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Buckling behaviour of aluminium alloy columns under fire conditions

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ABSTRACT

This paper presents a systematic investigation on the buckling behaviour of aluminium alloy columns under fire conditions. One hundred and eight aluminium alloy columns, including sixty rectangular tubes and forty eight circular tubes, were tested under axial load at elevated temperature and at ambient temperature as reference. All the column specimens failed by flexural buckling. Finite element (FE) models implemented in the non-linear code ANSYS were established and verified against the experimental results. To develop a further understanding, 8829 FE models considering geometrical and material nonlinearity were conducted with four kinds of material properties, thirty four kinds of sections and five elevated temperature points. According to the FE results and statistical regression method, formulae to estimate the stability coefficients of aluminium alloy columns under fire conditions were proposed. Finally, the proposed formulae were compared with the experimental results and the stability coefficients from existing codes. It is found that the proposed formulae can provide accurate stability coefficients of aluminium alloy columns under fire conditions.

1. Introduction

With advantages of lightness, high strength-to-weight ratio, favourable durability, corrosion resistance and pleasing appearance, aluminium alloy members are increasingly used in structural applications all over the word, such as Shanghai International Gymnastic Center (China), Shanghai Science and Technology Museum (China), Sea World of Texas (America), Dome of Discovery (UK), Aviodrome Museum of Schiphol Airport (Holland) and Butterfly House of Maruseppu (Japan), etc [1]. However, the elastic modulus of aluminium alloys is much lower than steel. Therefore, the problem of stability is of greater importance in the design of structures with aluminium alloys than those with structural steel.

More and more researchers have devoted their efforts to the study on the buckling behaviour of aluminium alloy columns. Earlier studies on the buckling behaviour of aluminium alloy columns at ambient temperature have carried out in American and European since 1930s [2]. For the time being, extensive experimental studies, finite element (FE) simulations and theoretical analyses have been conducted. Zhu et al. [3–6] performed a systematic investigation on 6061-T6 and 6063-T5 aluminium alloy tubular columns of circular and rectangular hollow sections and developed design rules which accurately predict the ultimate strength of aluminium welded and non-welded columns. Liu et al. [7,8] explored the buckling behaviour of aluminium alloy columns with irregular-shaped cross section through experimental and numerical studies. Wang et al. [9] and Adeoti et al. [10] compared the experimental results of 6082 aluminium alloy columns with the buckling strengths predicted by several current aluminium structure design codes, and indicated that the Rasmussen-Rondal formulation [11] provides the closest and generally conservative strength predictions. Yuan et al. [12] carried out a comprehensive experimental programme to investigate the local buckling and postbuckling strengths of aluminium alloy I-section stub columns and indicated that the predicted compressive strength from the design codes is generally conservative. The achievements on the buckling behaviour of aluminium alloy columns at ambient temperature are abundant, and rules for prediction of buckling behaviour of aluminium alloy columns at ambient temperature have been included in current leading design standards, such as American Aluminium Design Manual [13], Australian/New Zealand Standard [14], Eurcode 9 for Design of aluminium structures [15] and Chinese Code for Design of Aluminium Structures (GB 50429) [16], etc.

Recently, researchers started to pay attention to the buckling behaviour of aluminium alloy columns under fire conditions gradually. Maljaars et al. [17] investigated the flexural buckling of fire exposed aluminium columns through FE simulations and proposed a new method for predicting their ultimate strength. To study the local buckling of aluminium structures exposed to fire, Maljaars et al. [18,19] also conducted tests and established FE models of aluminium alloy

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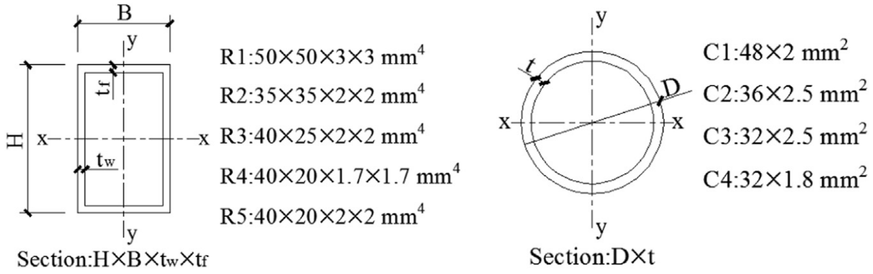

Fig. 1. Section dimension.

Fig. 2. Tensile coupons.

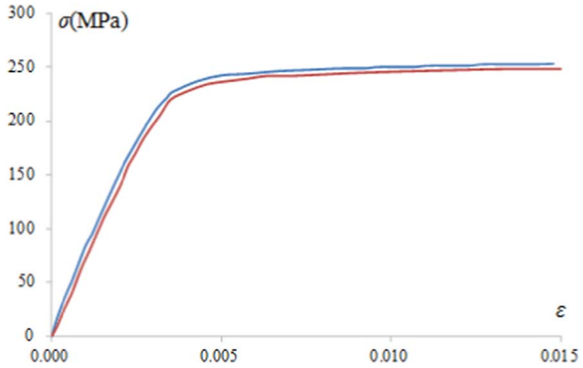

Fig. 3. Stress-strain curves of tensile coupons.

columns with square hollow and angular sections. Liu et al. [20] presented the buckling behaviour of fire exposed aluminium alloy columns with irregular-shaped section by means of FE simulations. According to the aforementioned achievements, it is found that compared with the achievements of aluminium alloy columns at ambient temperature, research results on performance of aluminium alloy columns at elevate temperature are limited.

This paper is aimed to develop a full understanding of the buckling behaviour of aluminium alloy columns under fire conditions and provide an effective method for designers to accurately estimate their ultimate strength. Firstly, a series of tests on the buckling behaviour of fire exposed aluminium alloy columns were conducted. Secondly, the FE models of fire exposed aluminium alloy columns were established and verified against the experimental results. Thirdly, 8829 FE models were analyzed to develop a further understanding and formulae to estimate the stability coefficients of aluminium alloy columns under fire conditions were proposed. Finally, the proposed formulae were compared with the experimental results and the stability coefficients from existing codes.

2. Experimental program

2.1. Specimen

A total of 108 aluminium alloy column specimens, including 60 rectangular tubes and 48 circular tubes, were tested under axial compressive load at elevated temperature and at ambient temperature as reference. All the column specimens were extruded by 6061-T6 aluminium alloy. Five cross-sections (R1–R5) were selected for the rectangular tubes and four cross-sections (C1–C4) were selected for the circular tubes, as shown in Fig. 1. The effective length of each specimen L_e was 962 mm. The tests were conducted under steady state fire condition. Six temperatures were adopted, including 20 °C(T1), 100 °C(T2), 200 °C(T3), 300 °C(T4), 350 °C(T5) and 400 °C(T6). For each temperature, two identical column specimens (A and B) were tested. The column specimens are labeled by the cross-section and temperature. The label R3-T3A (or R3-T3B), for example, defines a test specimen with rectangular hollow cross-section $40 \times 25 \times 2 \times 2\,\mathrm{mm}^4$ was tested at temperature 200 °C.

2.2. Material properties

The material properties of aluminium alloy were obtained from tensile tests on coupons according to the Chinese testing standard [21]. Two tensile coupons were cut directly from aluminium alloy columns.

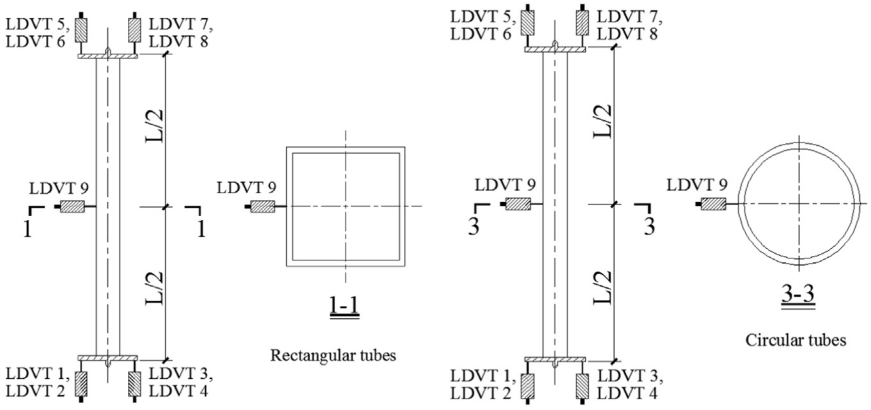

Fig. 4. Arrangement of LVDTs.