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# Buckling resistance of perforated steel angle members

Giuseppe Brando *, Gianfranco De Matteis

*Department of Engineering and Geology, University "G d'Annunzio" of Chieti-Pescara, Italy*

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ABSTRACT

The detrimental effect due to perforations on the buckling resistance of perforated hot-rolled steel L-shaped members in compression is evaluated in the current paper.
FEM numerical models are used in order to carry out buckling and non linear analyses with the aim of detecting both the critical and the collapse load of the studied elements in case of one or more holes.
The obtained results show that, although the critical load is not strongly influenced by the presence of holes, the load bearing capacity, when members are characterized by middle–low slenderness, could be significantly diminished when drillings of common sizes are applied on one of the two section legs, meaning that current methods given by the codes are not fully conservative. As a consequence, specific stability curves are determined and proposed as useful alternative design procedure.

## 1. Introduction

Hot-rolled steel angle elements are commonly used in a wide range of structural applications, such as latticed transmission towers, industrial plants, where they are employed as supporting structures of pipes or elevators, light trussed roofs, storage pallet racks, shelves, etc. Also, they are often used for both lateral and roof braces of industrial buildings.

In the last decades many analytical and experimental researches have been devoted to the performance evaluation of angle members in compression.

Two main aspects have been dealt with [1]: (*i*) the evaluation of the detrimental effect on the member collapse resistance due to the eccentricity of the connections located at the ends [2–6] and (*ii*) the assessment of the growth of the collapse load due to the contribution of the connections which could be characterized by a certain flexural stiffness [7–10].

As results of these research activities, guidelines and recommendations have been provided in order to deal with the stability of such structural members in a more precise way. An example is provided by the ASCE 10–90 [11] document, where it has been recognized that members characterized by slenderness lower than 120 are significantly influenced by eccentric axial loadings, whereas, for higher slenderness values, the rotational stiffness of end connections plays a more relevant role. In the first case, the buckling length factor $k$ to be attributed to the elements should be expressed consistently to the following equations, depending on the fact that the load eccentricity is present only on one (Eq. (1)) or both (Eq. (2)) ends, respectively:

$$\frac{k \cdot l}{r} = 30 + 0.75 \cdot \left(\frac{l}{r}\right) \tag{1}$$

$$\frac{k \cdot l}{r} = 60 + 0.5 \cdot \left(\frac{l}{r}\right) \tag{2}$$

where

$k$ is the buckling length factor;
$l$ is the element length; and
$r$ is the radius of gyration.

On the contrary, for angle members fixed at only one end or at both ends and which are characterized by slenderness ranging from 120 to 225, Eqs. (3) and (4) can be applied, respectively.

$$\frac{k \cdot l}{r} = 28.6 + 0.762 \cdot \left(\frac{l}{r}\right) \tag{3}$$

$$\frac{k \cdot l}{r} = 46.2 + 0.615 \cdot \left(\frac{l}{r}\right). \tag{4}$$

Also other documents provide similar recommendations, such as AISC [12], ECCS [13] and AISI [14], the last being focused on cold formed steel elements.

Although the above issues are well framed in the current scientific literature, there is a large number of topics that are not still dealt with satisfyingly. One example is represented by the evaluation of the

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* Corresponding author at: Department of Engineering and Geology, University "G. d'Annunzio" of Chieti-Pescara, V.le Pindaro 62, 65127, Pescara, Italy. Tel./fax: +39 085 4537213.

*E-mail address:* gbrando@unich.it (G. Brando).

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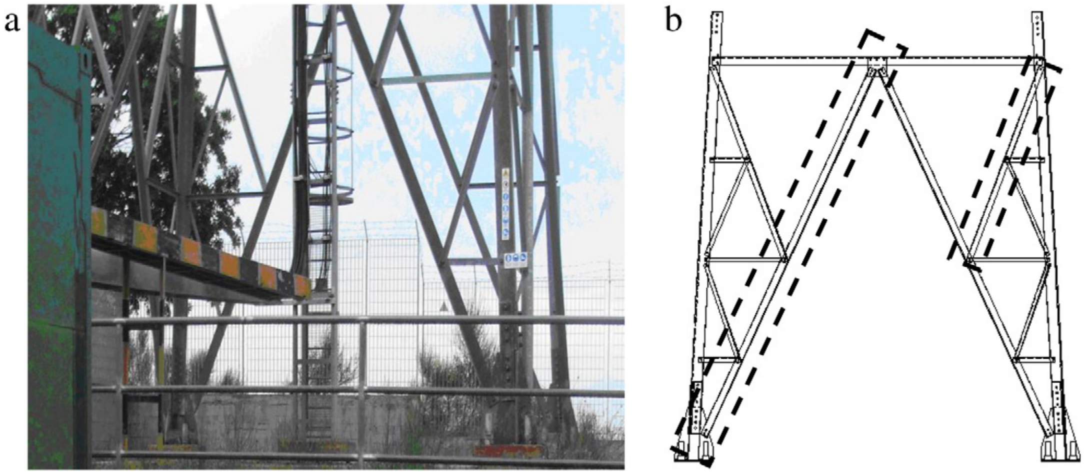

**Fig. 1.** (a) Base shaft of a transmission tower and (b) its graphical representation.

detrimental effect on the collapse resistance due to holes placed along the length of angle elements in compression.

Actually, it has been always assumed that, even though holes should be considered like imperfections, they do not influence significantly the member resistance in compression. This assumption appears to be acceptable only if holes are placed at the ends, or if the slenderness of the perforated member is so high that the effect of imperfections is negligible.

Nevertheless, in a significant number of practical cases, such conditions are not verified. Consequently, it is not possible to neglect the member weakening due to drilling applied along its length, in particular when holes are centrifuged with respect to the weak inertia axis around which buckling could develop. A typical example is provided in Fig. 1a, where the base shaft of a transmission tower is depicted. As evidenced in Fig. 1b, there are some members that are perforated along their length in correspondence of the section that are effectively constrained only in the plane of the drilled leg of the elements, whereas, on the other hand, no significant restrain is provided along the other directions.

Similarly, central parts of certain truss side elements are not restrained in the out of-plane direction. An example is provided by the evidenced element of the Polonceau truss shown in Fig. 2.

In the current paper a numerical study on perforated angle members, carried out in order to detect the effects on the buckling resistance provoked by the holes, is presented. To this purpose, FEM numerical models are used in order to carry out both buckling and non linear analyses, which allow to detect the critical and the collapse loads respectively. On the basis of the obtained results, stability curves are provided. These represent a useful design tool that can be included in current codes and guidelines.

## 2. Numerical analysis

### 2.1. The case studies

Four angle sections have been considered. The geometrical properties are listed in Table 1, where $t$ is the thickness of the two legs, $b$ and $h$ the legs width, $e_x$ and $e_y$ the eccentricities of the medium plane of each leg with respect to the center of area, $A$ is the area, and $I_{max}$ and $I_{min}$ the two values of the second moment of area with respect to the principal central axes.

The adopted cross-sections, considering that a steel grade S235 has been assumed, have been classified according to Eurocode 3 [15]. Although all the sections, apart the L70×70×7, belong to class IV, it should be underlined that their performance is not affected by local buckling mechanism provided that, according to Eurocode 3 part 1.5 [16], the reduction factor for plate buckling $\rho$ (related to the flanges slenderness) is equal to 1. This assumption has been also corroborated by the critical mode shapes retrieved by the buckling analyses that will be described forward in the paper.

For each cross-section, eight lengths of the profiles have been taken into account. As a consequence, thirty-two elements characterized by different slenderness have been considered. Table 2 lists for each of them the considered length ($L$), the relative radius of gyration ($r$), the slenderness ratio ($\lambda = k \cdot L/r$, where a unitary value has been assumed for the buckling length factor $k$), the eulerian critic load ($N_{cr}$), the normalized slenderness ($\tilde{\lambda} = \sqrt{N_y/N_{cr}}$, where $N_y = A \cdot f_y$ is the yielding axial load) and the collapse buckling load according to Eurocode 3.

For each member, both non-perforated and perforated configurations have been considered. For the latter, hole diameters $d_{50} = 21$ mm,

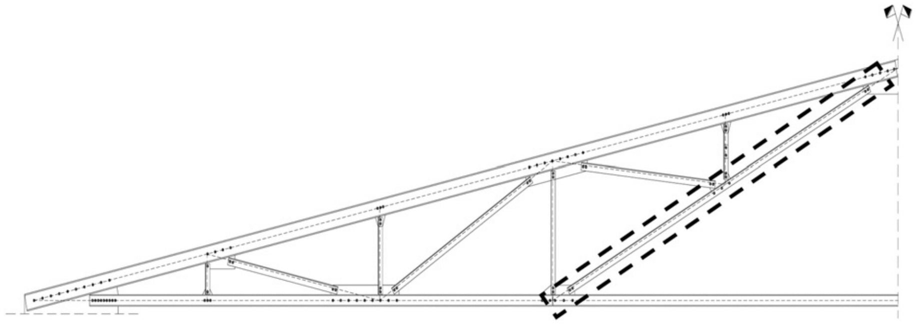

**Fig. 2.** A typical truss in which elements drilled along the span are present.