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Behaviors and design method for distortional buckling of thin-walled irregular-shaped aluminum alloy struts under axial compression

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ABSTRACT

Since an aluminum alloy structural component can be manufactured through extrusion technology, the cross section can easily comprise various longitudinal stiffeners to strengthen the thin wall and to hold the partition wall panel. In this paper, experimental and numerical investigations on distortional buckling behaviors of thin-walled irregular-shaped aluminum alloy stub columns under axial compression were carried out. Initial geometric imperfections of six extruded aluminum alloy columns were measured using LVDT. The ultimate strength, failure deformation, out-of-plane displacement and strain development of six test specimens were recorded and used to verify a Finite Element Model (FEM) developed by the finite element software ABAQUS. The open plates in the irregular-shaped section had low distortional buckling resistance, which causes the premature failure of the studied columns. 117 columns with different length and plate thickness were numerically simulated by the verified FEM to reveal the influences of plate thickness on column distortional buckling behaviors. The Direct strength method (DSM) was applied and it was essential to determine column distortional buckling stress before performing DSM to calculate column ultimate strength. A modified calculation method for distortional buckling stress of the irregular-shaped aluminum alloy columns was proposed. Distortional buckling stresses of 81 aluminum alloy columns with different plate thickness were analyzed by the FEM to evaluate the modified calculation method. It was accurate and more efficient to use the modified calculation method to calculate distortional buckling stress of the irregular-shaped aluminum alloy columns in DSM.

1. Introduction

The aluminum alloy has wide applications in building structures due to its high strength to weight ratio, outstanding corrosion resistance and good workability. The extrusion manufacturing process ensures an aluminum alloy column can be in irregular-shaped cross section to satisfy both the structure and integration requirements. The irregular-shaped section is often applied in the green house as side columns and the channels in the section can hold the Fiber Reinforced Plastic (FRP) wall to meet the integration requirement of the green house, as shown in Fig. 1. The irregular-shaped section consisted of a closed part P1 and an open part P2, as shown in Fig. 2. t_1 and t_2 represented plate thickness of P1 and P2 respectively and they were both 2 mm in Fig. 2. The closed part P1 could provide good local and global buckling resistance for aluminum alloy columns. The distortional buckling would probably affect the open part P2 due to its low buckling stress and can greatly reduce column axial stiffness and ultimate strength.

Aluminum alloy columns with regular-shaped cross section, such as H section and circular hollow section, had been widely studied. Wang et al. [1] studied stability resistance and failure mode of axial-loaded 7A04 high-strength aluminum alloy angle columns through test and numerical simulation. Based on the test and FE analyses results, a modified design method was proposed for predicting the buckling resistance of 7A04 high-strength aluminum alloy columns. Adeoti et al. [2] performed 30 column tests to study global flexural buckling behaviors and ultimate strength of 6082-T6 aluminum alloy columns with H section and box section. A column curve formula was proposed and it was capable of producing accurate strength for extruded members of 6082-T6 aluminum-alloys failed by flexural buckling under axial compression. Yuan et al. [3] studied the local buckling and post-buckling behaviors of H-section aluminum alloy columns. Based on the obtained experimental post-buckling stress, the design provisions in current design standards were evaluated. It was revealed that the predicted compressive strengths from the four design standards were generally conservative, especially for the cross-sections made of aluminum alloys with pronounced strain hardening properties. Zhu et al. [4,5] applied both finite element analysis and test to investigate local buckling and flexural buckling behaviors of aluminum alloy circular hollow section columns. Design rules were

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Nomenclature

A	area of the whole cross section
A_1	cross-sectional area of flange
a	depth of lip stiffener
b	flange width
b_1, b_2, b_3	plate width of different plates in the irregular-shaped section
C_c	correction factor for boundary conditions
C_w	reduction factor of web rotational stiffness to account for web bending
D	plate flexural rigidity of the web
E	Young's modulus
$f_{0.1}$	stress of aluminum alloy when plastic strain is 0.001
$f_{0.2}$	yield stress of aluminum alloy
$f_{\varepsilon 0}$	stress of aluminum alloy when plastic strain is ε_0
f_u	ultimate stress of aluminum alloy
h	web width
h_x, h_y	x, y coordinates of flange-web junction
I_x, I_y	second moments of area of flange about the x and y axes
I_{xy}	product second moment of area of flange about the x and y axes
J	torsion constant of flange
k_w	stress coefficient
k_x	stiffness of lateral restraint
$k_{\Phi,S}$	stiffness of rotational restraint for steel columns
k_{Φ}	stiffness of rotational restraint for aluminum alloy columns
L	length of a column
n	a parameter which determines material hardening behaviors
P	axial load
P'	buckling loads
$P_{cr,D}$	critical load of distortional buckling
P_{DSM}	ultimate strength of a column calculated by Direct Strength Method
P_{crd}, P_{cre}, P_{crl}	distortional, global and local buckling load
P_{nd}	ultimate strength of a column failed by distortional buckling
P_{ne}	ultimate strength of a column failed by global buckling
P_{nl}	ultimate strength of a column failed by local and global buckling
P_u	ultimate strength of a column
$P_{u,test}$, $P_{u,FEA}$	ultimate strength obtained from tests and finite element model
P_y	yield strength of the section ($Af_{0.2}$)
t	plate thickness
t_1, t_2	plate thickness of the closed part and the open part of the section
t_w, t_f	plate thickness of web and flange
V_1, V_2, V_3	measured imperfection amplitude of different plates in the section
$\bar{x}$,$\bar{y}$	x, y coordinates of the centroid of the flange
x_0, y_0	x, y coordinates of the shear center of the flange
α	ultimate strength in comparison with yield strength (P_u/P_y)
δ	out-of-plane displacement measured by LVDTs
ε_u	material ultimate strain
θ_1, θ_2	rotational angels of the flange
λ	buckling half wave length
λ_{FEA}	buckling half wave length predicted by finite element model
ν	Poisson's ratio
σ_a	average stress of a column
$\sigma_{cr,D}$	distortional buckling stress calculated by the original expressions
$\sigma_{cr,D,FEA}$	distortional buckling stress predicted by finite element model
$\sigma_{cr,D,M1}$, $\sigma_{cr,D,M2}$	distortional buckling stress calculated by the modified expressions
σ_u	ultimate stress of a column
σ_w	local buckling stress of the web

proposed for aluminum alloy circular hollow section columns with transverse welds at the ends of the columns.

At present, several codes are available for designing aluminum alloy members, such as American Aluminum design manual (AA) [6], EN1999-1 [7] and GB50429 [8]. These design codes employ effective section properties to calculate the ultimate strength of an aluminum alloy column and are mainly used to design regular-shaped aluminum alloy columns, such as H section and tube section. The irregular-shaped section has various plates, which makes it too tedious to determine the effective section of an aluminum alloy column. Direct strength method (DSM) [9], which is included in the appendix of AISI [10], uses whole section properties and buckling stress to calculate ultimate strength of a column. Although DSM was originally applied to cold-formed steel members, it could also be used to design aluminum alloy columns [11].

For the widely application of aluminum alloy in buildings, it is necessary to study the buckling behaviors of the columns with irregular-shaped section. Liu et al. [12–14] tested aluminum alloy columns with various complicated sections and carried out numerical parameter analysis, studied the effects of local and global buckling on the irregular-shaped aluminum alloy columns both at ambient temperature and

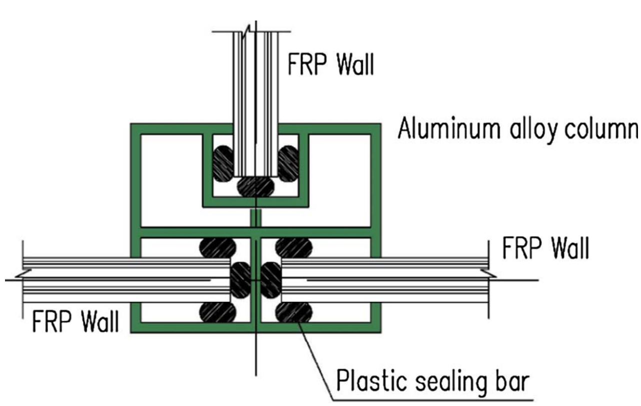

Fig. 1. Connection of the aluminum alloy column.

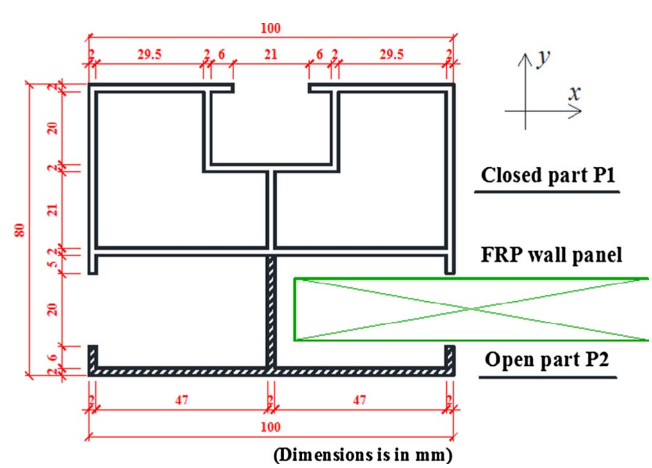

Fig. 2. Dimension of the irregular-shaped section.