NONLINEAR ELASTIC-PLASTIC 3D-FINITE ELEMENT MODELLING OF SEMI-RIGID STEEL END–PLATE CONNECTIONS

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Summary:
Although the effect of semi-rigid steel beam-to-column connections on the behaviour of steel frames and their substantial economical benefits are recognized nowadays, many structural analyses still consider connections as either fixed or pinned. For that reasons, there is need to be able the generate moment-rotation responses of semi-rigid connections that can be used for analysis and design proposes. Numerical elastic-plastic 3D finite models was performed in order to establish a numerical analysis method for evaluating deformation of extended end-plate-beam-to-column joint for varying thickness of end plates. There were used contact elements between bolts and beam and column. This kind of model was generated by using the FEM software package ANSYS version 14. The study were performed the influence of thickness of end plates on moment-rotation curves for analysing joints and proved that the FE technique was capable of prediction connection response to an acceptable degree of accuracy.

Keywords: Steel joints, end plate, FE modeling, nonlinear analysis

Introduction

Cost optimization is one of the most important items in steel construction in order to be competitive in the market of buildings. The joints determine almost 50 % of the total cost of steel structure. The cost of joints can decrease substantially if stiffeners between flanges can be avoided (Bijlaard 2006). The distribution of forces and moments in the structure due to the loading is a result of the strength and stiffness distribution in the structure. So the structural characteristics of the joints such as stiffness, strength and rotation capacity, together with those of the structural components like beams and columns, produce these forces in the joints. This means that the choices made by the designer in designing the joints, including the connecting parts, are of direct influence on the level of forces and moments in these joints. In fact construction is joining components such as column and beams together while designing is making choices for components taking the structural properties such as strength as stiffness into account.

In traditional design it is assumed that the joints are stiff and strong and the forces and moments in the structure can be determined using the linear-elastic theory (Bródka et al., 2011). Because it is assumed that the joints were stiff, it needs to be checked whether the joints are really stiff.

In modern design the joints are considered as structural components such as column and beams with properties as stiffness, strength and deformation capacity. These structural properties of the joints are incorporated into the design on the same level as those of column and beams. The joint layout should only be influenced by fabrication considerations for easy and safe construction on-site.

Eurocode 3 part 1-8 “Design of Joints” (EN 1993-1-8) provides the rules to determine the structural behaviour of joints in terms of strength, stiffness and deformation capacity. If the designed joints are out of scope of Eurocode 3, experiments and FEM modeling have to be carried out to obtain reliable design values for the structural properties.

Aim of studies

The aim of these studies is to develop the FEM model of extended end-plate beam-to-column connections (Fig.1) and obtained moment-rotation curves for varying thickness of end plates, from very small thickness to thicker one.

There were used hot rolled sections IPE240 as a beam, HEB200 as a column and 10.9 grade high strength bolts with a diameter of 16 mm. In testing joints according to EC3 (ENV 1993-1-8) there were involved three thicknesses of end plate: 6 mm, 10 mm and 20 mm. All parts of connection (without bolts) were designed from steel grade S235. Key geometric parameters of specimen are shown in Fig.2

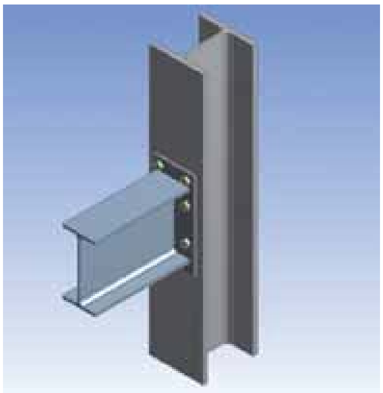

Fig. 1. Extended end-plate beam-to-column connection

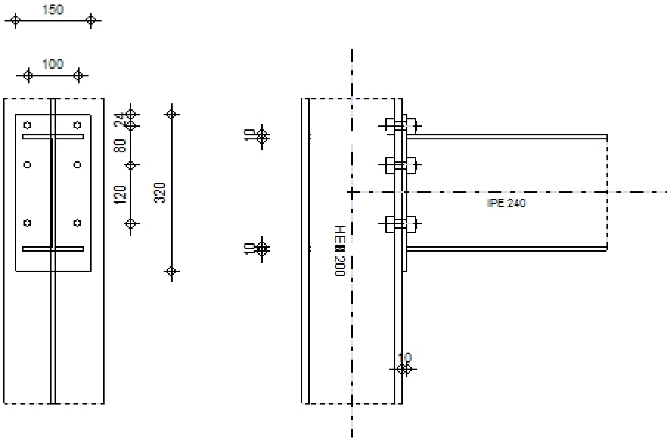

Fig. 2. Geometry of beam-to-column joint.

Modelling of bolted joints is rather complex problem because it involves geometrical and material non linearity, and the contact problem between components of the connections as well as a selection of suitable type of finite elements for modeling joint components. In spite of this difficulties and complexities, a large number of advanced FE studies have been conducted on end plate connections (Giżejowski et al.2008,2010, Chen and Du, 2007, Maggi et al.,2005, Abolmali et al., 2005) and other types of connections (Jabłońska-Krysiewicz 2011, Huang et al.,2010, Reinosa et al., 2008, Kim and Oh, 2007, Urbonas and Daniunas 2006, Citipitioglu, 2002) to provides stiffness, strength and ductility estimates for large variety of connection geometries. In general, these detailed studies have attempted to develop global connection behaviour responses, for example moment-rotation curves, that can be readily incorporated into modern structural analysis programs like ADINA, COSMOS, NASTRAN, ANSYS, and ABACUS. This objective was addressed through the using the FEM software package ANSYS version 14 (ANSYS Manual 2013).

FE modeling

General

The numerical tests were carried out by code ANSYS –Workbench version 14 (ANSYS Manual 2013). Solid 186 elements were used to mesh the beam, column, end plate and bolts. Contact surfaces between the flange of column and end plate, the bolt shanks and end plate and flange of column, and nuts and heads of bolts and flange of column and end plate are meshed by Conta174 elements. The description of these elements taken from ANSYS Manual (ANSYS Manual 2013) is listed in the next section. The coefficient of friction of 0.2 is employed for contact surfaces. The meshed FE models of connection and bolt are shown in Fig.3.

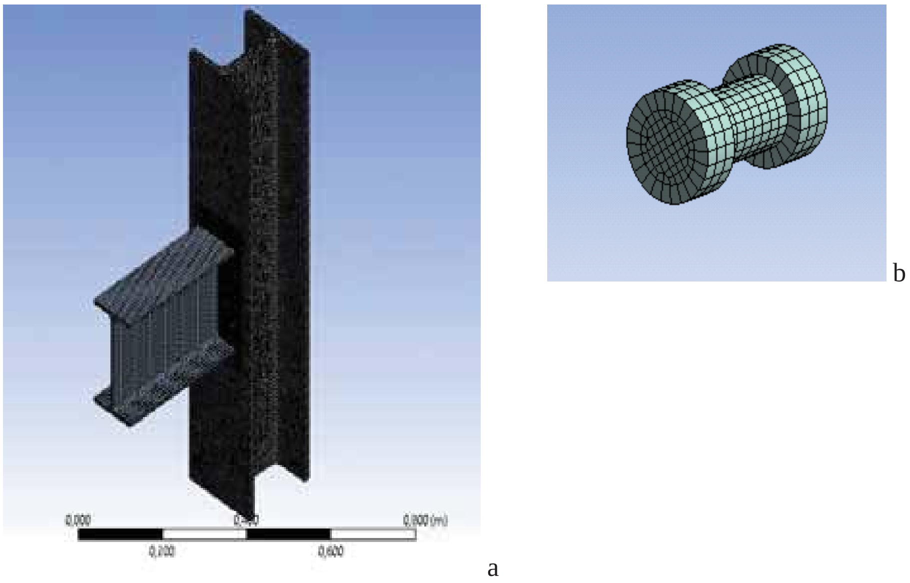

Fig. 3. Finite element models: a) end plate-beam-to-column-connection, b) bolt.

Element description

Solid 186

Solid 186 is used for the 3-D modeling of solid structures. The element is defined by twenty nodes having three of freedom at each node: translation in the nodal x, y and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection and large strain capabilities. Geometry of the element is shown in Fig.4.

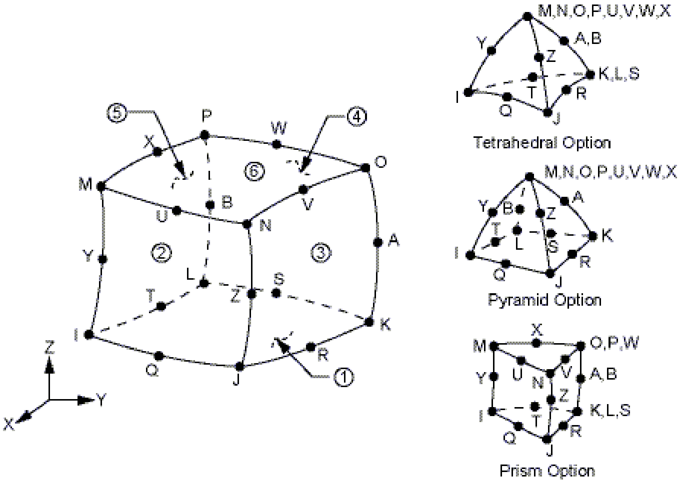

Fig. 4. Geometry of Solid 186 element (ANSYS Manual 2013)

Conta174

Conta174 is used to represent contact and sliding between 3-D “target” surfaces (Targe170) and deformable surfaces, defined by this element. The element is applicable to 3-D structural and coupled field contact analyses. This element is located on the surfaces of 3-D solid elements. It has the same geometric characteristics as the solid element face with which it is connected. Contact occurs when element surface penetrates one of the target segment elements (Targe 170) on a specified target surface. Coulomb and shear stress friction is allowed. In Fig.5 there are shown geometry of the element.

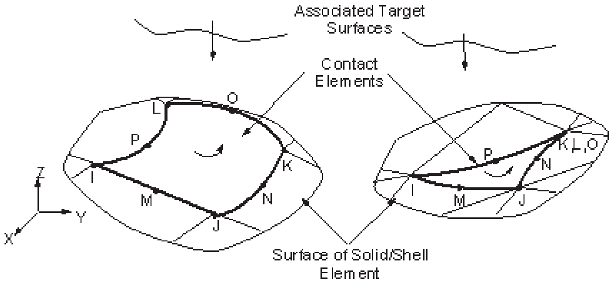

Fig. 5. Geometry of Conta174 element (ANSYS Manual 2013)

Material property

The 3-D model uses the bilinear isotropic hardening option for plate elements of joints. The von Mises yield criteria was employed to define the plasticity. For this option is preferred for large strain analyses. The material behaviour is described by bilinear stress-strain curve. The initial slope of the curve is taken as the elastic modulus of the material. At the yield stress, the curve is continuous along the second slope defined by the tangent modulus (Fig.6). The tangent modulus is defined as about 0.1 % of the initial modulus of elasticity. For bolts there are used linear model of material. The material property of plate components and bolts in joints are listed in Table.1.

Tab.1. Material properties

Elements	Yield stress [MPa]	Ultimate stress [MPa]	Elastic modulus [GPa]	Tangent modulus [MPa]
Beam, column, End plate	235	360	210	360
Bolts	900	1000	210	-

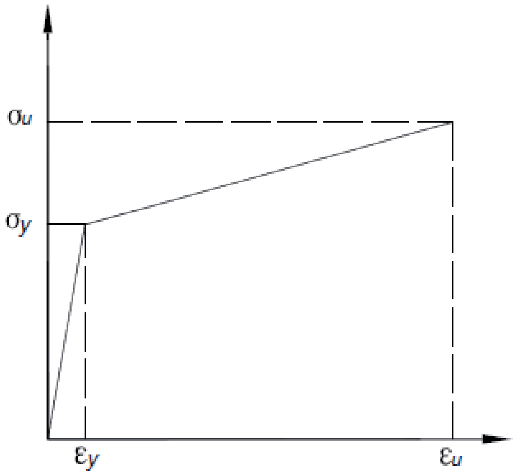

Fig. 6. Stress-strain curves for plate elements of connection

Testing results

Three numerical analyses for vary thicknesses of end plate were made. The bending moment and axial forces were applied to free end of beam section in 10 steps of load to keep respectively value of moment in each connection. The comparison of moment-rotation curves achieved from FE model calculation for thicknesses 6mm,10mm and 20mm was depicted on Fig.7.

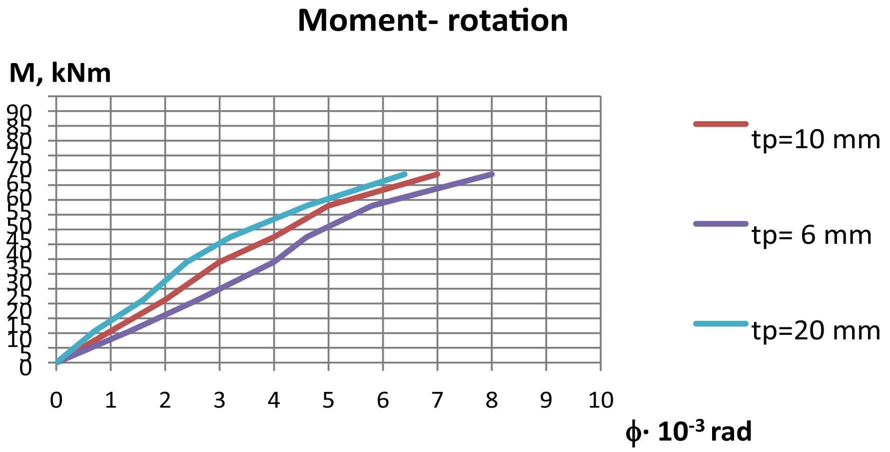

Fig. 7. Moment rotation curves for vary thicknesses of end plate

We can see that initial connection stiffness is affected by end plate thickness what is according to initial stiffness $S_{j,ini}$ obtained from formulas proposed by Pisarek and Kozłowski (Bródka, Kozłowski, 1996) based on component method described in EC3 (EN 1993-1-8) for such kind of joints. In Table 2. there are shown values of $S_{j,ini}$ for each connection.

Tab. 2. Initial stiffness values for connections with end plate thicknesses of 6mm, 10mm and 20mm.

End plate thickness [mm]	Initial stiffness $S_{j,ini}$ [kNm/rad]
6	4980
10	5955
20	7590

For each connection moment-rotation curve from FEM there were compared with curve calculated according EC3 model. For all thickness of end-plate there were obtained good agreement. To show it M-ϕ curve from FE and Eurocode 3 were depicted in Fig.8. We can see that the FE results lightly overestimates results achieved from component method from EC3. It was caused probably by using linear model of material for bolts in numerical analysis.

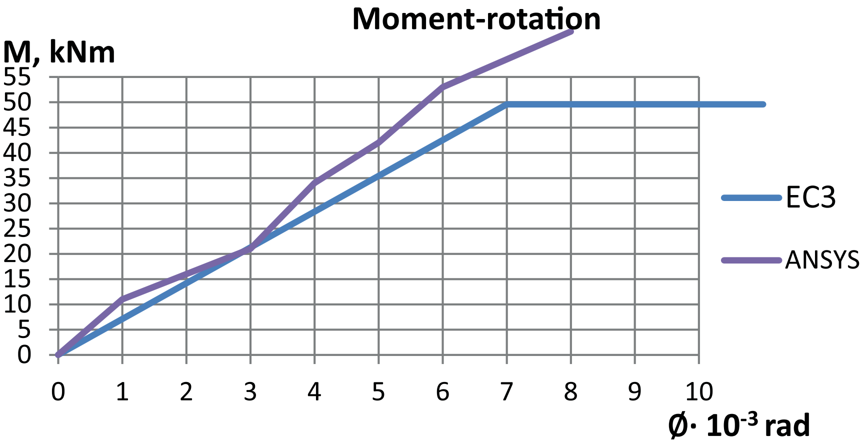

Fig. 8. Moment-rotation curve for connection with end-plate thickness value 20 mm.

The deformation of end plate has important influence on response of the connection, specially on displacement of beam. Using of thicker end plate causes increasing in displacement values of end of IPE section. To notice this effect in connection behaviour there is shown deformation of end plate in each step of load in Fig.9. Based on this results it can be observed 14 % decreasing in deformation value for joint with 10 mm plate and 24% for 20 mm in compare to 6mm end plate thickness. Additionally, to confirm that the joint behaviour is governed by geometry of its components the views of deformed shapes at ultimate state of load are shown in Fig.10.

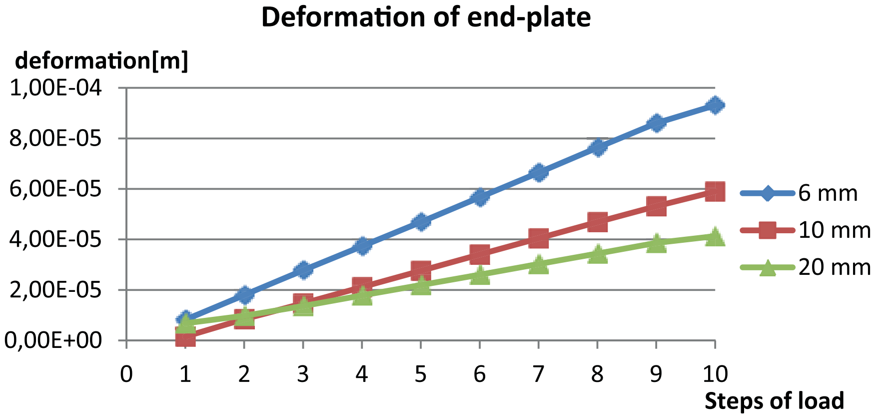

Fig. 9. Curves deformation versus steps of load for different values of end plates.

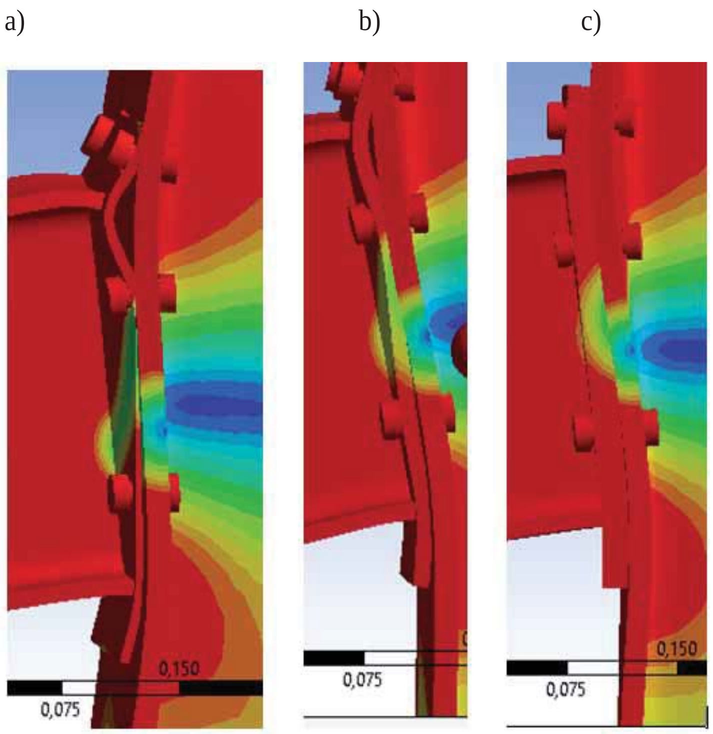

Fig.10. Deformed shapes at ultimate state of load for end plate value: a) 6 mm, b) 10 mm, and c) 20 mm.

These results show that in case of employment of using thicker end plate it does not come to its breaking away from column flange. For thinner end plate the flexural mechanism of its collapse has a much effect on ultimate shape of connection. This phenomena was observed by Maggi (Maggi et al, 2005) in experimental tests and numerical analyses of steel bolted en-plate joints. The mechanisms of destruction of analyzed connections are according to component method which is described in Part 1-8 of Eurocode 3.

Conclusions

In order to establish a numerical analysis method for estimating moment-rotation curves of end-plate-beam-to-column connections 3-D FE analyses have been performed. Finite element models have included material, geometric, and contact nonlinearities and large displacements. The numerical investigation has shown that thickness of end plate is one of most important parameters for representing connection behaviour and its influence on connection response is significant. It was observed that initial stiffness was proportional to increasing of the end- plate thickness, while the free end of beam displacement was inversely proportional. Moment –rotation curves from numerical investigation showed good agreement with curves calculated according to component method from EC3.

Finally, the results of numerical tests has conducted that FE method is a powerful tool to improve the knowledge about connections.

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