Metal Structures

Design Project I

Steel truss – examples of calculation (part II)

Algorithm

Calculation of each metal structure can be divided into few groups of problem:

- Initial assumptions about geometry of structure (initial drawing);
- Analysis of loads and actions;
- Calculation of elements (resistance, stability, deflection);
- Calculation of connections and joints between elements (stiffness, resistance);
- Final drawings and documentatnion;

→ Des #1 / 11

7 examples of calculations for various sub-parts of steel truss will be presented:

Ist example: roofing selection;

IInd example: purlin

IIIrd example: truss member;

IVth example: roof bracing.

Vth example: node;

VIth example: field splice;

Theoretical explanations of above problems will be detaily presented during lectures, here are way of calculation only.

→ Des Ex #1 / 3

Stiffness of joint in second, besides resistance, parameter important for joints. According to Eurocode, we must check, if our assumption about joint - rigid or hinged - is true for real geometry and real cross-sections of members. Sometimes, because of big difference betweem assumption and real behaviour of joint, we must make static calculations once again.

Part of structure	Condition	
	Resistance	Stifness
Member	ULS	SLS (deflection)
Joint	ULS	Qualification for different type of joint (hinged, semi-rigid, rigid)

Analysis or stifness and resistance is made based on components method. (more information will be presented on lecture #14,

→ Des #1 / 73

Vth example of calculations – truss node (truss joint)

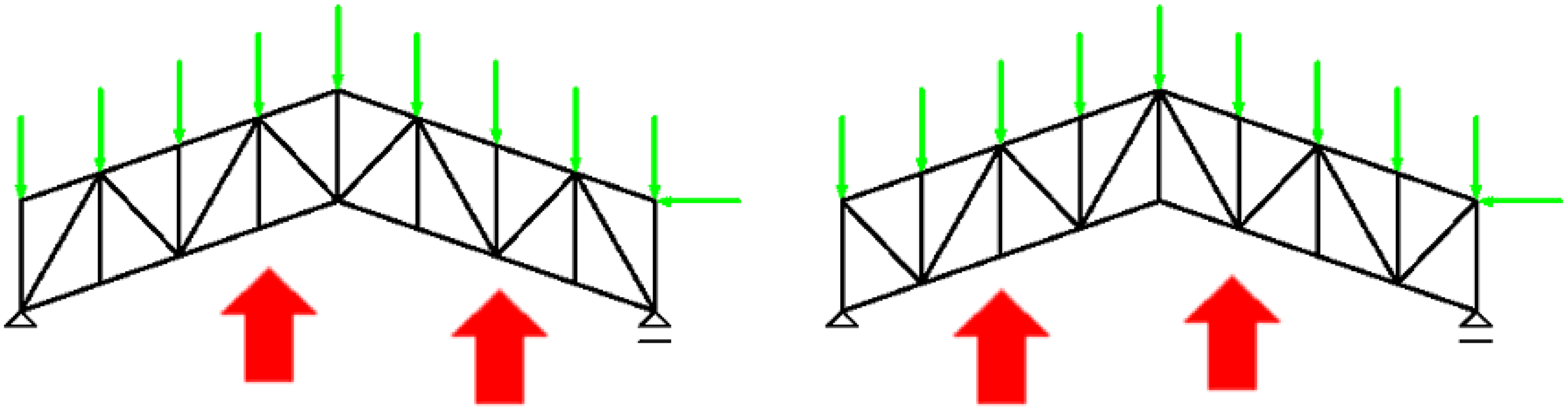
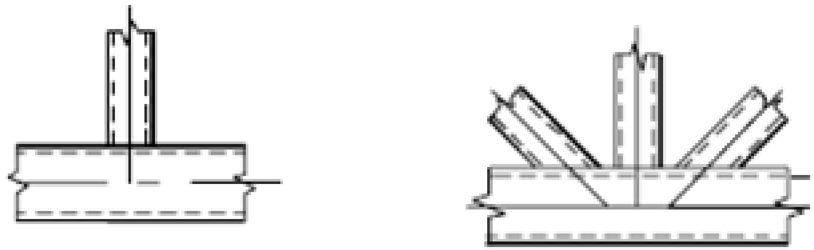


Photo: Author



T joint

KT joint

Photo: EN 1993-1-8 fig. 7.1

Two types of joints: T and KT will be presented in calculations.

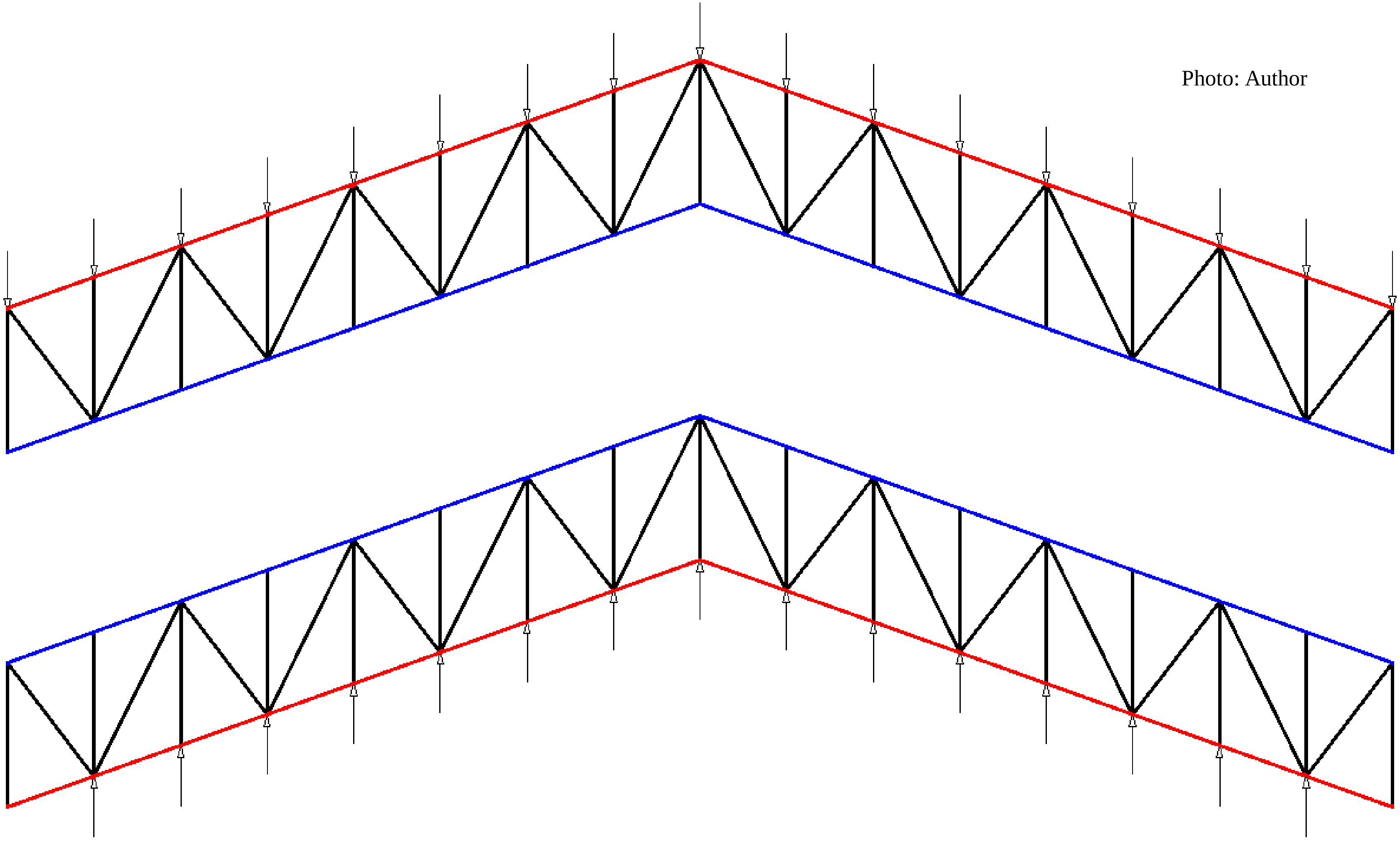


Photo: Author

There is possible, than two main situation must be analysed for truss: top chord compressed and bottom chord compressed. So, for both types of node, two groups of result must be taken into consideration.

T joint:

Vertical bar:

ϕ 51 x 3,2

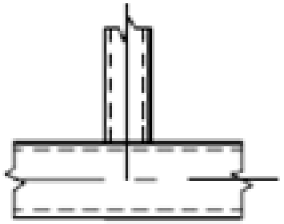
$N_{1, Ed}$

$d_1 = 51$ mm

(New complex of data)

S235

Photo: EN 1993-1-8 fig. 7.1



$\theta = 90^o$

T joint

Chord:

ϕ 88,9 x 8,0

$A_0 = 20{,}3$ cm^2

$t_0 = 8{,}0$ mm

$d_0 = 88{,}9$ mm

Case in chord	$N_{P, Ed}$ [kN] (chord)	$N_{1, Ed}$ [kN] (vertical bar)
Tension in chord	-294,928	113,383
Compression in cord	87,578	-35,321

(New complex of data)

KT joint:

ϕ 51 x 3,2

$\underline{N_{3, Ed}}$

d_3 = 51 mm

t_2 = 3,2 mm

$\theta_3 = 80^o$

ϕ 51 x 3,2

$\underline{N_{1, Ed}}$

d_1 = 51 mm

t_1 = 3,2 mm

$\theta_1 = 65^o$

ϕ 51 x 3,2

$\underline{N_{2, Ed}}$

d_2 = 51 mm

t_3 = 3,2 mm

$\theta_2 = 40^o$

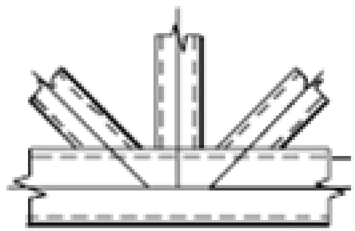
Chord:

ϕ 88,9 x 8,0

$A_0 = 20{,}3\ cm^2$

t_0 = 8,0 mm

d_0 = 88,9 mm



KT joint

Photo: EN 1993-1-8 fig. 7.1

Numbering of members is very important: 1-3-2

Distance between chords 1 500 mm

Case in chord	$N_{P, Ed, left}$ [kN]	$N_{P, Ed, right}$ [kN]	$N_{1, Ed}$ [kN]	$N_{2, Ed}$ [kN]	$N_{3, Ed}$ [kN]
Tension in chord	-217,852	-320,607	-62,711	106,074	-11,520
Compression in cord	75,217	199,887	75,064	-119,343	8,824

Range of validity (EN 1993-1-8 tab. 7.1)

Every procedures, presented in EN 1993-1-8 for trusses CHS-CHS, can be applicated, only if:

- diameter ratio $0{,}2 \leq$ web member / chord $\leq 1{,}0$

  Analysed case: 51 / 88,9 = 0,57 ok

- chord dimension $10 \leq$ diameter / thickness ≤ 50

  Analysed case: 88,9 / 8 = 11,11 ok

- gap or overlap → #t / 10 – 12, 18 – 21

<u>Stiffness</u> – verification, if real structure behaves as ideal truss

- or rather as frame.

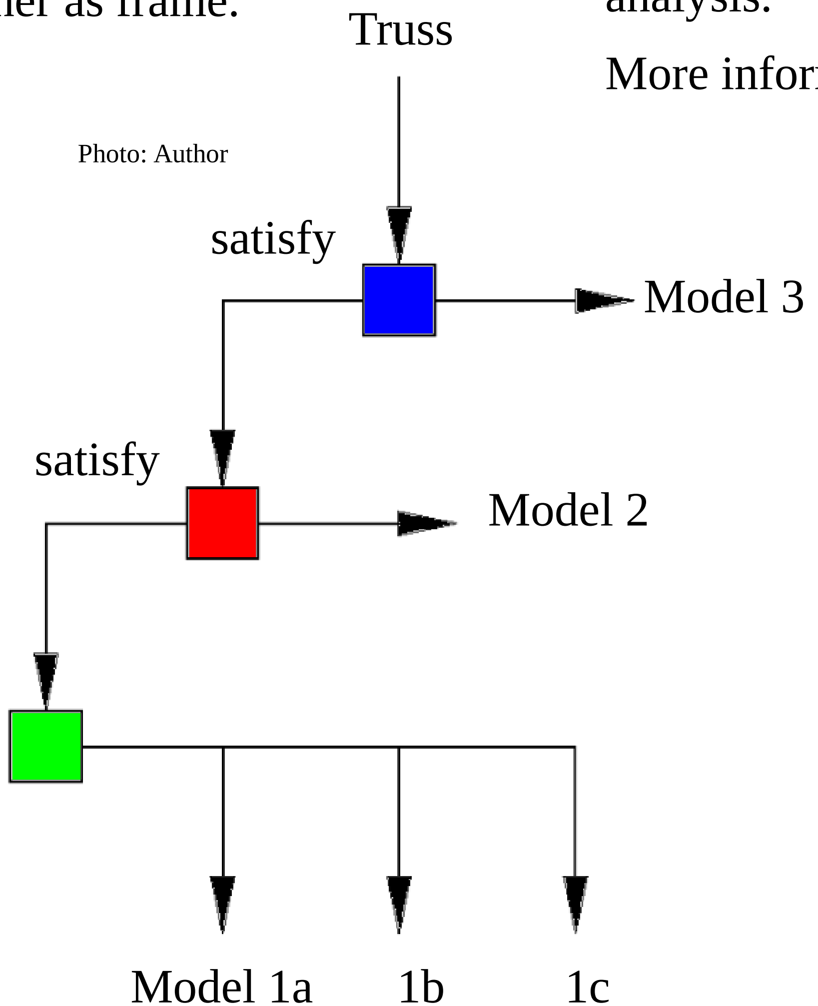


Photo: Author

In your range of project you make many simplification. Of course, for real project must be made full version of analysis.

More information will be presented on lecure #9.

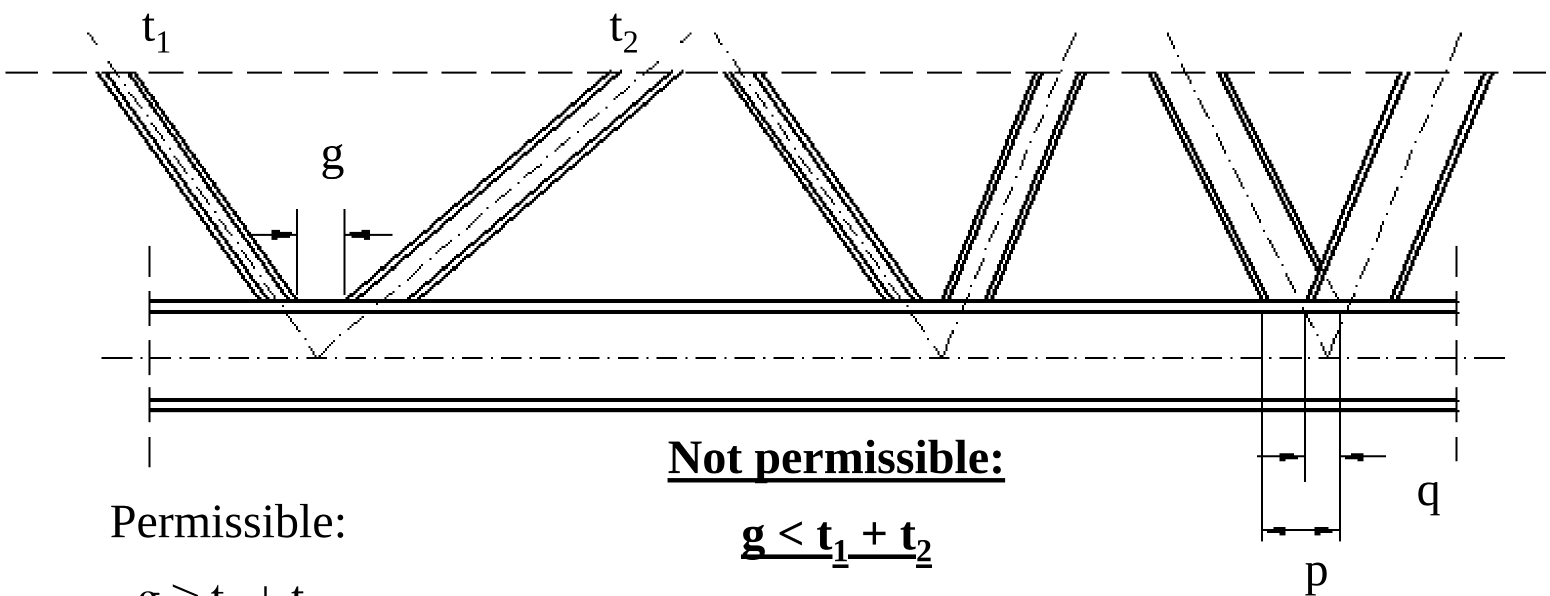
Five various models of truss structure must be taken into consideration. The choice of model is determined by satisfy or dissatisfy of three block of conditions.

„Blue” part – conditions concern type of cross-section of truss membes (generally satisfied for CHS section classes I and II).

„Red” part - general definition of truss (loads only in joits, satisfied in this project).

„Green” part – relative position of members in joints. <u>Only this part will be checked as part of project.</u>

Relative position of truss members in joint, accepted by Eurocode:



<u>Not permissible:</u>

<u>$g < t_1 + t_2$</u>

<u>or</u>

<u>$q / p < 0,25$</u>

Permissible:

$g \geq t_1 + t_2$

(gap joint)

Permissible:

$q / p \geq 0,25$

$g = -q$

(overlap joint)

Recommendation: $q / p < 0,6$

Photo: Author

EN 1993-1-8 7.1

In case of problem (not permissible position of members):

web members must be slightly twisted, to change their position at joint.

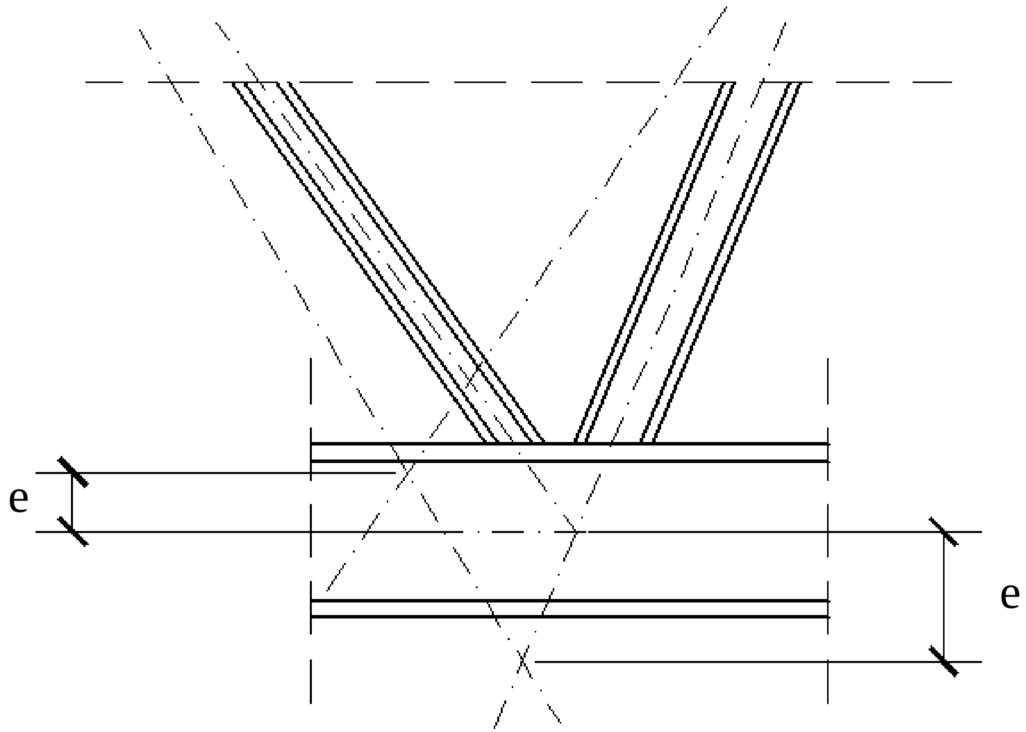


Photo: Author

It makes eccentricities e. Eccentricities make non-zero values of bending moment.

EN 1993-1-8 defines three situations:

- no eccentricity (Model 1a, #t / 10), ideal joint;
- small eccentricity (Model 1b, #t / 10), secondary bending moment acts on chord;
- big eccentricity (Model 1c, #t / 10), secondary bending moment acts on chors and joint.

Problem concerns only joints with more than one web member connected to chord. Problem does’t concern joint type T.

Resistance of truss joint.

Six various models of joint's destruction (various local phenomena) must be analised. Not all are equally important for various shapes of truss joints. Satisfaction of conditions presented in EN 1993-1-8 tab. 7.1 allows taken into consideration 1-2 mechanism only of destruction for each type of joint.

Photo: scielo.br

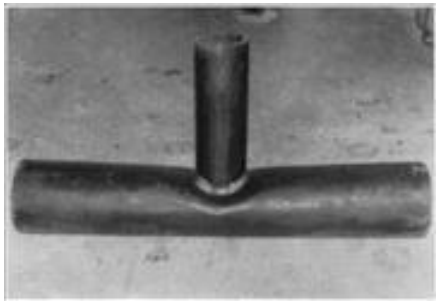


Photo: offshoremechanics.asmedigitalcollection.asme.org

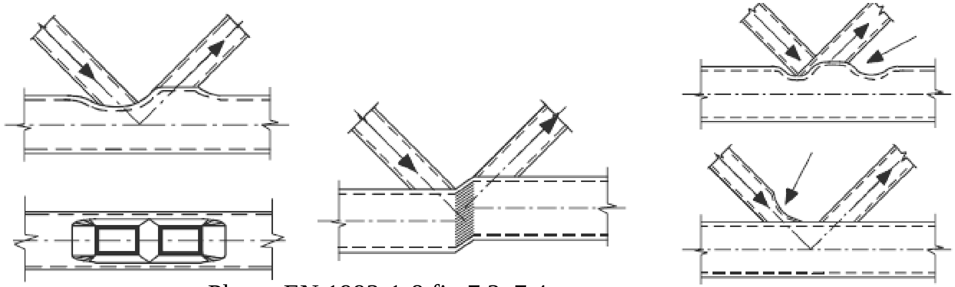


Photo: EN 1993-1-8 fig 7.3, 7.4

General formula of resistance for joints in truss chord – web members as CHS-CHS

(EN 1993-1-8 (7.3)):

$$N_{i,\,Ed} / N_{i,\,Rd} + (M_{ip,\,i,\,Ed} / M_{ip,\,i,\,Rd})^2 + M_{op,\,i,\,Ed} / M_{op,\,i,\,Rd} \leq 1{,}0$$

$N_{i,\,Ed}$ – force in web member;

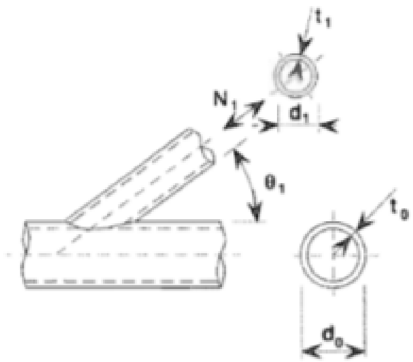
$N_{i,\,Rd}$ – resistance of joint under axial force;

$M_{ip,\,i,\,Ed}$, $M_{op,\,i,\,Rd}$ - secondary bending moments in joints (effect of big eccentricity), in plane (ip) and out of plane (op – in case of spatial truss). In your range of project, $M_{op,\,i,\,Rd} = 0$.

Formulas for $N_{i,\,Rd}$ for truss CHS-CHS are presented in EN 1993-1-8 tab. 7.2, 7.3, 7.4, 7.5, 7.6, 7,7. Joints T and KT are listed in:

- 7.2;
- 7.5 (for T-joint under bending moment; not important for Your range of project);
- 7.6.

Chord face failure - T and Y joints



$$N_{1,Rd} = \frac{\gamma^{0,2} k_p f_{y0} t_0^2}{\sin\theta_1}(2,8 + 14,2\beta^2)/\gamma_{M5}$$

Photo: EN 1993-1-8 tab. 7.2

T joint, condition 1

Punching shear failure for K, N and KT gap joints and T, Y and X joints [i = 1, 2 or 3]

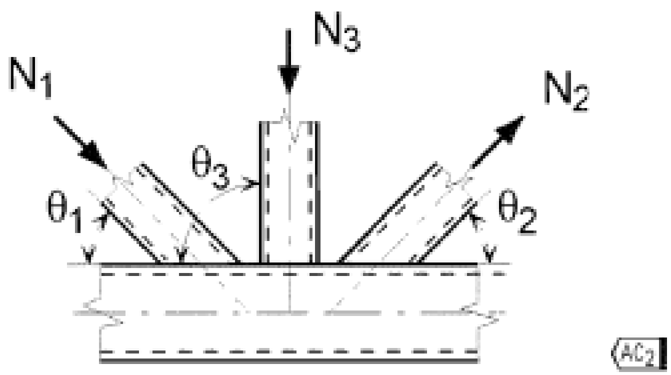
When $d_i \leq d_0 - 2t_0$: $N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_i \frac{1+\sin\theta_i}{2\sin^2\theta_i}/\gamma_{M5}$

Photo: EN 1993-1-8 tab. 7.2

KT joint, condition 1

T joint, condition 2

(AC2) Members 1 and 3 are here in compression and member 2 is here in tension.



$$N_{1,Ed}\sin\theta_1 + N_{3,Ed}\sin\theta_3 \leq N_{1,Rd}\sin\theta_1$$
$$N_{2,Ed}\sin\theta_2 \leq N_{1,Rd}\sin\theta_1$$

where $N_{1,Rd}$ is the value of $N_{1,Rd}$ for a K joint from Table 7.2 but with $\frac{d_1}{d_0}$ replaced by: $\frac{d_1 + d_2 + d_3}{3d_0}$

Photo: EN 1993-1-8 tab. 7.6

KT joint, condition 2

T joint, condition 1:

EN 1993-1-8 tab. 7.2:

$N_{1,\,Rd} = \gamma^{0,2}\, k_p\, f_{y0}\, t_0^2\, (2{,}8 + 14{,}2\, \beta) / (\gamma_{M5} \sin \theta)$

$k_p =$

for compressive $N_{P,\,Ed}$: min [1,0 ; $1{,}0 - 0{,}3\, n_p\, (1 + n_p)$]

for tensile $N_{P,\,Ed}$: 1,0

EN 1993-1-8 1.5:

$\gamma = d_0 / 2\, t_0$

$\beta = d_1 / d_0$

$\gamma_{M5} = 1{,}0$

$n_p = N_{P,\,Ed} / (A_0\, f_{y0}\, \gamma_{M5})$

Case in chord	$N_{P,\,Ed}$ [kN]	$N_{1,\,Ed}$ [kN]	n_p	k_p	γ	β	$N_{1,\,Rd}$ [kN]	$N_{1,\,Ed} / N_{1,\,Rd}$
Comp.	87,578	-35,321	0,183	0,935	5,556	0,576	216,978	0,163
Tens.	-294,928	113,383	0,618	1,000			232,062	0,489
	Chord	Bar	Chord	Chord	Chord	Bar / Chord	Bar	Bar

T joint, condition 2:

Condition 2 is important for initial assumption only:

$$d_1 \le d_0 - 2\ t_0$$

$$d_1 = 51\ \text{mm}$$

$$t_0 = 8{,}0\ \text{mm}$$

$$d_0 = 88{,}9\ \text{mm}$$

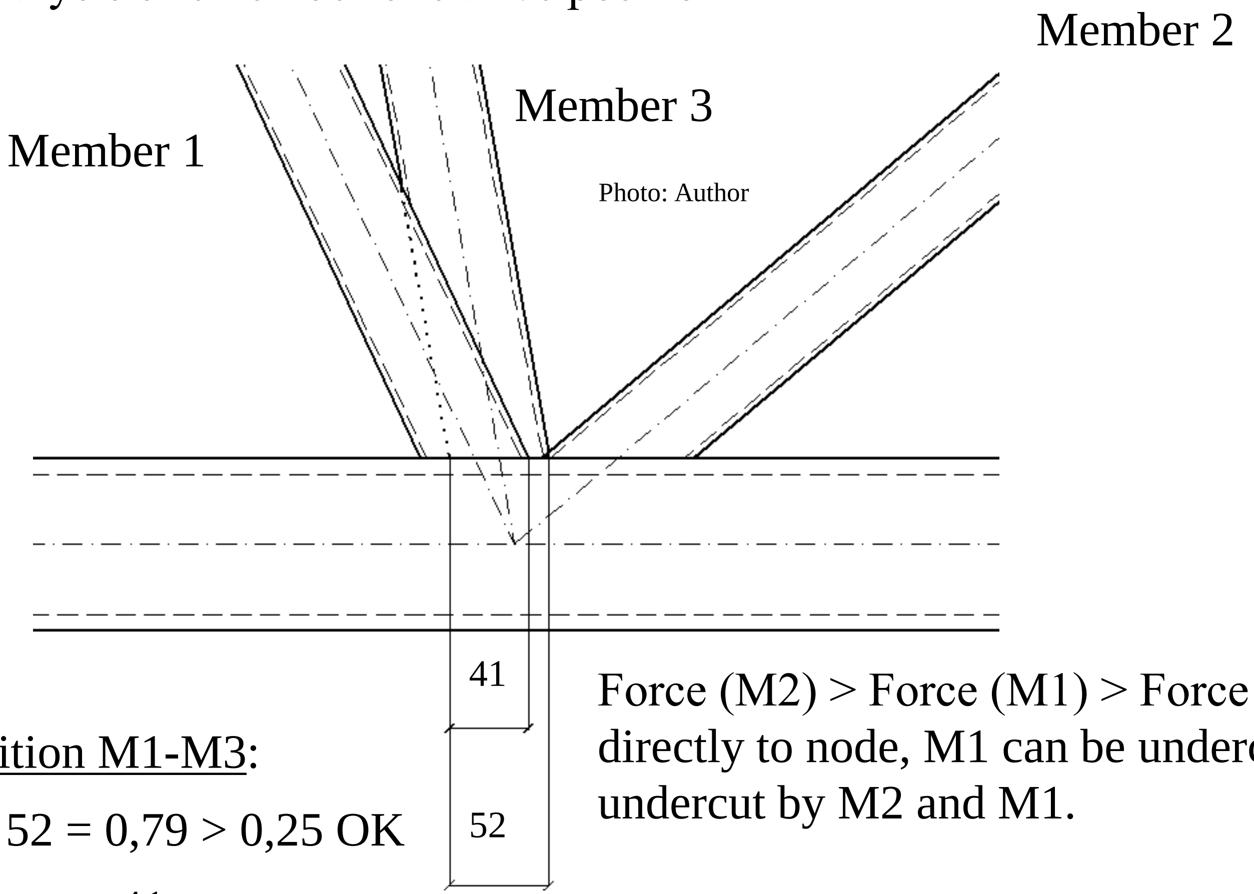
$$d_0 - 2\ t_0 = 72{,}9\ \text{mm}$$

Condition important for checking

$$N_{1,\ Rd} = f_{y0}\ t_0\ \pi\ d_1\ (1 + \sin\theta)\ /\ [\ 2\ (\sqrt{3})\ \gamma_{M5}\ (\sin\theta)^2] = 173{,}907\ \text{kN}$$

Case in chord	$N_{P,\ Ed}$ [kN]	$N_{1,\ Ed}$ [kN]	$N_{1,\ Rd}$ [kN]	$N_{1,\ Ed}\ /\ N_{1,\ Rd}$
Comp.	87,578	-35,321	173,907	0,203
Tens.	-294,928	113,383		0,652
	Chord	Bar	Bar	Bar

KT joint, analysis of emember's relative position



Position M1-M3:

q / p = 41 / 52 = 0,79 > 0,25 OK

g = -q = -41 mm

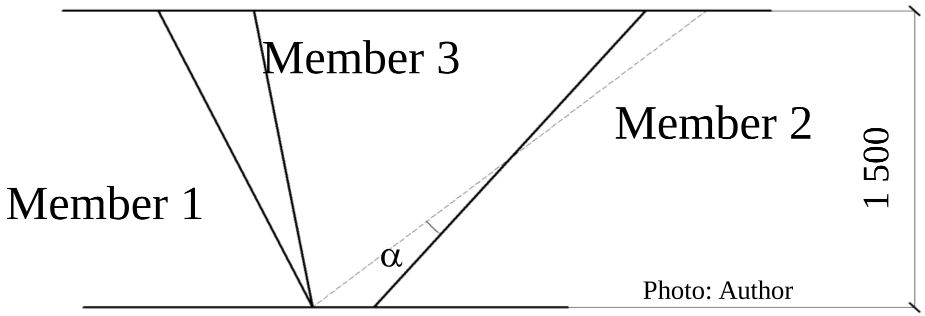
q / p > 0,6

so, according to recommendation, connection between braces and chord face should be checked for shear.

Force (M2) > Force (M1) > Force (M3) → M2 goes directly to node, M1 can be undercut by M2, M3 is undercut by M2 and M1.

Position M2-M3:

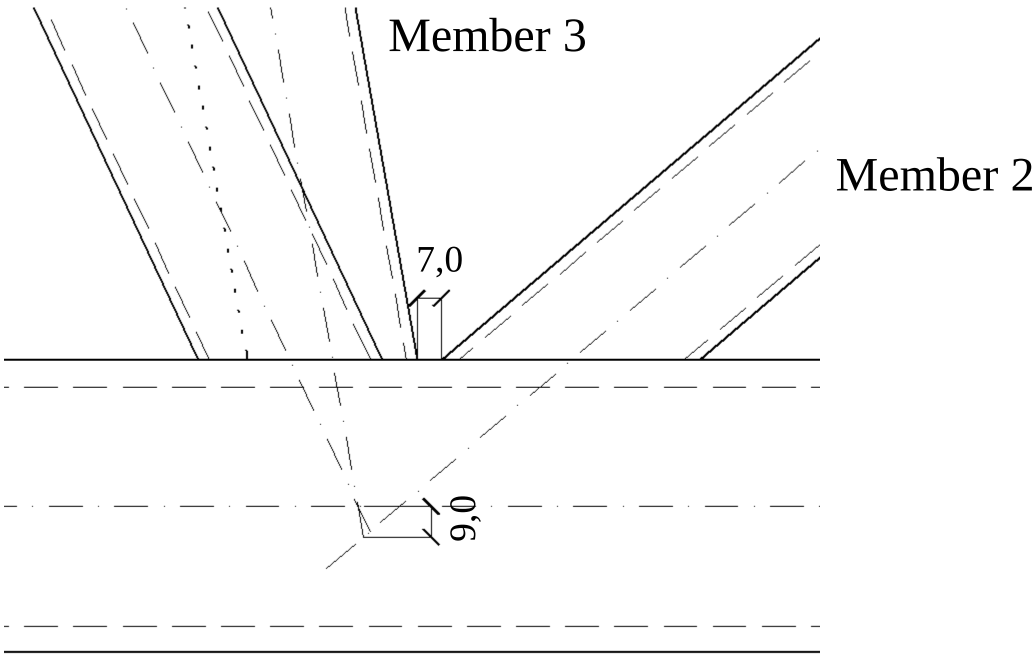
Wrong situation, position M3 must be changed.



Thanks to rotarion of α, new distance between M2 and M3 will be enough. It should be non smaller than

(wall thickness M2) + (wall thickness M3)

this means non smaller than 6,4 mm.



In analysed case, it is enough $\alpha = 0{,}4^{o}$.

$g = 7$ mm > $t_3 + t_2 = 6{,}4$ mm **OK**

Eccentricity is very small (9mm).

- Eccentricity is very small. For chord, secondary bending moment

$$M = 320,607 \cdot 0,009 = 2,885 \text{ kNm}$$

should be analysed. In Your range of project, this effect could be neglected.

- In full version project, for every joints must be made this type of geometrical analysis of nodes.
- In full version of project, impact of secondary bending moments on chors and joints must be calculated.

KT joint, condition 1:

Condition 1 is important for initial assumption only:

$$d_i \leq d_0 - 2\ t_0$$

$$d_1 = d_2 = d_3 = 51\ \text{mm}$$

$$t_0 = 8{,}0\ \text{mm}$$

$$d_0 = 88{,}9\ \text{mm}$$

$$d_0 - 2\ t_0 = 72{,}9\ \text{mm}$$

Condition important for checking

Case in chord	$N_{P, Ed, left}$ [kN]	$N_{P, Ed, right}$ [kN]	$N_{1, Ed}$ [kN]	$N_{2, Ed}$ [kN]	$N_{3, Ed}$ [kN]
Tension in chord	-217,852	-320,607	-62,711	106,074	-11,520
Compression in cord	75,217	199,887	75,064	-119,343	8,824

$$N_{1, Rd} = f_{y0}\, t_0\, \pi\, d_1\, (1 + \sin \theta_1) / [\, 2\, (\sqrt{3})\, \gamma_{M5}\, (\sin \theta_1)^2] = 80{,}721 \text{ kN}$$

$$N_{2, Rd} = f_{y0}\, t_0\, \pi\, d_2\, (1 + \sin \theta_2) / [\, 2\, (\sqrt{3})\, \gamma_{M5}\, (\sin \theta_2)^2] = 138{,}290 \text{ kN}$$

$$N_{3, Rd} = f_{y0}\, t_0\, \pi\, d_3\, (1 + \sin \theta_3) / [\, 2\, (\sqrt{3})\, \gamma_{M5}\, (\sin \theta_3)^2] = 71{,}181 \text{ kN}$$

Member	$N_{i, Ed}$	$N_{i, Ed} / N_{i, Rd}$
1	-62,711	0,777
	75,064	0,930
2	106,074	0,767
	-119,343	0,863
3	-11,520	0,162
	8,824	0,124

KT joint, condition 2:

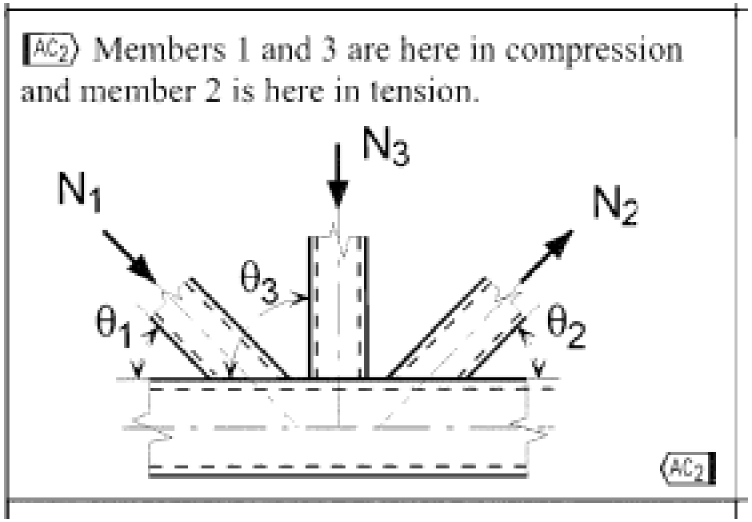


Photo: EN 1993-1-8 tab. 7.6

Condition important for situation:

$N_{1, Ed}$ compressive (> 0);

$N_{2, Ed}$ tensile (< 0);

$N_{3, Ed}$ compressive (> 0);

Because of symmetry about member 3, mirror case the same will be taken into consideration:

$N_{1, Ed}$ tensile (< 0);

$N_{2, Ed}$ compressive (> 0);

$N_{3, Ed}$ compressive (> 0);

c-t-c or **t-c-c**

Case in chord			$N_{1, Ed}$ [kN]	$N_{2, Ed}$ [kN]	$N_{3, Ed}$ [kN]
Tens.			-62,711 (t)	106,074 (c)	-11,520 (t)
Comp.			75,064 (c)	-119,343 (t)	8,824 (c)

$N_{1, Ed}$	$N_{2, Ed}$	$N_{3, Ed}$	
t	c	t	Situation unimportant for condition 2
c	t	c	Condition important

KT joint, condition 2: two requirements must be satisfied

$$N_{1,\,Ed} \sin\theta_1 + N_{3,\,Ed} \sin\theta_3 \leq N_{1,\,Rd} \sin\theta_1$$

and

$$N_{2,\,Ed} \sin\theta_2 \leq N_{1,\,Rd} \sin\theta_1$$

$N_{1,\,Rd}$ according to EN 1993-1-8 tab 7.2 node K,
with $\beta = d_1 / d_0$ replaced by $\beta = (d_1 + d_2 + d_3) / (3\,d_0)$:

$$N_{1,\,Rd} = k_g\, k_p\, f_{y0}\, t_0^2\, (1{,}8 + 10{,}2\,\beta) / (\gamma_{M5} \sin\theta_1)$$

$k_p =$

for compressive $N_{P,\,Ed}$: $\min [\,1{,}0 \;;\; 1{,}0 - 0{,}3\, n_p\, (1 + n_p)]$

for tensile $N_{P,\,Ed}$: 1,0 (not important in analysed case)

$n_p = N_{P,\,Ed} / (A_0\, f_{y0}\, \gamma_{M5})$

$k_g = \gamma^{0{,}2} \{1 + 0{,}024\, \gamma^{1{,}2} / [1 + \exp((0{,}5\, g / t_0) - 1{,}33)]\}$

$\gamma = d_0 / 2\, t_0$

KT joint, condition 2:

First requirement concerns relation between members 1 and 3. So, in formula, will be use value of g for M1-M3; g = -41 mm (→ #t / 18)
Second rquirement concerns member 2. So, in formula, will be use value of g for M3; g = 7 mm (→ #t / 19)

Case in chord	$N_{P, Ed}$ [kN]	n_p	k_p	γ	β	k_g	$N_{1, Rd} \sin \theta_1$ [kN]
Comp.	Max ($N_{P, Ed, left}$; $N_{P, Ed, right}$) 199,887	0,419	0,821	5,556	0,036	(g = -41 mm, first requirement) 1,641	44,351
						(g = 7 mm, second requirement) 1,143	30,892

KT joint, condition 2:

$$N_{1,\,Ed}\sin\theta_1 + N_{3,\,Ed}\sin\theta_3 \le N_{1,\,Rd}\sin\theta_1$$

$$75{,}064 \cdot \sin 65^o + 8{,}824 \cdot \sin 80^o \le 44{,}351$$

$$76{,}721 \le 44{,}351$$ wrong

$$N_{2,\,Ed}\sin\theta_2 \le N_{1,\,Rd}\sin\theta_1$$

$$119{,}343 \cdot \sin 40^o \le 30{,}892$$

$$76{,}712 \le 30{,}892$$ wrong

KT joint, sceond condition is unsatisfied.

In formula of resistance

$$N_{1,\,Rd} = k_g\, k_p\, f_{y0}\, t_0^2\, (1{,}8 + 10{,}2\, \beta) / (\gamma_{M5}\, \sin \theta_1)$$

the biggest impact has thickness of chord's wall t_0 (generally it is strongly nonlieary influence, because k_g the same is function of, amon others, t_0). Probably wall 14,2 mm has enough resistance. Unfortunatelly this thickness has not CHS 88,9 but CHS 101,1. This means change value parameters k_p , k_g and β. Additionally, new diameter of chord changes relative position of web members in joint (→ #t / 18 – 19). Total analysis of joint must be made once again.

Very important notice: chors CHS 88,9x3,2 is enough because of resistance and stability of bar. But could be not enough because of resistance of joint. Sometimes total static calculation must bre made once again because of change od element.

→ Lec #3 / 96

Algorithm

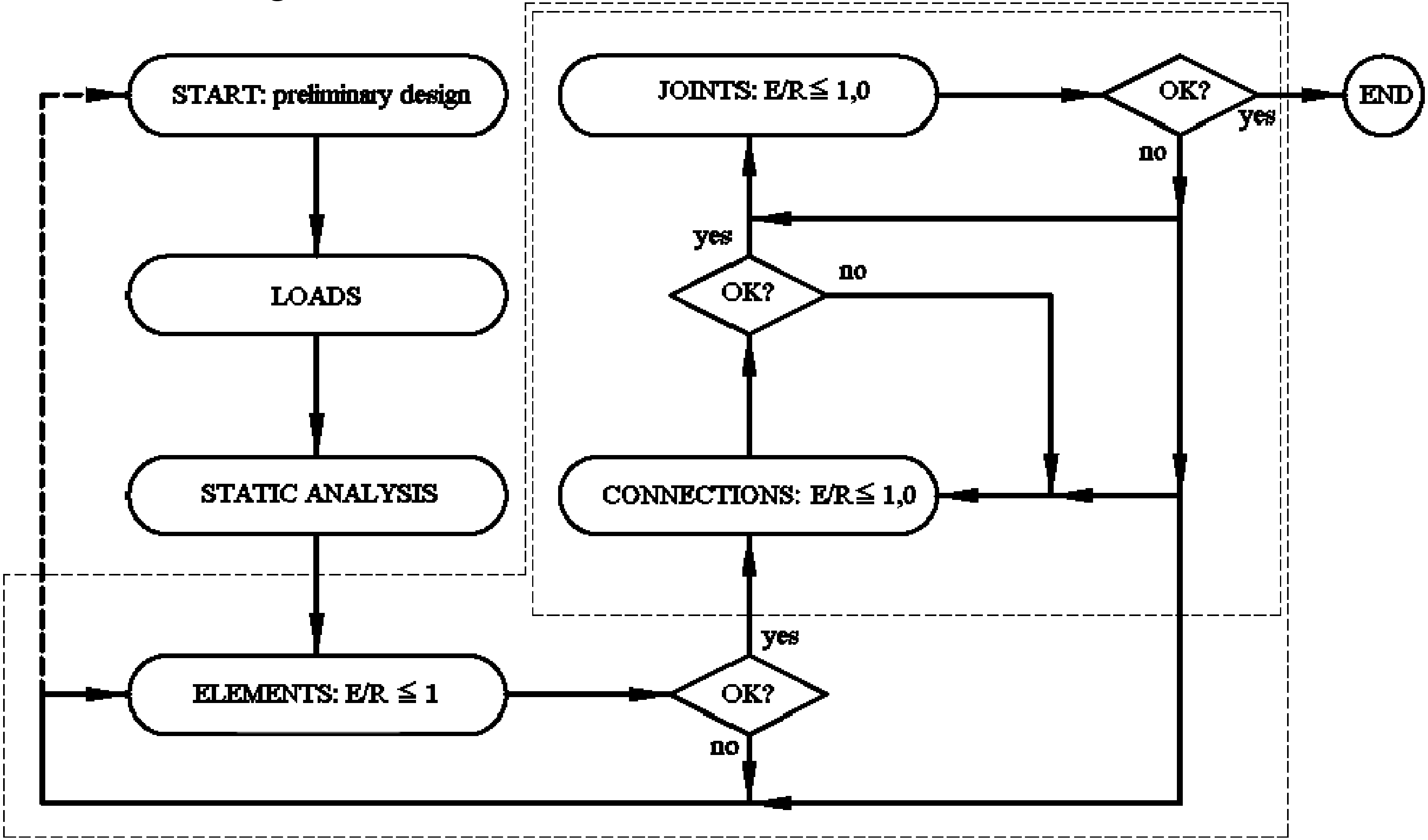
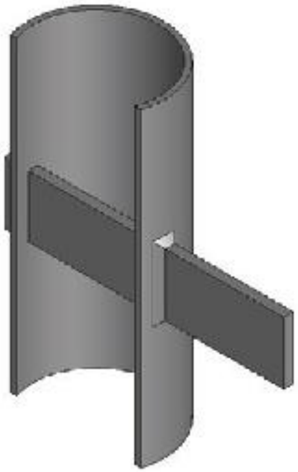


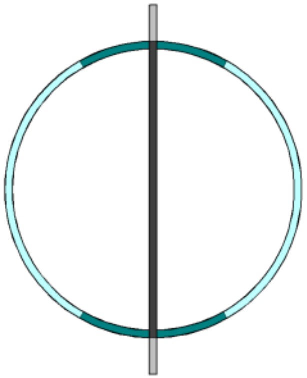
Photo: Author

Solution bases on experience, not quite on EN 1993-1-8: fork plate.



Gusset plate, which goes through CHS and suppors both faces. Thanks to this, CHS is resisted for local deformation under forces from web members. It makes something like I-beam (two „flanges" and fork plate as web). According to EN 1993-1-8, I-beams are resist on chord face failure.

Photo: Branch Plate-to-Circular Hollow Structural Section Connections. I: Experimental Investigation and Finite-Element Modeling, A. Voth, J. Packer, Journal of Structural Engineering, 1 August 2012



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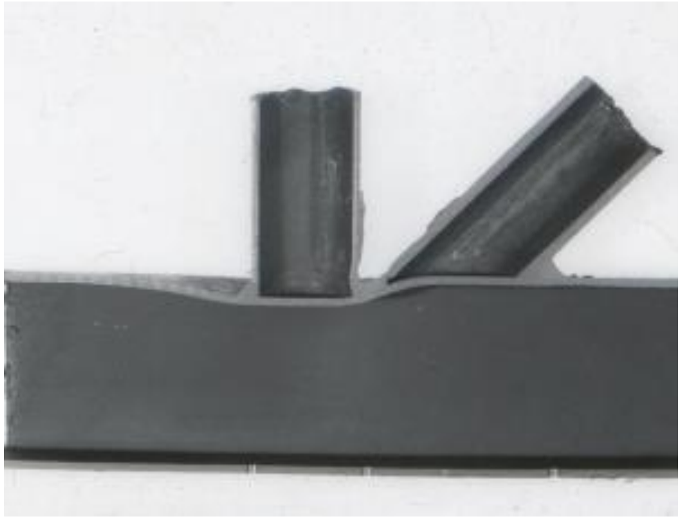
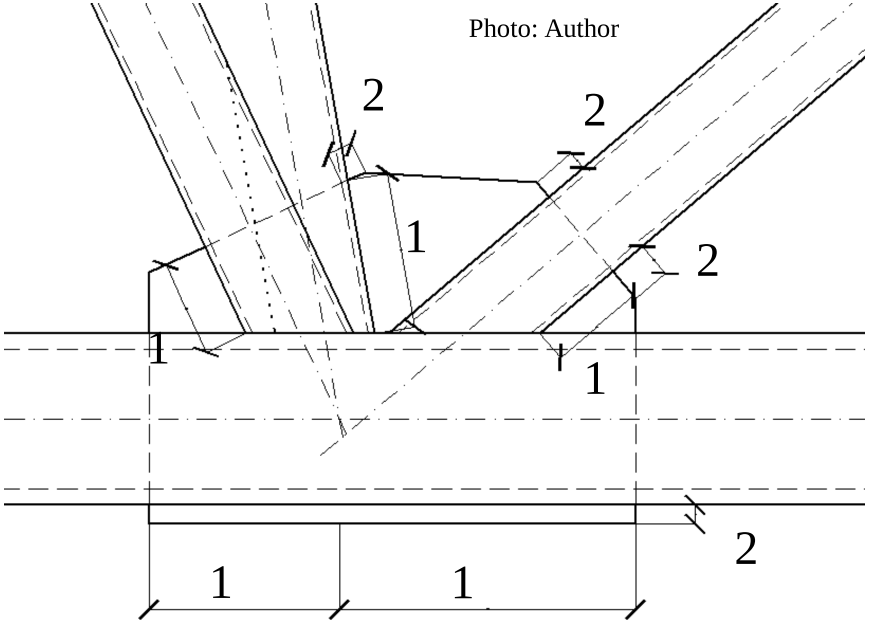


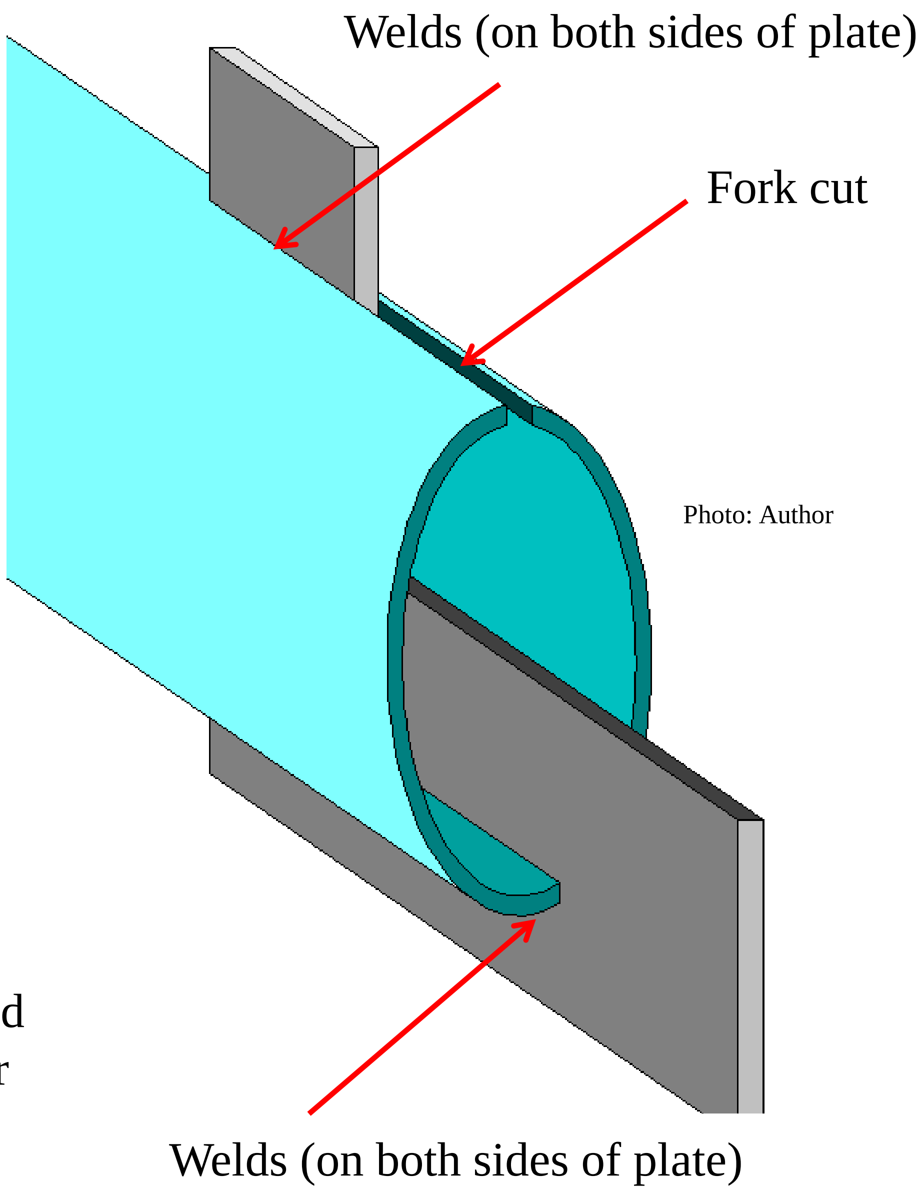
Photo: tatasteel.com

Chord face failure



1 – length enough for weld, calculated for axial force in bar

2 – lenght enougt to thickness of weld (+/- 10 mm)



In Your range of project is enough to presented information "resistance of joint is satisfied" or "fork plate must be applicated".

Welds

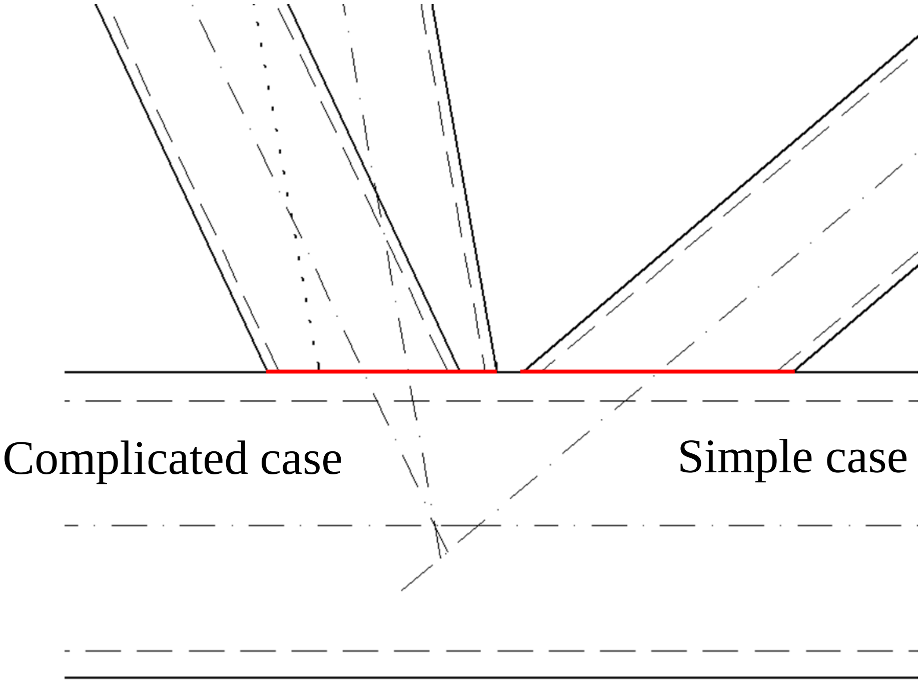
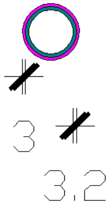


Photo: Author



S235 → $f_u = 360$ MPa, $\beta_w = 0{,}80$

(EN 1993-1-8 tab 4.1)

Simple:

CHS diameter 51 mm

CHS thickness of flange 3,2 mm

Thickness of weld 3 mm

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

$$N_{Ed} = -119{,}343$$

Simplification true only if angle between elements ≥ 60^o

For angle ≤ 60^o situation is much more complicated (→ Lec #17)

$\sigma = N_{Ed} / A = 234{,}466$ MPa

$\tau = 0$ MPa

$\sigma_{\perp} = \tau_{\perp} = \sigma / \sqrt{2} = 165{,}792$ MPa

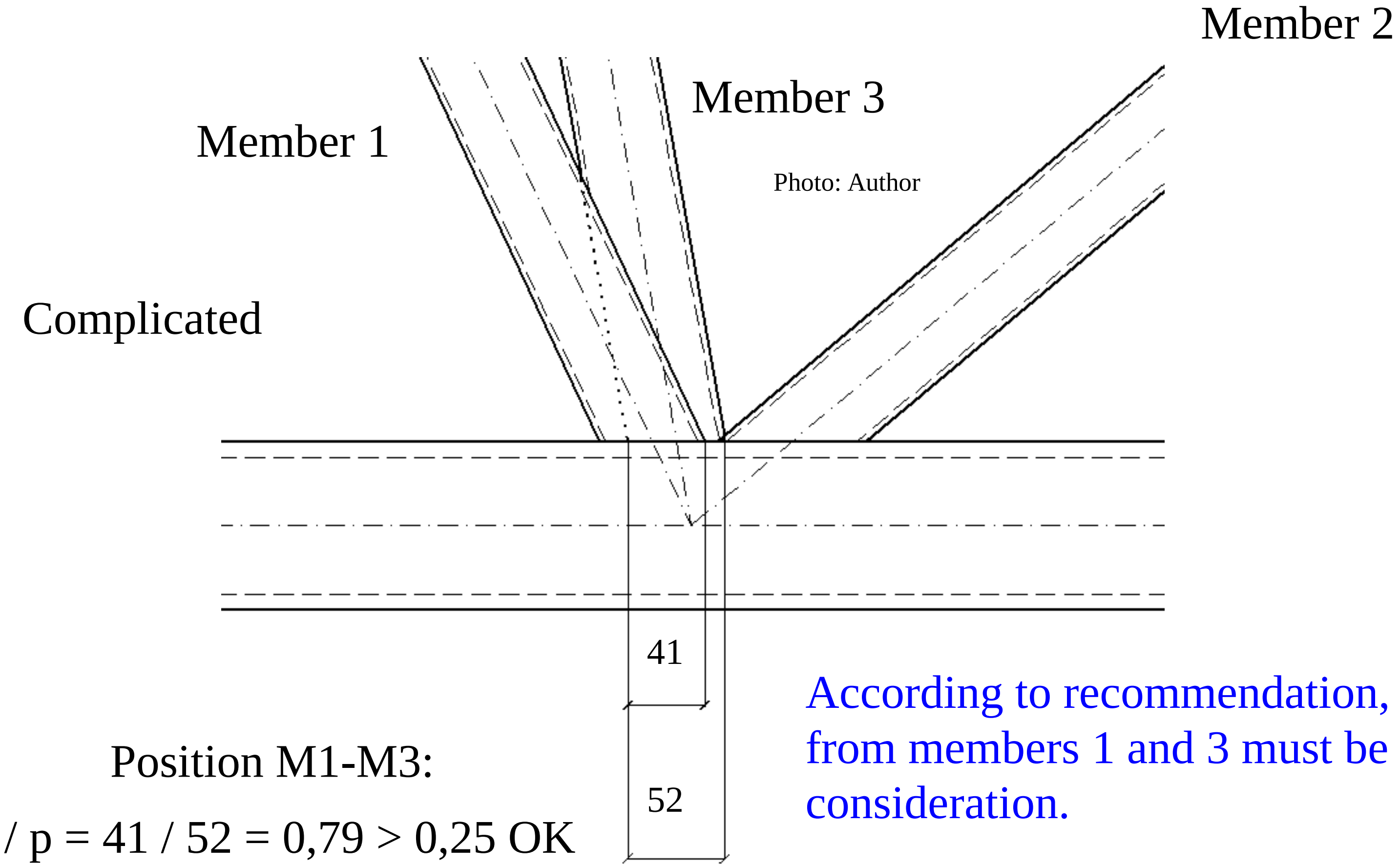
$\tau_{\parallel} = \tau = 0{,}000$ MPa

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

EN 1993-1-8 (4.1):

Condition 1: $\sqrt{[(\sigma_{\perp})^2 + 3(\tau_{\parallel}^{\,2} + \tau_{\perp}^{\,2})]} = 331{,}584 \text{ MPa} < f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$

Condition 2: $\sigma_{\perp} = 165{,}792 \text{ MPa} < 0{,}9 f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$



Position M1-M3:

q / p = 41 / 52 = 0,79 > 0,25 OK

g = -q = -41 mm

q / p > 0,6

so, according to recommendation, connection between braces and chord face should be checked for shear.

According to recommendation, common effect from members 1 and 3 must be taken into consideration.

Case in chord	$N_{1, Ed}$ [kN]	$N_{3, Ed}$ [kN]
Tension in chord	-62,711	-11,520
Compression in cord	75,064	8,824

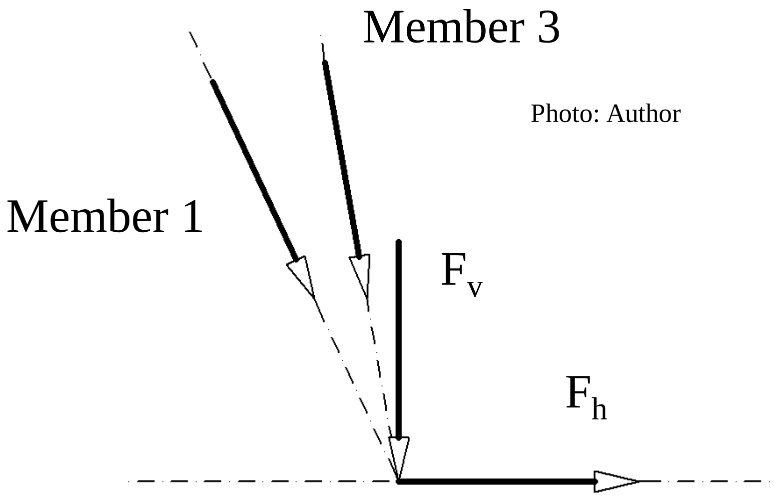


Photo: Author

Axian forces in membes 1 and 3 must be recalculated to horizontal and vertical froces

Case in chord	$N_{1, Ed}$ [kN]	$N_{3, Ed}$ [kN]	F_h [kN]	F_v [kN]
Tension in chord	-62,711	-11,520	28,503	68,280
Compression in cord	75,064	8,824	33,256	76,721

Simplification: common weld

(Member 1 + Member 3) – (Chord)

is 2 times bigger than in previous case

$$A = 2 \cdot \pi \cdot [(51 / 2 + 3)^2 - (51 / 2)^2] = 1\,018 \text{ mm}^2$$

$\sigma = F_v / A = 75{,}364$ MPa

$\tau = F_h / A = 32{,}668$ MPa

$\sigma_\perp = \tau_\perp = \sigma / \sqrt{2} = 53{,}290$ MPa

$\tau_\parallel = \tau = 32{,}668$ MPa

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

EN 1993-1-8 (4.1):

Condition 1: $\sqrt{[(\sigma_\perp)^2 + 3(\tau_\parallel^2 + \tau_\perp^2)]} = 120{,}669 \text{ MPa} < f_u / (\beta_w \gamma_{M2}) = 360{,}000 \text{ MPa}$

Condition 2: $\sigma_\perp = 53{,}290 \text{ MPa} < 0{,}9\, f_u / \gamma_{M2} = 259{,}200 \text{ MPa}$

VI^th example of calculations – field splice

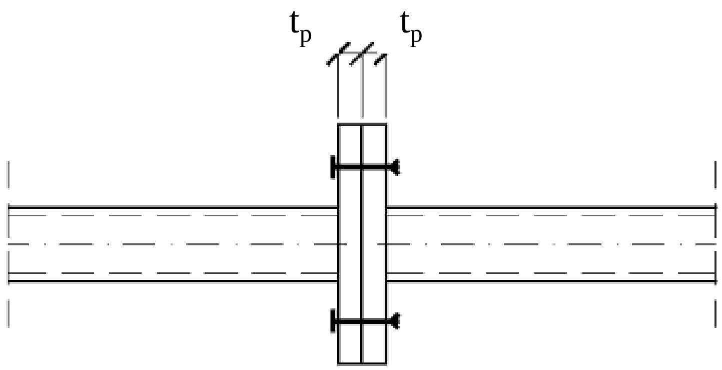


Photo: Author

CHS 76,1 x 4,6

S235: f_y = 235 MPa

f_u = 360 MPa

Max compressive force: not important for such one joint.

Max tensile force: N_{Ed} = -297,345 kN

(New complex of data)

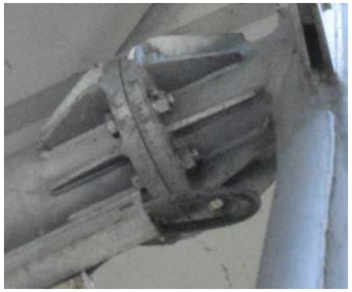


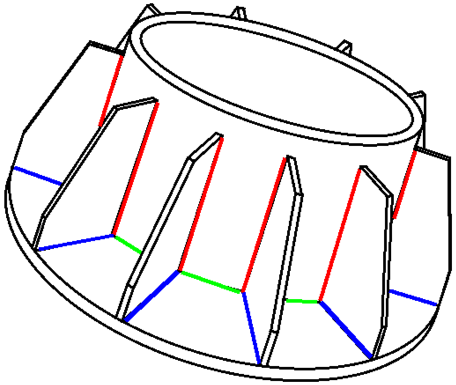
Photo: Author

Photo: encrypted-tbn0.gstatic.com

Photo: en.wikiarquitectura.com

Calculation of resistance for such type of joint based on literature only, not on Eurocodes. Only general information about position of bolts could be analysed accordind Eurocode.

Photo: Author



Application of longitudinal stiffeners increase stiffness and resistance of joint and welds (longer welds → bigger geometry → smaller stresses in welds). But in calculation formulas influence of stiffeners for resistance is not taken into consideration.

Stiffness

In analysed case (splice joint for CHS truss), it is enough to take into consideration right thickness of end plate (→ #t / 41). Application of longitudinal stigffness is recommended.

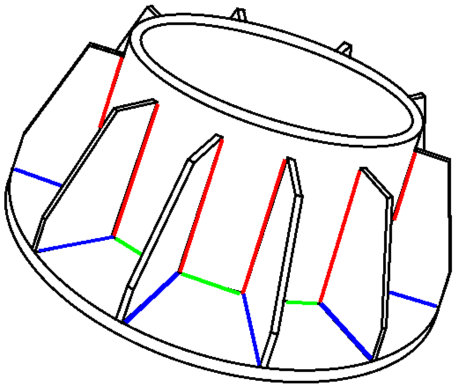


Photo: Author

Welds

Information about initial assumptions of weld's thickness will be presented in Lec. #17. In analysed case (axial force only) area of weld should be about 2 times bigger than area of CHS cross-section. There is enough, than weld's thickness is equal 5 mm.

Tensile and compressive forces exist in joint, accordintd to various directions of forces in chord. According to experience, category D of bolted joint is recommended (more infromation will be presented on lecture #18). For category D, according to EN 1993-1-8, each classes of bolts are accepted. Classes of bolts from 5.6 to 10.8 are recommended. For these classes, according to experience, recommended are bolts non smalled than M20.

Assumption into calculation: bolts: M24, class 8.8

M24 $\rightarrow$ diameted of shank = d = 24 mm ; A_s (cross-section of treaten portion) = 3,53 cm^2

Class: X.Y

$X = f_{ub} / 100 \rightarrow f_{ub} = 100\,X = 800$ MPa

$Y = 10\,f_{yb} / f_{ub} \rightarrow f_{yb} = 10\,X\,Y = 640$ MPa

For bolt M24, according to EN 1090-2, diameter of holes for bolt is 2mm greater than diameter of shank:

$d_0 = 24 + 2 = 26$ mm

Bolt	A_S $[cm^2]$	A $[cm^2]$ $(\pi d^2 / 4)$
M 16	1,61	2,01
M 20	2,45	3,14
M 24	3,53	4,52
M 30	5,61	7,07

Area of the most often applicated bolts

Dimensions of bolt for category D (b = 0) in EN ISO 4017.

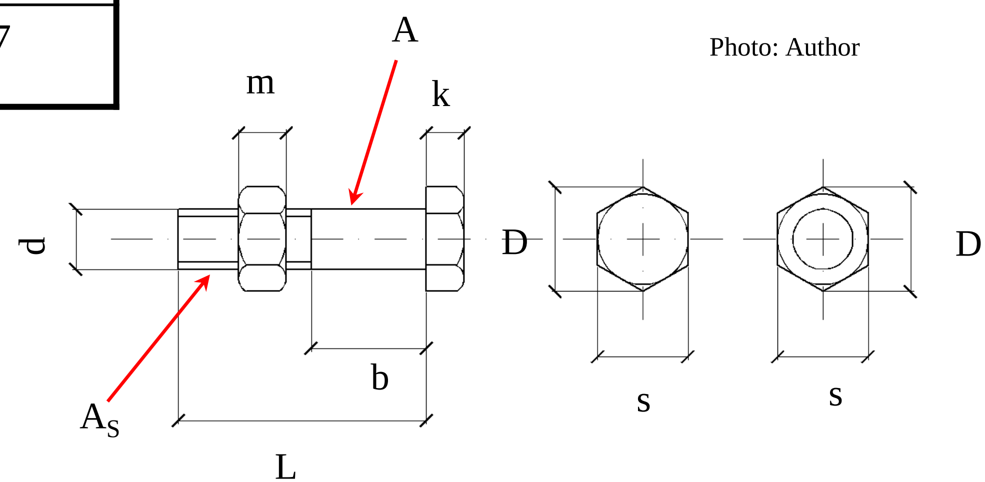


Photo: Author

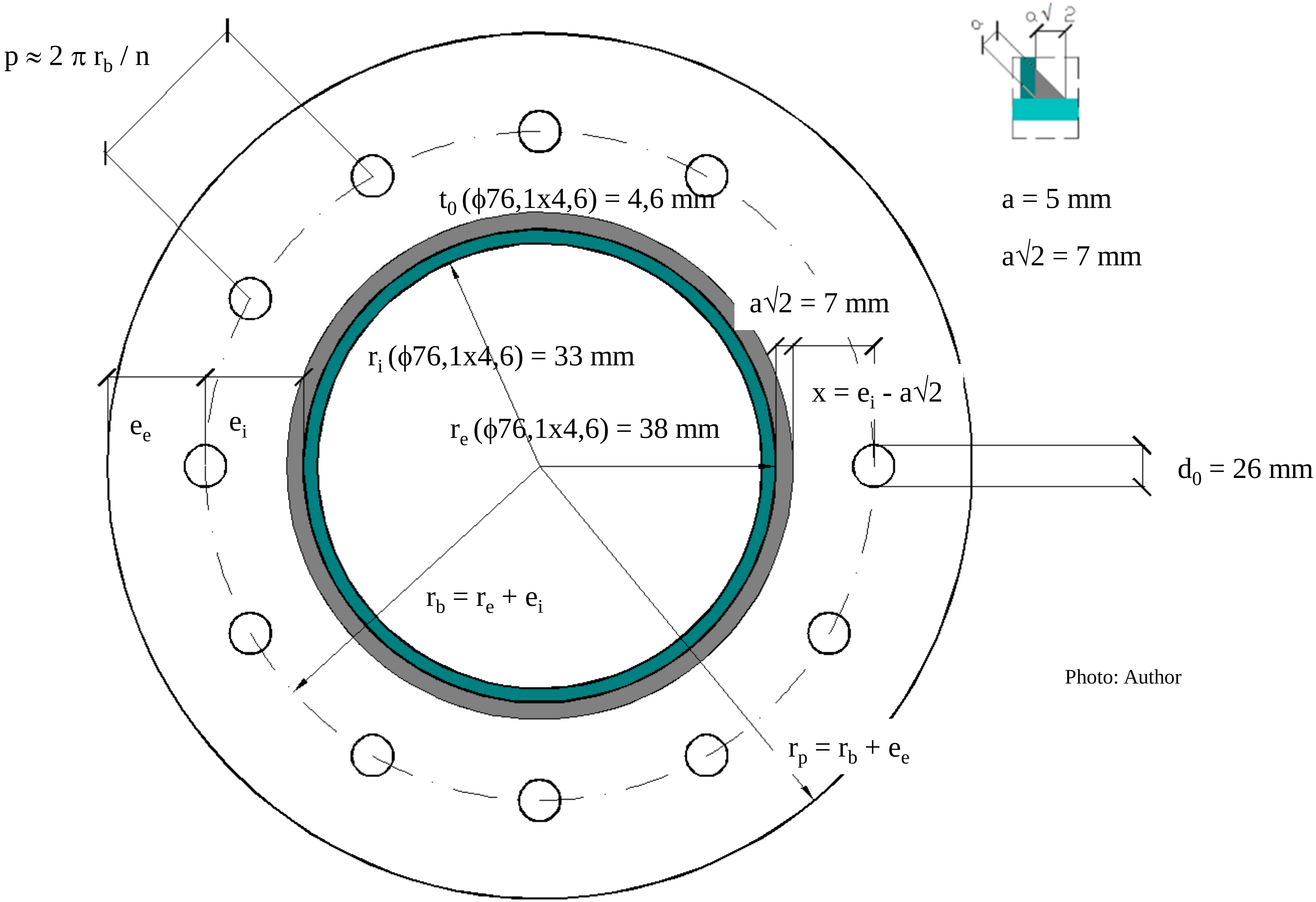


Photo: Author

Recommendation according to experience:

$1{,}5\ d \le e_i \le 2{,}0\ d \rightarrow 36\ mm \le e_i \le 48\ mm$

and

$x \ge 0{,}9\ d + 5\ mm \rightarrow x \ge 27\ mm$

and

$x = e_i - a\sqrt{2} \rightarrow x = e_i - 7\ mm$

So, into calculation:

$e_i = 40\ mm\ (x = 33\ mm)$

$r_b = r_e + e_i = 78\ mm$

$2\ \pi\ r_b\ = 490\ mm$

Recommendation according to experience:

$t = 2{,}0\ \sqrt{\{c\ F_{t,Rd}\ /\ [f_y\ (2c + d)]\}}$; $c = x - d_0 / 2 = 20\ mm$; $F_{t,\ Rd} = 0{,}9\ f_{ub}\ A_s\ /\ \gamma_{M2} = 225{,}920\ kN$

$t_p \ge 35$ mm, so into calcuation: $t_p = 35$ mm

Estimation according to EN 1993-1-8 (not completely right)

$1{,}2\ d_0 \leq e_e \leq 4{,}0\ t_p + 40\ mm \rightarrow 31\ mm \leq e_e \leq 180\ mm$, so into calculation $e_e = 35\ mm$

and

$2{,}2\ d_0 \leq p \leq \min(14{,}0\ t_p\ ;\ 200\ mm) \rightarrow 57\ mm \leq p \leq 200\ mm$

According to experience:

n (number of bolts) ≥ 4

$p \approx 2\ \pi\ r_b\ /\ n = 490\ mm\ /\ n$

So, into calculation:

$p = 98\ mm$

$n = 5$

Resistance

Photo: knkmpk.blogspot.com

Photo: forgemag.com

Resistance of such type of joint is the smallest walue of:

- plate destruction (but bolts are safe);
- bolts destruction (but plate is safe);
- common destruction of bolts and plate;

→ Des #1 / 86

Field splice is VIth example of calculations in Example Part

Plate destruction (according to experience)

$$N_{pl,\,Rd} = t_p^2\, f_y\, \pi\, k\, /\, (2\, \gamma_{M0})$$

$$r_l = r_e - t_0 / 2 = 36 \text{ mm}$$

$$k_1 = \ln(r_b / r_l) = 0{,}773$$

$$k_2 = k_1 + 2 = 2{,}773$$

$$k = [k_2 + \sqrt{(k_2^2 - 4k_1^2)}] / (2\, k_1) = 3{,}283$$

$$N_{pl,\,Rd} = 1\ 187{,}640 \text{ kN}$$

Bolts destruction (according to EN 1993-1-8; more information will be presented on lecture #18)

Resistance of **n** bolt under tensile axian force (in analysed case n = 5):

$N_{p,\,Rd} = n\ [\ \min\ (F_{t,\,Rd} \quad ; \quad B_{p,\,Rd})]$

and, for bolted joint category B:

$B_{p,\,Rd} \geq 0{,}7\ F_{t,\,Rd}$ (if not, t_p must be increased)

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

$F_{t,\,Rd} = 0{,}9\ f_{ub}\ A_s\ /\ \gamma_{M2} = 225{,}920\ kN$

$B_{p,\,Rd} = 0{,}6\ \pi\ d\ t_p\ f_u\ /\ \gamma_{M2} = 465{,}008\ kN$

$B_{p,\,Rd} \geq 0{,}7\ F_{t,\,Rd}$ OK

$N_{p,\,Rd} = 5\ [\ \min\ (225{,}920 \quad ; 465{,}00)] = 1\ 129{,}600\ kN$

Common destruction of bolts and plate (according to experience)

$$N_{pl\text{-}b,\,Rd} = n\, F_{t,\,Rd} / \{1 - (1 / k_2) + (1 / [k_2 \ln(r_r / r_b)])\}$$

$e_{eff} = \min (e_e \;\; ; \;\; 1{,}25\, e_i) = \min (35 \;\; ; \;\; 50) = 35$ mm

$r_r = r_e + e_i + e_{eff} = 113$ mm

$k_1 = 0{,}773$

$k_2 = 2{,}773$

$N_{pl\text{-}b,\,Rd} = 700{,}638$ kN

Resistance of join:

$N_{j,\ Rd} = \min(N_{pl,\ Rd} \quad ; \quad N_{b,\ Rd} \quad ; \quad N_{pl\text{-}b,\ Rd}) =$

$= \min(1\ 187{,}640 \quad ; \quad 1\ 129{,}600 \quad ; \quad 700{,}638) = 700{,}638\ kN$

$N_{Ed} / N_{j,\ Rd} = 0{,}424 < 1{,}0$ **OK**

Length of bolt

For category D, bolt with thread along entire shank length are recommended. One washer – under nut – is recommended. Free end of bolt should not be shorter than 1P and no longer than diameter. More information will be given in Lec #18.

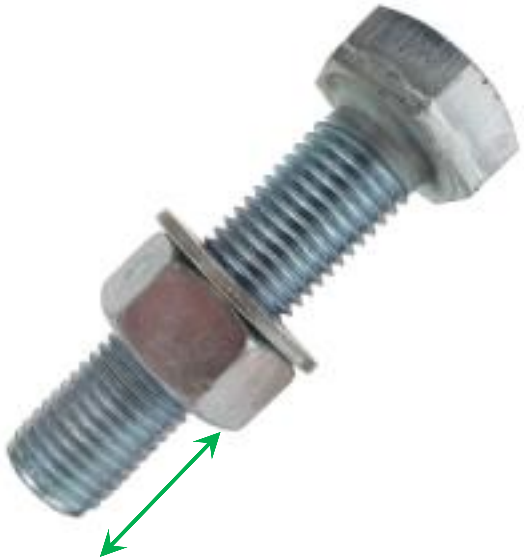


Photo: parkersteel.co.uk

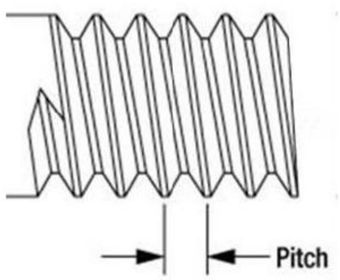


Photo: u-bolts-r-us.co.uk

EN ISO 4017:

Bolt	P [mm]
M16	2,0
M20	2,5
M24	3,0
M30	3,5

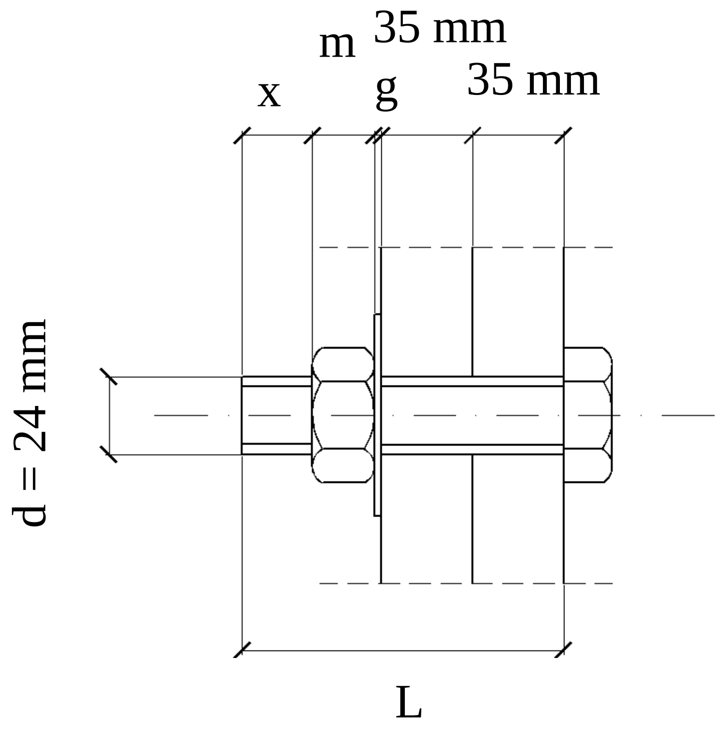


Photo: Author

$$24 \geq x \geq 3$$

$$L = x + 21{,}5 + 4 + 35 + 35 =$$

$$= 99 – 120 \text{ mm}$$

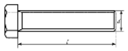
EN 14 399-5:

Bolt	g [mm]
M16	4,0
M20	4,0
M24	4,0
M30	5,0

EN ISO 4032:

Bolt	m [mm]
M16	14,8
M20	18,0
M24	21,5
M30	25,6

According EN ISO 4017, for theoretical lengt of bolt 99 – 120 mm coul be cover by bolts of real length 100, 110 and 120 mm. 100 mm is taken into consideration.



PN – 85/M-82105

D IN 933 ISO 4017

DIN 961 ISO 8676

EN 24018 EN 24017 EN 28676

100 szt/kg

możliwe odchylenia +/- 10%

	M 4	M 5	M 6	M 7	M 8	M 10	M 12	M 14	M 16	M 18	M 20	M 22	M 24	M 27	M 30
8		0,233	0,386												
10		0,257	0,42		0,873										
85					3,30	5,38	7,72	11,2	15,00	19,40	24,70	30,80	37,30	50,728	65,101
90					3,46	5,63	8,08	11,7	15,70	20,20	25,80	32,10	39,30	52,631	67,434
95					3,52	5,98	8,44	12,2	16,40	21,00	26,80	33,30	40,80	54,534	69,767
100					3,77	6,13	8,8	12,7	17,00	21,80	27,90	34,60	42,30	56,437	72,1
110					3,789	6,543	9,504		17,94		29,815		45,03	60,243	76,766
120					3,808	7,03	10,207		19,24		31,863		47,99	64,049	81,432
130					3,963	7,527	10,915		20,53		33,911		50,96	67,855	86,098
140					4,118	8,024	11,82		21,83		35,959		53,89	71,661	90,764
150						8,521	12,539		23,12		38,007		56,84	75,467	95,43

Unit mass is, in this case,

42,30 kg / 1000 pcs

Photo: nycz.pl

Thank you for attention

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