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FINITE ELEMENT MODELLING OF THE BEHAVIOUR OF STEEL END-PLATE CONNECTIONS

Although the effect of semi-rigid steel beam-to-column connections on the behaviour of steel frames and their substantial economic 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. Characteristic of the joints can be found using FEM models. The objective of the analysis was to find moment-rotation curves for end-plate connections. The analyzed splices were shaped considering typical recommendations for such connections. 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. Analysis was done for non-preloaded high strength bolts. This kind of model was generated by using the FEM software package ANSYS version 14. Results show moment-rotation curves for thicknesses 6mm, 10mm and 20mm of end-plate. The study confirmed 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. The results can be used in advanced structural analysis of beams and frames.

Keywords: steel joints, end- plate, FE modelling, nonlinear analysis

1. 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 [5]. The distribution of forces and moments in the structure due to the loading is a result

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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 and stiffness into account [12].

Existing design procedures for steel frames have been modified during the last three decades to incorporate the semi-rigid behavior of the connections into the frame design process. However, if one consider the large number of variables related to connection geometry, connection components, and constitutive relationships for their materials, the task of deriving simplified guidelines for the incorporation of semi-rigid behavior into design is a formidable analytical assignment. This task is further complicated by the need to treat the problem in three dimensions, to consider nonlinear geometric and material effects and to include the effects of initial imperfections and residual stresses [13, 15]. In spite of these difficulties and complexities, in the past two decades a large number of advanced FE studies have been conducted on end-plate connections to provide stiffness, strength and ductility estimates for a large variety of connection geometries [1, 7, 9, 10, 13]. These FE models have been used to develop moment-rotation curves, to verify design methodologies based on yield lines and other plastic design concepts, and to asseses local behavior in the connection components, such as bolts and end –plate [11] and in-plane and out-of-plane bending [14].

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.

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. For steel frames it has proved that the application if joint end-plates with the thickness of 50-75 % of the bolt diameter may result in a better frame ductility performance than the corresponding to a thicker end-plate where the end-plate thickness is at least that of the bolt diameter [2, 4, 10].

2. Description of the specimen

Three configurations of specimens were analyzed. 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. The bolts were no-preloaded. In testing joints three thicknesses of end-plate were used: 6 mm, 10 mm and 20 mm. Applied end-plate thickness 6 mm and 10 mm were relatively thin, i.c. of the about 40-60 % of the bolt diameter . All parts of connections (without bolts) were designed from steel grade S235. Key geometric parameters of specimens are shown in Fig.2.

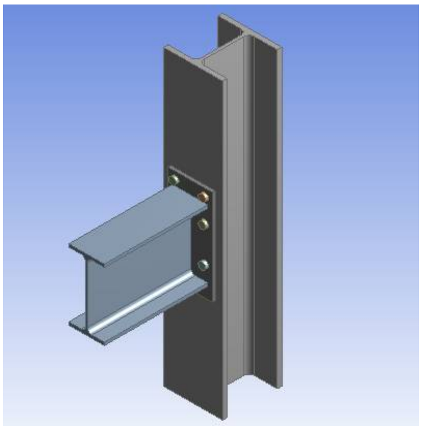

Fig.1. Extended end-plate beam-to-column connection

Rys. 1. Połączenie belki ze słupem z blachą czołową wystającą

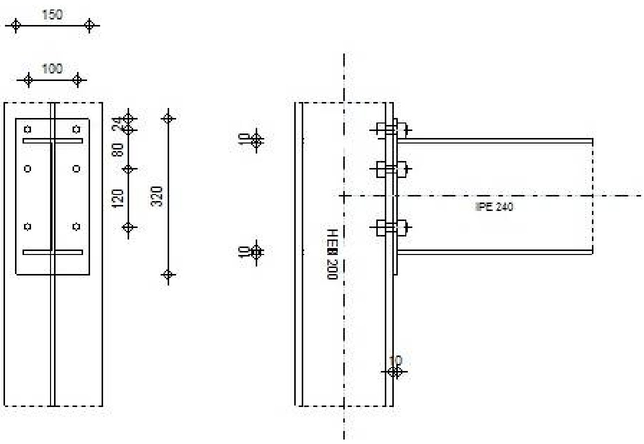

Fig.2. Geometry of beam-to-column joint.

Rys. 2. Geometria węzła łączącego belkę ze słupem

3. Finite element modelling

3.1. General

The numerical tests were carried out by code ANSYS –Workbench version 14 [3]. 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 [3] 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.

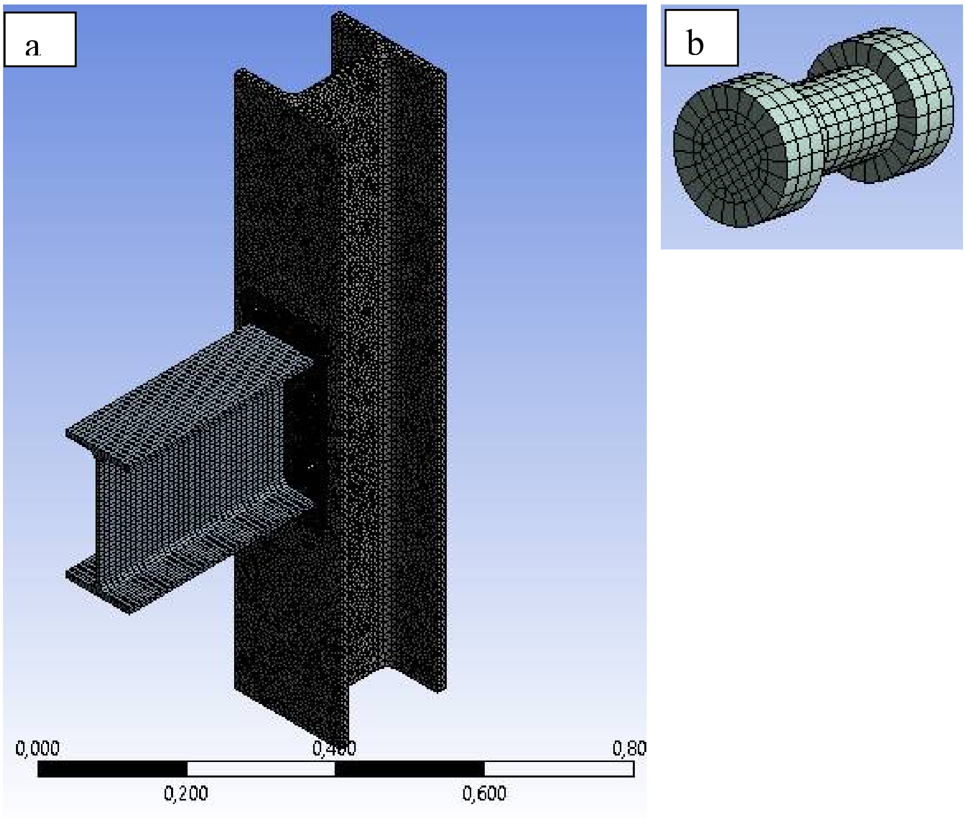

Fig.3. Finite element models: a) end plate-beam-to-column-connection, b) bolt

Rys. 3. Model numeryczny: a) połączenia belki ze slupem z blachą wystającą, b) śruby

3.2. Element description

3.2.1. 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.

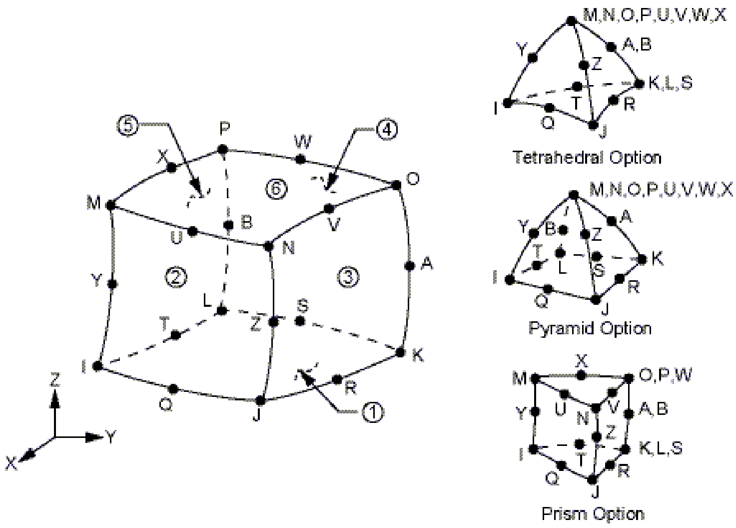

Fig.4. Geometry of Solid 186 element [3]

Rys. 4. Geometria elementu bryłowego 186 [3]

3.2.2. 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.

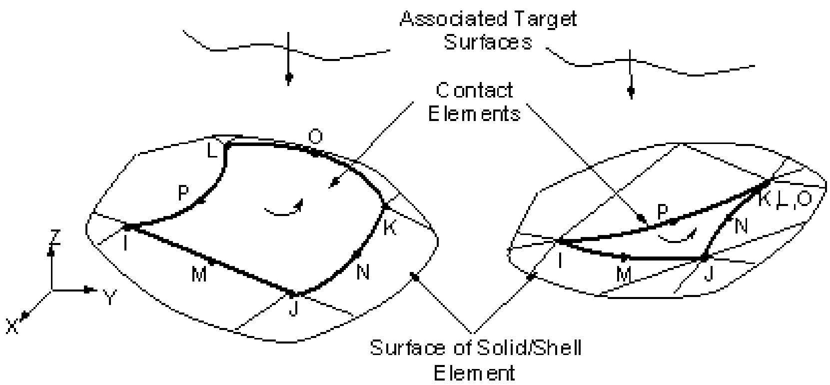

Fig.5. Geometry of Conta174 element [3]
Rys. 5. Geometria elementu Contal 174 [3]

3.3. Material property

The 3-D model uses the bilinear isotropic hardening option for plate elements of joints. The Huber- 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.

Table.1. Material properties
Tabela 1. Właściwości materiałowe

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	-

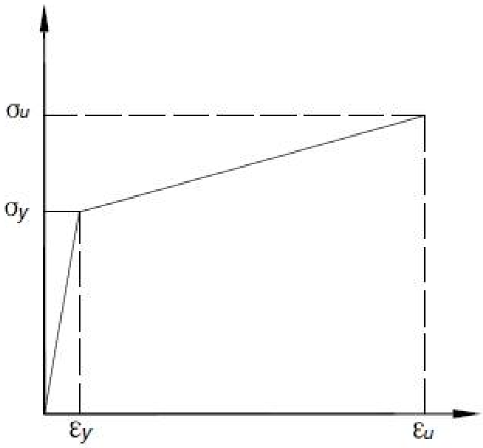

Fig.6. Stress-strain curves for plate elements of connection

Rys. 6. Krzywa naprężenie – odkształcenie płytowego elementu połączenia

4. Simulation 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.

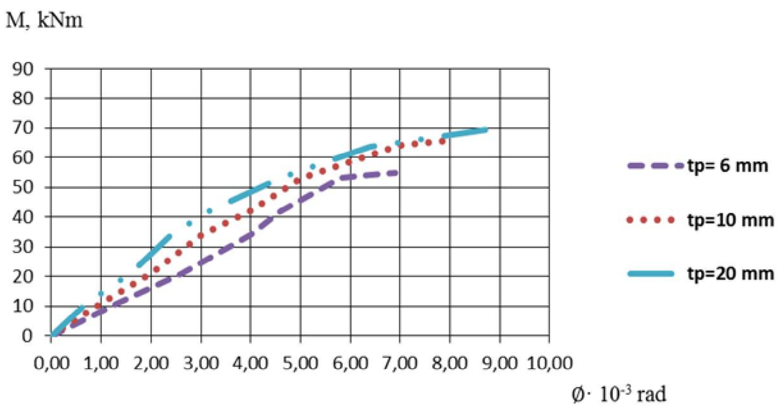

Fig.7. Moment rotation curves for vary thicknesses of end-plate

Rys. 7. Zależność moment –obrót dla różnych grubości blachy czołowej

For each connection moment-rotation curve from FEM there were compared with curve calculated according EC3 model obtained from formulas proposed by Pisarek and Kozłowski [6] based on component method described in EC3 [8] for such kind of joints. For all thicknesses of end-plates there were obtained 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. To show it M-□ curves from FE and Eurocode 3 were depicted in Fig.8 to Fig.10 for vary thicknesses of end-plates.

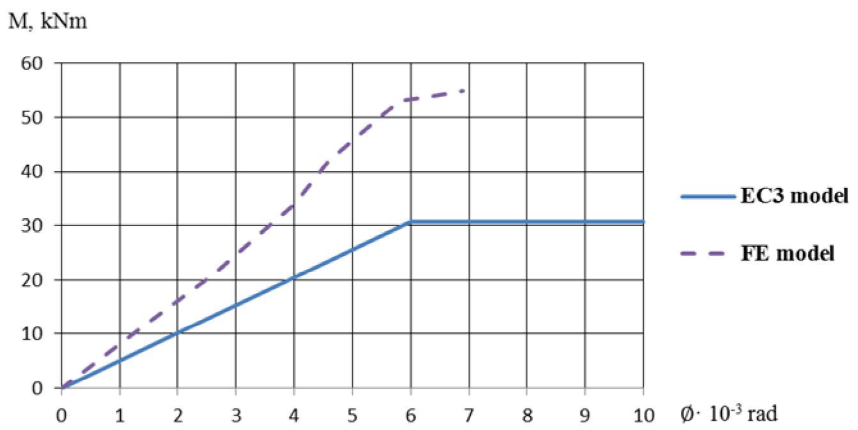

Fig.8. Moment- rotation curve for connection with end-plate thickness 6 mm

Rys. 8. Zależność moment –obrót dla połączenia z blachą czołową grubości 6 mm

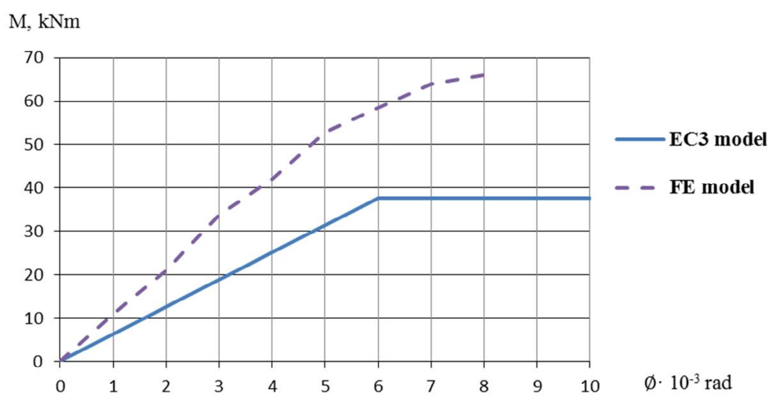

Fig.9. Moment- rotation curve for connection with end-plate thickness 10 mm

Rys. 9. Zależność moment –obrót dla połączenia z blachą czołową grubości 10 mm

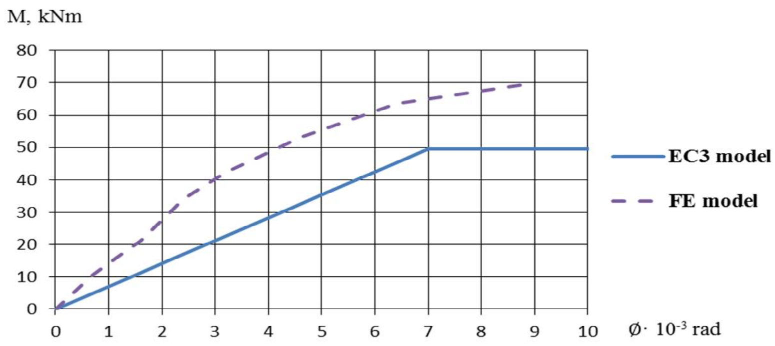

Fig.10. Moment- rotation curve for connection with end-plate thickness 20 mm

Rys. 10. Zależność moment –obrót dla połączenia z blachą czołową grubości 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 versus of bending moment in Fig.11. 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 ,specially the thickness of end-plate, the views of deformed shapes at ultimated state of load are shown in Fig.12. It can be seen from this figure that there is a local deformation at the top of end-plate, particularly around the top and the middle bolt holes. There is lack of substantial deformation in the bolts exposed to the highest tensile stresses.

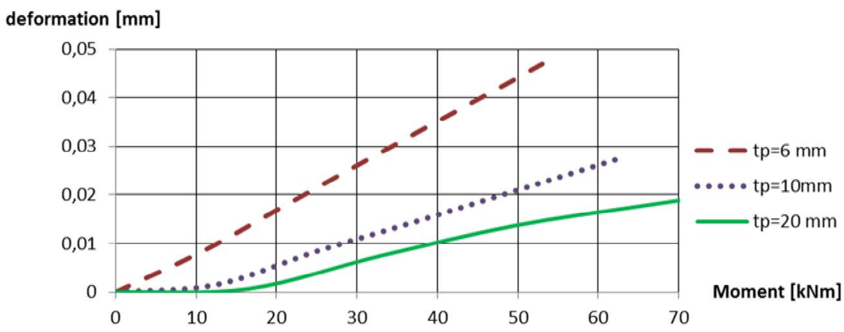

Fig.11. Deformation of the top of the end-plate

Rys. 11. Deformacja górnej krawędzi blachy czołowej

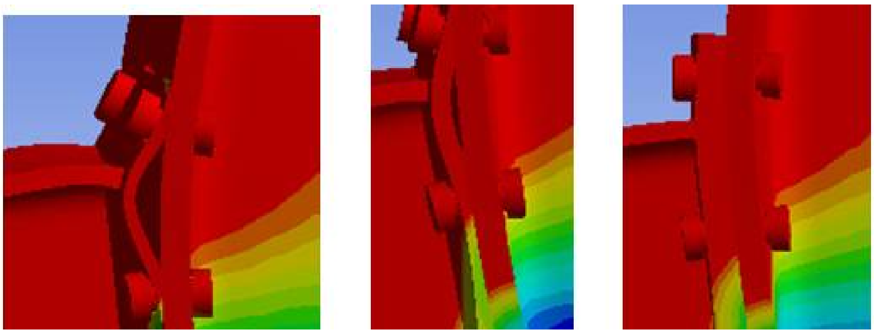

Fig.12. Deformed shapes at ultimate state of load for end plate value: a) 6 mm, b) 10 mm, and c) 20 mm.

Rys. 12. Kształty deformacji w stadium końcowym obciążenia dla blach czołowych grubości: a) 6 mm, b) 10 mm i c) 20 mm

In FE models we can show that the using of thicker plate does not come to breaking away from column flange. For thiner one the flexural mechanism of its collapse has a much effect on ultimate shape of connection.The obtained numerical results confirm the phenomena which was observed by Maggi [13] and Giżejowski [10] in experimental tests and numerical analyses of steel bolted en-plate joints.

5. Concluding remarks

The results presented herein focused on the behavioral variations of bolted extended end plate connections due to changes in plate thickness. In order to establish a numerical analysis method for estimating moment-rotation curves of joints 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.

These results have shown that the FE method was a powerful tool to improve the knowledge about connections design. They could be used in advanced structural analysis of frames.

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MODELOWANIE MES ZACHOWANIA SIĘ DOCZOŁOWEGO POŁĄCZENIA ŚRUBOWEGO

S t r e s z c z e n i e

Pomimo, że obecnie znane są ekonomiczne korzyści uwzględniania półsztywnych połączeń belek ze słupami na zachowanie się stalowych konstrukcji ramowych, wiele analiz konstrukcji wciąż bierze pod uwagę jedynie węzły idealnie sztywne bądź przegubowe. Z tego powodu istnieje potrzeba stworzenia charakterystyk moment - obrót węzłów półsztywnych, które mogłyby służyć w analizach i projektowaniu. Charakterystyki połączeń mogą być uzyskiwane przy użyciu modeli MES. Celem badań było znalezienie krzywej moment – obrót doczołowego połączenia śrubowego. Rozważany węzeł został ukształtowany według zaleceń dla typowych połączeń. Wykonano sprężysto – plastyczny, przestrzenny model MES w celu oceny odkształceń śrubowego węzła belki ze słupem z wystającą blachą czołową dla różnych grubości tej blachy. Do zasymulowania styku pomiędzy belką a słupem wykorzystano elementy kontaktowe. Analizę prowadzona dla niesprzężonych śrub wysokiej wytrzymałości. Siatkowanie zostało wygenerowane przy użyciu pakiet oprogramowania ANSYS wersja 14. Jako wyniki otrzymano krzywe zależności moment - obrót dla blachy czołowej o grubości odpowiednio 6 mm, 10 mm i 20 mm. Badania potwierdziły wpływ grubości blachy czołowej na charakterystykę moment – obrót dla analizowanych węzłów i udowodniły, że metoda MES może służyć do określenia odpowiedzi węzła akceptowalną dokładnością, a wyniki mogą być używane w zaawansowanej analizie konstrukcji Ram lub pojedynczych belek.

Słowa kluczowe: węzły stalowe, blacha czołowa, modelowanie MES, analiza nieliniowa

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