

A numerical-informational approach for characterising the ductile behaviour of the T-stub component. Part 1: Refined finite element model and test validation



J. Fernandez-Ceniceros^{a,*}, A. Sanz-Garcia^b, F. Antoñanzas-Torres^a, F.J. Martinez-de-Pison^a

^a EDMANS Research Group, Department of Mechanical Engineering, Universidad de La Rioja, C/Luis de Ulloa 20, Logroño 26004, Spain¹

^b Division of Biosciences, University of Helsinki, Viikinkaari 5 E (P.O. Box 56), 00014 Helsinki, Finland

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ABSTRACT

In the component-based method, the ductility characterisation of the tension component plays a primary role in accurately predicting the rotation capacity of the whole connection. In this paper, a refined finite element (FE) model is presented to assess the complete force–displacement response of the T-stub component, from the initial stiffness up to the fracture point. The refined FE model includes a non-linear continuum damage mechanics model that considers the onset of the damage, the damage evolution law, and the component failure. A parametric study was conducted to evaluate the influence of the damage parameters in the overall response of the T-stub component. The numerical results obtained from the refined FE model strongly agree with the experimental results of 18 test specimens. The comparison reveals the proposed FE model's satisfactory accuracy, with an average fitting error below 9%. This paper constitutes the first part of a comprehensive methodology based on combining FE analysis and soft computing techniques. The ultimate goal of this methodology is to predict the key parameters that define the force–displacement response of the T-stub component.

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1. Introduction

Bolted connections exhibit a highly non-linear behaviour due to their component's interactions, stress concentrations, slippages, large deformations and the non-linear properties of materials. Traditionally, steel connections were considered to be rigid or pinned, regardless of their actual behaviour. This assumption grossly over-simplified the calculation process at the expense of non-optimised designs and higher costs. However, after the introduction of the 'semi-rigid concept', many researchers focused their efforts on accurately predicting parameters such as the initial stiffness, maximum resistance, and rotation capacity in order to approximate the actual moment–rotation response of the connection. To this end, different approaches have been applied to this problem during the last four decades: experimental, empirical, analytical, numerical and mechanical models [1].

Numerous experimental programs have been carried out to study the complex behaviour of beam-to-column bolted

connections for several decades [2–7]. Despite the fact that laboratory tests represent one of the most realistic means of reproducing the behaviour of the structure, the high costs involved in these tests render them impractical during an extensive program. However, the availability of a reduced number of experimental tests is an essential requirement to validate other kinds of models such as empirical, analytical, numerical or mechanical ones.

Empirical models are capable of closely fitting the connection response to the tests, by calibrating several parameters. Their main drawbacks are, on the one hand, the limited range of application to the joint configurations used for setting up the formulation and, on the other hand, the lack of physical meaning in their parameters, which are exclusively derived from regression analysis [8].

A wide variety of analytical models have also been introduced to model the complex behaviour of bolted connections. These models provide the assessment of the moment–rotation curve based on a classical formulation of structural analysis. Even though the simplifications assumed by analytical formulae may lead to some discrepancies with experimental results, these models are easily applicable and suitable for hand-calculation. In addition, they present physical meaning in their parameters, which are directly derived from geometric and mechanical properties.

Regarding numerical models, the FE method constitutes a powerful tool to simulate the real behaviour of bolted connections,

* Corresponding author. Address: Civil and Mechanical Department, University of La Rioja, Departamental building, Luis de Ulloa, 20, 26004 Logroño, Spain. Tel.: +34 941 299 274, mobile: +34 690 205 105.

E-mail address: julio.fernandezc@unirioja.es (J. Fernandez-Ceniceros).

¹ <http://www.mineriadatos.com>.

taking into consideration geometrical and mechanical non-linearities. Thanks to the latest advances in the computational field, the modelling process has evolved from simple two-dimensional (2D) models to more complex and detailed three-dimensional (3D) ones. Moreover, these numerical models are able to deal with many different issues such as contact algorithms, large strains, plasticity models or damage mechanics. Nowadays, despite the computational advances not only in software but also in hardware, the use of FE simulations is still a time-consuming procedure. Thus, the FE method continues to be a support tool for validating theoretical models or estimating internal variables that cannot be measured in experiments (e.g., stress and strain fields, contact and prying forces, etc.).

Finally, mechanical or spring models represent a step forward in the development of both analytical and empirical models. The principle basis of these models consists of dividing the whole connection into individual and simpler components, each one characterised by their force–displacement response in terms of stiffness and maximum strength. The moment–rotation relationship of the complete bolted connection is determined by assembling all the individual responses of its components in a spring system. A particular example of this mechanical approach is the so-called component-based method, which in fact has been adopted as a calculation procedure by well-known regulatory codes such as Eurocode 3 [9].

All the above-mentioned methods exhibit advantages and disadvantages in relation to their accuracy, generalisation capacity, range of application or calculation time. Considering these parameters, the component-based method appears nowadays to be a balanced solution for the assessment of bolted connections. However, this method still requires a more detailed characterisation of their components that accounts for material plasticity, contacts or progressive damage in order to obtain an accurate non-linear response of the connection, including its rotation capacity. This present research introduces a hybrid numerical-informational methodology based on combining FE simulations and soft computing techniques. The approach aims to properly describe the constitutive law of the basic components in bolted beam-to-column connections. The particular case under study herein focuses on the behaviour of the T-stub component because of its utmost importance within the overall response of the whole connection. The geometry of the T-stub (Fig. 1b) represents an ideal component which can be identified in several zones of an end-plate beam-to-column connection (Fig. 1a). The paper deals exclusively with the assessment of the force–displacement curve of the ideal T-stub component.

1.1. The T-stub model

The T-stub model was initially introduced by Zoetemeijer in 1974 [10] to represent the tension zone in bolted beam-to-column connections. This type of connection is considered the primary source of deformability and, because of this, the rotation capacity of the whole connection is strongly influenced by this component. The study of the T-stub model has traditionally been conducted through the isolated component, herein referred to as *equivalent T-stub*. This model comprises two t-shape profiles tied by their flanges by one or more bolt rows (Fig. 1) [11]. In this context, Bursi and Jaspart [12,13] made significant advances in understanding the isolated T-stub behaviour by creating a 3D FE model, validated through a well-known experimental program. This experimental program consists of preloaded and non-preloaded specimens T1 and T2, widely used in the reviewed literature because of the in-depth information available regarding their geometry and the mechanical properties of constitutive materials. Other notable research in the numerical modelling of the T-stub connections has been performed by Mistakidis et al. [14], Sherbourne and Bahaari [15], and more recently Girão et al. [16,17] who offered insight into the failure modes and the ductility characterisation of the welded T-stub connections.

Analytical models have also been developed to assess the initial stiffness and the strength of the equivalent T-stub [10,18–20]. The works conducted by Piluso et al. [21,22], Swanson and Leon [23], Girão et al. [17], and Lemonis and Gantes [24] should also be noted. All of these studies offer sophisticated analytical models able to predict the force–displacement response by means of piecewise linear functions. Some of them take into account material non-linearities, distributed loads at the bolt location, bending of bolts, contact phenomena or shear deformations. However, the more advanced models require iterative procedures to accomplish the connection response. Therefore, they are not actually suitable for hand calculation.

Even though remarkable advances have been achieved in the accurate characterisation of the equivalent T-stub, several questions still remain unsolved. In order to enhance the performance of the calculation process, efforts should focus on the following limitations:

- The behaviour of the equivalent T-stub is inherently 3D and this should be taken into account. This 3D effect becomes significant in wide T-stubs, where the deformation of the flange along the bolt line is non-uniform.

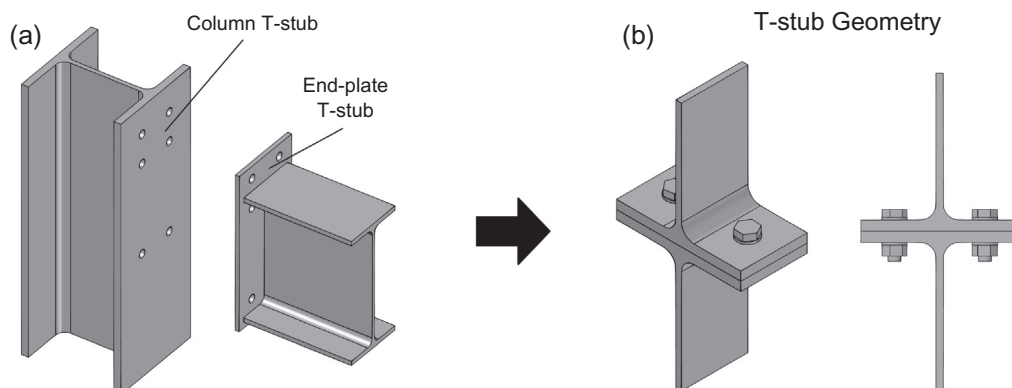


Fig. 1. Characterisation of the bolted T-stub component. (a) End-plate beam-to-column connection, and (b) T-stub geometry.

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