The Second Generation Eurocodes

Key changes and benefits through design examples

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Equivalent T-stub in tension for aluminium joint members

Gianfranco De Matteis, Giuseppe Brando

EUROCODES

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EN 1999

Design of aluminium structures

Member method for a bolted end-plate beam-to-column joint

Data:

Beam H 170x314,7x15x15

- h_b = 314,7 mm
- b_b = 170 mm
- t_{wb} = 15 mm
- t_{fb} = 15 mm

Steel bolts M18 – 10.9

- n_b = 8
- d = 18 mm
- A_s = 192 mm
- f_y = 900 MPa
- f_u = 1000 MPa

Column H 250x220x15x14,5

- h_c = 220 mm
- b_c = 250 mm
- t_{wc} = 15 mm
- t_{fc} = 14,5 mm

Alloy EN AW 6060 - T6 *

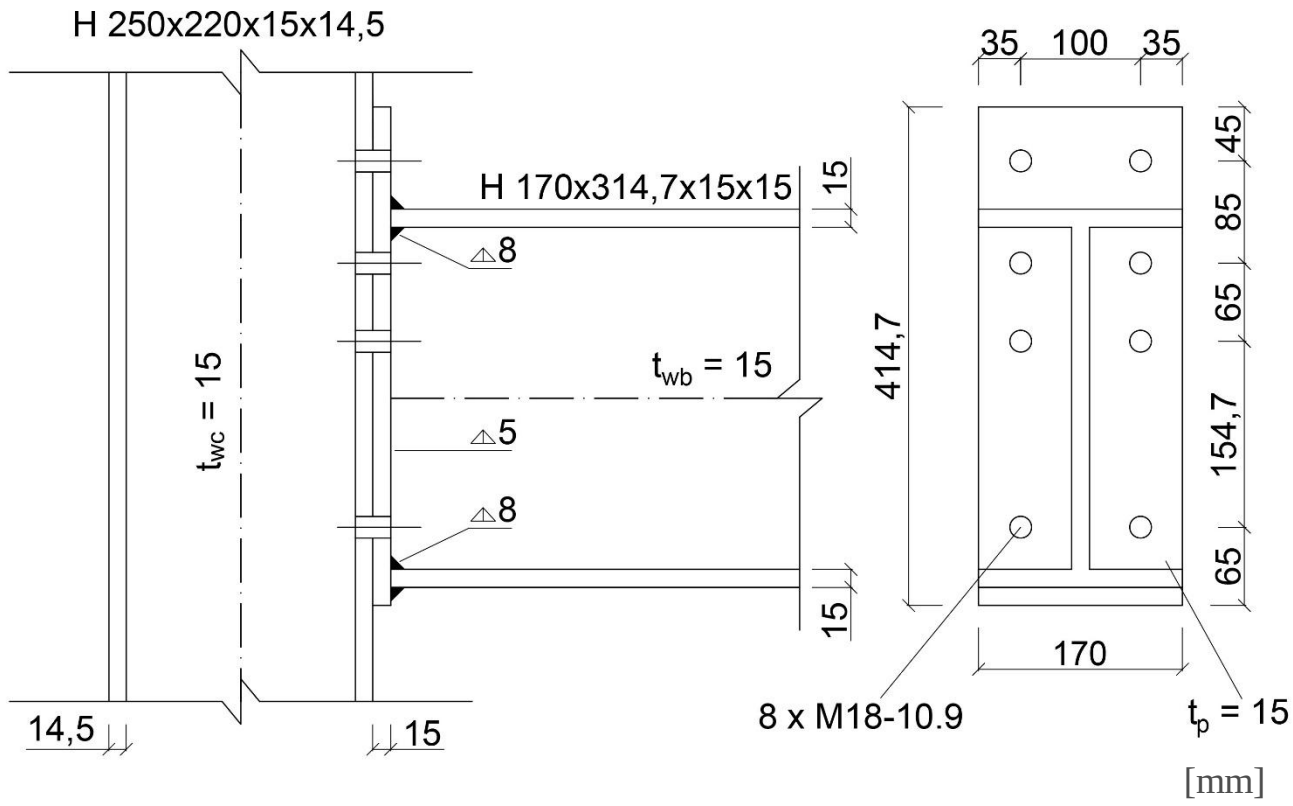
- f_o = 260 MPa
- f_u = 310 MPa
- A = 10 %
- $f_{o,haz}$ = 125 MPa
- $f_{u,haz}$ = 185 MPa

End-plate 170x414,7x15

- h_p = 414,7 mm
- b_p = 170 mm
- t_p = 15 mm

Welds

- MIG-welded fillet welds
- a_b = 8 mm (beam flange to end plate weld throat thickness)
- a_{bw} = 5 mm (beam web to end plate weld throat thickness)



Beam and column made of **extruded aluminium profiles**

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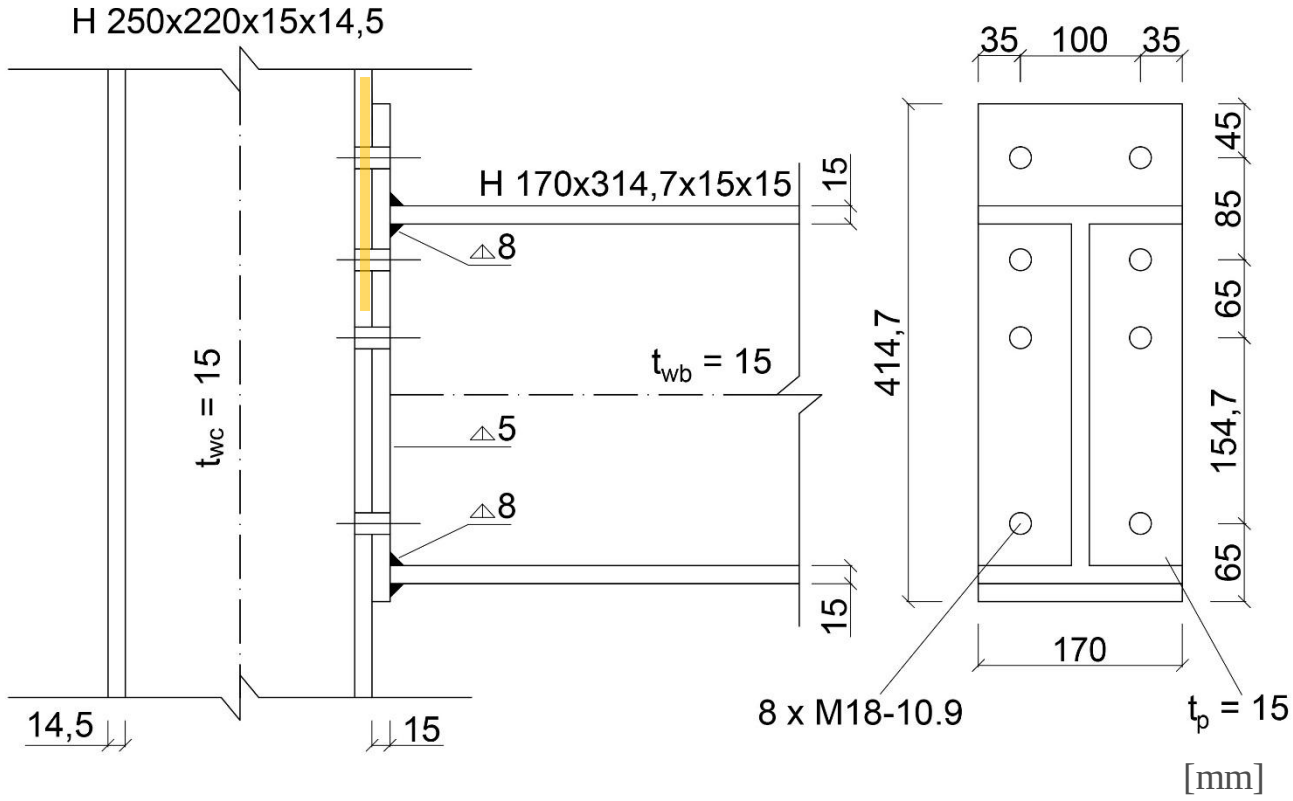
Member method for a bolted end-plate beam-to-column joint

Basic members of the joint:

- Column web panel in shear
- Column web in transverse compression
- Column web in transverse tension
- Column flange in bending
- End-plate in bending
- Column flange and web in compression
- Beam web in tension

= Equivalent T-stub in tension
(section 10.10 of EN 1999-1-1:2003)



Further data:

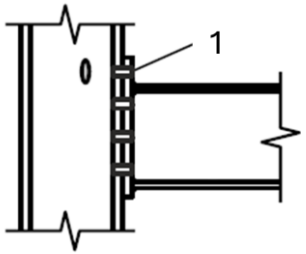
- g = 28,7 mm (Fig.10.36 - EN1999-1-1:2023*)
- e = 35 mm
- e_1 = 45 mm
- p_{1-2} = 85 mm
- p_{2-3} = 65 mm

Resistance evaluation for equivalent T-stub in tension

Effective lengths (*Table 10.8 "Effective length for column flanges"*∗):

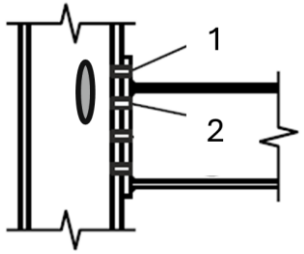
- **Bolt row 1**
  - **Bolt row considered individually – end bolt row**

$l_{eff,cp\,1} = 2\pi g = 180{,}33$ mm
$l_{eff,cp\,2} = \pi g + 2e_1 = 180{,}16$ mm
$l_{eff,cp} = \min(l_{eff,cp\,1}; l_{eff,cp\,2}) = 180{,}16$ mm
$l_{eff,nc\,1} = 4g + 1{,}25e = 158{,}55$ mm
$l_{eff,nc\,2} = 2g + 0{,}625e + e_1 = 124{,}28$ mm
$l_{eff,nc} = \min(l_{eff,nc\,1}; l_{eff,nc\,2}) = 124{,}28$ mm
$\mathbf{l_{eff,1} = \min(l_{eff,cp}; l_{eff,nc}) = 124{,}28\ mm}$
$\mathbf{l_{eff,2} = l_{eff,nc} = 124{,}28\ mm}$



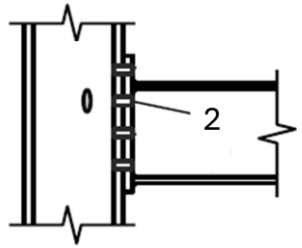
  - **Bolt row considered as a part of a group – first bolt row**

$l_{eff,cp\,1} = \pi g + p = 175{,}16$ mm (con p=p1-2)
$l_{eff,cp\,2} = 2e_1 + p = 175$ mm (con p=p1-2)
$\mathbf{l_{eff,cp} = \min(l_{eff,cp\,1}; l_{eff,cp\,2}) = 175\ mm}$
$l_{eff,nc\,1} = 2g + 0{,}625e + 0{,}5p = 121{,}78$ mm
$l_{eff,nc\,2} = 2e_1 + 0{,}5p = 132{,}5$ mm
$\mathbf{l_{eff,nc} = \min(l_{eff,nc\,1}; l_{eff,nc\,2}) = 121{,}78\ mm}$



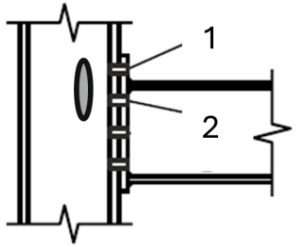
- **Bolt row 2**
  - **Bolt row considered individually – inner bolt row**

$l_{eff,cp} = 2\pi g = 180{,}33$ mm
$l_{eff,nc} = 4g + 1{,}25e = 158{,}55$ mm
$\mathbf{l_{eff,1} = \min(l_{eff,cp}; l_{eff,nc}) = 158{,}55\ mm}$
$\mathbf{l_{eff,2} = l_{eff,nc} = 158{,}55\ mm}$



  - **Bolt row considered as a part of a group – internal bolt row**

$l_{eff,cp} = 2p = 170$ mm (con p=p1-2)
$l_{eff,nc} = p = 85$ mm (con p=p1-2)



- **Bolt row 3 : neglected**

Resistance evaluation for equivalent T-stub in tension

Prying forces (*10.10.2 "Prying Forces in typical T-stub Stand-alone connection"**):

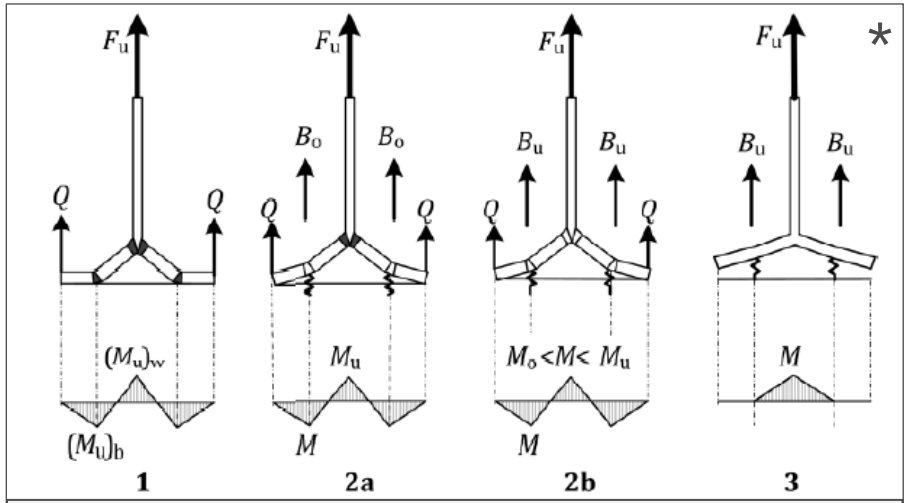
$L_b = 46\ mm$ → Bolt elongation length, equal to the grip length + ½ · (height of the bolt head + height of the nut)

$L_{b,p} = \frac{26 \cdot 4p_2^3 \cdot A_s \cdot n_b}{\sum l_{eff,1} \cdot t_f^3} = 48{,}63\ mm$ → Formula (10.49)

$L_b < L_{b,p}$ → PRYING FORCE ✓ ***Formulae for the case in which prying forces Q develop***

Resistance of T-stub (*10.10.3 "General rules for resistance evaluation"**):

- $F_{u,1,Rd}$ (**Mode 1**: Flange failure by developing four hardening plastic hinges, two of which are at the web-to-flange connection and two at the bolt location)
- $F_{u,2a,Rd}$ (**Mode 2a**: Flange failure by developing two hardening plastic hinges with bolt forces at the elastic limit)
- $F_{u,2a,Rd}$ (**Mode 2b**: Failure with yielding of the flange at the elastic limit)
- $F_{u,2a,Rd}$ (**Mode 3**: Bolt failure)



$F_{u,Rd} = \min(F_{u,1,Rd}; F_{u,2a,Rd}; F_{u,2b,Rd}; F_{u,3,Rd})$

Resistance evaluation for equivalent T-stub in tension

Resistance of T-stub (*10.10.3 "General rules for resistance evaluation"*):

- **MODE 1**
  - **BOLT ROW 1 considered individually**

$$F_{u,1,Rd\,(1)} = \frac{2 \cdot (M_{u,1})_w + 2 \cdot (M_{u,1})_b}{g} = 211{,}85\ \text{kN}$$

  - **BOLT ROW 2 considered individually**

$$F_{u,1,Rd\,(2)} = \frac{2 \cdot (M_{u,1}) + 2 \cdot (M_{u,2})}{g} = 270{,}38\ \text{kN}$$

  - **BOLT ROW 1 + BOLT ROW 2**

$$F_{u,1,Rd\,(1+2)} = \frac{2 \cdot (M_{u,1}) + 2 \cdot (M_{u,2})}{g} = 315{,}68\ \text{kN}$$

- **MODE 2a**
  - **BOLT ROW 1 considered individually**

$$F_{u,2a,Rd\,(1)} = \frac{2 \cdot M_{u,2} + e_e \cdot \sum B_o}{g + e_e} = 210{,}48\ \text{kN}$$

  - **BOLT ROW 2 considered individually**

$$F_{u,2a,Rd\,(2)} = \frac{2 \cdot M_{u,2} + e_e \cdot \sum B_o}{g + e_e} = 223{,}67\ \text{kN}$$

  - **BOLT ROW 1 + BOLT ROW 2**

$$F_{u,2a,Rd\,(1+2)} = \frac{2 \cdot M_{u,2} + e_e \cdot \sum B_o}{g + e_e} = 390{,}82\ \text{kN}$$

- $M_{u,1}$
- $M_{u,2}$
- e_e
- B_o

+ all parameterts on which they depend are detailed in 10.10.3.1 of EN 1999-1-1:2023

Resistance evaluation for equivalent T-stub in tension

Resistance of T-stub (*10.10.3 "General rules for resistance evaluation"**):

- **MODE 2b**
  - **BOLT ROW 1 considered individually**

$$F_{u,2b,Rd\,(1)} = \frac{2 \cdot M_{o,2} + e_e \cdot \sum B_u}{g + e_e} = 200{,}26\ \text{kN}$$

  - **BOLT ROW 2 considered individually**

$$F_{u,2b,Rd\,(2)} = \frac{2 \cdot M_{o,2} + e_e \cdot \sum B_u}{g + e_e} = 213{,}76\ \text{kN}$$

  - **BOLT ROW 1 + BOLT ROW 2**

$$F_{u,2b,Rd\,(1+2)} = \frac{2 \cdot M_{o,2} + e_e \cdot \sum B_u}{g + e_e} = 303{,}82\ \text{kN}$$

- **MODE 3**
  - **BOLT ROW 1 considered individually**

$$F_{u,3,Rd\,(1)} = \sum B_u = 276{,}48\ \text{kN}$$

  - **BOLT ROW 2 considered individually**

$$F_{u,3,Rd\,(2)} = \sum B_u = 276{,}48\ \text{kN}$$

  - **BOLT ROW 1 + BOLT ROW 2**

$$F_{u,3,Rd\,(1+2)} = \sum B_u = 552{,}96\ \text{kN}$$

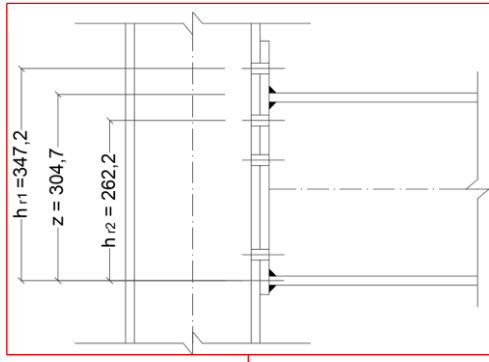
- $M_{o,2}$
- e_e
- B_u

\+ all parameterts on which they depend are detailed in 10.10.3.1 of EN 1999-1-1:2023

Resistance evaluation for equivalent T-stub in tension

Resistance of T-stub:

- **BOLT ROW 1:** $\mathbf{F_{u,Rd\,(1)}} = \min(F_{u,1,Rd\,(1)}; F_{u,2a,Rd\,(1)}; F_{u,2b,Rd\,(1)}; F_{u,3,Rd\,(1)}) = \mathbf{200,26\ kN}$
- **BOLT ROW 2:** $\mathbf{F_{u,Rd\,(2)}} = \min(F_{u,1,Rd\,(2)}; F_{u,2a,Rd\,(2)}; F_{u,2b,Rd\,(2)}; F_{u,3,Rd\,(2)}) = \mathbf{213,76\ kN}$
- **BOLT ROW group (1 +2):** $\mathbf{F_{u,Rd\,(1+2)}} = \min(F_{u,1,Rd\,(1+2)}; F_{u,2a,Rd\,(1+2)}; F_{u,2b,Rd\,(2)}; F_{u,3,Rd\,(1+2)}) = \mathbf{303,82\ kN}$



- **Moment resistance of BOLT ROW 1:** $M_{Rd(1)} = F_{u,Rd\,(1)} \cdot h_{r1}$
- **Moment resistance of BOLT ROW 2:** $M_{Rd(2)} = F_{u,Rd\,(2)} \cdot h_{r2}$

$$M_{Rd(1and2)} = \sum_{r=1}^{n} h_r \cdot F_{u,Rd\,(r)} = 125,58\ \text{kNm}$$

- **Moment resistance of BOLT ROW group (1 + 2):**

$$M_{Rd\,(1+2)} = F_{u,Rd\,(1+2)} \cdot z = 92,57\ \text{kN}$$

Resistance of column flange in bending:

$$\mathbf{M_{Rd,fc} = M_{Rd,T-stub} = \min(M_{j,Rd(1and2)}; M_{j,Rd(1+2)}) = 92,57\ kNm}$$

Thank you!