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BOLTED CONNECTIONS ON CIRCULAR END PLATES

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Abstract: *Bolted connections on circular end plate are used on column with circular pipe cross-section joints, ducts joints and other member joint. SR EN 1993-1-8:2006 and technical specialized literature do not contain reglementations in the case of circular end plate. This code develops in detail the rectangular end plate calculus, which presents conceptual deficiencies, with negative effects on the structural security (end plate plastification scenarios, plastic distribution of the bolt tensile forces). This paper presents the circular end plate constitution and calculus, as required in steel structural designing; the relations are based on the end plate elastic behaviour and on elastic distribution of the bolt tensile forces.*

Key words: *steel, member, end plate joint, connection, bolt.*

1. Application Field

- column with circular hollow section joints;
- duct joints;
- other member joints.

2. Composition and Calculation Principle

Joints components:

- circular end plate, transmitting stresses from structural member to bolts;
- bolts;
- member active area (compression stresses zone balancing tension stresses in bolts.

Calculation parameters:

- active area length [z_0];
- resulting tension stresses in bolts [N_a];
- resulting compression stresses on active area of structural member cross section [N_c];
- rows number of active bolts.

Equations system:

- plane sections hypothesis equation, in elastic calculus of joint components;
- equivalence equation between strains and stresses [M_y; N];
- the equations system has no explicit results; consequently an iterative solving is necessary, which is difficult for the designing practice.
- a calculus solution, including the following stages is suggested in this work:
  - member strength checking in joint adjacent section;
  - rotation centre and active area length

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determination;
- stresses determination and checking in joint section.

3. Member strength checking

- The strength checking is performed in joint adjacent section, in composed [M_y; N];
- The parameters [m_y; n; ρ] are to be used in the joint components calculus;
- In the calculus relations [the algebric sign] is used as follows:
  - [upper algebric sign] – when [N] is a tension stress;
  - [lower algebric sign] – when [N] is a compressing stress.
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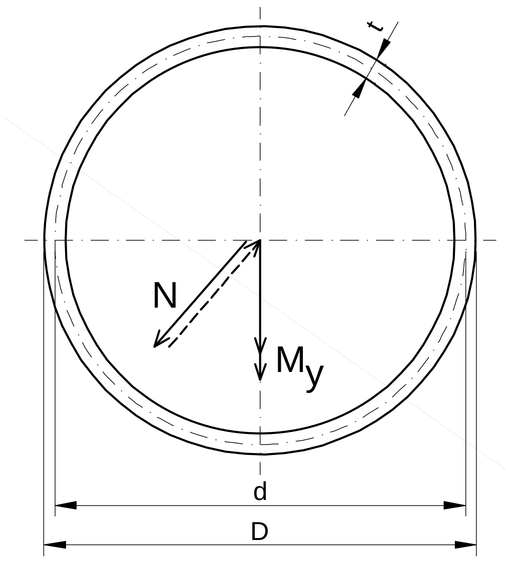


Fig. 1

D – outer diameter
t – thickness
d – middle diameter
d = D – t

$$\alpha_0 = 1 - \frac{2 \cdot t}{D}$$

- Elastic cross-section characteristics:

$$A = \frac{\pi \cdot D^2}{4} \cdot \left(1 - \alpha_0^2\right)$$

$$W_{ey} = \frac{\pi \cdot D^3}{32} \cdot \left(1 - \alpha_0^4\right)$$

$$\rho = \frac{W_{ey}}{A}$$

ρ - represents central core radius

- The design moment resistance and tension resistance:

$$M_{ey} = \alpha_{ey} \cdot R$$

$$N_e = A \cdot R$$

- Checking:

$$m_y = \frac{M_y}{M_{ey}} \leq 1,0$$

$$n = \frac{N}{N_e} \leq 1,0$$

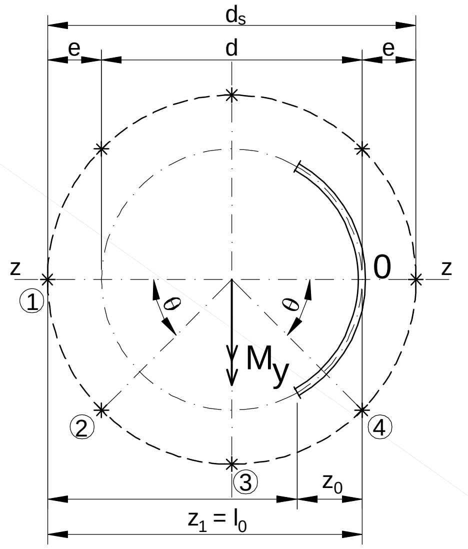
$$m_y + n \leq 1,0$$

4. Active area length evaluation

- The active area means compression zone of member cross-section, defined by the length [z_0], (fig. 2a);
- The active-area length [z_0] is evaluated by considering the rotation center [0] on the middle diameter [d] of the hollow section (fig. 2a);
- The [d_s] circle diameter on which the bolts are located,

$$d_s = d + 2 \cdot e$$

where: [e] – represents the distance to the hollow section.



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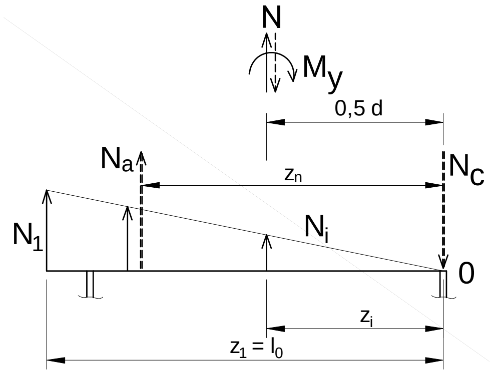

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Fig. 2.

- Characteristics in $[z_i]$ coordinates

  $z_1 = l_0$

  $z_2 = 0.5 \cdot d + 0.5 \cdot d_s \cdot \cos\theta$

  $z_3 = 0.5 \cdot d$

  $z_4 = 0.5 \cdot d - 0.5 \cdot d_s \cdot \cos\theta$

  $$\sum z_i = z_1 + 2 \cdot \left[z_2 + z_3 + \ldots \right]$$

  $$\sum z_i^2 = z_1^2 + 2 \cdot \left[z_2^2 + z_3^2 + \ldots \right]$$

where:

l_0 – represents the distance between the rotation centre [0] and the maximum tension bolt;

θ – bolt angle;

The calculus includes only the $[z_i]$ coordinates with positive algebric sign.

- Position of the resulting tensile forces $[N_a]$ in bolts,

  $$z_n = \frac{\sum z_i^2}{\sum z_i}$$

  $$N_a = \left[m_y \pm \alpha_1 \cdot n \right] \cdot \frac{M_{ey}}{z_n}$$

where:

$$\alpha_1 = \frac{0,5 \cdot d}{\rho}$$

[upper algebric sign] – when [N] is a tensile force;

- The resulting compression forces $[N_c]$

  $$\alpha_2 = \frac{z_n - 0,5 \cdot d}{\rho}$$

  $$N_c = \left[m_y \mp \alpha_2 \cdot n \right] \cdot \frac{M_{ey}}{z_n}$$

where:

  [upper algebric sign] – when [N] is a tensile force;

- Checking in [N],

  $N_a - N_c = \pm N$

  The checking is implicitely performed if $[N_a; N_c]$ are right calculated

- Checking in [M],

  $N_a \cdot \left(z_n - 0,5 \cdot d \right) + N_c \cdot 0,5 \cdot d = M_y$

  The checking is implicitely performed if $[N_a; N_c]$ are right calculated

- Maximum force $[N_1]$ (fig. 2b),

  $$N_1 = N_a \cdot \frac{z_1}{\sum z_i}$$

- Bolts necessary diameter,

  $$d = 1,3 \cdot \left[\frac{1,25 \cdot N_1}{R_{ib}} \right]^{0,5}$$

where: $[R_{ib}]$ – represents the design value of resistance in $[\sigma]$ stresses.

- Bolts checking,

  $N_{e1} = A_s \cdot R_{ib}$

$$n_1 = \frac{1,25 \cdot N_1}{N_{e1}} \le 1,0$$

- Evaluation $[z_0]$,

$$\alpha = 0,75 \cdot \frac{n_1}{m_y \mp n} \cdot \frac{R_{ib}}{R} \cdot \frac{A_s}{A_b}$$

$$\xi = \frac{1}{1+\alpha} \cdot \frac{z_1}{d}$$

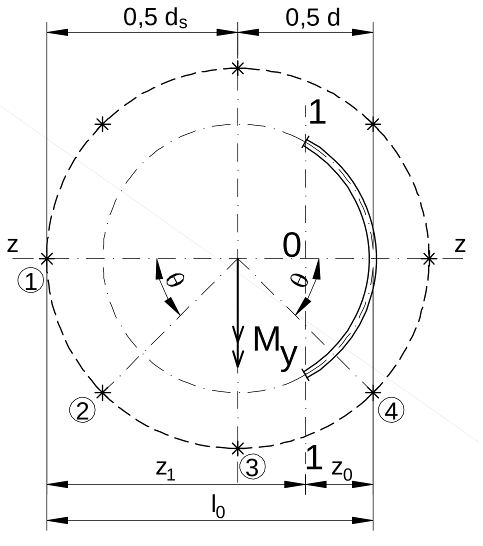
$$z_0 = \xi \cdot d$$

where:
$[R]$ represents the design value of structural steel resistance;
$[R_{ib}]$ – design value of bolt resistance;
$[A_s]$ – tensile stress area, of a bolt;
$[A_b]$ – nominal area of a bolt;

$$A_b = \frac{\pi \cdot d^2}{4}$$

5. Calculus characteristics of joint section

- The calculus characteristics are determined as per axe [1-1], which defines the member cross-section compression area (fig. 3a).



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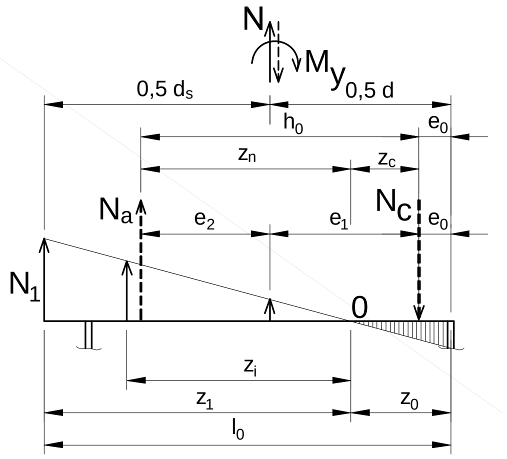

b

Fig. 3.

- Characteristics in $[z_i]$ coordinates

$z_1 = [l_0] - z_0$
$z_2 = [0.5 \cdot d + 0.5 \cdot d_s \cdot \cos\theta] - z_0$
$z_3 = [0.5 \cdot d] - z_0$
$z_4 = [0.5 \cdot d - 0.5 \cdot d_s \cdot \cos\theta] - z_0$

$$\sum z_i = z_1 + 2 \cdot \left[z_2 + z_3 + ...\right]$$

$$\sum z_i^2 = z_1^2 + 2 \cdot \left[z_2^2 + z_3^2 + ...\right]$$

only the $[z_i]$ coordinates having positive algebric sign are introduced in calculus.

- $[z_n]$ position of the resultant $[N_a]$,

$$z_n = \frac{\sum z_i^2}{\sum z_i}$$

- $[e_0]$ position,

$$e_0 = \left[0,010 + 0,240 \cdot \xi\right] \cdot d$$

- $[z_c]$ position of the resultant $[N_c]$,

$z_c = z_0 - e_0$

- $[h_0]$ level arm,

$h_0 = z_n + z_c$

- $[A_0]$ equivalent area of the compression surface of the member cross-section,

- for $[\xi \le 0.5]$,

$$A_0 = \frac{\arccos(1 - 2 \cdot \xi)}{2 \cdot \pi} \cdot A$$

- for [ξ > 0.5],

$$A_0 = \left[0,250 + \frac{\arcsin(2 \cdot \xi - 1)}{2 \cdot \pi}\right] \cdot A$$

where:
[ξ] – represents active zone coefficient;
[A] – member cross-section area.

6. Efforts. Joints members resistance checking.

- $[N_a]$ resultant of tensile efforts in bolts.

$e_1 = 0.5 \cdot d - e_0$

$$\alpha_1 = \frac{e_1}{\rho}$$

$$N_a = \left[m_y \pm \alpha_1 \cdot n\right] \cdot \frac{M_{ey}}{h_0}$$

where:
[upper algebric sign] – when [N] is a tensile force.

- $[N_c]$ resultant of compression efforts on the member cross-section active area,

$e_2 = (h_0 + e_0) - 0.5 \cdot d$

$$\alpha_2 = \frac{e_2}{\rho}$$

$$N_c = \left[m_y \mp \alpha_2 \cdot n\right] \cdot \frac{M_{ey}}{h_0}$$

where:
[upper algebric sign] – when [N] is a tensile force.

- Checking in [N] axial force,

$N_a - N_c = \pm N$

- Checking in $[M_0]$ bending moment,

$$N_a \cdot z_n + N_c \cdot z_c = M_y \pm N \cdot (0,5 \cdot d - z_0)$$

- Checking of the bolt with $[N_1]$ maxim effort,

$$N_1 = N_a \cdot \frac{z_1}{\sum z_i}$$

$$N_{e1} = A_s \cdot R_{ib}$$

$$n_1 = \frac{N_1}{N_{e1}} \leq 1,0$$

- Checking of the compressed zone of cross-section member,

$$N_{ec} = A_0 \cdot R$$

$$n_c = \frac{N_c}{N_{ec}} \leq 1,0$$

- $[z_0]$ re-evaluation,

$$\alpha = \frac{n_1}{n_c} \cdot \frac{R_{ib}}{R} \cdot \frac{A_s}{A_b}$$

$$\xi = \frac{1}{1 + \alpha} \cdot \frac{z_1}{d}$$

$$z_0 = \xi \cdot d$$

7. Bolt location on the end plate.

- The location of bolts defines the determining way of the end plate thickness $[t_0]$ (fig. 4),

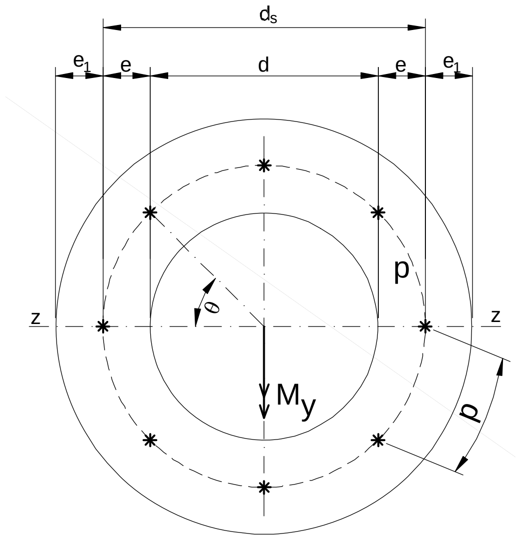

Fig. 4.

- The dimension [e] measured between bolts axis and the medium circle of hollow section,

$$e \geq 0,5 \cdot \left[\sin\frac{\theta}{2} - \frac{d_m}{d}\right] \cdot d$$

where:
[d] – is the medium diameter of hollow section;
$[d_m]$ – medium diameter of bolts head;

[θ] – angle between radius of two bolts consecutive;

$$\theta = \frac{\pi}{2};\ \left|\frac{\pi}{4};\ \frac{\pi}{6};\ \frac{\pi}{8}\right|;\ \frac{\pi}{10};....$$

- The dimension [e_1] measured between bolts axis and the end plate edge,

$$e_1 \geq 1{,}25 \cdot d_m$$

- The distance [p] measured on [d_s] circle,

$$p \leq [2 \cdot e + d_m]$$

$$p = r \cdot \theta \quad \text{(effective distance)}$$

It is recommended to provide end plate stiffness between bolts.

8. The thickness of the end plate.

- The end plate thickness [t_0],

$$t_0 = k_0 \cdot \left[\alpha_0 \cdot n_1 \cdot \frac{R_{ib}}{R} \cdot A_s\right]^{0,5}$$

$$\alpha_0 = \frac{1}{1 + \frac{d_m}{2 \cdot e}}$$

where:

k_0 – dimensioning coefficient

$$n_1 = \frac{N_1}{N_{e1}}$$

- In cases when the level arm effect is taken into account,

$k_0 = \sqrt{\frac{3}{2}}$, for dimensioning through elastic calculus;

$k_0 = 1{,}0$, for dimensioning through plastic calculus.

- In cases when the level arm effect cannot be taken into account,

$k_0 = \sqrt{3}$, for dimensioning through elastic calculus;

$k_0 = \sqrt{2}$, for dimensioning through plastic calculus.

- The level arm effect can be taken into account under the following conditions:

a) Bolts are located as per item 7;
b) The end plate remains plane after welding;
c) The end plate fulfills the contact conditions on erection.

- The end plate thickness [t_0] may be determined by plastic calculus only for secondary members, without imperative requirements on the members continuity in joint.

It is recommended:

$$k_0 = \sqrt{\frac{3}{2}}$$

Conclusions

The calculus proposed in the paper is necessary for practice design, because the codes and technical specialized literature do not contain reglementation in this cases.

The calculus is based on principles entire necessary in calculus connections (elastic behaviour principle, plan sections principle, ...).

Based on these principles we arrived in this paper to a correct calculus favourable for the structural security (active area, maximum efforts in bolts, end plate thickness.

SR EN 1993-1-8:2006 contains in general provisions with negative effects on the structural security.

References

1. *** SR EN 1993-1-8:2006: Eurocode 3*: Design of steel structures – Part 1-8: Design of joints.*
2. *** SR EN 1993-1-1:2006: Eurocode 3*: Design of steel structures – Part 1-1: General rules and rules for buildings.*