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Short communication

Full plastic capacity of equal angle sections under biaxial bending and normal force

A.E. Charalampakis *

National Technical University of Athens, Athens, Greece

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ABSTRACT

Steel angle members are usually designed by elastic methods, which may lead to uneconomical design. In order to make use of the plastic reserves of the section, the knowledge of its exact failure surface is important. In this study, it is shown that idealizing the section with lines of no thickness, which is common in the literature, entails a significant error when the neutral axis intersects a leg at a small angle. A simple interaction formula is proposed, which is shown to be very accurate based on an exhaustive analysis of all common angle sections listed in the tables. Further increase in accuracy is achieved through analytical relations for the cross-sectional properties, both elastic and plastic, that are derived. The proposed analysis forms the base of inelastic design and does not address stability issues.

1. Introduction

Steel angle members are widely used in lightweight structures such as steel trusses. These structures are usually designed by elastic methods, which may be uneconomical, while many design codes are unnecessarily conservative when applied to the bending of angle section beams [1]. In order to take advantage of the plastic reserve of an angle section, or address stability issues, the knowledge of its failure surface is important. This task is not trivial due to the geometry of the section.

2. Analysis based on idealized section

Under the assumption that the leg's thickness is small compared to its length, the angle section is typically idealized by lines without geometrical thickness running along the midline of the actual section, e.g. [1–4]. Further assuming that the section is divided to two regions of constant compressive and tensile stress allows for the derivation of simplified yet useful formulae for the full plastic interaction curve. One such approach was recently presented by Cho and Chan [2] and will be elaborated further.

Analysis is performed for a specific level of normal force controlled by parameter n, which is the ratio of the axial load to the squash load of the section. It is assumed that the neutral axis intersects both legs as shown in Fig. 1, where b is the length of the leg of the idealized section, t its (non-geometrical) thickness and γ_1, γ_2 dimensionless parameters controlling the intersection points.

Based on Fig. 1(a) and following the methodology described in [2], the interaction curve for the case of tension at the heel and compression at the toes is given by:

$$n^2 + m_v + \left(\frac{m_u}{1+n}\right)^2 = 1, \tag{1}$$

where $m_v = M_v/M_{vp}$ and $m_u = M_u/M_{\mathrm{up}}$ are the ratio of the moment to the corresponding plastic moment of the section. For the case of compression at the heel and tension at the toes (Fig. 1(b)), the following relation is derived:

$$n^2 - m_v + \left(\frac{m_u}{1-n}\right)^2 = 1. \tag{2}$$

Eqs. (1) and (2) provide the two parts of the interaction curve, which intersect at $(\pm\sqrt{(1-n^2)^3/(1+n^2)}, 2n(1-n^2)/(1+n^2))$, while the limits are $-1 \le n \le 1$, $-\sqrt{(1-n^2)^3/(1+n^2)} \le m_u \le \sqrt{(1-n^2)^3/(1+n^2)}$ and $-(1-n^2) \le m_v \le 1-n^2$.

To validate the results obtained by Eqs. (1) and (2), a recently presented generic algorithm was employed [5]. The algorithm can be used for the analysis of arbitrary sections under biaxial bending and axial load under the Bernoulli–Euler assumption that plane sections remain plane after deformation. The geometry of the cross-section is described by curvilinear polygons, i.e. closed polygons with edges that are straight lines or circular arcs. Thus, the angle section is described exactly by a nine-node

* Tel.: +30 2107721657; fax: +30 2107721651.
E-mail addresses: achar@mail.ntua.gr, achar@technologismiki.com.

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