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NAJNOVIJE EVROPSKE PREPORUKE ZA PRORAČUN ŠIROKIH VEZA GREDA- STUB SA ČEONOM PLOČOM

Rezime:

Veze sa širokom čeonom pločom, odnosno sa četiri zavrtnja u redu imaju značajnu primenu u čeličnim konstrukcijama u zgradarstvu. Međutim, trenutna verzija evropskog standarda EN 1993-1-8, ne daje preporuke za projektovanje ovakvih veza, već se ograničava samo na primenu uskih veza. Proteklih godina širom Evrope su vršena istraživanja sa ciljem da se proširi primena evrokoda i na veze sa širokim čeonim pločama. U ovom radu su prikazana najnovija istraživanja u ovoj oblasti, kao i osnovne specifičnosti proračuna nosivosti momentne veze sa četiri zavrtnja u jednom redu.

Ključne riječi:

veza greda-stub, čeona ploča, široka veza, T-element, Evrokod 3.

THE LATEST EUROPEAN RECOMMENDATIONS WITH REGARDS TO BEAM-COLUMN END PLATE CONNECTION

Summary:

Connections made by use of wide end plates, i.e., by means of four bolts in one row are widely used in steel structures, i.e., in building engineering. On the other hand, the applicable version of European standard EN 1993-1-8, does not provide recommendations for designing of such connections but rather limits itself to application of somewhat narrow bonds). Extensive research has been conducted in recent years throughout Europe in order to extend implementation of Eurocode with regards to connections made by wide end plates. This paper will show the latest research conducted in this engineering field, as well as key calculation points relating to resistance of a rigid joint made by use of four bolts in one row.

Key words:

Beam-to-column connection, end plate, wide connection, T-element, Eurocode 3

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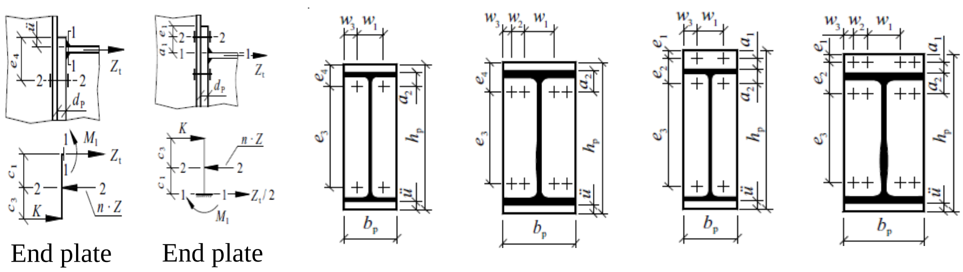
1. GENERAL DATA

Rigid joint performed by an end plate and top quality bolts represents both one simple and rational solution. Such connection can be applied at joints between beam supports and columns, prefabricated splices and supports' connections at an adequate angle (grillage structures). Complex behaviour of such a connection depends on numerous parameters which affect its resistance such as: number, arrangement and diameter of bolts, end plate dimensions, both beam and column cross section dimensions, steel mechanical properties, bracing and column base connections.

2. RETROSPECTION OF RESEARCH CONDUCTED IN THE PAST

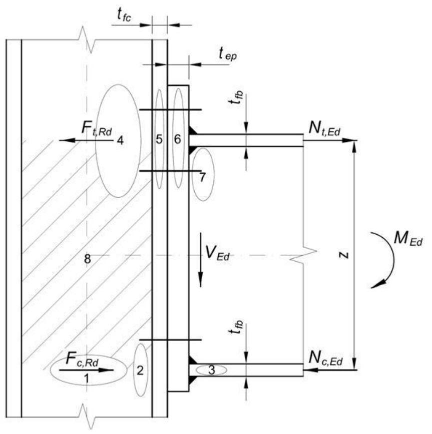
Recommendations regarding calculation of rigid joint by use of an end plate applicable in building engineering (DSTV, 1978 - *Typisierte Verbindungen im Stahlochbau*) [1] were published in Germany back in 1978. According to such recommendations, 4 types of connections were defined (image 1): end plates with an overhang; with two bolts (A1) and four bolts in a row (A2) and end plates with no overhang; with two bolts (B1) and four bolts in a row (B2). Connections made by use of four bolts in one row were defined as wide connections. Recommendations in terms of bolts' arrangement, end plate thickness and columns supports were put forward depending on the connection type available. As for connections of type A1 and B1, tension force is the same in all bolts, whereas in connections of A2 and B2 type, due to somewhat bigger deformity of end plate edge parts, the force in external bolts is reduced (by 80%). This standard also allows application of column connection on a base, as well as inclusion of a bracing on a column's web. Models used in the calculation were confirmed through experimental research conducted at the Univeristy of Karlsrue in 1961. These recommendations were directly made part of until recently applicable standard referred to as SRPS U.E7.140/1985 [2].



End plate with no overhang | End plate with an overhang | Type B1 | Type B2 | Type A1 | Type A2

Image1. Types of end plate according to recommendations [1]

According to EN 1993-1-8: Designing of Steel Structures, Part 1-8: Calculation of Connections [3], calculation of rigid joint by use of an end plate and top qulity screws has been made only for narrow connections made by two bolts in one row. Solution to four bolts in one row has not been included in this standrad. Analytical model for which the calculation of beam-to-column connection with an end plate is made, includes the analysis on resistance of all components transferring load at three typical stress zones: tension, compression and shearing. Resistance of a specific tension zone is defined as a resistance of the weakest component in such a zone. It is important to highlight the fact that on no account is a resistance of seams to be the weakest component, which is achieved by adequate selection of seam thickness by meeting the level of maximal tensions. Components of one rigid joint made between the beam and column by use of an end plate with an overhang are displayed in image 2.

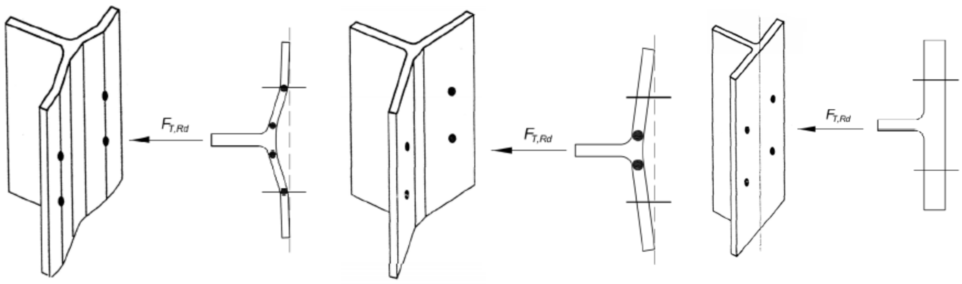


Zones	Component connections
Compression zone	1. Web buckling resistance 2. Web compression resistance 3. Compression resistance of a beam flange
Tension zone	4. Web tension resistance 5. Web flange flexural resistance and bolt tension resistance (T-element) 6. End plate flexural resistance and bolt tension resistance (T-element) 7. Web tension resistance
Shear zone	8. Web shearing surface resistance

Image 2. Componenets of rigid joint between beam-column performed by use of end plate

In order to simplify calculation of a connection made at a tension zone, the term of equivalent T-element has been introduced so as to calculate the stress resistance of a web flange (or stress resistance of an end plate) and tension resistance of bolts.

Calculated resistance of an equivalent T-element flange is decided based on geometry of a key component which also represents adequate effective length $\Sigma\ell_{eff}$ for the appropriate fracture model. Effective length is different for both individual bolt rows and for groups of bolts, and it represents adequate replacable length of an equivalent T-element which is of exactly the same plastic resistance as the considered model and shape of fracture.



a) Fracture model 1 *b) Fracture model 2* *c) Fracture model 3*

Image3. Fracture models of equivalent T-elements for two bolts in one row [3]

According to EN 1993-1-8 [3] there are three potential mechanisms, i.e., calculated fracture models of equivalent T-element with two bolts in a row:

- **fracture model 1** – fracture amidst complete plasticifaction of T-element base, typical of either web flange or of end plates of somewhat smaller thickness with an accentuated lever mechanism (image 3a);

- **fracture model 2** – fracture of bolts accompanied by plastification of T-element flange is typical of either web flange or of end plates of average thickness followed by somewhat insignificant lever effect (image 3b);

- **fracture model 3** - fracture of bolts, typical of either web flange or of end plates of great thickness where there is no lever effect (image 3c).

Rigid joint performed by wide end plates and four bolts in a row is reasonably applied in building engineering, most of all at connections made between wide beam supports and a column. If we bear in mind the complexity of stress-deformation condition in all typical zones of this connection, the apparent understatement present in currently applicable European standard [3] makes its application even more difficult.

Europe has seen some intesified research in the last couple of years in terms of behaveour of such connections in an atempt to both implement and standardize obtained results. The most significant contributions were given by Weynand in 2008, and three years later by Demonceau [4]. Analytical formulae put forward intended for the calculation of rigid joints by use of four bolts in one row were confirmed in experiments conducted within AiF-Project 15059 at Univeristy of Dortmund, Univeristy of Aachen and Univeristy of Köln. The aforementioned research will be published in 2013. German standard DIN EN 1993-1-8 [5] Item 6.2.4 makes reference to results of specified research and to defined fracture models.

3. COMPARATIVE ANALYSIS OF BOTH NARROW AND WIDE END PLATE RIGID JOINTS AND CALCULATION OF RESISTANCE

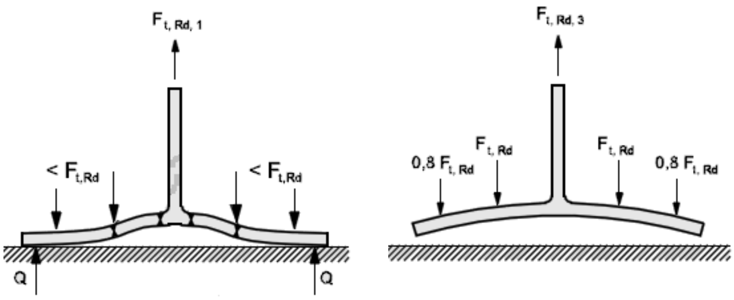
As there are four bolts in one row and difference in behaviour of such connections when compared to connections with two bolts in one row, it is important to define new fracture models for wide connections made with an end plate and also to define new formulae so as to calculate resistance of an equivalent T-element.

Demonceau [4] defines 3 fracture models in an equivalent T-element with four bolts in one row (image 4). Fracture models 1 and 3 are similar to solution to two bolts in one row. In analytical terms, fracture model 1 represents plastification of T-element flange between the web and bolts sitting closer to T-element web. Fracture model 3 defines bolt fracture with some difference when compared to calculated resistance at the connection made with two bolts in one row. When bolts, which are closest to T-element web, reach calculated tension resistance due to deformability of T-element flange, the force in external bolts reaches altogether 80% of tension resistance as it was defined in until recently applicable standard SRPS U.E7.140/1985 [2].

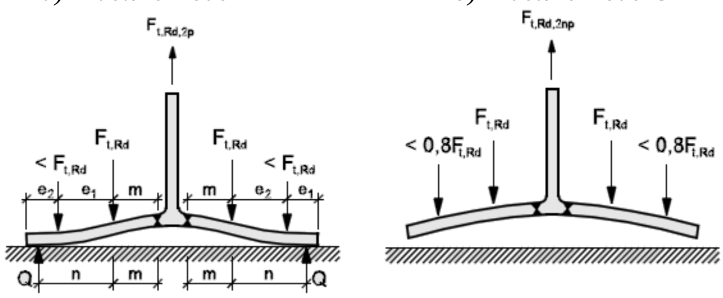
Fracture model 2 is such to include simultaneous plastification of T-element flange and fracture of internal bolt row. In this case, calculated resistance of T-element with two bolts in one row cannot be implemented directly to T-element with four bolts in one row due to external bolts, i.e., due to bolts located near the bottom of T-element flange. Specified fracture model also defines other fracture model subgroups such as:

- **fracture model „2p“,** which meets polygonal fracture form with forces amidst lever effect at ends of T-element (image 4c);

- **fracture model„2np“** which meets both circular and polygonal fracture form with no forces amidst lever effect at T-element ends (image 4d).



a) Fracture model 1 *b) Fracture model 3*



c) Fracture model 2- with lever forces *d) Fracture model 2- with no lever forces*

Image 4. Fracture models of equivalent T-element with four bolts in one row [4]

Calculated resistance of an equivalent T-element for all three fracture models has been dipslayed in table 1, as well as resistance for the connection made by two bolts in one row to EN 1993-1-8 [3] and for four bolts in one row, to [4].

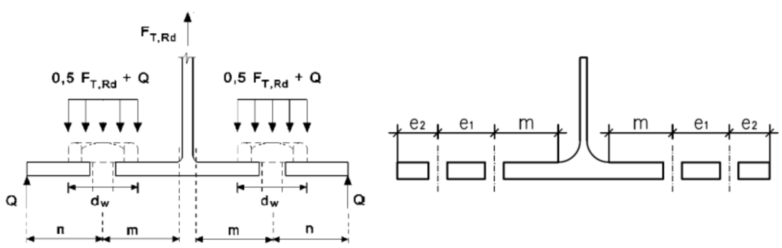


Image 5. Defintion of parameters for T-element fitted with two [3] and four bolts [4] in a row

In order to decide calcuation values of plastic resistance moment of a cross section of an equivalent T-element flange, it is important to define effective lengths of a replacable T-element. Because there are four bolts in one row, it is necessary to define new formulae for effective lengths. There are many different formulae which allowed us to define all potential fracture lines. Table 2 only shows one part of formulae for effective lengths of an equivalent T-element, for both circular and polygonal fracture form, according to [4].

Table 1. Calculation value of equivalent T-element for two [3] and four bolts in one row [4]

Fracture models	T-element fitted with two bolts	T-element fitted with four bolts
Model 1	$F_{T,1,Rd}=\frac{(8n-2e_w)M_{pl,1,Rd}}{2mn-e_w(m+n)}$	$F_{T,1,Rd}=\frac{(8n-2e_w)M_{pl,1,Rd}}{2mn-e_w(m+n)}$
Model 2	$F_{T,2,Rd}=\frac{2M_{pl,2,Rd}+n\Sigma F_{t,Rd}}{m+n}$	$F_{T,2,Rd}=\min(F_{Rd,2,p};F_{Rd,2,np})$ $F_{Rd,2,p}=\frac{2M_{pl,2,Rd}+\frac{\sum B_{t,Rd}}{2}(\frac{n_1^2+2n_2^2+2n_1n_2}{n_1+n_2})}{(m+n_1+n_2)}$ $F_{Rd,2,np}=\frac{2M_{pl,1,Rd}+\frac{\sum B_{t,Rd}}{2}n_1}{(m+n_1)}$
Model 3	$F_{T,3,Rd}=\sum F_{t,Rd}$	$F_{T,3,Rd}=\frac{\sum F_{t,Rd}}{2}(1+0{,}8)=0{,}9\sum F_{t,Rd}$

$M_{pl,1,Rd}=0{,}25\sum \ell_{eff,1}t_f^2 f_y/\gamma_{M0}$,

$M_{pl,2,Rd}=0{,}25\sum \ell_{eff,2}\, t_f^2\; f_y/\gamma_{M0}$,

where:

$M_{pl,1,Rd}$ means plastic resistance moment of a flange cross-section at plastification zone for fracture model 1;

$M_{pl,2,Rd}$ means plastic resistance moment of a flange cross-section at plastification zone for fracture model 2.

$\sum F_{t,Rd}$ total resistance $F_{t,Rd}$ for all bolts fitted to T-element,

$e_w= d_w/4$, where d_w is either shim diameter or width through relevant points at the head of either bolt or nut,

for T-element with two bolts in a row n is defined in image 5, whereas $n\leq 1{,}25m$,

for T-elements with four bolts in a row $n= e_1+e_2$ ali $n\leq 1{,}25m$, $n_1= e_1$ i $n_2= e_2$, whereas $n\leq 1{,}25m+n_1$ as displayed in image 5.

It is crucial to highlight that there is a key difference in defining an equivalent T-element for rows of bolts located both above and below the tied flange:

- in the event of bolts located above the flange (bolts at an overhang of čeone ploče) T-element is defined as a T-element with two bolts (T-element web is in fact a beam), the presence of four bolts in one row only affects values of effective lengths,

- in the event of bolts located right below the base, the observed element is fitted with four bolts in one row (T-element web is the beam web).

Table 2. Effective lengths with four bolts in one row u [4]

	Circular fracture form	Polygonal fracture form
External bolt row	$\ell_{\text{eff, I}} = 4\pi m_{\text{x}}$ $\ell_{\text{eff, II}} = \pi m_{\text{x}} + w + 2e_1$ $\ell_{eff,III} = 2(\pi m_x + e_1)$ $\ell_{eff,IV} = \pi m_x + 2(e_1 + e_2)$ $\ell_{eff,c} = \min(l_{eff,I}; l_{eff,II};$ $l_{eff,III}; l_{eff,IV})$	$\ell_{eff,V} = 2m_x + 0{,}625e_x + (e_1 + e_2)$ $\ell_{eff,VI} = 4m_x + 1{,}25e_x + e_1$ $\ell_{eff,VII} = 2m_x + 0{,}625e_x + e_1 + 0{,}5w$ $\ell_{eff,VIII} = 0{,}5(2e_1 + 2e_2 + w)$ $\ell_{eff,VIII} = 8m_x + 2{,}5e_x$ $\ell_{eff,c} = \min(l_{eff,V}; l_{eff,VI}; l_{eff,VII};$ $l_{eff,VIII}; l_{eff,IX})$
Internal bolt row	$\ell_{eff,c} = l_{eff,X} = 4\pi m_1$	$\ell_{eff,nc} = l_{eff,XI} = \alpha m_1$
Internal bolt row observed as part of a bolt group	$\ell_{eff,XII} = \pi m_x + p + e_1^{'}$ $\ell_{eff,XIII} = 2(\pi m_1 + p)$ $\ell_{eff,c} = \min(l_{eff,XII}; l_{eff,XIII})$	$\ell_{eff,XIV} = \alpha m_1 + 0{,}5p \quad (2m_1 + 0{,}625(e_1^{'} + e_2^{'}))$ $\ell_{eff,nc} = l_{eff,XIV}$

Dimensions used in formulae for deciding effective lengths for the equivalent T-element fitted with four bolts in one row, as well as typical forms of fracture have all been displayed in image 6.

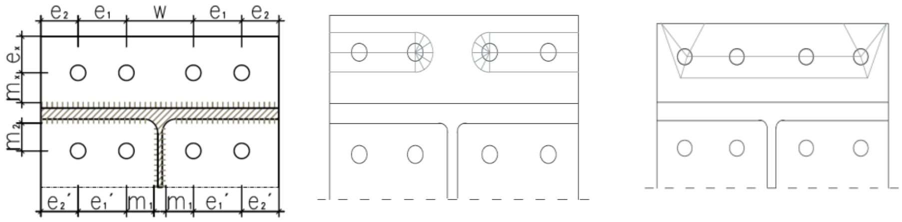


Image 6. Definition of parameters used for deciding effective lengths and individual forms of fracture [4]

Behaviour of rigid joints with four bolts in one row has been widely analysed in numerous doctoral theses across Europe. Björn Schmidt [6] conducted experimental research at the University of Dortmund on how the rigid joint behaves with two beam supports and one end plate, fitted with both two and four bolts in one row. The experiment showed that some parameters had changed, such as the size of beam members, thickness of end plates and bolt diameters. In addition, parameter analysis regarding behaviour of such joints was presented and conclusions were drawn on slab-bolt diameter thickness joint (t_p/d_0) and on fracture model of an equivalent T-element. This thesis also specified some formulae which defined equivalent T-element length for both circular and polygonal fracture form.

4. CONCLUSION

Behaviour of rigid joints with four bolts in one row represents one area of scientific research of great interest where both significant and experimental tests have been carried out across Europe in order to extend the field of application of currently applicable technical standard. It is expected that the results obtained from such research would soon become part of EN 1993-1-8, i.e., before the new generation of Eurocodes on structure emerge, expected in 2020. Until then, calculation of such connections in every day practice can be based on recommendations which have been briefly displayed in this Study.

LITERATURE

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