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Effective length of aluminium T-stub connections by parametric analysis

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ABSTRACT

The paper presents a parametric analysis carried out on welded aluminium T-stubs by means of Finite Element models. The applied models are suitably calibrated on the basis of available experimental tests. The study is carried out on a large variety of specimens with different features and different type of bolts, in order to analyse all possible failure mechanisms. Totally, 43 models are analysed and the obtained results are carefully elaborated in order to check the reliability of the methods presently provided by Eurocode 9. The paper represents a significant extension of the experimental and numerical analyses carried out by the authors in the past, which were especially devoted to analyse the definition of "effective length" for aluminium T-stubs. The obtained results allow to yield interesting outcomes that should be incorporated in future editions of relevant codes dealing with aluminium structures.

1. Introduction

It is well known, that some aluminium alloys exhibit special properties, such as corrosion resistance, versatility, reversibility, reasonable ductility and lightness, especially if compared to other conventional materials like steel. Consequently, they highly attract designers for their employment in building projects [1].

Nevertheless, only few studies have been undertaken in the past for the identification of the behaviour of aluminium connections and joints for structural purposes. This leads to state that the current Eurocode 9 [2] approach on joints design is generally not complete enough for formulating a reliable component method, contrarily to the one already recommended by Eurocode 3 [3] for steel joints, this being based on the outcomes of several researches and specific studies carried out in the last four decades.

The paramount role of T-stub in the component method formulation for defining both strength and stiffness of joints is widely recognised. It is a typical component of bolted joints used to model column flange in bending, end plate in bending and flange cleats in bending, etc.

The so-called T-stub consists of two T-section elements, symmetrically connected to each other in their flanges by one or more series of bolt rows, which undergo flexural deformations due to a pulling force usually transmitted by webs transversally located at the centre of the flanges (see Fig. 1).

The T-stub behaviour is governed by various phenomena, namely the bolts strength and deformability, the flexural stiffness of the flange, the geometrical properties that can entail different yield lines on the connected plates when incipient collapse phenomena involve the whole system, etc.

In the last years, many researches have been devoted to enhance the knowledge on T-stub connections. These have been developed by means of experimental, analytical and numerical analyses. Interesting experimental tests have been provided by Girao Coelho et al. [4], who dealt with extended end plate connections for determining the influence of both material grade and plate thickness. De Matteis et al. [5,6] investigated for the first time the possibility of extending the provision for T-stub given by Eurocode 3 also to aluminium joints. Piluso and Rizzano [7] performed experimental analyses on bolted steel T-stubs under cyclic loads. Moreover, theoretical models have been provided by Lemonis and Gante [8] and Stamatopoulos and Ermopoulos [9], who investigated the influence of the T-stub flexibility. Also, numerical analyses have been developed by Mistakidis et al. [10], who proposed a computationally non-cumbersome 2-D numerical FEM model, by Girão Coelho et al. [11], who dealt with both rolled and welded T-stub models, by Efthymiou [12], De Matteis et al. [13] and Xu et al. [14].

With particular regard to aluminium connections, the current version of Eurocode 9 provides formulations based on the "*k*-method" which has been proposed by the authors. The current paper represents an extension with respect to the previous researches, which were based on the assumption of the same "effective length" for aluminium T-stubs as provided by EC3-Part 1.8 for steel T-stub. Hence, a parametric study implemented on the basis of FEM numerical aluminium T-stub models is provided in order to identify the effects of the most important geometrical and mechanical parameters on failure modes, yield patterns and, therefore, on the

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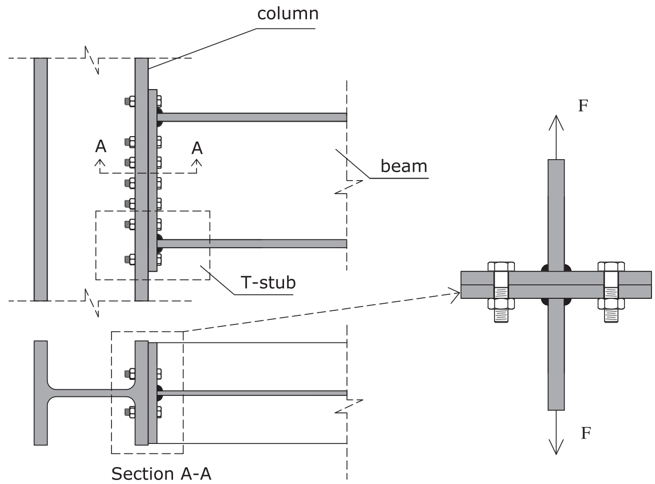

Fig. 1. Idealization and schematization of T-stub.

actual effective length which is able to return the T-stub ultimate strength according to the simplified formulation presently adopted in EC9.

2. Aluminium T-stub failure mechanisms (EC9 *k-method*)

T-stub connections must be designed taking into account all the possible yielding mechanisms and failure modes. For aluminium connections, EC9 (Annex-*k*) proposes the *k*-method for the calculation of ultimate strength of T-stub connections. This method also accounts for strain hardening and reduced ductility of the base material.

Four failure mechanisms are detected, namely "*mode* 1" – complete flange failure, "*mode* 2*a*" – partial flange failure with the attainment of elastic strength in bolts, "*mode* 2*b*" – bolts failure with the attainment of the elastic strength in flanges and "*mode* 3" which consists in the complete bolts failure (see Fig. 2).

The ultimate resistance of the T-stub failure modes 1, 2a, 2b and 3 are given in Eqs. (1)–(4), respectively.

$$F_{u,Rd,1} = \frac{2(M_{u,1})_w + 2(M_{u,1})_b}{m} \tag{1}$$

$$F_{u,Rd,2a} = \frac{2(M_{u,2}) + n\sum B_0}{m+n} \tag{2}$$

$$F_{u,Rd,2b} = \frac{2(M_{0,2}) + n\sum B_u}{m+n} \tag{3}$$

$$F_{u,Rd,3} = \sum B_u \tag{4}$$

The actual collapse load of the T-stub joint is determined from the minimum value of the resisting forces governing the failure modes.

In the above equations, B_u and B_o are the ultimate and conventional elastic tensile strength of bolts, respectively. $(M_{u,1})_w$ and $(M_{u,1})_b$ are the plastic moments of the critical flange cross sections, located close to the T-stub web and bolt rows, respectively, when a failure "*mode* 1" arises (Eqs. (5) and (6)). $M_{u,2}$ (Eq. (7)) is the plastic moment of the flange when the failure type is "*mode* 2". $M_{0,2}$ (Eq. (8)) is the elastic moment at 0.2% proof strength.

$$(M_{u,1})_w = 0.25 \times t_f^2 \cdot \Sigma\ell_{eff,u,1} \times f_{0,haz} \times \frac{1}{k} \tag{5}$$

$$(M_{u,1})_b = 0.25 \times t_f^2 \cdot \Sigma\ell_{eff,u,1} \times f_u \times \frac{1}{k} \tag{6}$$

$$M_{u,2} = 0.25 \times t_f^2 \cdot \Sigma\ell_{eff,u,2} \times f_u \times \frac{1}{k} \tag{7}$$

$$M_{0.2} = 0.25 \cdot t_f^2 \times \ell_{eff,u,2} \times f_{0.2} \times \frac{1}{k} \tag{8}$$

In Eqs. (5)–(8), $\ell_{eff,u,1}$ and $\ell_{eff,u,2}$ are the flange section effective lengths, defined according to the failure mode and the yield line developing (circular or non-circular pattern), $f_{0.2}$ and f_u are the conventional yield and ultimate stress, respectively of the base material, $f_{0,haz}$ is the ultimate strength of the heat affected zone, t_f is the flange thickness, m is the distance of the weld seams from the centre of bolts, n is the minimum between $1.25m$ and the distance e of bolts from the flange edges (see Fig. 2).

The k factor is defined as:

$$\frac{1}{k} = \frac{f_{0.2}}{f_u} \cdot \left(1 + \psi \cdot \frac{f_u - f_{0.2}}{f_{0.2}}\right) \tag{9}$$

where

$$\psi = \frac{\varepsilon_u - 1.5 \cdot \varepsilon_{0.2}}{1.5 \cdot (\varepsilon_u - \varepsilon_{0.2})} \tag{10}$$

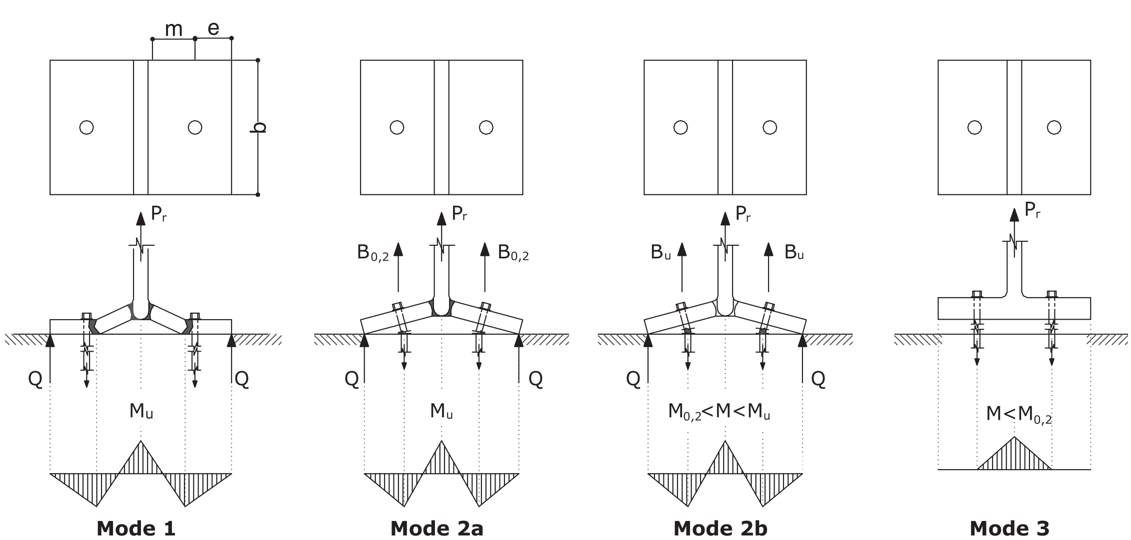

Fig. 2. Failure modes of aluminium T-stubs prescribed by EC9.