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EXPERIMENTAL STUDY ON THE STRESSES AT THE I-BEAM END-PLATE MOMENT CONNECTION

EKSPERIMENTALNO ODREĐIVANJE NAPONA ČEONE MOMENTNE VEZE I-PROFILA

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- bending
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Ključne reči
- čeona zavrtanjska veza
- savijanje
- čvrstoća

Abstract

The paper deals with experimental study of the stresses at the bolted end-plate moment connection. The design parameters are adopted to include prying effects in joint. A stress level is obtained in the elements where the highest values occur in the tension zone of the end-plate. The accompanied finite element analysis is performed for comparing purposes with experimental results. It is shown that end-plate thickness should be the unavoidable joint parameter in structural analysis of frame-like structures.

Izvod

U radu je izvršena analiza rezultata eksperimentalnog ispitivanja čvrstoće zavrtanjske veze tipa čeone ploče. Parametri spoja su usvojeni tako da uključuju efekat dodatnog polužnog istezanja zavrtnjeva. Prateća analiza konačnim elementima spoja je izvršena sa ciljem obezbeđivanja podloge za upoređivanje rezultata dobijenih eksperimentom. Pokazano je da je debljina čeone ploče, a samim tim i njena krutost, važan parametar spoja i mora biti sagledana u strukturalnoj analizi ramovskih konstrukcija.

INTRODUCTION

Structural steel connections are vital parts of structures because they ensure continuity at the intersection members and foundations. Generally, structural steel connections-joints are composed of plates or parts of sections which are shop welded in controlled conditions and bolted together on site. They transmit internal forces and moments in a structure, and strength is of major importance.

The emphasis here is on moment end-plate connections which are used in beam-to-column joints, Fig. 1.

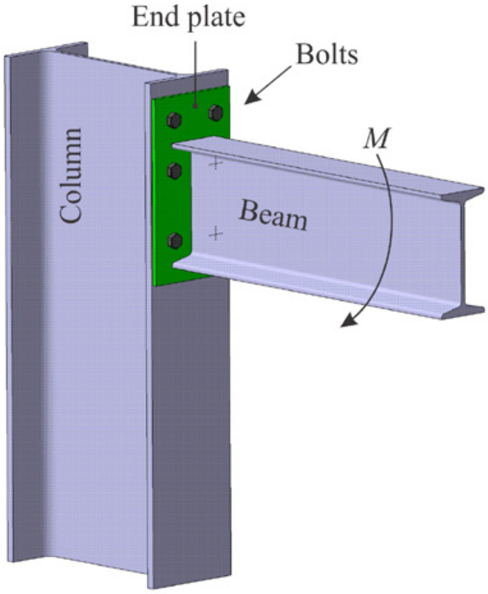

Figure 1. Extended end-plate moment connection.

There are many advantages of these connections such as: easy method of connecting members on the site; less expensive then welding, fast erection process of structures, etc. They are widely used in civil engineering practice for steel frames. Also, they are present in mechanical engineering as common joints in structures of gantry cranes, Fig. 2.

Figure 2. Steel frame of the gantry crane.

The rigidity of joints needs to be considered in structural analysis due to associated linear and rotational movements which affect the distribution of forces and moments. The complexity in the design of the end-plate joint is coming from different components of distinctive properties and geometrical discontinuities.

Previous researches in this topic have two directions. One is dedicated to the design procedures that include prying effects on end-plate connections. Analysis in /1/ (Chasten) indicates that the end-plate connection considering the prying force will improve the plastic deformation capacity of joints even with small thickness in the connection plate. For the case that includes the usage of thick plate to avoid calculation of prying force, it leads to low ductility and therefore, it is unsuitable for seismic design. The emphasis on prying action into account in the design of bolted connections is given in /2/ (Rui Bai), where many design equations are discussed and compared in Chinese, AISC and HK manuals or codes. The second direction is dedicated to connections subjected to cyclic loading. Sumner /3/ performed cyclic tests on extended end-plate moment connections which showed that the four bolts unstiffened- and the eight bolts stiffened end-plate moment connections meet the requirements for use in seismic regions. Several investigations of the large capacity end-plate joints have been conducted to provide a design method, /4, 5/, which lead to be specified in the American code, /7/.

In recent years, the proposed design methods of these joints are accompanied with finite element models and results. The 3D finite element model is presented in /7/ (Dessouki) to model the behaviour of the extended end-plate moment connections on two configurations: four bolts and extended with multiple rows.

Experimental research is of major importance because it provides the best verification of analytical or numerical models. Strain-stress measurements, /8/, stand for very desirable results in structural analysis of different types of frames. Experimental studies of end-plate connections are used to investigate its parameters both in statics and dynamics problems. It is shown in /9/ that the beam web hole in flush end-plate connections allows the plastic hinge to move away from the connection zone toward the connection beam, which is desirable in seismic design provisions.

In this paper, experimental study is performed to obtain the stress state of the simple extended unstiffened end-plate moment connection with 6 bolts (as depicted in Fig. 1). Given are basic design requisitions of the joint which are implemented in the experimental study in order to include prying effects on the end-plate connection, along with finite element analysis (FEA) of the postulated model. Thus, numerical and experimental studies of the title problem are performed, as good practice in structural analysis, /10/.

MODEL DEFINITION

The adopted testing model includes a beam IPN 160 (DIN 1025-1) which is connected to the column IPE 270 (EURONORM 19-57). All steel members are made of structural steel S235 with yield strength f_y = 235 MPa, ultimate tensile strength f_u = 360 MPa, modulus of elasticity E = 210000 MPa and Poisson's ratio ν = 0.3. The bolted connection is non-preloaded with bolts M12-10.9 which have tension resistance of $F_{t,Rd}$ = 60 kN each (EN 1993-1-8).

The input force (F) in the experimental bending test goes from 1 kN to 20 kN (Fig. 3) on the arm of 600 mm.

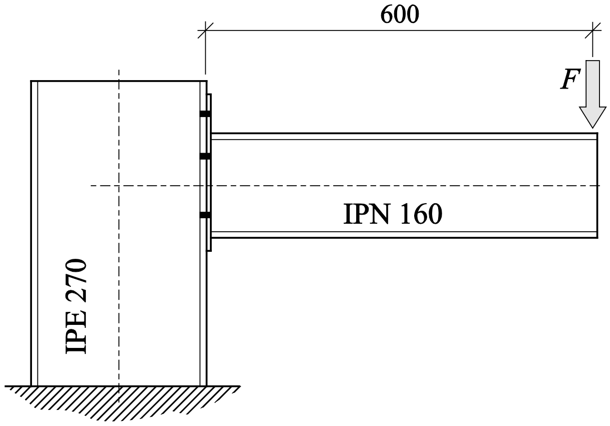

Figure 3. Static load case.

Prying effects are intended to be included on end-plate connection. Hence, the thickness of the end plate is adopted as t_{EP} = 6 mm which is an approximated value to be smaller than theoretical values for minimum thickness intended to prevent prying effects. Simple calculation is used (according to authors) from the Chinese code /2/ and the following Eq.(1):

$$t_{\min} = \sqrt{\frac{3e_2 B_t}{b \cdot f}} \,. \quad (1)$$

Here, B_t ($F_{t,Rd}$ in this case) is the design tensile capacity of a bolt and f is design strength (f_u in this case). Other notations in Eq.(1) are depicted in Fig. 4, along with exact data of the model. According to the previous equation, a thickness of $t_{\min}$ = 15 mm is obtained.

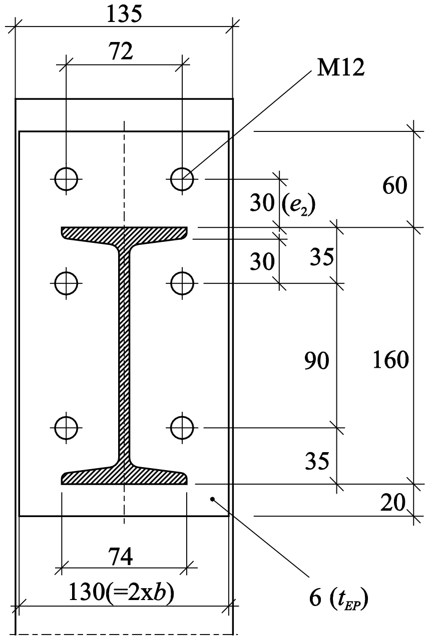

Figure 4. Geometrical parameters of the joint.

FINITE ELEMENT ANALYSIS OF THE JOINT

Finite element analysis (FEA) is performed as the starting point for the insight of the stress state in the end-plate joint. All the steel members are modelled with 4-node shell elements assuming ideal elastic-plastic material. Bolts and welds are modelled as nonlinear springs. The geometry is as postulated in the model definition and the load case is as in Fig. 3, with value of F_{max} = 20 kN.

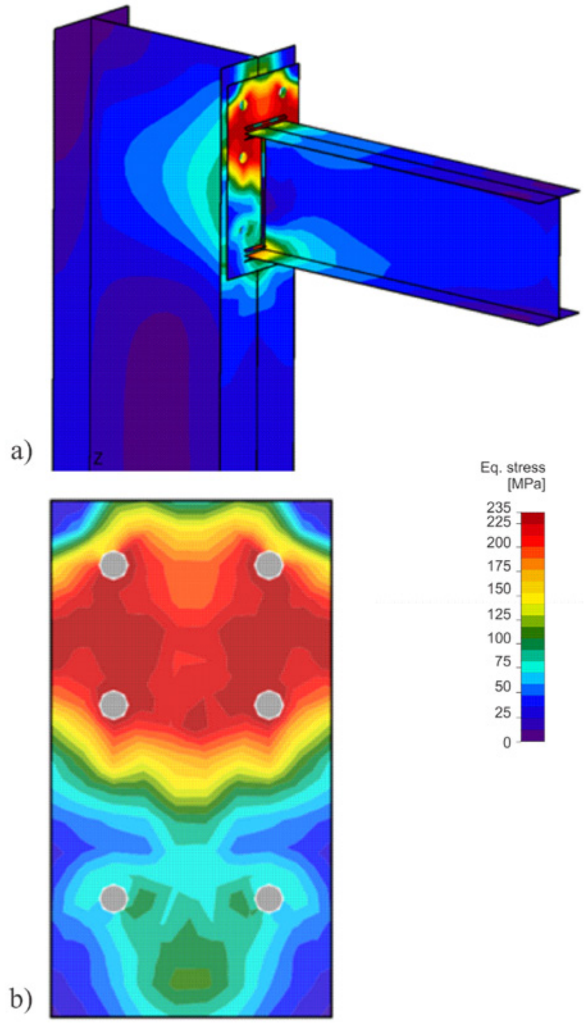

Figure 5. Stress values: a) overall, b) end plate.

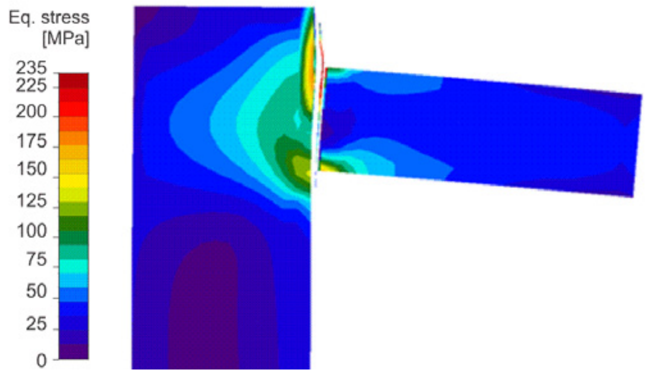

Figure 6. Deformed shape of joint (side view).

Due to the relatively small thickness of the end plate, the prying effect is obvious with high influence on rotational movement of the joint.

Resulting equivalent stresses (von Mises) are calculated and shown below. The resistance of the column web in tension, the column flange in bending and the beam web in tension are higher than end-plate in bending which stands as a base for experimental study. One may see that the highest stress values occur at the end plate in the tension zone of the beam, with maximal values of 235 MPa (close to yield strength) in the middle of the vertical distance of the bolts in the tension zone (Fig. 5b). Hence, they occur in the bending zone of the end plate which complies with the presence of the prying effects.

EXPERIMENTAL RESULTS AND DISCUSSION

The bending test of the end-plate connection is performed on the model, defined previously, with load and geometrical parameters presented in Figs. 3 and 4. The acting force (*F*) is applied with a hydraulic press (Fig. 7a). The strain measurement is arranged on the end-plate and ending beam flanges (Fig. 7b) with a rosette YEFRA-5 (measuring points at M1, M2 and M3) and strain gauges at M4, M5, M6, M7, M8, M9, M10 and M11. The main strain parameters are intended to be obtained in the tension zone (M1, M2, M3, M8, M9) while other measuring points stand only for the control of the conditions during the experiment.

Strains are measured with the device SPIDER 8 which gives the corresponding values of the stresses. In the case of the rosette, the principal stress values are obtained according to following:

$$\sigma_{1,2} = \frac{E}{1-\nu}\frac{\varepsilon_a+\varepsilon_c}{2} \pm \frac{E\sqrt{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_c-\varepsilon_b)^2}}{\sqrt{2}(1+\nu)}, \quad (2)$$

where: ε_a, ε_b, and ε_c are the measuring values of strains in referent directions (M1: *a*, M2: *b*, M3: *c*).

Equivalent stress values are calculated upon the above mentioned values with

$$\sigma_{eq} = \sqrt{\sigma_1^2+\sigma_2^2-\sigma_1\sigma_2} \,. \quad (3)$$

In the following table, the results are obtained for stresses at measuring points along with calculated values of stresses at the placed rosette for values of acting load in the range of 1-20 kN.

It is obvious that the highest values of the stress occur at the tension zone of the joint, on the upper part of end-plate which stands here as the critical point of the joint. For the maximal acting force of *F* = 20 kN, the equivalent stress at the placed rosette reaches 235 MPa which is close to yield stress. Also, there is a difference between the values of stresses in the beam where the pressured flange has higher values than the tension flanges which is affected with flexibility of the end-plate.

If compared with values in Fig. 5, at the location between the horizontal distance of the upper bolts, the experimentally obtained stresses have higher values. So, one may expect that the values in the middle of the tension zone of the end-plate would be even higher than 235 MPa which is obtained by FEA.

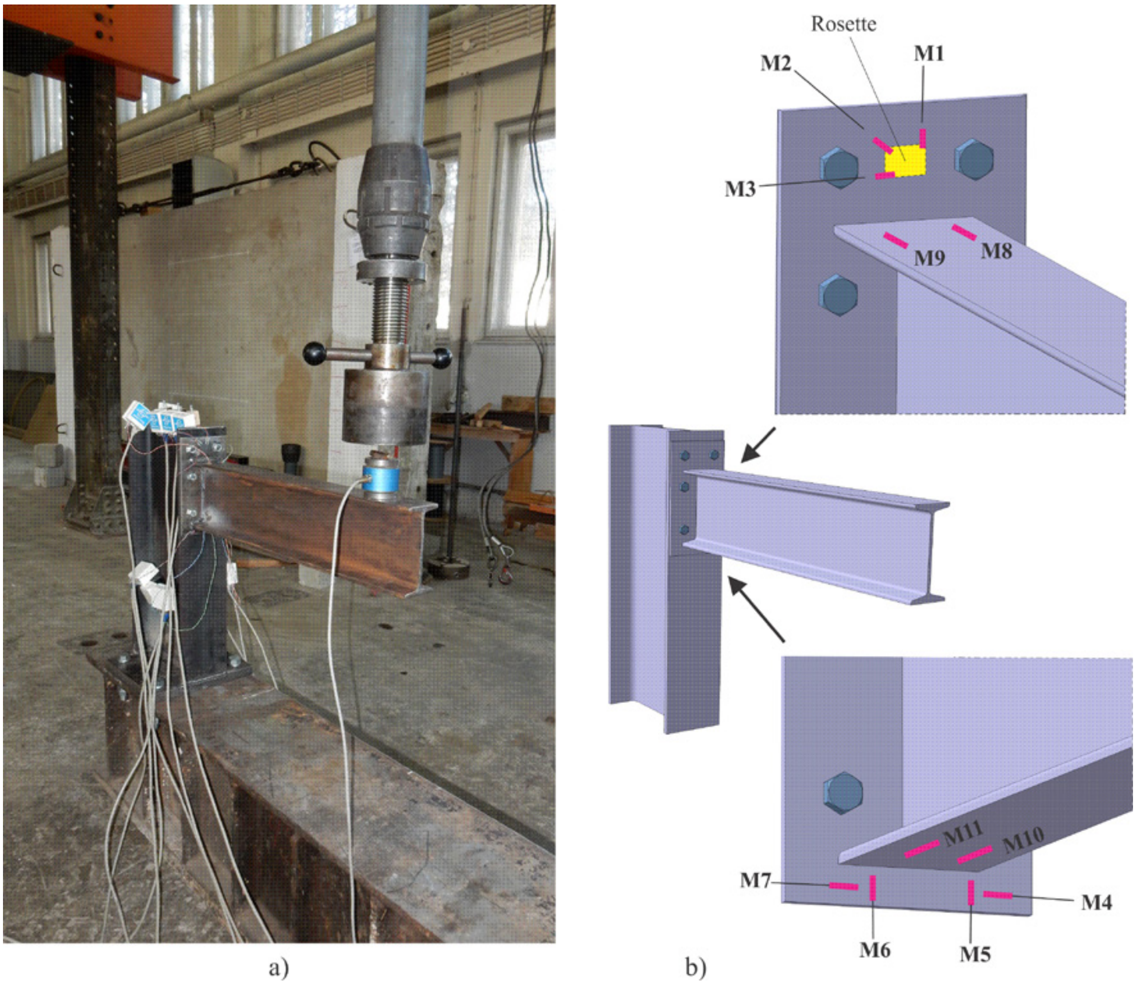

Figure 7. a) Experimental setting; b) location of the measuring points.

Table 1. Stress values at measuring points.

F	M1	M2	M3	σ_1	σ_2	σ_{eq}	M4	M5	M6	M7	M8	M9	M10	M11
kN	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
1	3	3	2	4	3	4	0	0	0	-1	9	7	0	-1
2	6	5	3	8	6	7	-1	-1	-1	-2	17	15	-1	-2
4	11	9	7	14	11	13	-2	-2	-3	-4	34	28	-4	-5
6	14	14	12	20	17	19	-5	-4	-5	-7	46	40	-13	-8
8	13	17	17	24	20	22	-7	-5	-6	-11	61	53	-20	-13
10	2	12	21	24	10	21	-8	-7	-8	-15	64	59	-30	-25
12	-9	11	28	28	-1	28	-12	-8	-10	-19	67	60	-49	-43
14	-39	5	46	38	-28	57	-16	-9	-12	-23	68	62	-66	-68
16	-80	-1	73	54	-64	102	-20	-11	-13	-28	71	65	-88	-82
18	-131	-11	107	75	-108	160	-29	-12	-16	-38	75	69	-113	-109
20	**-195**	**-21**	**156**	**107**	**-163**	**235**	**-41**	**-17**	**-20**	**-49**	**80**	**72**	**-140**	**-135**

CONCLUSION

The experimental bending test is performed in the case of a 6-bolt extended end-plate moment connection with an accompanied FEA. Although FEA can be a worthy tool for this kind of analysis, it needs appropriate and special modelling of the engaged elements, i.e. requires good understanding of the behaviour of the joint to avoid misleading results. Generally, it is shown that all the elements of the joint need to be properly designed with emphasis on bolts and the end-plate. The end-plate is often unfairly disregarded in calculations. It is obvious from the experiment that its thickness has a high influence on the stress level in the joint which affects the integrity of the moment connection. Thus, the stiffness of the joints depends on all of the belonging structural elements which should be especially considered in the investigation of the dynamic behaviour of the structure as a whole.

ACKNOWLEDGEMENT

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ESIS ACTIVITIES

CALENDAR OF CONFERENCES, TC MEETINGS, and WORKSHOPS

July 1-2, 2019	TC12 Annual Meeting The 1st International Symposium on Risk Analysis and Safety of Complex Structures and Components (IRAS 2019)	Porto, Portugal	link
July 15-17, 2019	TC14 Meeting International Conference on Stents: Materials, Mechanics and Manufacturing	London, UK	http://moamrg.co.uk/ICS3M2019
September 4-6, 2019	First European Conference Structural Integrity of Additively Manufactured Materials	Trondheim, Norway	https://www.esiam.eu/
September 13-15, 2019	6th Summer School on Fracture Mechanics	Cracow, Poland	http://summerschool2019.tu.kielce.pl/
November 13-15, 2019	TC11: 4th International Workshop on Thermo-Mechanical Fatigue	Berlin, Germany	link
March 30 - April 3, 2020	VAL4, 4th International Conference on Material and Component Performance under Variable Amplitude Loading	Darmstad, Germany	First Announcement
June 27–28, 2020	7th Summer School on "Fracture Mechanics and Structural Integrity"	Funchal, Madeira, Portugal	https://www.ecf23.eu/
June 29–July 3, 2020	23rd European Conference on Fracture - ECF23	Funchal, Madeira, Portugal	https://www.ecf23.eu/
September 6-10, 2020	TC4 Meeting - Fracture of Polymers, Composites and Adhesives	Les Diablerets, Switzerland	link