Welded joints examples
Celsius®355 NH
**CONTENTS**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RHS T-Joint Moment in Plane</td>
<td>03</td>
</tr>
<tr>
<td>2</td>
<td>CHS Gap K-Joint</td>
<td>09</td>
</tr>
<tr>
<td>3</td>
<td>CHS Overlap K-Joint</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>RHS Gap K-Joint</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>RHS Overlap K-Joint</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>RHS Chord CHS Bracings Gap K-Joint</td>
<td>23</td>
</tr>
<tr>
<td>7</td>
<td>RHS Chord CHS Bracings Overlap K-Joint 82.7</td>
<td>29</td>
</tr>
<tr>
<td>8</td>
<td>RHS Chord CHS Bracings Overlap K-Joint 102.7</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>RHS Chord RHS Bracings Overlap KT-Joint</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>CHS Chord CHS Bracings Gap KT-Joint</td>
<td>41</td>
</tr>
<tr>
<td>11</td>
<td>CHS Chord CHS Bracings Overlap KT-Joint</td>
<td>46</td>
</tr>
<tr>
<td>12</td>
<td>UB Chord RHS Bracings Gap K-Joint</td>
<td>52</td>
</tr>
</tbody>
</table>
# 1 RHS T-Joint Moment In Plane

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

## Dimensions

- **b₀ = 150 mm**
- **b₁ = 150 mm**
- **h₀ = 150 mm**
- **h₁ = 150 mm**
- **t₀ = 10.0 mm**
- **t₁ = 8.0 mm**

## Validity limits check

**Chord:**

\[
\frac{(b₀-3 \cdot t₀)}{t₀} ; \frac{(h₀-3 \cdot t₀)}{t₀} \leq 38c \quad \text{(Class 1 or 2 compression)}
\]

\[
38c = 38 \sqrt{\frac{235}{f_{y0}}} = 38 \sqrt{\frac{235}{355}} = 30.92
\]

\[
\frac{(b₀-3 \cdot t₀)}{t₀} = \frac{(h₀-3 \cdot t₀)}{t₀} = \frac{(150-3 \times 10)}{10} = 12
\]

∴ PASS

\[
\frac{b₀}{t₀} \leq 35
\]

\[
\frac{b₀}{t₀} = \frac{150}{10} = 15
\]

∴ PASS

\[
\frac{h₀}{t₀} \leq 35
\]

\[
\frac{h₀}{t₀} = \frac{150}{10} = 15
\]

∴ PASS

**Compression brace:**

\[
\frac{b₁}{t₁} ; \frac{h₁}{t₁} \leq 35
\]

\[
\frac{b₁}{t₁} = \frac{150}{8} = 18.75
\]

∴ PASS

\[
\frac{h₁}{t₁} = \frac{150}{8} = 18.75
\]

∴ PASS

**Compression brace:**

\[
\frac{(b₁-3 \cdot t₁)}{t₁} ; \frac{(h₁-3 \cdot t₁)}{t₁} \leq 38c \quad \text{(Class 1 or 2 compression)}
\]

\[
38c = 38 \sqrt{\frac{235}{f_{y0}}} = 38 \sqrt{\frac{235}{355}} = 30.92
\]

\[
\frac{(b₁-3 \cdot t₁)}{t₁} = \frac{(h₁-3 \cdot t₁)}{t₁} = \frac{(150-3 \times 8)}{8} = 15.75
\]

∴ PASS

0.25 \leq b₁/b₀ \leq 1.0

\[
\frac{b₁}{b₀} = \frac{150}{150} = 1.0
\]

∴ PASS

0.5 \leq h₁/b₀ \leq 2.0

\[
\frac{h₁}{b₀} = \frac{150}{150} = 1.0
\]

∴ PASS

0.5 \leq h₁/b₁ \leq 2.0

\[
\frac{h₁}{b₁} = \frac{150}{150} = 1.0
\]

∴ PASS

30° \leq θ₁ \leq 90°

\[
θ₁ = 90°
\]

∴ PASS

---

**Diagram:**

- RHS 150 x 150 x 8
- SHS 150 x 150 x 10
- N₁,Ed = 19.2 kN
- Mₚ₁,Ed = 54 kNm
- N₀,Ed = 350 kN
- Mₚ₀,Ed = 16.6 kNm
- Mₚ₀,0,Ed = 35.8 kNm
Axial: Chord face failure (deformation)  
(valid when $\beta \leq 0.85$)

$$\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \quad \therefore \text{check not required}$$

Although this check is not required in this particular case, the chord end stress factor calculation for is shown below for information as it includes moments:

<table>
<thead>
<tr>
<th>RHS chord end stress factor, $k_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHS chord most compressive stress, $\sigma_{0,Ed}$:</td>
</tr>
<tr>
<td>$\sigma_{0,Ed} = \frac{N_{0,Ed}}{A_0} + \frac{</td>
</tr>
</tbody>
</table>

Note: Moment is additive to compressive stress which is positive for moments. For RHS chords use most compressive chord stress.

$$A_0 = 54.9 \text{ cm}^2 = 5490 \text{ mm}^2$$

$$\sigma_{0,Ed} = \frac{136 \times 1000}{54.9 \times 10^2} + \frac{35.8 \times 1000 \times 1000}{236 \times 10^3}$$

$$\sigma_{0,Ed} = 176.47 \text{ N/mm}^2$$

Chord factored stress ratio, $n$;

$$n = \left( \frac{\sigma_{0,Ed}}{\sigma_{0,Ed}} \right) = \left( \frac{176.47}{355} \right)$$

$$n = 0.497$$

Using formulae:  

For $n > 0$ (compression):

$$k_n = 1.3 - \frac{0.4 \times n}{\beta} \quad \text{but} \quad k_n \leq 1.0$$

$$k_n = 1.3 - \frac{0.4 \times 0.497}{1.0} \leq 1.0$$

$$k_n = 1.101 \quad \text{but} \leq 1.0 \quad \therefore k_n = 1.0$$

(However, not required in this case as chord deformation not critical as $\beta > 0.85$)
**Axial: Chord shear**
(valid for X-joints with \(\cos \theta_1 > h_1/h_0\))

As this is a T-joint with \(\theta_1 = 90^\circ\) this check is not required.

**Axial: Chord side wall buckling**
(valid when \(\beta = 1.0\))

\[N_{tURd} = \frac{k_n f_b t_0}{\sin \theta_1} \left( \frac{2 h_1}{\sin \theta_1} + 10 t_0 \right)/\gamma_{Ms} \]

\(\beta = 1.0\) : check required

**Chord side wall buckling strength, \(f_b\)**

For compression brace, T-joint:

\[\lambda_{cr} = 3.46 \left( \frac{h_0}{t_0} - 2 \right) \frac{1}{\sin \theta_1} \]

\[\lambda_{cr} = 3.46 \left( \frac{150}{10} - 2 \right) \frac{1}{\sin 90^\circ} = 0.589 \]

Using formulae:

From EN 1993-1-1:2005, 6.3.1.2, flexural buckling reduction factor, \(\chi\):

\[\phi = 0.5 \left( 1 + \alpha \left( \lambda_{cr} - 0.2 \right) + \lambda_{cr}^2 \right) \]

\[\phi = 0.5 \left( 1 + 0.21 \left( 0.589 - 0.2 \right) + 0.589^2 \right) = 0.714 \]

\[\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{cr}^2}} \text{ but } \chi \leq 1.0 \]

\[\chi = \frac{1}{0.714 + \sqrt{0.714^2 - 0.589^2}} \text{ but } \chi \leq 1.0 \]

\[\chi = 0.895 \]

\[f_b = \chi f_{y0} \text{ (for T- and Y-joints with compression in bracing)} \]

\[f_b = 0.895 \times 355 = 318 \text{ N/mm}^2 \]

Using graph:

From graph, for \(\frac{\lambda_{cr}}{\chi} = 0.589\):

\[\chi = 0.895 \]

\[N_{tURd} = \frac{1.0 \times 318 \times 10}{\sin 90^\circ} \left( \frac{2 \times 150}{\sin 90^\circ} + 10 \times 10 \right)/1.0 \]
Axial: Chord punching shear
(valid when $0.85 \leq \beta \leq 1 - 1/\gamma$)

$$\gamma = \frac{b_0}{2t_0} = \frac{150}{2 \times 10} = 7.5$$

$$0.85 \leq 1.0 \leq 1 - \frac{1}{7.5} = 0.867$$

∴ Check not required

Axial: Bracing failure (effective width)
(valid when $\beta \geq 0.85$)

$\beta = 1.0$

∴ check required

$$N_{t, Rd} = f_{y1} t_1 \left( 2 h_1 - 4 t_1 + 2 b_{eff,i} \right)/\gamma_{M5}$$

where:

$$b_{eff,i} = \frac{10 t_0}{b_0} \times \frac{f_{y0} t_0}{f_{y1} t_1} b_i \quad \text{but} \quad b_{eff,i} \leq b_i$$

$$b_{eff,i} = \frac{10 \times 10}{150} \times \frac{355 \times 10}{355 \times 8} \times 150 = 125 \text{ mm} \quad \text{but} \quad b_{eff,i} \leq 150 \text{ mm}$$

$$b_{eff,i} = 125 \text{ mm}$$

$$N_{t, Rd} = 355 \times 8 \left( 2 \times 150 - 4 \times 8 + 2 \times 125 \right)/1.0$$

$$N_{t, Rd} = 1471 \text{ kN} \quad > \quad 19.2 \text{ kN} \quad \therefore \text{PASS}$$

Moment in plane: Chord face failure (deformation)
(valid when $\beta \leq 0.85$)

$$\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \quad \therefore \text{check not required}$$

Reference

5.3.3
6.3
### Welded Joints Examples
#### RHS T-Joint Moment In Plane

**Moment in plane: Chord side wall crushing**  
(valid when $0.85 < \beta \leq 1.0$)

\[
\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \quad \therefore \text{check required}
\]

\[
M_{\text{p,1Rd}} = 0.5 f_{yk} t_0 \left( h_1 + 5 t_0 \right)^2 / \gamma_{M5}
\]

where:

\[
f_{yk} = f_{y0} \quad \text{ (for T-joints)}
\]

\[
\therefore f_{yk} = 355 \text{ N/mm}^2
\]

\[
M_{\text{p,1Rd}} = 0.5 \times 355 \times 10 \left( 150 + 5 \times 10 \right)^2 / 1.0
\]

\[
M_{\text{p,1Rd}} = 71 \text{ kNm} > 54 \text{ kNm} \quad \therefore \text{PASS}
\]

**Moment in plane: Bracing failure (effective width)**  
(valid when $0.85 < \beta \leq 1.0$)

\[
\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \quad \therefore \text{check required}
\]

\[
M_{\text{p,1Rd}} = f_{y1} \left[ W_{\text{pl,ip,1}} - \left( 1 - \frac{b_{\text{eff,1}}}{b_1} \right) b_1 \left( h_1 - t_1 \right) t_1 \right] / \gamma_{M5}
\]

where:

\[
W_{\text{pl,ip,1}} = 237 \text{ cm}^3 = 237000 \text{ mm}^3
\]

\[
b_{\text{eff,1}} = 125 \text{ mm}
\]

\[
M_{\text{p,1Rd}} = 355 \left[ 237000 - \left( 1 - \frac{125}{150} \right) 150 \left( 150 - 8 \right) \right] / 1.0
\]

\[
M_{\text{p,1Rd}} = 74.1 \text{ kNm} > 54 \text{ kNm} \quad \therefore \text{PASS}
\]

**Summary**

Axial joint resistance for brace 1 limited by chord side wall buckling and moment in plane resistance by chord side wall crushing resistance.

Axial joint resistance,  
\[N_{1\text{Rd}} = 1272 \text{ kN} > 19.2 \text{ kN} \quad \therefore \text{PASS}\]

Moment in plane joint resistance,  
\[M_{\text{p,1Rd}} = 71 \text{ kNm} > 54 \text{ kNm} \quad \therefore \text{PASS}\]
Interaction check
When more than one type of force exists, e.g. axial and moments in plane, an interaction check is required;

\[
\frac{|N_{Ed}|}{N_{Rd}} + \frac{|M_{ip,Ed}|}{M_{ip,Rd}} + \frac{|M_{op,Ed}|}{M_{op,Rd}} \leq 1.0 \quad \text{(for RHS chords)}
\]

As there are no moments out of plane;

\[
\frac{19.2}{1272} + \frac{54}{71} + \frac{0}{M_{op,Rd}} = 0.776
\]

\[
0.776 \leq 1.000 \quad \therefore \text{PASS}
\]
References are generally to Tata Steel publication 'Design of Welded Joints' (unless otherwise stated).

Note: Brace 1 usually designated compression and brace 2 tension.

### Dimensions

- \( d_0 = 219.1 \text{ mm} \)
- \( d_1 = 139.7 \text{ mm} \)
- \( d_2 = 114.3 \text{ mm} \)
- \( t_0 = 12.5 \text{ mm} \)
- \( t_1 = 5.0 \text{ mm} \)
- \( t_2 = 3.6 \text{ mm} \)

### Validity limits check

#### \( 10 \leq d_0/t_0 \leq 50 \)
- \( d_0/t_0 = 219.1/12.5 = 17.53 \)
- \( \therefore \) PASS

#### \( d_0/t_0 \leq 70c^2 \) (Class 1 or 2 for compression chord)
- \( c^2 = 70 \left( \sqrt{235/fy_0} \right)^2 = 70(235/355) = 46.34 \)
- \( 17.53 < 46.34 \)
- \( \therefore \) PASS

#### \( d_0/t_0 \leq 70c^2 \) (Class 1 or 2 for compression brace)
- \( c^2 = 70 \left( \sqrt{235/fy_0} \right)^2 = 70(235/355) = 46.34 \)
- \( d_1/t_1 = 139.7/5.0 = 27.94 < 46.34 \)
- \( \therefore \) PASS

#### \( d_0/t_0 \leq 70c^2 \) (Class 1 or 2 for compression brace)
- \( c^2 = 70 \left( \sqrt{235/fy_0} \right)^2 = 70(235/355) = 46.34 \)
- \( d_1/t_1 = 139.7/5.0 = 27.94 < 46.34 \)
- \( \therefore \) PASS

#### \( 0.2 \leq d_1/d_0 \leq 1.0 \)
- \( d_1/d_0 = 139.7/219.1 = 0.64 \)
- \( \therefore \) PASS

#### \( d_2/d_0 \leq 1.0 \)
- \( d_2/d_0 = 114.3/219.1 = 0.52 \)
- \( \therefore \) PASS

#### \(-0.55 \leq e \leq +0.25 \)
- \( -0.55 \times 219.1 \leq e \leq +0.25 \times 219.1 \)
- \( -120.5 \leq e \leq +54.8 \)
- \( e = 0 \text{ mm} \)
- \( \therefore \) PASS

#### \( g \geq t_1 + t_2 \)
- \( t_1 + t_2 = 5 + 3.6 = 8.6 \text{ mm} \)
- \( g = 40 \text{ mm} \)
- \( \therefore \) PASS

#### \( 30^\circ \leq \theta_1 \leq 90^\circ \)
- \( \theta_1 = 45^\circ \)
- \( \therefore \) PASS

#### \( 30^\circ \leq \theta_2 \leq 90^\circ \)
- \( \theta_2 = 45^\circ \)
- \( \therefore \) PASS

---

**Diagram and Analysis**

- \( N_{1,Ed} = 500 \text{ kN} \)
- \( N_{2,Ed} = -400 \text{ kN} \)
- \( N_{p,Ed} = 1000 \text{ kN} \)
- \( N_{0,Ed} = 1636 \text{ kN} \)

---

**Reference**

5.1.1 Figure 27

(EN 1993-1-1) Table 5.2
Chord face failure (deformation)

Compression brace (1):

\[ N_{t,Ed} = \frac{k_g k_p f_y 0 t_2^2}{\sin \theta_1} \left( 1.8 + 10.2 \frac{d_1}{d_0} \right) / \gamma_{M_5} \]

<table>
<thead>
<tr>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.3</td>
</tr>
</tbody>
</table>

Gap/lap function, \( k_g \)

\[ \gamma = \frac{d_0}{2t_0} = \frac{219.1}{2 \times 12.5} = 8.764 \]

Using formulae: \( k_g = 1.761 \)

Using graph: \( k_g = 1.761 \)

Note: \( g \) is positive for a gap and negative for an overlap

\[ k_g = 8.764^{0.2} \left[ 1 + \frac{0.024 \gamma^{1.2}}{1 + \exp(0.5g/t_0 - 1.33)} \right] \]

from graph; \( g/t_0 = 40/12.5 = 3.2 \)

\[ k_g = 8.764^{0.2} \left[ 1 + \frac{0.024 \times 8.764^{1.2}}{1 + \exp(0.5 \times 40/12.5 - 1.33)} \right] \]

<table>
<thead>
<tr>
<th>CHS chord end stress factor, ( k_p )</th>
</tr>
</thead>
</table>

CHS chord least compressive applied factored stress, \( \sigma_{p,Ed} \):

\[ \sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{p,0,Ed}}{W_{el,p,0}} + \frac{M_{p,0,Ed}}{W_{el,op,0}} \]

Note: Moment is additive to compressive stress which is positive for moments. For CHS chords use least compressive chord stress.

\[ \sigma_{p,Ed} = \frac{1000 \times 1000}{81.1 \times 10^2} = 123.30 \text{ N/mm}^2 \]

Chord factored stress ratio, \( n_p \):

\[ n_p = \left( \frac{\sigma_{p,Ed}}{f_y 0} \right) = \left( \frac{123.30}{355} \right) = 0.347 \]

Using formulae: \( n_p > 0 \) (compression):

\[ k_p = 1 - 0.3 n_p (1 + n_p) \quad \text{but} \leq 1.0 \]

from graph; \( k_p = 0.860 \)

<table>
<thead>
<tr>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.2.2</td>
</tr>
<tr>
<td>5.1.2.1</td>
</tr>
<tr>
<td>5.1.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.2.2</td>
</tr>
<tr>
<td>Fig.29</td>
</tr>
<tr>
<td>5.1.2.1</td>
</tr>
<tr>
<td>Fig.28</td>
</tr>
</tbody>
</table>
Welded Joints Examples  CHS Gap K-Joint

\[
N_{1,Rd} = \frac{1.761 \times 0.860 \times 355 \times 12.5^2}{\sin 45^\circ} \left( 1.8 + 10.2 \times \frac{139.7}{219.1} \right) / 1.0
\]

\[N_{1,Rd} = 986 \text{ kN}\]

Tension brace (2):

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

\[N_{2,Rd} = \frac{\sin 45^\circ}{\sin 45^\circ} \times 986\]

\[N_{2,Rd} = 986 \text{ kN}\]

**Chord punching shear**

(valid when \(d_i \leq d_0 - 2t_0\))

\(d_i \leq d_0 - 2t_0\)

\(d_1 = 139.7 \text{ mm} < 194.1 \text{ mm} \therefore \text{check chord punching shear}\)

\(d_2 = 114.3 \text{ mm} < 194.1 \text{ mm} \therefore \text{check chord punching shear}\)

\[
N_{i,Rd} = \frac{f_y t_0}{\sqrt{3}} \times \frac{d_i}{2 \sin^2 \theta_i} \times \frac{1 + \sin \theta_i}{\gamma_{MS}}
\]

Brace (1):

\[
N_{1,Rd} = \frac{355}{\sqrt{3}} \times 12.5 \times \pi \times 139.7 \times \frac{1 + \sin 45^\circ}{2 \sin^2 45^\circ} / 1.0
\]

\[N_{1,Rd} = 1919 \text{ kN}\]

Brace (2):

\[
N_{2,Rd} = \frac{355}{\sqrt{3}} \times 12.5 \times \pi \times 114.3 \times \frac{1 + \sin 45^\circ}{2 \sin^2 45^\circ} / 1.0
\]

\[N_{2,Rd} = 1570 \text{ kN}\]

Joint strength dictated by chord face failure for both bracings;

**Brace 1 joint resistance**,  \(N_{1,Rd} = 986 \text{ kN} > 500 \text{ kN} \therefore \text{PASS}\)

**Brace 2 joint resistance**,  \(N_{2,Rd} = 986 \text{ kN} > 400 \text{ kN} \therefore \text{PASS}\)

Reference

5.1.3
3 CHS Overlap K-Joint

References are generally to Tata Steel publication 'Design of Welded Joints' (unless otherwise stated).

N1,Ed = 500 kN
N2,Ed = - 400 kN

CHS 139.7x5.0
CHS 114.3x3.6

Note: Brace 1 usually designated compression and brace 2 tension

Dimensions

$\frac{d_0}{t_0} = 219.1/12.5 = 17.53$  \hspace{1cm} \therefore \text{PASS}

$\frac{d_0}{t_0} \leq 70c^2$ (Class 1 or 2 for compression chord)

$70c^2 = 70 \times \left(\sqrt{\frac{235}{f_{y0}}}\right)^2 = 70(\frac{235}{355}) = 46.34$

$17.53 < 46.34$  \hspace{1cm} \therefore \text{PASS}

$\frac{d_1}{t_1} = 139.7/5.0 = 27.94$  \hspace{1cm} \therefore \text{PASS}

$\frac{d_2}{t_2} = 114.3/3.6 = 31.75$  \hspace{1cm} \therefore \text{PASS}

$\frac{d_1}{d_0} \leq 1.0$

$\frac{d_1}{d_2} = 139.7/219.1 = 0.64$  \hspace{1cm} \therefore \text{PASS}

$\frac{d_2}{d_0} = 114.3/219.1 = 0.52$  \hspace{1cm} \therefore \text{PASS}

$-0.55 \leq e \leq 0.25\ d_0$

$-0.55 \times 219.1 \leq e \leq +0.25 \times 219.1$

$-120.5 \leq e \leq +54.8$

$e = -42.2$ mm  \hspace{1cm} \therefore \text{PASS}

$25\% \leq \lambda_{ov} \leq 100\%$

$\lambda_{ov} = |g| \sin \theta_i/d_i \times 100\%$

$\lambda_{ov} = 45 \sin 45^\circ/114.3 \times 100\%$

$\lambda_{ov} = 27.8\%$  \hspace{1cm} \therefore \text{PASS}

$30^\circ \leq \theta_1 \leq 90^\circ$

$\theta_1 = 45^\circ$  \hspace{1cm} \therefore \text{PASS}

$\theta_2 = 45^\circ$  \hspace{1cm} \therefore \text{PASS}
Chord face failure (deformation)

Compression brace (1):

\[ N_{t,Ed} = \frac{k_g k_p f_y0 t_0^2}{\sin \theta_1 \left( 1.8 + 10.2 \frac{d_1}{d_0} \right)} / \gamma_{M5} \]

Gap/overlap function, \( k_g \)

\[ \gamma = \frac{d_0}{2t_0} = \frac{219.1}{2 \times 12.5} = 8.764 \]

Using formulae:

\[ k_g = \gamma^{0.2} \left[ 1 + \frac{0.024 \gamma^{1.2}}{1 + \exp(0.5 \gamma / t_0 - 1.33)} \right] \]

Using graph:

\[ k_g = 8.764^{0.2} \left[ 1 + \frac{0.024 \times 8.764^{1.2}}{1 + \exp(0.5 \times (-45)/12.5 - 1.33)} \right] \]

Note: \( g \) is positive for a gap and negative for an overlap

\( k_g = 2.024 \) from graph;

\( g/t_0 = -45/12.5 = -3.6 \)

CHS chord end stress factor, \( k_p \)

CHS chord least compressive applied factored stress, \( \sigma_{p,Ed} \):

\[ \sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{p,0,Ed}}{W_{elip,0}} + \frac{M_{p,0,Ed}}{W_{elop,0}} \]

Note: Moment is additive to compressive stress which is positive for moments. For CHS chords use least compressive chord stress.

\[ \sigma_{p,Ed} = \frac{1000 \times 1000}{81.1 \times 10^2} = 123.30 \text{ N/mm}^2 \]

Chord factored stress ratio, \( n_p \):

\[ n_p = \left( \frac{\sigma_{p,Ed}}{f_y0} \right) = \left( \frac{123.30}{355} \right) = 0.347 \]

Using formulae:

For \( n_p > 0 \) (compression):

\[ k_p = 1 - 0.3n_p \left( 1 + n_p \right) \quad \text{but} \leq 1.0 \]

\[ k_p = 1 - 0.3 \times 0.347 \left( 1 + 0.347 \right) \quad \text{but} \leq 1.0 \]

\( k_p = 0.860 \) from graph;
Chord punching shear check not required for overlapping bracings

Localised shear check for overlapping bracings not required as overlap not greater than 60%.

Therefore, joint strength dictated by chord face failure for both bracings;

\[N_{1,Rd} = \frac{2.024 \times 0.860 \times 355 \times 12.5^2}{\sin 45^\circ} \left( 1.8 + \frac{10.2 \times 139.7}{219.1} \right) / 1.0\]

\[N_{1,Rd} = 1134 \text{ kN}\]

Tension brace (2):

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

\[N_{2,Rd} = \frac{\sin 45^\circ}{\sin 45^\circ} \times 1134\]

\[N_{2,Rd} = 1134 \text{ kN}\]

Brace 1 joint resistance, \(N_{1,Rd} = 1134 \text{ kN} > 500 \text{ kN} \therefore \text{PASS}\)

Brace 2 joint resistance, \(N_{2,Rd} = 1134 \text{ kN} > 400 \text{ kN} \therefore \text{PASS}\)
# 4 RHS Gap K-Joint

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

![Diagram of RHS Gap K-Joint](image)

### Dimensions

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>200 mm</td>
<td>$b_1$</td>
</tr>
<tr>
<td>$h_0$</td>
<td>200 mm</td>
<td>$h_1$</td>
</tr>
<tr>
<td>$t_0$</td>
<td>10.0 mm</td>
<td>$t_1$</td>
</tr>
</tbody>
</table>

### Validity limits check

**Chord:**

$$\frac{(b_0-3 \ t_0)}{t_0} \leq 38 \varepsilon$$  (Class 1 or 2 compression)

$$38 \varepsilon = 38 \sqrt{235/f_y0} = 38 \sqrt{(235/355)} = 30.92$$

$$\frac{(b_0-3 \ t_0)}{t_0} = \frac{(200-3 \times 10)}{10} = 17 \quad \therefore \text{PASS}$$

$$\frac{b_0}{t_0} \leq 35$$

$$\frac{b_0}{t_0} = \frac{200}{10} = 20 \quad \therefore \text{PASS}$$

$$\frac{h_0}{t_0} \leq 35$$

$$\frac{h_0}{t_0} = \frac{200}{10} = 20 \quad \therefore \text{PASS}$$

**Compression brace:**

$$\frac{b_1}{t_1} ; \frac{h_1}{t_1} \leq 35 \quad \therefore \text{PASS}$$

$$\frac{b_1}{t_1} = \frac{120}{5} = 24$$

$$\frac{h_1}{t_1} = \frac{120}{5} = 24$$

**Compression brace:**

$$\frac{(b_1-3 \ t_1)}{t_1} ; \frac{(h_1-3 \ t_1)}{t_1} \leq 38 \varepsilon$$  (Class 1 or 2 compression)

$$38 \varepsilon = 38 \sqrt{235/f_y0} = 38 \sqrt{(235/355)} = 30.92$$

$$\frac{(b_1-3 \ t_1)}{t_1} = \frac{(120-3 \times 5)}{5} = 21 \quad \therefore \text{PASS}$$

$$\frac{(h_1-3 \ t_1)}{t_1} = \frac{(120-3 \times 5)}{5} = 21 \quad \therefore \text{PASS}$$

**Tension brace:**

$$\frac{b_2}{t_2} ; \frac{h_2}{t_2} \leq 35$$

$$\frac{b_2}{t_2} = \frac{120}{5} = 24$$

$$\frac{h_2}{t_2} = \frac{120}{5} = 24$$

$$\frac{b_2}{b_0} \geq 0.35$$

$$\frac{b_1}{b_0} = \frac{120}{200} = 0.6 \quad \therefore \text{PASS}$$

$$\frac{b_2}{b_0} = \frac{120}{200} = 0.6 \quad \therefore \text{PASS}$$

$$0.1+0.01 \frac{b_0}{t_0} \leq \frac{b_1}{b_0} \leq 1.0$$

$$0.1+0.01 \frac{b_0}{t_0} = 0.3$$

$$\frac{b_1}{b_0} = \frac{120}{200} = 0.6 \quad \therefore \text{PASS}$$

$$\frac{b_2}{b_0} = \frac{120}{200} = 0.6 \quad \therefore \text{PASS}$$
0.5 ≤ h_0/b_0 ≤ 2.0 \quad h_0/b_0 = 200/200 = 1.0 \quad \therefore \text{PASS}

0.5 ≤ h_1/b_1 ≤ 2.0 \quad h_1/b_1 = 120/120 = 1.0 \quad \therefore \text{PASS}

h_2/b_2 = 120/120 = 1.0 \quad \therefore \text{PASS}

-0.55 \ h_0 \leq e \leq +0.25 \ h_0 \quad -0.55 \times 200 \leq e \leq +0.25 \times 200

-110.0 \leq e \leq +50.0

\quad e = +5.0 \text{ mm} \quad \therefore \text{PASS}

30° \leq \theta_1 \leq 90° \quad \theta_1 = 45° \quad \therefore \text{PASS}

\theta_2 = 45° \quad \therefore \text{PASS}

g \geq t_1 + t_2 \quad 40 \geq 5 + 5 = 10 \text{ mm} \quad \therefore \text{PASS}

0.5 \ b_0(1-\beta) \leq g \leq 1.5 \ b_0(1-\beta) \quad g = 40 \text{ mm}

\beta = (b_1+b_2+h_1+h_2)/(4 \ b_0)

\beta = (120+120+120+120)/(4\times200) = 0.6

0.5 \times 200(1-0.6) \leq g \leq 1.5 \times 200(1-0.6)

40 \text{ mm} \leq g \leq 120 \text{ mm} \quad \therefore \text{PASS}

-0.55 \ h_0 \leq e \leq +0.25 \ h_0 \quad e = 5 \text{ mm}

-0.55 \times 200 \leq e \leq +0.25 \times 200

-110 \leq e \leq +50 \quad \therefore \text{PASS}

\textbf{Chord face failure (deformation) – brace 1}

\textbf{Note: Brace 1 usually designated compression and brace 2 tension.}

\textbf{Compression brace (1):}

\[ N_{IRd} = \frac{8.9 \ k_n \ f_{y0} \ t_0}{\sin \theta_i} \sqrt{\frac{b_1 + b_2 + h_1 + h_2}{4 \ b_0}} / \gamma_{M5} \]
**RHS chord end stress factor, \( k_n \)**

RHS chord most compressive applied factored stress, \( \sigma_{0,Ed} \):

\[
\sigma_{0,Ed} = \frac{N_{0,Ed}}{A_0} + \frac{M_{p,0,Ed}}{W_{el,p,0}} + \frac{M_{op,0,Ed}}{W_{el,op,0}}
\]

Note: Moment is additive to compressive stress which is positive for moments. For RHS chords use most compressive chord stress.

\[
\sigma_{0Ed} = \frac{1920 \times 1000}{74.9 \times 10^2} = 256.34 \text{ N/mm}^2
\]

Chord factored stress ratio, \( n \):

\[
n = \left( \frac{\sigma_{0,Ed}}{f_{y0}} \right) = \left( \frac{256.34}{355} \right)
\]

\( n = 0.722 \)

Using formulae:

For \( n > 0 \) (compression):

\[
k_n = 1.3 - \frac{0.4 n}{\beta} \quad \text{but} \quad k_n \leq 1.0
\]

\[
k_n = 1.3 - \frac{0.4 \times 0.722}{0.6} \quad \text{but} \quad \leq 1.0
\]

\( k_n = 0.819 \)

Using graph:

From graph, for \( \beta = 0.6 \); \( k_n = 0.819 \)

\[
\gamma = \frac{b_0}{2t_0} = \frac{200}{2 \times 10} = 10
\]

\[
N_{tRd} = \frac{8.9 \times 0.819 \times 355 \times 10^2 \times \sqrt{10} \times \left[ \frac{120 + 120 + 120}{4 \times 200} \right]}{\sin 45^\circ} / 1.0
\]

\( N_{tRd} = 694 \text{ kN} \)
Chord shear between bracings check – brace 1

\[ N_{IRd} = \frac{f_{y0} A_{v,0}}{\sqrt{3} \sin \theta_i} / \gamma_{M5} \]

where:

for RHS bracings:

\[ \alpha = \frac{1}{\sqrt{1 + \frac{4 g^2}{3 t_0^2}}} = 0.212 \]

\[ A_{v,0} = (2 h_0 + \alpha b_0) t_0 \]

\[ A_{v,0} = (2 \times 200 + 0.212 \times 200)10 = 4424 \text{ mm}^2 \]

\[ N_{IRd} = \frac{355 \times 4424}{\sqrt{3} \sin 45^\circ} / 1.0 \]

\[ N_{IRd} = 1282 \text{ kN} \]

Bracing Effective width – brace 1

\[ N_{IRd} = f_{yi} t_i (2 h_i - 4 t_i + b_i + b_{eff}) / \gamma_{M5} \]

where:

\[ b_{eff,j} = \frac{10 t_i}{b_0} \times f_{y0} t_0 \times b_i \text{ but } b_{eff,j} \leq b_i \]

\[ b_{eff,j} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 5} \times 120 = 120 \text{ mm} \text{ but } b_{eff,j} \leq 120 \text{ mm} \]

\[ b_{eff,i} = 120 \text{ mm} \]

\[ N_{IRd} = 355 \times 5 (2 \times 120 - 4 \times 5 + 120 + 120) / 1.0 \]

\[ N_{IRd} = 817 \text{ kN} \]
Chord punching shear – brace 1
(valid when $\beta \leq 1 - 1/\gamma$)

$$0.6 \leq 1 - 1/10 = 0.9 \text{ mm} \quad \therefore \text{ check chord punching shear}$$

$$N_{1\text{Rd}} = \frac{f_y t_0}{\sqrt{3}} \sin \theta_i \left( \frac{2 h_i}{\sin \theta_i} + b_i + b_{e,p,i} \right) / \gamma_{M5}$$

where:

$$b_{e,p,i} = \frac{10}{b_0} b_i \quad \text{but} \quad b_{e,p,i} \leq b_i$$

$$b_{e,p,i} = \frac{10 \times 10}{200} \times 120 = 60 \text{ mm} \quad \text{but} \quad b_{e,p,i} \leq 120 \text{ mm}$$

$$b_{e,p,i} = 60 \text{ mm}$$

$$N_{1\text{Rd}} = \frac{355 \times 10}{\sqrt{3}} \sin 45^\circ \left( \frac{2 \times 120}{\sin 45^\circ} + 120 + 60 \right) / 1.0$$

$$N_{1\text{Rd}} = 1506 \text{ kN}$$

Summary - brace 1
Joint strength for brace 1 dictated by chord face deformation.

$$\therefore \text{ Brace 1 joint resistance, } N_{1\text{Rd}} = 694 \text{ kN} > 650 \text{ kN} \quad \therefore \text{ PASS}$$

Brace 2
Repeat brace resistance formulae for brace 2.

Note: As both braces are of same geometry, brace 2 resistance will be the same:

Chord face deformation, $N_{2\text{Rd}} = 694 \text{ kN}$

Chord shear check, $N_{2\text{Rd}} = 1282 \text{ kN}$

Bracing effective width, $N_{2\text{Rd}} = 817 \text{ kN}$

Punching shear, $N_{2\text{Rd}} = 1506 \text{ kN}$

$$\therefore \text{ Brace 2 joint resistance, } N_{2\text{Rd}} = 694 \text{ kN} > 650 \text{ kN} \quad \therefore \text{ PASS}$$
### Chord axial load resistance in gap

Check: \( N_{0,\text{gap,Rd}} \geq N_{0,\text{gap,Ed}} \)

\[
N_{0,\text{gap,Rd}} = \left[ \left( A_0 - A_{v,0} \right) f_y0 + A_{v,0} f_y0 \right] \sqrt{1 - \left( \frac{V_{0,\text{Ed}}}{V_{\text{pl,0,Rd}}} \right)^2} / \gamma_{M5}
\]

where:

- \( A_0 = 74.9 \text{ cm}^2 = 7490 \text{ mm}^2 \)
- \( A_{v,0} = 4424 \text{ mm}^2 \)
- \( V_{0,\text{Ed}} = \max\left( |N_{1,\text{Ed}| \sin \theta_1, |N_{2,\text{Ed}}| \sin \theta_2 \right) \)
- \( V_{0,\text{Ed}} = \max\left( 650 | \sin 45^\circ, -650 | \sin 45^\circ \right) = \max (459.6, 459.6) \)
- \( V_{0,\text{Ed}} = 459.6 \text{ kN} \)
- \( V_{\text{pl,0,Rd}} = \frac{A_{v,0} f_y0 \sqrt{3}}{\gamma_{M0}} \)
- \( V_{\text{pl,0,Rd}} = \frac{4424 \times (355/\sqrt{3})}{1.0} = 906.7 \text{ kN} \)

### Change of chord axial force in K-joint

\[
N_{0,\text{gap,Ed}} = \max\left( N_{p,\text{Ed}} + N_{1,\text{Ed}} \cos \theta_1, N_{0,\text{Ed}} + N_{2,\text{Ed}} \cos \theta_2 \right)
\]

\[
N_{0,\text{gap,Ed}} = \max\left( 1000 + 650 \cos 45^\circ, 1920 + (-650) \cos 45^\circ \right)
\]

\[
N_{0,\text{gap,Ed}} = \max\left( 1460, 1460 \right) = 1460 \text{ kN}
\]

\[
N_{0,\text{gap,Rd}} = \left[ \left( 7490 - 4424 \right) 355 + 4424 \times 355 \sqrt{1 - \left( 459.6 / 906.7 \right)^2} \right] / 1.0
\]

\[
N_{0,\text{gap,Rd}} = 2442 \text{ kN} > 1460 \text{ kN} \quad \therefore \text{PASS}
\]
5 RHS Overlap K-Joint

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

N₁,Ed = 600 kN
N₂,Ed = -600 kN
Np,Ed = 1000 kN
N₀,Ed = 1849 kN

Dimensions

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>b₀</td>
<td>200 mm</td>
<td>b₁</td>
<td>120 mm</td>
</tr>
<tr>
<td>h₀</td>
<td>200 mm</td>
<td>h₁</td>
<td>120 mm</td>
</tr>
<tr>
<td>t₀</td>
<td>10.0 mm</td>
<td>t₁</td>
<td>5.0 mm</td>
</tr>
</tbody>
</table>

Validity limits check

Chord:

\[(b₀-3 t₀)/t₀ \leq 38\% \text{ (Class 1 or 2 compression)}\]

\[38\% = 38 \sqrt{(235/f_y)} = 38 \sqrt{(235/355)} = 30.92\]

\[(b₀-3 t₀)/t₀ = (200-3 \times 10)/10 = 17 \quad \therefore \text{PASS}\]

\[(h₀-3 t₀)/t₀ = (200-3 \times 10)/10 = 17 \quad \therefore \text{PASS}\]

Compression brace:

\[(b₁-3 t₁)/t₁ \leq 33\% \text{ (Class 1 compression)}\]

\[33\% = 33 \sqrt{(235/f_y)} = 33 \sqrt{(235/355)} = 26.85\]

\[(b₁-3 t₁)/t₁ = (120-3 \times 5)/5 = 21 \quad \therefore \text{PASS}\]

\[(h₁-3 t₁)/t₁ = (120-3 \times 5)/5 = 21 \quad \therefore \text{PASS}\]

Tension brace:

\[b₁/t₁ ; h₁/t₁ \leq 35\]

\[b₂/t₂ = 120/5 = 24 \quad \therefore \text{PASS}\]

\[h₂/t₂ = 120/5 = 24 \quad \therefore \text{PASS}\]

\[0.25 \leq b₁/b₀ \leq 1.0\]

\[b₁/b₀ = 120/200 = 0.6 \quad \therefore \text{PASS}\]

\[b₂/b₀ = 120/200 = 0.6 \quad \therefore \text{PASS}\]

\[0.5 \leq h₁/b₀ \leq 2.0\]

\[h₁/b₀ = 120/200 = 1.0 \quad \therefore \text{PASS}\]

\[h₂/b₂ = 120/120 = 1.0 \quad \therefore \text{PASS}\]

\[-0.55 h₀ \leq e \leq +0.25 h₀\]

\[-0.55 \times 200 \leq e \leq +0.25 \times 200\]

\[-110.0 \leq e \leq +50.0\]

\[e = -50.1 \text{ mm} \quad \therefore \text{PASS}\]

\[25\% \leq \lambda_{ov}\]

\[\lambda_{ov} = |g| \sin \theta_i / h_i \times 100\%\]

\[\lambda_{ov} = 70 \sin 45^\circ/120 \times 100\%\]

\[\lambda_{ov} = 41.2\% \quad \therefore \text{PASS}\]

\[b₁/b_j \geq 0.75\]

\[b₁/b_j = 120/120 = 1.0 \quad \therefore \text{PASS}\]
Bracing Effective width – Overlapping brace, i (2)

Note: Only the overlapping brace (i) need be checked. The resistance of the overlapped brace (j) is based on an efficiency ratio to that of the overlapping brace.

Overlapping brace, i (2):
For $25\% \leq \lambda_{ov} < 50\%$

\[
N_{i,Rd} = f_{yi} t_i \left( b_{eff,i} + b_{e,ov} + 2 h_{ov} \frac{\lambda_{ov}}{50} - 4 t_i \right) / \gamma_M
\]

where:

\[
b_{eff,i} = \frac{10 t_0}{b_0} \times \frac{f_{yi}}{f_{yi}} b_i \quad \text{but} \quad b_{eff,i} \leq b_i
\]

\[
b_{eff,i} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 5} \times 120 = 120 \text{ mm} \quad \text{but} \quad b_{eff,i} \leq 120 \text{ mm}
\]

\[
b_{eff,i} = 120 \text{ mm}
\]

\[
b_{e,ov} = \frac{10 t_j}{b_j} \times \frac{f_{yi}}{f_{yi}} b_i \quad \text{but} \quad b_{e,ov} \leq b_i
\]

\[
b_{e,ov} = \frac{10 \times 5}{120} \times \frac{355 \times 5}{355 \times 5} \times 120 \quad \text{but} \quad b_{e,ov} \leq 120
\]

\[
b_{e,ov} = 50 \text{ mm}
\]

\[
N_{i,Rd} = 355 \times 5 \left( 120 + 50 + 2 \times 120 \times 41.2 \frac{50}{5} - 4 \times 5 \right) / 1.0
\]

\[
N_{i,Rd} = N_{2,Rd} = 617 \text{ kN} \quad > \quad 600 \text{ kN} \quad \therefore \text{PASS}
\]

Bracing Effective width – Overlapped brace, j (1)

\[
N_{j,Rd} = N_{i,Rd} \left( A_j f_{yj} \right) \left( A_i f_{yi} \right)
\]

where:

\[
A_j = A_1 = 22.7 \text{ cm}^2 = 2270 \text{ mm}^2
\]

\[
A_i = A_2 = 22.7 \text{ cm}^2 = 2270 \text{ mm}^2
\]

\[
N_{j,Rd} = 617 \times \frac{2270 \times 355}{2270 \times 355}
\]

\[
N_{j,Rd} = N_{1,Rd} = 617 \text{ kN} \quad > \quad 600 \text{ kN} \quad \therefore \text{PASS}
\]

Reference
5.3.3
5.3.2.2
5.3.3
## 6 RHS Chord CHS Bracings Gap K-Joint

References are generally to Tata Steel publication 'Design of Welded Joints' (unless otherwise stated).

**ALL MATERIAL; CELSIUS 355 to EN 10210**

### Dimensions

- \( b_0 = 200 \text{ mm} \)
- \( h_0 = 200 \text{ mm} \)
- \( t_0 = 10.0 \text{ mm} \)
- \( d_1 = 114.3 \text{ mm} \)
- \( t_1 = 6.3 \text{ mm} \)
- \( d_2 = 114.3 \text{ mm} \)
- \( t_2 = 6.3 \text{ mm} \)

### Validity limits check

**Chord:**

\[
\frac{(b_0-3 \cdot t_0)}{t_0} \leq 38 \ (\text{Class 1 or 2 compression})
\]

\[
38c = 38 \sqrt[235]{f_y} = 38 \sqrt[235]{355} = 30.92
\]

\[
\frac{(b_0-3 \cdot t_0)}{t_0} = \frac{(200-3 \cdot 10)}{10} = 17 \quad \therefore \text{Pass}
\]

\[
\frac{(h_0-3 \cdot t_0)}{t_0} \leq 38 \ (\text{Class 1 or 2 compression})
\]

\[
\frac{(h_0-3 \cdot t_0)}{t_0} = \frac{(200-3 \cdot 10)}{10} = 17 \quad \therefore \text{Pass}
\]

\[
\frac{b_0}{t_0} \leq 35 \quad \frac{b_0}{t_0} = \frac{200}{10} = 20 \quad \therefore \text{Pass}
\]

\[
\frac{h_0}{t_0} \leq 35 \quad \frac{h_0}{t_0} = \frac{200}{10} = 20 \quad \therefore \text{Pass}
\]

**Compression brace:**

\[
\frac{d_1}{t_1} \leq 50c \ (\text{Class 1 or 2 compression})
\]

\[
50c = 50 \sqrt[235]{f_y} = 50 \sqrt[235]{355} = 40.7
\]

\[
\frac{d_1}{t_1} = \frac{114.3}{6.3} = 18.1 \leq 40.7 \quad \therefore \text{Pass}
\]

**Tension brace:**

\[
d_1/t_1 \leq 50 \quad \frac{d_1}{t_1} = \frac{114.3}{6.3} = 18.1 \quad \therefore \text{Pass}
\]

\[
0.4 \leq d_2/b_0 \leq 0.8 \quad \frac{d_1}{b_0} = \frac{114.3}{200} = 0.57 \quad \therefore \text{Pass}
\]

\[
\frac{d_2}{b_0} = \frac{114.3}{200} = 0.57 \quad \therefore \text{Pass}
\]

References:

- 5.3.1 Figure 37 (EN 1993-1-1) Table 5.2
- (EN 1993-1-1) Table 5.2
Welded Joints Examples  RHS Chord CHS Bracings Gap K-Joint

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.5 \leq \frac{h_0}{b_0} \leq 2.0$</td>
<td>$\frac{h_0}{b_0} = \frac{200}{200} = 1.0$</td>
<td>PASS</td>
</tr>
<tr>
<td>$-0.55 h_0 \leq e \leq +0.25 h_0$</td>
<td>$-0.55 \times 200 \leq e \leq +0.25 \times 200$</td>
<td>$e = +23.0 \text{ mm}$</td>
</tr>
<tr>
<td>$-110.0 \leq e \leq +50.0$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chord face failure (deformation) – brace 1

Note: Brace 1 usually designated compression and brace 2 tension.

Compression brace (1):

$$N_{IRd} = \frac{8.9 \cdot k_n \cdot f_{y0} \cdot b_0^2 \cdot \sqrt{\frac{d_1 + d_2}{4}}}{\sin \theta_i} \cdot \frac{1}{\gamma_{M5}}$$

RHS chord end stress factor, $k_n$

RHS chord most compressive applied factored stress, $\sigma_{0,Ed}$:

$$\sigma_{0,Ed} = \frac{N_{0,Ed}}{A_0} + \frac{M_{0,0,Ed}}{W_{el,ip,0}} + \frac{M_{0,0,Ed}}{W_{el,op,0}}$$

Note: Moment is additive to compressive stress which is positive for moments. For RHS chords use most compressive chord stress.

$$\sigma_{0,Ed} = \frac{1920 \times 1000}{74.9 \times 10^2} = 256.34 \text{ N/mm}^2$$

Chord factored stress ratio, $n$:

$$n = \frac{\sigma_{0,Ed}}{f_{y0}} = \frac{256.34}{355}$$

$n = 0.722$

Reference

5.3.3

5.3.2.1

5.3.2.1
Using formulae: Using graph:

<table>
<thead>
<tr>
<th>For ( n &gt; 0 ) (compression):</th>
<th>[ k_n = 1.3 - \frac{0.4 \ n}{\beta} \quad \text{but} \quad k_n \leq 1.0 ]</th>
<th>From graph, for ( \beta = 0.6 ): ( k_n = 0.819 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_n = 1.3 - \frac{0.4 \times 0.722}{0.6} ) but ( \leq 1.0 )</td>
<td>( \gamma = \frac{b_0}{2t_0} = \frac{200}{2 \times 10} = 10 )</td>
<td>( N_{t,1} = 661 \text{kN} \ldots 661 \times \frac{\pi}{4} = 519 \text{kN} )</td>
</tr>
</tbody>
</table>

Chord shear between bracings check – brace 1

\[ N_{t,1} = \frac{f_{y,0} A_{v,0}}{\sqrt{3} \sin \theta_i} / \gamma_{M5} \]

where:

- for CHS bracings:
  - \( \alpha = 0 \)
  - \[ A_{v,0} = (2h_0 + \alpha b_0) t_0 \]
  - \[ A_{v,0} = (2 \times 200 + 0 \times 200) t_0 = 4000 \text{mm}^2 \]

\[ N_{t,1} = \frac{355 \times 4000}{\sqrt{3} \sin 45^\circ} / 1.0 \]

\[ N_{t,1} = 1159 \text{kN} \ldots \frac{\pi}{4} = 910 \text{kN} \]
Bracing Effective width – brace 1

\[ N_{Rd} = f_{y1} t_1 (2 d_i - 4 t_i + d_i + b_{eff}) / \gamma_{M5} \]

where:

\[ b_{eff,i} = \frac{10 t_0}{b_0} \times \frac{f_{y0} t_0}{f_{y1} t_1} d_i \quad \text{but} \quad b_{eff,i} \leq d_i \]

\[ b_{eff,i} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 120 = 95.2 \text{ mm} \quad \text{but} \quad b_{eff,i} \leq 120 \text{ mm} \]

\[ b_{eff,i} = 95.2 \text{ mm} \]

\[ N_{Rd} = 355 \times 6.3 (2 \times 114.3 - 4 \times 6.3 + 114.3 + 95.2) / 1.0 \]

\[ N_{tRd} = 923 \text{ kN}, ..., \times \frac{\pi}{4} = 725 \text{ kN} \]

Chord punching shear – brace 1

(valid when \( \beta \leq 1 - 1/\gamma \))

\[ \beta \leq 1 - 1/\gamma \]

\[ 0.6 \leq 1 - 1/10 = 0.9 \text{ mm} \quad \therefore \text{check chord punching shear} \]

\[ N_{tRd} = \frac{f_{y0} t_0}{\sqrt{3} \sin \theta_i} \left( \frac{2 d_i}{\sin \theta_i} + d_i + b_{e,p,i} \right) / \gamma_{M5} \]

where:

\[ b_{e,p,i} = \frac{10 t_0}{b_0} d_i \quad \text{but} \quad b_{e,p,i} \leq d_i \]

\[ b_{e,p,i} = \frac{10 \times 10}{200} \times 114.3 = 57.2 \text{ mm} \quad \text{but} \quad b_{e,p,i} \leq 120 \text{ mm} \]

\[ b_{e,p,i} = 57.2 \text{ mm} \]

\[ N_{tRd} = \frac{355 \times 10}{\sqrt{3} \sin 45^\circ} \left( \frac{2 \times 114.3}{\sin 45^\circ} + 114.3 + 57.2 \right) / 1.0 \]

\[ N_{tRd} = 1434 \text{ kN}, ..., \times \frac{\pi}{4} = 1126 \text{ kN} \]

Summary - brace 1

Joint strength for brace 1 dictated by chord face deformation.

\[ \therefore \text{Brace 1 joint resistance,} \quad N_{tRd} = 519 \text{ kN} \quad > \quad 500 \text{ kN} \quad \therefore \text{PASS} \]
Brace 2

Repeat brace resistance formulae for brace 2.

Note: As both braces are of same geometry, brace 2 resistance will be the same:

Chord face deformation,
\[ N_{2,Rd} = 519 \text{kN} \]

Chord shear check,
\[ N_{2,Rd} = 910 \text{kN} \]

Bracing effective width,
\[ N_{2,Rd} = 725 \text{kN} \]

Punching shear,
\[ N_{2,Rd} = 1126 \text{kN} \]

\[ \therefore \text{Brace 2 joint resistance, } N_{2,Rd} = 519 \text{kN} > 500 \text{kN} \therefore \text{PASS} \]

Chord axial load resistance in gap

Check:
\[ N_{0,\text{gap,Rd}} \geq N_{0,\text{gap,Ed}} \]

\[ N_{0,\text{gap,Rd}} = \left[ (A_0 - A_v,0) f_y,0 + A_v,0 f_y,0 \sqrt{1 - \left( \frac{V_{0,Ed}}{V_{pl,0,Rd}} \right)^2} \right] / \gamma_M \]

where:

\[ A_0 = 74.9 \text{ cm}^2 = 7490 \text{ mm}^2 \]

\[ A_v,0 = 4000 \text{ mm}^2 \]

\[ V_{0,Ed} = \max( |N_{1,Ed}| \sin \theta_1, |N_{2,Ed}| \sin \theta_2) \]

\[ V_{0,Ed} = \max( |500| \sin 45^\circ, |-500| \sin 45^\circ) = \max (354, 354) \]

\[ V_{0,Ed} = 354 \text{kN} \]

\[ V_{pl,0,Rd} = \frac{A_v,0 (f_y,0 \sqrt{3})}{\gamma_M} \]  

\[ V_{pl,0,Rd} = 4000 \times \frac{(355 \sqrt{3})}{1.0} = 819.8 \text{kN} \]
\[ N_{0,\text{Ed}} = 1212 \]
\[ 354 \]
\[ N_{0,\text{gap,Ed}} = 1566 \]
\[ 354 \]
\[ N_{0,\text{Ed}} = 1920 \]

**Change of chord axial force in K-joint**

\[ N_{0,\text{gap,Ed}} = \max (N_{p,\text{Ed}} + N_{1,\text{Ed}} \cos \theta_1, N_{0,\text{Ed}} + N_{2,\text{Ed}} \cos \theta_2) \]

\[ N_{0,\text{gap,Ed}} = \max (1212 + 500 \cos 45^\circ, 1920 + (-500) \cos 45^\circ) \]

\[ N_{0,\text{gap,Ed}} = \max (1566, 1566) = 1566 \text{ kN} \]

\[ N_{0,\text{gap,Rd}} = \left[ (7490 - 4000) \times 355 + 4000 \times 355 \sqrt{1 - \left(\frac{354}{819.8}\right)^2} \right] / 1.0 \]

\[ N_{0,\text{gap,Rd}} = 2520 \text{ kN} > 1566 \text{ kN} \quad \therefore \text{PASS} \]
7 RHS Chord CHS Bracings Overlap K-Joint 82.7

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

NOTE: BRACE ‘j’ USUALLY DESIGNATED COMPRESSION AND BRACE ‘i’ TENSION.

Dimensions

\[
\begin{align*}
h_0 &= 100.0 \text{ mm} \\
b_0 &= 200.0 \text{ mm} \\
d_i &= 114.3 \text{ mm} \\
d_j &= 114.3 \text{ mm} \\
t_i &= 6.3 \text{ mm} \\
t_j &= 6.3 \text{ mm} \\
f_{ui} &= 470 \text{ N/mm}^2 \\
f_{uj} &= 470 \text{ N/mm}^2
\end{align*}
\]

\[(f_{ui} & f_{uj} \text{ from EN10210-1:2006 Table A.3)}\]

For Eccentricity,

\[
e = \left[ \frac{d_i}{2 \sin \theta_i} + \frac{d_j}{2 \sin \theta_j} + g \right] \times \left[ \frac{\sin \theta_i \times \sin \theta_j}{\sin (\theta_i + \theta_j)} \right] - \frac{h_0}{2}
\]

where \(g = \frac{\lambda_{ov} \times d_i}{100 \times \sin \theta_i} \)

\[
g = \frac{82.7 \times 114.3}{100 \times \sin (60^\circ)} \\
g = -109.1 \text{ mm}
\]

Reference

ALL MATERIAL;
CELSIUS 355 to EN 10210

\[N_{i,Ed} = -400kN\]

\[N_{j,Ed} = 500kN\]

\[N_{p,Ed} = 1000kN\]

\[N_{0,Ed} = 1636kN\]

6.5 Figure 57
Validity limits check

\[ b_0/t_0 \leq 38\varepsilon^2 \] (Class 1 or 2 for compression chord)

\[ 38\varepsilon^2 = 38 \times [(235/f_y0)]^2 = 38(235/355) = 25.15 \]

\[ b_0/t_0 = 200.0/10.0 = 20.0 < 25.15 \quad \therefore \text{PASS} \]

\[ d/t \leq 50\varepsilon^2 \] (Class 1 for compression brace)

\[ 50\varepsilon^2 = 50 \times [(235/f_y0)]^2 = 50(235/355) = 33.10 \]

\[ d/t = 114.3/6.3 = 18.14 < 33.10 \quad \therefore \text{PASS} \]

\[ 0.4 \leq d/b_0 \leq 0.8 \]

\[ d/b_0 = 114.3/200.0 = 0.57 \quad \therefore \text{PASS} \]

\[ 0.5 \leq h_0/b_0 \leq 2.0 \]

\[ h_0/b_0 = 100.0/200.0 = 0.50 \quad \therefore \text{PASS} \]

\[ -0.55 \leq e \leq +0.25 \]

\[ e = -19.5 \text{ mm} \quad \therefore \text{PASS} \]

\[ \lambda_{ov} \geq 25\% \]

\[ \lambda_{ov} = |g| \times \sin \theta_i/d_i \times 100\% \quad \therefore \text{PASS} \]

\[ \lambda_{ov} = 109.1 \sin 60^\circ/114.3 \times 100\% \]

\[ \lambda_{ov} = 82.7\% \quad \therefore \text{PASS} \]

\[ 30^\circ \leq \theta_i \leq 90^\circ \]

\[ \theta_i = 30^\circ \quad \therefore \text{PASS} \]

\[ \theta_i = 60^\circ \quad \therefore \text{PASS} \]

\[ d/d_j \geq 0.75 \]

\[ d/d_j = 114.3/114.3 = 1.0 \quad \therefore \text{PASS} \]

Brace Effective Width:

Overlapping brace (i):

\[ N_{L,rd} = f_y l_1 (d_i + d_{e,ov} + 2d_i - 4t_j) / \gamma_{M5} \]

where:

\[ d_{e,ov} = \frac{10}{d_j/l_j} \times \frac{f_y l_1}{f_y l_1} \times d_j \]

but \[ d_{e,ov} \leq d_i \]

Reference

(EN1993-1-1) (Table 5.2)

5.3 Figure 37

5.3.3

5.3.2.2
Welded Joints Examples      RHS Chord CHS Bracings Overlap K-Joint 82.7

\[ d_{e,ov} = \frac{10}{114.3/6.3} \times \frac{355 \times 6.3 \times 114.3}{355 \times 6.3} \]  but  \( d_{e,ov} \leq 114.3 \)

\[ d_{e,ov} = 63 \ but \leq 114.3 \therefore d_{e,ov} = 63 \text{mm} \]

\[ N_{i,Rd} = 355 \times 6.3 \times (114.3 + 63 + 228.6 - 25.2) / 1.0 \]

\[ N_{i,Rd} = 851 \text{kN} \rightarrow 851 \times \pi / 4 = 668 \text{kN} \ > \ 400 \text{kN} \therefore \text{PASS} \]

**Brace Effective Width:**

Overlapped Brace (j):

\[ N_{j,Rd} = N_{i,Rd} \times \left( \frac{A_j \times f_{j,i}}{A_i \times f_{i,i}} \right) \]

where:

\[ A_j = 21.4 \text{cm}^2 = 2140 \text{mm}^2 \]
\[ A_i = 21.4 \text{cm}^2 = 2140 \text{mm}^2 \]

\[ N_{j,Rd} = 668 \times \left( \frac{2140 \times 355}{2140 \times 355} \right) \]

\[ N_{j,Rd} = 668 \text{kN} \ > \ 500 \text{kN} \therefore \text{PASS} \]

**Overlapping Bracings Shear Check For CHS Bracings:**

Vertical component of \( N_{i,Ed} \) & \( N_{j,Ed} \):

\[ \therefore N_{i,v,Ed} = N_{i,Ed} \times \sin(\theta_i) \text{ & } N_{j,v,Ed} = N_{j,Ed} \times \sin(\theta_j) \]

\[ N_{i,v,Ed} = 400 \times \sin(60^\circ) = 346.4 \text{kN} \]
\[ N_{j,v,Ed} = 500 \times \sin(30^\circ) = 250 \text{kN} \]

% vert. component diff. = \[\frac{346.4 - 250}{346.4} \times 100 = 27.8\% \]

\[ \Rightarrow \text{As difference between brace vertical component > 20\% hidden toe needs welding.} \]

Reference

5.3.3
Shear Check valid when $80\% < \lambda_{ov} < 100\%$ and overlapped brace hidden toe welded;

\[
N_{i,Ed} \cos \theta_i + N_{j,Ed} \cos \theta_j \leq \ldots \ldots
\]

\[
= \frac{\pi}{4} \times \left[ \frac{f_{u,i}}{\sqrt{3}} \times \left( \frac{100 - \lambda_{ov}}{100} \right) \times 2d_i + d_{\text{eff},i} \right] \times t_i - \frac{f_{u,j}}{\sqrt{3}} \times \left( 2d_j + c_s \times d_{\text{eff},j} \right) \times t_j \times \frac{1}{\gamma_M5}
\]

where:

\[
d_{\text{eff},i} = \frac{10 t_i}{b_0} \times \frac{f_{y,0} t_0}{f_{y,j} t_j} \times d_i \quad \text{but} \leq d_i
\]

\[
d_{\text{eff},j} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 114.3 \quad \text{but} \leq 114.3
\]

\[
d_{\text{eff},j} = 91.4 \leq 114.3 \therefore d_{\text{eff},j} = 91.4 \text{mm}
\]

where:

\[
d_{\text{eff},j} = \frac{10 t_j}{b_0} \times \frac{f_{y,0} t_0}{f_{y,j} t_j} \times d_j \quad \text{but} \leq d_j
\]

\[
d_{\text{eff},j} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 114.3 \quad \text{but} \leq 114.3
\]

\[
d_{\text{eff},j} = 91.4 \leq 114.3 \therefore d_{\text{eff},j} = 91.4 \text{mm}
\]

where:

\[c_s = 2\text{ (hidden toe welded)}\]

\[
\therefore N_i \cos \theta_i + N_j \cos \theta_j \leq \ldots \ldots
\]

\[
= \frac{\pi}{4} \times \left[ \frac{470}{\sqrt{3}} \times \left( \frac{100 - 82.7}{100} \right) \times (2 \times 114.3) + 91.4 \right] \times 6.3 + \frac{470}{\sqrt{3}} \times \left( (2 \times 114.3) \times 2 \times 91.4 \right) \times 6.3 \times \frac{1}{1} = 1307 \text{ kN}
\]

\[
\therefore 400 \times \cos (60^\circ) + 500 \times \cos (30^\circ) = 633 \text{ kN} \leq 1307 \text{ kN} \therefore \text{PASS}
\]
8 RHS Chord CHS Bracings Overlap K-Joint 102.7

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

ALL MATERIAL; CELSIUS 355 to EN 10210

N_{i,Ed} = 500kN

N_{p,Ed} = 1000kN

N_{0,Ed} = 1636kN

NOTE: BRACE ‘j’ USUALLY DESIGNATED COMPRESSION AND BRACE ‘i’ TENSION.

Dimensions

\[ h_0 = 100.0 \text{ mm} \quad b_0 = 200.0 \text{ mm} \quad d_i = 114.3 \text{ mm} \quad d_{j} = 114.3 \text{ mm} \]
\[ t_0 = 10.0 \text{ mm} \quad t_i = 6.3 \text{ mm} \quad t_{j} = 6.3 \text{ mm} \]
\[ f_{u,i} = 470 \text{ N/mm}^2 \quad f_{u,j} = 470 \text{ N/mm}^2 \]

\( f_{u,i} \& f_{u,j} \) from EN10210-1:2006 Table A.3

For Eccentricity;

\[ e = \left[ d_{i} \cdot \frac{d_{j}}{2 \times \sin \theta_{i}} + g \right] \times \left[ \frac{\sin \theta_{i} \times \sin \theta_{j}}{\sin \left( \theta_{i} + \theta_{j} \right)} \right] \times \frac{h_0}{2} \]

where \( g = \frac{\lambda_{ov} \times d_{i}}{100 \times \sin \theta_{i}} \)

\[ 102.7 \times 114.3 \]
\[ 100 \times \sin (60^\circ) \]
\[ g = -135.5 \text{ mm} \]

6.5 Figure 57
\[
e = \frac{114.3}{2 \times \sin(60^\circ)} + \frac{114.3}{2 \times \sin(30^\circ)} + \left( -135.5 \right) \times \frac{\sin(60^\circ) \times \sin(30^\circ)}{\sin(60^\circ) + 30^\circ} = \frac{100}{2}
\]

\[
e = -30.6 \text{ mm}
\]

Validity limits check

- \( b_0/t_0 \leq 38c^2 \) (Class 1 or 2 for compression chord)
  
  \[
  38c^2 = 38 \sqrt{(235/f_y)^2} = 38(235/355) = 25.15
  \]
  
  \[
b_0/t_0 = 200.0/10.0 = 20.0 < 25.15
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( d/t_i \leq 50c^2 \) (Class 1 for compression brace)
  
  \[
  50c^2 = 50 \sqrt{(235/f_y)^2} = 50(235/355) = 33.10
  \]
  
  \[
d/t_i = 114.3/6.3 = 18.14 < 33.10
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( d/t_i \leq 50 \) (Tension Brace)
  
  \[
d/t_i = 114.3/6.3 = 18.14 \leq 50
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( 0.4 \leq d/b_0 \leq 0.8 \)
  
  \[
d/b_0 = 114.3/200.0 = 0.57
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( 0.5 \leq b_0/b_0 \leq 2.0 \)
  
  \[
b_0/b_0 = 100.0/200.0 = 0.50
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \(-0.55 \leq e \leq +0.25 \)
  
  \[
e = -30.6 \text{ mm}
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( \lambda_{ov} \geq 25\% \)
  
  \[
  \lambda_{ov} = |g| \sin \theta_i / d_i \times 100\%
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( 30^\circ \leq \theta_i \leq 90^\circ \)
  
  \[
  \theta_i = 30^\circ
  \]
  
  \[
  \therefore \text{PASS}
  \]

- \( d/d_j \geq 0.75 \)
  
  \[
  d/d_j = 114.3/114.3 = 1.0
  \]
  
  \[
  \therefore \text{PASS}
  \]

Brace Effective Width:

Overlapping brace (i):

\[
N_{i,Rd} = f_y t_i (d_i + d_{e,ov} + 2d_i - 4t_i) / \gamma_M \text{ where } \lambda_{ov} \geq 80\%;
\]

where:

\[
d_{e,ov} = \frac{10}{d_i / t_i} \times \frac{f_y \times t_i \times d_i}{f_y \times t_i} \text{ but } d_{e,ov} \leq d_i
\]

\[
d_{e,ov} = \frac{10}{114.3 / 6.3} \times \frac{355 \times 6.3 \times 114.3}{355 \times 6.3} \text{ but } d_{e,ov} \leq 114.3
\]

\[
d_{e,ov} = 63 \text{ but } \leq 114.3 \therefore d_{e,ov} = 63 \text{ mm}
\]
Welded Joints Examples  RHS Chord CHS Bracings Overlap K-Joint 102.7

\[
N_{i,Rd} = 355 \times 6.3 \times (114.3 + 63 + 228.6 - 25.2) / 1.0
\]

\[
N_{i,Rd} = 851 \text{kN} \quad \rightarrow 851 \times \pi/4 = 668 \text{kN} > 400 \text{kN} \quad \therefore \text{PASS}
\]

**Brace Effective Width:**

Overlapped Brace (j):  
\[
N_{j,Rd} = N_{i,Rd} \times \left(\frac{A_j \times f_{y,j}}{A_i \times f_{y,i}}\right)
\]

where:

\[
A_j = 21.4 \text{ cm}^2 = 2140 \text{ mm}^2
\]

\[
A_i = 21.4 \text{ cm}^2 = 2140 \text{ mm}^2
\]

\[
N_{j,Rd} = 668 \times \frac{(2140 \times 355)}{(2140 \times 355)}
\]

\[
N_{j,Rd} = 668 \text{kN} > 500 \text{kN} \quad \therefore \text{PASS}
\]

**Overlapping Bracings Shear Check for CHS Bracings:** where \(\lambda_{ov} > 100\%\);

\[
N_{i,Ed} \cos \theta_i + N_{j,Ed} \cos \theta_j \leq \ldots.\ldots.
\]

\[
\ldots \frac{\pi}{4} \times \frac{f_{u,i}}{\sqrt{3}} \times \left(\frac{3 \times d_j + d_{eff,j}}{f_{y,j} \times t_j \times d_j}ight) \times \frac{1}{\gamma_{M5}}
\]

where:

\[
d_{eff,j} = \frac{10t_0}{b_0} \times \frac{f_{y,0} \times t_0}{f_{y,j} \times t_j} \times d_j \quad \text{but} \leq d_j
\]

\[
d_{eff,j} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 114.3 \quad \text{but} \leq 114.3
\]

\[
d_{eff,j} = 91.4 \leq 114.3 \quad \therefore d_{eff,j} = 91.4 \text{ mm}
\]

\[
\therefore N_{i,Ed} \cos \theta_i + N_{j,Ed} \cos \theta_j \leq \ldots.\ldots.
\]

\[
\ldots \frac{\pi}{4} \times \frac{470}{\sqrt{3}} \times \left(\frac{3 \times 114.3 + 91.4}{\sin(30)}\right) \times \frac{6.3}{\gamma_{M5}} \times \frac{1}{\gamma_{M5}}
\]

\[
N_i \cos \theta_i + N_j \cos \theta_j \leq 673 \text{kN}
\]

\[
400 \times \cos(60^\circ) + 500 \times \cos(30^\circ) = 633 \text{kN} \leq 673 \text{kN} \quad \therefore \text{PASS}
\]
9 RHS Chord RHS Bracings Overlap KT-Joint

References are generally to Tata Steel publication 'Design of Welded Joints' (unless otherwise stated).

**NOTE:** Brace 'j' designated overlapped, Brace 'i' overlapping

Brace ‘1’ SHS is 90 x 90 x 5.0, Brace ‘2’ and ‘3’ is SHS 100 x 100 x 6.3

**Dimensions**

\[
\begin{align*}
\text{h}_0 &= 200.0 \text{ mm} \\
\text{h}_1 &= 90.0 \text{ mm} \\
\text{h}_2 &= 100.0 \text{ mm} \\
\text{h}_3 &= 100.0 \text{ mm} \\
\text{b}_0 &= 200.0 \text{ mm} \\
\text{b}_1 &= 90.0 \text{ mm} \\
\text{b}_2 &= 100.0 \text{ mm} \\
\text{b}_3 &= 100.0 \text{ mm} \\
\text{t}_0 &= 10.0 \text{ mm} \\
\text{t}_1 &= 5.0 \text{ mm} \\
\text{t}_2 &= 6.3 \text{ mm} \\
\text{t}_3 &= 6.3 \text{ mm} \\
\gamma_\text{MS} &= 1.0 \\
A_1 &= 23.2 \text{ cm}^2 \\
A_2 &= 16.7 \text{ cm}^2 \\
A_3 &= 23.2 \text{ cm}^2
\end{align*}
\]

This example is to show how to calculate a KT-Joint with SHS chord and braces. The method of checking a KT-Joint depends on the direction of the brace forces, gap or overlap and chord section profile. This example is for;

- One diagonal brace opposite direction to the other two bracings
- Both diagonal bracings overlapping
- Rectangular chord and bracings

With this configuration, the joint can be checked like two separate K-joints. Please be aware that different brace angle and overlap values may change how the joint is calculated and you should refer to the Tata Design of Welded Joints literature before tackling any joint to make sure you are using the correct method and formulae. The force combination of the braces can be seen at 5.6.2 Figure 51(c) (as a (from left to right) compression-compression-tension) of our Design Of Welded Joints literature.

Reference

45° 50°

\[e_1 = -50.0\]

\[e_2 = -40.4\]

\[N_{1,Ed} = 492 \text{kN}\]

\[N_{2,Ed} = -650 \text{kN}\]

\[N_{3,Ed} = 150 \text{kN}\]

SHS 200 x 200 x 10.0
GEOMETRIC CALCULATIONS

For Eccentricity; Brace 1 in relation to Brace 3;

\[ e_1 = \left( \frac{b_1}{2 \sin \theta_1} + \frac{b_3}{2 \sin \theta_3} + g \right) \times \left( \frac{\sin \theta_1 \times \sin \theta_3}{\sin (\theta_1 + \theta_3)} \right) - \frac{h_0}{2} \]

Brace 1 to 3 overlap, \( \lambda_{ov} = 50\% \);

where;  
\[ g = \frac{\lambda_{ov} \times b_1}{100 \times \sin \theta_1} \]
\[ g_1 = \frac{50.0 \times 90.0}{100 \times \sin(45^\circ)} = -1 \]
\[ g_1 = -63.6 \text{mm} \] (gap is negative as it’s an overlap)

\[ e_1 = \left( \frac{90.0}{2 \sin(45^\circ)} + \frac{100.0}{2 \sin(90^\circ)} + (-63.6) \right) \times \left( \frac{\sin(45^\circ) \times \sin(90^\circ)}{\sin(45^\circ + 90^\circ)} \right) - \frac{200.0}{2} \]

\[ = -50.0 \text{ mm} \]

For Eccentricity, Brace 2 in relation to Brace 3;

\[ e_2 = \left( \frac{b_2}{2 \sin \theta_2} + \frac{b_3}{2 \sin \theta_3} + g \right) \times \left( \frac{\sin \theta_2 \times \sin \theta_3}{\sin (\theta_2 + \theta_3)} \right) - \frac{h_0}{2} \]

Brace 2 to 3 overlap, \( \lambda_{ov} = 50\% \);

where;  
\[ g_2 = \frac{\lambda_{ov} \times b_2}{100 \times \sin \theta_2} \]
\[ g_2 = \frac{50.0 \times 100}{100 \times \sin(50^\circ)} \]
\[ g_2 = -65.3 \text{ mm} \] (gap is negative as it’s an overlap)

\[ e_2 = \left( \frac{100.0}{2 \sin(50^\circ)} + \frac{100.0}{2 \sin(90^\circ)} + (-65.3) \right) \times \left( \frac{\sin(50^\circ) \times \sin(90^\circ)}{\sin(50^\circ + 90^\circ)} \right) - \frac{200.0}{2} \]

\[ = -40.4 \text{ mm} \]

Validity limits check for both K-Joints

\( \frac{(b_0-3 \ t_0)/t_0}{(h_0-3 \ t_0)/t_0} \leq 38\% \) (Class 1 or 2 for chord)
\[ 38\% = 38 \left( \sqrt{\frac{235/f_y}{100}} \right) = 38 \sqrt{\frac{235}{355}} = 30.92 \]
\[ \frac{(b_0-3 \ t_0)/t_0}{(h_0-3 \ t_0)/t_0} = \frac{(200-3 \times 10)/10 = 17}{10} = \text{PASS} \]
\[ \frac{(h_0-3 \ t_0)/t_0}{(h_0-3 \ t_0)/t_0} = \frac{(200-3 \times 10)/10 = 17}{10} = \text{PASS} \]

\( \frac{(b_1-3 \ t_1)/t_1}{(h_1-3 \ t_1)/t_1} \leq 33\% \) (Class 1 for compression braces)

Reference

6.5 Figure 57

Validity limits check for both K-Joints

38\% = 38 \left( \sqrt{\frac{235/f_y}{100}} \right) = 38 \sqrt{\frac{235}{355}} = 30.92
\[ \frac{(b_0-3 \ t_0)/t_0}{(h_0-3 \ t_0)/t_0} = \frac{(200-3 \times 10)/10 = 17}{10} = \text{PASS} \]
\[ \frac{(h_0-3 \ t_0)/t_0}{(h_0-3 \ t_0)/t_0} = \frac{(200-3 \times 10)/10 = 17}{10} = \text{PASS} \]

5.3 Figure 37

\( \frac{(b_1-3 \ t_1)/t_1}{(h_1-3 \ t_1)/t_1} \leq 33\% \) (Class 1 for compression braces)
\[ \varepsilon = 33 \sqrt{\frac{235}{f_{y0}}} = 33 \sqrt{\frac{235}{205}} = 26.85 \]

\[ \begin{align*}
\frac{b_1}{t_1} & = \frac{90-3 \times 5}{5} = 15 & \text{PASS} \\
\frac{h_1}{t_1} & = \frac{90-3 \times 5}{5} = 15 & \text{PASS} \\
\frac{b_2-3}{t_2} & = \frac{100-3 \times 6.3}{6.3} = 12.9 & \text{PASS} \\
\frac{h_2-3}{t_2} & = \frac{100-3 \times 6.3}{6.3} = 12.9 & \text{PASS}
\end{align*} \]

\[ \frac{b_1}{t_1}, \frac{h_1}{t_1} \leq 35 \quad \text{Tension Brace} \]

\[ \begin{align*}
\frac{b_2}{t_2} & = 100.0/6.3 = 15.9 & \text{PASS} \\
\frac{h_2}{t_2} & = 100.0/6.3 = 15.9 & \text{PASS}
\end{align*} \]

\[ \begin{align*}
0.25 \leq \frac{h_0}{b_0} & \leq 1.0 & b_1/b_0 = 90.0/200.0 = 0.45 & \text{PASS} \\
0.5 \leq \frac{h_0}{b_0} & \leq 2.0 & h_0/b_0 = 200.0/200.0 = 1.0 & \text{PASS}
\end{align*} \]

\[ \begin{align*}
\lambda_{ov} & \geq 25\% & \lambda_{ov,1} = \left| \frac{g}{h_1} \right| \sin \frac{\theta_1}{h_1} \times 100\% \\
\lambda_{ov,1} & = 63.6 \times \sin 45^\circ/90 \times 100\% & \text{PASS} \\
\lambda_{ov,2} & = 65.3 \times \sin 50^\circ/100 \times 100\% & \text{PASS}
\end{align*} \]

\[ \begin{align*}
30^\circ \leq \theta_1 \leq 90^\circ & \quad \theta_1 = 45^\circ & \text{PASS} \\
\theta_2 & = 50^\circ & \text{PASS} \quad \theta_3 = 90^\circ & \text{PASS}
\end{align*} \]

\[ \begin{align*}
b_1/b_3 & \geq 0.75 & b_1/b_3 = 90.0/100.0 = 0.9 & \text{PASS} \\
b_2/b_3 & = 100.0/100.0 = 1.0 & \text{PASS}
\end{align*} \]

**Brace 1 & 3 as overlap K-Joint**

**Brace Effective Width Failure for 50% \( \leq \lambda_{ov} \leq 80\%;**

\[ N_{LRd} = f_{y1} t_1 \left( b_{eff,1} + b_{e,ov} + 2 h_1 - 4 t_1 \right) / \gamma_{M5} \]

where;

\[ b_{e,ov,1} = \frac{10 t_3}{b_3} \times \frac{f_{y3} t_3}{f_{y1} t_1} \times b_1 \text{ but } b_{e,ov,1} \leq b_1 \]

- Reference: 6.5 Figure 57
- 5.3.3 (K- & N-Overlap Sect)
- 5.3.2.2
Welded Joints Examples  
RHS Chord RHS Bracings Overlap KT-Joint

\[ b_{e,ov,1} = \frac{10 \times 6.3}{100.0} \times \frac{355 \times 6.3}{355 \times 5.0} \times 90.0 \text{ but } b_{e,ov,1} \leq 90.0 \]

\[ b_{e,ov,1} = 71.4 \text{ but } 90.0 \therefore b_{e,ov,1} = 71.4 \text{ mm} \]

where;

\[ b_{eff,1} = \frac{10 \times t_0}{b_0} \times \frac{f_y0 \times t_0}{f_y1 \times t_1} \times b_1 \text{ but } b_{eff,1} \leq b_1 \]

\[ b_{eff,1} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 5.0} \times 90 \text{ but } b_{eff,1} \leq 90 \]

\[ b_{eff,1} = 90 \text{ mm but } b_{eff,1} \leq 90 \therefore b_{eff,1} = 90 \text{ mm} \]

\[ N_{1,Rd} = 355 \times 5.0 \times (90.0 + 71.4 + 2 \times 90 - 4 \times 5.0)/1.0 \]

\[ N_{1,Rd} = 570 \times 90 > 492 \text{ kN} \therefore \text{PASS} \]

For overlapped Brace (3):

\[ \frac{N_p}{N_{1,Rd}} = \frac{A_j \times f_y}{A_1 \times f_y} \]

\[ A_3 = 23.2 \text{ cm}^2 = 2320 \text{ mm}^2 \]

\[ A_1 = 16.7 \text{ cm}^2 = 1670 \text{ mm}^2 \]

\[ N_{3,Rd} = 570 \times \frac{(2320 \times 355)}{(1670 \times 355)} \]

\[ N_{3,Rd} = 792\text{kN} > 150\text{kN} \therefore \text{PASS} \]

**Brace 2 & 3 as overlap K-Joint**

Brace Effective Width Failure for 50% \( \leq \lambda_{ov} \leq 80\% \);

\[ b_{e,ov,2} = \frac{10t_3}{b_3} \times \frac{f_y3 \times t_3}{f_y2 \times t_2} \times b_2 \text{ but } b_{e,ov,2} \leq b_2 \]

Reference

5.3.2.2

5.3.2.2

5.3.3 (K- & N-Overlap Sect)

(Tata Technical Guide TST02)
Welded Joints Examples      RHS Chord RHS Bracings Overlap KT-Joint

\[ b_{e,ov,2} = \frac{10 \times 6.3}{100.0} \times \frac{355 \times 6.3}{355 \times 6.3} \times 100.0 \text{ but } b_{e,ov,2} \leq 100.0 \]

\[ b_{e,ov,2} = 63 \text{ but } \leq 100.0 \therefore b_{e,ov,2} = 63 \text{ mm} \]

where;

\[ b_{eff,2} = \frac{10 \times t_0}{b_0} \times \frac{f_y0 \times t_0}{f_y2 \times t_2} \times b_2 \text{ but } b_{eff,2} \leq b_2 \]

\[ b_{eff,2} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 100 \text{ but } b_{eff,2} \leq 100 \]

\[ b_{eff,2} = 79.4 \text{ mm but } b_{eff,2} \leq 100 \therefore b_{eff,2} = 79.4 \text{ mm} \]

\[ N_{2,Rd} = 355 \times 6.3 \times (79.4 + 63 + 2 \times 100 - 4 \times 6.3) / 1.0 \]

\[ N_{2,Rd} = 709 \text{ kN} > 650 \text{ kN} \therefore \text{PASS} \]

For Overlapped Brace (3):

where:

\[ N_{3,Rd} = N_{3,Rd} \times \frac{(A_1 \times f_y)}{(A_1 \times f_y)} \]

\[ A_3 = 23.2 \text{ cm}^2 = 2320 \text{ mm}^2 \]

\[ A_2 = 23.2 \text{ cm}^2 = 2320 \text{ mm}^2 \]

\[ N_{3,Rd} = 709 \times \frac{(2320 \times 355)}{(2320 \times 355)} \]

\[ N_{3,Rd} = 709 \text{ kN} > 150 \text{ kN} \therefore \text{PASS} \]

SUMMARY

Here, the validity limits are combined to include all three braces and then for the calculations, due to the nature of the joint, it can be treated as two overlap K-Joints. This means Brace 3 (the vertical overlapped brace) is checked twice in relation to Brace 1 and Brace 2 and must pass on both of these checks. It is important to check the joint configuration and refer to our Design of Welded Joints literature to make sure the correct method and formulae is used.

Reference

5.3.2.2
5.3.3 (K- & N-Overlap Sect)
(Tata Technical Guide TST02)
10 CHS Chord CHS Bracings Gap KT-Joint

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

ALL MATERIAL;
CELSIUS 355 to EN 10210

\[
N_{3,Ed} = 113\text{kN}
\]

\[
N_{1,Ed} = 369\text{kN}
\]

\[
N_{2,Ed} = -488\text{kN}
\]

\[
e_1 = 46.8\text{mm}
\]

\[
e_2 = 21.2\text{mm}
\]

NOTE: Brace ‘1’ CHS is 88.9 x 5.0, Brace ‘2’ and ‘3’ is CHS 101.6 x 6.3

Dimensions

\[
d_0 = 193.7\text{mm} \quad d_1 = 88.9\text{mm} \quad d_2 = 101.6\text{mm} \quad d_3 = 101.6\text{mm}
\]

\[
t_0 = 10.0\text{mm} \quad t_1 = 5.0\text{mm} \quad t_2 = 6.3\text{mm} \quad t_3 = 6.3\text{mm}
\]

\[
\gamma_{M5} = 1.0 \quad A_1 = 13.2\text{cm}^2 \quad A_2 = 18.9\text{cm}^2 \quad A_3 = 18.9\text{cm}^2
\]

This example is to show how to calculate a gap KT-Joint with CHS chord and braces. The recommendations for an all-CHS gap KT-Joint are in EN1993-1-8 Table 7.6. The method of checking a KT-Joint depends on the direction of the brace forces, gap or overlap and chord section profile. This example is for:

- One diagonal brace opposite direction to the other two bracings
- Both diagonal bracings have a gap to the central brace
- Circular chord and bracings

With this configuration, the joint capacity is based on the most highly loaded compression brace for chord face failure and punching shear failure for each brace. Please be aware that different brace angle and gap values may change how the joint is calculated and you should refer to the Tata Design of Welded Joints literature before tackling any joint to make sure you are using the correct method and formulae. The force combination of the braces can be seen at 5.6.2 Figure 51(c) (as a (from left to right) compression-compression-tension) of our Design Of Welded Joints literature.
### Geometric Calculations

For Eccentricity; Brace 1 in relation to Brace 3;

\[
e_1 = \left[\frac{d_1}{2 \times \sin \theta_1} + \frac{d_3}{2 \times \sin \theta_3} + g\right] \times \left[\frac{\sin \theta_1 \times \sin \theta_3}{\sin (\theta_1 + \theta_3)}\right] \frac{d_0}{2}
\]

Brace 1 to 3 gap, \(g_1 = 30\)mm;

\[
e_1 = \left[\frac{88.9}{2 \times \sin (45^\circ)} + \frac{101.6}{2 \times \sin (90^\circ)} + 30.0\right] \times \left[\frac{\sin (45^\circ) \times \sin (90^\circ)}{\sin (45^\circ + 90^\circ)}\right] \frac{193.7}{2}
\]

\[= 46.8\text{ mm}\]

For Eccentricity, Brace 2 in relation to Brace 3;

\[
e_2 = \left[\frac{d_2}{2 \times \sin \theta_2} + \frac{d_3}{2 \times \sin \theta_3} + g\right] \times \left[\frac{\sin \theta_2 \times \sin \theta_3}{\sin (\theta_2 + \theta_3)}\right] \frac{d_0}{2}
\]

Brace 2 to 3 gap, \(g_2 = 52\)mm;

\[
e_2 = \left[\frac{101.6}{2 \times \sin (30^\circ)} + \frac{101.6}{2 \times \sin (90^\circ)} + 52.0\right] \times \left[\frac{\sin (30^\circ) \times \sin (90^\circ)}{\sin (30^\circ + 90^\circ)}\right] \frac{193.7}{2}
\]

\[= 21.2\text{ mm}\]

### Validity limits check for both K-Joints

<table>
<thead>
<tr>
<th>Condition</th>
<th>Expression</th>
<th>Result</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10 \leq d_0/t_0 \leq 50 )</td>
<td>(d_0/t_0 = 193.7/10.0 = 19.37)</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_0/t_0 \leq 70\varepsilon^2) (Class 1 or 2 for chord)</td>
<td>(70\varepsilon^2 = 70 \sqrt{(235/f_{y0})^2} = 70 \sqrt{(235/355)^2} = 46.34)</td>
<td>(d_0/t_0 = 19.37 \leq 46.34)</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_1/t_1 \leq 50)</td>
<td>(d_1/t_1 = 88.9/5.0 = 17.78)</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_2/t_2 = 101.6/6.3 = 16.13)</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_2/t_3 = 101.6/6.3 = 16.13)</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_3/t_3 \leq 70\varepsilon^2) (Class 1 or 2 for compression bracings)</td>
<td>(70\varepsilon^2 = 70 \sqrt{(235/f_{y0})^2} = 70 \sqrt{(235/355)^2} = 46.34)</td>
<td>(d_3/t_3 = 16.13)</td>
<td>PASS</td>
</tr>
<tr>
<td>(0.2 \leq d/d_0 \leq 1.0)</td>
<td>(d_1/d_0 = 88.9/193.7 = 0.46)</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_2/d_0 = 101.6/193.7 = 0.52)</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(d_2/d_0 = 101.6/193.7 = 0.52)</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(-0.55 &lt; d_0 \leq +0.25 d_0)</td>
<td>(-0.55 \times 193.7 \leq e \leq +0.25 \times 193.7)</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(-106.5 \leq e \leq +48.4)</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(e_1 = 46.8\text{ mm})</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
<tr>
<td>(e_2 = 21.2\text{ mm})</td>
<td>()</td>
<td>()</td>
<td>PASS</td>
</tr>
</tbody>
</table>
g ≥ t₁ + t₂ but ≤ 12t₀

for g₁,₂ ≥ t₁ + t₃ = 5.0 + 6.3 = 11.3 mm but ≤ 12t₀

12t₀ = 12 x 10.0 = 120 mm

g₁,₂ = 30 mm

g₂,₃ = 52 mm

∴ PASS

30° ≤ θ₁ ≤ 90°

θ₁ = 45°

θ₂ = 30°

θ₃ = 90°

∴ PASS

Chord Face Failure (deformation):

Based on compression brace with most compressive load;

Compression brace (1):

\[
N_{1,Rd} = \frac{k_g \times k_p \times f_{y0} \times t_0^2}{\sin \theta_1} \times \left( 1.8 + 10.2 \times \frac{d_1 + d_2 + d_3}{3 \times d_0} \right) / \gamma_{M5}
\]

Gap/lap factor, k₉:

Using Formulae:

\[
k_9 = \gamma^{0.2} \left[ 1 + \frac{0.024 \gamma^{1.2}}{1 + \exp(0.5g / t_0 - 1.33)} \right]
\]

where;

\[
\gamma = \frac{d_0}{2t_0} = \frac{193.7}{2 \times 10.0} = 9.69
\]

Note: (g) is positive for gap and negative for overlap.
Use the largest gap between two bracings having significant forces acting in opposite direction.

Using Formulae:

\[
k_9 = 9.69^{0.2} \left[ 1 + \frac{0.024 \times 9.69^{1.2}}{1 + \exp(0.5 \times 52 / 10.0 - 1.33)} \right]
\]

k₉ = 1.70

Using Graph:

From graph;

\[
g/t_0 = 52/10.0 = 5.2
\]

k₉ = 1.70

For graph

5.1.2.2 Fig. 29

Reference

5.1.3 (K- & N-Joints)

5.1.2.2 (k₉)

6.3 (γ)
CHS chord end stress factor, $k_p$

CHS chord least compressive applied factored stress, $\sigma_{p,Ed}$:

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

Note: Moment is additive to compressive stress which is positive for moments.
For CHS chords use least compressive chord stress.

$$\sigma_{p,Ed} = \frac{512 \times 1000}{57.7 \times 10^2} = 88.7 \text{ N/mm}^2$$

Chord factored stress ratio, $n_p$:

$$n_p = \left(\frac{\sigma_{p,Ed}}{f_y}\right) = \left(\frac{88.7}{355}\right) = 0.25$$

Using formulae:

For $n_p > 0$ (compression):

$$k_p = 1 - 0.3 n_p (1 + n_p) \quad \text{but} \quad \leq 1.0$$

$$k_p = 1 - 0.3 \times 0.25 (1 + 0.25) \quad \text{but} \quad \leq 1.0$$

$$k_p = 0.91$$

Using graph:

For graph:

$$k_p = 0.91$$

Reference

5.1.2.1

For graph

5.1.2.1 Fig. 28

$$N_{1,Rd} = \frac{1.70 \times 0.91 \times 355 \times 10.0^2}{\sin 45^\circ} \times \left(1.8 + 10.2 \times \frac{88.9 + 101.6 + 101.6}{3 \times 193.7}\right) / 1.0$$

$$N_{1,Rd} = 538 \text{kN} > 369 \text{kN} : \text{PASS}$$

For this type of configuration (see 5.6.2 Figure 51(c)):

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

$$369 \times \sin 45^\circ + 113 \times \sin 90^\circ \leq 538 \times \sin 45^\circ$$

$$374 \text{ kN} \leq 380 \text{ kN} : \text{PASS}$$
\[ N_{2,Ed} \times \sin \theta_2 \leq N_{1,Rd} \times \sin \theta_1 \]

\[ 448 \times \sin 30^\circ \leq 538 \times \sin 45^\circ \]

\[ 244 \text{ kN} \leq 380 \text{ kN} \quad \therefore \text{PASS} \]

**Check for Chord Punching Shear failure:**

Valid if: \( d_i \leq d_0 - 2t_0 \) where \( d_0 - 2t_0 = 193.7 - (2 \times 10.0) = 173.7 \text{ mm} \)

\( d_1 = 88.9 \text{ mm} \)
\( d_2 = 101.6 \text{ mm} \)
\( d_3 = 101.6 \text{ mm} \)

Therefore check for Chord Punching Shear;

\[ N_{1,Rd} = \frac{f_y \cdot t_0 \cdot \pi \cdot d_1 \cdot \left(1 + \sin \theta_1\right)}{2 \times \sin^2 \theta_1 / \gamma_M} \]

For Brace 1;

\[ N_{1,Rd} = \frac{355}{\sqrt{3}} \times 10.0 \times \pi \times 88.9 \times \frac{1 + \sin 45^\circ}{2 \times \sin^2 45^\circ} / 1.0 \]

\[ N_{1,Rd} = 977 \text{ kN} > 369 \text{ kN} \quad \therefore \text{PASS} \]

For Brace 2;

\[ N_{2,Rd} = \frac{355}{\sqrt{3}} \times 10.0 \times \pi \times 101.6 \times \frac{1 + \sin 30^\circ}{2 \times \sin^2 30^\circ} / 1.0 \]

\[ N_{2,Rd} = 1963 \text{ kN} > 488 \text{ kN} \quad \therefore \text{PASS} \]

For Brace 3;

\[ N_{3,Rd} = \frac{355}{\sqrt{3}} \times 10.0 \times \pi \times 101.6 \times \frac{1 + \sin 90^\circ}{2 \times \sin^2 90^\circ} / 1.0 \]

\[ N_{3,Rd} = 654 \text{ kN} > 113 \text{ kN} \quad \therefore \text{PASS} \]

**Summary**

Here, the validity limits are combined to include all three braces. The eccentricity values use both brace 1 and 2 (diagonals) in relation to brace 3 (the vertical brace). It is important to check the joint configuration and refer to our Design of Welded Joints literature to make sure the correct method and formulae is used. To re-iterate this is a theoretical method which is not supported by research or tests.
11 CHS Chord CHS Bracings Overlap KT-Joint

References are generally to Tata Steel publication ‘Design of Welded Joints’ (unless otherwise stated).

NOTE: Brace ‘j’ designated overlapped, Brace ‘i’ overlapping

Brace ‘1’ CHS is 88.9 x 5.0, Brace ‘2’ and ‘3’ is CHS 101.6 x 6.3

Dimensions

\[
\begin{align*}
 d_0 &= 193.7 \text{ mm} \\
 t_0 &= 10.0 \text{ mm} \\
 \gamma_M &= 1.0 \\
 A_1 &= 13.2 \text{ cm}^2 \\
 A_2 &= 18.9 \text{ cm}^2 \\
 A_3 &= 18.9 \text{ cm}^2 \\
 f_{u1} &= 470 \text{ N/mm}^2 \\
 f_{u2} &= 470 \text{ N/mm}^2 \\
 f_{u3} &= 470 \text{ N/mm}^2
\end{align*}
\]

This example is to show how to calculate an overlap KT-Joint with CHS chord and braces. Please be aware that there are no recommendations for an overlap KT-Joint in EN1993-1-8 or elsewhere as far as Tata Steel is aware. This is a Tata Steel method and is included in the Tata Steel Design of Welded Joints literature. It is a theoretical method which is not supported by research or tests. The method of checking a KT-Joint depends on the direction of the brace forces, gap or overlap and chord section profile. This example is for:

- One diagonal brace opposite direction to the other two bracings
- Both diagonal bracings overlapping
- Circular chord and bracings

With this configuration, the joint capacity is based on the most highly loaded compression brace for chord face failure. Please be aware that different overlap values may change how the joint is calculated and you should refer to the Tata Design of Welded Joints literature before tackling any joint to make sure you are using the correct method and formulae. The force combination of the braces can be seen at 5.6.2 Figure 51(c) (as a (from left to right) compression-compression-tension) of our Design Of Welded Joints literature. Due to one of the braces falling within the limits (overlapping percentage) for the localised brace-to-chord shear check, this calculation has also been completed.
Geometric Calculations

For Eccentricity; Brace 1 in relation to Brace 3;

\[
e_1 = \left( \frac{d_1}{2 \times \sin \theta_1} + \frac{d_3}{2 \times \sin \theta_3} + g \right) \times \left[ \frac{\sin \theta_1 \times \sin \theta_3}{\sin (\theta_1 + \theta_3)} \right] - \frac{d_0}{2}
\]

Brace 1 to 3 overlap, \( \lambda_{ov} = 71.6\% \);

where; 
\[
g = \frac{\lambda_{ov} \times d_1}{100 \times \sin \theta_1}
\]
\[
g_1 = 71.6 \times 88.9 \times 100 \times \sin(45^\circ) \times -1
\]
\[
g_1 = -90 \text{ mm} \quad \text{(gap is negative as it's an overlap)}
\]

\[
e_1 = \left( \frac{88.9}{2 \times \sin(45^\circ)} + \frac{101.6}{2 \times \sin(90^\circ)} + (-90.0) \right) \times \left[ \frac{\sin(45^\circ) \times \sin(90^\circ)}{\sin(45^\circ + 90^\circ)} \right] - \frac{193.7}{2}
\]  

\[= -73.2 \text{ mm}\]

For Eccentricity, Brace 2 in relation to Brace 3;

\[
e_2 = \left( \frac{d_2}{2 \times \sin \theta_2} + \frac{d_3}{2 \times \sin \theta_3} + g \right) \times \left[ \frac{\sin \theta_2 \times \sin \theta_3}{\sin (\theta_2 + \theta_3)} \right] - \frac{d_0}{2}
\]

Brace 2 to 3 overlap, \( \lambda_{ov} = 65.2\% \);

where; 
\[
g_2 = \frac{\lambda_{ov} \times d_2}{100 \times \sin \theta_2}
\]
\[
g_2 = 65.2 \times 101.6 \times 100 \times \sin(50^\circ)
\]
\[
g_2 = -86.5 \text{ mm} \quad \text{(gap is negative as it's an overlap)}
\]

\[
e_2 = \left( \frac{101.6}{2 \times \sin(50^\circ)} + \frac{101.6}{2 \times \sin(90^\circ)} + (-86.5) \right) \times \left[ \frac{\sin(50^\circ) \times \sin(90^\circ)}{\sin(50^\circ + 90^\circ)} \right] - \frac{193.7}{2}
\]  

\[= -60.4 \text{ mm}\]

Validity limits check for both K-Joints

\[10 \leq \frac{d_0}{t_0} \leq 50 \quad \frac{d_0}{t_0} = 193.7/10.0 = 19.37 \quad \therefore \text{PASS}
\]
\[\frac{d_0}{t_0} \leq 70 \epsilon^2 \quad \text{(Class 1 or 2 for chord)}
\]
\[
70 \epsilon^2 = 70 \sqrt{(235/fy0)}^2 = 70 \sqrt{(235/355)}^2 = 46.34
\]
\[
\frac{d_0}{t_0} = 19.37 \leq 46.34 \quad \therefore \text{PASS}
\]
Welded Joints Examples  CHS Chord CHS Bracings Overlap KT-Joint

\[
d_i/t_i \leq 50 \quad d_1/t_1 = 88.9/5.0 = 17.78 \quad \therefore \text{PASS} \\
d_2/t_2 = 101.6/6.3 = 16.13 \quad \therefore \text{PASS} \\
d_3/t_3 = 101.6/6.3 = 16.13 \quad \therefore \text{PASS}
\]

\[
d_i/t_i \leq 70\pi^2 \text{ (Class 1 or 2 for compression bracings)} \\
70\pi^2 = 70 \left(\sqrt{235/f_y}\right)^2 = 70 \sqrt{(235/355)^2} = 46.34 \\
d_1/t_1 = 17.78 \quad \therefore \text{PASS} \\
d_2/t_2 = 16.13 \quad \therefore \text{PASS} \\
\]

\[
d_i/t_i = 88.9/193.7 = 0.46 \quad \therefore \text{PASS} \\
d_2/b_0 = 101.6/193.7 = 0.52 \quad \therefore \text{PASS} \\
d_3/b_0 = 101.6/193.7 = 0.52 \quad \therefore \text{PASS} \\
\]

\[
-0.55 d_0 \leq e \leq +0.25 d_0 \quad -0.55 \times 193.7 \leq e \leq +0.25 \times 193.7 \\
-106.5 \leq e \leq +48.4 \\
e_1 = -73.2 \text{ mm} \quad \therefore \text{PASS} \\
e_2 = -60.4 \text{ mm} \quad \therefore \text{PASS} \\
\]

\[
\lambda_{ov} \geq 25\% \\
\lambda_{ov,1} = |g| \sin \theta_1 / d_1 \times 100\% \\
\lambda_{ov,1} = 90.0 \times \sin 45^\circ / 88.9 \times 100\% \quad \therefore \text{PASS} \\
\lambda_{ov,2} = 86.5 \times \sin 50^\circ / 101.6 \times 100\% \quad \therefore \text{PASS} \\
\lambda_{ov,2} = 65.2\% \quad \therefore \text{PASS} \\
\]

\[
30^\circ \leq \theta_1 \leq 90^\circ \\
\theta_1 = 45^\circ \quad \therefore \text{PASS} \\
\theta_2 = 50^\circ \quad \therefore \text{PASS} \\
\theta_3 = 90^\circ \quad \therefore \text{PASS} \\
\]

**Chord Face Failure (deformation):**

**Compression brace (1):**

\[
N_{1,Rd} = \frac{k_g \times k_p \times f_y \times t_0}{\sin \theta_1} \times \left(1.8 + 10.2 \times \frac{d_1}{d_0}\right) / \gamma_{M5} \\
\]

**Gap/lap factor, \( k_g \):**

\[
k_g = \gamma^{0.2} \left[1 + \frac{0.024 \gamma^{1.2}}{1 + \exp(0.5g / t_0 - 1.33)} \right] \\
\text{where;} \\
\gamma = \frac{d_0}{2t_0} = \frac{193.7}{2 \times 10.0} = 9.69 \\
\]

Note: \( g \) is positive for gap and negative for overlap

Use the smallest overlap for \( g \)

---

**Reference**

(EN1993-1-1) Table 5.2

5.1.1 Figure 27

6.5 Figure 57

5.1.3 (K- & N-Joints)

5.1.2.2 (\( k_g \))

6.3 (\( \gamma \))
Using Formulae:  Using Graph:
\[ k_g = 9.690.2 \left[ 1 + \frac{0.024 \times 9.69^{1.2}}{1 + \exp(0.5 \times (-86.5)/10.0 - 1.33)} \right] \]
\[ k_g = 2.15 \]

\[ g/t_0 = -86.5/10.0 = -8.7 \]
\[ k_g = 2.15 \]

CHS chord end stress factor, \( k_p \)

CHS chord least compressive applied factored stress, \( \sigma_{p,Ed} \):

\[ \sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{p,0,Ed}}{W_{el,p,0}} + \frac{M_{op,0,Ed}}{W_{el,op,0}} \]

Note: Moment is additive to compressive stress which is positive for moments. For CHS chords use least compressive chord stress.

\[ \sigma_{p,Ed} = \frac{512 \times 1000}{57.7 \times 10^2} = 88.7 \text{ N/mm}^2 \]

Chord factored stress ratio, \( n_p \):

\[ n_p = \left( \frac{\sigma_{p,Ed}}{f_y} \right) = \left( \frac{88.7}{355} \right) = 0.25 \]

Using formulae:  Using graph:

For \( n_p > 0 \) (compression):

\[ k_p = 1 - 0.3 n_p (1 + n_p) \quad \text{but} \quad \leq 1.0 \]
\[ k_p = 1 - 0.3 \times 0.25 (1 + 0.25) \quad \text{but} \quad \leq 1.0 \]

\[ k_p = 0.91 \]

from graph;

\[ k_p = 0.91 \]

\[ N_{1,Rd} = \frac{2.15 \times 0.91 \times 355 \times 10.0^2}{\sin 45^\circ} \times \left( 1.8 + 10.2 \times \frac{88.9}{193.7} \right) / 1.0 \]

\[ N_{1,Rd} = 637 \text{ kN} > 369 \text{ kN} \quad \therefore \text{PASS} \]

Tension Brace (2):

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

\[ N_{2,Rd} = \frac{\sin 45^\circ \times 637}{\sin 50^\circ} \]

\[ N_{2,Rd} = 588 \text{ kN} > 488 \text{ kN} \quad \therefore \text{PASS} \]

Chord Punching shear not required for overlapping bracings
Localised Brace-to-Chord Shear Check for overlapped Joints:

Although this failure mode check was included as a corrigendum in section 7.1.2 (6) of EN 1993-1-8, no equations have been included in tables 7.2, 7.10, 7.21 or 7.24. In their absence, the following criteria for adequacy of the shear connection may be used. They are based on research by CIDECT but expressed using EN1993-1-8 symbols.

Modified equation only applicable when brace 3 is the overlapped brace (j) and diagonals 1 and 2 overlap (i).

For KT-Joint overlap joint check 60% < $\lambda_{ov,1}$ or $\lambda_{ov,2}$ < 100%:

$$\left( N_{1,Ed} \cos \theta_1 - N_{2,Ed} \cos \theta_2 + N_{3,Ed} \cos \theta_3 \right) \leq \ldots$$

$$\frac{\pi}{4} \times \left( \frac{f_{u1}}{\sqrt{3}} \times \left( \frac{100 - \lambda_{ov,1}}{100} \right) \times 2d_1 + d_{eff,1} \right) \times t_1 + \frac{f_{u2}}{\sqrt{3}} \times \left( \frac{100 - \lambda_{ov,2}}{100} \right) \times 2d_2 + d_{eff,2} \times t_2 \right) \ldots$$

$$\frac{f_{u3}}{\sqrt{3}} \times \left( \frac{c_{s1} \times d_{eff,3} + c_{s2} \times d_{eff,3}}{\sin \theta_3} \right) \times \frac{1}{\gamma_{M5}}$$

where Brace Effective Width (overlapping braces):

$$d_{eff,i} = \frac{12 \times t_0 \times f_y \times t_0 \times t_0}{d_0 \times f_{yi} \times t_1} \times d_i \text{ but } d_{eff,i} \leq d_i$$

$$d_{eff,1} = \frac{12 \times 10.0}{193.7} \times \frac{355 \times 10.0}{355 \times 5.0} \times 88.9 \text{ but } d_{eff,1} \leq 88.9$$

$$d_{eff,1} = 110.1 \text{ but } d_{eff,1} \leq 88.9$$

$$d_{eff,1} = 88.9 \text{mm}$$

$$d_{eff,2} = \frac{12 \times 10.0}{193.7} \times \frac{355 \times 10.0}{355 \times 6.3} \times 101.6 \text{ but } d_{eff,2} \leq 101.6$$

$$d_{eff,2} = 100 \text{ but } d_{eff,2} \leq 101.6$$

$$d_{eff,2} = 100 \text{ mm}$$
where Brace Effective Width (overlapped brace);

\[ d_{\text{eff},i} = \frac{12t_0}{d_0} \times \frac{f_y t_0}{f_y t_j} \times d_j \text{ but } d_{\text{eff},i} \leq d_j \]

\[ d_{\text{eff},3} = \frac{12 \times 10.0}{193.7} \times \frac{355 \times 10.0}{355 \times 6.3} \times 101.6 \text{ but } d_{\text{eff},3} \leq 101.6 \]

\[ d_{\text{eff},3} = 100 \text{ but } d_{\text{eff},3} \leq 101.6 \]

\[ d_{\text{eff},3} = 100 \text{ mm} \]

Assume the hidden toes of braces 1 & 2 are NOT welded therefore;

\[ c_{s1} = 1 \]
\[ c_{s2} = 1 \text{ (if hidden toe/s welded } c_s = 2) \]

Therefore,

\[ \left( 369 \cos 45^\circ - (-488 \cos 50^\circ + 113 \cos 90^\circ) \right) \leq \ldots \ldots \]

\[ \quad \pi \times \frac{470}{\sqrt{3}} \times \left[ \frac{100 - 71.6}{100} \right] \times 2 \times 88.9 + 88.9 \times 5.0 \times \frac{470}{\sqrt{3}} \times \left[ \frac{100 - 65.2}{100} \right] \times 2 \times 101.6 + 100 \times 6.3 \]

\[ + \frac{470}{\sqrt{3}} \times \left( \frac{1 \times 100 + 1 \times 100}{6.3} \right) \times \frac{1.0}{1.0} \]

\[ 575 \text{ kN} \leq \frac{\pi}{4} \times (267467 + 380971 + 341907) \times 1.0 \]

\[ 575 \text{ kN} \leq \frac{\pi}{4} \times (989745) \]

\[ 575 \text{ kN} \leq 778 \text{ kN \:: \: PASS} \]

**Summary**

Here, the validity limits are combined to include all three braces. The eccentricity values use both brace 1 and 2 (diagonal) in relation to brace 3 (the vertical overlapped brace). The localised brace-to-chord shear check has been completed due to the high overlap. Please note that even if one brace is within limits for the brace-to-chord shear check, the check will still have to be calculated. In this example both diagonal braces overlap within the limits for the shear check. The brace-to-chord shear check equation sees the addition of the horizontal loads of the 3 bracings, the 2 angled braces having loads that result in the same horizontal direction. This means the brace 2 load (negative tension load) had to be subtracted so that the double-negative created a positive result so that the equation calculated correctly. It is important to check the joint configuration and refer to our Design of Welded Joints literature to make sure the correct method and formulae is used. To re-iterate this is a theoretical method which is not supported by research or tests.
12 UB Chord RHS Bracings Gap K-Joint

References are generally to Tata Steel publication 'Design of Welded Joints' (unless otherwise stated).

**Dimensions**

- \( b_0 = 125.3 \text{ mm} \)
- \( h_0 = 311.0 \text{ mm} \)
- \( t_w = 9.0 \text{ mm} \)
- \( t = 14.0 \text{ mm} \)
- \( d_w = h_0 - 2(t - t_0) = 265.2 \text{ mm} \)
- \( r_0 = 8.9 \text{ mm} \)

**Validity limits check**

**Chord: Web**

- \( d_w/t_w \leq 38 \varepsilon \) (Class 1 or 2 compression)
- \( d_w/t_w = 265.2/9 = 29.5 \)
- \( d_w \leq 400 \)  

**Chord: Flange**

- \( c_f/t_f \leq 10 \varepsilon \) (Class 1 or 2 compression)
- \( c_f = (b_0 - 2r_0 - t_w)/2 = (125.3 - 2 \times 8.9 - 9)/2 = 49.25 \)
- \( c_f/t_f = 49.25/14.0 = 3.52 \)

**Compression and Tension brace**

- \( h/t_i \leq 35 \)
- \( b/t_i \leq 35 \)
- \( h/b_i = 1.0 \)

**Compression brace**

- \( (b_1 - 3t_1)/t_1 \leq (h_1 - 3t_1)/t_1 \leq 38 \varepsilon \) (Class 1 or 2 compression)
- \( 38 \varepsilon = 38 \sqrt{235/355} = 30.92 \)

**Material**

- **BRACES**: CELSIUS S355 to EN 10210
- **UB CHORD**: ADVANCE S355 to EN 10025

**Reference**

5.7.1 Figure 55  
(EN1993-1-1  
Table 5.2)
Welded Joints Examples  UB Chord RHS Bracings Gap K-Joint

\[ g \geq t_1 + t_2 = 6.3 + 6.3 = 12.6 \]
\[ g = 165.8 \text{ (zero eccentricity)} \quad \therefore \text{PASS} \]
\[ 30^\circ \leq \theta_1 \leq 90^\circ \quad \theta_1 = 45^\circ \quad \therefore \text{PASS} \]
\[ 30^\circ \leq \theta_2 \leq 90^\circ \quad \theta_2 = 45^\circ \quad \therefore \text{PASS} \]

**Chord Web Yielding:**

\[ N_{t,Rd} = \frac{f_y \times t_w \times b_{w,j}}{\sin \theta_i} \gamma_{M5} \]

where...

\[ b_{w,j} = \frac{h_i}{\sin \theta_i} + 5(t_f + r_0) \quad \text{but } \leq 2t_i + 10(t_f + r_0) \]

\[ b_{w,1} = \frac{100}{\sin 45^\circ} + 5(14.0 + 8.9) \quad \text{but } \leq 2 \times 6.3 + 10(14.0 + 8.9) \]

\[ b_{w,1} = 255.92 \quad \text{but } \leq 241.6 \]

\[ b_{w,1} = 241.6 \text{ mm} \quad \text{and } b_{w,2} = b_{w,1} \text{ as same brace and angle dimensions.} \]

Therefore;

\[ N_{t,Rd} = \frac{355 \times 9.0 \times 241.6}{\sin 45^\circ} / 1.0 = 1092 \text{ kN} \]

and \[ N_{t,Rd} = N_{t,Rd} \text{ as same brace and angle dimensions} \]

\[ 1092 > 150 \text{ kN} \quad \therefore \text{PASS} \]

**Chord Shear:**

\[ N_{v,Rd} = \frac{f_y \times A_v}{\sqrt{3} \times \sin \theta_i} \gamma_{M5} \]

where...

\[ A_v = A_0 - (2 - \alpha) \times b_0 \times t_i + (t_w + 2r) \times t_f \]

where...

\[ \alpha = \left( \frac{1}{1 + \frac{4 \times g^2}{3 \times t_f^2}} \right)^{0.5} = \left( \frac{1}{1 + \frac{4 \times 165.8^2}{3 \times 14.0^2}} \right)^{0.5} \]

\[ \alpha = 0.073 \]

\[ A_{v,0} = 6120 - (2 - 0.073) \times 125.3 \times 14.0 + (9.0 + 2 \times 8.9) \times 14.0 \]

\[ A_{v,0} = 3114.9 \text{ mm}^2 \]
Welded Joints Examples  UB Chord RHS Bracings Gap K-Joint

\[ N_{1,Rd} = 903 \text{ kN} \]

and \( N_{2,Rd} = N_{1,Rd} \) as same brace and angle dimensions

\[ 903 \text{ kN} > 150 \text{ kN} \quad : \quad \text{PASS} \]

**Bracing Effective Width:**

\[ N_{1,Rd} = 2 \times f_y \times t_i \times p_{\text{eff},i} / \gamma_{M5} \]

Check if Bracing Effective Width required (Page 60 Welded Joints Literature):

\[
g / t_i \leq 20 - 28 \beta
\]

\[ 165.8 / 14.0 \leq 20 - 28 (100+100+100+100/4 \times 125.3) \]

\[ 11.8 \leq 2.4 \quad : \quad \text{Check Effective Width;} \]

where...

\[ p_{\text{eff},i} = t_w + 2r + 7t_i \times (f_y / f_y) \]

but \( \leq b_i + h_i - 2t_i \) for K or N gap joints

\[ p_{\text{eff},1} = 9.0 + 2 \times 8.9 + 7 \times 14.0 \times (355/355) \]

but \( \leq 100 + 100 - 2 \times 6.3 \)

\[ p_{\text{eff},1} = 124.8 \text{ but } \leq 187.4 \]

and \( p_{\text{eff},2} = p_{\text{eff},1} \) as same brace and angle dimensions

\[ N_{1,Rd} = 2 \times 355 \times 6.3 \times 124.8 = 1.0 \]

\[ 558 \text{ kN} > 150 \text{ kN} \quad : \quad \text{PASS} \]

and \( N_{2,Rd} = N_{1,Rd} \) as same brace and angle dimensions

**Chord Axial Force Resistance in gap:**

\[ N_{0,\text{gap,Rd}} = \left( A_0 - A_{v,0} \right) \times f_y + A_{v,0} \times f_y \times \sqrt{1 - \left( \frac{V_{0,Ed}}{V_{pl,0,Rd}} \right)^2} / \gamma_{M5} \]

where...

\[ V_{0,Ed} = \max \left( \left| N_{1,Ed} \right| \times \sin \theta_1, \left| N_{2,Ed} \right| \times \sin \theta_2 \right) \]

\[ V_{0,Ed} = \max \left( \lceil 150 \rceil \times \sin 45^\circ, \lceil -150 \rceil \times \sin 45^\circ \right) \]
$V_{0,Ed} = 106.1\text{kN}$

where...

$$V_{pl,0,Rd} = A_{x,0} \left( f_y \frac{f}{\sqrt{3}} \right) = \frac{3141.8 \times \left( 355 / \sqrt{3} \right)}{1.0}$$

$$V_{pl,0,Rd} = 643.9\text{kN}$$

$$N_{0,gap,Rd} = \left[ (6120 - 3141.8) \times 355 + 3141.8 \times 355 \times \sqrt{1 - \frac{106.1}{643.9}} \right] / 1.0$$

$N_{0,gap,Rd} = 2077\text{kN}$

check; $N_{0,gap,Rd} \geq N_{0,gap,Ed}$

Therefore; $N_{0,gap,Ed} = 356.1\text{kN}$

$2077\text{kN} \geq 356.1\text{kN}$ : PASS

Reference

5.7.4