Metal Structures

Lecture XVII

Welds

Contents

Types of calculations

Types of welds (→ #16 / 16)

Welds						
Fillet			Butt		Plug	Flare groove
„Normal”	Intermittent	All round	Full penetration	Partial penetration		
All types of load		Shear forces only	All types of load		Shear forces only	
Calculations: as filled			Calculations: as butt	Calculations: as filled	Calculations: as plug	Calculations: as filled

EN 1993-1-8 tab 4.7.1

Full penetration butt welds

4.7.1 Full penetration butt welds

(1) The design resistance of a full penetration butt weld should be taken as equal to the design resistance of the weaker of the parts connected, provided that the weld is made with a suitable consumable which will produce all-weld tensile specimens having both a minimum yield strength and a minimum tensile strength not less than those specified for the parent metal.

4.7.1 Spoiny czołowe z pełnym przetopem

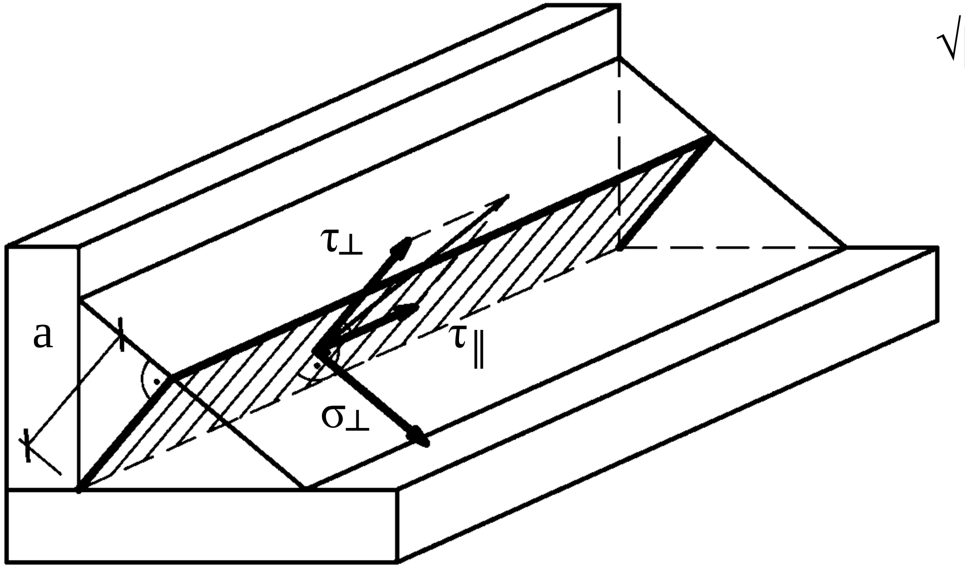
(1) Nośność obliczeniową spoin czołowych z pełnym przetopem przyjmuje się równą nośności obliczeniowej słabszej z łączonych części, pod warunkiem, że spoina będzie wykonana z odpowiedniego materiału wykazującego przy próbie rozciągania spoiny minimalną granicę plastyczności i minimalną wytrzymałość nie mniejsze od wartości nominalnych dla materiału rodzimego.

Full penetration butt welds

Satisfied of technical requirement for weld + sufficient load-bearing weaker element → calculations of weld load-bearing is not necessary

Filled welds
Directional method

Photo: Author



$$\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel{}^2 + \tau_\perp{}^2)]} \leq f_u / (\beta_w\ \gamma_{M2})$$

and

$$\sigma_\perp \leq 0{,}9 f_u / \gamma_{M2}$$

EN 1993-1-8 (4.1)

$$f_u = \min (\ f_{u1}\ ;\ f_{u2}\ )$$

$$\gamma_{M2} = 1{,}25$$

steel	S 235	S 275	S 355	S 420	S 460
β_w	0,80	0,85	0,90	1,00	

EN 1993-1-8
tab 4.1

Filled welds
Directional method

Geometry of welds: $A \;\; J_y \;\; J_z \;\; A_{Vy} \;\; A_{Vz} \;\; J_0$

Loads (cross-section forces): $N_{Ed} \;\; M_{y,\,Ed} \;\; M_{z,\,Ed} \;\; V_{y,\,Ed} \;\; V_{z,\,Ed} \;\; M_{T,\,Ed}$

$$\sigma = \pm N_{Ed} / A \pm M_{y,\,Ed}\, z / J_y \pm M_{z,\,Ed}\, y / J_z$$

$$\tau_{(1,\,2)} = \pm \tau\, (V_{y,\,Ed} / A_{Vy}\, ,\, V_{z,\,Ed} / A_{Vz}\, ,\, M_{T,\,Ed} / J_0)$$

$$\sigma_{\perp} = \sigma / \sqrt{2}$$

$$\tau_{\perp} = \sigma / \sqrt{2} + \tau_1 \quad \text{(usually } \tau_1 = 0\text{)}$$

$$\tau_{\parallel} = \tau_2 \text{ (usually } \tau_2 = \tau\text{)}$$

Filled welds
Simplified method

Geometry of welds: A J_y J_z A_{Vy} A_{Vz} J_0

Loads (cross-section forces): N_{Ed} $M_{y, Ed}$ $M_{z, Ed}$ $V_{y, Ed}$ $V_{z, Ed}$ $M_{T, Ed}$

$$F_{w, Ed} = (\sigma_\perp + \tau_\perp + \tau_\parallel)\, a$$

$$F_{w, Rd} = f_u \sqrt{3}\, a / (\beta_w \gamma_{M2})$$

$$F_{w, Ed} \leq F_{w, Rd}$$

EN 1993-1-8 (4.2), (4.3), (4.4)

Geometry of welds: geometrical characteristics (A J_y J_z A_{Vy} A_{Vz} J_0) = projection of welds cross-section on plane paralell or perpendicular to load.

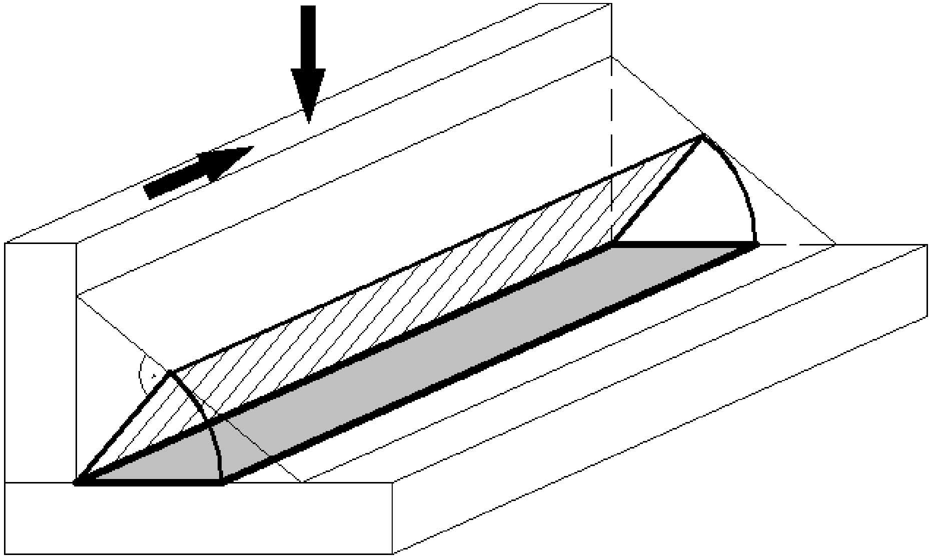


Photo: Author

Geometry of filled welds

$a \geq 3$ mm $\qquad l_{min} = \max(6a;\ 30\text{ mm})$

(EN 1993-1-8)

$0{,}2\ t_2 \leq a \leq 0{,}7\ t_1$

$t_2 \geq t_1$

(PN-B 3200)

$150\ a \geq l$

(EN 1993-1-8)

Example 1

Filled welds

Welds between web and web plate or between transverse stiffeners and web

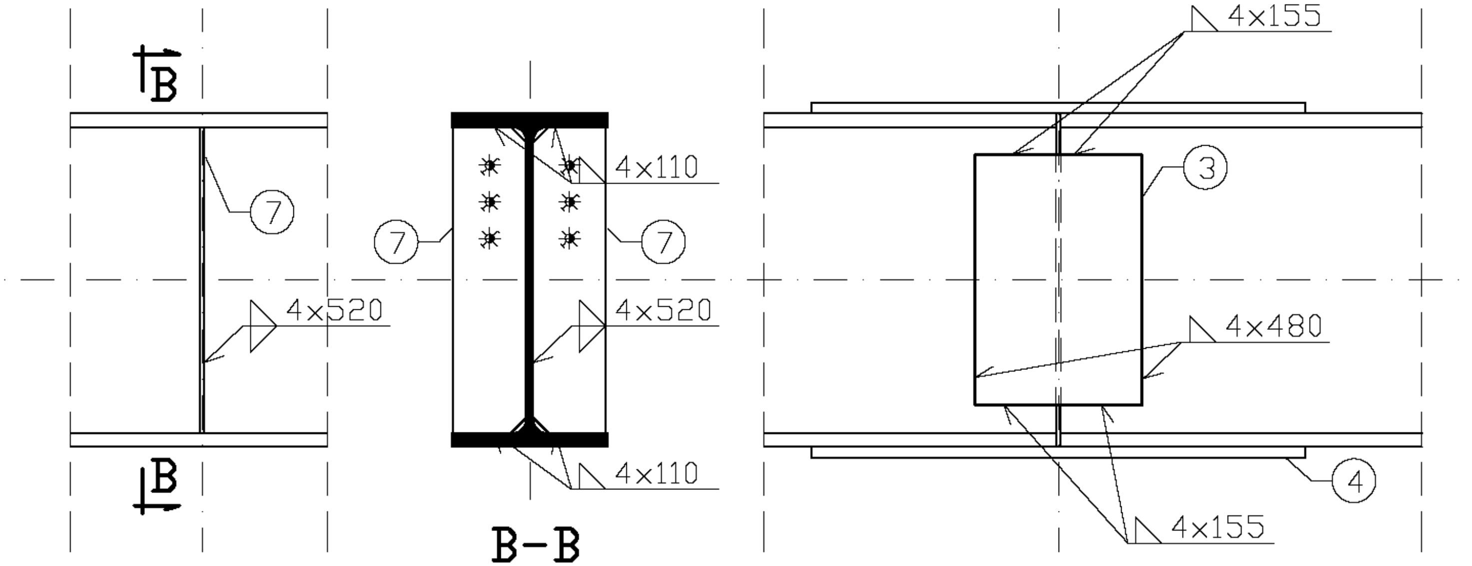


Photo: steelconstruction.info

Photo: Author

Geometry of welds and loads

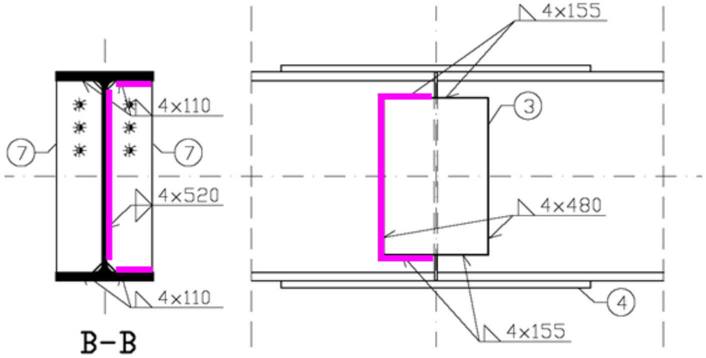
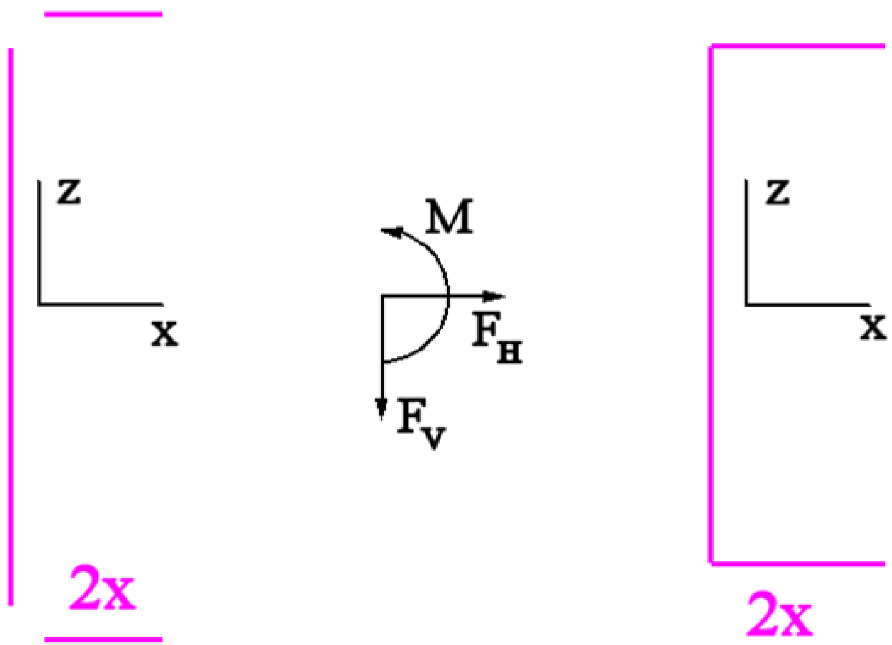


Photo: Author



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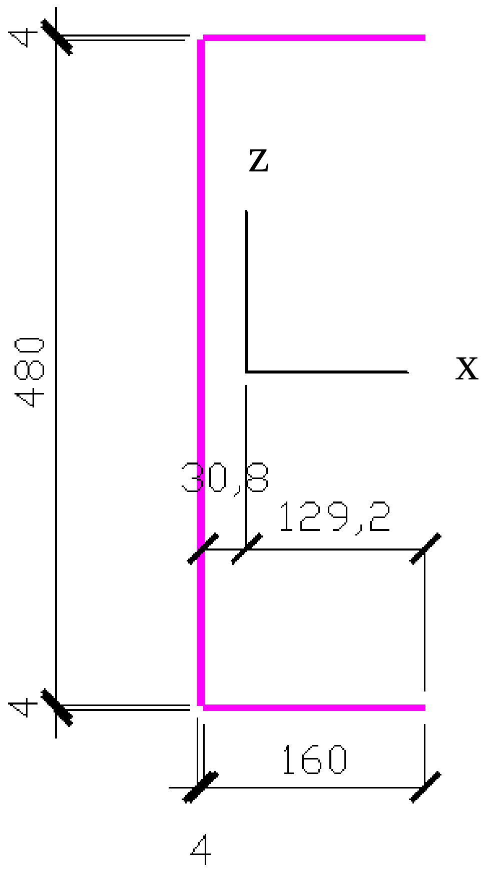


S235

$F_H = 154{,}6$ kN

$F_V = 201{,}7$ kN

$M = 34{,}1$ kNm

$$A = 2 \cdot 4 \cdot (160 + 480 + 160) = 6\,400 \text{ mm}^2$$

$$J_x = 2 \cdot [\,4 \cdot 480^3 / 12 + 2 \cdot 4 \cdot 160 \cdot (80{+}2)^2\,] =$$

$$= 90\,941\,440 \text{ mm}^4$$

$$J_z = 2 \cdot [2 \cdot 4 \cdot 160^3 / 12 + 2 \cdot 4 \cdot 160 \cdot (129{,}2 - 80)^2 +$$

$$+ 2 \cdot 4 \cdot 480 \cdot (80 + 2 - 30{,}8)^2] =$$

$$28\,060\,535 \text{ mm}^4$$

$$J_o \approx J_x + J_z = 119\,001\,975 \text{ mm}^4$$

There are three different methods of distribution forces $F_H + F_V$ and recalculation them to shear stress τ:

a) Both forces must be recalculated to stress $\tau_{\parallel}$ (parallel to weld axis);

b) F_H produces horizontal τ; F_V produces vertical τ; these stresses are paralell or perpendicular to weld axis;

c) F_H acts only on horizontal part of weld and produces $\tau_{\parallel}$ for its part;

F_V acts only on vertical part of weld and produces $\tau_{\parallel}$ for its part;

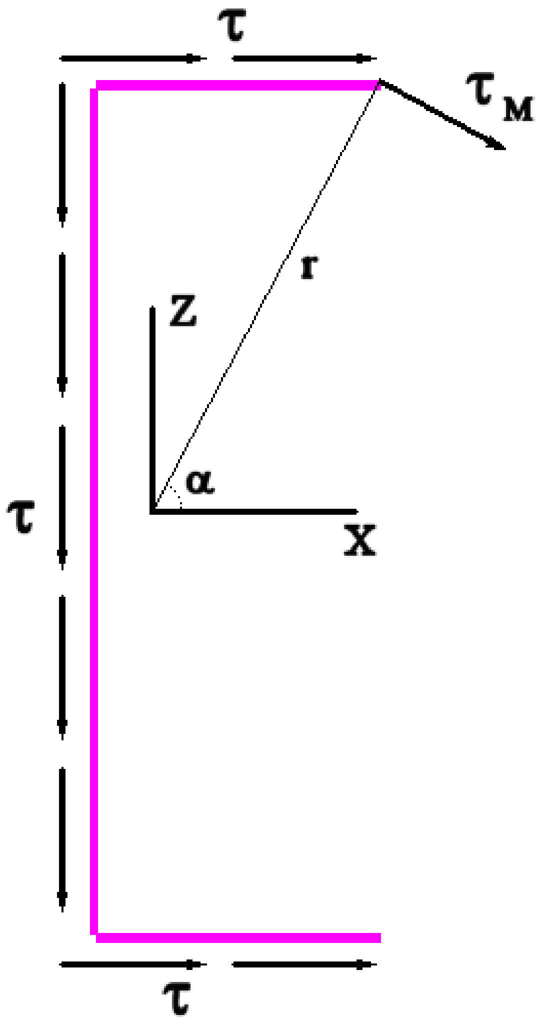


Photo: Author

Example 1a

$$\tau = (F_H + F_V) / A = 55{,}672\ \text{MPa}$$

$$\overline{\tau}_M = M\ \overline{r} / J_o$$

$$r_{max} = \sqrt{[(480+4)^2 + (129{,}2)^2]} = 500{,}9\ \text{mm}$$

$$\tau_{Mmax} = M\ r_{max} / J_o = 143{,}533\ \text{MPa}$$

$$\alpha = 15^o$$

$$\tau_{\parallel F} = \tau = 55{,}672 \text{ MPa}$$

$$\tau_{\parallel M} = \tau_{Mmax} \cos \alpha = 138{,}642 \text{ MPa}$$

$$\tau_{\perp M} = \tau_{Mmax} \sin \alpha = 37{,}149 \text{ MPa}$$

$$\sigma_{\perp} = 0{,}000 \text{ MPa}$$

$$\tau_{\parallel} = \tau_{\parallel M} + \tau_{\parallel F} = 194{,}314 \text{ MPa}$$

$$\tau_{\perp} = \tau_{\perp M} = 37{,}149 \text{ MPa}$$

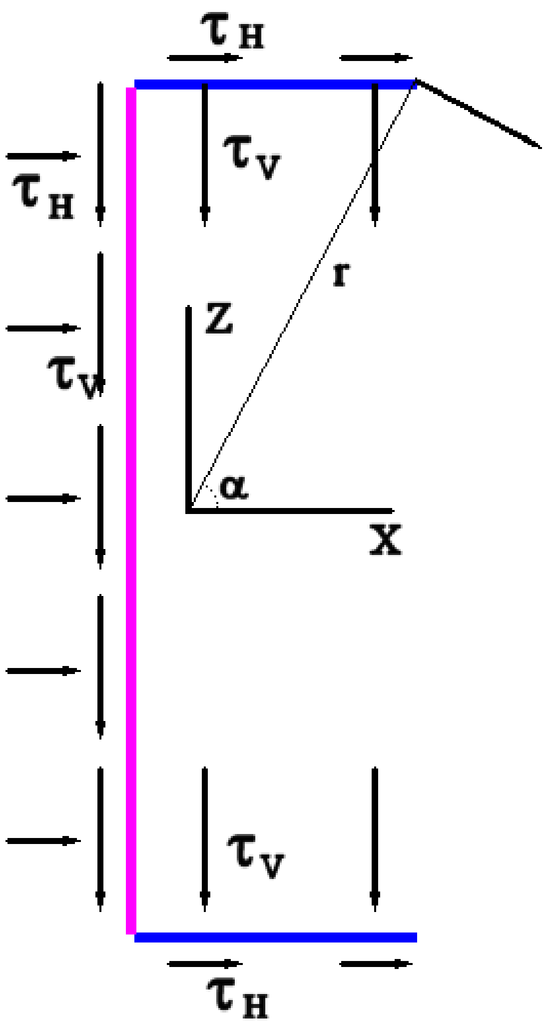
$$f_u / (\beta_w \gamma_{M2}) = 360 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 342{,}657 \text{ MPa} < 360 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Photo: Author



Example 1b

$A = 6\ 400\ mm^2$

$J_o = 119\ 001\ 975\ mm^4$

$\tau_H = F_H / A = 24{,}156$ MPa

$\tau_V = F_V / A = 31{,}516$ MPa

$\tau_{Mmax} = M\ r_{max} / J_o = 143{,}533$ MPa

$$\tau_{\parallel F} = \tau_H = 24{,}156 \text{ MPa}$$

$$\tau_{\perp F} = \tau_V = 31{,}516 \text{ MPa}$$

$$\tau_{\parallel M} = \tau_{Mmax} \cos\alpha = 138{,}642 \text{ MPa}$$

$$\tau_{\perp M} = \tau_{Mmax} \sin\alpha = 37{,}149 \text{ MPa}$$

$$\tau_{\parallel} = \tau_{\parallel M} + \tau_{\parallel F} = 162{,}798 \text{ MPa}$$

$$\tau_{\perp} = \tau_{\perp F} + \tau_{\perp M} = 68{,}665 \text{ MPa}$$

$$\sigma_{\perp} = 0{,}000 \text{ MPa}$$

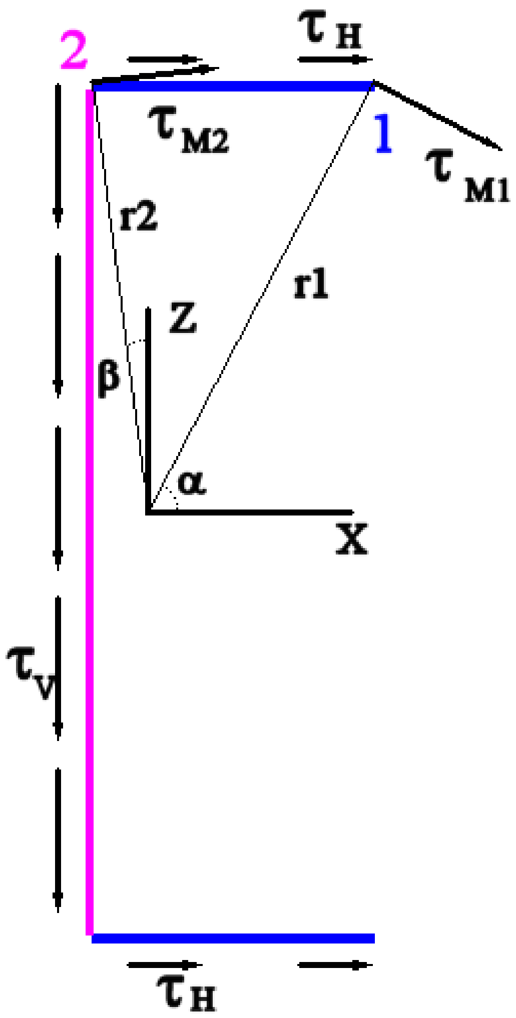
$$f_u / (\beta_w \gamma_{M2}) = 360 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 306{,}030 < 360 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Photo: Author



Example 1c

$$A_H = 2 \cdot 4 \cdot (160 + 160) = 2\ 560\ \text{mm}^2$$

$$A_V = 2 \cdot 4 \cdot 480 = 3\ 840\ \text{mm}^2$$

$$A = A_H + A_V = 6\ 400\ \text{mm}^2$$

$$J_o = 119\ 001\ 975\ \text{mm}^4$$

$$\tau_{H1} = F_H / A_H = 60{,}390\ \text{MPa}$$

$$\tau_{V1} = 0 / A_V = 0{,}000\ \text{MPa}$$

$$\tau_{M1} = M\ r_1 / J_o = 143{,}533\ \text{MPa}$$

$$\tau_{H2} = 0 / A_H = 0{,}000\ \text{MPa}$$

$$\tau_{V2} = F_V / A_V = 52{,}526\ \text{MPa}$$

$$\tau_{M2} = M\ r_2 / J_o = 138{,}971\ \text{MPa}$$

For point 1

$$\tau_{\parallel 1} = \tau_{H1} + \tau_{M1} \cos\alpha = 199{,}032 \text{ MPa}$$
$$\tau_{\perp 1} = \tau_{V1} + \tau_{M1} \sin\alpha = 37{,}149 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp 1})^2 + 3(\tau_{\parallel 1}^2 + \tau_{\perp 1}^2)]} = 350{,}670 \text{ MPa} < 360 \text{ MPa}$

Condition 2: $\sigma_{\perp 1} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

For point 2

$$\tau_{\parallel 2} = \tau_{H2} + \tau_{M2} \cos\alpha = 191{,}223 \text{ MPa}$$
$$\tau_{\perp 2} = \tau_{V2} + \tau_{M2} \sin\alpha = 8{,}726 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp 2})^2 + 3(\tau_{\parallel 2}^2 + \tau_{\perp 2}^2)]} = 331{,}553 \text{ MPa} < 360 \text{ MPa}$

Condition 2: $\sigma_{\perp 2} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Conclusions

Condition	Method a	Method b	Method c
$\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} / [f_u / (\beta_w \gamma_{M2})]$	0,952	0,850	0,921
$\sigma_{\perp} / (0{,}9 f_u / \gamma_{M2})$	0,000	0,000	0,000

Effort of welds is similar for each method of calculations. There is no matter, which type of model will be taken into consideration.

Example 2

Filled welds

Welds between gusset plate and girder or column

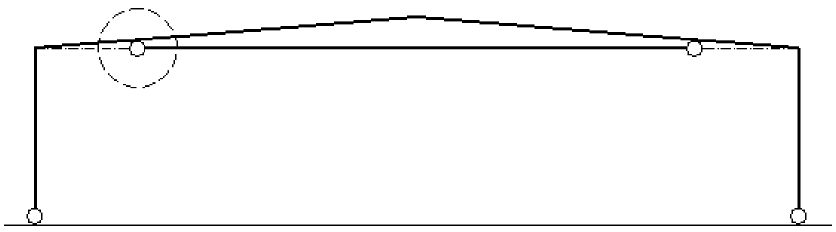


Photo: Author

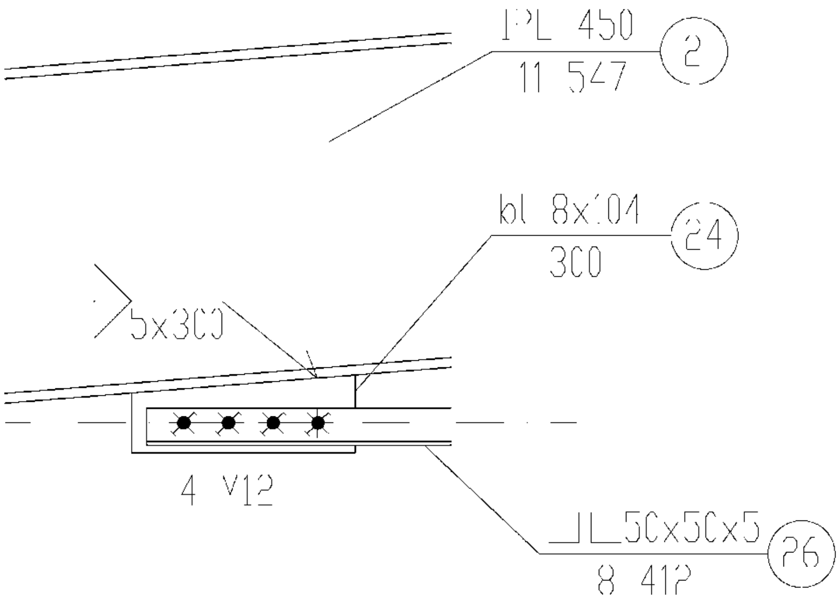


Photo: kobexstal.pl

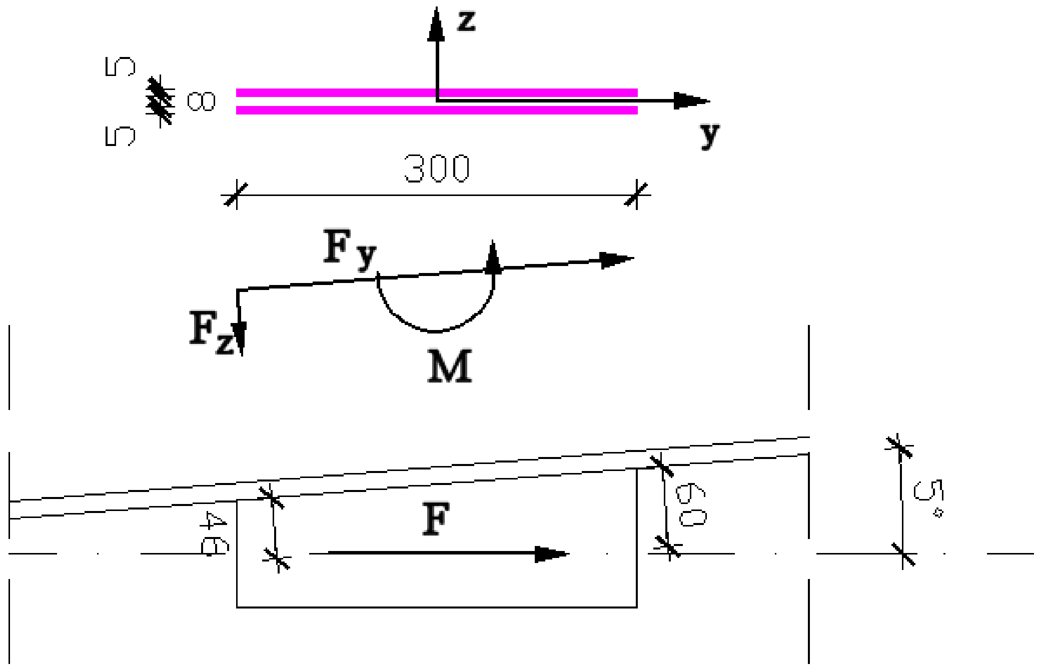


Photo: Author

S235

$F = 161{,}5$ kN

$\alpha = 5^o$

$e = (46 + 60)/2 = 53$ mm

$M = F\,e = 8{,}398$ kNm

$F_y = F \cos\alpha = 160{,}885$ kN

$F_z = F \sin\alpha = 14{,}076$ kN

$A = 2 \cdot 5 \cdot 300 = 3\,000$ mm^2

$A_V = A$

$W_z = 2 \cdot 5 \cdot 300^2 / 6 = 150\,000$ mm^3

$$\sigma_{max} = F_z / A + M / W_z = 4{,}692 \text{ MPa} + 55{,}987 \text{ MPa} = 58{,}320 \text{ MPa}$$

$$\tau = F_y / A_V = 53{,}628 \text{ MPa}$$

$$\sigma_\perp = \sigma_{max} / \sqrt{2} = 37{,}703 \text{ MPa}$$

$$\tau_\perp = \sigma_{max} / \sqrt{2} = 37{,}703 \text{ MPa}$$

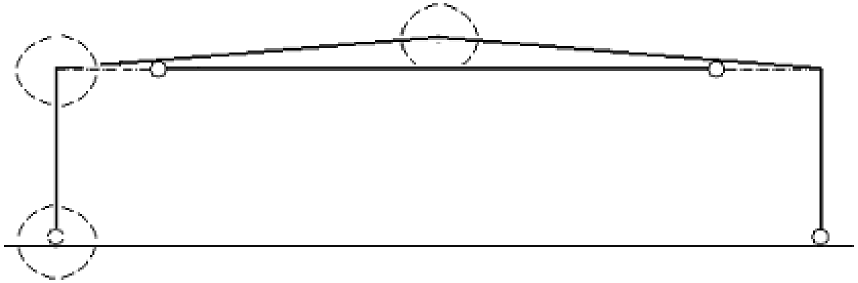
$$\tau_\parallel = \tau = 53{,}628 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel{}^2 + \tau_\perp{}^2)]} = 119{,}641 \text{ MPa} < 360{,}000 \text{ MPa}$

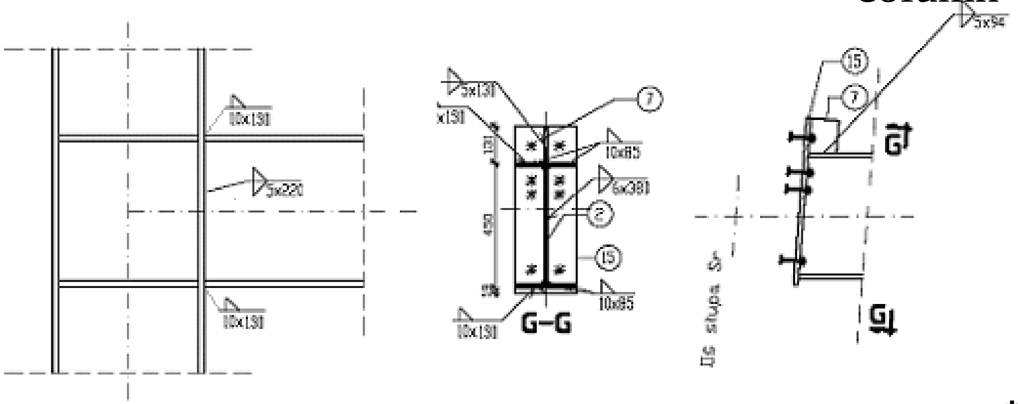
Condition 2: $\sigma_\perp = 37{,}703 \text{ MPa} < 259{,}200 \text{ MPa}$

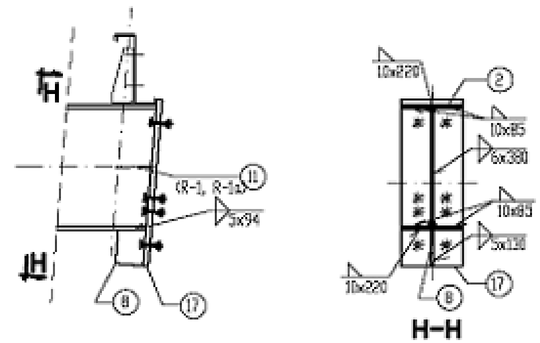


Example 3

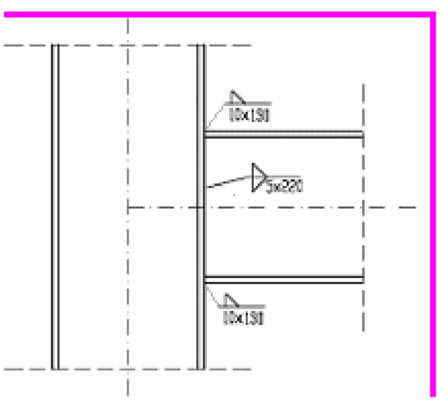
Filled welds

Welds between end-plate and girder or between base plate and column or between girder and column



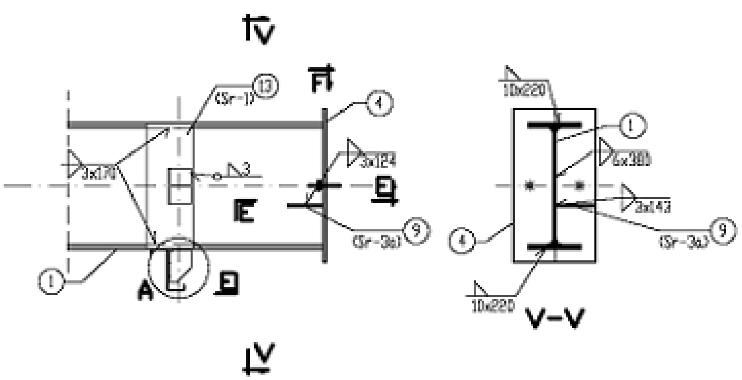


3a, 3b



3c, 3d

Photo: Author



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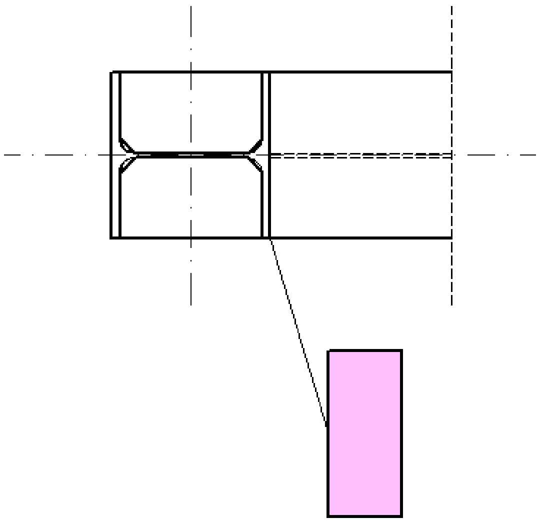
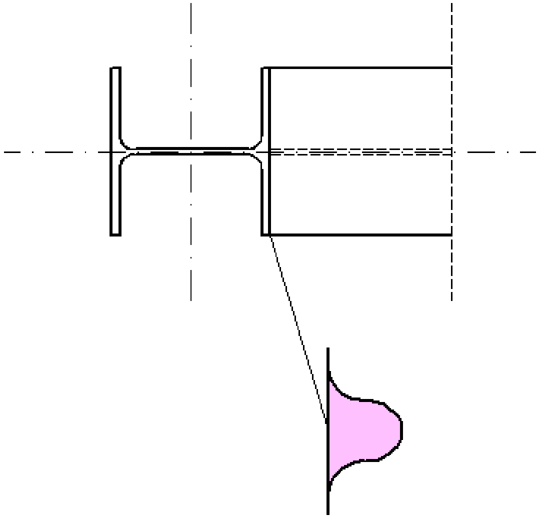




This example is calculated for three cases:

a) According to experience; thickness of welds according to #t / 10

b) Thickness of welds according to EN 1993-1-8 p.4.10.(5)

c) Beam-column without horizontal stiffeners (nonlinear distribution of stress in welds)

Photo: Author

Example 3a

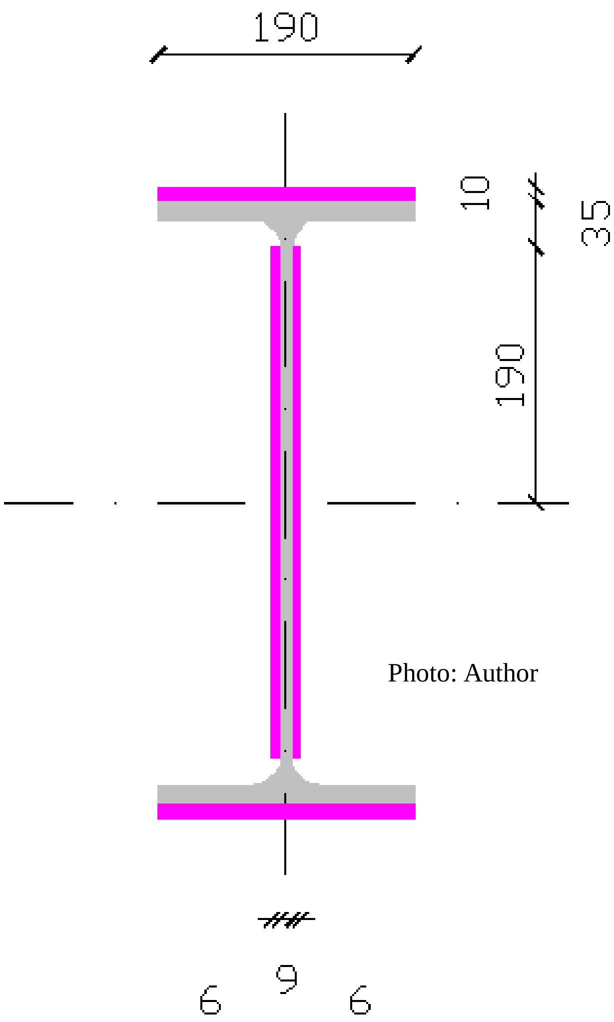


Photo: Author

S235

IPE 450

End-plate thickness 30 mm

According to #t / 10:

$0{,}2\ t_2 \leq a \leq 0{,}7\ t_1$

$t_2 \geq t_1$

Flange – end-plate:

t_f = 14,6 mm

$t_{e\text{-}p}$ = 30 mm

t_1 = 14,6

t_2 = 30

6 mm ≤ a ≤ 10,2 mm

a = 10 mm

Flange – web:

t_w = 9,4 mm

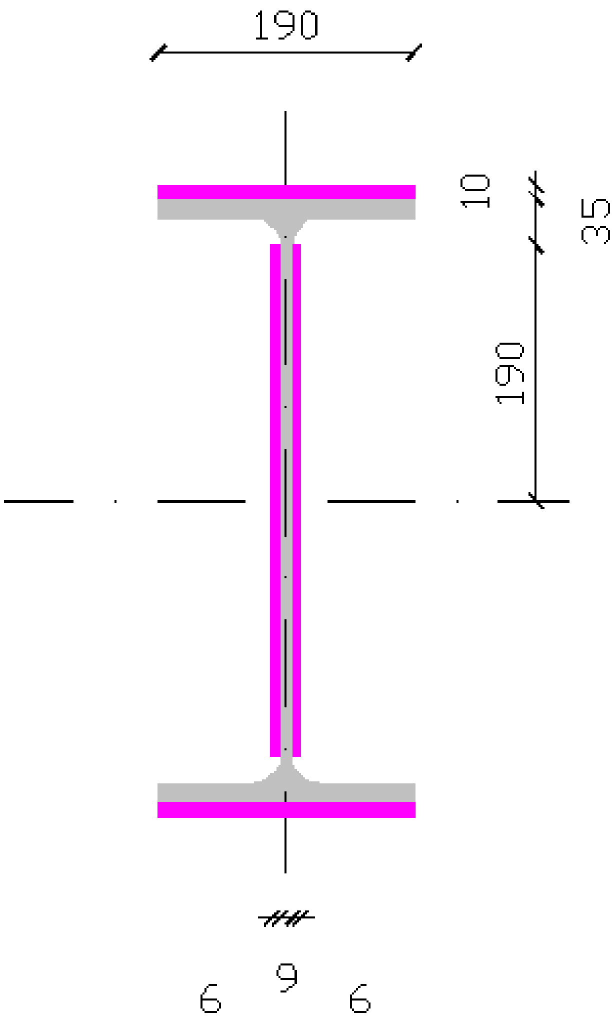
$t_{e\text{-}p}$ = 30 mm

t_1 = 19

t_2 = 30

6 mm ≤ a ≤ 6,6 mm

a = 6 mm



$$A = 2 \cdot 6 \cdot 380 + 2 \cdot 10 \cdot 190 = 8\ 360\ \text{mm}^2$$

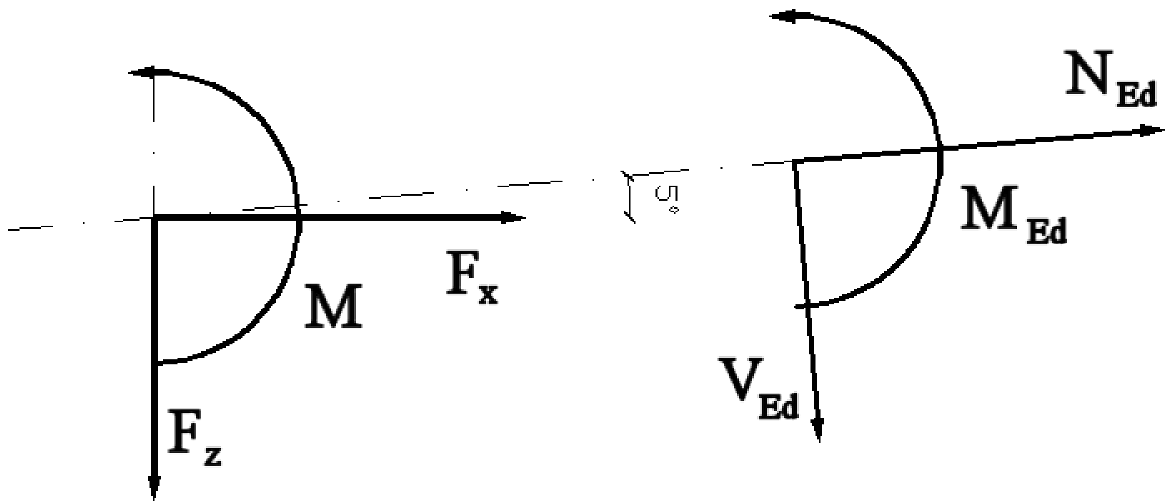
$$A_V = 2 \cdot 6 \cdot 380 = 4\ 560\ \text{mm}^2$$

$$J_y = 2 \cdot 6 \cdot 380^3 / 12 + 2 \cdot 10 \cdot 190 \cdot (190 + 35 + 5)^2 =$$

$$= 255\ 892\ 000\ \text{mm}^4$$

Photo: Author

Photo: Author



Recalculation from axis of element to axis of weld:

$$\alpha = 5^o$$

$$M_{Ed} = 247{,}1 \text{ kNm} \quad N_{Ed} = 213{,}0 \text{ kN} \quad V_{Ed} = 68{,}5 \text{ kN}$$

$$M = M_{Ed} = 247{,}1 \text{ kNm}$$

$$F_x = N_{Ed} \cos \alpha + V_{Ed} \sin \alpha = 218{,}169 \text{ kN}$$

$$F_z = - N_{Ed} \sin \alpha + V_{Ed} \cos \alpha = 49{,}675 \text{ kN}$$

Stress blocks

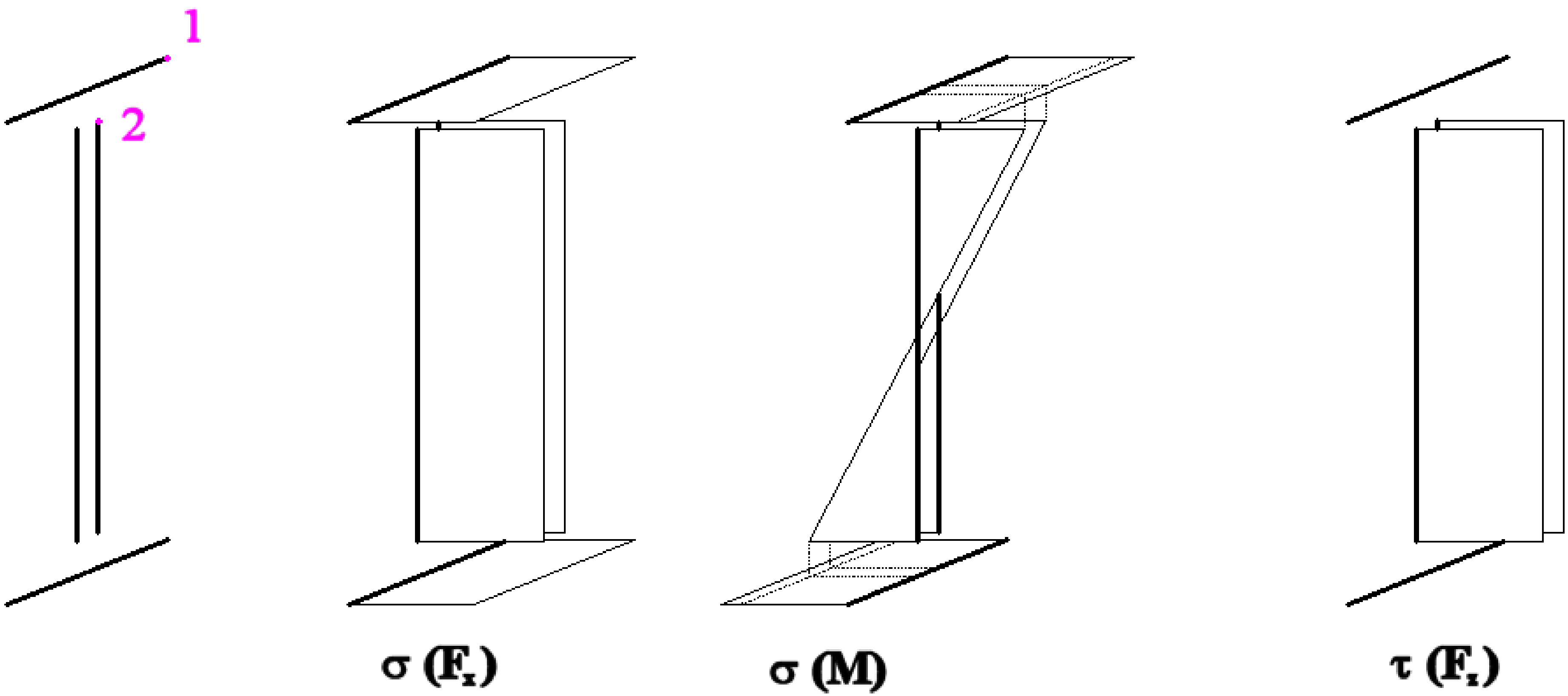


Photo: Author

$$\sigma\ (F_{x1}) = \sigma\ (F_{x2}) = F_x\ /\ A = 26{,}097\ \text{MPa}$$

$$\sigma\ (M_1) = M\ z_1\ /\ J_y$$

$$\sigma\ (M_2) = M\ z_2\ /\ J_y$$

$$z_1 = 235\ \text{mm}$$

$$z_2 = 190\ \text{mm}$$

$$\sigma\ (M_1) = 226{,}952\ \text{MPa}$$

$$\sigma\ (M_2) = 183{,}493\ \text{MPa}$$

$$\tau\ (F_{z1}) = 0{,}000\ \text{MPa}$$

$$\tau\ (F_{z2}) = 10{,}893\ \text{MPa}$$

$$\sigma_1 = \sigma\,(F_{x1}) + \sigma\,(M_1) = 253{,}049\ \text{MPa}$$

$$\sigma_2 = \sigma\,(F_{x2}) + \sigma\,(M_2) = 209{,}590\ \text{MPa}$$

$$\tau_1 = \tau\,(F_{z1}) = 0{,}000\ \text{MPa}$$

$$\tau_2 = \tau\,(F_{z2}) = 10{,}893\ \text{MPa}$$

$$\sigma_{\perp 1} = \tau_{\perp 1} = \sigma_1 / \sqrt{2} = 178{,}933\ \text{MPa}$$

$$\sigma_{\perp 2} = \tau_{\perp 2} = \sigma_2 / \sqrt{2} = 148{,}203\ \text{MPa}$$

$$\tau_{\parallel 1} = \tau_1 = 0{,}000\ \text{MPa}$$

$$\tau_{\parallel 2} = \tau_2 = 10{,}893\ \text{MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

For point 1

Condition 1: $\sqrt{[(\sigma_{\perp 1})^2 + 3(\tau_{\parallel 1}{}^2 + \tau_{\perp 1}{}^2)]} = 357{,}866 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp 1} = 178{,}933 \text{ MPa} < 259{,}200 \text{ MPa}$

For point 2

Condition 1: $\sqrt{[(\sigma_{\perp 2})^2 + 3(\tau_{\parallel 2}{}^2 + \tau_{\perp 2}{}^2)]} = 297{,}006 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp 2} = 148{,}203 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 3b

S235

IPE 450

EN 1993-1-8   4.10.(5):

Resistance of welds between flange and plate = resistance of flange for axial force

IPE 450 → $b_f = 190$ mm ; $t_f = 14{,}6$ mm

$$N_{Rd,\,f} = b_f\, t_f\, f_y / \gamma_{M0} = 651{,}890 \text{ kN}$$

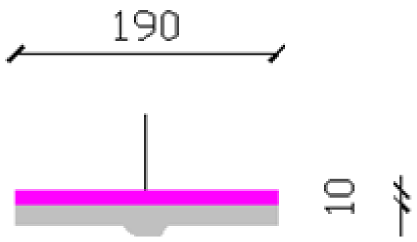


Photo: Author

$$A = 10 \cdot 190 = 1\,900\ \text{mm}^2$$

$$\sigma = N_{Rd,\,f} / A = 343{,}100\ \text{MPa}$$

$$\sigma_\perp = \tau_\perp = \sigma / \sqrt{2} = 242{,}608\ \text{MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000\ \text{MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200\ \text{MPa}$$

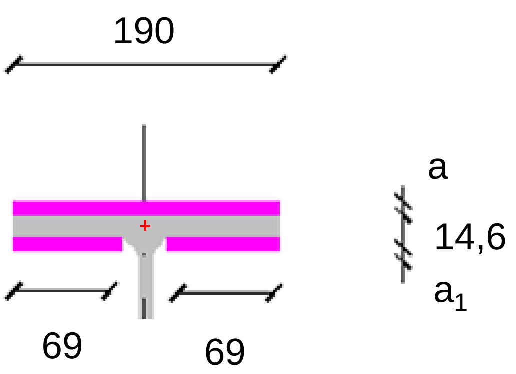
Condition 1: $\sqrt{[(\sigma_{\perp 1})^2 + 3(\tau_{\parallel 1}{}^2 + \tau_{\perp 1}{}^2)]} = 485{,}216\ \text{MPa} > 360{,}000\ \text{MPa}$

Condition 2: $\sigma_{\perp 1} = 242{,}608\ \text{MPa} < 259{,}200\ \text{MPa}$

Welds assumed according to experience could be too weak according to Eurocode

Photo: Author

Increasing resistance: welds on both sides of flange



Recommendation: centre of gravity for welds in the same point as centre of gravity for flange.

$$190 \cdot a \cdot (14{,}6 + a) / 2 = 2 \cdot 69 \cdot a_1 \cdot (14{,}6 + a_1) / 2$$

$$a_1 \approx 1{,}3\ a$$

According to simplified method:

$$\sigma = N_{Rd} / (\Sigma l_i\ a)$$

$$\sigma_\perp = \tau_\perp = \sigma / \sqrt{2}$$

$$F_{w,\,Ed} = (\sigma_\perp + \tau_\perp)\ a$$

Formulas could be applicated for a = const; in analysed case will be applicated $\min(a\ ;\ a_1) = a$ and $\Sigma l_i\ a = \Sigma l_i\ a_i$

$$F_{w,\,Rd} = f_u \sqrt{3}\ a / (\beta_w\ \gamma_{M2})$$

$$F_{w,\,Ed} \leq F_{w,\,Rd}$$

$$\Sigma l_i\, a_i = \; b_f + 2\,(b_f - 2r - t_w)\,/\,2 = 190 \cdot a + 2\,(190 - 2 \cdot 21 - 9{,}4) \cdot a_1\,/\,2 =$$

$$= 190 \cdot a + 2\,(190 - 2 \cdot 21 - 9{,}4) \cdot 1{,}3 \cdot a\,/\,2 = 370{,}18 \cdot a$$

$$\sigma = N_{Rd}\,/\,(\Sigma l_i\, a_i)$$

$$\sigma_{\perp} = \tau_{\perp} = \sigma\,/\,\sqrt{2}$$

$$F_{w,\,Ed} = (\sigma_{\perp} + \tau_{\perp})\, a = 2\,\sigma\, a\,/\,\sqrt{2} = \sqrt{2}\,\sigma\, a = \sqrt{2}\, N_{Rd}\, a\,/\,(370{,}18\, a) = \sqrt{2}\, N_{Rd}\,/\,370{,}18$$

$$F_{w,\,Rd} = f_u \sqrt{3}\, a\,/\,(\beta_w\, \gamma_{M2})$$

$$F_{w,\,Ed} \leq F_{w,\,Rd}$$

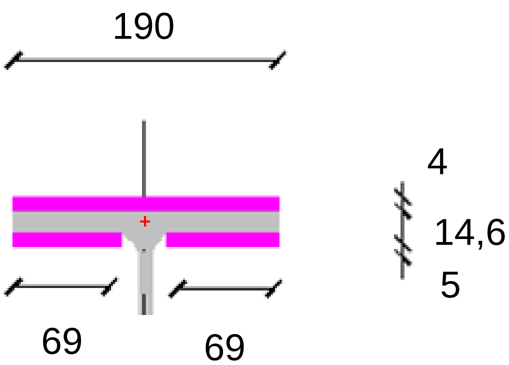
$$\sqrt{2}\, N_{Rd}\,/\,370{,}18 \leq f_u \sqrt{3}\, a\,/\,(\beta_w\, \gamma_{M2})$$

$$\sqrt{2}\, N_{Rd}\, \beta_w\, \gamma_{M2}\,/\,(370{,}18\, \sqrt{3}\, f_u) \leq a$$

$$4{,}0 \text{ mm} \leq a$$

There will be taken into consideration 4 mm over flange and $1{,}3 \cdot 4 = 5$ mm under flange.

Photo: Author



Resistance of welds = resistance of flange:

$$A = 190 \cdot 4 + 2\ (190 - 2 \cdot 21 - 9{,}4) \cdot 5 / 2 = 1\ 453\ \text{mm}^2$$

$$\sigma = N_{Rd,\ f} / A = 448{,}651\ \text{MPa}$$

$$\sigma_{\perp} = \tau_{\perp} = \sigma / \sqrt{2} = 317{,}244\ \text{MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000\ \text{MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200\ \text{MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp 1})^2 + 3(\tau_{\parallel 1}{}^2 + \tau_{\perp 1}{}^2)]} = 634{,}488\ \text{MPa} > 360{,}000\ \text{MPa}$

Condition 2: $\sigma_{\perp 1} = 317{,}244\ \text{MPa} > 259{,}200\ \text{MPa}$

Welds assumed according simplified method are too weak.

Condition „resistance of welds = resistance of flange” is satisfied for welds 7 mm over flange and 9 mm under flange; nearly two times bigger than from simplified method.

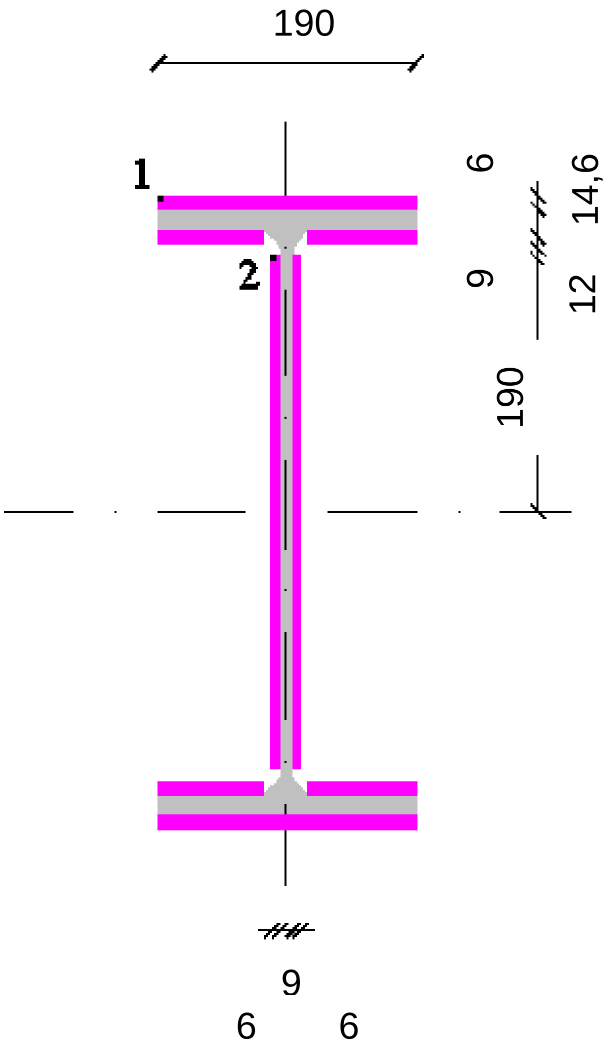


Photo: Author

„Full" resistance (bending moment + axial force + shear force):

$$A = 2 \cdot 6 \cdot 380 + 2 \cdot 6 \cdot 190 + 4 \cdot 9 \cdot 69 = 9\,324 \text{ mm}^2$$

$$A_V = 2 \cdot 6 \cdot 380 = 4\,560 \text{ mm}^2$$

$$J_y = 2 \cdot 6 \cdot 380^3 / 12 + 2 \cdot 6 \cdot 190 \cdot (450 / 2 + 3)^2 +$$

$$+ 4 \cdot 9 \cdot 69 \cdot (190 + 12 + 4{,}5)^2 =$$

$$= 279\,318\,869 \text{ mm}^4$$

In analogy to example 3a, we calculate stresses in points 1 and 2

$$\sigma\,(F_{x1}) = \sigma\,(F_{x2}) = F_x / A = 23{,}402 \text{ MPa}$$

$$\sigma\,(M_1) = M_{Ed}\, z_1 / J_y$$

$$\sigma\,(M_2) = M_{Ed}\, z_2 / J_y$$

$$z_1 = 231 \text{ mm}$$

$$z_2 = 190 \text{ mm}$$

$$\sigma\,(M_1) = 204{,}355 \text{ MPa}$$

$$\sigma\,(M_2) = 168{,}084 \text{ MPa}$$

$$\tau\,(F_{z1}) = 0{,}000 \text{ MPa}$$

$$\tau\,(F_{z2}) = 10{,}893 \text{ MPa}$$

$$\sigma_1 = \sigma\,(F_{x1}) + \sigma\,(M_1) = 227{,}757 \text{ MPa}$$

$$\sigma_2 = \sigma\,(F_{x2}) + \sigma\,(M_2) = 191{,}486 \text{ MPa}$$

$$\tau_1 = \tau\,(F_{z1}) = 0{,}000 \text{ MPa}$$

$$\tau_2 = \tau\,(F_{z2}) = 10{,}893 \text{ MPa}$$

$$\sigma_{\perp 1} = \tau_{\perp 1} = \sigma_1 / \sqrt{2} = 161{,}049 \text{ MPa}$$

$$\sigma_{\perp 2} = \tau_{\perp 2} = \sigma_2 / \sqrt{2} = 135{,}401 \text{ MPa}$$

$$\tau_{\parallel 1} = \tau_1 = 0{,}000 \text{ MPa}$$

$$\tau_{\parallel 2} = \tau_2 = 10{,}893 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$
$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

For point 1

Condition 1: $\sqrt{[(\sigma_{\perp 1})^2 + 3(\tau_{\parallel 1}^2 + \tau_{\perp 1}^2)]} = 322{,}650 \text{ MPa} > 360{,}000 \text{ MPa}$

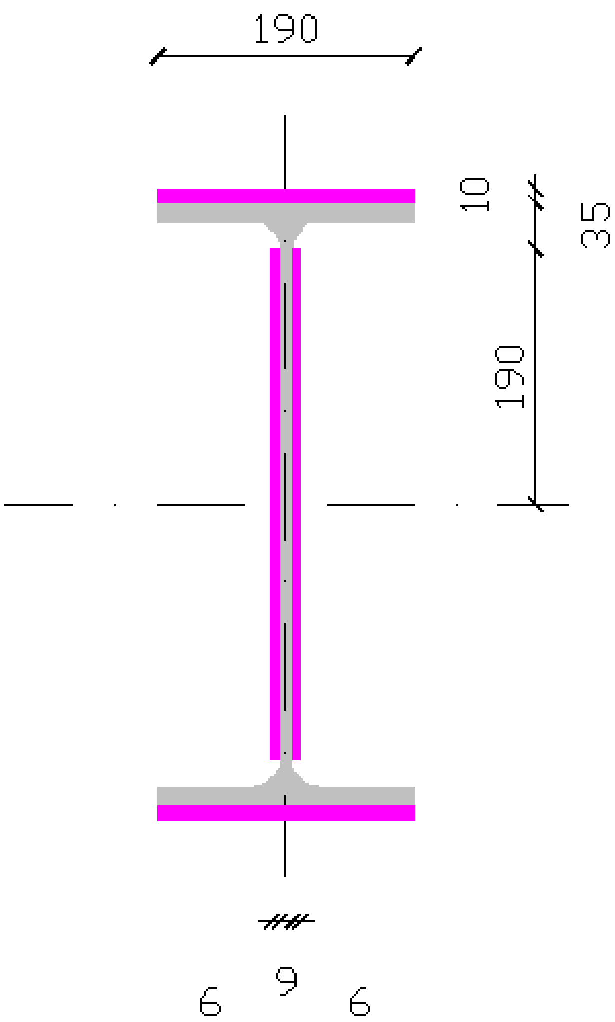
Condition 2: $\sigma_{\perp 1} = 161{,}049 \text{ MPa} < 259{,}200 \text{ MPa}$

For point 2

Condition 1: $\sqrt{[(\sigma_{\perp 2})^2 + 3(\tau_{\parallel 2}^2 + \tau_{\perp 2}^2)]} = 271{,}458 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp 2} = 135{,}401 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 3c



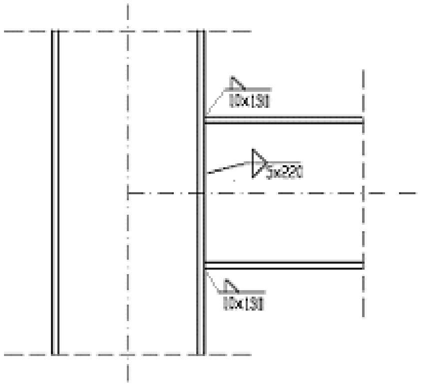
S235

IPE 450 (beam)

HEB 600 (column)

When there are no horizontal stiffeners in joint beam-column; we must make reduction for length of horizontal welds (EN 1993-1-8 p.4.10.(2))

Photo: Author



Effective length of horizontal welds:

$$b_{eff} = \min (b_{bf} \;\; ; \;\; t_{cw} + 2s + 7\,k\,t_{cf})$$

IPE 450 (beam) → $b_{bf} = 190$ mm ; $t_{bf} = 14{,}6$ mm

HEB 600 (column) → $t_{cf} = 30$ mm ; $t_{cw} = 15{,}5$ mm ; $r = 27$ mm

Hot-rolled column: $s = r$

Welded column: $s = a\sqrt{2}$

$$k = \min [\, 1{,}0 \;\; ; \;\; (t_{cf} \,/\, t_{bf})(f_{y,\,cf} \,/\, f_{y,\,bf}) \,]$$

IPE 450 (beam) → b_{bf} = 190 mm ; t_{bf} = 14,6 mm

HEB 600 (column) → t_{cf} = 30 mm ; t_{cw} = 15,5 mm ; r = 27 mm

Hot-rolled column: s = r = 27 mm

$$k = \min [\, 1{,}0 \;;\; (t_{cf} / t_{bf})(f_{y,\,cf} / f_{y,\,bf}) \,] = \min (1{,}0 \;;\; 2{,}055) = 1{,}0$$

Effective length of horizontal welds:

$$b_{eff} = \min (\, b_{bf} \;;\; t_{cw} + 2s + 7\,k\,t_{cf} \,) = \min (190 \;;\; 15{,}5 + 2 \cdot 27 + 7 \cdot 1 \cdot 30) =$$

$$= \min (190 \;;\; 279{,}5) = 190 \text{ mm}$$

There is no reduction for this situation. Rest calculations are completely the same as in previous examples (3b fore example).

Conclusions

Condition	Point	Example a	Example b, simplified	Example b, second checking	Example c
$\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}{}^2 + \tau_{\perp}{}^2)] / [f_u / (\beta_w \gamma_{M2})]}$	1	0,994		0,896	0,896
	2	0,690		0,621	0,621
$\sigma_{\perp} / (0{,}9 f_u / \gamma_{M2})$	1	0,825		0,754	0,754
	2	0,572		0,522	0,522
Resistance of welds = resistance of flange, EN 1993-1-8 4.10.(5)		No	No	Yes	Yes

Welds according to experience could not satisfied condition EN 1993-1-8 4.10.(5);

Welds assumed according to simplified method could be too weak;

In case of no horizontal stiffeners, length of horizontal welds should be reduced.

Example 4

Filled welds

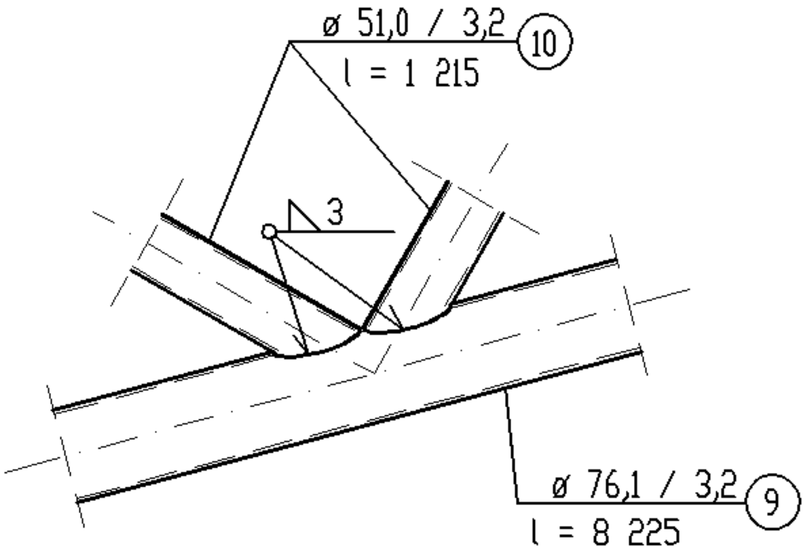


Photo: Author

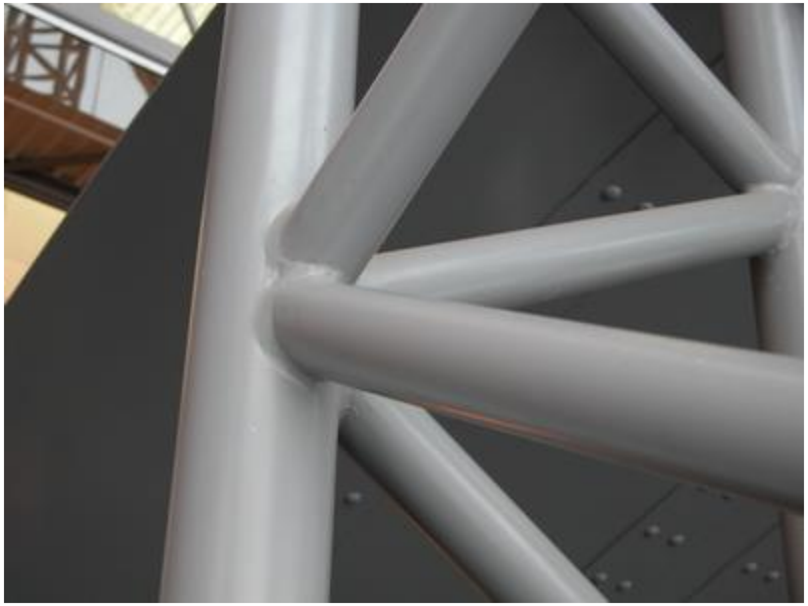


Photo: tboake.com

Welds between web member and chord of steel truss

This example is calculated for two cases:

a) Ideal truss;

b) Non-ideal truss;

According to Eurocodes, we must satisfy many requirements to can calculate real truss as ideal truss (axial forces only). Sometimes - when part of these requirements are not satisfy - we must take into calculations local bending moments in nodes of truss. More information will be presented on Lecture #21.

Example 4a

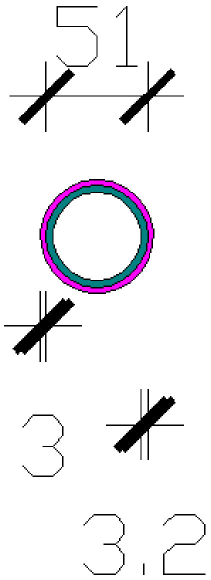


Photo: Author

S235

CHS diameter 51 mm

CHS thickness of flange 3,2 mm

Thickness of weld 3 mm

$$A = \pi \cdot [(51 / 2 + 3)^2 - (51 / 2)^2] = 509 \text{ mm}^2$$

$$N_{Ed} = 64{,}73 \text{ kN}$$

$$\sigma = N_{Ed} / A = 127{,}171 \text{ MPa}$$
$$\tau = 0 \text{ MPa}$$

$$\sigma_{\perp} = \tau_{\perp} = \sigma / \sqrt{2} = 89{,}923 \text{ MPa}$$
$$\tau_{\parallel} = \tau = 0{,}000 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 254{,}342 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 89{,}923 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 4b

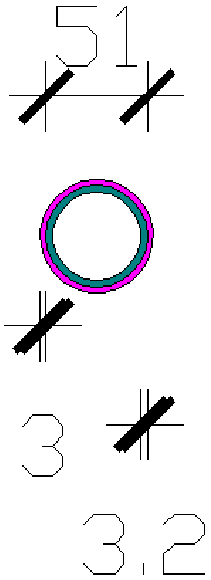


Photo: Author

S235

$$A = \pi \cdot [(51 / 2 + 3)^2 - (51 / 2)^2] = 509 \text{ mm}^2$$

$$J = \pi \cdot [(51 / 2 + 3)^4 - (51 / 2)^4] / 4 = 186\,080 \text{ mm}^4$$

$$W = J / (r + a) = 186\,080 / (51 / 2 + 3) = 6\,529 \text{ mm}^3$$

$$N_{Ed} = 64{,}73 \text{ kN}$$

$$M_{Ed} = 2{,}24 \text{ kNm}$$

$$\sigma = N_{Ed} / A + M_{Ed} / W = 127{,}171 + 343{,}085 \text{ MPa} = 470{,}256$$

$$\tau = 0 \text{ MPa}$$

$$\sigma_{\perp} = \tau_{\perp} = \sigma / \sqrt{2} = 332{,}521 \text{ MPa}$$

$$\tau_{\parallel} = \tau = 0{,}000 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 665{,}042 \text{ MPa} > 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 332{,}521 \text{ MPa} > 259{,}200 \text{ MPa}$

Conclusions

Condition	Example a	Example b
$\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]}$ / $[f_u / (\beta_w\ \gamma_{M2})]$	0,707	1,847
$\sigma_\perp / (0{,}9 f_u / \gamma_{M2})$	0,347	1,283

Effort in welds in truss is very big even for very small value of bending moment.
Better way is satisfied each conditions for calculations truss as ideal truss.

Above calculation based on very big simplification. First of all, area of weld is much more bigger than only ring around CHS. This is true for weld between CHS and flat member for axis of CHS perpendicular to plane.

For joint CHS-CHS, shape of weld is much more complicated.

Photo: pclgroupcncmachine.com

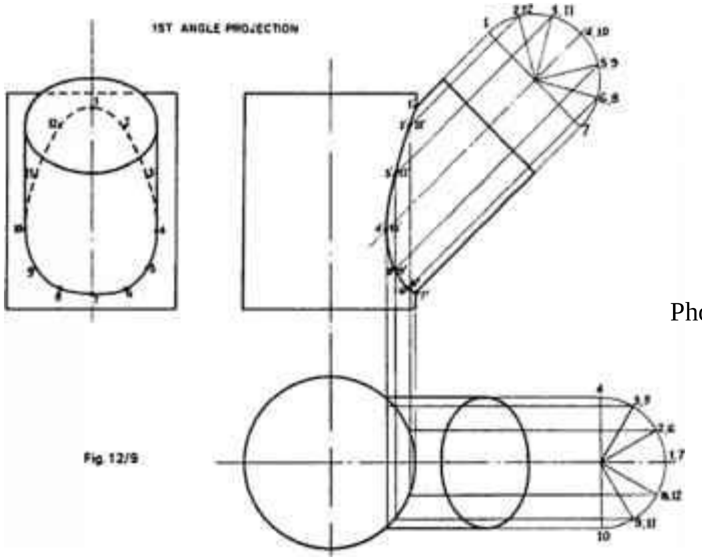
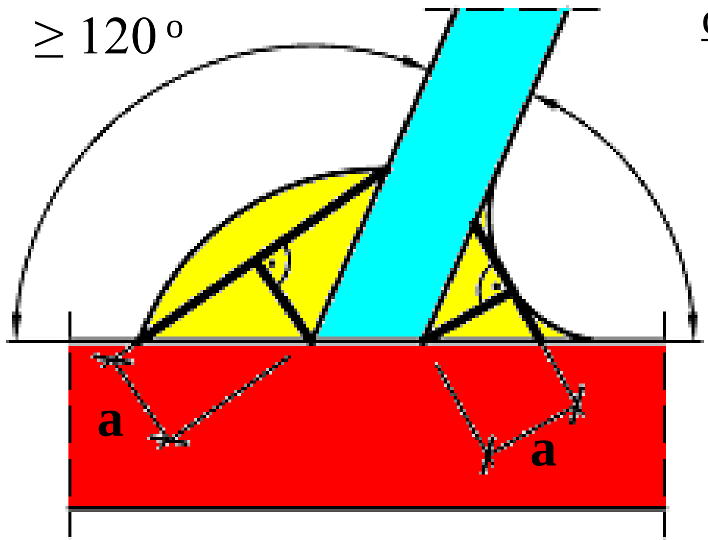


Photo: joshuanava.biz

Second reason, much more important: strong restriction for angle between elements in case of fillet welds (→ #16 / 24): 60º – 120º (EN 1993-1-8 p.4.3.2.1):

This part of welds must be tested experimentally



This part of welds must be calculated as butt partial penetration weld

Photo: Author

Next problem: according to EN 1993-1-8 4.7.2(1): „design resistance of a partial penetration butt weld should be determined using the method for a deep penetration fillet”. So, for angle ≤ 60º : fillet weld as but weld, but butt weld as filled weld, fillet weld as but weld, but butt weld as filled weld…

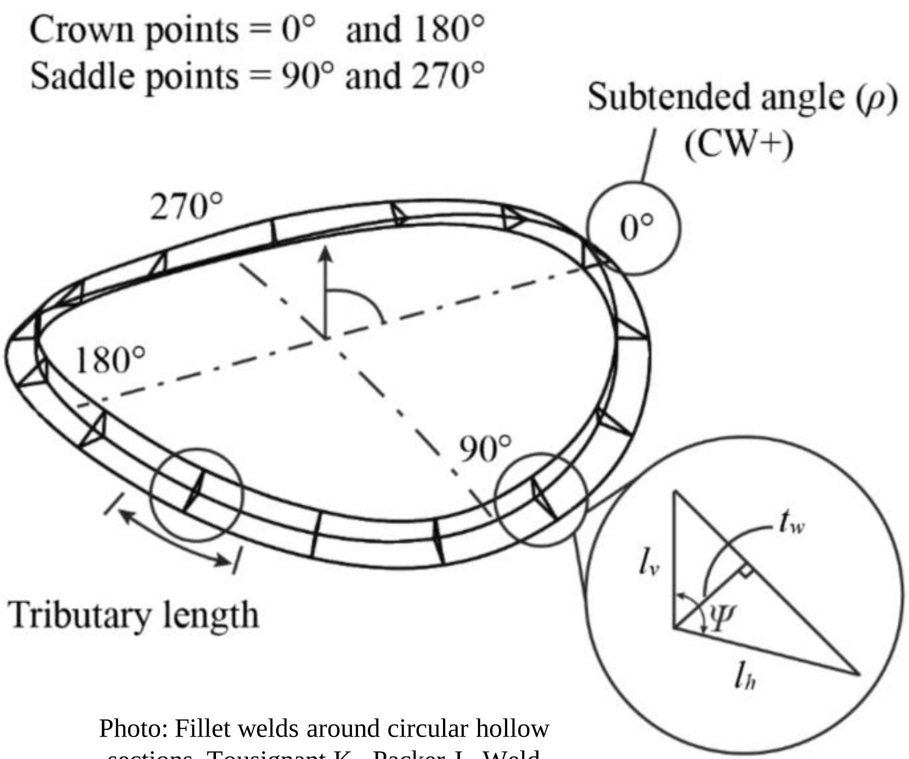


Photo: Fillet welds around circular hollow sections, Tousignant K., Packer J., Weld World 63, 421–433 (2019)

Angle Ψ between two CHS varies along weld. It is possible for ranges to occur simultaneously in which

- $\Psi \geq 120^{o}$ (fillet welds tested experimentally);
- $120^{o} > \Psi > 60^{o}$ ("normal" fillet welds);
- $\Psi \leq 60^{o}$ (fillet welds counted as butt welds with partial penetration).

Therefore, technical requirements specify need to use both butt and fillet welds, depending on angle value.

Standard EN 1090-2 presents technical requirements for making of welds CHS-CHS. Technical requirements for b**utt welds** are presented on fig. E2.

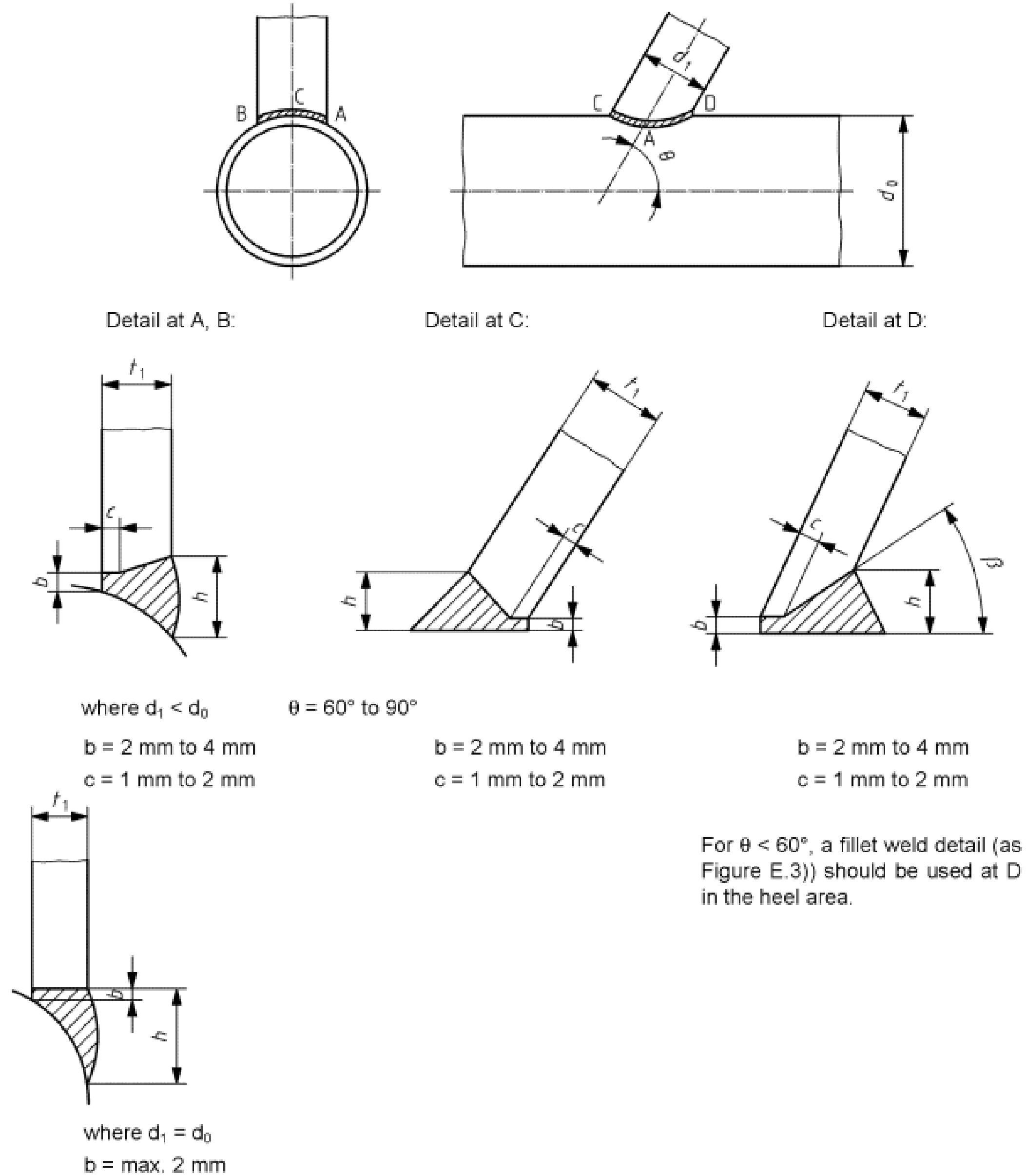


Photo: EN 1090-2 fig. E2

Technical requirements for **fillet welds** are presented on fig. E2.

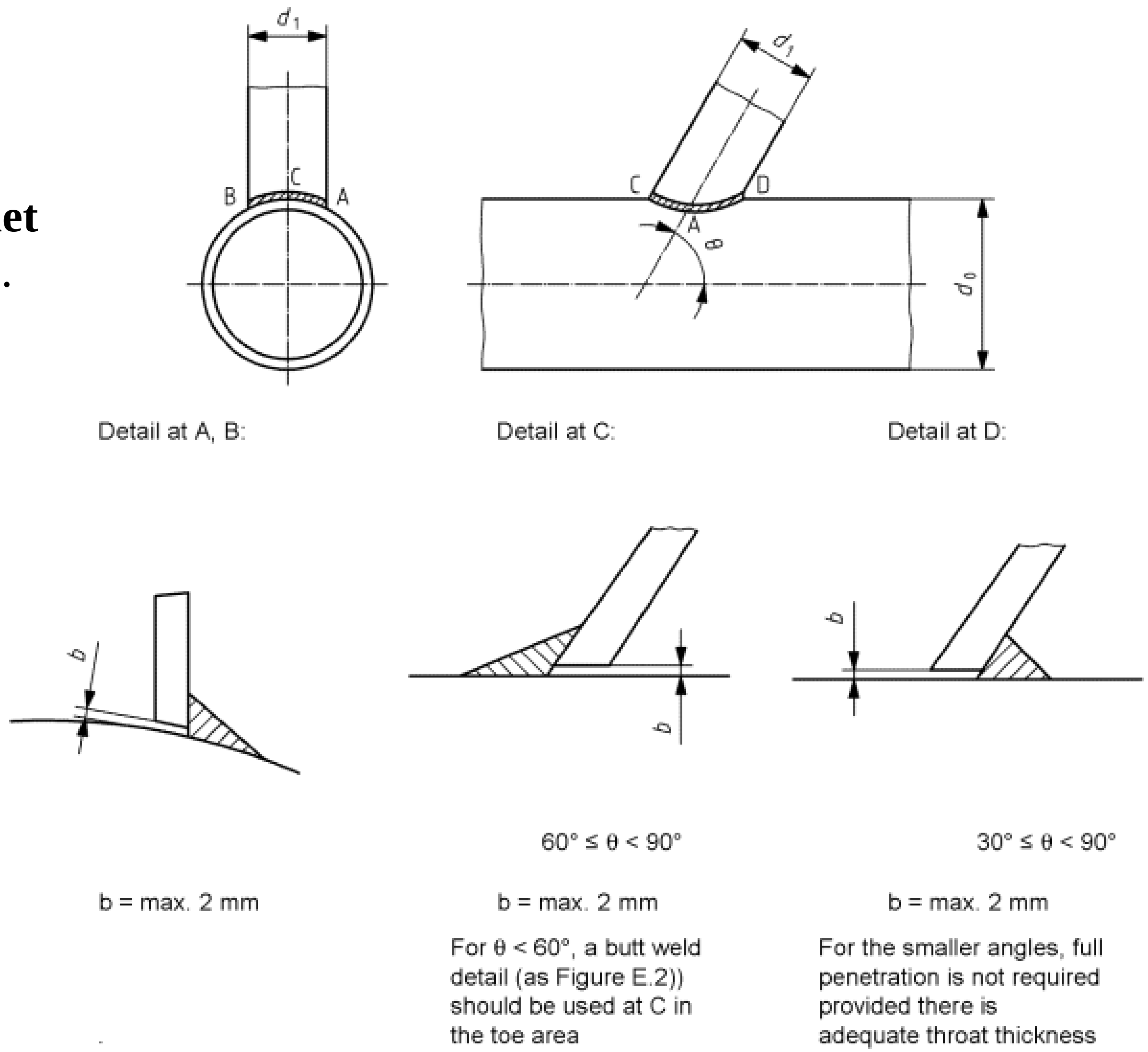


Photo: EN 1090-2 fig. E3

Conclusion: change of type of welds (fillet / butt) is recommended for joints between two CHS and two RHS.
1, 2, 3, 4 - order of making welds to minimalisation of residual strains and stresses.

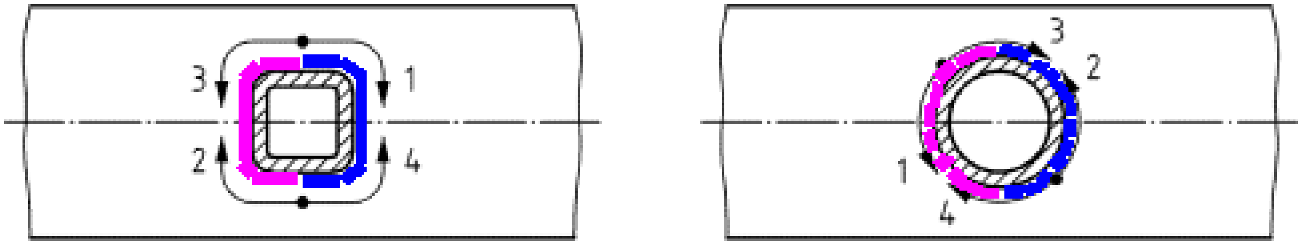


Photo: EN 1090-2 fig. E1

Resistance of such type of weld can be calculated as for mixed joint.

Mixed joints

Interaction between filled and all round welds or plug welds

Geometry of plug welds and / or filled all round welds must be added to geometry of „normal" fillet welds:

$$A = A_{plug} + A_{all\ round} + A_{\text{"normal"}}$$

$$J_y = J_{plug,\ y} + J_{all\ round,\ y} + J_{\text{"normal"},\ y}$$

$$J_z = J_{plug,\ z} + J_{all\ round,\ z} + J_{\text{"normal"},\ z}$$

More complicated is interaction between butt and fillet welds. Information is presented in literature only, not in Eurocode.

$$Area = A_{butt} + A_{fillet} \cdot 0,5$$

Olny axial force is accepted in this case. Next step of calculation according to calculation of „normal" fillet welds.

Conclusions

Accurate weld analysis in the case of CHS joints is extremely complicated:

- weld forms a curved line in three dimensions;
- opening angle between the CHS walls varies along the joint;
- it is recommended to use both butt and fillet welds in one node;
- cooperation of these two types of welds is little described in literature.

Example 5

Filled welds

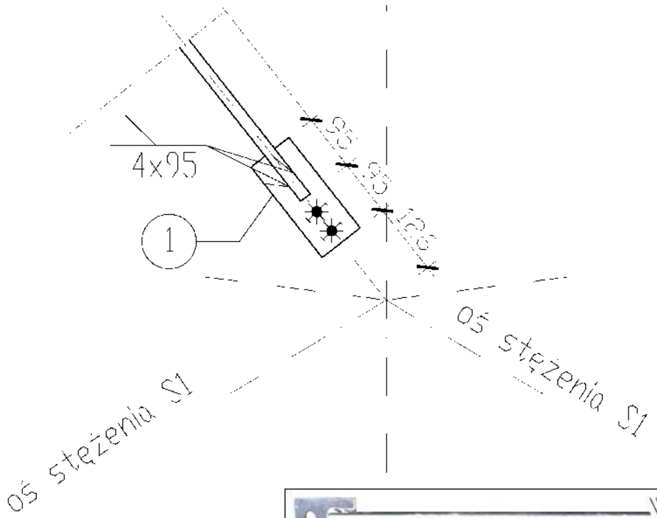
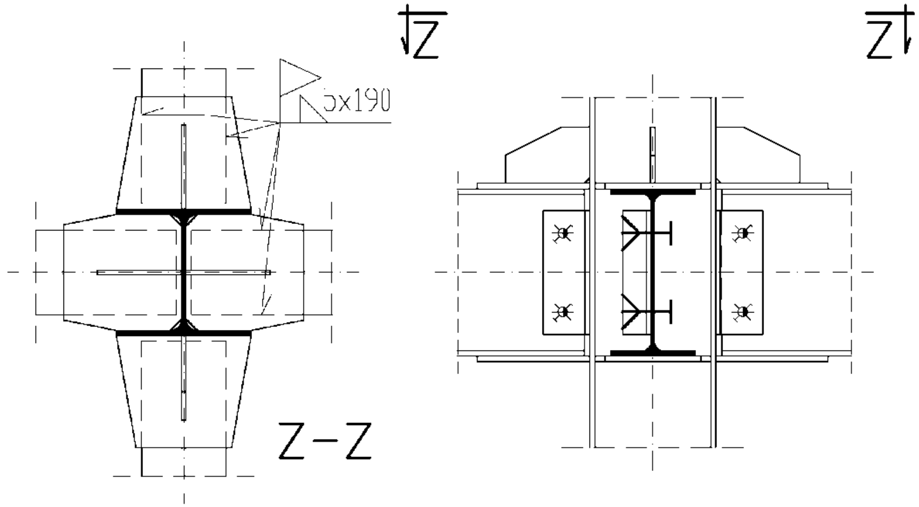


Photo: Author

Photo: scottmetals.com.au



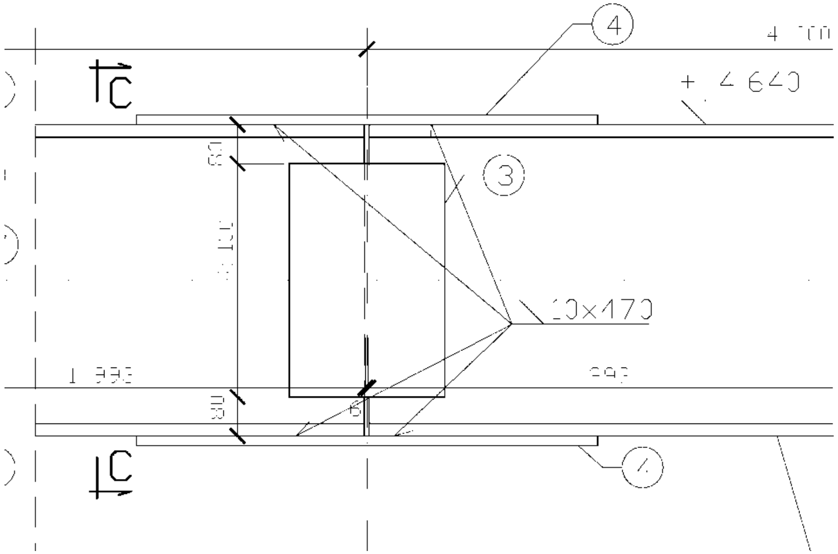


Photo: Author

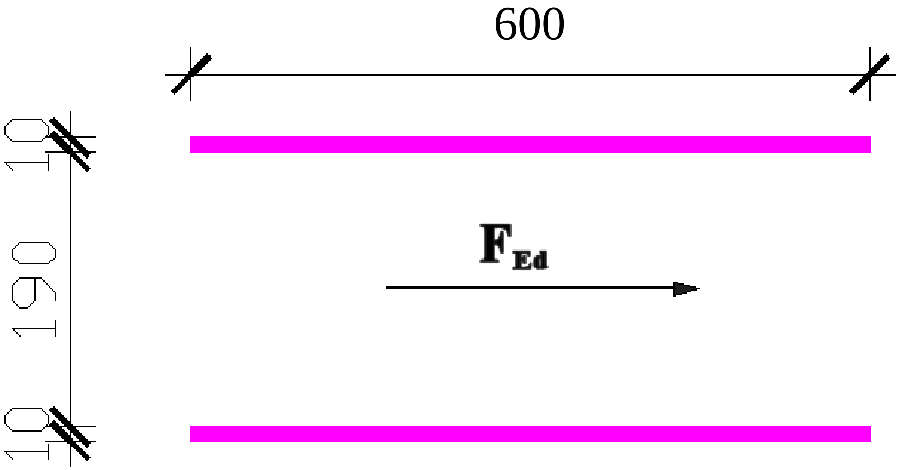
Welds between gusset plate and bracing or between flange plate and flange

This example is calculated for two cases:

a) When $l_{weld} \leq 150$ a

b) When $l_{weld} > 150$ a

Example 5a



S235

$$A_V = 2 \cdot 10 \cdot 600 = 12\ 000\ mm^2$$

$$F_{Ed} = 2\ 374{,}3\ kN$$

Photo: Author

$$\sigma = 0 \text{ MPa}$$

$$\tau = F_{Ed} / A_V = 197{,}833 \text{ MPa}$$

$$\sigma_\perp = \tau_\perp = \sigma / \sqrt{2} = 0{,}000 \text{ MPa}$$

$$\tau_\parallel = \tau = 197{,}833 \text{ MPa}$$

$f_u / (\beta_w \gamma_{M2}) = 360{,}000$ MPa

$0{,}9 f_u / \gamma_{M2} = 259{,}200$ MPa

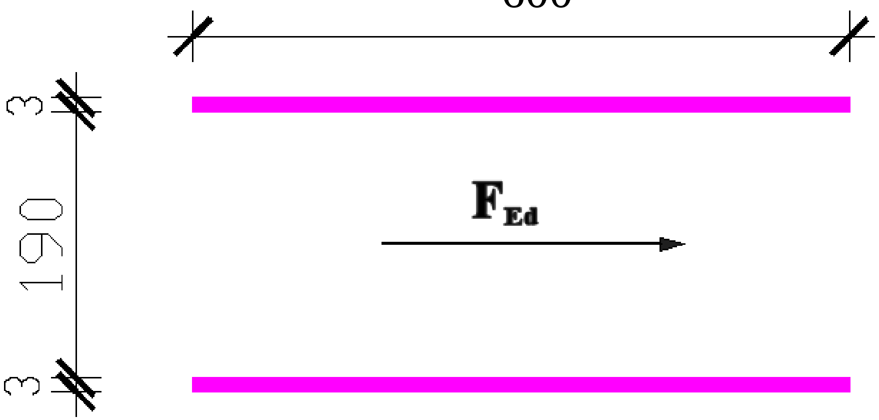
Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel{}^2 + \tau_\perp{}^2)]} = 342{,}657$ MPa < 360,000 MPa

Condition 2: $\sigma_\perp = 0{,}000$ MPa < 259,200 MPa

Example 5b

Photo: Author

S235



$A_V = 2 \cdot 3 \cdot 600 = 3\ 600\ mm^2$

$F_{Ed} = 712{,}3\ kN$

Force = 30% Example 5a

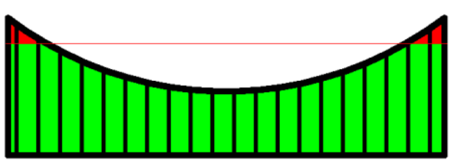
Area = 30% Example 5a

Effort the same

But…

$l = 600\ mm > 150\ a = 450\ mm$

Long joint



For long joint we have non-linear distribution of shear stress along weld. Values at the end is bigger than in central part. We assume constant value for calculations – is possible, that at the end real value of stress will be bigger than resistance.

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} \leq \beta_{LW} f_u / (\beta_w \gamma_{M2})$

Condition 2: $\sigma_\perp \leq 0{,}9\ \beta_{LW} f_u / \gamma_{M2}$

Values of β_{LW} for different types and lengths of welds:

Length of weld:	0 - ∞		
Between flange and web in welded I-beam	1,0		
Length of weld:	L < 1,700 m	1,700 m < L < 8,500 m	L > 8,500 m
Between transverse stiffeners and plates in welded I-beam	1,0	1,1 - L / 17	0,6
Length of weld:	L < 150 a	150 a < L < 900 a	L > 900 a
All other cases	1,0	1,2 - 0,2 L / (150 a)	0,0

EN 1993-1-8 (4.9), (4.10)

$$\beta_{LW} = 1{,}2 - 0{,}2 \cdot 600 / 450 = 0{,}933$$

$$\beta_{LW} f_u / (\beta_w \gamma_{M2}) = 336{,}000 \text{ MPa}$$
$$0{,}9\, \beta_{LW} f_u / \gamma_{M2} = 241{,}920 \text{ MPa}$$

$$\sigma = 0 \text{ MPa}$$

$$\tau = F_{Ed} / A_V = 197{,}861 \text{ MPa}$$

$$\sigma_\perp = \tau_\perp = \sigma / \sqrt{2} = 0{,}000 \text{ MPa}$$

$$\tau_\parallel = \tau = 197{,}861 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} = 342{,}705 \text{ MPa} > 336{,}000 \text{ MPa}$

Condition 2: $\sigma_\perp = 0{,}000 \text{ MPa} < 241{,}920 \text{ MPa}$

Conclusions

Condition	Example a	Example b
$\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} / [f_u / (\beta_w \gamma_{M2})]$	0,952	1,020
$\sigma_\perp / (0{,}9 f_u / \gamma_{M2})$	0,000	0,000

There is possible, that for very long welds resistance will be smaller than stress in weld.

Example 6

Filled welds

Welds between lacings and laced member or between battens and battened member - lacing or battens is L-section

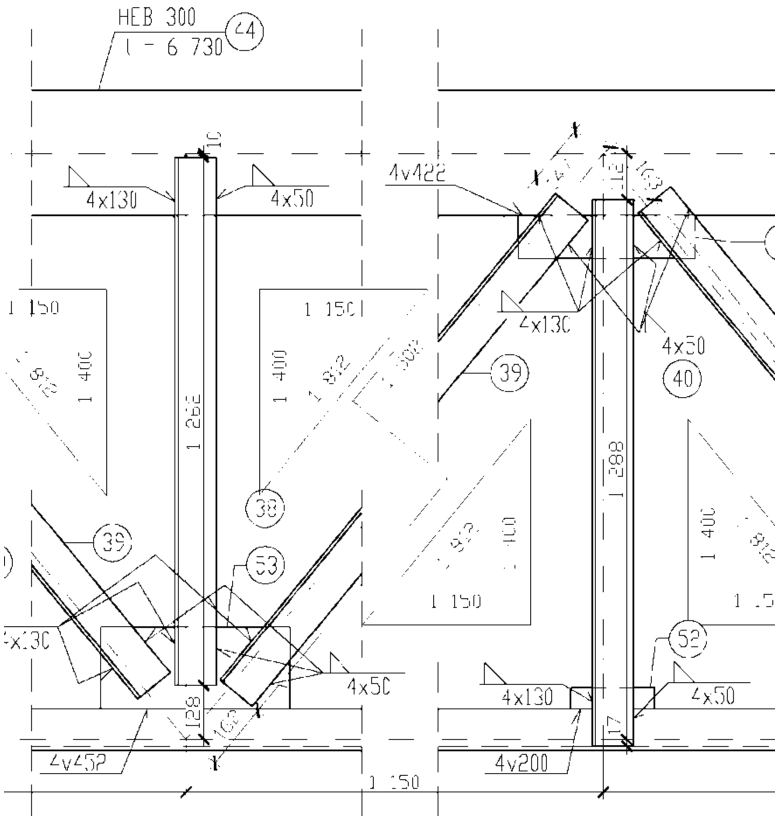


Photo: Author

Photo: Behaviour of Single Laced Columns versus Double Laced Columns, P. F. Hasheela

For L-sections distance between axis of bar and centre of gravity for welds are very important. Because of this, there are two cases:

a) Distance = 0

b) Distance ≠ 0

Example 6a

No eccentricities – different length of welds

(centre of gravity for welds at the same axis as centre of graviry for L-section)

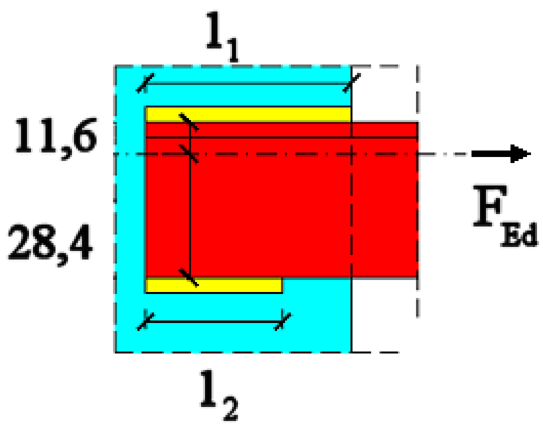


Photo: Author

S235

L 40x40x5

a = 3 mm

F_{Ed} = 182,2 kN

$e_1 = 11,6 + a / 2 = 13,1$ mm

$e_2 = 28,4 + a / 2 = 29,9$ mm

$e_1 \cdot l_1 = e_2 \cdot l_2$

$l_1 = 2,284\ l_2$

Assumption:

l_1 = 205 mm

l_2 = 90 mm

$$\Sigma l = l_1 + l_2 = 295 \text{ mm}$$

$$A_V = a \; \Sigma l = 3 \cdot 295 = 885 \text{ mm}^2$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

$$\sigma = 0 \text{ MPa}$$

$$\tau_\parallel = \tau = F_{Ed} / A_V = 205{,}877 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel{}^2 + \tau_\perp{}^2)]} = 356{,}587 < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_\perp = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 6b

Eccentricities – the same length of welds as for previous situation:

$$205 + 90 = 295 \approx 150 + 150$$

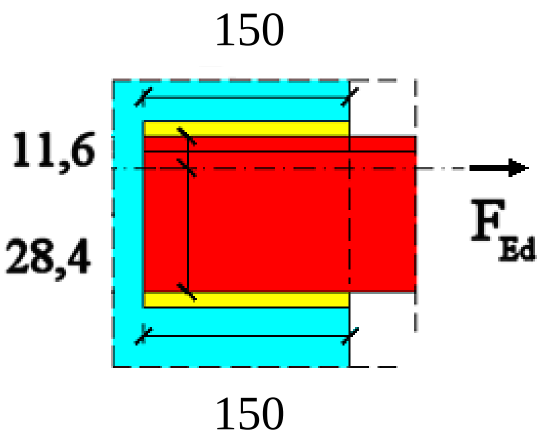


Photo: Author

S235

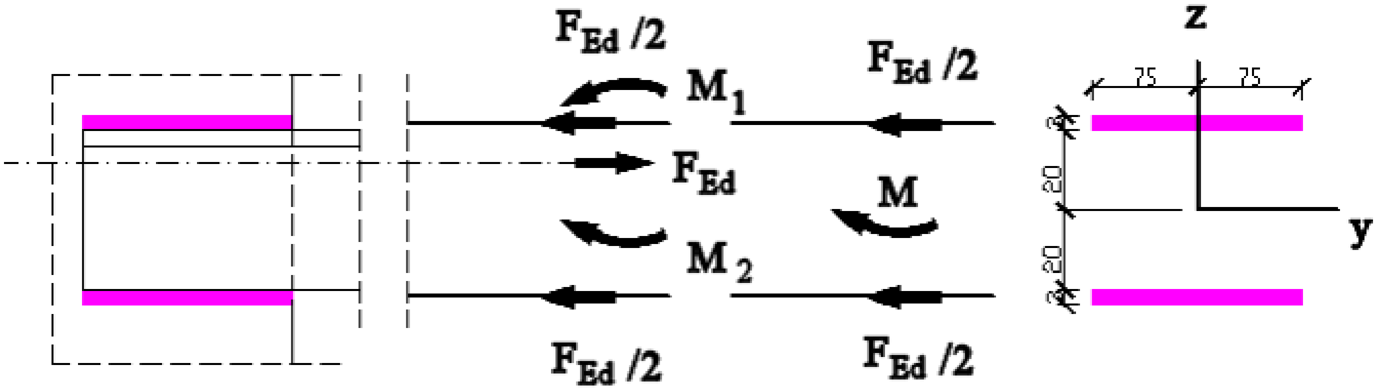
L 40x40x5

$a = 3$ mm

$F_{Ed} = 182{,}2$ kN

$$A_V = 2 \cdot 3 \cdot 150 = 900 \text{ mm}^2$$

Photo: Author



$$M_1 = e_1 F_{Ed} / 2 = 1{,}194 \text{ kNm}$$

$$M_2 = e_2 F_{Ed} / 2 = 2{,}724 \text{ kNm}$$

$$M = M_2 - M_1 = 1{,}530 \text{ kNm}$$

$$J_y = 2 \cdot 3 \cdot 150 \cdot (21{,}5)^2 = 416\,025 \text{ mm}^4$$

$$J_z = 2 \cdot 3 \cdot 150^3 / 12 = 1\,687\,500 \text{ mm}^4$$

$$J_o = J_y + J_z = 2\,103\,525 \text{ mm}^4$$

Calculation as for example 1:

$$\tau_F = F_{Ed} / A_V = 205{,}877 \text{ MPa}$$

$$\tau_M = M\, r_{max} / J_o$$

$$r_{max} = \sqrt{(75^2 + 23^2)} = 78{,}4 \text{ mm}$$

$$\sin\alpha = 23 / 78{,}4$$

$$\tau_M = 57{,}029 \text{ MPa}$$

$$\tau_{M\parallel} = \tau_M \sin\alpha = 16{,}731 \text{ MPa}$$

$$\tau_{M\perp} = \tau_M \cos\alpha = 54{,}521 \text{ MPa}$$

$$\sigma = 0 \text{ MPa}$$

$$\tau_{\parallel} = \tau_{M\parallel} + \tau_F = 222{,}608 \text{ MPa}$$

$$\tau_{\perp} = \tau_{M\perp} = 54{,}521 \text{ MPa}$$

$$\sigma_{\perp} = 0{,}000 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$
$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} = 396{,}964 \text{ MPa} > 360{,}000 \text{ MPa}$

Condition 2: $\sigma_\perp = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Conclusions

Condition	Example a	Example b
$\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]}$ / $[f_u / (\beta_w \gamma_{M2})]$	0,991	1,103
$\sigma_\perp / (0{,}9 f_u / \gamma_{M2})$	0,000	0,000

Effort for non-zero value of eccentricity is bigger than for no eccentricity even for very small value of bending moment.

Example 7

Welds between web and flange
in welded I-beam

Filled welds

For this type of welds:
stress in welds = stress in I-beam;
We no calculate geometry of welds

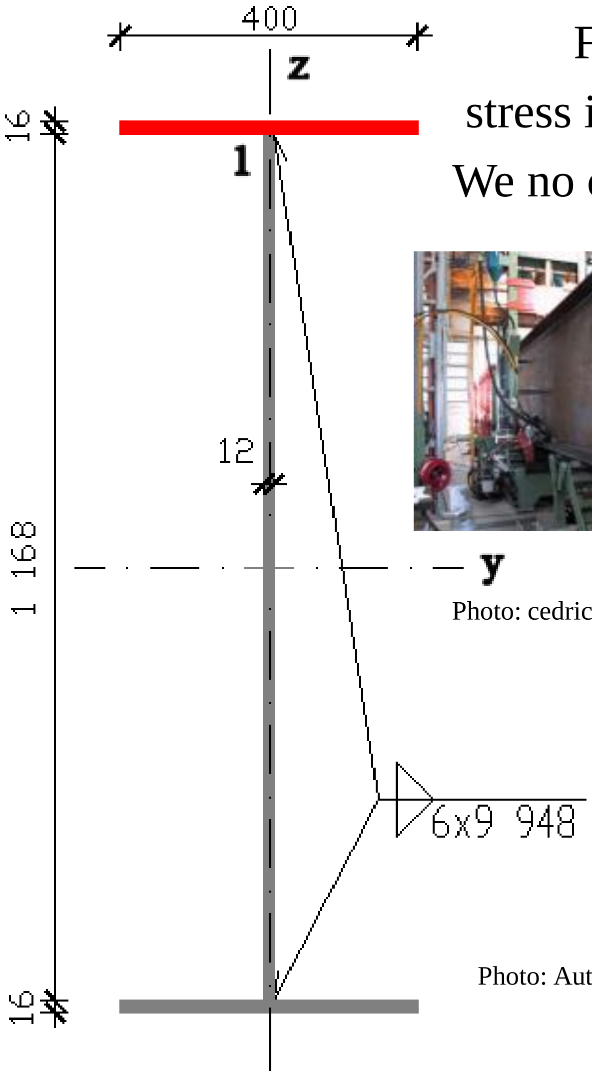


Photo: cedricbodeengineering.com

Photo: Author

S235

a = 6 mm

$$A_I = 2 \cdot 16 \cdot 400 + 1\,168 \cdot 12 = 26\,816 \text{ mm}^2$$

$$A_{V\,I} = 1\,168 \cdot 12 = 14\,016 \text{ mm}^2$$

$$J_{y\,I} = 12 \cdot 1\,168^3 / 12 +$$
$$+ 2 \cdot 16 \cdot 400 \cdot (1\,168 / 2 + 16 / 2)^2 =$$
$$= 6\,079\,352\,832 \text{ mm}^4$$

$$S_y = 16 \cdot 400 \cdot (1\,168 / 2 + 16 / 2) = 3\,788\,800 \text{ mm}^3$$

$$z_1 = 1\,168 / 2 = 584 \text{ mm}$$

$$W_{yI1} = J_{y\,I} / z_1 = 10\,409\,850 \text{ mm}^3$$

$$M_{Ed} = 1\,254{,}2 \text{ kNm}$$

$$V_{Ed} = 1\,325{,}9 \text{ kN}$$

There are three examples:

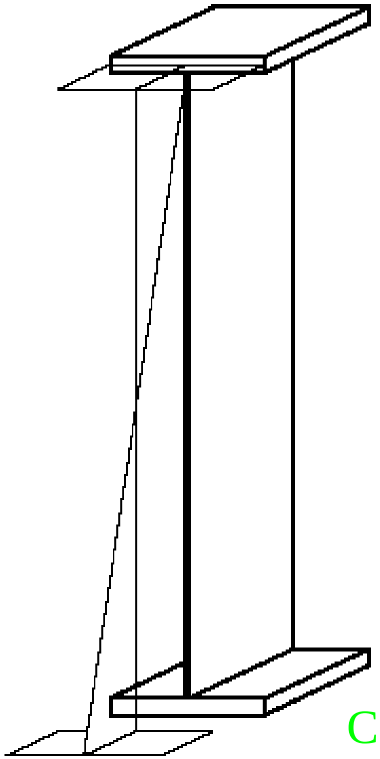
a) Continous welds

b) Intermitted welds

c) Continous welds and local transverse load

Photo: Author

Example 7a



$$\sigma_1 = M_{Ed} / W_{yI1} = 120{,}482 \text{ MPa}$$

$$\tau_1 = V_{Ed}\, S_y / (2\, a\, J_{y\,I}) = 68{,}861 \text{ MPa}$$

$$\tau_{\parallel} = \sigma_1 + \tau_1 = 189{,}343 \text{ MPa}$$

$$\tau_{\perp} = 0 \text{ MPa}$$

$$\sigma_{\perp} = 0 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 267{,}771 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 7b

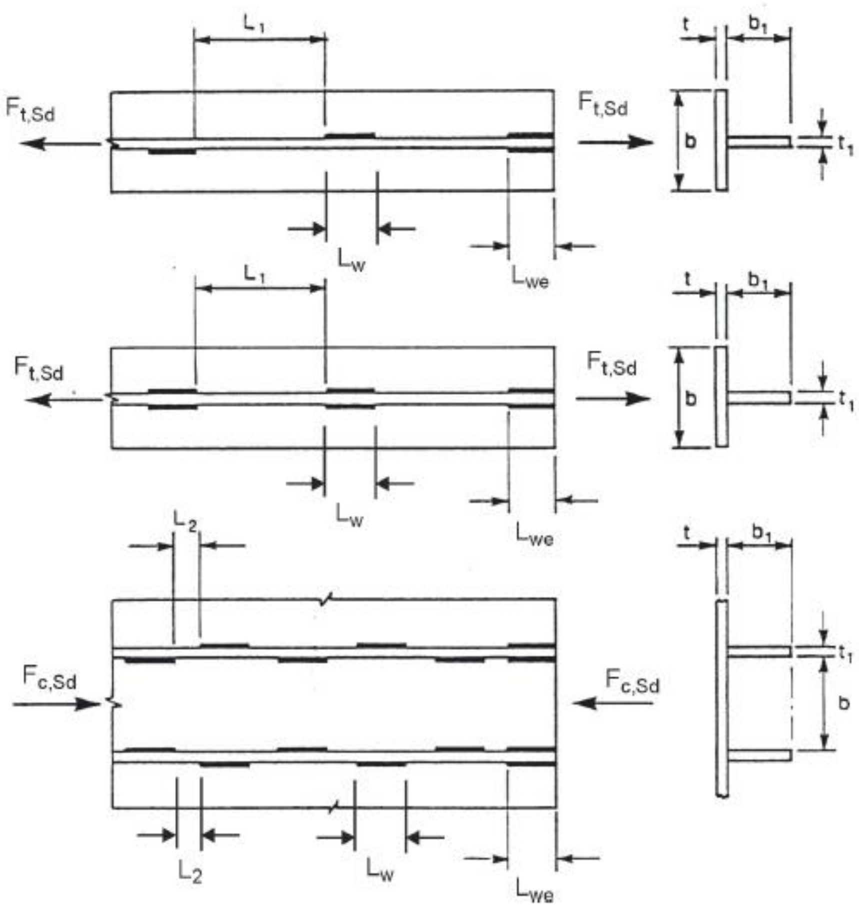


Photo: EN 1993-1-8 fig 4.1

Filled intermitted welds reduce length of welds and consuming of electrodes. Ttis type of welds could be applicated to type of joint as flange-web only. So, they can't be applicated in case such as in example 5b.

For analysed case (→ #16 / 19):

$b = 400$ mm

$t = 16$ mm

$b_1 = 1\,168$ mm

$t_1 = 12$ mm

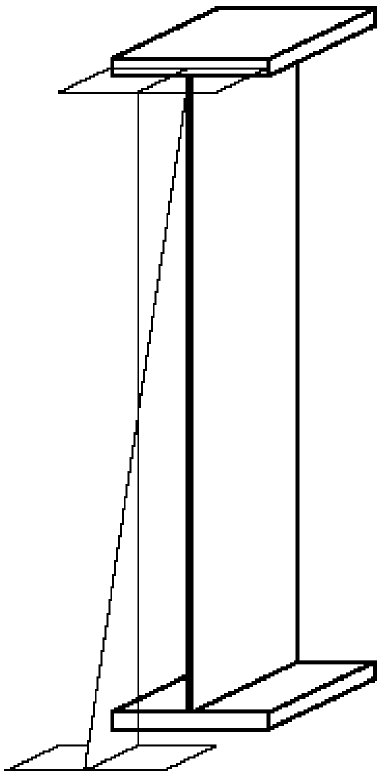
$L_w \geq \min(0{,}75\, b \;\; ; 0{,}75\, b_1) =$

$= \min(300 \;\; ; \;\; 876) = 300$ mm

$L_2 \leq \min(12\, t \;\; ; \;\; 12\, t_1 \;\; ; \;\; 0{,}25\, b \;\; ; \;\; 200 \text{ mm}) =$

$= \min(192 \;\; ; \;\; 144 \;\; ; \;\; 100 \;\; ; \;\; 200) = 100$ mm

Photo: Author



Into consideration are taken:

$L_w = 350$ mm

$L_2 = 50$ mm

$$\tau_{\parallel} = (\sigma_1 + \tau_1)\,(L_w + L_1) / L_w = 216{,}392 \text{ MPa}$$

$$\tau_{\perp} = 0 \text{ MPa}$$

$$\sigma_{\perp} = 0 \text{ MPa}$$

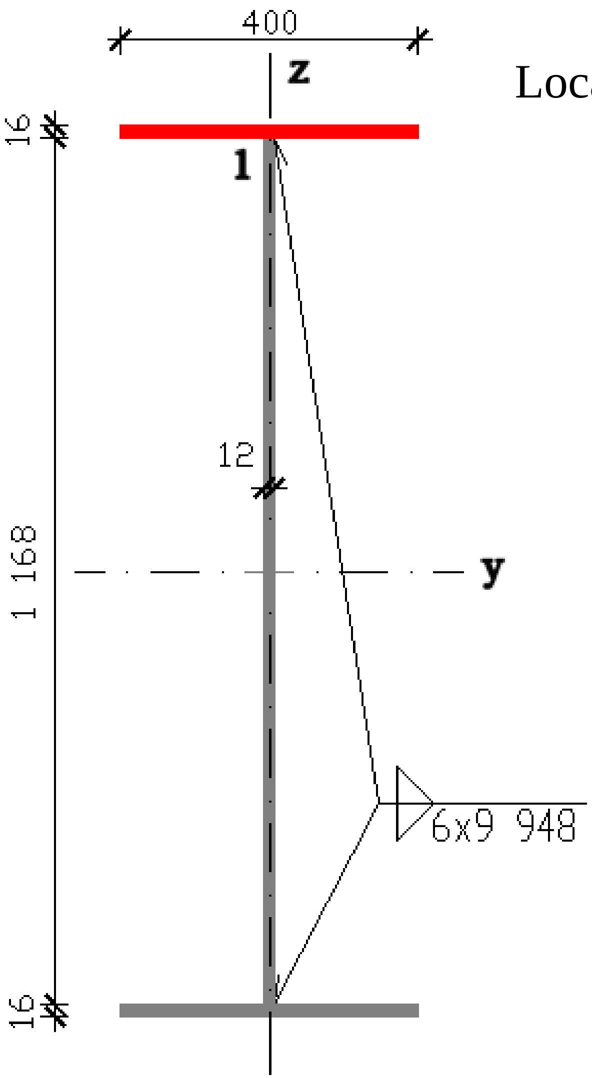
$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

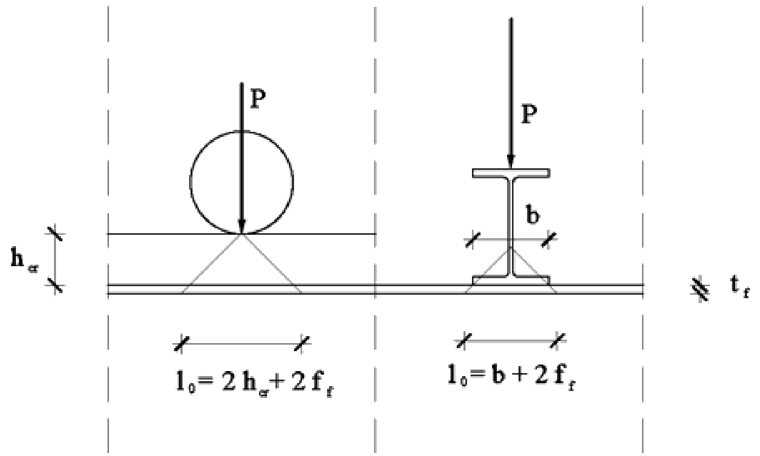
Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 374{,}802 \text{ MPa} > 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 0{,}000 \text{ MPa} < 259{,}200 \text{ MPa}$

Example 7c



Local transverse load - under wheel of crane or under secondary beam



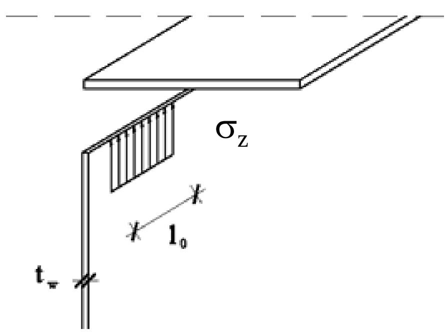


Photo: Author

S235

$P = 136{,}4$ kN

$l_0 = 212$ mm

$\sigma_z = P / (l_0\ 2\ a) = 53{,}616$ MPa

$$\tau_{\parallel} = \sigma_1 + \tau_1 = 189{,}343 \text{ MPa}$$

$$\tau_{\perp} = \sigma_{\perp} = \sigma_z / \sqrt{2} = 37{,}912 \text{ MPa}$$

$$f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$$

$$0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$$

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)]} = 336{,}603 \text{ MPa} < 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 37{,}912 \text{ MPa} < 259{,}200 \text{ MPa}$

Conclusions

Condition	Example a	Example b	Example c
$\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} / [f_u / (\beta_w \gamma_{M2})]$	0,744	1,041	0,935
$\sigma_\perp / (0{,}9 f_u / \gamma_{M2})$	0,000	0,000	0,146

Transversal force changes type of stresses distribution in welds. Application of intermitted welds must be very careful.

Example 8

Welds in castellated beams

Photo: rfstearns.com

Photo: gunungsteel.com

Photo: H. W. Al-Thabhawee, A. Mohammed, Experimental study for strengthening octagonal castellated steel beams using circular and octagonal ring stiffeners , IOP Conf. Ser.: Mater. Sci. Eng. 584 / 2019

Welds between two parts of I-beam or I-bam and expansion plate

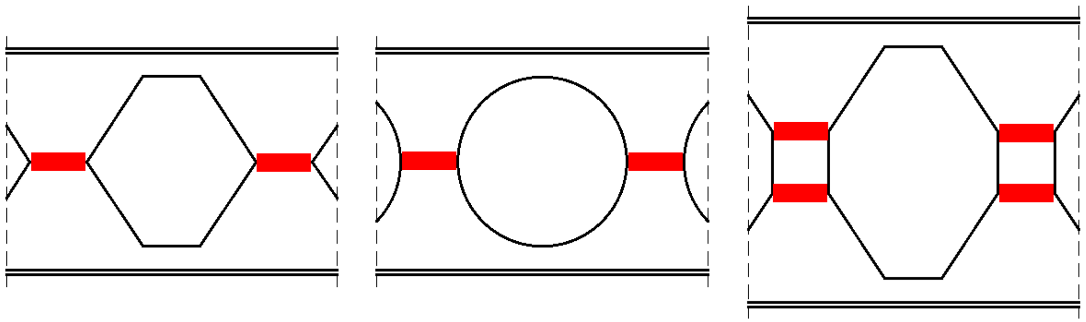
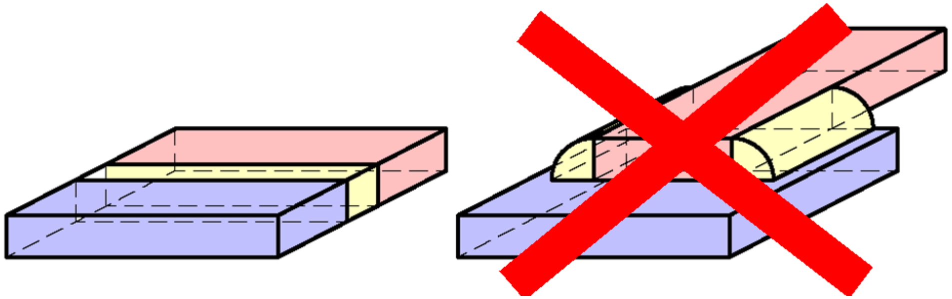


Photo: Author



In such locations of welds, it is not possible to make an overlapping contact. All parts of member must lie in the same plane. Only butt welds are allowed.

Butt welds: satisfied of technical requirement for weld + sufficient load-bearing weaker element → calculations of weld load-bearing is not necessary (→ #t / 5)

Example 9

Truss splice joint

Photo: encrypted-tbn0.gstatic.com

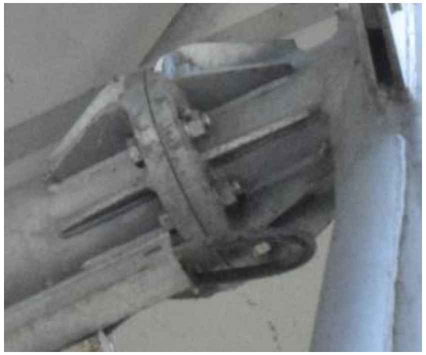


Photo: Author

Welds between:

truss bar and end plate, area A_1

truss bar and longitudinal stiffeners, area A_2

longitudinal stiffeners and end plate, area A_3

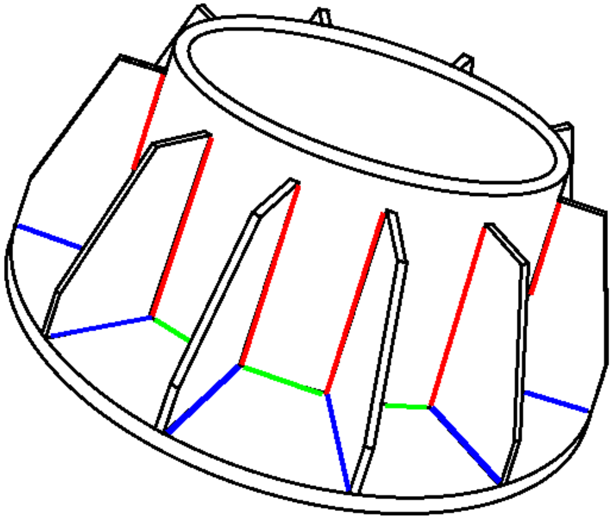
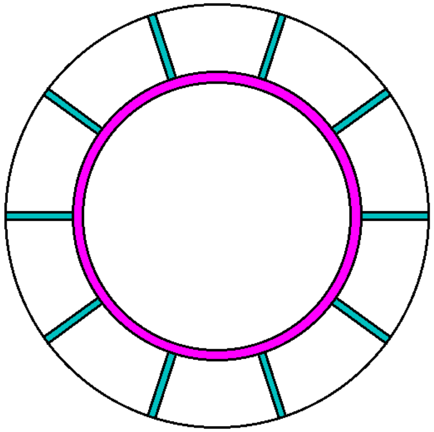


Photo: Author

Photo: Author



Global axial force N_{Ed} is distributed between cross-section of CHS and cross-section of stiffeners:

$$N_{Ed,\,CHS} = N_{Ed}\, A_{CHS} / (A_{CHS} + A_{St})$$

$$N_{Ed,\,St} = N_{Ed}\, A_{St} / (A_{CHS} + A_{St})$$

Welds between	Force	Force orientation in relation to weld	Calculation as in example	Stress in welds
truss bar and end plate	$N_{Ed,\,CHS}$	Perpendicular	#4a	$\sigma = N_{Ed,\,CHS} / A_1$ $\sigma_\perp = \tau_\perp = \sigma / \sqrt{2}$ $\tau_\parallel = 0$
truss bar and longitudinal stiffeners	$N_{Ed,\,St}$	Parallell	#5a	$\tau_\parallel = N_{Ed,\,St} / A_2$ $\sigma_\perp = \tau_\perp = 0$
longitudinal stiffeners and end plate	$N_{Ed,\,St}$	Perpendicular	#3a	$\sigma = N_{Ed,\,St} / A_3$ $\sigma_\perp = \tau_\perp = \sigma / \sqrt{2}$ $\tau_\parallel = 0$

Example 10

Filled all round welds

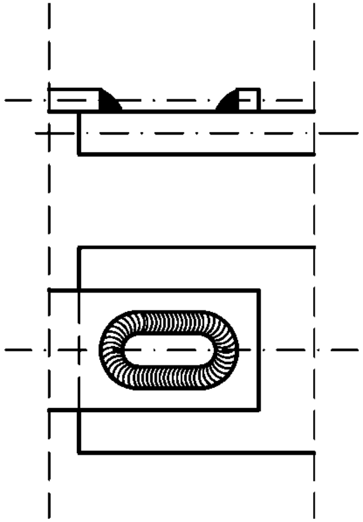
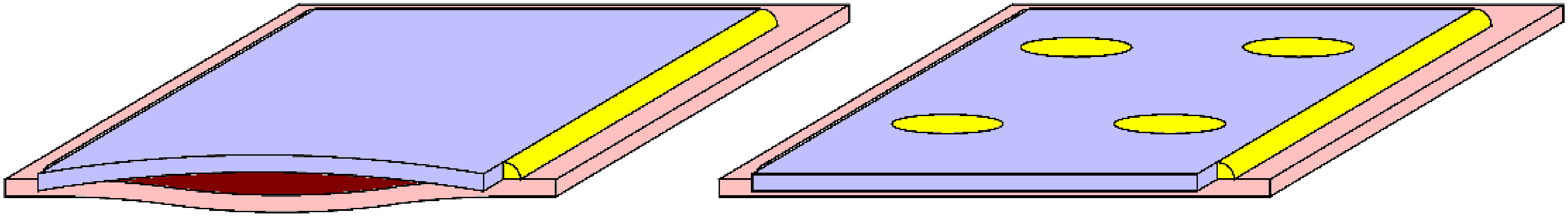


Photo: Author

Auxiliary for big flange plate, web plate, etc.

(to inter-connect imperfected components or to prevent the buckling or separation)

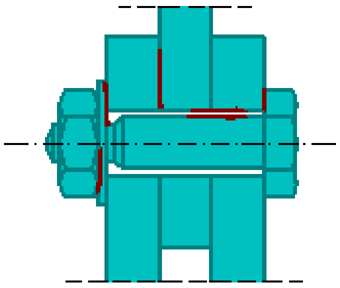
The same type of calculation as in example 1



Crevice

Photo: Author

Photo: epg.science.cmu.ac.th



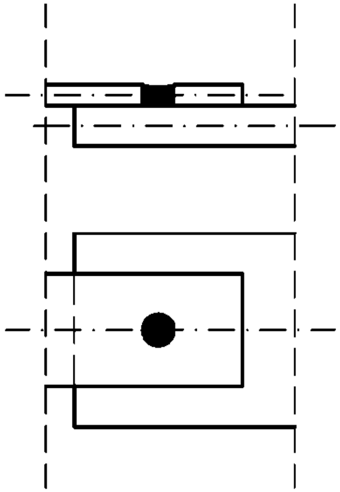
Limited air circulation and limited oxygen access, uneven distribution of sparingly and easily soluble salts on the surface of gap, increased aggressiveness of environment inside gap

→ #7 / 18

Contact (bimetalic): different chemical composition of alloys or contact of different metals. In presence of water/electrolyte, galvanic cell and directed movement of electrons is created. As a result, less noble metal corrodes in the presence of a more noble metal.

Photo: wikipedia

Example 11



Plug welds

Auxiliary for big flange plate, web plate, etc.
(to inter-connect imperfected components or to prevent the buckling or separation)

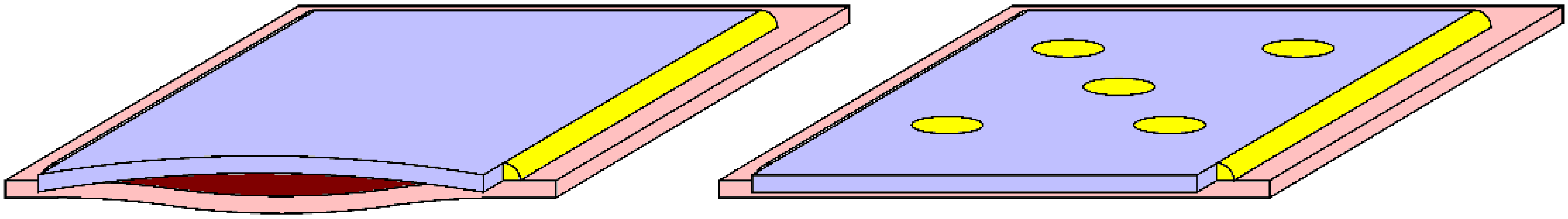


Photo: Author

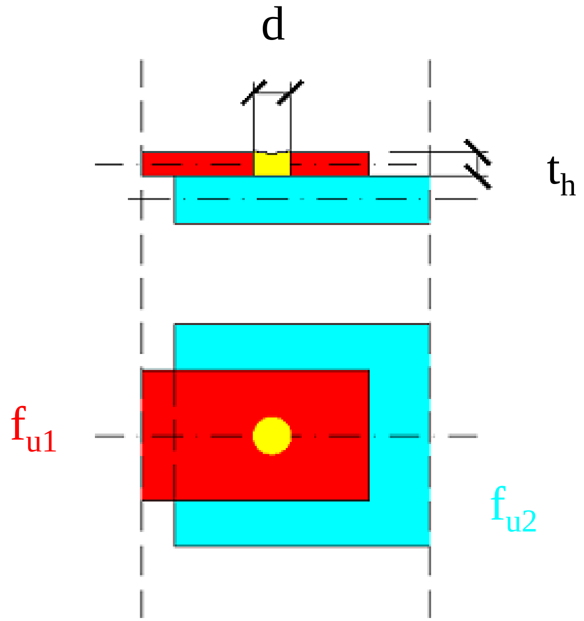


Photo: Author

The same type of calculation as in example 1

$$F_{w,\,Rd} = A_w\, f_u / (\sqrt{3}\, \beta_w\, \gamma_{M2})$$

$$A_w = \pi\, d^2 / 4$$
$$f_u = \min(f_{u1};\, f_{u2})$$
$$\gamma_{M2} = 1{,}25$$

steel	S 235	S 275	S 355	S 420	S 460
β_w	0,80	0,85	0,90	1,00	

EN 1993-1-8 tab 4.1

Examination issues

Initial assumptions about geometry of filled welds

Resistance of filled welds

Recalculation from cross-sectional forces to stresses for different types of welds

Gusset plate - blacha węzłowa
End-plate - blacha czołowa
Base plate - blacha stopowa

Thank you for attention

tmichal@pk.edu.pl