Thin-Walled Structures 127 (2018) 62–75

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Numerical Slenderness Approach for design of complex aluminum extrusions subjected to flexural loading

Yongwook Kim[a,*,1,2], Teoman Peköz[b]

[a] Civil and Environmental Engineering Manhattan College 3825 Corlear Ave, Leo Engineering Bldg. 309 Bronx, NY 10463, United States
[b] Civil & Environmental Engineering, Cornell University, Ithaca, NY 14853, USA

ARTICLE INFO

Keywords:
Aluminum
Extrusion
Numerical
Slenderness
Local buckling
Flexural

ABSTRACT

Aluminum structural members can be extruded to various cross-sectional shapes, including additional elements projecting out of flat flanges or webs. The additional elements contribute to flexural strength increase due to local buckling strength increase. In this study, a general design approach is developed for complex extrusions, accounting for the local buckling strength increase. This approach uses numerical buckling analyses, while the overall framework of the existing specification provisions is maintained. The approach is evaluated through parametric studies of seven different kinds of cross-sections, using finite element analysis. The FEA models and the parametric study results are validated through physical tests.

1. Introduction

One of the most attractive aspects of aluminum as a structural material is that it can be extruded. Through extrusion, the cross-section can be a wide range of shapes. For example, extrusion is the best process for producing cross-sectional shapes with multiple lips or grooves to accept thermal breakers in window panels, to grip rubber gaskets of flood walls, or to become screw chases to hold dome panels. Making such cross-sections using hot-rolled steel shapes or cold-formed shapes is almost impossible or not practical due to limitations inherent in the shapes.

A hypothetical extrusion shape shown in Fig. 1b, has additional component elements attached to the flanges of a simple I-shaped wide flange section (Fig. 1a). The additional elements contribute to the increase of bending moment capacity, as the two physical properties of the beam increases; (1) increase of the section modulus; (2) increase of the local buckling stress under bending. The buckling moments of the two sections are computed using CUFSM program [11] and compared in Fig. 2. The vertical axis is the ratio of the buckling moment (M_{cr}) over the yield moment (M_y). The buckling moment (M_{cr}) is defined as the critical local buckling stress times the section modulus; while the yield moment (M_y) is defined as the yield stress times the section modulus. Mathematically, the ratio (M_{cr} /M_y) is simplified into the critical buckling stress divided by the yield stress (F_{cr} /F_y); and physically, the fraction means the degree of difficulty to experience the local buckling regardless of the section modulus.

However, the advantage of the increased member capacity was usually disregarded in the specifications due to the difficulty of considering all possible geometric variations. For example, in order to calculate the compressive nominal stress of the complex extrusion (Fig. 1b) under bending using conventional specification approaches, such as Specification for Aluminum Structures (SAS) [2], flanges and web of the cross-section are considered as independent flat plates with idealized boundary conditions without considering the advantage from the additional elements. In order to consider geometric variations of aluminum extrusions, a new design approach is needed based on numerical buckling analyses. In addition, the conventional approaches in SAS [2], did not fully account for the plastic or hardening behavior of compact aluminum extrusions.

Schafer [14], and Schafer and Peköz [13] incorporated numerical buckling analyses into the specification approaches for cold-formed steel members. The approach is called the Direct Strength Method (DSM), which was later adopted by Zhu and Young [25] for potential application to aluminum structures. However, these studies did not fully account for the plastic capacity beyond the initiation of the material yielding. Shifferaw and Schafer [15] later addressed the inelastic reserve bending capacity of cold-formed steel members in the DSM format. A similar effort to use numerical buckling analysis for the analysis of aluminum columns with complex cross-sections was made by Mennink [12].

* Corresponding author.
E-mail addresses: yongwook.kim@manhattan.edu (Y. Kim), tp26@cornell.edu (T. Peköz).
[1] Formerly Graduate Research Assistant and Postdoctoral Associate at Cornell University.
[2] Full postal address: 3825 Corlear Ave, Leo Engineering Bldg. 309, Manhattan College, Bronx, NY, 10463, USA.

https://doi.org/10.1016/j.tws.2018.01.029
Received 22 August 2017; Received in revised form 21 December 2017; Accepted 21 January 2018
0263-8231/

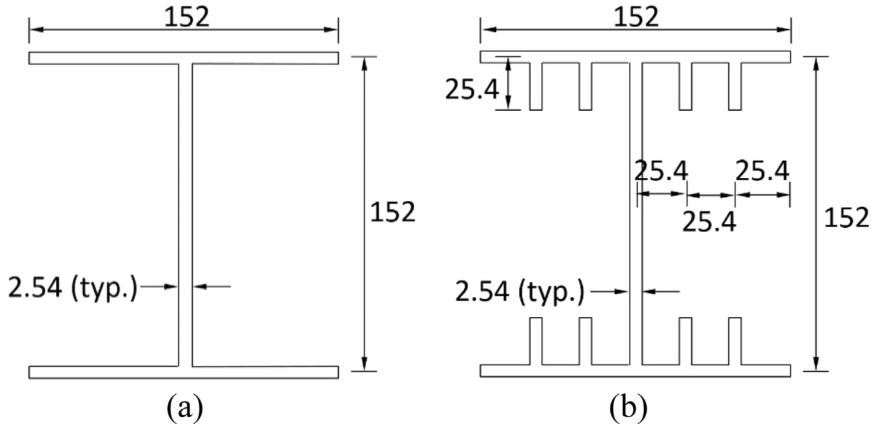

Fig. 1. (a) Simple I-shaped section (b) complex extrusion.

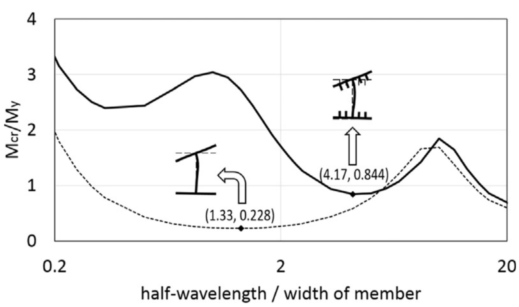

Fig. 2. Buckling analyses by CUFSM program for simple and complex extrusions.

Su, Young and Gardner [17–21] developed the Continuous Strength Method (CSM) to address plastic and hardening behavior of aluminum members beyond the initiation of yielding. In this approach, numerical buckling analysis was adopted to address a gradual change of cross-sectional slenderness amongst different members, instead of traditional classification approaches. The studies are especially beneficial to statically indeterminate continuous structures, where multiple plastic hinges can form. Su, Young and Gardner [22] also performed additional bending tests and numerical parametric studies for square and rectangular hollow sections with intermediate stiffeners for comparison to various international specifications and CSM. More recently, Su, Young and Gardner [23] re-evaluated cross-sectional slenderness limits in European specifications for aluminum columns and beams, based on approximately 900 numerical and test data.

Kim and Peköz [9] suggested a method to incorporate plastic and hardening strength of aluminum alloy flexural members within the framework of SAS [2], but the study mainly focused on doubly symmetric simple extrusion shapes. Wang et al. [24] performed three point bending tests and numerical parametric studies for I-shaped aluminum sections. The study focused more on the effect of the concentrated load, such as web crippling, or the diagonal buckling and tension field action, than the effect of the local buckling stress in the longitudinal direction. Feng et al. [7] performed bending tests for perforated and non-perforated rectangular and square hollow aluminum sections, and compared the results with the approaches of various international specifications.

Although the previous studies include extensive experimental and numerical data, most of them focused on simple extrusions, such as square and rectangular hollow sections, where potential use of the approach to complex extrusions, such as Fig. 1b, was not fully addressed.

Thus, the objective of the present study is to develop a new design approach based on numerical buckling analyses to consider virtually all possible geometric variations of aluminum extrusions, simple and complex extrusions, doubly and singly symmetric sections, considering plastic or hardening strength, while the framework of the conventional specification, SAS [2], is maintained.

The approach is composed of overall two steps:

- Step 1: Compute the nominal stress for each of the two component elements of a section – flanges and web, based on the section's slenderness determined numerically.
- Step 2: Compute the nominal moment capacity of the section combing all the nominal stresses of the component elements determined in Step 1.

As part of Step 1, Section 2 presents a method of how to use numerical buckling analysis results within the framework of the existing specification approaches to evaluate the components' nominal stresses. To account for the plastic capacity and the strain hardening of aluminum alloy flexural members, simplified shape factor expressions are also introduced for sections symmetrical and unsymmetrical about bending axis, of which details are explained in Section 3. The shape factor expressions are incorporated in the equations for Step 1.

For Step 2, four different approaches to computing the nominal moment capacity are explained in Section 4. In Section 5, experiments are presented to verify the Finite Element Analysis (FEA) models and the approaches presented in this study. Based on the two step method presented in this study, numerical parametric studies were conducted, and the results are discussed in Section 6 for seven different kinds of shapes, including simple and complex extrusions. Experimental results by others are also incorporated in this study to further validate the developed approaches.

2. Numerical Slenderness Approach – Methodology to evaluate the nominal stresses of compressive component elements of a flexural member

In SAS [2], the nominal stress for a compressive component element varies according to the equivalent slenderness ratio (λ_p), which falls into one of three ranges, yielding, inelastic buckling, and post buckling ranges, as shown in Fig. 3. The equivalent slenderness ratio is defined in Eq. (1), which can be derived from Eq. (2):

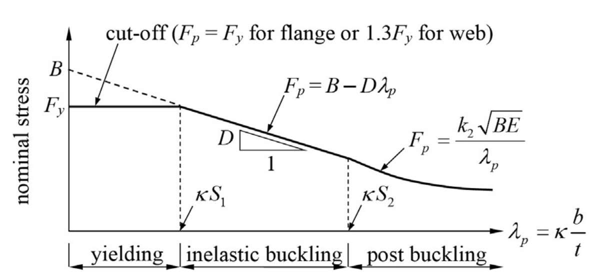

Fig. 3. Nominal stress for a component element in the SAS [2].