5. Lattice truss – design of chords

5.1 The buckling lengths of the chords

Tab.: The buckling lengths of the lattice chords

<table>
<thead>
<tr>
<th></th>
<th>lattice truss made of</th>
<th>lattice truss made of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L-profiles</td>
<td>hollow sections</td>
</tr>
<tr>
<td>upper chord</td>
<td>in-plane distance between joints</td>
<td>0,9 · distance between joints</td>
</tr>
<tr>
<td></td>
<td>out-of-plane distance between purlins</td>
<td>0,9 · distance between purlins</td>
</tr>
<tr>
<td>bottom chord</td>
<td>out-of-plane distance between longitudinal bracing (conservatively)</td>
<td>distance between transverse bracing (conservatively)</td>
</tr>
<tr>
<td>vertical chords and diagonals</td>
<td>in-plane distance between connection gravity centre ( \cong 0,9L_{teor} )</td>
<td>0,75 · ( L_{teor} )</td>
</tr>
<tr>
<td></td>
<td>out-of-plane ( L_{teor} )</td>
<td>0,75 · ( L_{teor} )</td>
</tr>
</tbody>
</table>

The buckling lengths of the lattice truss made of hollow sections assume welded penetrated joints. Otherwise the buckling lengths will be the same as in lattice truss made of L-profiles.

The bottom chord is stabilized only by columns and by the longitudinal bracing between the trusses. This bracing is designed with the maximum distance about 12 m. Therefore, the out-of-plane buckling length can be taken conservatively as a distance between the bracing. Because of changing compression force at the bottom chord, the out-of-plane critical buckling length can be determined more accurately by the stability calculation, using the numerical software.

The bottom chord in the model is supported in the places of transverse bracing; the load should represent the same distribution of the normal forces corresponding to the worst design situation. The result of the stability calculation is the buckling coefficient (the ratio between critical Euler load and the actual (real) load)

\[
k = 1,527 \quad \text{for the first buckling mode}
\]

the critical force

\[
N_{cr} = k \cdot N_{Ed} = 1,527 \cdot 102,87 = 157,1 \text{ kN}
\]

the critical length

\[
L_{cr} = \pi \sqrt{\frac{EL}{N_{cr}}} = \pi \sqrt{\frac{210000 \cdot 6,91 \cdot 10^6}{157,1 \cdot 10^3}} = 9548 \text{ mm}
\]

Note: Provided conservatively

\[
L_{cr} = 12000 \text{ mm}
\]

then the critical force will be

\[
N_{cr} = \frac{\pi^2 \cdot E \cdot I}{L_{cr}^2} = 99,5 \text{ kN}
\]
5.2 Design of the chords – tension forces

The chords of the lattice truss are designed of hot rolled circular hollow sections from the steel Grade S235J0 - $f_y = 355\text{MPa}$.

the design resistance assuming the uniformly distributed stress over the cross-section

$$ N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{A \cdot 355}{1,0} $$

<table>
<thead>
<tr>
<th>prut</th>
<th>N_{es}</th>
<th>Profil</th>
<th>A</th>
<th>N_{es,Rd}</th>
<th>N_{es}/N_{es,Rd}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kN)</td>
<td>(mm$^2$)</td>
<td>(kN)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>294,8</td>
<td>TR 152 x 5,6</td>
<td>2576</td>
<td>795,2</td>
<td>0,371</td>
</tr>
<tr>
<td>H</td>
<td>130,5</td>
<td>TR 108 x 5,6</td>
<td>1802</td>
<td>556,3</td>
<td>0,235</td>
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<tr>
<td>D₁</td>
<td>185,1</td>
<td>TR 82,5 x 4</td>
<td>986</td>
<td>304,4</td>
<td>0,608</td>
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<tr>
<td>D₂</td>
<td>40,5</td>
<td>TR 82,5 x 4</td>
<td>986</td>
<td>304,4</td>
<td>0,133</td>
</tr>
<tr>
<td>D₃</td>
<td>51,4</td>
<td>TR 51 x 3,2</td>
<td>481</td>
<td>148,5</td>
<td>0,347</td>
</tr>
<tr>
<td>D₄</td>
<td>20,4</td>
<td>TR 51 x 3,2</td>
<td>481</td>
<td>148,5</td>
<td>0,137</td>
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<tr>
<td>V₁</td>
<td>13,5</td>
<td>TR 42,4 x 3,2</td>
<td>394</td>
<td>121,5</td>
<td>0,111</td>
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<tr>
<td>V₂</td>
<td>11,0</td>
<td>TR 42,4 x 3,2</td>
<td>394</td>
<td>121,5</td>
<td>0,091</td>
</tr>
</tbody>
</table>

5.3 Design of the chords – compression forces

the design buckling resistance of a compression member should be taken as

$$ N_{b,Rd} = \frac{\chi \cdot A \cdot f_y}{\gamma_{M1}} $$

for Class 1, 2 and 3 cross-section

<table>
<thead>
<tr>
<th>chord</th>
<th>N_{es}</th>
<th>Profil</th>
<th>L</th>
<th>L_{cr} / L</th>
<th>A</th>
<th>I</th>
<th>\lambda</th>
<th>\varnothing</th>
<th>N_{cr}</th>
<th>\lambda</th>
<th>\chi</th>
<th>N_{es,Rd}</th>
<th>N_{es}/N_{es,Rd}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kN)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm$^2$)</td>
<td>\cdot 10$^5$</td>
<td>(mm)</td>
<td>\varnothing</td>
<td>(kN)</td>
<td>(kN)</td>
<td></td>
<td></td>
<td>(kN)</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>-102,9</td>
<td>TR 152 x 5,6</td>
<td>12000</td>
<td>(-)</td>
<td>9548</td>
<td>2576</td>
<td>6910,0</td>
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<td>3,643</td>
<td>157089</td>
<td>184,36</td>
<td>0,157</td>
<td>143,5</td>
</tr>
<tr>
<td>H</td>
<td>-295,3</td>
<td>TR 108 x 5,6</td>
<td>3004</td>
<td>0,9</td>
<td>2704</td>
<td>1802</td>
<td>2368,3</td>
<td>0,976</td>
<td>1,058</td>
<td>671510</td>
<td>74,58</td>
<td>0,682</td>
<td>436,5</td>
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<tr>
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<td>3499</td>
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<td>986</td>
<td>761,8</td>
<td>1,236</td>
<td>1,372</td>
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<tr>
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<td>2747</td>
<td>986</td>
<td>761,8</td>
<td>1,293</td>
<td>1,451</td>
<td>209308</td>
<td>98,81</td>
<td>0,474</td>
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<td>D₃</td>
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<td>481</td>
<td>137,9</td>
<td>2,123</td>
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<td>37877</td>
<td>162,24</td>
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<td>481</td>
<td>137,9</td>
<td>2,228</td>
<td>3,194</td>
<td>34411</td>
<td>170,21</td>
<td>0,182</td>
<td>31,1</td>
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<tr>
<td>V₁</td>
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<td>TR 42,4 x 3,2</td>
<td>1950</td>
<td>0,75</td>
<td>1463</td>
<td>394</td>
<td>76,2</td>
<td>1,376</td>
<td>1,571</td>
<td>73834</td>
<td>105,17</td>
<td>0,430</td>
<td>60,1</td>
</tr>
<tr>
<td>V₂</td>
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<td>0,75</td>
<td>1688</td>
<td>394</td>
<td>76,2</td>
<td>1,588</td>
<td>1,907</td>
<td>55458</td>
<td>121,35</td>
<td>0,338</td>
<td>47,2</td>
</tr>
</tbody>
</table>

$$ N_{cr} = \frac{\pi^2 E \cdot I}{L^2} \quad \lambda = \pi \cdot \frac{E}{\sigma_{cr}} \quad \bar{\lambda} = \sqrt{\frac{A \cdot f_y}{N_{cr}}} \quad \chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \quad \chi \leq 1 $$

buckling curve ,,a“  \[ \alpha = \alpha = 0,21 \]

Note.: the slenderness of the chord should be smaller than \( \lambda < 200 \)
5.4 Design of the joint chords – punching shear failure and chord shear failure

5.4.1 Common requirements and structural principles for hollow truss girders

*Tab.: Types of joints in hollow section lattice girders*

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Image of Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>K joint</td>
<td><img src="image1" alt="K joint Image" /></td>
</tr>
<tr>
<td>KT joint</td>
<td><img src="image2" alt="KT joint Image" /></td>
</tr>
<tr>
<td>N joint</td>
<td><img src="image3" alt="N joint Image" /></td>
</tr>
<tr>
<td>T joint</td>
<td><img src="image4" alt="T joint Image" /></td>
</tr>
<tr>
<td>X joint</td>
<td><img src="image5" alt="X joint Image" /></td>
</tr>
<tr>
<td>Y joint</td>
<td><img src="image6" alt="Y joint Image" /></td>
</tr>
<tr>
<td>DK joint</td>
<td><img src="image7" alt="DK joint Image" /></td>
</tr>
<tr>
<td>KK joint</td>
<td><img src="image8" alt="KK joint Image" /></td>
</tr>
<tr>
<td>X joint</td>
<td><img src="image9" alt="X joint Image" /></td>
</tr>
<tr>
<td>TT joint</td>
<td><img src="image10" alt="TT joint Image" /></td>
</tr>
<tr>
<td>DY joint</td>
<td><img src="image11" alt="DY joint Image" /></td>
</tr>
<tr>
<td>XX joint</td>
<td><img src="image12" alt="XX joint Image" /></td>
</tr>
</tbody>
</table>
Even if bolted connections to hollow sections are utilized to assemble prefabricated elements or space structures, the most used method to assemble CHS members is welding, especially for trusses. According to EN 1993-1-8, the design joint resistances of connections between hollow sections and of connections of hollow sections to open sections, should be based on the following failure modes as applicable:

- Chord face failure (plastic failure of the chord face) or chord plastification (plastic failure of the chord cross-section);
- Chord side wall failure (or chord web failure) by yielding, crushing or instability (crippling or buckling of the chord side wall or chord web) under the compression brace member;
- Chord shear failure (the chord cross-section may collapse in the gap section, because of the combination of axial force, shear force and bending moment);
- Punching shear failure of a hollow section chord wall (crack initiation leading to rupture of the brace members from the chord member);
- Brace failure with reduced effective width (cracking in the welds or in the brace members);
- Local buckling failure of a brace member or of a hollow section chord member at the joint location.

- The chords should satisfy conditions for the steel Grade 1 or 2 for pure bending
- The nominal wall thickness of hollow sections should be limited to a minimum of 2.5 mm and should not be greater than 25 mm unless special measures have been taken to ensure that the through thickness properties of the material is adequate
- The angles between the upper or bottom chords and vertical chords and/or diagonals and between adjacent chords should not be smaller than 30°.
- The excentricity in the joints in tension chords can be neglected, if the excentricity satisfy following limits:  
  
  \[ -0.55d_0 \leq e \leq 0.25d_0 \]

  where \( e \) is the excentricity – see figure,
  \( d_0 \) is the diameter \( d \) of the hollow section.
The gap between the adjacent diagonals and/or vertical chords should be larger than \((t_1 + t_2)\), where \(t_1, t_2\) are the thicknesses of the adjacent members, see figure.

The overlap \(q\) should be larger than \(p/4\), see figure (sufficient connection for shear translation from the one member to the second one).

\[g \geq t_1 + t_2, \quad q \geq \frac{p}{4}\]

where
\[d_0, t_0\] are the diameter and the thickness of a upper or bottom chord
\[d_i, t_i\] are the diameter and the thickness of a diagonals and vertical chords

If relevant, the member with the smaller thickness should overlap the member with the greater thickness.

If relevant, the member with the smaller yield strength should overlap the member with the greater yield strength.

The ancillary moments in the joints due to real bending stiffness of the joint can be neglected if:

\[
0,2 \leq \frac{d_i}{d_0} \leq 1,0 \quad 10 \leq \frac{d_0}{t_0} \leq 50 \quad 10 \leq \frac{d_i}{t_i} \leq 50 \quad (10 \leq \frac{d_i}{t_i} \leq 40 \text{ for X joints})
\]

Provided the conditions mentioned above are satisfy, the design capacity of the truss joint can be determined for two following failure modes:

(a) Plastic failure by shear punching for – the K and N joints with a gap or a overlap
(b) Chord shear failure – the K, N, KT and T,Y and X joints with a gap
• In case of welded joints the weld should be made around whole perimeter of the hollow section. The fillet weld and/or butt weld should be used in the connection. In the overlap zone the weld should not be done at the hidden part.

• The weld should be designed to the plastic capacity of the connected section. This is done if the throat thickness satisfy following conditions:

\[
\frac{a}{t} \geq 0.84\alpha \\
\frac{a}{t} \geq 0.87\alpha \\
\frac{a}{t} \geq 1.01\alpha
\]

Where \( \alpha = \gamma_{M5} \cdot \gamma_{Mw} \cdot \frac{1}{1.25} \)

According to Czech standards NAD: \( \gamma_{M5} = 1.0 \), \( \gamma_{Mw} = 1.25 \)

5.4.2 Chord shear failure

The chord cross-section may collapse in the gap section, because of the combination of axial force, shear force and bending moment.

The K, N and KT joints with the gab and all T, Y and X joints if \( d_i \leq d_0 - 2t_0 \) should be checked. The design capacity of the joint should satisfy:

\[
N_{Ed} \leq N_{i,Rd}
\]

where

\[
N_{i,Rd} = \frac{f_{y0} \cdot t_0 \cdot \pi \cdot d_i \cdot 1 + \sin \theta_i}{2 \sin^2 \theta_i} \cdot \frac{d_i}{\gamma_{M5}}
\]

where

- \( d_0, t_0 \) are the diameter and the thickness of a upper or bottom chord
- \( d_i, t_i \) are the diameter and the thickness of a diagonals and vertical chords
- \( \phi_i \) is the angle between the bottom or upper chord and diagonal
- \( f_{y0} \) is the yield strength of the bottom or upper chord
- \( \gamma_{M5} = 1.0 \) is the partial coefficient of the joint
5.4.3 Punching shear failure of a hollow section chord wall

Crack initiation leading to rupture of the brace members from the chord member.

The solution below is valid for K joint and its modification for KT joint. Other types of joints can be found in EN 1993-1-8.

*Tab.*: The design capacity of the K joint

\[
N_{1,Rd} = \frac{k_g \cdot k_p \cdot f_{y0} \cdot t_0^2 \left( 1.8 + 10.2 \cdot \frac{d_1}{d_0} \right)}{\sin \theta} \gamma_{M,5}
\]

\[
N_{2,Rd} = \frac{\sin \theta_1 \cdot N_{1,Rd}}{\sin \theta_2}
\]

*Tab.*: The design capacity of the KT joint – modification of the K joint

Chord 1 je should be in compression
Chord 2 je should be 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 value \(N_{1,Rd}\) for K joint

The ratio \(\frac{d_1}{d_0}\) should be substitute by:

\[
\frac{d_1 + d_2 + d_3}{3d_0}
\]
The coefficient $k_g$ can be determined from the formula and/or from the graph (see below):

$$k_g = \gamma^{0.2} \left( 1 + \frac{0.024 \cdot \gamma^{1.2}}{1 + e^{0.5g/(2t_0)^{1.33}}} \right)$$

where $\gamma = \frac{d_0}{2t_0}$

The coefficient $k_p$ can be determined using following formulas:

for $n_p > 0$ (compression): $k_p = 1 - 0.3n_p(1 + n_p)$ but $k_p \leq 1.0$

for $n_p \leq 0$ $k_p = 1$

where $n_p = \frac{\sigma_{p,Ed}}{\gamma_{M5}}$

where $\sigma_{p,Ed}$ is the stress in the bottom or upper chord from the equations:

$$\sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{0,Ed}}{W_{e,0}}$$

(compression - positive, tension - negative)

$$N_{p,Ed} = N_{0,Ed} - \sum_{i=0}^{I_o} N_{i,Ed} \cos \theta_i$$

where $N_{0,Ed}$ is the normal force in the bottom or upper chord at the joint

$M_{0,Ed}$ is the moment in the bottom or upper chord at the joint
5.4.4 Design calculation of the truss joint made of hollow section

Edge joint of the bottom chord (load combination C6 from the numerical simulation)

Geometrical conditions:

\[ g_1 = 15.4\,mm \]
\[ g_2 = 25.2\,mm \]

The geometrical condition \( g = 15.4\,mm \geq t_1 + t_3 = 4 + 3.2 = 7.2\,mm \) is satisfied.

\[
0.2 \leq \frac{d_1}{d_0} = \frac{82.5}{152} = 0.54 \leq 1.0
\]
\[
0.2 \leq \frac{d_3}{d_0} = \frac{42.4}{152} = 0.28 \leq 1.0
\]
\[
10 \leq \frac{d_0}{t_0} = \frac{152}{5.6} = 27.1 \leq 50
\]
\[
10 \leq \frac{d_1}{t_1} = \frac{82.5}{4} = 20.6 \leq 50
\]
\[
10 \leq \frac{d_3}{t_3} = \frac{42.4}{3.2} = 13.3 \leq 50
\]

satisfied
Chord shear failure:

Diagonal D_1

\[ N_{2,Rd} = \frac{f_{yd} t_0 \pi d_1}{\sqrt{3}} \cdot \frac{1 + \sin \theta_2}{2 \sin^2 \theta_2} \cdot \frac{355 \cdot 5,6 \cdot \pi \cdot 82,5 \cdot 1 + \sin 31}{2 \cdot \sin^2 31} = 849,5 \cdot 10^3 N \]

\[ N_{2,Rd} = 849,5 kN \geq N_{2,Ed} = D_1 = 185,1 kN \]

\( \Rightarrow \) The capacity of the joint in chord shear failure is satisfy.

Diagonal D_2

\( \Rightarrow \) The capacity of the joint in chord shear failure is satisfy.

Punching shear failure:

**K joint:** Diagonal D_2

\[ N_{1,Ed} = \frac{k_g k_p f_{yd} t_0^2}{\sin \theta_1} \left( 1,8 + 10,2 \cdot \frac{d_1 + d_2 + d_3}{3d_0} \right) \]

Coefficient \( k_p \):

\[ n_p = \frac{\sigma_{p,Ed}}{\gamma_{M5}} \]

where \( \sigma_{p,Ed} \) is a tension stress, so \( \sigma_{p,Ed} < 0 \Rightarrow k_p = 1,0 \)

Coefficient \( k_g \):

\[ g_1 = 15,4 \]

\[ t_0 = 5,6 \]

\[ \gamma = \frac{d_0}{2 \cdot t_0} = \frac{152}{2 \cdot 5,6} = 13,6 \Rightarrow k_g \approx 2,3 \]

Design capacity of the compression diagonal:

\[ N_{1,Rd} = \frac{2,3 \cdot 1,0 \cdot 355 \cdot 5,6^2}{\sin 35} \cdot \left( 1,8 + 10,2 \cdot \frac{2 \cdot 82,5 + 42,4}{3 \cdot 152} \right) = 287,5 \cdot 10^3 N \]

**KT joint:**

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

\[ N_{2,Ed} \sin \theta_3 \leq N_{1,Rd} \sin \theta_1 \]

\[ 114,7 \cdot \sin 35 + 29,5 \cdot \sin 90 = 95,3 kN \leq 287,5 \cdot \sin 35 = 164,9 kN \]

\[ 185,1 \cdot \sin 31 = 95,3 kN \leq 164,9 kN \]

\( \Rightarrow \) The capacity of the joint in punching shear failure is satisfy.
5.5 Optional design – joint connection using the connection plate

Advantage: simple details
Disadvantage: worse static behavior, worse aesthetic viewpoint

Tab.: Commonly used thicknesses of the connection plates

<table>
<thead>
<tr>
<th>L (m)</th>
<th>8</th>
<th>10</th>
<th>12.5</th>
<th>15</th>
<th>18</th>
<th>21</th>
<th>25</th>
<th>27.5</th>
<th>more</th>
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<tr>
<td>30</td>
<td>10</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Tab.: Design of the chords – compression forces – primary design
(some of the primary designed members should be changed because of static requirement)

<table>
<thead>
<tr>
<th>prut</th>
<th>N_{ed}</th>
<th>Profil</th>
<th>L</th>
<th>L_{cr} / L</th>
<th>A</th>
<th>I</th>
<th>\lambda'</th>
<th>\Phi</th>
<th>N_{cr}</th>
<th>\lambda</th>
<th>\chi</th>
<th>N_{b,Rd}</th>
<th>N_{Ed} / N_{t,Rd}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kN)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm²)</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>S</td>
<td>102,9</td>
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<td>161.80</td>
<td>0.20</td>
<td>28.04</td>
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Tab.: Design of the chords – compression forces – new design

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<th>prut</th>
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<th>Profil</th>
<th>L</th>
<th>L_{cr} / L</th>
<th>A</th>
<th>I</th>
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<th>N_{b,Rd}</th>
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<td>(mm)</td>
<td>(mm)</td>
<td>(mm²)</td>
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<td>161.80</td>
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</tbody>
</table>

Tab.: Design of the chords – compression forces – primary design
(some of the primary designed members should be changed because of static requirement)
The fillet weld:

\[ F_\mu = \sum F_x = D_1 \cdot \cos \theta_1 + D_2 \cdot \cos \theta_2 = 185,1 \cdot \cos 31 + 114,7 \cdot \cos 35 = 252,6 \text{kN} \]

\[ F_\perp = \sum F_y = 0,0 \text{kN} \]

\[ M = 0,109 \cdot D_1 \cdot \sin \theta_1 + 0,0175 \cdot V_1 + 0,126 \cdot D_2 \cdot \sin \theta_2 = 
\]

\[ = 0,109 \cdot 185,1 \cdot \sin 31 + 0,0175 \cdot 29,5 + 0,126 \cdot 114,7 \cdot \sin 35 = 19,2 \text{kNm} \]

\[ A_{\text{weld}} = 2 \cdot 3 \cdot 565 = 3390 \text{mm}^2 \]

\[ W_{\text{weld}} = 2 \cdot \frac{1}{6} \cdot 3 \cdot 584^2 = 341,1 \cdot 10^3 \text{mm}^3 \]

\[ \tau_\mu = \frac{F_\mu}{A} = \frac{252,6 \cdot 10^3}{3390} = 74,5 \text{MPa} \]

\[ \sigma_w = \frac{M}{W} = \frac{19,2 \cdot 10^6}{341,1 \cdot 10^3} = 56,3 \text{MPa} \]

\[ \sigma_\perp = \tau_\perp = \frac{\sigma_w}{\sqrt{2}} = \frac{56,3}{\sqrt{2}} = 39,8 \text{MPa} \]

\[ \sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_\parallel^2)} = \sqrt{39,8^2 + 3(39,8^2 + 74,5^2)} = 151,6 \text{MPa} \leq \frac{f_u}{\beta_w \cdot \gamma_{M2}} = \frac{510}{0,9 \cdot 1,25} = 453,3 \text{MPa} \]

\[ \beta_w \text{ – korekční součinitel koutových svarů} \]

S235 \( \Rightarrow \) 0.8

S355 \( \Rightarrow \) 0.9

S420 \( \Rightarrow \) 1.0

\[ \sigma_\perp = 39,8 \text{MPa} \leq \frac{f_u}{\gamma_{M2}} = \frac{510}{1,25} = 408 \text{MPa} \]

\[ \Rightarrow \text{Satisfy} \]