Thin-Walled Structures 107 (2016) 627–647

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Interacted buckling failure of thin-walled irregular-shaped aluminum alloy column under axial compression

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ARTICLE INFO

Article history:
Received 12 January 2016
Received in revised form
14 June 2016
Accepted 11 July 2016
Available online 25 August 2016

Keywords:
Aluminum alloy column
Irregular-shaped cross-section
Interacted buckling failure modes
Ultimate strength

ABSTRACT

Interacted buckling behaviors and ultimate strength of thin-walled aluminum alloy columns with irregular-shaped cross section were studied using a verified Finite Element Model (FEM). Six interacted buckling failure modes were studied, which were: (1) the interaction of Local bucking and sectional Yielding (LY); (2) the interaction of Local and Global buckling (LG); (3) the interaction of Distortional buckling and sectional Yielding (DY); (4) the interaction of Distortional and Global buckling (DG); (5) the interaction of Local bucking, Distortional bucking and sectional Yielding (LDY or DLY); and (6) the interaction of Local, Distortional and Global buckling (LDG). The load-axial displacement curve, the deflection-axial displacement curve, the development of the axial stress at different positions in the section at mid-span, the out-of-plane displacement at failure along the column length and the axial stress distribution at failure across the section at mid-span were presented. The local buckling and distortional buckling were detected by the turning points on the load-axial displacement curves. The out-of-plane displacement along the column length at failure was used to illustrate the failure mode of the column. Ultimate strengths and failure modes of 174 columns failed by interacted buckling failure modes were investigated by both FEM and current design approaches. For the ultimate strength of the columns under DY failure mode, the results predicted by North American specification for the design of cold-formed steel structural members of American Iron and Steel Institute (AISI) were higher than FEM simulation results. The ultimate strength predicted by American Aluminum Design Manual (AA), Direct Strength Method (DSM), European Code (EN1999) and Chinese Design Specification for Aluminum Alloy Structures (GB50429) were lower than FEM simulation results, no matter what kind of failure modes the column encountered. Mean values of P_{AA}/P_{FEA}, P_{EC9}/P_{FEA} and P_{GB}/P_{FEA} were 0.81, 0.79 and 0.74. DSM could precisely predict the Global buckling (G), LG and DY failure modes. However, for the columns failed by LY, DG, LDY and LDG, they were LG, G, DY and LG when predicted by DSM, respectively. The applicability of DSM to thin-walled aluminum alloy columns with irregular-shaped cross section should be investigated further.

1. Introduction

The aluminum alloy is a widely-used metallic structure material due to its high strength to weight ratio, excellent corrosion resistance and outstanding low temperature performance. An aluminum alloy column can be easily extruded to flexible section to meet both the structure and integration requirements [1]. For example, column in Fig. 1 is usually used as side columns in the sun-house. The section includes a closed part P1 and an open part P2. Plate thicknesses of P1 and P2 are t_1 and t_2, respectively, as shown in Fig. 2(a). The closed part provides good local and global buckling resistance. The channels can hold the Fiber Reinforced Plastic (FRP) wall to satisfy the integration requirements. t_1 and t_2 is 2 mm, as shown in Fig. 2(b). The column could be subjected to single buckling mode, such as local buckling, distortional buckling or global buckling, or interactive buckling modes depending on the column length and plate thickness. The center-to-center distance of plates in the section will not change when t_1 and t_2 varies, as shown in Fig. 2(b).

Current design codes for aluminum alloy structures provide design guides for columns with regular-shaped cross section, such as H-section and box-section. American Aluminum Design Manual (AA) [1], European Code EN1999 [2] and Chinese Design Specification for Aluminum Alloy Structures (GB50429) [3] provide design methods for aluminum alloy columns based on effective section to account for the influence of the local buckling on the ultimate strength. The extruded aluminum alloy columns usually have complex section shape. It is tedious to find out the effective

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http://dx.doi.org/10.1016/j.tws.2016.07.008

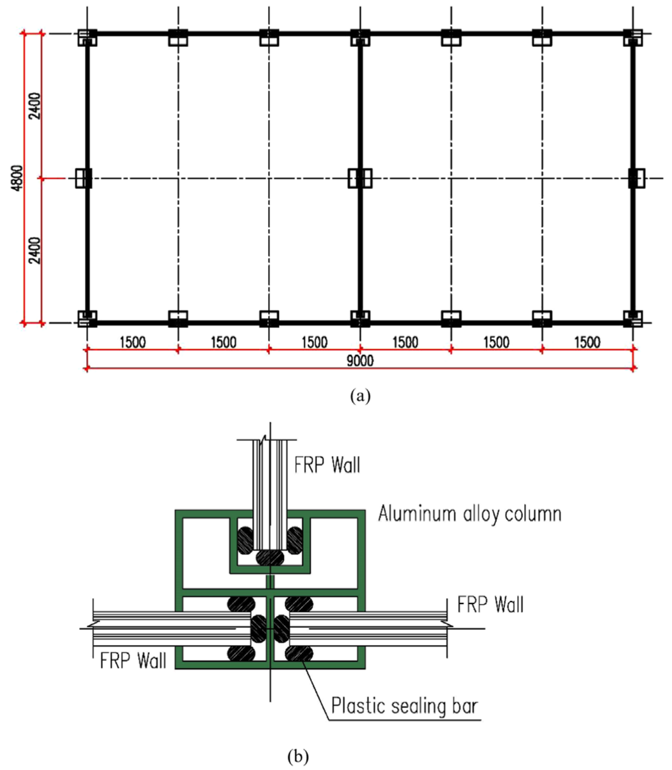

Fig. 1. Layout and connection details of the aluminum alloy column. (a) Layout of the sun house, (b) connection details of the side column and the FRP wall.

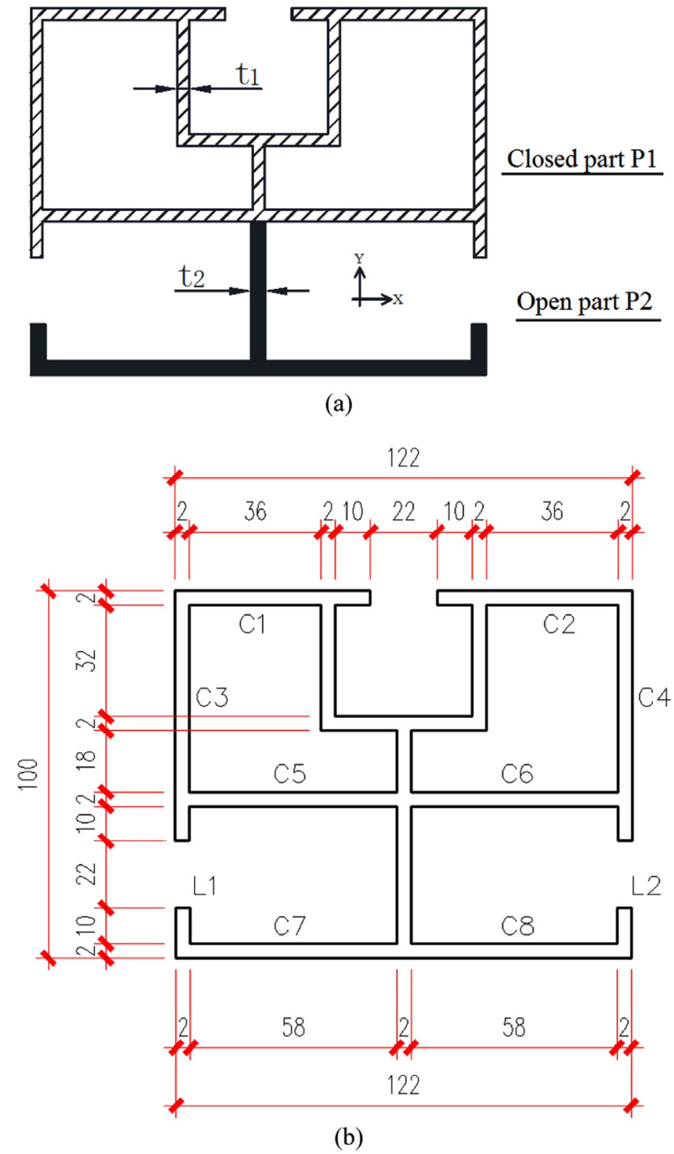

Fig. 2. Cross-section of the irregular-shaped thin-walled aluminum alloy column. (a) Closed part P1 and open part P2 in the section, (b) dimensions and plate numbers of the cross section (in mm).

section. American Iron and Steel Institute specification for the design of cold-formed steel structural members (AISI) [5] for the design of thin-walled steel members provides a Direct Strength Method (DSM) [4], which is based on the whole section of the column. LG and DY can be considered in DSM.

At present, researches on aluminum alloy members are mainly focused on regular cross-sections such as circular, square, rectangular and angle sections. Wang et al. [6] and Adeoti et al. [7] carried out tests to study flexural buckling behaviors of columns with H-section, box-section and circular hollow section made of 6082-T6 aluminum alloy. Yuan et al. [8] tested 15 extruded aluminum alloy stub columns with slender I-sections failed by local and global buckling. Zhu and Young [9–13] studied local and flexural buckling behaviors of aluminum alloy columns with box-section and circular section through finite element simulation and tests.

Local buckling behaviors of aluminum alloy members with irregular sections should be studied further. Liu et al. [14,15] tested stiffened closed-section aluminum alloy columns to study their local buckling behaviors and ultimate strength. Test results were compared with Finite Element Model (FEM) predictions and current design codes. Mennink [16] carried out 40 tests on extrusions with 12 types of complex cross section shapes. The specimens were obtained from commercially available extrusions used in greenhouse. Various specimen lengths were determined in order to obtain either single local, distortional and global buckling, or their interactions.

This paper presented buckling behaviors and ultimate strengths of the thin-walled aluminum alloy columns with irregular-shaped cross section. A FEM was developed using the software ABAQUS and was verified by test results. Six interactive failure modes were studied, which were.

(1) Interaction of local bucking and sectional yielding (LY);
(2) interaction of local and global buckling (LG);
(3) interaction of distortional buckling and sectional yielding (DY);
(4) interaction of distortional and global buckling (DG);
(5) interaction of local bucking, distortional bucking and sectional yielding (LDY or DLY); and
(6) interaction of local, distortional and global buckling (LDG).

Load-axial displacement curve, deflection-axial displacement curve, development of the axial stress at different positions in the section at mid-span, out-of-plane displacement along the column and stress distribution across the section at mid-span were presented. Ultimate strength of the columns failed by different buckling failure modes were obtained by FEM and current design codes.

2. Finite element model and verification

2.1. Finite element model

The FEM of the column was developed using the finite element software ABAQUS. The column was meshed using S4R, a 4-node