Thin-Walled Structures 122 (2018) 585–596

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Experimental investigation and parametric analysis on overall buckling behavior of large-section aluminum alloy columns under axial compression

Z.X. Wang[a,*], Y.Q. Wang[a], Jeong Sojeong[a], Y.W. Ouyang[b]

[a] Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China
[b] Shanghai Tongzheng Aluminum Engineering Co., Ltd., Shanghai 200030, PR China

ARTICLE INFO

Keywords:
Aluminum alloy
Large-section
Experimental investigation
Parametric analysis
Finite element analysis

ABSTRACT

Experimental investigation was conducted on large-section extruded aluminum alloy columns of I-section and rectangular hollow section (RHS). Altogether seven columns with different slenderness ratios were comprised. The failure modes and stability resistance as well as load-displacement responses were identified. It was found that all tested specimens failed in flexural buckling. An extensive parametric analysis on 180 specimens was carried out with general FEA software ANSYS to evaluate the reliability level of the current design specifications including American aluminum design manual, Eurocode 9 and Chinese code GB 50429. The design stability resistance advised by Eurocode 9 and Chinese code GB 50429 is conservative, while that of American aluminum design manual slightly overestimates the practical stability resistance. Based on the parametric analysis results, a new design method was proposed to improve the design accuracy.

1. Introduction

Aluminum alloy members are increasingly applied in constructions since 1950s all over the world because of its good corrosion resistance, light weight, high strength and ease of production [1–3]. Combined with frequently applied large slenderness ratio and its lower Young's modulus (about 70,000 MPa), the buckling behavior usually occurs on aluminum alloy columns.

The research on overall buckling behavior of aluminum alloy columns dates back to the middle of the last century. Based on a series of experimental and numerical investigations [4–7], America Aluminum Association promulgated their first edition of the *Specification for Aluminum Structures* in 1967. European Convention for Constructional Steelwork (ECCS) also proposed their first aluminum alloy design code [8] in 1978 including overall stability design criteria. Since then the overall buckling behavior of aluminum alloy columns has attracted a large number of researchers. Over the past few years, the overall buckling behavior of aluminum alloy columns with different section shapes, including circular hollow sections [9,10], H-sections [11,12], square and rectangular hollow sections [11,13,14], angle sections [15], and irregular shaped cross sections [16], has been intensively experimentally investigated.

However, almost all the above researches focused on small-section (section height $\leq$ 200 mm) aluminum alloy members. And the overall stability design criteria in current design specifications including American aluminum design manual [17], Eurocode 9 [18], Australian/New Zealand Standard [19] and Chinese standards GB50429-2007 [20] are also mainly drawn from investigation on small-section members. The reasons of the extensive study on small-section aluminum alloy members are: (i) large-section members were not necessarily used in practical engineering in the past; (ii) the development of large-section aluminum alloy members was limited by the immature extrusion technology. However, the situation is different right now in that the increasing demand in engineering and the improvement of the extrusion technology has made the large-section aluminum alloy members more widely used. For instance, a large number of 550 mm-section-height large-section aluminum alloy members have been used in reticulated shell of Usnisa Palace in Nanjing, China (Fig. 1). Therefore, the lack of experimental work and relevant study on large-section members has been a concern, which is the main focus of the paper.

First, experimental investigation on overall buckling behavior of large-section extruded aluminum alloy columns including I-sections and rectangular hollow sections (RHS) was conducted in the paper. Then, the test results and corresponding numerical results were compared with the current design specifications which are American aluminum design manual [17], Eurocode 9 [18] and Chinese code GB 50429 [20]. At last, a more rational design procedure was proposed for large-section aluminum alloy columns failed by overall buckling under axial compression.

---

* Corresponding author.
E-mail address: 1534307298@qq.com (Z.X. Wang).

http://dx.doi.org/10.1016/j.tws.2017.11.003
Received 16 June 2017; Received in revised form 22 October 2017; Accepted 2 November 2017

Nomenclature

A	area of cross-section
A_{eff}	effective area of cross-section
B	overall width of cross-section
E_0	initial Young's modulus
$f_{0.2}$	nominal yield stress (0.2% proof stress)
f_u	ultimate stress
H	overall depth of cross-section
i_y	inertia radius about y axis
k	stiffness of the rotation springs
L	length of specimen
L_0	effective length of specimen
N_{AA}	predicted stability resistance by American Aluminum design manual
N_{EC9}	predicted stability resistance by EC9
N_{FEA}	numerical value of stability resistance by FEA
N_{GB}	predicted stability resistance by GB 50429
$N_{proposed}$	predicted stability resistance by proposed design method
N_{PA}	stability resistance of the parametric analysis
N_u	stability resistance in the tests
n	exponent in Ramberg-Osgood expression
t_f	thickness of flange
t_w	thickness of web
ΔV, Δv	overall geometric imperfection
α	imperfection factor
ε_u	ultimate strain at tension failure
λ	Slenderness ratio
$\bar{\lambda}$	nondimensional slenderness ratio defined in GB 50429
λ_0	effective flexural slenderness about minor axis
$\bar{\lambda}_0$	limit of horizontal plateau
λ_n	nondimensional slenderness ratio defined in EC9
λ_y	slenderness ratio about minor axis
θ_{yield}	yield rotation angle of rotation springs
ρ_c	local buckling reduction factor

2. Experimental investigation

2.1. Test specimens

Tests were conducted on 7 large-section aluminum alloy columns including 4 I-section columns and 3 RHS columns, with all the specimens extruded and fabricated by 6061-T6 aluminum alloy. The section height of all the columns is 550 mm which is larger than that in any other existing research.

The dimensions of each specimen are shown in Table 1 using the symbols defined in Fig. 2. In Table 1, L is the measured length of the column and A is the area of the cross-section. λ_y refers to the slenderness ratio about the minor axis ranging from 58.37 to 116.74 for I-section columns and 28.96–48.23 for RHS columns. The specimens were labeled according to the section shape, column length and material type. For example, the label “R-L3510-T6” defines the specimen as follows: the first letter R indicates that the section shape is RHS, while the L3510 indicates the measured length of 3510 mm of the specimen, and the last term T6 indicates that the material of the column is 6061-T6.

Both ends of the specimens were milled flat by finishing machine to make a uniform distribution of loads.

2.2. Material properties

Prior to the loading tests, tensile coupon tests were conducted to determine the material properties of the aluminum alloy. The dimensions of the tension coupons were detailed in Fig. 3. The tension coupons were cut from the web and flange of the specimens along the longitudinal direction. There are 12 tension coupons, which is divided into four groups with three identical coupons in each. The tests were conducted on hydraulic universal testing machine in accordance with ASTM E8M-97 standard [21] and GB/T 228.1 [22]. The deformation of the coupons was measured by both strain gauges and extensometer.

Fig. 1. Usnisa Palace on Niushou mountain in Nanjing, China.

The coupons tension almost did not result in necking. There was a very sudden failure process with loud sound. The average measured material properties are shown in Table 2, where E_0 is the initial Young's modulus, $f_{0.2}$ is the nominal yield stress (0.2% proof stress), f_u is the ultimate stress, n is the exponent in Ramberg-Osgood expression [23] and ε_u is the ultimate strain at the failure of the tension coupons. The full stress-strain curves of the aluminum alloy are shown in Fig. 4.

As shown in Fig. 4, there is a difference between the material properties of I-section columns and RHS columns. The strength of RHS columns is about 20% higher than the strength of I-section columns probably owing to the different extrusion process. However, the material properties of flange and web from same section are nearly the same.

2.3. Initial geometric imperfection

The initial geometric imperfection impinges on the stability resistance of the metallic structures and therefore was measured before testing for all the columns. The imperfection was measured with the combination of optical theodolite and vernier caliper, and this measuring method was successfully applied in steel columns [24,25].

The schematic diagram of the initial geometric imperfection measurement is shown in Fig. 5. The overall geometric imperfection is actually the deviation of the section centroid from the axis connecting the centroid of two end sections, i.e. Δv_1, Δv_2 and Δv_3 in Fig. 5. The measurement was conducted on two ends and the quarter points about both major axis and minor axis. The maximum value of Δv_1, Δv_2 and Δv_3 was taken as the initial geometric imperfection ΔV (shown in Table 3), which would be applied in further numerical investigation. It was found that the $\Delta V/L$ of all the columns in both axes are no more than 0.4%, indicating that the extrusion forming could make a smaller initial geometric imperfection.

2.4. Test configuration

All of the columns were loaded by a 12,000 kN servo-control rig between pinned-ended bearings. The test configuration is shown in Fig. 6. Two pole hinges were attached to the testing machine to supply hinged boundary condition which ensured the flexible rotation of the end sections. The distance between each column end and the rotation