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CONSIDERATION OF STRUCTURAL ELEMENTS CHARACTERISTICS ON THE STRESSES AT THE I-BEAM END-PLATE MOMENT CONNECTION

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Summary: *The paper deals with numerical study on the stresses at the bolted end-plate moment connection, with application of finite element analysis. The prying effects in the joint are considered for the comparative analysis with analytical model of bolt calculation. There are observed three basic models of the joint which reflect variation of the joint stiffness, along with the cases of different parameters of end-plate thickness. It is shown that several parameters have effects on the stresses at the joint and need to be considered in the structural analysis of the frame structures. Also, there are given some recommendations for practical usage for the design of this kind of joints.*
Key words: End -plate joints, I-beam, FEA, bending, stresses

1. INTRODUCTION

The structural connections-joints are of high importance in the design of various framed structures. They ensure continuity of structural elements, i.e. transmit the internal forces and moments throughout the whole structure. Generally, there are two basic ways of connecting elements: by welding or by bolts.

Nowadays, the bolted joints have precedence for connecting members on the site because they are better to assure the designed geometry of the structure and fast erection process. However, they provide spot connections which stand for discontinuity at structures and consequently for discontinuity in distribution of forces.

The object of this work is moment end-plate connections in beam-to-column joints. They are widely used in civil and mechanical engineering practice. The extensive survey on these connections is given by Murrey [1], with theoretical background of design procedures and several design examples. Since it is closely related to AISC specifications and American engineering practice, the postulations are different and rarely used here where European standard prevails [2]. Eurocode 3 (EC3) presents the behaviour of the joints, according to the method of global analysis, with classification of

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joints (in short) as pinned, rigid and semi-rigid.

The complexity in the design of the end-plate joint is coming from the different components involved, thus, it is needed to provide the strength check of following parts: column flange, bolts, end-plate and welded connection of beam to end-plate. Therefore, the stiffness of joints is important characteristic which reflects the rotational resistance of a connection to applied moment. It is often described with a moment versus rotation or M-Ø diagram which can be obtained by experimental tests or by guidelines in the structural codes. EC3 gives the component method for prediction of this important diagram for semi-rigid joints, but the process is sometimes time-consuming and limited in calculations. Therefore, numerical models can be very useful in this kind of issues, along with experimental, empirical and analytical ones.

In recent years, the finite element analysis (FEA) is highly present in the calculation of the joints. The early studies (1980s) started with correlation of results from 2D to 3D models. Nowadays, there are many FEA for different models and problems of end-plate joint calculation and there are very important where there is a lack of experimental results, when is needed understanding of local structural effects or to generate extensive parametric studies. Diaz at all [3] presented full 3D ANSYS model of steel beam-to-column bolted extended end-plate joint and its behavior with application of contact and sliding between elements, bolt pre-tension and geometric and material non-linearity. The similar object was studied in [4], with exposure to seismic or cyclic loads. The parametric study was made with following considerations: the ratio between the width of the column flange to its thickness, the ratio between the depth of the column web to its thickness, the thickness of the end-plate in the limit, the grade of steel. Cyclic tests on extended end-plate moment connections are also given in [5] which showed that the four bolts unstiffened and the eight bolts stiffened end-plate moment connections meet the requirements for use in seismic regions. The 3D finite element model is presented in [6] to model the behavior of the extended end-plate moment connections on two configurations: four bolts and extended with multiple rows.

In this paper, FEA is performed on the several cases of the simple extended unstiffened 4-bolt (in tension region) end-plate moment connections. The parameters of the joint elements are varied in order to show their effect on the stiffness and the strength of the joint.

2. DEFINITION OF JOINT MODEL

The beam-to-column joint is primarily designed upon the beam capacity. Here, the beam is adopted as IPN 160 (DIN 1025-1) and stands for base elements for all the models which reflects the arrangements of bolts depicted in Fig. 2a. There are considered 3 basic models which correspond to different column element: Model 1 (M_1) - HEM 240, Model 2 (M_2) - IPE 270, Model 3 (M_3) - HEA 140 (Fig. 2b). All the steel members are made of structural steel S235 with following characteristics: yield strength f_y=235 MPa, ultimate tensile strength f_u=360 MPa, modulus of elasticity E=210000 MPa and Poisson's ratio v=0,3.

The models of columns represent different bending stiffness, from high to low, with preservation of bending capacity of joint. The intention is to include the parameters of the sections, like flange width and web width, in simulation of behavior of the joint.

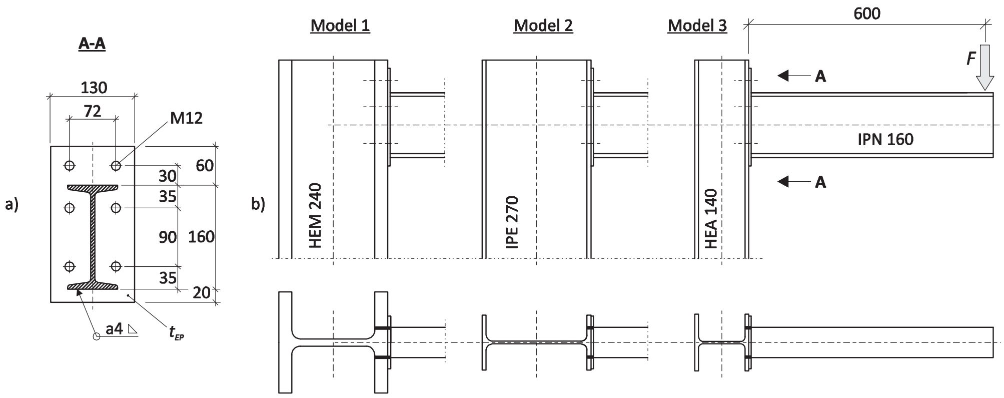


Fig. 2 *a) Geometrical arrangements of bolts, b) Joint models*

The moment is applied throughout the force F acting on the arm of 600 mm. Generally, the force is considered with intensity up to 20 kN, which is smaller then maximal allowed force (with allowable stress of 15,7 kN/cm^2, one may calculate this force as 30,6 kN).

The influence of other structural elements of joints is considered with cases which have variations of end plate thickness. Variation includes following thicknesses (t_{EP}) of the endplate: 6, 12, 15, 20, 25 and 30 mm. This postulation gives possibility to observe the prying effects on the connection. The class of the implemented bolts M12 is 10.9 because this bolt class is highly recommended for this kind of joints.

3. ANALYTICAL MODEL

One may found simple calculation of bolt tension forces at this joint subjected to moment M [7]. For the loading case with force F=20 kN (Fig. 2b) the forces for bolt in upper row are F_{t1}=22,3 kN and in second row F_{t2}=14,5 kN. When simplified model is used, the force in each bolt in tension zone is F_{tz}=19,3 kN. Shear forces are not considered due to low intensity.

In previous engineering practice, the thickness of the end-plate was adopted mostly upon the experiential criterion. In domestic literature [7], the recommended value for this is equal to the value of the bolt diameter (12 mm in this case). However, the calculation is time-consuming when prying effects are included, along with the fact that calculation algorithm differs in engineering codes. For parameters depicted in figure 2, when simple calculation (according to authors) from Chinese code is used [8], one may obtain:

$$t_{min} = \sqrt{\frac{3 \cdot e_2 \cdot B_t}{b \cdot f}} \cong 15\ mm$$

where: e_2=30 mm - distance from the edge B_t=60 kN - tensile capacity of bolt with class 10.9, b=65 mm - half-width of end-plate, f=360 MPa.

The presented values are obtained for comparation purpose with results from FEA. It has to be pointed out that previous values are dealing with the strength of the joint with no implication on the joint rotational resistance.

4. FINITE ELEMENT ANALYSIS OF THE JOINT

As mentioned before, FEA becomes useful and common tool for the calculation of various structural problems. Here, FEA is performed for the insight of the stress state in the end-plate joint. All the steel members are modeled with 4-node shell elements assuming ideal elastic-plastic material. Bolts and welds are modeled as nonlinear springs. The geometry is postulated in chapter 2 with value of force as F_{max}=20 kN.

The equivalent stresses (von Mises) are calculated for all the models with the 6 mm plate thickness and for basic postulation of bolts with class 10.9 (Fig. 4).

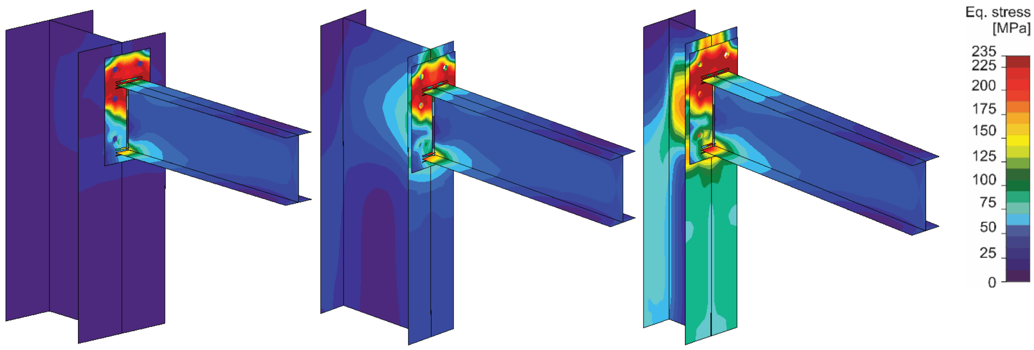


Fig. 4 *Stress state: M_1, M_2, M_3, respectively*

It is common for all the results that end-plate strength is the critical point of joint. This could be expected due to low thickness of the plate which produced similar stress state for all the models with the highest values of 235 MPa (as yield strength) in tension zone. The other parts have sufficient strength, with obvious fact that stress values are increased with lowering the stiffness of the column. This is related to the thicknesses of the column section elements, as shown by results for M_3.

First, it is obtained results for bolt forces due to the influence of end plate thickness. As mentioned, variation includes following thicknesses (t_{EP}) of the endplate: 6, 12, 15, 20, 25 and 30 mm. There are given results for bolt force in upper row F_{t1} (FEA) and second row F_{t2} (FEA) for models 1, 2, 3 on Figure 5. Also, there are shown analytical values for the bolt forces denoted as F_{t1} and F_{t2}, as given in previous chapter.

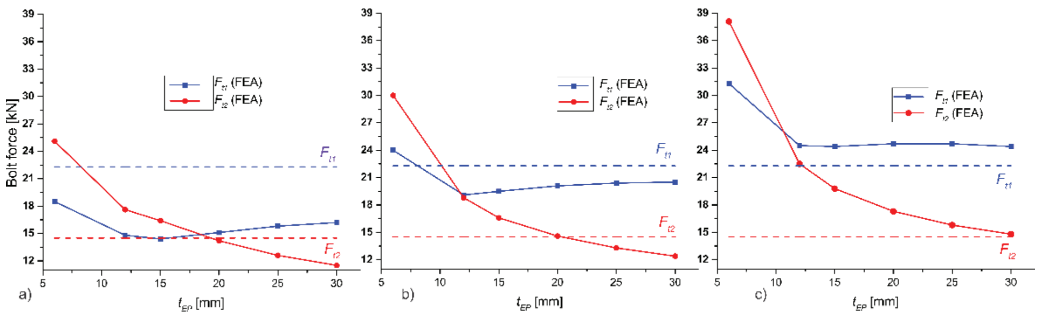


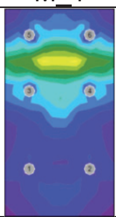
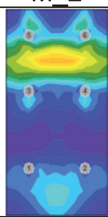
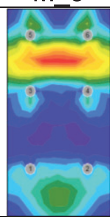
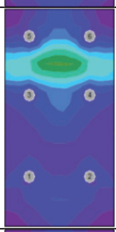
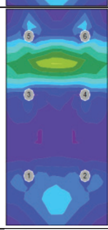
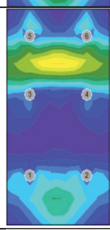
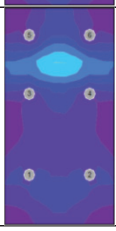
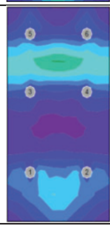
Fig. 5 *Bolt forces - a) Model 1, b) Model 2, c) Model 3*

Furthermore, the stress state in end-plate is investigated on all the models. The presentation is given in following table for chosen thicknesses of end-plate, i.e. for 12, 15 and 20 mm. This is done due to the fact that stress state for thickness of 6 mm is given at fig. 4 and relevance of results for thickness equal and bigger from 25 mm (low level of stresses).

5. ANALYSIS OF RESULTS AND DISCUSSION

There is clear difference in results of bolt forces, for all the models at figure 5 calculated with FEA and analytically. However, analytical values for F_{t1} and F_{t2} are calculated with assumption of fully rigid case. The highest deviation of results is obvious for the case of 6 mm thickness of end-plate which implies very high impact of prying effects. So, this can be classified as unacceptable in design. If started with value of thickness as bolt diameter, 12 mm in this case, the values of bolt forces in second row are bigger then in first row, for M_1 and M_2. This is due to low bending stiffness of end-plate compared with column flange stiffness. The higher values for end-plate thickness give better allocation of bolt forces.

Table 1 *Stress state in the end-plate*

t_{EP}	Stress level		
[mm]	M_1	M_2	M_3
12			
15			
20			

Furthermore, as stiffness of the column decrease, like M_1 to M_3, the values of stresses in end-plate increase in all the zones (Table 1). The equivalent stresses show that high values of 235 MPa is present for thickness of 12 mm while for 25 mm the stresses are in safe zone.

6. CONCLUSION

It is performed finite element analysis of the unstiffened end-plate beam-to-column joint with 4 bolts. Three basic models are concerned with variation of end-plate thickness. With restriction to several presented cases, one may found following:

- the value of end-plate thickness which is equal to bolt diameter, considered as minimum value, give uncertain results for stress check
- the prying effects should be considered and starting valued of end-plate thickness needs to be calculated according to chosen code
- the high disproportion of stiffness of beam and column should be avoided or calculated in detail.

General conclusions can be drawn only by analytical model which is difficult to postulate due to many parameters involved in this kind of joint. Extension would be to perform experimental testing of several joint models which is time-consuming and sometimes expensive. Thus, customized finite element software appears as very useful tool for calculation of steel connections with obvious fact that they need some kind of verification of results.

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