ADVANCED MODELLING OF END PLATE JOINTS

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INTRODUCTION

End-plate joints are due to their simplicity and cost one of the most common connections in steel structures. End-plate joints are usually designed using the analytical component method. This method allows relatively precise design of joints with usual geometry. The designed joint must contain only known components which are described in the design codes or literature. Another limitation of the component method can be faced when the joint is loaded by combinations of internal forces, as some combinations (for example combination of strong and weak axis bending moments or combination with the axial force) are not supported. Silva (2008) [1] tries to solve this problem by creating a matrix that takes into account the influence of a combination of internal forces. However, this issue is very wide and its solution is just at the beginning. The component method allows fairly accurate calculation of bending moment capacity and rotational stiffness.

On the other hand, numerical finite element method can be used for the design of joints. However, this method is nowadays usually used for research purposes but it is applied for the design of joints only in some special cases. There are many reasons. Application of this method is time-consuming. Introduction of non-linearity of the bolts, welds or web stiffeners exhibiting stability problems bring difficulties. Prediction of failure of individual parts of the joint is also unclear because of stress peaks. Despite these problems, many numerical models have already been created in the past. These models were usually used for parametric studies and were based on the results of experiments. Results of these studies are very useful, however these studies did not consider the possibility of using finite element method for everyday design of joints to make it available as an alternative approach to the design of joints which can not be designed using the component method.

This paper examines numerical models of T-stub as first step to create the whole model of end plate joint.

1 STATE OF THE ART

1.1 Bolts

Many approaches that use different element types were applied for numerical models of the bolts in the past. Krishnamurthy and Graddy (1976) [2] created 2-D models and used shell elements for bolts. 3-D models started to be used when powerful computers were available. In these models, spring elements were used by Bahaari and Sherbourne (1996) [3] and beam elements by Bursi and Jaspart (1998) [4].

Later, solid elements were applied to models of bolts. However, some simplifications were necessary in numerical models because of the time and computational limits. Kukretti and Zhou (2006) [5] created a numerical model of the bolts, which neglects the washers and considered a constant nominal diameter of the bolt shank along the entire length. Chen and Du (2007) [6] neglected washers in their model too and considered a constant effective diameter of the shanks along the entire length. Wheeler et al. (2000) [7] developed a model that considers the nominal diameter in the shank and effective diameter in the threaded part. Washers are usually introduced as increase of the height of the bolt head and nut. The length of the shank or the thread corresponds to total thickness of steel plates in all three above mentioned models. Gantes et al. (2003) [8] considered the effective length of the shaft according to Agerskov's model (1976) [9]. This model takes into account the deformation of the nut and the thread. Washers in this model are considered by increasing the height of the bolt head and the nut.

Wu et al. (2012) [10] tried to create the most accurate model of the bolt, in which the separate washers and the thread are modeled. This model can not be used in the T-stub or the whole joint model due to its complexity. The results were compared with the results of the four above-mentioned simplified models. Based on this comparison, a new simplified model based on the model by Wheeler et al. (2000) [7] was created. The washers were introduced as increased height of the bolt head and the nut but were separated from the bolt shank in this model. This modification takes into account the correct length of the bolt shank and the model exhibits more precise behavior.

1.2 End plate

A lot of numerical models of end plate joints were created in the past. Krishnamurthy (1976) [2] performed one of the first studies. He created a 3-D numerical model of solid elements. His analysis assumed elastic material behavior only and preloaded bolts. A simplified 2-D shell model was calibrated on the basis of the 3-D model. The 2-D model was used for a further parametric study. Kukreti et al. (1987) [11] performed a similar process for obtaining the moment-rotation relationship of end-plate joints. Bursi and Jaspart (1998) [4] noted that the 2-D numerical models show higher stiffness compared to 3-D models because the 3-D stress pattern is neglected.

3-D models began more frequent with the development of computer technologies. Kukreti et al. (1989) [12] created a 3-D numerical model of reinforced T-stubs. Solid elements were used for the flanges and bolts, while shell elements were used for web and stiffeners. Studies of the influence of element size and various plasticity criteria were also conducted. Several authors created 3-D numerical models based on shell and beam elements.

Link elements according to Chasten et al. (1992) [13] or contact elements according to Sherbourne and Bahaari (1994) [14] can be used to ensure contact between the column flange and the endplate. These models show good agreement with experimental results. However, the accuracy of shell models decreases with increasing thickness and thus the stiffness of the endplate. This is due to the fact that the shell elements neglect shear stress which can lead to overestimation of bending moment capacity and prying forces in case of thick end plates, see Krishnamurthy (1996) [7]. However, some inaccuracies can be observed in models of solid elements also. According to Wheeler et al. (2000) [7], these inaccuracies in solid element models are caused by inaccurate determination of bearing capacity of bolt elements under combined tension and bending. Bursi and Jaspart (1998) [4] created 3-D numerical models using solid elements.

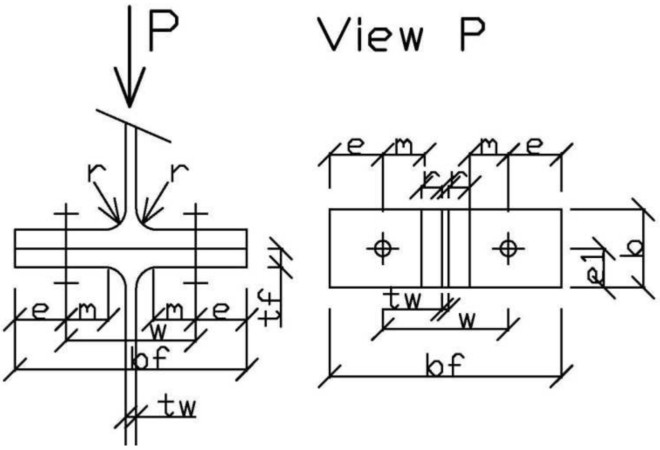
Jetteur and Cescotto [16] studied the effect of the number of elements across the thickness of the end plate. They found that a model with only one element layer gives incorrect results. A model with two element layers gives good results only in the elastic region. Models with three or more element layers provide good results even in areas of large deformations.

2 EXPERIMENTS

A T-stub model is commonly used to predict the behaviour of the endplate. Two samples of T-stubs connected by a pair of M24 8.8 bolts were designed and experimentally tested to investigate the behaviour of the end-plate. T-stubs were made from hot-rolled HEB-sections from which one flange was removed. Dimensions of the specimens are given in Table 1.

Table 1. Dimensions of specimens

Sample	T-stub										Bolts
	Section	t_f	t_w	b_f	R	b	w	e_1	m	e	
		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	
1	HEB 300	17,8	10,6	300	27	98,8	164	49,4	55,1	68	M24 8.8
2	HEB 400	23,1	13,6	300	27	99,6	169	49,8	56,1	65,5	M24 8.8



3 NUMERICAL MODELING

3.1 Model of the bolt

The numerical model is created in Midas FEA software. A solid numerical model of the bolt was created first and a beam model was created based on the results of the solid model. A Beam model is much easier to create and less time consuming.

The solid numerical model is based on the model by Wu et al. (2012) [10]. The nominal diameter is considered in the shank and the effective core diameter is considered in the threaded part. Washers are modeled separately. Contact elements allowing the transmission of pressure and friction are used between the bolt and the washer. The solid model is shown in Figure 1a.

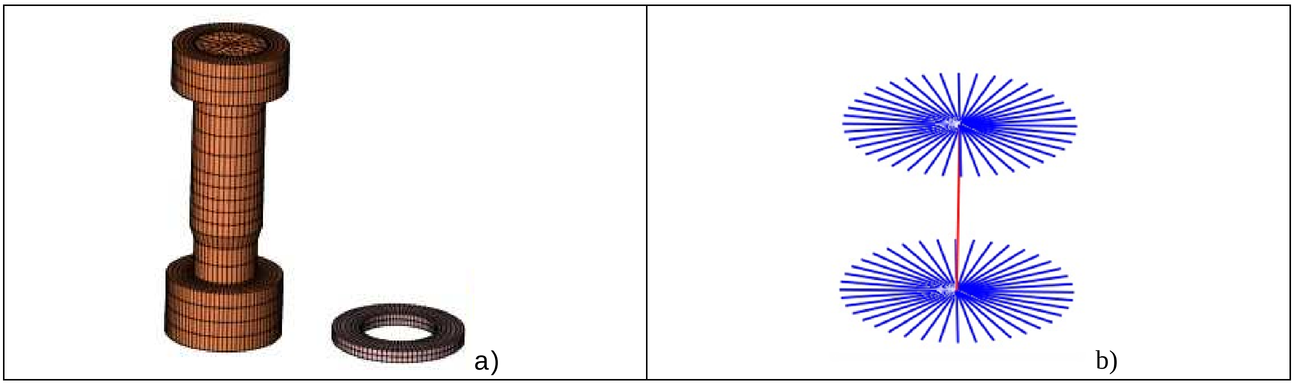

a)
b)

Fig. 1. a) Solid model of the bolt b) Beam model of the bolt

The solid numerical model is primarily used for parametric studies and for better understanding of the bolt behaviour, which can be studied experimentally only in a limited extent.

The simplified numerical model using beam elements is shown in Figure 1b. Beam elements with six degrees of freedom are used for the bolt shank and rigid elements are used for the transfer of the bolt force into the flanges of T-stubs. The length of the rigid elements corresponds to the radius of the bolt shank. The stiffness of the beam elements representing the bolt shank was evaluated in a numerical study.

Agerskov (1976) [9] developed the analytical model that considers the deformation of the shank, threaded part, nuts and washers. Stiffness is determined from the sum of these parts deformation. A similar approach is used in the analytical model according to the German guideline VDI2230 [17]. A Simplified procedure is used in Eurocode 3 when the constant cross-section corresponding to the core is used along the entire length of the bolt which is taken as the clamping length. The stiffness calculated from these data is then reduced to 80%.

The parametric study of the stiffness for the bolt M24 8.8 was done with the solid model. The length of the shank was the variable parameter, the length of the threaded part remained constant. The comparison of the results of the previously described analytical models to the results of the numerical model is shown in Figure 2.

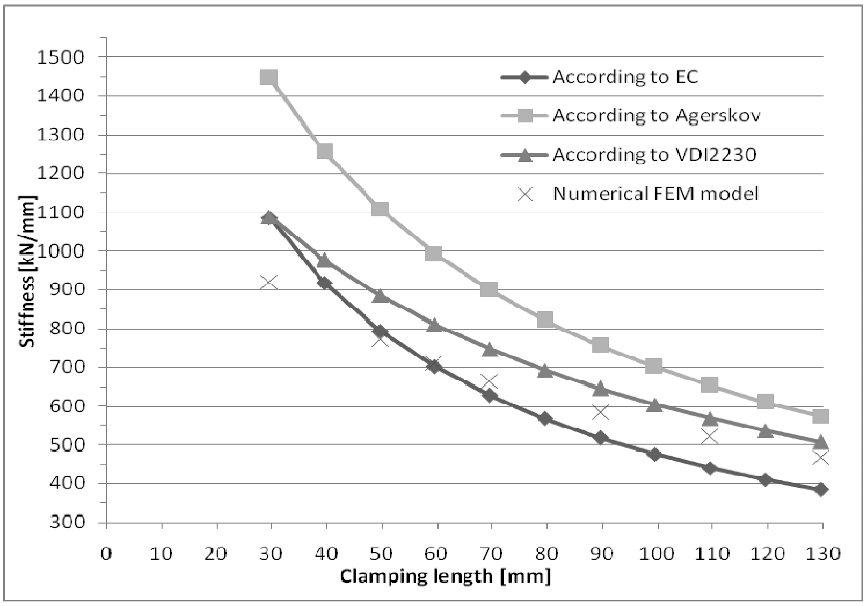


Fig. 2. Parametric study of bolt stiffness

The clamping length of the bolts used in the experiments was about 90 mm. The model according to the German VDI2230 seems to be the most suitable and the stiffness of the beam model is considered by this model.

3.2 T-stub model

Two different numerical models were developed: a detailed solid model and a simplified shell model. Reinforcing shell elements are used in the simplified model at connection of the web of the T-stub to its flange. The location of the reinforcing elements significantly affects the behaviour of the T-stub. The beam model of the bolts is used in the shell model while the solid bolt model is used for the solid model of the T-stub. Both models are shown in Figure 3.

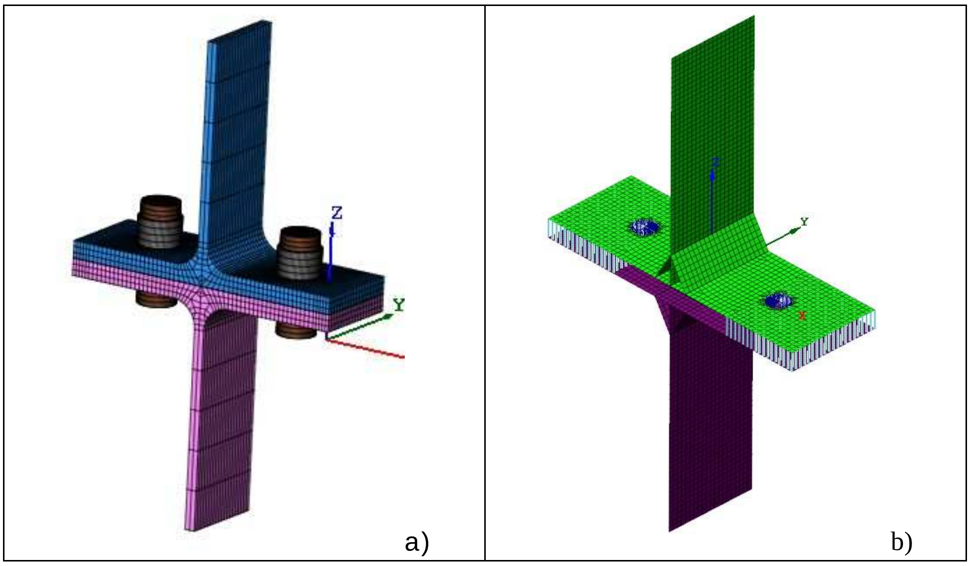


Fig. 3. a) Solid model of T-stub; b) Shell model of T-stub

Two approaches are used for transmission of compressive forces between the flanges of T-stubs. Contact elements are used in the solid model and compression only spring elements connecting the nodes of the flanges are used in the shell model. Both models use multi-linear stress-strain material diagram. The parameters were obtained by standard tensile test of the used steel.

The results of both numerical models were compared to experimental results. The comparison is made on the basis of deformation of the T-stub. The results for Sample 1 are shown on Fig. 4.

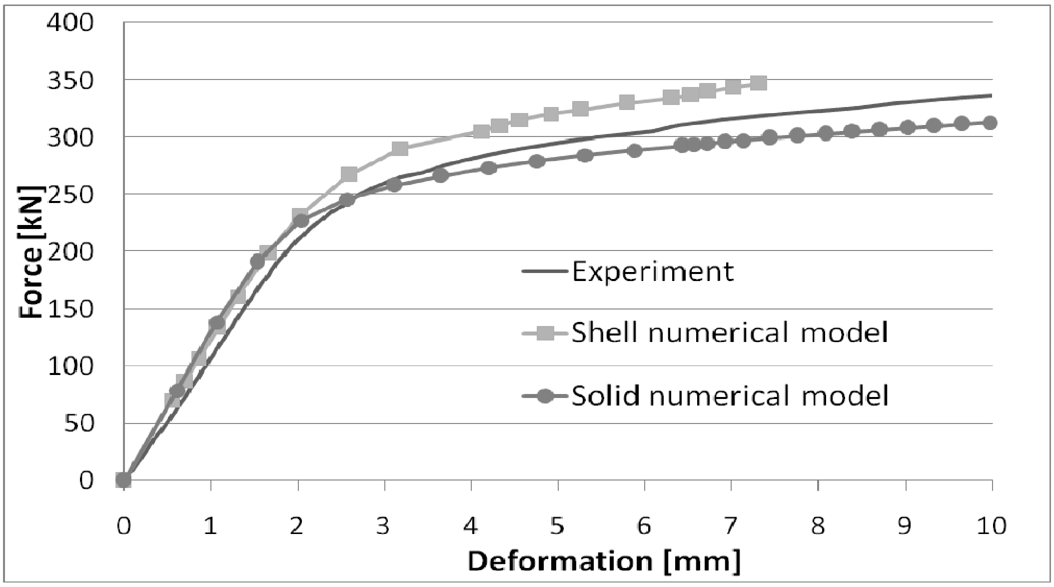


Fig. 4. Results of numerical models compared to the experiment, Sample 1

It is clear from this graph that both numerical models have higher initial stiffness compared to the experiment. The plastic deformation of the flange starts earlier compared to experiment in the shell model, but later in the solid model. The shell model shows slightly lower post-limit stiffness compared to experiment. Despite some differences it can be concluded that both models show good agreement with the experiment of Sample 1. Similar results were achieved for Sample 2.

4 SUMMARY AND ACKNOWLEDGMENT

Two different numerical models were developed. Both models show very good agreement with the experiments. Although the shell model brings some simplifications, good choice of bolt element stiffness and position of the reinforcing elements at the connection of web to flange leads to satisfactory results. Creating and computational time of the shell model is faster compared to the solid model and thus more suitable for the design of endplate joints.

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