evaluated in this study. The results obtained from experimental and numerical investigation were used to compare with the design strength predictions by the Direct Strength Method and to propose modification on Direct Strength Method for cold-formed steel SOHS columns. The applicability and reliability of the existing and modified DSM were examined through reliability analysis.

2. Experimental investigation

2.1. Test specimens

The test specimens consisted of 19 pin-ended columns. All the SOHS investigated in this study were cold-formed from hot-extruded seamless steel circular hollow sections. The test specimens are categorized into four series according to the cross-section geometry of SOHS as defined using the nomenclature in Fig. 2. The nominal dimensions ($D \times B \times t$) of SOHS are 93 × 62 × 5.5, 107 × 68 × 6.5, 108 × 79 × 5.5 and 125 × 85 × 6.5, where D, B, t are the overall depth, overall width and wall thickness of the sections, respectively. The nominal cross-section aspect ratio (D/B) of the specimens varies slightly from 1.37 to 1.57. All the SOHS columns are labeled such that the nominal cross-section geometry, the specimen type and the specimen length can be identified. The letters C in the last part of the specimen label indicates a pin-ended column. The following letter L together with the number designates the length of the actual specimen, whereas the symbol # denotes a repeated test. The measured specimen dimensions are reported in Table 1, where r_o and r_i are the external and internal corner radii, respectively, and L is the actual specimen length.

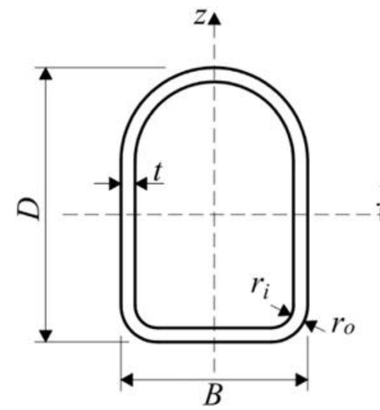

Fig. 2. Cross-section geometry of SOHS.

2.2. Material properties

Material properties of cold-formed steel semi-oval hollow sections were determined by tensile coupon tests at three critical locations, i.e. flat web, tip of semi-circular portion and the corner. The obtained material properties were incorporated into the numerical study and were used in the design strength predictions. The results of the tensile coupon tests have been reported by Chen and Young [3], while a summary of the test results is presented in Table 2.

2.3. Geometric imperfection measurements

The initial global geometric imperfections ω_g of the pin-ended columns were obtained based on the measurements taken on flat flange near the corner at mid-height and near both ends of the specimens in the buckling direction using a Leica TCR405 total-station prior to testing. The initial global imperfection is positive when the specimen is bowed in the same direction as the bending direction, and vice versa. The measured values are reported in Table 1. The average absolute value of the normalized initial global imperfection at mid-length was 1/12606 for the test column specimens. The negligibly small value of initial global geometric imperfection demonstrates the great straightness of the tubes.

2.4. Test setup and procedure

A total of 19 column tests was conducted as pin-ended to examine the load-carrying capacity and load-end shortening history of the cold-formed steel SOHS. The column samples were cut to specified specimen lengths of 200, 440, 850, 1200 and 1500 mm with both ends milled flat before welding of 25.4 mm thick end plates.

The test setup and test rig of pin-ended columns of various lengths are shown in Figs. 3 and 4. A special bearing system, which consists of a pair of pit plates with V-shaped grooves and wedge plates with knife-edges, was designed to replicate pinned end conditions and to allow free rotations about major axis as well as to restrain rotations about the orthogonal axis. The specimens were adjusted on the slotted wedge plates to a designated eccentricity (the aimed eccentricity of zero for column tests in this case) before being bolted to the wedge plates. For the test setup of columns with actual specimen lengths of 850, 1200 and 1500 mm, the upper pit plate was fixed and the lower one was installed on a special ball bearing at the bottom as shown in Fig. 4. Before testing, a small preloading of 3 to 5 kN was applied to