Engineering Structures 81 (2014) 181–194

Contents lists available at ScienceDirect

Engineering Structures

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

Influence of the flexural rigidity of the bolt on the behavior of the T-stub steel connection

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ARTICLE INFO

Article history:
Received 28 January 2014
Revised 22 September 2014
Accepted 23 September 2014

Keywords:
Bolt bending
Finite element model
Interaction *M/N*
Steel connections
T-stub connection

ABSTRACT

T-stubs are generally used to represent the tension zone of bolted moment resisting connections. The bolts are considered at present as components loaded only in tension. This paper investigates the influence of the bolt bending on the behavior of the T-stubs. A 3D finite element model was first developed and validated by comparison with experimental results found in the literature. The numerical model was then used to analyse the behavior of various T-stubs regarding mainly the values of the axial tensile forces and the bending moments in the bolts. The results show the influence of the bolt bending moment on the failure mode of some T-stubs. The numerical model was also used to evaluate the accuracy of the analytical interaction formula determining the resistance of isolated bolts subjected to bending moment and axial tensile force. Finally, an analytical model is proposed to evaluate the bending moments and the axial tensile forces in the bolts considered as T-stub components. The comparisons with the numerical model results show that the analytical model represents well the behavior of T-stubs considering the bending moments in the bolts.

1. Introduction

The tension zone of bolted connections, such as beam-to-column, is modeled according to the Eurocode 3 (EC3) recommendations [1] using T-stubs components (Fig. 1). These T-stubs exhibits a complex mechanical behavior due mainly to the evolution of the contact zones between the components. To analyze this behavior, it is necessary to consider the plate thickness, the bolts positions, the bolt preloads, the mechanical properties of the bolts and plates and the evolution of the contact zones between the components [2–4].

The resistance of the T-stubs is mainly controlled by the flange's bending resistance and the tensile strength of the bolts. However, it had been reported in early research that the bolts were strongly bent at failure [5–8]. Later on, Swanson et al. [9] carried out several tests and finite element analyses on individual T-stubs to show that the behavior of the T-stubs was partly influenced by the bending of the bolts. On the basis of the available data, Mimoune and Mimoune [10] suggested that the bending of the bolts should be taken into account in the design of the T-stubs. Girão Coelho et al. [11,12] reported that nineteen bolted T-stubs connections, out of the thirty-two tested, failed by combined bending and tension bolt fracture. They observed that the bending of the bolts was present from the beginning of loading and that in the T-stub connection the bolt behaved in tension and bending due to the deformation of the T-stub flanges. Fig. 2 shows the deformed shape of the T-stub and the related bending of a bolt. The bending of the bolts had also been reported by Abidelah [13] in a 3D finite element analysis of the T-stubs behavior.

This has led several authors to include the bending of the bolt in their analysis of the T-stub behavior. Minas and Charlis [14] developed an analytical model to predict the complete load–displacement curve of T-stub connections. The ultimate strength of the bolt was estimated by taking into account its deformation in tension and bending. Stamatopoulos and Ermopoulos [15] were the first to propose a design procedure to determine the ultimate capacity of a T-stub that took into account the effect of the bolts' bending. However, the effects of the prying forces were neglected in the analysis. The influence of bending on the bolts' strength was determined by considering the interaction between the bending moment (M_b) and the axial tensile force (F_b). They concluded that, due to the flexibility of the T-stub flange, the bending moment in the bolts influenced the strength of the T-stub. Herrera et al. [16] studied the behavior of built-up T-stubs subjected to tensile loading by using numerical and experimental models. Their

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http://dx.doi.org/10.1016/j.engstruct.2014.09.041
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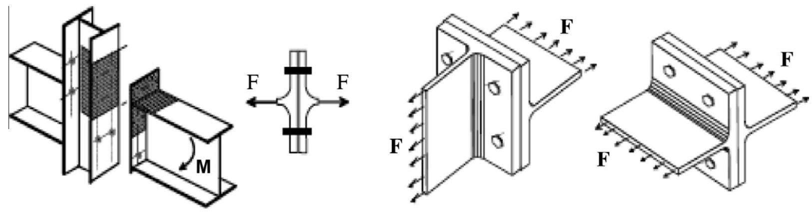
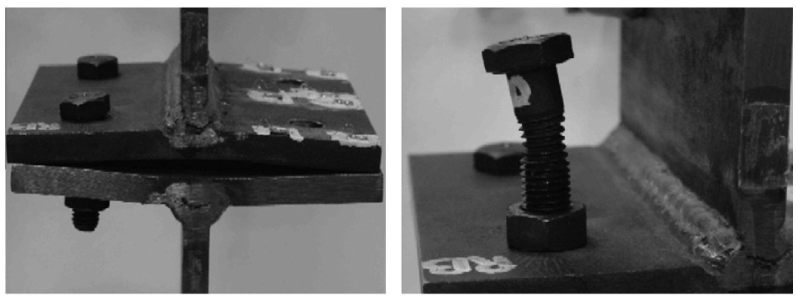


(a) (b)

Fig. 1. Beam–column connection (a) and definition of the T-stub (b).



(A) (B)

Fig. 2. Deformed shape of a T-stub at failure (A) and detail of an unbroken bolt after failure of T-stub (B) [8].

numerical model was able to reproduce the bending of the bolts due to the prying effect in the T-stub flange.

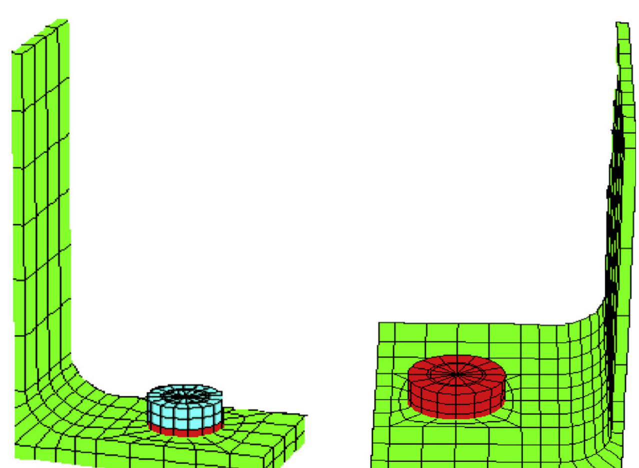
In this paper, a nonlinear 3D finite element model validated on existing experimental results has been developed to predict the real behavior of the T-stubs. The analyses have been performed for T-stubs without bolts preloads covering the common configurations in steel structures and considering the most severe configuration for bolts. The model is used to evaluate the evolution of the bending moment (M_b) and the axial force (F_b) in the bolt depending on the T-stub loading. In parallel, the interaction curves of isolated bolts, representing their resistance under combination of moment and axial force, are defined analytically and validated numerically. A parametric study has been performed to evaluate the influence of the bolt bending moment on the behavior of the T-stub by varying the flange thickness and the bolt diameter. Then, an analytical model that takes into account the bending of the bolt, in addition to the axial force, has been proposed to predict the strength and the stiffness of the T-stubs. It has been validated by comparing its results with those given by the FE model.

2. Numerical modeling

2.1. Description of the numerical model

A three dimensional finite element model was developed using Cast3m [17] to predict the behavior of bolted T-stub connections and to quantify the axial forces and the bending moments in the bolts throughout the history of loading. Solid finite elements with twenty nodes (CU20) were used to model one eighth of the whole T-stub and the attached bolts by considering three planes of symmetry (Figs. 3 and 4). This solid finite element that has been selected after testing different types of elements and mesh densities has been found to give a good compromise between the size of the elements and the stability of the numerical solution adopted [13]. The model took into account the two sources of non-linearity which are the plastic behavior of material and the evolution of the contact area between the two flanges (the bottom one being considered as a rigid surface) and between the flanges and the bolts.

However, although the ZX and ZY planes were geometrical planes of symmetry, the XY plane did not meet such a criterion since the bolt elongation is not symmetrical along the Z direction. Some authors [18,19] proposed to use an "equivalent bolt" that complies with the requirements for symmetry in the XY plane. It had the same geometrical stiffness as that of the actual bolt by considering that its elongation was equal to half of the actual bolt elongation [20]. In order to simplify the model, the diameter of the bolt shank had been taken equal to the bolt nominal diameter value and the washer diameter equal to that of the bolt head. The boundary conditions were taken into account by fixing the nodes in the ZX and ZY planes. Contact phenomena exist in the plane XY between the flange surface and the washers (under the bolt



(a) Tb_M12 (b) Tg_M16

Fig. 3. One eighth of the whole T-stub.