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Characterization of web panel components in double-extended bolted end-plate steel joints

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ABSTRACT

The prediction of the behaviour of joints relies on experimental and numerical tests that provide accurate information for the characterization of the various joint components. This paper presents the calibration and validation of a parametric FE model of a beam-to-column double extended end-plate steel joint, using test results, and characterizes the web panel components using the validated FE models. The model implemented in the ABAQUS FE package which takes into account the non-linear geometrical and material behaviour, non-linear contact and slip. The calibration/validation of the model is based on results from an experimental research programme on three double-extended end-plate partial-strength beam-to-column joints. The behaviour of the joints is characterized both globally and in terms of the critical components. The experimental and numerical results are compared, revealing good agreement, allowing their further use in the more detailed components assessment. Thus, based on the validated stress and deformation fields of FE results, a procedure is proposed to extract the force-deformation behaviour of the column web components. The results are compared with those obtained from Eurocode 3 and from the literature.

1. Introduction

Predicting the behaviour of beam-to-column steel joints remains an important task, as properly detailed steel joints are crucial to achieve safety and economy of a structure. Double extended end-plate beam-to-column connections have the potential to offer a solution with moderate to low costs, particularly for cases that do not require full strength/rigid joints. Given that the behaviour of bolted joints is generally much more complex than the connected elements and influence the overall structural response, simple and reliable models are essential that can be incorporated in advanced analyses of the structures.

Eurocode 3 part 1–8 (EC3-1-8) [1] establishes unified procedures concerning the modelling of steel joints as the assembly of basic components. The underlying component method (CM) uses a suitable assemblage of non-linear springs and rigid links to determine the resistance, stiffness and rotation capacity of steel joints.

The mechanical characteristics of the components are obtained from experimental tests using specimens similar to the component to be characterized, e.g. T-stub, or using complete full-scale connections. While in the first case acceptable experimental parametric and statistical characterization is possible, in the second case the required number of specimens to have acceptable statistical significance is prohibitively expensive. Therefore, numerical simulations are an effective way to overcome this difficulty, given that the developed FE models reliably reproduce the behaviour of the real joints [2].

This paper aims to contribute to the mechanical characterization of components in double-extended beam-to-column joints using a detailed parametric numerical model developed in ABAQUS [3] and taking advantage of the Python programing language to develop a scripting interface for ABAQUS. The model applies to end-plate beam-to-column joints and considers a three dimensional detailed representation of the various connection components taking into account the several phenomena involved in the connection behaviour, namely the nonlinearities related to the geometry, contact, slip and material properties. Since further developments of the study will also deal with cyclic loading, a combined isotropic and kinematic material-hardening model is also included in order to characterize the joint behaviour under load reversal.

The calibration of the numerical model is based on the results of an experimental research programme and it is comprehensively described in this paper.

In the following sections, the monotonic behaviour of the joints is characterized, both globally and also in terms of the critical components, comparing the results of the experimental, numerical and analytical models. Using the validated FE models a detailed procedure is described to isolate column web components, namely the column

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web panel in shear and the column web in transverse compression or tension, and to identify their mechanical behaviour analysing the stress and deformation fields in the FE models. The results are compared with those of EC3-1-8 [1] and with other models available in the literature.

2. Literature review

2.1. Introduction

Beam-to-column joints modelling must deal with a variety of phenomena, mainly in bolted connections that make the prediction of its mechanical behaviour a complex task [4]. As summarized by Faella et al. [5], the methods for predicting the joint behaviour can be divided in five different categories: empirical models, analytical models, mechanical models, finite element models and physical models (experimental testing).

Mechanical models have gained wide acceptance because they achieve a good balance between accuracy (accounting for resistance, deformability and ductility) and ease of use. Joints are decomposed in several parts, called components, that represent a specific part of a joint that, depending on the type of loading, make an identified contribution to one or more of its structural properties [6]. The constitutive relations of the components and the way they are assembled determine the joint behaviour. The relation between the components and the joint's mechanical properties is determined through equilibrium and compatibility relations. In the framework of EC3-1-8 [1], the implementation of the component method allows for the determination of the resistance, stiffness and rotation capacity of a variety of steel joint configurations.

Finite element models provide the most sophisticated and realistic representation of joint behaviour but their use in design is very time consuming and cumbersome, presents convergence and calibration difficulties and is prohibitively expensive if combined with physical models [7].

This section presents a brief state of the art on bolted end-plate beam-to-column joint modelling and behaviour focussed on the use of mechanical models and finite element models.

2.2. Characterization of the column web panel components

A bolted beam-to-column steel joint may be divided in two main parts [8]: column web panel and connection(s) (left and/or right beams). In many situations, the column web panel controls the behaviour of the joint. Especially under cyclic loading conditions, the column web panel provides large energy dissipation. In this paper, special attention is paid to deriving the components associated with the column web in double extended bolted end-plate joints.

Fig. 1 illustrates the contributions to the deformation of the column web panel resulting from the combined effect of tensile and compressive forces generated by the bending moment in the beam. The load-introduction and shear effects are identified in Fig. 1; they require appropriate characterization of the components behaviour which are associated to the column web in tension, column web in compression and the column web in shear. Annex A summarizes the related design models, figures, equations and notations.

The characterization of the column web panel was the subject of relevant research work conducted by Krawinkler and his co-workers [9] who studied the column web behaviour, mainly subjected to shear, using experimental tests on welded joints stiffened with continuity plates. They concluded about the significant post-yielding resistance, due to the strain hardening and the bending contribution of the boundary elements composed by the column flanges and the transverse stiffeners, and proposed a trilinear model for the shear force versus distortion of the panel zone. The relevant features of the model are illustrated in Fig. A.2 and the

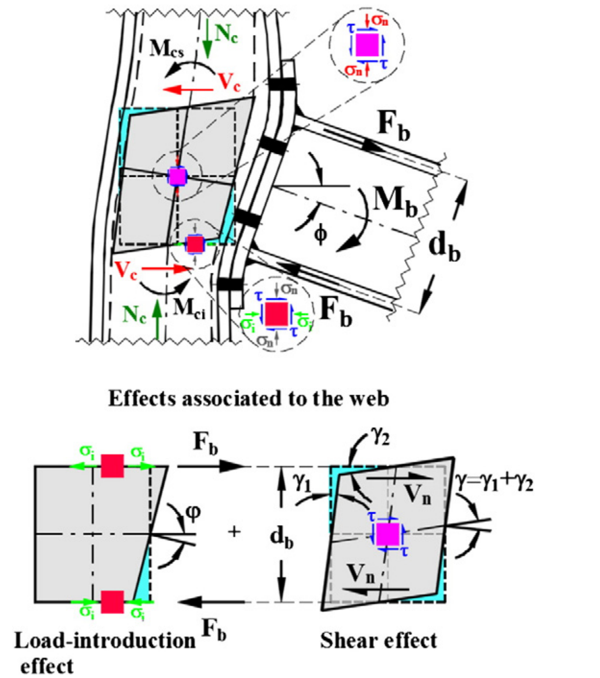

Fig. 1. Behaviour of the unstiffened column web panel in an external node end-plate connections.

formulation is summarized in Table A.2, using the notation adopted by Faella et al. [5].

Following Zoetemeijer's work [10] on the definition of the relevant stress interactions when the load-introduction effect due to the beam forces is considered, a research programme was conducted at the University of Innsbruck to separately characterize the components due to shear and load-introduction effects in the column web panel using experimental tests on welded joints. The insights gained in the characterization of the web panel behaviour were exploited by Jaspart [8,11] to develop multi-linear analytical models (AJM) for the two identified deformation modes in the web panel, namely the load-introduction, due to the beam moment binary forces, and the distortion due to the pure shear installed in the panel. The induced forces in the web panel produce a complex stress state with three stress components, as depicted in Fig. 1: τ is the shear stress associated with the shear forces on the contour of the column web panel; σ_i is the horizontal normal stress associated with the load-introduction and σ_n is vertical normal stress due to the axial load and bending of the column. The analytical model determines the strength of the column web panel by analysing its stress state. In the application of the Von Mises yield criterion, some simplifications were proposed by Zoetemeijer [10] and Jaspart [11] for the stress interactions: (i) due to the localized effect of the σ_i stresses in the assessment of the shear resistance only the τ–σ_n interaction needs to be considered; and (ii) for the assessment of the load-introduction resistance only the τ–σ_i interaction needs to be considered, because σ_n has a low influence on the load-introduction resistance for axial load in the column lower than $0.7N_{pl,Rd}$.

Subsequently, analytical models were developed for welded joints [11] and further adjusted for bolted joints in the case of the load-introduction, summarized in Annex A, Fig. A.3, Tables A.3 and A.4. In the extrapolation from welded joints to bolted end-plate joints there are relevant differences that must be taken into account [11]. For the load-introduction effect, based on a beam on elastic foundation model, the deformation in welded joints is similar in the tension and compression zones. However, for bolted end-plate joints, because of the different ways of applying the tension and compression loads by the beam (see Fig. 1) the corresponding F_b–Δ