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Buckling behaviors of thin-walled aluminum alloy column with irregular-shaped cross section under axial compression in a fire

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ABSTRACT

Failure modes of the thin-walled aluminum alloy column with irregular shaped cross section at ambient temperature and elevated temperatures in a fire were studied using a verified finite element model. The studied failure modes included the sectional yielding, interaction of local buckling and sectional yielding, interaction of local and global buckling, and global buckling. The finite element model was verified by experimental results from the ultimate strength, the failure modes and the failure deformation. Deformation shape along the column failed by different failure modes was presented. Stresses development at the middle span section was greatly affected by the failure modes. Ultimate strengths of a series of aluminum alloy columns with different length, cross section dimension were analyzed by the finite element analysis and current design codes at different temperatures in a fire. The current design codes greatly underestimated the ultimate strength of the thin-walled aluminum alloy column with irregular shaped cross section. Design method provided by EN1999-1-2 can give an accurate prediction of the ultimate strength of a short thin-walled aluminum alloy column with irregular shaped cross section at temperatures lower than 250 °C. A modification to the design method in EN1999-1-2 was proposed for predicting the ultimate strength of the aluminum alloy column with length longer than 500 mm and at temperatures higher than 250 °C. Ultimate strength predicted by the modified equation agreed well with finite element analysis results.

1. Introduction

Aluminum alloy is one of the widely used metallic structural materials for its high strength-to-weight ratio, good workability and outstanding corrosion resistance. The cross-section of an aluminum alloy member can be very complex for it can be made through extrusion. Both structural and service functions can be integrated in the cross-section. That means, on one hand, aluminum alloy members should have enough capacities to keep members from global buckling, distortional buckling, local buckling or sectional yielding. On the other hand, the cross-section should have channels to fit the Fiber Reinforced Plastic (FRP) wall. In this paper, the studied irregular-shaped thin-walled aluminum alloy column was used as corner columns in the sun-house, as shown in Fig. 1. The cross-section of the column was an open section which consisted of plain plates and curve plates, as shown in Fig. 2. Buckling behaviors of the irregular-shaped thin-walled aluminum alloy column at ambient and high temperatures in a fire was studied.

Many countries had published design manuals on aluminum alloy members with regular sections at the ambient temperature, such as the circular section, the box section or the H-section. In 1970s, the American Aluminum Association had already published Specifications for Aluminum Structures [1] and the European Convention for Constructional Steelwork published the European Recommendations for Aluminum alloy structures [2]. Now many countries have published their own design codes for aluminum alloy members, including the American Aluminum Design Manual (AA) [3], the Australian/New Zealand Standard [4], the European Code (EC9) [5,6] and the Chinese Design Specification for Aluminum Structures (GB50429) [7].

Researches on behaviors of aluminum alloy columns have never stopped. Zhu and Young [8,9,10,11] studied buckling behaviors of aluminum alloy columns with circular sections by means of model test and numerical simulation. Batista [12] used the effective width and the direct strength integrated approach to predict the strength of cold-formed column undergoing local–global buckling interaction. However, most of the researchers focused on the aluminum alloy members with traditional sections such as channel section, circle section, Z-section and H-section. The buckling behavior and strength of an irregular-shaped aluminum alloy members have rarely been investigated.

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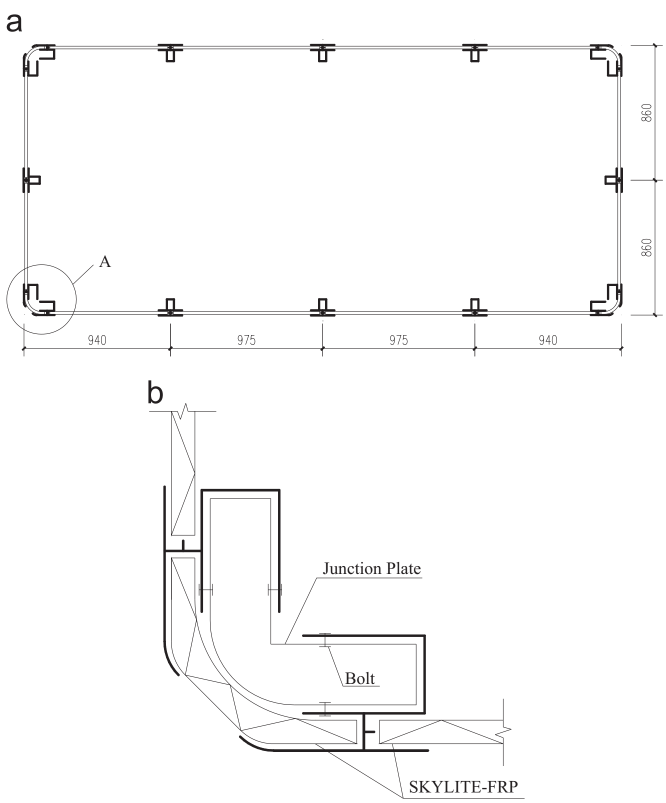

Fig. 1. Application of the irregular-shaped thin-walled aluminum alloy column (a) layout of aluminum alloy columns and (b) connection of the aluminum alloy column with the Fiber Reinforced Plastic (FRP).

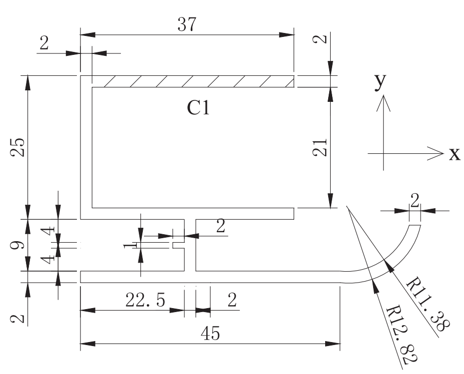

Fig. 2. Cross-section of the irregular-shaped thin-walled aluminum alloy column.

Behaviors of aluminum alloy members at elevated temperatures in a fire had also been presented. Maljaars et al. [13,14,15] studied flexural buckling and local buckling of square hollow section and I-shaped section columns exposed to fire and proposed a new method for predicting ultimate strength of fire exposed aluminum alloy columns. Fogle et al. [16] showed failure modes and strengths of fire exposed aluminum alloy plates under compression load. Khatibi et al. [17] presented a coupled thermal–mechanical finite element model for analyzing the tensile softening, deformation and fail of aluminum alloy plate exposed to fire. However, these researches still focused on the aluminum alloy columns with traditional regular cross-section.

In this paper, a Finite Element Model (FEM) was developed using the finite element software ABAQUS 6.11 and verified against test results of aluminum alloy columns with the studied cross section at ambient temperature. Steady state analysis was used for the fire resistance analysis. Four failure modes of the column were studied, which were the sectional yielding, the interaction of local buckling and the sectional yielding, the interaction of local buckling and the global buckling, and the global buckling. Lateral deflection and stress development of the column failed at different failure modes were presented. Parametric study on columns with different lengths and cross-section dimensions were carried out by finite element analysis. Buckling strengths of columns at elevated temperatures in a fire obtained from FEM simulations were compared with those obtained from current design codes. The design method for flexural buckling of aluminum alloy column exposed to fire in EN 1999-1-2 [6] could not give accurate predictions for aluminum alloy columns with the studied section. A modified equation was proposed by considering both reduction factors for yield strength and Young's modulus.

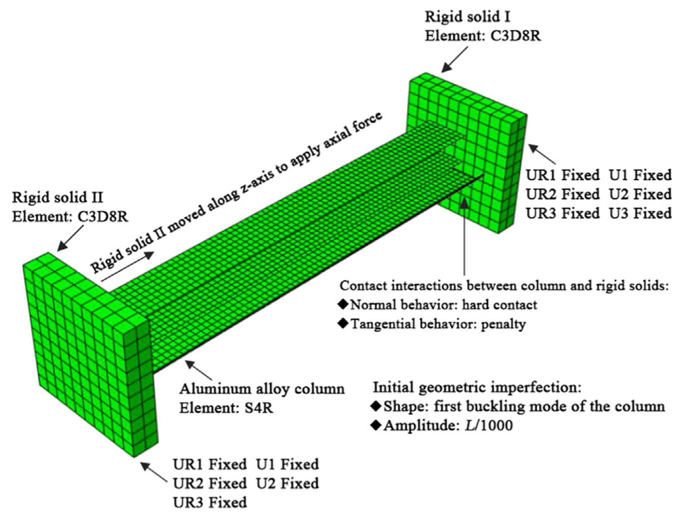

Fig. 3. FEM of the studied aluminum alloy column.

2. Finite element model and verification

2.1. Finite element model

Behaviors of the aluminum alloy column with irregular cross section were simulated through the finite element software ABAQUS, as shown in Fig. 3. The aluminum alloy column was meshed using S4R, a 4-node reduced integration shell element. Two rigid solids were used to simulate the loading machine, which was meshed using C3D8R, a 8-node linear reduced integrated structural brick element. The mesh size was 5×5 mm which was chosen as results of mesh sensitive analysis considering both CPU time and accuracy. Contact interactions were defined between the aluminum alloy column and the rigid solid. The normal behavior of the contact was hard contact which meant no penetration between the contact pair. The tangential behavior was defined as penalty with friction coefficient of 0.17 [21]. One rigid solid was fixed and the other rigid solid moved in the z-axis to apply the axial compression load to the aluminum alloy column.

Mechanical properties of the aluminum alloy columns adopted those obtained from the tensile couple test, as listed in Table 1. The rigid solid was steel with Young's modulus of 205 GPa. The residual stress in an extruded member was very small and was neglected in the simulation [18]. Initial global geometric imperfection adopted a half sinusoid curve along the column. The amplitude of initial geometric imperfection took $L/1000$, where L was the column length.

2.2. Verification

The finite element model was verified by five columns with the studied irregular-shaped cross-section carried by the authors and 11 tubular columns carried by Zhu and Young [10]. Columns were