TATA STEEL

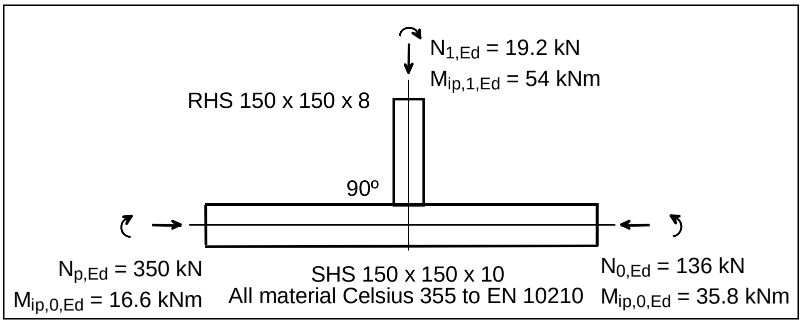
Welded joints examples
Celsius®355 NH

CONTENTS

1 RHS T-Joint Moment In Plane

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

Reference



Dimensions

b_0 = 150 mm b_1 = 150 mm
h_0 = 150 mm h_1 = 150 mm
t_0 = 10.0 mm t_1 = 8.0 mm

Validity limits check

5.3.1 Figure 37

Chord:
$(b_0\text{-}3\ t_0)/t_0$; $(h_0\text{-}3\ t_0)/t_0 \leq 38\varepsilon$ (Class 1 or 2 compression)

(EN 1993-1-1) Table 5.2

$38\varepsilon = 38\ \sqrt{}(235/f_{y0}) = 38\sqrt{}(235/355) = 30.92$
$(b_0\text{-}3\ t_0)/t_0 = (150\text{-}3 \times 10)/10 = 12$ $\therefore$PASS
$(h_0\text{-}3\ t_0)/t_0 = (150\text{-}3 \times 10)/10 = 12$ $\therefore$PASS

$b_0/t_0 \leq 35$ $b_0/t_0 = 150/10 = 15$ $\therefore$PASS
$h_0/t_0 \leq 35$ $h_0/t_0 = 150/10 = 15$ $\therefore$PASS

Compression brace:
b_i/t_i ; $h_i/t_i \leq 35$ $b_1/t_1 = 150/8 = 18.75$ $\therefore$PASS
$h_1/t_1 = 150/8 = 18.75$ $\therefore$PASS

Compression brace:
$(b_1\text{-}3\ t_1)/t_1$; $(h_1\text{-}3\ t_1)/t_1 \leq 38\varepsilon$ (Class 1 or 2 compression)

(EN 1993-1-1) Table 5.2

$38\varepsilon = 38\ \sqrt{}(235/f_{y0}) = 38\sqrt{}(235/355) = 30.92$
$(b_1\text{-}3\ t_1)/t_1 = (150\text{-}3 \times 8)/8 = 15.75$ $\therefore$PASS
$(h_1\text{-}3\ t_1)/t_1 = (150\text{-}3 \times 8)/8 = 15.75$ $\therefore$PASS

$0.25 \leq b_i/b_0 \leq 1.0$ $b_1/b_0 = 150/150 = 1.0$ $\therefore$PASS

$0.5 \leq h_0/b_0 \leq 2.0$ $h_0/b_0 = 150/150 = 1.0$ $\therefore$PASS

$0.5 \leq h_i/b_i \leq 2.0$ $h_1/b_1 = 150/150 = 1.0$ $\therefore$PASS

$30° \leq \theta_i \leq 90°$ $\theta_1 = 90°$ $\therefore$PASS

Reference

Axial: Chord face failure (deformation) 5.3.3
(valid when $\beta \leq 0.85$)

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

6.3

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;

RHS chord end stress factor, k_n

RHS chord most compressive
stress, $\sigma_{0,Ed}$;

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

5.3.2.1

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

A_0 = 54.9 cm^2 = 5490 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;

$$n = \left(\frac{\sigma_{0,Ed}}{f_{y0}}\right) = \left(\frac{176.47}{355}\right)$$

5.3.2.1

$$n = 0.497$$

Using formulae:	Using graph:
For n > 0 (compression): $k_n = 1.3 - \frac{0.4\ n}{\beta}$ but $k_n \leq 1.0$ $k_n = 1.3 - \frac{0.4 \times 0.497}{1.0} \leq 1.0$ $k_n = 1.101$ but ≤ 1.0 $\therefore k_n = 1.0$	From graph, for β = 1.0; k_n = 1.0

5.3.2.1

5.3.2.1
Fig. 38

(However, not required in this case as chord deformation not critical as β>0.85)

Reference

Axial: Chord shear

5.3.3

(valid for X-joints with Cos $\theta_1 > h_1/h_0$) As this is a T-joint with θ_1 = 90° this check is not required.

Axial: Chord side wall buckling

5.3.3

(valid when β = 1.0) $\beta = 1.0 \therefore$ check required

$$N_{1Rd} = \frac{k_n\ f_b\ t_0}{\sin\theta_1}\left(\frac{2\ h_1}{\sin\theta_1} + 10\ t_0\right) / \gamma_{M5}$$

5.3.3

Chord side wall buckling strength, f_b

For compression brace, T-joint:

5.3.2.3

$$\bar{\lambda} = 3.46\ \frac{\left(\frac{h_0}{t_0} - 2\right)\sqrt{\frac{1}{\sin\theta_i}}}{\pi\sqrt{\frac{E}{f_{y0}}}}$$

where: E = 210000 N/mm^2

6.1 (For ‘E’)

$$\bar{\lambda} = 3.46\ \frac{\left(\frac{150}{10} - 2\right)\sqrt{\frac{1}{\sin 90^\circ}}}{\pi\sqrt{\frac{210000}{355}}} = 0.589$$

Using formulae:	Using graph:
From EN 1993-1-1:2005, 6.3.1.2, flexural buckling reduction factor, χ; From EN 1993-1-1:2005, table 6.1, $\alpha = 0.21$ (curve ‘a’) $\phi = 0.5\left(1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^{\ 2}\right)$ $\phi = 0.5\left(1 + 0.21\left(0.589 - 0.2\right) + 0.589^{\ 2}\right) = 0.714$ $\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$ but $\chi \le 1.0$ $\chi = \frac{1}{0.714 + \sqrt{0.714^2 - 0.589^2}}$ but $\chi \le 1.0$ $\chi = 0.895$	From graph, for $\bar{\lambda} = 0.589$; $\chi = 0.895$

(EN 1993-1-1) Table 6.1

(EN 1993-1-1) 6.3.1.2

5.3.2.3 Fig. 40

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

5.3.2.3

$f_b = 0.895 \times 355 = 318$ N/mm^2

$$N_{1Rd} = \frac{1.0 \times 318 \times 10}{\sin 90^\circ}\left(\frac{2 \times 150}{\sin 90^\circ} + 10 \times 10\right) / 1.0$$

	Reference
Axial: Chord punching shear	5.3.3
(valid when $0.85 \le \beta \le 1 - 1/\gamma$)	
$\gamma = \frac{b_0}{2\ t_0} = \frac{150}{2 \times 10} = 7.5$	6.3
$0.85 \le 1.0 \le 1 - \frac{1}{7.5} = 0.867$	
$\therefore$ Check not required	
Axial: Bracing failure (effective width)	
(valid when $\beta \ge 0.85$)	5.3.3
$\beta = 1.0$	6.3
$\therefore$ check required	
$N_{1,Rd} = f_{y1}\ t_1 \left(2\ h_i - 4\ t_1 + 2\ b_{eff,i}\right) / \gamma_{M5}$	5.3.3
where:	
$b_{eff,i} = \frac{10\ t_0}{b_0} \times \frac{f_{y0}\ t_0}{f_{yi}\ t_i}\ b_i \quad \text{but} \quad b_{eff,i} \le b_i$	5.3.2.2
$b_{eff,i} = \frac{10 \times 10}{150} \times \frac{355 \times 10}{355 \times 8} \times 150 = 125\ \text{mm} \quad \text{but} \quad b_{eff,i} \le 150\ \text{mm}$	
$b_{eff,i} = 125$ mm	
$N_{1,Rd} = 355 \times 8\ \left(2 \times 150 - 4 \times 8 + 2 \times 125\right) / 1.0$	
$\boxed{N_{1,Rd} = 1471\ \text{kN} \quad > \quad 19.2\ \text{kN} \quad \therefore \text{PASS}}$	
Moment in plane: Chord face failure (deformation)	5.3.5.1
(valid when $\beta \le 0.85$)	
$\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \qquad \therefore \text{check not required}$	6.3

Reference

Moment in plane: Chord side wall crushing 5.3.5.1
(valid when 0.85 < β ≤ 1.0)

$$\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \qquad \therefore \text{check required}$$ 6.3

$$M_{ip,1,Rd} = 0.5\, f_{yk}\; t_0\; (h_1 + 5\, t_0)^2 \;/\, \gamma_{M5}$$ 5.3.5.1

where:

$f_{yk} = f_{y0}$ (for T-joints) 5.3.2.4

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

$$M_{ip,1,Rd} = 0.5 \times 355 \times 10\ (150 + 5 \times 10)^2\ /1.0$$

$$\boxed{M_{ip,1,Rd} = 71\,\text{kNm} \quad > \quad 54\,\text{kNm} \quad \therefore \text{PASS}}$$

Moment in plane: Bracing failure (effective width) 5.3.5.1
(valid when 0.85 < β ≤ 1.0)

$$\beta = \frac{b_1}{b_0} = \frac{150}{150} = 1.0 \qquad \therefore \text{check required}$$ 6.3

$$M_{ip,1,Rd} = f_{y1}\left[W_{pl,ip,1} - \left(1 - \frac{b_{eff,1}}{b_1}\right) b_1\,(h_1 - t_1)\,t_1\right] / \,\gamma_{M5}$$ 5.3.5.1

where:

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

$b_{eff,1} = 125\ \text{mm}$

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

$$\boxed{M_{ip,1,Rd} = 74.1\,\text{kNm} \quad > \quad 54\,\text{kNm} \quad \therefore \text{PASS}}$$

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, $\boxed{N_{1,Rd} = 1272\ \text{kN} \quad > \quad 19.2\,\text{kN} \quad \therefore \text{PASS}}$

Moment in plane joint resistance, $\boxed{M_{ip,1,Rd} = 71\,\text{kNm} \quad > \quad 54\,\text{kNm} \quad \therefore \text{PASS}}$

Reference

2.3

Interaction check

When more than one type of force exists, e.g. axial and moments in plane, an interaction check is required;

$$\frac{\left|N_{i,Ed}\right|}{N_{i,Rd}} + \frac{\left|M_{ip,i,Ed}\right|}{M_{ip,i,Rd}} + \frac{\left|M_{op,i,Ed}\right|}{M_{op,i,Rd}} \leq 1.0 \qquad \text{(for RHS chords)}$$

As there are no moments out of plane;

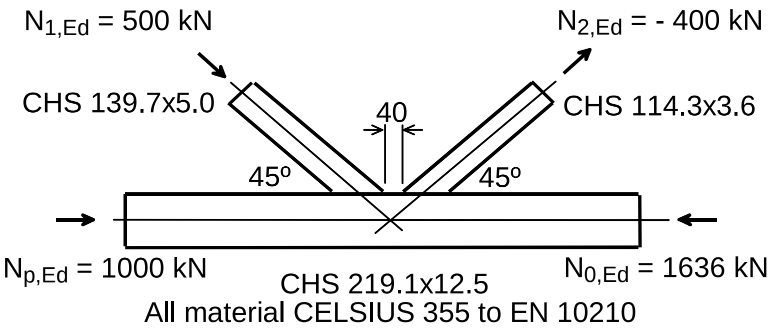
$$\frac{19.2}{1272} + \frac{54}{71} + \frac{0}{M_{op,i,Rd}} = 0.776$$

$$\boxed{0.776 \quad \leq \quad 1.000 \qquad \therefore \text{PASS}}$$

2 CHS Gap K-Joint

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

Reference



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

Dimensions

d_0 = 219.1 mm	d_1 = 139.7 mm	d_2 = 114.3 mm
t_0 = 12.5 mm	t_1 = 5.0 mm	t_2 = 3.6 mm

Validity limits check

			5.1.1 Figure 27
$10 \leq d_0/t_0 \leq 50$	$d_0/t_0 = 219.1/12.5 = 17.53$	∴PASS	
$d_0/t_0 \leq 70\varepsilon^2$ (Class 1 or 2 for compression chord)			(EN 1993-1-1) Table 5.2
	$70\varepsilon^2 = 70\,[\surd(235/f_{y0})]^2 = 70(235/355) = 46.34$		
	$17.53 < 46.34$	∴PASS	
$d_i/t_i \leq 70\varepsilon^2$ (Class 1 or 2 for compression brace)			(EN 1993-1-1) Table 5.2
	$70\varepsilon^2 = 70\,[\surd(235/f_{y0})]^2 = 70(235/355) = 46.34$		
	$d_1/t_1 = 139.7/5.0 = 27.94 < 46.34$	∴PASS	
$d_i/t_i \leq 50$	$d_1/t_1 = 139.7/5.0 = 27.94$	∴PASS	
	$d_2/t_2 = 114.3/3.6 = 31.75$	∴PASS	
$0.2 \leq d_i/d_0 \leq 1.0$	$d_1/d_0 = 139.7/219.1 = 0.64$	∴PASS	
	$d_2/d_0 = 114.3/219.1 = 0.52$	∴PASS	
$-0.55\, d_0 \leq e \leq +0.25\, d_0$	$-0.55 \times 219.1 \leq e \leq +0.25 \times 219.1$		
	$-120.5 \leq e \leq +54.8$		
	$e = 0$ mm	∴PASS	
$g \geq t_1 + t_2$	$t_1 + t_2 = 5 + 3.6 = 8.6$ mm		
	$g = 40$ mm	∴PASS	
$30° \leq \theta_i \leq 90°$	$\theta_1 = 45°$	∴PASS	
	$\theta_2 = 45°$	∴PASS	

Reference

Chord face failure (deformation)

Compression brace (1):

Chord face failure, $N_{1,Rd} = \dfrac{k_g\, k_p\, f_{y0}\, {t_0}^2}{\sin\theta_1}\left(1.8 + 10.2\dfrac{d_1}{d_0}\right) / \gamma_{M5}$ 5.1.3

Gap/lap function, k_g	
$\gamma = \dfrac{d_0}{2t_0} = \dfrac{219.1}{2\times 12.5} = 8.764$	
Using formulae:	Using graph:
$k_g = \gamma^{0.2}\left[1 + \dfrac{0.024\gamma^{1.2}}{1+\exp(0.5g/t_0 - 1.33)}\right]$ Note: g is positive for a gap and negative for an overlap $k_g = 8.764^{0.2}\left[1 + \dfrac{0.024\times 8.764^{1.2}}{1+\exp(0.5\times 40/12.5 - 1.33)}\right]$ $k_g = 1.761$	from graph; g/t_0 = 40/12.5 = 3.2 k_g = 1.761

6.3

5.1.2.2

5.1.2.2 Fig.29

CHS chord end stress factor, k_p	
CHS chord least compressive applied factored stress, $\sigma_{p,Ed}$; $\sigma_{p,Ed} = \dfrac{N_{p,Ed}}{A_0} + \dfrac{\lvert M_{ip,0,Ed}\rvert}{W_{el,ip,0}} + \dfrac{\lvert M_{op,0,Ed}\rvert}{W_{el,op,0}}$ Note: Moment is additive to compressive stress which is positive for moments. For CHS chords use least compressive chord stress. $\sigma_{p,Ed} = \dfrac{1000\times 1000}{81.1\times 10^2} = 123.30\ \text{N/mm}^2$ Chord factored stress ratio, n_p; $n_p = \left(\dfrac{\sigma_{p,Ed}}{f_{y0}}\right) = \left(\dfrac{123.30}{355}\right) = 0.347$	
Using formulae:	Using graph:
For $n_p > 0$ (compression): $k_p = 1 - 0.3\, n_p\, (1 + n_p)$ but ≤ 1.0 $k_p = 1 - 0.3\times 0.347\,(1 + 0.347)$ but ≤ 1.0 $k_p = 0.860$	from graph; k_p = 0.860

5.1.2.1

5.1.2.1

5.1.2.1

5.1.2.1 Fig.28

Reference

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

$$\boxed{N_{1,Rd} = 986 \text{ kN}}$$

Tension brace (2):

5.1.3

$$N_{2,Rd} = \frac{\sin \theta_1}{\sin \theta_2} N_{1,Rd}$$

$$N_{2,Rd} = \frac{\sin 45°}{\sin 45°} \times 986$$

$$\boxed{N_{2,Rd} = 986 \text{ kN}}$$

Chord punching shear

5.1.3

(valid when $d_i \le d_0 - 2\ t_0$)

$d_i \le d_0 - 2\ t_0$

$d_i \le 219.1 - 2 \text{ x } 12.5 = 194.1$ mm

$d_1 = 139.7$ mm < 194.1 mm ∴check chord punching shear

$d_2 = 114.3$ mm < 194.1 mm ∴check chord punching shear

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

Brace (1):

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

$$\boxed{N_{1,Rd} = 1919 \text{ kN}}$$

Brace (2):

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

$$\boxed{N_{2,Rd} = 1570 \text{ kN}}$$

Joint strength dictated by chord face failure for both bracings;

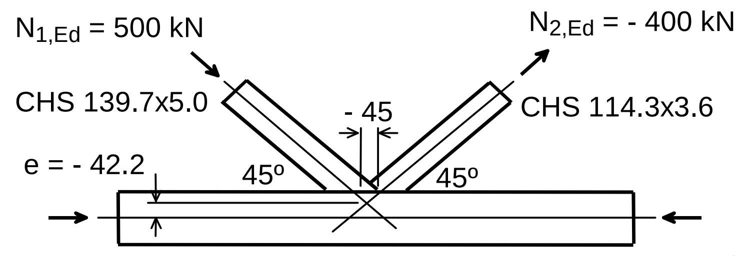
$$\boxed{\text{Brace 1 joint resistance, } N_{1,Rd} = 986 \text{ kN} > 500 \text{ kN} \therefore \text{PASS}}$$

$$\boxed{\text{Brace 2 joint resistance, } N_{2,Rd} = 986 \text{ kN} > 400 \text{ kN} \therefore \text{PASS}}$$

3 CHS Overlap K-Joint

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

Reference



All material CELSIUS 355 to EN 10210

Note: Brace 1 usually designated compression and brace 2 tension

Dimensions

d_0 = 219.1 mm	d_1 = 139.7 mm	d_2 = 114.3 mm
t_0 = 12.5 mm	t_1 = 5.0 mm	t_2 = 3.6 mm

Validity limits check — 5.1.1 Figure 27

$10 \leq d_0/t_0 \leq 50$ $d_0/t_0 = 219.1/12.5 = 17.53$ ∴PASS

$d_0/t_0 \leq 70\varepsilon^2$ (Class 1 or 2 for compression chord) — (EN 1993-1-1) Table 5.2

$70\varepsilon^2 = 70\ [\sqrt{(235/f_{y0})}]^2 = 70(235/355) = 46.34$

$17.53 < 46.34$ ∴PASS

$d_i/t_i \leq 70\varepsilon^2$ (Class 1 or 2 for compression brace) — (EN 1993-1-1) Table 5.2

$70\varepsilon^2 = 70\ [\sqrt{(235/f_{y0})}]^2 = 70(235/355) = 46.34$

$d_1/t_1 = 139.7/5.0 = 27.94 < 46.34$ ∴PASS

$d_i/t_i \leq 50$ $d_1/t_1 = 139.7/5.0 = 27.94$ ∴PASS

$d_2/t_2 = 114.3/3.6 = 31.75$ ∴PASS

$0.2 \leq d_i/d_0 \leq 1.0$ $d_1/d_0 = 139.7/219.1 = 0.64$ ∴PASS

$d_2/d_0 = 114.3/219.1 = 0.52$ ∴PASS

$-0.55\ d_0 \leq e \leq +0.25\ d_0$ $-0.55 \times 219.1 \leq e \leq +0.25 \times 219.1$

$-120.5 \leq e \leq +54.8$

$e = -42.2$ mm ∴PASS

$25\% \leq \lambda_{ov} \leq 100\%$ $\lambda_{ov} = |g| \sin\theta_i / d_i \times 100\%$ ∴PASS

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

$\lambda_{ov} = 27.8\%$ ∴PASS

$30° \leq \theta_i \leq 90°$ $\theta_1 = 45°$ ∴PASS

$\theta_2 = 45°$ ∴PASS

Reference

Chord face failure (deformation)

Compression brace (1):

Chord face failure, $$N_{1,Rd} = \frac{k_g\, k_p\, f_{y0}\, t_0^{\,2}}{\sin\theta_1}\left(1.8 + 10.2\,\frac{d_1}{d_0}\right) / \gamma_{M5}$$

5.1.3

Gap/lap function, k_g	
$\gamma = \frac{d_0}{2\,t_0} = \frac{219.1}{2\times 12.5} = 8.764$	
Using formulae:	Using graph:
$k_g = \gamma^{0.2}\left[1 + \frac{0.024\gamma^{1.2}}{1 + \exp\left(0.5g/t_0 - 1.33\right)}\right]$ Note: g is positive for a gap and negative for an overlap $k_g = 8.764^{0.2}\left[1 + \frac{0.024\times 8.764^{1.2}}{1 + \exp\left(0.5\times\left(-45\right)/12.5 - 1.33\right)}\right]$ $k_g = 2.024$	from graph; g/t_0 = -45/12.5 = -3.6 k_g = 2.024

6.3

5.1.2.2

5.1.2.2
Fig. 29

CHS chord end stress factor, k_p	
CHS chord least compressive applied factored stress, $\sigma_{p,Ed}$; $\sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{\left\lvert M_{ip,0,Ed}\right\rvert}{W_{el,ip,0}} + \frac{\left\lvert M_{op,0,Ed}\right\rvert}{W_{el,op,0}}$ 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; $n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right) = \left(\frac{123.30}{355}\right) = 0.347$	
Using formulae:	Using graph:
For $n_p > 0$ (compression): $k_p = 1 - 0.3\, n_p\,(1 + n_p)$ but ≤ 1.0 $k_p = 1 - 0.3\times 0.347\,(1 + 0.347)$ but ≤ 1.0 $k_p = 0.860$	from graph; k_p = 0.860

5.1.2.1

5.1.2.1

5.1.2.1

5.1.2.1
Fig. 28

Reference

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

$$\boxed{N_{1,Rd} = 1134 \text{ kN}}$$

Tension brace (2):

$$N_{2,Rd} = \frac{\sin \theta_1}{\sin \theta_2} N_{1,Rd}$$ 5.1.3

$$N_{2,Rd} = \frac{\sin 45°}{\sin 45°} \times 1134$$

$$\boxed{N_{2,Rd} = 1134 \text{ kN}}$$

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;

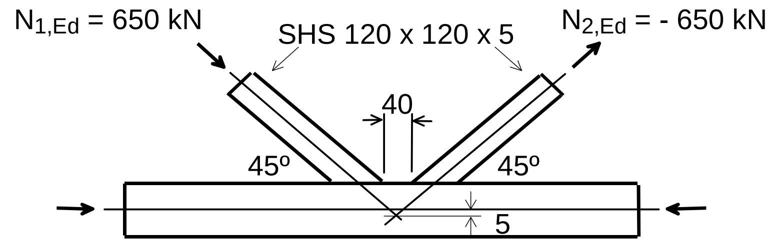
$$\boxed{\text{Brace 1 joint resistance}, \quad N_{1,Rd} = 1134 \text{ kN} \quad > \quad 500 \text{ kN} \quad \therefore \text{PASS}}$$

$$\boxed{\text{Brace 2 joint resistance}, \quad N_{2,Rd} = 1134 \text{ kN} \quad > \quad 400 \text{ kN} \quad \therefore \text{PASS}}$$

4 RHS Gap K-Joint

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

Reference



All material Celsius 355 to EN 10210

Dimensions

b_0 = 200 mm	b_1 = 120 mm	b_2 = 120 mm
h_0 = 200 mm	h_1 = 120 mm	h_2 = 120 mm
t_0 = 10.0 mm	t_1 = 5.0 mm	t_2 = 5.0 mm

Validity limits check

5.3.1 Figure 37

Chord:

$(b_0\text{-}3\ t_0)/t_0$; $(h_0\text{-}3\ t_0)/t_0 \leq 38\varepsilon$ (Class 1 or 2 compression)

(EN 1993-1-1) Table 5.2

	$38\varepsilon = 38\ \sqrt{(235/f_{y0})} = 38\sqrt{(235/355)} = 30.92$	
	$(b_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$	∴PASS
	$(h_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$	∴PASS
$b_0/t_0 \leq 35$	$b_0/t_0 = 200/10 = 20$	∴PASS
$h_0/t_0 \leq 35$	$h_0/t_0 = 200/10 = 20$	∴PASS

Compression brace:

b_i/t_i ; $h_i/t_i \leq 35$	$b_1/t_1 = 120/5 = 24$	∴PASS
	$h_1/t_1 = 120/5 = 24$	∴PASS

Compression brace:

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

(EN 1993-1-1) Table 5.2

	$38\varepsilon = 38\ \sqrt{(235/f_{y0})} = 38\sqrt{(235/355)} = 30.92$	
	$(b_1\text{-}3\ t_1)/t_1 = (120\text{-}3 \times 5)/5 = 21$	∴PASS
	$(h_1\text{-}3\ t_1)/t_1 = (120\text{-}3 \times 5)/5 = 21$	∴PASS

Tension brace:

b_i/t_i ; $h_i/t_i \leq 35$	$b_2/t_2 = 120/5 = 24$	∴PASS
	$h_2/t_2 = 120/5 = 24$	∴PASS
$b_i/b_0 \geq 0.35$	$b_1/b_0 = 120/200 = 0.6$	∴PASS
	$b_2/b_0 = 120/200 = 0.6$	∴PASS
$0.1+0.01\ b_0/t_0 \leq b_i/b_0 \leq 1.0$	$0.1+0.01\ b_0/t_0 = 0.3$	
	$b_1/b_0 = 120/200 = 0.6$	∴PASS
	$b_2/b_0 = 120/200 = 0.6$	∴PASS

Reference

$0.5 \leq h_0/b_0 \leq 2.0$	$h_0/b_0 = 200/200 = 1.0$	$\therefore$PASS
$0.5 \leq h_i/b_i \leq 2.0$	$h_1/b_1 = 120/120 = 1.0$ $h_2/b_2 = 120/120 = 1.0$	$\therefore$PASS $\therefore$PASS
$-0.55\ h_0 \leq e \leq +0.25\ h_0$	$-0.55 \times 200 \leq e \leq +0.25 \times 200$ $-110.0 \leq e \leq +50.0$ $e = +5.0$ mm	$\therefore$PASS
$30° \leq \theta_i \leq 90°$	$\theta_1 = 45°$ $\theta_2 = 45°$	$\therefore$PASS $\therefore$PASS
$g \geq t_1 + t_2$	$40 \geq 5 + 5 = 10$ mm	$\therefore$PASS
$0.5\ b_0(1-\beta) \leq g \leq 1.5\ b_0(1-\beta)$	$g = 40$ mm $\beta = (b_1+b_2+h_1+h_2)/(4\ b_0)$ $\beta = (120+120+120+120)/(4x200) = 0.6$ $0.5 \times 200(1-0.6) \leq g \leq 1.5 \times 200(1-0.6)$ 40 mm $\leq g \leq 120$ mm	$\therefore$PASS
$-0.55\ h_0 \leq e \leq +0.25\ h_0$	$e = 5$ mm $-0.55 \times 200 \leq e \leq +0.25 \times 200$ $-110 \leq e \leq +50$	$\therefore$PASS

Chord face failure (deformation) – brace 1

Note: Brace 1 usually designated compression and brace 2 tension. 5.3.3

Compression brace (1):

$$N_{i,Rd} = \frac{8.9\ k_n\ f_{y0}\ t_0^{\ 2}\ \sqrt{\gamma}}{\sin\theta_i}\left(\frac{b_1 + b_2 + h_1 + h_2}{4\ b_0}\right) / \gamma_{M5}$$

5.3.3

Reference

RHS chord end stress factor, k_n

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

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

5.3.2.1

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;

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

5.3.2.1

$$n = 0.722$$

Using formulae:	Using graph:
For n > 0 (compression): $k_n = 1.3 - \frac{0.4\,n}{\beta}$ but $k_n \le 1.0$ $k_n = 1.3 - \frac{0.4 \times 0.722}{0.6}$ but ≤ 1.0 $k_n = 0.819$	From graph, for $\beta = 0.6$; $k_n = 0.819$

5.3.2.1

5.3.2.1
Fig. 38

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

6.3

$$N_{1,Rd} = \frac{8.9 \times 0.819 \times 355 \times 10^2 \times \sqrt{10}}{\sin 45^\circ} \times \left[\frac{120 + 120 + 120 + 120}{4 \times 200}\right] / 1.0$$

$$\boxed{N_{1,Rd} = 694 \text{ kN}}$$

Chord shear between bracings check – brace 1

Reference

$$N_{i,Rd} = \frac{f_{y0}\ A_{v,0}}{\sqrt{3}\ \sin\theta_i} / \gamma_{M5}$$

5.3.3

where:

for RHS bracings:

$$\alpha = \sqrt{\frac{1}{1+\frac{4\ g^2}{3\ t_0{}^2}}} = \sqrt{\frac{1}{1+\frac{4\times 40^2}{3\times 10^2}}} = 0.212$$

5.3.2.5

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

5.3.2.5

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

$$N_{i,Rd} = \frac{355\times 4424}{\sqrt{3}\ \sin 45°} / 1.0$$

$$\boxed{N_{1,Rd} = 1282\ \text{kN}}$$

Bracing Effective width – brace 1

$$N_{i,Rd} = f_{yi}\ t_i\ (2\ h_i - 4\ t_i + b_i + b_{eff}) / \gamma_{M5}$$

5.3.3

where:

$$b_{eff,i} = \frac{10\ t_0}{b_0} \times \frac{f_{y0}\ t_0}{f_{yi}\ t_i}\ b_i \quad \text{but} \quad b_{eff,i} \le b_i$$

5.3.2.2

$$b_{eff,i} = \frac{10\times 10}{200} \times \frac{355\times 10}{355\times 5} \times 120 = 120\ \text{mm} \quad \text{but} \quad b_{eff,i} \le 120\ \text{mm}$$

$b_{eff,i}$ = 120 mm

$$N_{i,Rd} = 355\times 5\ (2\times 120 - 4\times 5 + 120 + 120) / 1.0$$

$$\boxed{N_{1,Rd} = 817\ \text{kN}}$$

Reference

Chord punching shear – brace 1 5.3.3

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

$\beta \leq 1 - 1/\gamma$

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

$$N_{i,Rd} = \frac{f_{y0}\ t_0}{\sqrt{3}\ \sin\theta_i}\left(\frac{2\ h_i}{\sin\theta_i} + b_i + b_{e,p,i}\right) / \gamma_{M5}$$ 5.3.3

where:

$$b_{e,p,i} = \frac{10\ t_0}{b_0}\,b_i \quad \text{but} \quad b_{e,p,i} \leq b_i$$ 5.3.2.2

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

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

$$N_{i,Rd} = \frac{355 \times 10}{\sqrt{3}\ \sin 45°}\left(\frac{2 \times 120}{\sin 45°} + 120 + 60\right) / 1.0$$

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

Summary - brace 1

Joint strength for brace 1 dictated by chord face deformation.

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

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, $\boxed{N_{2,Rd} = 694\text{ kN}}$

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

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

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

$\therefore$ Brace 2 joint resistance, $\boxed{N_{2,Rd} = 694\text{ kN} \quad > \quad 650\text{ kN} \quad \therefore \text{PASS}}$

Reference

Chord axial load resistance in gap 5.3.3

Check: $N_{0,gap,Rd} \geq N_{0,gap,Ed}$

$$N_{0,gap,Rd} = \left[\left(A_0 - A_{v,0} \right) f_{y0} + A_{v,0}\ f_{y0}\ \sqrt{1 - \left(V_{0,Ed} / V_{pl,0,Rd} \right)^2} \right] / \gamma_{M5}$$ 5.3.3

where:

$A_0 = 74.9\ cm^2 = 7490\ mm^2$

$A_{v,0} = 4424\ mm^2$ 5.3.2.5

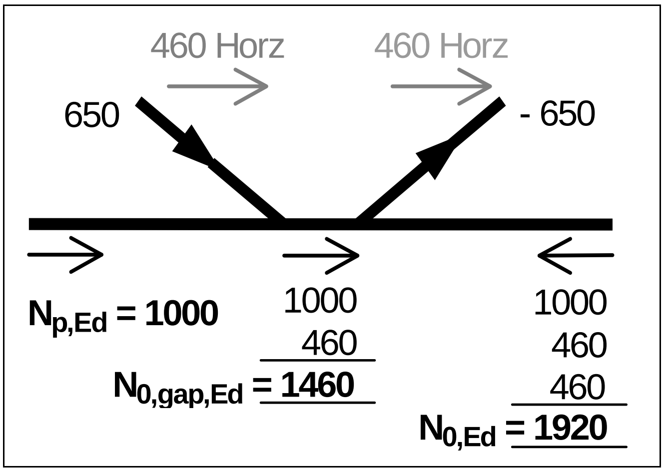
$V_{0,Ed} = \max(|N_{1,Ed}| \sin \theta_1 , |N_{2,Ed}| \sin \theta_2)$ 5.3.3

$V_{0,Ed} = \max(|650| \sin 45° , |-650| \sin 45°) = \max (459.6, 459.6)$

$V_{0,Ed} = 459.6$ kN

$$V_{pl,0,Rd} = \frac{A_{v,0}\ (f_{y0} / \sqrt{3})}{\gamma_{M0}}$$ 5.3.3 (EN 1993-1-1) 6.2.6 (2)

$$V_{pl,0,Rd} = \frac{4424 \times (355 / \sqrt{3})}{1.0} = 906.7\ kN$$



Change of chord axial force in K-joint

$N_{0,gap,Ed} = \max (N_{p,Ed} + N_{1,Ed} \cos \theta_1, N_{0,Ed} + N_{2,Ed} \cos \theta_2)$ 5.3.3

$N_{0,gap,Ed} = \max (1000 + 650 \cos 45°, 1920 + (-650) \cos 45°)$

$N_{0,gap,Ed} = \max (1460, 1460) = 1460$ kN

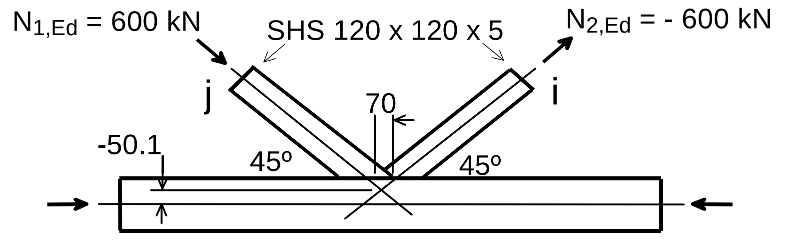
$$N_{0,gap,Rd} = \left[(7490 - 4424)\ 355 + 4424 \times 355\ \sqrt{1 - (459.6 / 906.7)^2} \right] / 1.0$$

$$\boxed{N_{0,gap,Rd} = 2442\ kN \quad > \quad 1460\ kN \quad \therefore PASS}$$

5 RHS Overlap K-Joint

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

Reference



All material Celsius 355 to EN 10210

Dimensions

b_0 = 200 mm	b_1 = 120 mm	b_2 = 120 mm
h_0 = 200 mm	h_1 = 120 mm	h_2 = 120 mm
t_0 = 10.0 mm	t_1 = 5.0 mm	t_2 = 5.0 mm

Validity limits check 5.3.1 Figure 37

Chord:

$(b_0\text{-}3\ t_0)/t_0$; $(h_0\text{-}3\ t_0)/t_0 \le 38\varepsilon$ (Class 1 or 2 compression) (EN 1993-1-1) Table 5.2

$38\varepsilon = 38\ \sqrt{}(235/f_{y0}) = 38\sqrt{}(235/355) = 30.92$

$(b_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

$(h_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

Compression brace:

$(b_1\text{-}3\ t_1)/t_1$; $(h_1\text{-}3\ t_1)/t_1 \le 33\varepsilon$ (Class 1 compression) (EN 1993-1-1) Table 5.2

$33\varepsilon = 33\ \sqrt{}(235/f_{y0}) = 33\sqrt{}(235/355) = 26.85$

$(b_1\text{-}3\ t_1)/t_1 = (120\text{-}3 \times 5)/5 = 21$ ∴PASS

$(h_1\text{-}3\ t_1)/t_1 = (120\text{-}3 \times 5)/5 = 21$ ∴PASS

Tension brace:

b_i/t_i ; $h_i/t_i \le 35$ $b_2/t_2 = 120/5 = 24$ ∴PASS

$h_2/t_2 = 120/5 = 24$ ∴PASS

$0.25 \le b_i/b_0 \le 1.0$ $b_1/b_0 = 120/200 = 0.6$ ∴PASS

$b_2/b_0 = 120/200 = 0.6$ ∴PASS

$0.5 \le h_0/b_0 \le 2.0$ $h_0/b_0 = 200/200 = 1.0$ ∴PASS

$0.5 \le h_i/b_i \le 2.0$ $h_1/b_1 = 120/120 = 1.0$ ∴PASS

$h_2/b_2 = 120/120 = 1.0$ ∴PASS

$-0.55\ h_0 \le e \le +0.25\ h_0$ $-0.55 \times 200 \le e \le +0.25 \times 200$

$-110.0 \le e \le +50.0$

$e = -50.1$ mm ∴PASS

$25\% \le \lambda_{ov}$ $\lambda_{ov} = |g| \sin \theta_i / h_i \times 100\%$

$\lambda_{ov} = 70 \sin 45°/120 \times 100\%$

$\lambda_{ov} = 41.2\%$ ∴PASS

$b_i/b_j \ge 0.75$ $b_i/b_j = 120/120 = 1.0$ ∴PASS

Reference

Bracing Effective width – Overlapping brace, i (2) 5.3.3

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% $\leq \lambda_{ov} < 50\%$

$$N_{i,Rd} = f_{yi}\ t_i \left(b_{eff,i} + b_{e,ov} + 2\ h_i \frac{\lambda_{ov}}{50} - 4\ t_i \right) / \gamma_{M5}$$ 5.3.3

where:

$$b_{eff,i} = \frac{10\ t_0}{b_0} \times \frac{f_{y0}\ t_0}{f_{yi}\ t_i}\ b_i \quad \text{but} \quad b_{eff,i} \leq b_i$$ 5.3.2.2

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

$b_{eff,i}$ = 120 mm

$$b_{e,ov} = \frac{10\ t_j}{b_j} \times \frac{f_{yj}\ t_j}{f_{yi}\ t_i}\ b_i \quad \text{but} \quad b_{e,ov} \leq b_i$$ 5.3.2.2

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

$$b_{e,ov} = 50\ \text{mm}$$

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

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

Bracing Effective width – Overlapped brace, j (1)

$$N_{j,Rd} = N_{i,Rd} \frac{(A_j\ f_{yj})}{(A_i\ f_{yi})}$$ 5.3.3

where:

$A_j = A_1$ = 22.7 cm^2 = 2270 mm^2
$A_i = A_2$ = 22.7 cm^2 = 2270 mm^2

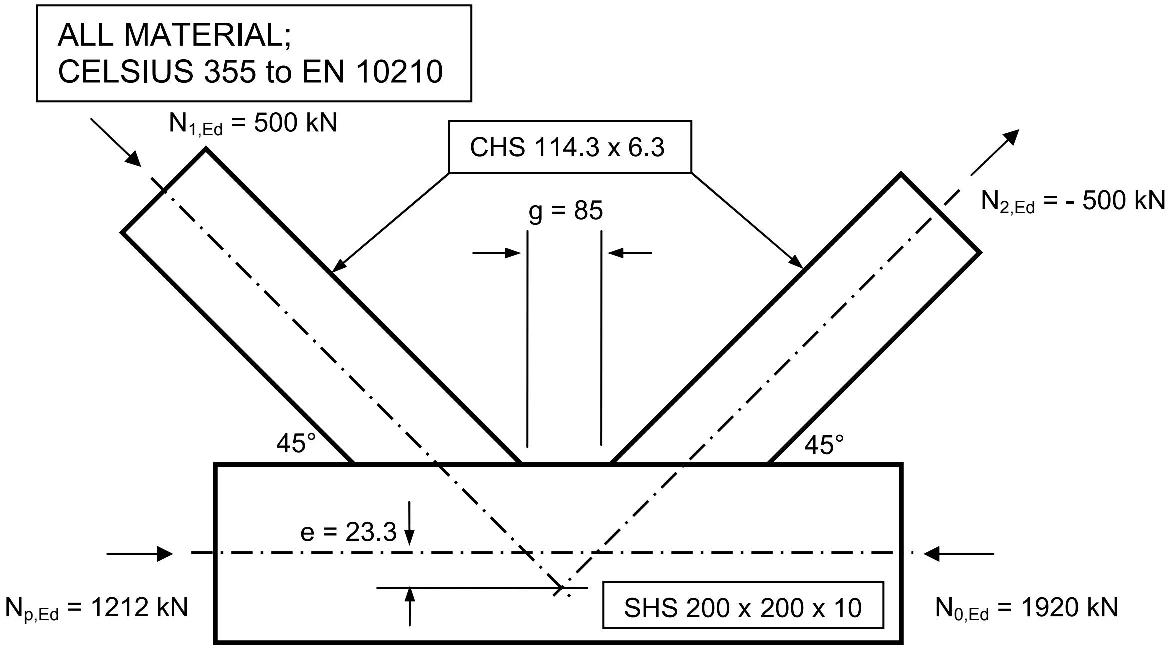
$$N_{j,Rd} = 617 \times \frac{(2270 \times 355)}{(2270 \times 355)}$$

$$\boxed{N_{i,Rd} = N_{1,Rd} = 617\ \text{kN} \quad > \quad 600\ \text{kN} \quad \therefore \text{PASS}}$$

6 RHS Chord CHS Bracings Gap K-Joint

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

<u>Reference</u>



Dimensions

b_0 = 200 mm	d_1 = 114.3 mm	d_2 = 114.3 mm
h_0 = 200 mm	t_1 = 6.3 mm	t_2 = 6.3 mm
t_0 = 10.0 mm		

Validity limits check

Chord:

$(b_0\text{-}3\ t_0)/t_0$; $(h_0\text{-}3\ t_0)/t_0 \le 38\varepsilon$ (Class 1 or 2 compression)

$38\varepsilon = 38\ \sqrt{(235/f_{y0})} = 38\sqrt{(235/355)} = 30.92$

5.3.1 Figure 37
(EN 1993-1-1)
Table 5.2

$(b_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

$(h_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

$b_0/t_0 \le 35$ $b_0/t_0 = 200/10 = 20$ ∴PASS

$h_0/t_0 \le 35$ $h_0/t_0 = 200/10 = 20$ ∴PASS

Compression brace:

$(d_1/t_1 \le 50\varepsilon$ (Class 1 or 2 compression)

(EN 1993-1-1)
Table 5.2

$50\varepsilon = 50\ \sqrt{(235/f_{y0})} = 50\sqrt{(235/355)} = 40.7$

$d_1/t_1 = 114.3/6.3 = 18.1 \le 40.7$ ∴PASS

Tension brace:

$d_i/t_i \le 50$ $d_2/t_2 = 114.3/6.3 = 18.1$ ∴PASS

$0.4 \le d_i/b_0 \le 0.8$ $d_1/b_0 = 114.3/200 = 0.57$ ∴PASS

$d_2/b_0 = 114.3/200 = 0.57$ ∴PASS

Reference

$0.5 \le h_0/b_0 \le 2.0$	$h_0/b_0 = 200/200 = 1.0$	∴PASS
$-0.55\ h_0 \le e \le +0.25\ h_0$	$-0.55 \times 200 \le e \le +0.25 \times 200$ $-110.0 \le e \le +50.0$ $e = +23.0$ mm	∴PASS
$30° \le \theta_i \le 90°$	$\theta_1 = 45°$ $\theta_2 = 45°$	∴PASS ∴PASS
$g \ge t_1 + t_2$	$85 \ge 6.3 + 6.3 = 12.6$ mm	∴PASS

Chord face failure (deformation) – brace 1

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

Compression brace (1):

$$N_{i,Rd} = \frac{8.9\ k_n\ f_{y0}\ t_0^2 \sqrt{\gamma}}{\sin\theta_i}\left(\frac{d_1 + d_2 + d_1 + d_2}{4\ b_0}\right) / \gamma_{M5}$$

5.3.3

RHS chord end stress factor, k_n

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

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

5.3.2.1

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;

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

5.3.2.1

$n = 0.722$

Reference

Using formulae:	Using graph:
For n > 0 (compression): $k_n = 1.3 - \frac{0.4\ n}{\beta}$ but $k_n \leq 1.0$ $k_n = 1.3 - \frac{0.4 \times 0.722}{0.6}$ but ≤ 1.0 $k_n = 0.819$	From graph, for $\beta = 0.6$; $k_n = 0.819$

5.3.2.1

5.3.2.1
Fig. 38

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

6.3

$$N_{1,Rd} = \frac{8.9 \times 0.819 \times 355 \times 10^2 \times \sqrt{10}}{\sin 45°} \times \left[\frac{114.3 + 114.3 + 114.3 + 114.3}{4 \times 200}\right] / 1.0$$

$$\boxed{N_{1,Rd} = 661\,\text{kN......}661 \times \frac{\pi}{4} = 519\ \text{kN}}$$

Chord shear between bracings check – brace 1

$$N_{i,Rd} = \frac{f_{y0}\ A_{v,0}}{\sqrt{3}\ \sin \theta_i} / \gamma_{M5}$$

5.3.3

where:

for CHS bracings:

$$\alpha = 0$$

5.3.2.5

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

5.3.2.5

$$A_{v,0} = (2 \times 200 + 0 \times 200)10 = 4000\ \text{mm}^2$$

$$N_{i,Rd} = \frac{355 \times 4000}{\sqrt{3}\ \sin 45°} / 1.0$$

$$\boxed{N_{1,Rd} = 1159\ \text{kN......} \times \frac{\pi}{4} = 910\ \text{kN}}$$

Bracing Effective width – brace 1 | <u>Reference</u>

$$N_{i,Rd} = f_{yi}\ t_i\ (2\ d_i - 4\ t_i + d_i + b_{eff}) / \gamma_{M5}$$

5.3.3

where:

$$b_{eff,i} = \frac{10\ t_0}{b_0} \times \frac{f_{y0}\ t_0}{f_{yi}\ t_i}\ d_i \quad \text{but} \quad b_{eff,i} \le d_i$$

5.3.2.2

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

$b_{eff,i}$ = 95.2 mm

$$N_{i,Rd} = 355 \times 6.3\ (2 \times 114.3 - 4 \times 6.3 + 114.3 + 95.2) / 1.0$$

$$\boxed{N_{1,Rd} = 923\ \text{kN.....} \times \frac{\pi}{4} = 725\ \text{kN}}$$

Chord punching shear – brace 1
(valid when $\beta \le 1 - 1/\gamma$)

5.3.3

$\beta \le 1 - 1/\gamma$

0.6 ≤ 1 – 1/10 = 0.9 mm ∴check chord punching shear

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

5.3.3

where:

$$b_{e,p,i} = \frac{10\ t_0}{b_0}\ d_i \quad \text{but} \quad b_{e,p,i} \le d_i$$

5.3.2.2

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

$b_{e,p,i}$ = 57.2 mm

$$N_{i,Rd} = \frac{355 \times 10}{\sqrt{3}\ \sin 45^\circ}\left(\frac{2 \times 114.3}{\sin 45^\circ} + 114.3 + 57.2\right) / 1.0$$

$$\boxed{N_{1,Rd} = 1434\ \text{kN........} \times \frac{\pi}{4} = 1126\ \text{kN}}$$

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

∴ Brace 1 joint resistance, $\boxed{N_{1,Rd} = 519\ \text{kN} \quad > \quad 500\ \text{kN} \quad \therefore \text{PASS}}$

Brace 2

Reference

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, $\boxed{N_{2,Rd} = 519\text{ kN}}$

Chord shear check, $\boxed{N_{2,Rd} = 910\text{ kN}}$

Bracing effective width, $\boxed{N_{2,Rd} = 725\text{ kN}}$

Punching shear, $\boxed{N_{2,Rd} = 1126\text{ kN}}$

$\therefore$ Brace 2 joint resistance, $\boxed{N_{2,Rd} = 519\text{ kN} \quad > \quad 500\text{ kN} \quad \therefore \text{PASS}}$

Chord axial load resistance in gap

Check: $N_{0,gap,Rd} \geq N_{0,gap,Ed}$

$$N_{0,gap,Rd} = \left[\left(A_0 - A_{v,0}\right) f_{y0} + A_{v,0}\ f_{y0}\ \sqrt{1-\left(V_{0,Ed} / V_{pl,0,Rd}\right)^2} \right] / \gamma_{M5}$$ 5.3.3

where:

A_0 = 74.9 cm^2 = 7490 mm^2

$A_{v,0}$ = 4000 mm^2 5.3.2.5

$V_{0,Ed}$ = max($|N_{1,Ed}|$ sin θ_1 , $|N_{2,Ed}|$ sin θ_2) 5.3.3

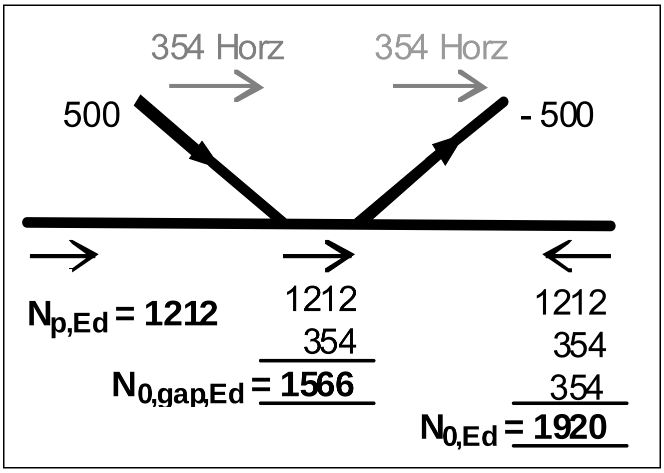
$V_{0,Ed}$ = max(|500| sin 45° , |-500| sin 45°) = max (354,354)

$V_{0,Ed}$ = 354 kN 5.3.2.2

$$V_{pl,0,Rd} = \frac{A_{v,0}\ (f_{y0} / \sqrt{3})}{\gamma_{M0}}$$ 5.3.3
(EN 1993-1-1)
6.2.6 (2)

$$V_{pl,0,Rd} = \frac{4000 \times (355 / \sqrt{3})}{1.0} = 819.8\text{ kN}$$

Reference



Change of chord axial force in K-joint

$N_{0,gap,Ed}$ = max ($N_{p,Ed}$ + $N_{1,Ed}$ cos θ_1, $N_{0,Ed}$ + $N_{2,Ed}$ cos θ_2) 5.3.3

$N_{0,gap,Ed}$ = max (1212 + 500 cos 45°, 1920 + (-500) cos 45°)

$N_{0,gap,Ed}$ = max (1566, 1566) = 1566 kN

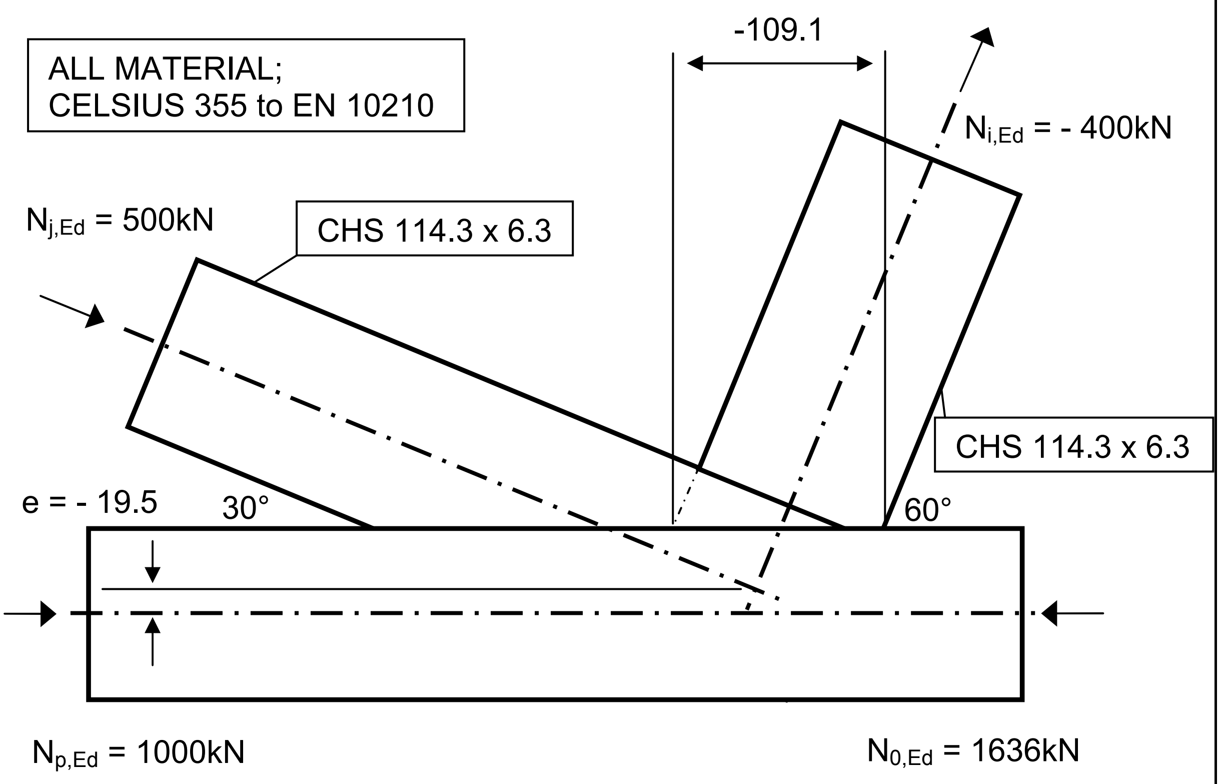
$$N_{0,gap,Rd} = \left[(7490 - 4000)\,355 + 4000 \times 355\,\sqrt{1 - (354\,/\,819.8)^2}\,\right] / 1.0$$

$$\boxed{N_{0,gap,Rd} = 2520 \text{ kN} \quad > \quad 1566 \text{ kN} \quad \therefore \text{PASS}}$$

7 RHS Chord CHS Bracings Overlap K-Joint 82.7

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

Reference



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

Dimensions

h_0 = 100.0 mm
t_0 = 10.0 mm
$f_{u,j}$ = 470 N/mm²

b_0 = 200.0 mm
t_i = 6.3 mm

d_i = 114.3 mm
t_j = 6.3 mm

d_j = 114.3 mm
$f_{u,i}$ = 470 N/mm²

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

For Eccentricity;

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

where $g = \dfrac{\lambda_{ov}\times d_i}{100\times\sin\theta_i}$

$$g = \frac{82.7\times 114.3}{100\times\sin\left(60^\circ\right)}$$

$$g = \underline{-109.1\,\text{mm}}$$

6.5 Figure 57

Reference

$$e = \left[\frac{114.3}{2\times\sin(60°)} + \frac{114.3}{2\times\sin(30°)} + (-109.1)\right]\times\left[\frac{\sin(60°)\times\sin(30°)}{\sin(60°+30°)}\right] - \frac{100}{2}$$

$$\underline{e = -19.5\text{ mm}}$$

Validity limits check

$b_0/t_0 \le 38\varepsilon^2$ (Class 1 or 2 for compression chord)			
	$38\varepsilon^2 = 38\,[\sqrt{(235/f_{y0})}]^2 = 38(235/355) = 25.15$		**(EN1993-1-1)** **(Table 5.2)**
	$b_0/t_0 = 200.0/10.0 = 20.0 < 25.15$	∴PASS	
$d_j/t_j \le 50\varepsilon^2$ (Class 1 for compression brace)			
	$50\varepsilon^2 = 50\,[\sqrt{(235/f_{y0})}]^2 = 50(235/355) = 33.10$		**(EN1993-1-1)** **(Table 5.2)**
	$d_j/t_j = 114.3/6.3 = 18.14 < 33.10$	∴PASS	
$d_i/t_i \le 50$ (Tension Brace)	$d_i/t_i = 114.3/6.3 = 18.14 \le 50$	∴PASS	
$0.4 \le d_i/b_0 \le 0.8$	$d_i/d_0 = 114.3/200.0 = 0.57$	∴PASS	
	$d_j/d_0 = 114.3/200.0 = 0.57$	∴PASS	
$0.5 \le h_0/\ b_0 \le 2.0$	$h_0/\ b_0 = 100.0/200.0 = 0.50$	∴PASS	
$-0.55\ h_0 \le e \le +0.25\ h_0$	$-0.55 \times 100.0 \le e \le +0.25 \times 100.0$		
	$-55 \le\ e\ \le +25$		
	$e = -19.5$ mm	∴PASS	
$\lambda_{ov} \geq 25\%$	$\lambda_{ov} = \lvert g\rvert \sin\theta_I / d_i \times 100\%$	∴PASS	
	$\lambda_{ov} = 109.1 \sin 60°/114.3 \times 100\%$		
	$\lambda_{ov} = 82.7\%$	∴PASS	
$30° \le \theta_I \le 90°$	$\theta_j = 30°$	∴PASS	
	$\theta_I = 60°$	∴PASS	
$d_i/d_j \ge 0.75$	$d_i/d_j = 114.3/114.3 = 1.0$	∴PASS	
			5.3 Figure 37

Brace Effective Width;

Overlapping brace (i):

$$N_{i,Rd} = f_{yi}t_i\left(d_i + d_{e,ov} + 2d_i - 4t_i\right)/\gamma_{M5}$$

5.3.3

where:

$$d_{e,ov} = \frac{10}{d_j/t_j}\times\frac{f_{yj}\times t_j}{f_{yi}\times t_i}\times d_i \quad \text{but} \quad d_{e,ov} \le d_i$$

5.3.2.2

Reference

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

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

$$\therefore \quad N_{i,Rd} = 355 \text{ x } 6.3 \text{ x } (114.3 + 63 + 228.6 - 25.2) / 1.0$$

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

Brace Effective Width;

Overlapped Brace (j):

$$N_{j,Rd} = N_{i,Rd} \times \frac{(A_j \times f_{yj})}{(A_i \times f_{yi})}$$

5.3.3

where:

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

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

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

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

Overlapping Bracings Shear Check For CHS Bracings;

Vertical component of $N_{i,Ed}$ & $N_{j,Ed}$;

$$\therefore \quad N_{i,v,Ed} = N_{i,Ed} \times \sin(\theta_i) \; \& \; N_{j,v,Ed} = N_{j,Ed} \times \sin(\theta_j)$$

$$\therefore \quad N_{i,v,Ed} = 400 \times \sin(60°) = 346.4 \text{kN}$$

$$\therefore \quad N_{j,v,Ed} = 500 \times \sin(30°) = 250 \text{ kN}$$

$$\therefore \quad \% \text{ vert. component diff.} = \frac{346.4 - 250}{346.4} \times 100 = 27.8\%$$

∴ As difference between brace vertical component $> 20\%$ hidden toe needs welding.

Shear Check valid when 80% < λ_{ov} < 100% and overlapped brace hidden toe welded;

Reference

$N_{i,Ed}\cos\theta_i + N_{j,Ed}\cos\theta_j \le ....$

$$......\frac{\pi}{4}\times\left[\frac{f_{u,i}}{\sqrt{3}}\times\frac{\left[\left(\frac{100-\lambda_{ov}}{100}\right)\times 2d_i + d_{eff,i}\right]\times t_i}{\sin\theta_i} + \frac{f_{u,j}}{\sqrt{3}}\times\frac{\left(2d_j + c_s\times d_{eff,j}\right)\times t_j}{\sin\theta_j}\right]\times\frac{1}{\gamma_{M5}}$$

5.3.3

where : $d_{eff,i} = \frac{10t_0}{b_0}\times\frac{f_{y,0}\times t_0}{f_{y,i}\times t_i}\times d_i$ but $\le d_i$

5.3.2.2

$d_{eff,i} = \frac{10\times10}{200}\times\frac{355\times10}{355\times6.3}\times114.3$ but ≤ 114.3

$d_{eff,i} = 91.4 \le 114.3 \therefore \underline{d_{eff,i} = 91.4\text{ mm}}$

where : $d_{eff,j} = \frac{10t_0}{b_0}\times\frac{f_{y,0}\times t_0}{f_{y,j}\times t_j}\times d_j$ but $\le d_j$

5.3.2.2

$d_{eff,j} = \frac{10\times10}{200}\times\frac{355\times10}{355\times6.3}\times114.3$ but ≤ 114.3

$d_{eff,j} = 91.4 \le 114.3 \therefore \underline{d_{eff,j} = 91.4\text{ mm}}$

where : $c_s = 2$ (hidden toe welded)

5.1.3

$\therefore$ $N_i\cos\theta_i + N_j\cos\theta_j \le ....$

$$.....\frac{\pi}{4}\times\left[\frac{470}{\sqrt{3}}\times\frac{\left[\left(\frac{100-82.7}{100}\right)\times(2\times114.3)+91.4\right]\times6.3}{\sin(60^\circ)} + \frac{470}{\sqrt{3}}\times\frac{((2\times114.3)+2\times91.4)\times6.3}{\sin(30^\circ)}\right]\times\frac{1}{1}$$

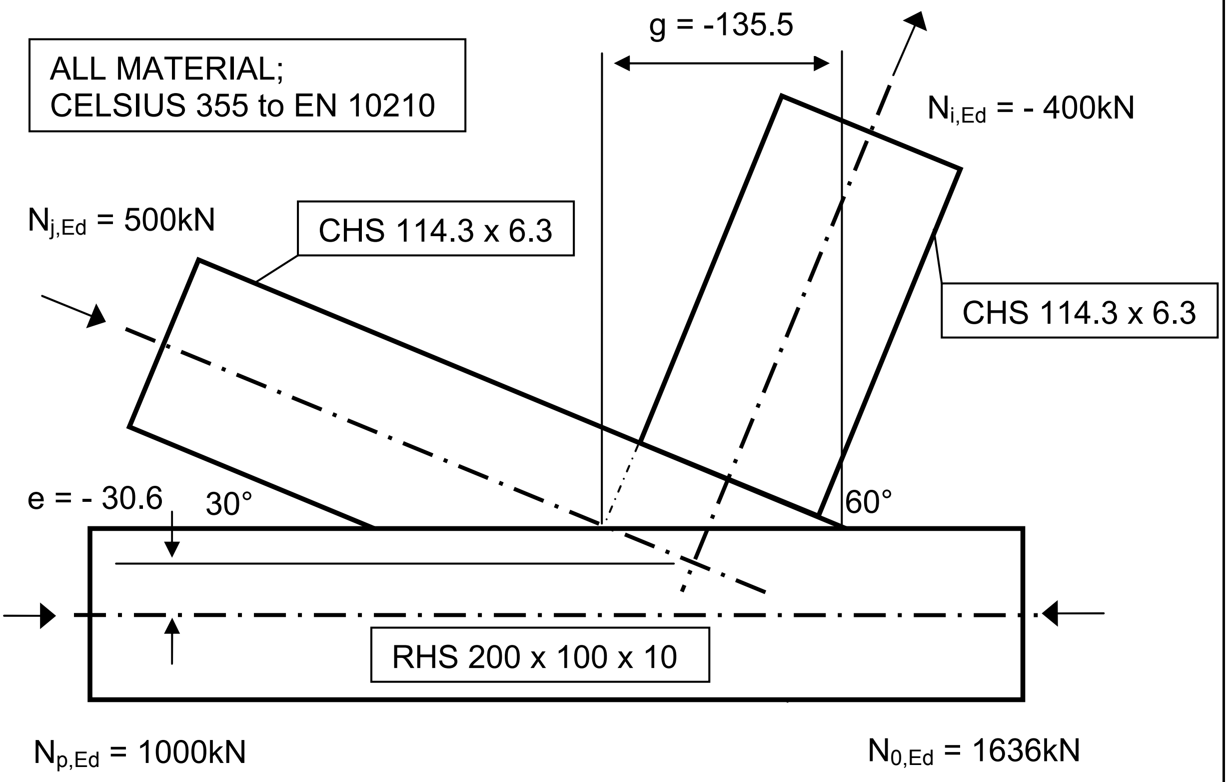
$\underline{= 1307\text{ kN}}$

$\therefore$ $\boxed{400\ \times\cos(60^\circ)+500\times\cos(30^\circ) = 633\text{ kN} \quad \le 1307\text{ kN} \quad \therefore \quad \text{PASS}}$

8 RHS Chord CHS Bracings Overlap K-Joint 102.7

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

Reference



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

Dimensions

h_0 = 100.0 mm	b_0 = 200.0 mm	d_i = 114.3 mm	d_j = 114.3 mm
t_0 = 10.0 mm	t_i = 6.3 mm	t_j = 6.3 mm	$f_{u,i}$ = 470 N/mm²
$f_{u,j}$ = 470 N/mm²			

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

For Eccentricity;

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

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

$$g = \frac{102.7 \times 114.3}{100 \times \sin(60°)}$$

$$g = \underline{-135.5 \text{ mm}}$$

6.5 Figure 57

Reference

$$e = \left[\frac{114.3}{2 \times \sin(60°)} + \frac{114.3}{2 \times \sin(30°)} + (-135.5)\right] \times \left[\frac{\sin(60°) \times \sin(30°)}{\sin(60° + 30°)}\right] - \frac{100}{2}$$

$$\underline{e = -30.6 \text{ mm}}$$

Validity limits check

$b_0/t_0 \leq 38\varepsilon^2$ (Class 1 or 2 for compression chord) — **(EN1993-1-1) Table 5.2**

$38\varepsilon^2 = 38\,[\sqrt{(235/f_{y0})}]^2 = 38(235/355) = 25.15$

$b_0/t_0 = 200.0/10.0 = 20.0 < 25.15$ ∴PASS

$d_j/t_j \leq 50\varepsilon^2$ (Class 1 for compression brace) — **(EN1993-1-1) Table 5.2**

$50\varepsilon^2 = 50\,[\sqrt{(235/f_{y0})}]^2 = 50(235/355) = 33.10$

$d_j/t_j = 114.3/6.3 = 18.14 < 33.10$ ∴PASS

$d_i/t_i \leq 50$ (Tension Brace) $d_i/t_i = 114.3/6.3 = 18.14 \leq 50$ ∴PASS

$0.4 \leq d_i/b_0 \leq 0.8$ $d_i/d_0 = 114.3/200.0 = 0.57$ ∴PASS

$d_j/d_0 = 114.3/200.0 = 0.57$ ∴PASS

$0.5 \leq h_0/b_0 \leq 2.0$ $h_0/b_0 = 100.0/200.0 = 0.50$ ∴PASS

$-0.55\,h_0 \leq e \leq +0.25\,h_0$ $-0.55 \times 100.0 \leq e \leq +0.25 \times 100.0$

$-55 \leq e \leq +25$

$e = -30.6$ mm ∴PASS

$\lambda_{ov} \geq 25\%$ $\lambda_{ov} = |g| \sin\theta_i / d_i \times 100\%$ ∴PASS

$\lambda_{ov} = 135.5 \sin 60°/114.3 \times 100\%$

$\lambda_{ov} = 102.7\%$ ∴PASS

$30° \leq \theta_i \leq 90°$ $\theta_j = 30°$ ∴PASS

$\theta_i = 60°$ ∴PASS

$d_i/d_j \geq 0.75$ $d_i/d_j = 114.3/114.3 = 1.0$ ∴PASS — **5.3 Figure 37**

Brace Effective Width;

Overlapping brace (i):

$$N_{i,Rd} = f_{yi} t_i \left(d_i + d_{e,ov} + 2d_i - 4t_i\right) / \gamma_{M5} \quad \text{where } \lambda_{ov} \geq 80\%;$$

5.3.3

where:

$$d_{e,ov} = \frac{10}{d_j / t_j} \times \frac{f_{yj} \times t_j}{f_{yi} \times t_i} \times d_i \ \text{ but } \ d_{e,ov} \leq d_i$$

5.3.2.2

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

$$d_{e,ov} = 63 \ \text{ but } \leq 114.3 \ \therefore \ d_{e,ov} = \underline{63 \text{ mm}}$$

Reference

$N_{i,Rd}$ = 355 x 6.3 x (114.3 + 63 + 228.6 – 25.2) / 1.0

$\boxed{N_{i,Rd} = 851 \text{ kN} \text{ -------> } 851 \times \pi/4 = \underline{668 \text{ kN}} \quad > \quad 400 \text{ kN} \quad \therefore \quad \text{PASS}}$

Brace Effective Width;

Overlapped Brace (j):

$$N_{j,Rd} = N_{i,Rd} \times \frac{\left(A_j \times f_{yj}\right)}{\left(A_i \times f_{yi}\right)}$$

5.3.3

where:

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

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

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

$$\boxed{N_{j,Rd} = 668 \text{ kN} \quad > \quad 500 \text{ kN} \qquad \therefore \qquad \text{PASS}}$$

Overlapping Bracings Shear Check for CHS Bracings; where $\lambda_{ov} > 100\%$;

$$N_{i,Ed} \cos\theta_i + N_{j,Ed} \cos\theta_j \le \ldots\ldots\ldots.$$

5.3.3

$$\ldots\ldots \frac{\pi}{4} \times \frac{f_{u,j}}{\sqrt{3}} \times \frac{\left(3 \times d_j + d_{eff,j}\right) \times t_j}{\sin\theta_j} \times \frac{1}{\gamma_{M5}}$$

where:

$$d_{eff,j} = \frac{10 t_0}{b_0} \times \frac{f_{y,0} \times t_0}{f_{y,j} \times t_j} \times d_j \qquad \text{but} \le d_j$$

5.3.2.2

$$d_{eff,j} = \frac{10 \times 10}{200} \times \frac{355 \times 10}{355 \times 6.3} \times 114.3 \qquad \text{but} \le 114.3$$

$$d_{eff,j} = 91.4 \le 114.3 \therefore \underline{d_{eff,j} = 91.4 \text{ mm}}$$

$$\therefore \qquad N_{i,Ed} \cos\theta_i + N_{j,Ed} \cos\theta_j \le \ldots\ldots\ldots.$$

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

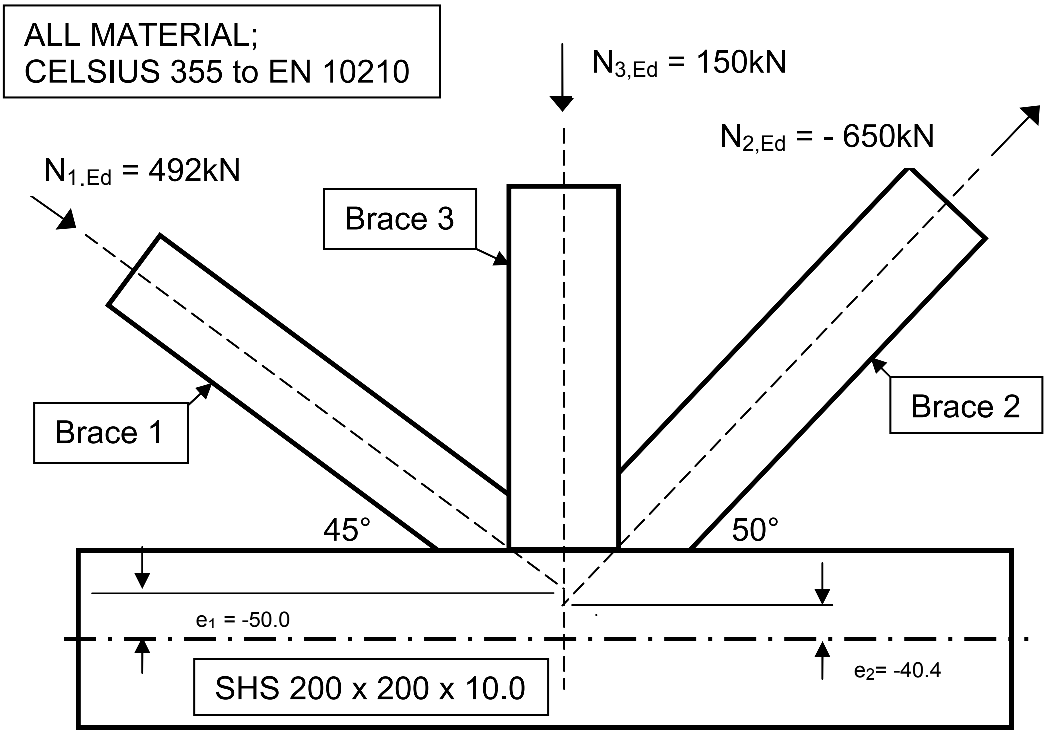
$$N_i \cos\theta_i + N_j \cos\theta_j \le \quad \underline{673 \text{ kN}}$$

$$\boxed{400 \times \cos\left(60°\right) + 500 \times \cos\left(30°\right) = 633 \text{ kN} \quad \le 673 \text{ kN} \quad \therefore \qquad \text{PASS}}$$

9 RHS Chord RHS Bracings Overlap KT-Joint

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

Reference



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

h_0 = 200.0 mm	h_1 = 90.0 mm	h_2 = 100.0 mm	h_3 = 100.0 mm
b_0 = 200.0 mm	b_1 = 90.0 mm	b_2 = 100.0 mm	b_3 = 100.0 mm
t_0 = 10.0 mm	t_1 = 5.0 mm	t_2 = 6.3 mm	t_3 = 6.3 mm
γ_{M5} = 1.0	A_1 = 23.2cm^2	A_2 = 16.7cm^2	A_3 = 23.2cm^2

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.

GEOMETRIC CALCULATIONS

Reference

For Eccentricity; Brace 1 in relation to Brace 3;

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

Brace 1 to 3 overlap, λ_{ov}= 50%;

where; $g = \frac{\lambda_{ov}\times b_i}{100\times\sin\theta_i}$

6.5 Figure 57

$$g_1 = \frac{50.0\times 90.0}{100\times\sin(45°)}\times -1$$

$g_1 = \underline{-63.6\,mm}$ (gap is negative as it's an overlap)

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

$= -50.0\,mm$

For Eccentricity, Brace 2 in relation to Brace 3;

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

Brace 2 to 3 overlap, λ_{ov}= 50%;

where; $g_2 = \frac{\lambda_{ov}\times b_2}{100\times\sin\theta_2}$

6.5 Figure 57

$$g_2 = \frac{50.0\times 100}{100\times\sin(50°)}$$

$g_2 = \underline{-65.3\text{ mm}}$ (gap is negative as it's an overlap)

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

$= -40.4$ mm

Validity limits check for both K-Joints

5.3 Figure 37

$(b_0\text{-}3\ t_0)/t_0$; $(h_0\text{-}3\ t_0)/t_0 \le 38\varepsilon$ (Class 1 or 2 for chord)

(EN1993-1-1) Table 5.2

$38\varepsilon = 38\ [\sqrt{(235/f_{y0})}] = 38\sqrt{(235/355)} = 30.92$

$(b_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

$(h_0\text{-}3\ t_0)/t_0 = (200\text{-}3 \times 10)/10 = 17$ ∴PASS

$(b_1\text{-}3\ t_1)/t_1$; $(h_1\text{-}3\ t_1)/t_1 \le 33\varepsilon$ (Class 1 for compression braces)

(EN1993-1-1) Table 5.2

Reference

$33\varepsilon = 33\,[\sqrt{(235/f_{y0})}] = 33\sqrt{(235/355)} = 26.85$

$(b_1\text{-}3\,t_1)/t_1 = (90\text{-}3 \times 5)/5 = 15$ ∴PASS

$(h_1\text{-}3\,t_1)/t_1 = (90\text{-}3 \times 5)/5 = 15$ ∴PASS

$(b_3\text{-}3\,t_3)/t_3 = (100\text{-}3 \times 6.3)/6.3 = 12.9$ ∴PASS

$(h_3\text{-}3\,t_3)/t_3 = (100\text{-}3 \times 6.3)/6.3 = 12.9$ ∴PASS

$b_i/t_i\ ;\ h_i/t_i \le 35$ (Tension Brace) $b_2/t_2 = 100.0/6.3 = 15.9$ ∴PASS

$h_2/t_2 = 100.0/6.3 = 15.9$ ∴PASS

$0.25 \le b_i/b_0 \le 1.0$ $b_1/b_0 = 90.0/200.0 = 0.45$ ∴PASS

$b_2/b_0 = 100.0/200.0 = 0.5$ ∴PASS

$b_3/b_0 = 100.0/200.0 = 0.5$ ∴PASS

$0.5 \le h_0/\,b_0 \le 2.0$ $h_0/\,b_0 = 200.0/200.0 = 1.0$ ∴PASS

$0.5 \le h_i/\,b_i \le 2.0$ $h_1/b_1 = 90.0/90.0 = 1.0$ ∴PASS

$h_2/b_2 = 100.0/100.0 = 1.0$ ∴PASS

$h_3/b_3 = 100.0/100.0 = 1.0$ ∴PASS

$-0.55\,h_0 \le e \le +0.25\,h_0$ $-0.55 \times 200.0 \le e \le +0.25 \times 200.0$

$-110 \le e \le +50$

$e_1 = -50$ mm ∴PASS

$e_2 = -40.4$ mm ∴PASS

$\lambda_{ov} \geq 25\%$ $\lambda_{ov,1} = |g|\,\sin\theta_1 / h_1 \times 100\%$

$\lambda_{ov,1} = 63.6 \times \sin 45°/90 \times 100\%$

$\lambda_{ov,1} = 50\%$ ∴PASS

$\lambda_{ov,2} = 65.3 \times \sin 50°/100 \times 100\%$ 6.5 Figure 57

$\lambda_{ov,2} = 50\%$ ∴PASS

$30° \le \theta_i \le 90°$ $\theta_1 = 45°$ ∴PASS

$\theta_2 = 50°$ ∴PASS

$\theta_3 = 90°$ ∴PASS

$b_i/b_j \geq 0.75$ $b_1/b_3 = 90.0/100.0 = 0.9$ ∴PASS

$b_2/b_3 = 100.0/100.0 = 1.0$ ∴PASS

Brace 1 & 3 as overlap K-Joint

Brace Effective Width Failure for 50% ≤λ_{OV}<80%;

$$N_{i,Rd} = f_{yi}\,t_i\left(b_{eff,i} + b_{e,ov} + 2h_i - 4t_i\right) / \gamma_{M5}$$

5.3.3 (K- & N-Overlap Sect)

where;

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

5.3.2.2

Reference

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

$$b_{e,ov,1} = 71.4 \text{ but } \leq 90.0 \therefore b_{e,ov,1} = 71.4 \text{ mm}$$

where;

$$b_{eff,1} = \frac{10 \times t_0}{b_0} \times \frac{f_{y0} \times t_0}{f_{y1} \times t_1} \times b_1 \text{ but } b_{eff,1} \leq b_1$$

5.3.2.2

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

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

$N_{1,Rd}$ = 355 x 5.0 x (90.0 + 71.4 + 2 x 90 – 4 x 5.0)/1.0

$$\boxed{N_{1,Rd} = 570 \text{ kN} > 492 \text{ kN} \quad \therefore \text{PASS}}$$

For overlapped Brace (3):

where; $$N_{j,Rd} = N_{i,Rd} \times \frac{(A_j \times f_{yj})}{(A_i \times f_{yi})}$$

5.3.3 (K- & N-Overlap Sect)

(Tata Technical Guide TST02)

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

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

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

$$\boxed{N_{3,Rd} = 792\text{kN} > 150\text{kN} \quad \therefore \text{PASS}}$$

Brace 2 & 3 as overlap K-Joint

Brace Effective Width Failure for 50% ≤λ_{OV}<80%;

$$b_{e,ov,2} = \frac{10t_3}{b_3} \times \frac{f_{y3} \times t_3}{f_{y2} \times t_2} \times b_2 \text{ but } b_{e,ov,2} \leq b_2$$

5.3.2.2

Reference

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

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

where;

$$b_{eff,2} = \frac{10 \times t_0}{b_0} \times \frac{f_{y0} \times t_0}{f_{y2} \times t_2} \times b_2 \text{ but } b_{eff,2} \leq b_2$$

5.3.2.2

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

$$b_{eff,2} = 79.4\,\text{mm} \text{ but } b_{eff,2} \leq 100 \;\therefore b_{eff,2} = 79.4 \text{ mm}$$

$N_{2,Rd}$ = 355 x 6.3 x (79.4 + 63 + 2 x 100 – 4 x 6.3) / 1.0

$$\boxed{N_{2,Rd} = 709 \text{ kN } > 650 \text{ kN} \qquad \therefore \text{PASS}}$$

For Overlapped Brace (3):

where: $$N_{j,Rd} = N_{i,Rd} \times \frac{(A_j \times f_{yj})}{(A_i \times f_{yi})}$$

5.3.3 (K- & N-Overlap Sect)

$$A_3 = 23.2 \text{ cm}^2 = 2320 \text{ mm}^2$$
$$A_2 = 23.2 \text{ cm}^2 = 2320 \text{ mm}^2$$

(Tata Technical Guide TST02)

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

$$\boxed{N_{3,Rd} = 709\text{kN} > 150\text{kN} \qquad \therefore \text{PASS}}$$

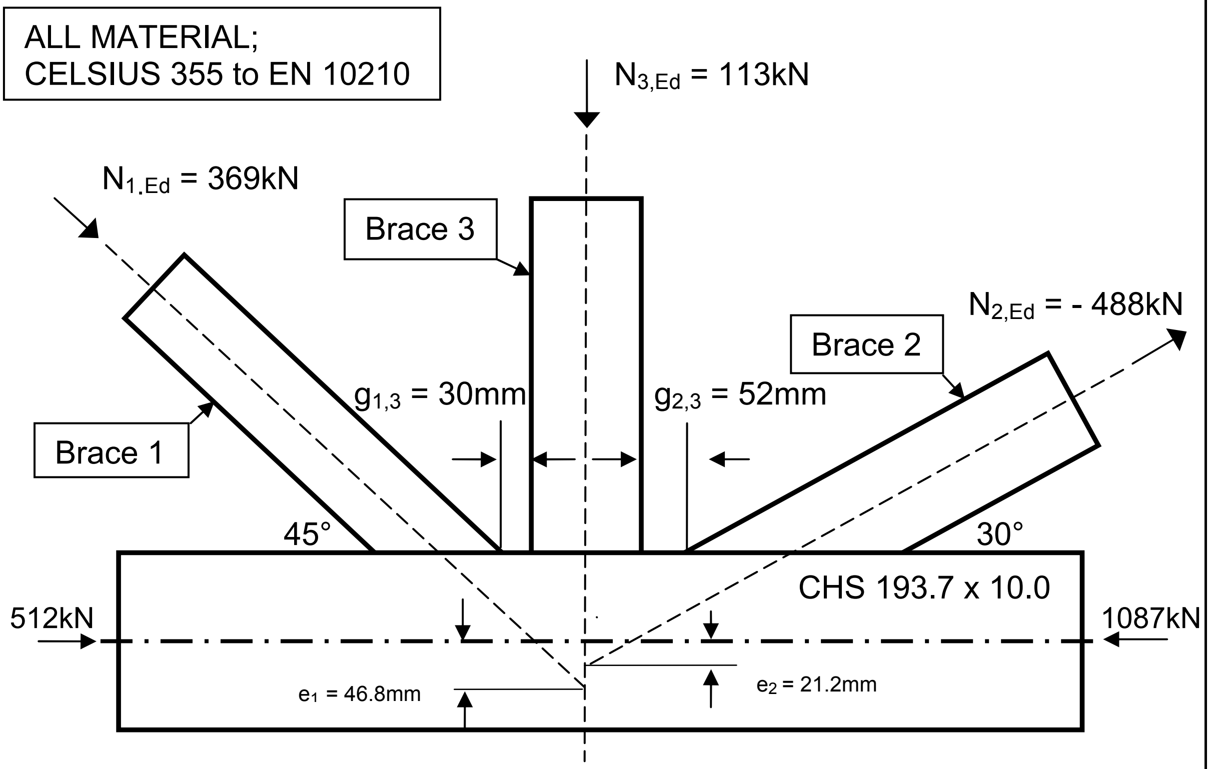
SUMMARY

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.

10 CHS Chord CHS Bracings Gap KT-Joint

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

Reference



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 mm	d_1 = 88.9 mm	d_2 = 101.6 mm	d_3 = 101.6 mm
t_0 = 10.0 mm	t_1 = 5.0 mm	t_2 = 6.3 mm	t_3 = 6.3 mm
γ_{M5} = 1.0	A_1 = 13.2cm^2	A_2 = 18.9cm^2	A_3 = 18.9cm^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

Reference

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 = 30mm;

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

$$\boxed{= 46.8\,\text{mm}}$$

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 = 52mm;

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

$$\boxed{= 21.2\,\text{mm}}$$

Validity limits check for both K-Joints

5.1.1 Figure 27

$10 \le d_0/t_0 \le 50$	$d_0/t_0 = 193.7/10.0 = 19.37$	∴PASS	
$d_0/t_0 \le 70\varepsilon^2$ (Class 1 or 2 for chord)			
	$70\varepsilon^2 = 70\,[\surd(235/f_{y0})]^2 = 70\surd\,(235/355)^2 = 46.34$		**(EN1993-1-1) Table 5.2**
	$d_0/t_0 = 19.37 \le 46.34$	∴PASS	
$d_i/t_i \le 50$	$d_1/t_1 = 88.9/5.0 = 17.78$	∴PASS	
	$d_2/t_2 = 101.6/6.3 = 16.13$	∴PASS	
	$d_3/t_3 = 101.6/6.3 = 16.13$	∴PASS	
$d_i/t_i \le 70\varepsilon^2$ (Class 1 or 2 for compression bracings)			
	$70\varepsilon^2 = 70\,[\surd(235/f_{y0})]^2 = 70\surd\,(235/355)^2 = 46.34$		**(EN1993-1-1) Table 5.2**
	$d_1/t_1 = 17.78$	∴PASS	
	$d_3/t_3 = 16.13$	∴PASS	
$0.2 \le d_i/d_0 \le 1.0$	$d_1/d_0 = 88.9/193.7 = 0.46$	∴PASS	
	$d_2/d_0 = 101.6/193.7 = 0.52$	∴PASS	
	$d_3/d_0 = 101.6/193.7 = 0.52$	∴PASS	
$-0.55\ d_0 \le e \le +0.25\ d_0$	$-0.55 \times 193.7 \le e \le +0.25 \times 193.7$		
	$-106.5 \le e \le +48.4$		
	$e_1 = 46.8$ mm	∴PASS	
	$e_2 = 21.2$ mm	∴PASS	

Reference

$g \geq t_1 + t_2$ but $\leq 12t_0$ for $g_{1,3} \geq t_1 + t_3 = 5.0 + 6.3 = 11.3$ mm but $\leq 12t_0$

$g_{2,3} \geq t_2 + t_3 = 6.3 + 6.3 = 12.6$ mm but $\leq 12t_0$

$12t_0 = 12 \times 10.0 = 120$ mm

$g_{1,3} = 30$ mm $\therefore$PASS

$g_{2,3} = 52$ mm $\therefore$PASS

$30° \leq \theta_i \leq 90°$ $\theta_1 = 45°$ $\therefore$PASS

$\theta_2 = 30°$ $\therefore$PASS

$\theta_3 = 90°$ $\therefore$PASS

Chord Face Failure (deformation);

Based on compression brace with most compressive load;

Compression brace (1);

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

5.1.3 (K- & N-Joints)

Gap/lap factor, k_g;

Using Formulae:

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

5.1.2.2 (k_g)

where;

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

6.3 (γ)

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:	Using Graph:
$k_g = 9.69^{0.2}\left[1 + \frac{0.024 \times 9.69^{1.2}}{1 + \exp(0.5 \times 52 / 10.0 - 1.33)}\right]$ $k_g = 1.70$	From graph; g/t_0 = 52/10.0 = 5.2 k_g = 1.70

For graph 5.1.2.2 Fig. 29

Reference

CHS chord end stress factor, k_p

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

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

5.1.2.1

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; $n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right) = \left(\frac{88.7}{355}\right) = 0.25$

5.1.2.1

Using formulae:	Using graph:
For $n_p > 0$ (compression): $k_p = 1 - 0.3\ n_p\ (1 + n_p)$ but ≤ 1.0 $k_p = 1 - 0.3 \times 0.25\ (1 + 0.25)$ but ≤ 1.0 $k_p = 0.91$	from graph; $k_p = 0.91$

5.1.2.1 (k_p)

For graph
5.1.2.1 Fig. 28

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

$$\boxed{N_{1,Rd} = 538\text{kN} > 369\text{kN} \quad \therefore \quad \text{PASS}}$$

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

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

5.6.2

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

$$\boxed{374\ \text{kN} \leq 380\ \text{kN} \quad \therefore \quad \text{PASS}}$$

Reference

$$\left|N_{2,Ed}\right| \times \sin\theta_2 \le N_{1,Rd} \times \sin\theta_1$$

$$448 \times \sin 30^\circ \le 538 \times \sin 45^\circ$$

$$\boxed{244\text{ kN} \le 380\text{ kN} \quad \therefore \quad \text{PASS}}$$

Check for Chord Punching Shear failure;

5.1.3

Valid if: $d_i \le d_0 - 2t_0$ where $d_0 - 2t_0 = 193.7 - (2 \times 10.0) = 173.7$ mm

$d_1 = 88.9$ mm

$d_2 = 101.6$ mm

$d_3 = 101.6$ mm

Therefore check for Chord Punching Shear;

5.1.3

$$N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} \times t_0 \times \pi \times d_1 \times \frac{1+\sin\theta_i}{2 \times \sin^2\theta_i} / \gamma_{M5}$$

For Brace 1;

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

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

For Brace 2;

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

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

For Brace 3;

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

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

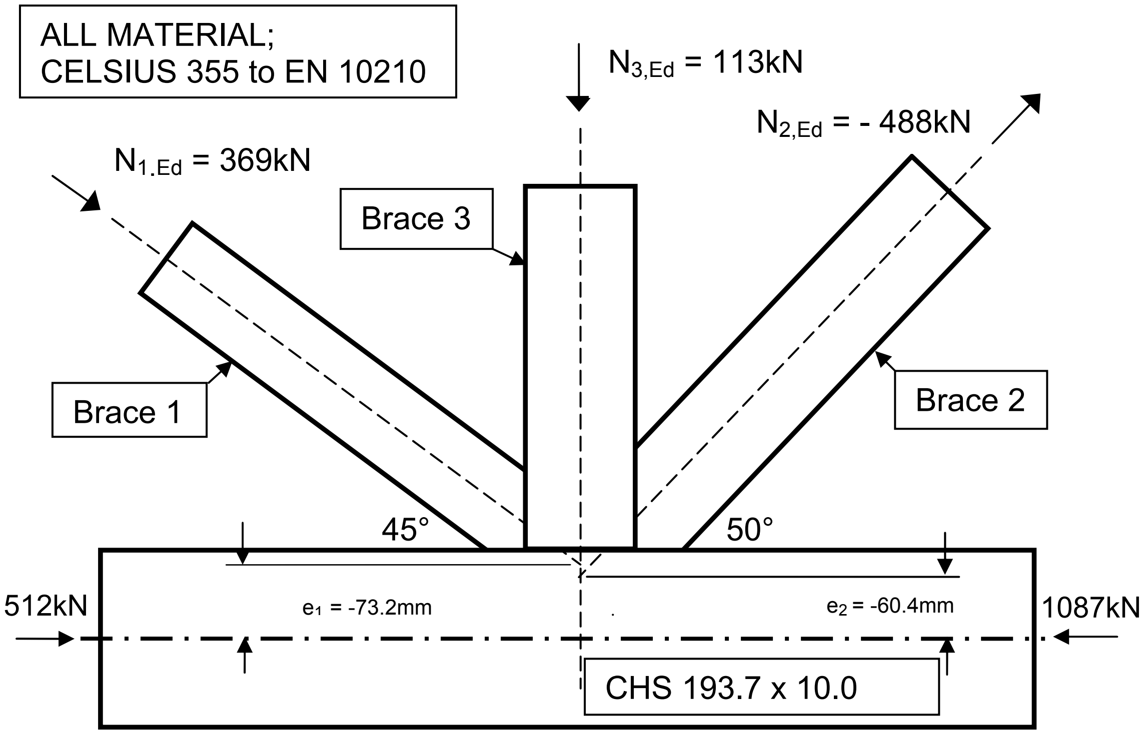
Summary

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).

Reference



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

d_0 = 193.7 mm	d_1 = 88.9 mm	d_2 = 101.6 mm	d_3 = 101.6 mm
t_0 = 10.0 mm	t_1 = 5.0 mm	t_2 = 6.3 mm	t_3 = 6.3 mm
γ_{M5} = 1.0	A_1 = 13.2 cm^2	A_2 = 18.9 cm^2	A_3 = 18.9 cm^2
	f_{u1} = 470 N/mm^2	f_{u2} = 470 N/mm^2	f_{u3} = 470 N/mm^2

'f_u' values taken from Product Standard EN10210-1 Table A.3 as required by UK National Annex

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

Reference

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, λ_{ov}= 71.6%;

where; $g = \frac{\lambda_{ov} \times d_1}{100 \times \sin\theta_1}$ — 6.5 Figure 57

$$g_1 = \frac{71.6 \times 88.9}{100 \times \sin(45^\circ)} \times -1$$

$g_1 = \underline{-90\,\text{mm}}$ (gap is negative as it's an overlap)

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

$$\boxed{= -73.2\,\text{mm}}$$

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, λ_{ov}= 65.2%;

where; $g_2 = \frac{\lambda_{ov} \times d_2}{100 \times \sin\theta_2}$ — 6.5 Figure 57

$$g_2 = \frac{65.2 \times 101.6}{100 \times \sin(50^\circ)}$$

$g_2 = \underline{-86.5\text{ mm}}$ (gap is negative as it's an overlap)

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

$$\boxed{= -60.4\text{ mm}}$$

Validity limits check for both K-Joints

5.1.1 Figure 27

$10 \le d_0/t_0 \le 50$ $d_0/t_0 = 193.7/10.0 = 19.37$ ∴PASS

$d_0/t_0 \le 70\varepsilon^2$ (Class 1 or 2 for chord)

$70\varepsilon^2 = 70\ [\sqrt{}(235/f_{y0})]^2 = 70\sqrt{}\ (235/355)^2 = 46.34$

$d_0/t_0 = 19.37 \le 46.34$ ∴PASS

(EN1993-1-1) Table 5.2

			Reference
$d_i/t_i \le 50$	$d_1/t_1 = 88.9/5.0 = 17.78$	∴PASS	
	$d_2/t_2 = 101.6/6.3 = 16.13$	∴PASS	
	$d_3/t_3 = 101.6/6.3 = 16.13$	∴PASS	
$d_i/t_i \le 70\varepsilon^2$ (Class 1 or 2 for compression bracings)			**(EN1993-1-1) Table 5.2**
	$70\varepsilon^2 = 70\,[\sqrt{(235/f_{y0})}]^2 = 70\sqrt{(235/355)}^2 = 46.34$		
	$d_1/t_1 = 17.78$	∴PASS	
	$d_3/t_3 = 16.13$	∴PASS	
$0.2 \le d_i/d_0 \le 1.0$	$d_1/b_0 = 88.9/193.7 = 0.46$	∴PASS	
	$d_2/b_0 = 101.6/193.7 = 0.52$	∴PASS	
	$d_3/b_0 = 101.6/193.7 = 0.52$	∴PASS	
$-0.55\ d_0 \le e \le +0.25\ d_0$	$-0.55 \times 193.7 \le e \le +0.25 \times 193.7$		5.1.1 Figure 27
	$-106.5 \le e \le +48.4$		
	$e_1 = -73.2$ mm	∴PASS	
	$e_2 = -60.4$ mm	∴PASS	
$\lambda_{ov} \ge 25\%$	$\lambda_{ov,i} = \lvert g \rvert \sin\theta_i / d_i \times 100\%$		6.5 Figure 57
	$\lambda_{ov,1} = 90.0 \times \sin 45°/88.9 \times 100\%$		
	$\lambda_{ov,1} = 71.6\%$	∴PASS	
	$\lambda_{ov,2} = 86.5 \times \sin 50°/101.6 \times 100\%$		
	$\lambda_{ov,2} = 65.2\%$	∴PASS	
$30° \le \theta_i \le 90°$	$\theta_1 = 45°$	∴PASS	
	$\theta_2 = 50°$	∴PASS	
	$\theta_3 = 90°$	∴PASS	

Chord Face Failure (deformation);

Compression brace (1);

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

5.1.3 (K- & N-Joints)

Gap/lap factor, k_g;

Using Formulae:

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

5.1.2.2 (k_g)

where;

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

6.3 (γ)

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

Use the smallest overlap for (g)

Reference

Using Formulae:	Using Graph:
$k_g = 9.69^{0.2}\left[1+\frac{0.024\times 9.69^{1.2}}{1+\exp\left(0.5\times(-86.5)/10.0-1.33\right)}\right]$ $k_g = 2.15$	From graph; g/t_0 = -86.5/10.0 = -8.7 k_g = 2.15

For graph
5.1.2.2 Fig. 29

CHS chord end stress factor, k_p

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

5.1.2.1

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

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

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

5.1.2.1

Chord factored stress ratio, n_p; $n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right) = \left(\frac{88.7}{355}\right) = 0.25$

5.1.2.1 (k_p)

Using formulae:	Using graph:
For $n_p > 0$ (compression): $k_p = 1 - 0.3\ n_p\ (1 + n_p)$ but ≤ 1.0 $k_p = 1 - 0.3\times 0.25\ (1+0.25)$ but ≤ 1.0 $k_p = 0.91$	from graph; k_p = 0.91

For graph
5.1.2.1 Fig. 28

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

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

Tension Brace (2);

5.1.3

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

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

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

Chord Punching shear not required for overlapping bracings

Localised Brace-to-Chord Shear Check for overlapped Joints;

Reference

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%;

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

5.1.3 (Modified for three braces)

$$\frac{\pi}{4}\times\left(\frac{f_{u1}}{\sqrt{3}}\times\frac{\left[\left(\frac{100-\lambda_{ov,1}}{100}\right)\times 2d_1 + d_{eff,1}\right]\times t_1}{\sin\theta_1} + \frac{f_{u2}}{\sqrt{3}}\times\frac{\left[\left(\frac{100-\lambda_{ov,2}}{100}\right)\times 2d_2 + d_{eff,2}\right]\times t_2}{\sin\theta_2}\right.........$$

$$\left. + \frac{f_{u3}}{\sqrt{3}}\times\frac{\left(c_{s1}\times d_{eff,3} + c_{s2}\times d_{eff,3}\right)\times t_3}{\sin\theta_3}\right)\times\frac{1}{\gamma_{M5}}$$

where Brace Effective Width (overlapping braces);

$$d_{eff,i} = \frac{12\,t_0}{d_0}\times\frac{f_{y0}\times t_0}{f_{yi}\times t_i}\times d_i \text{ but } d_{eff,i}\le d_i$$

5.1.2.3

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

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

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

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

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

$$\boxed{d_{eff,2} = 100\text{ mm}}$$

where Brace Effective Width (overlapped brace);

Reference

$$d_{eff,j}=\frac{12\,t_0}{d_0}\times\frac{f_{y0}\times t_0}{f_{yj}\times t_j}\times d_j \text{ but } d_{eff,j}\leq d_j$$

5.1.2.3

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

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

$$\boxed{d_{eff,3}=100\text{ mm}}$$

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

$$c_{s1}=1$$
$$c_{s2}=1\ (\text{If hidden toe/s welded } c_s=2)$$

5.1.3

Therefore;

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

$$\frac{\pi}{4}\times\left(\frac{470}{\sqrt{3}}\times\frac{\left[\left(\frac{100-71.6}{100}\right)\times 2\times 88.9+88.9\right]\times 5.0}{\sin 45^\circ}+\frac{470}{\sqrt{3}}\times\frac{\left[\left(\frac{100-65.2}{100}\right)\times 2\times 101.6+100\right]\times 6.3}{\sin 50^\circ}\ldots\ldots\right.$$

$$\left.+\frac{470}{\sqrt{3}}\times\frac{(1\times 100+1\times 100)\times 6.3}{\sin 90^\circ}\right)\times\frac{1.0}{1.0}$$

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

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

$$\boxed{575\text{ kN}\leq 778\text{ kN}\ \therefore\ \text{PASS}}$$

Summary

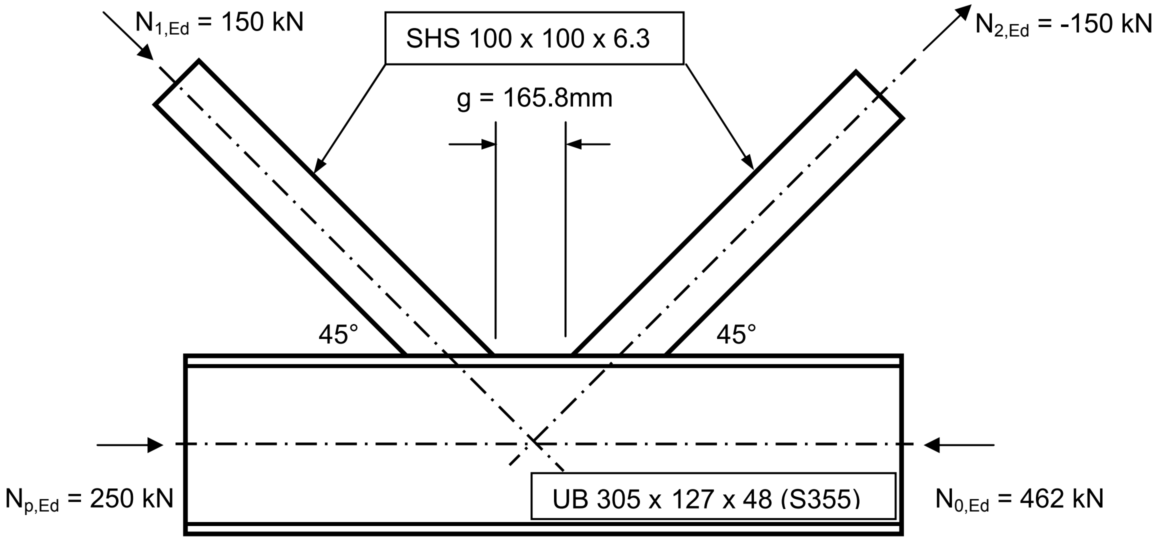
Here, the validity limits are combined to include all three braces. The eccentricity values use both brace 1 and 2 (diagonal) in relation to brace 3 (the vertical overlapped brace). The localised brace-to-chord shear check has been completed due to the high overlap. Please note that even if one brace 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).

Reference

MATERIAL;
BRACES: CELSIUS S355 to EN 10210
UB CHORD: ADVANCE S355 to EN 10025



Dimensions

b_0 = 125.3 mm
h_0 = 311.0 mm
t_w = 9.0 mm
t_f = 14.0 mm
$d_w = h_0 – 2 \times (t_f – r_0) = 265.2$ mm
r_0 = 8.9 mm

h_1 = 100.0 mm
b_1 = 100.0 mm
t_1 = 6.3 mm

h_2 = 100.0 mm
b_2 = 100.0 mm
t_2 = 6.3 mm

Validity limits check

5.7.1 Figure 55
(EN1993-1-1
Table 5.2)

Chord: Web;
$d_w/t_w \leq 38\varepsilon$ (Class 1 or 2 compression)
$38\varepsilon = 38 \sqrt{(235/f_{y0})} = 38 \sqrt{(235/355)} = 30.92$
$d_w/t_w = 265.2/9 = 29.5$ ∴PASS
$d_w \leq 400$ $d_w = 265.2$ ∴PASS

Chord: Flange;
$c_f/t_f \leq 10\varepsilon$ (Class 1 or 2 compression)

(EN1993-1-1
Table 5.2)

$10\varepsilon = 10 \sqrt{(235/f_{y0})} = 10 \sqrt{(235/355)} = 8.1$
$c_f = (b_0 – 2r_0 - t_w)/2 = (125.3 – 2 \times 8.9 – 9)/2 = 49.25$
$c_f/t_f = 49.25/14.0 = 3.52$ ∴PASS

Compression and Tension brace:
$h_i/t_i \leq 35$ $h_i/t_i = 100/6.3 = 15.87$ ∴PASS
$b_i/t_i \leq 35$ $b_i/t_i = 100/6.3 = 15.87$ ∴PASS
$h_i/b_i = 1.0$ $h_i/b_i = 100/100 = 1.0$ ∴PASS

Compression brace:
$(b_1 – 3t_1)/t_1$; $(h_1 – 3t_1)/t_1 \leq 38\varepsilon$ (Class 1 or 2 compression)
$38\varepsilon = 38 \sqrt{(235/355)} = 30.92$
$(b_1 – 3t_1)/ t_1 = (100 – 3 \times 6.3)/6.3 = 81.1/6.3 = 12.87$ ∴PASS

Reference

$g \geq t_1 + t_2 = 6.3 + 6.3 = 12.6$

$g = 165.8$ (zero eccentricity) ∴PASS

$30° \leq \Theta_1 \leq 90°$ $\Theta_1 = 45°$ ∴PASS

$30° \leq \Theta_2 \leq 90°$ $\Theta_2 = 45°$ ∴PASS

Chord Web Yielding;

$$N_{1,Rd} = \frac{f_{y0} \times t_w \times b_{w,i}}{\sin \theta_i} / \gamma_{M5}$$

5.7.4

where… $$b_{w,i} \frac{h_i}{\sin \theta_i} + 5\left(t_f + r_0\right) \quad \text{but} \leq 2t_i + 10\left(t_f + r_0\right)$$

5.7.2

$$b_{w,1} = \frac{100}{\sin 45°} + 5\left(14.0 + 8.9\right) \quad \text{but} \leq 2 \times 6.3 + 10\left(14.0 + 8.9\right)$$

$b_{w,1} = 255.92$ but ≤ 241.6

$\mathbf{b_{w,1} = 241.6}$ **mm** and $\mathbf{b_{w,2} = b_{w,1}}$ as same brace and angle dimensions.

Therefore;

$$N_{1,Rd} = \frac{355 \times 9.0 \times 241.6}{\sin 45°} / 1.0 = 1092 \text{ kN}$$

and $N_{2,Rd} = N_{1,Rd}$ as same brace and angle dimensions

1092 > 150 kN ∴PASS

Chord Shear;

$$N_{i,Rd} = \frac{f_{y0} \times A_{v0}}{\sqrt{3} \times \sin \theta_i} / \gamma_{M5}$$

5.7.4

where… $A_{v,0} = A_0 - (2 - \alpha) \times b_0 \times t_f + (t_w + 2r) \times t_f$ 5.7.3

where…

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

5.7.3

$\alpha = \mathbf{0.073}$

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

$\mathbf{A_{v,0} = 3114.9}$ $\mathbf{mm^2}$

Reference

$$\therefore \quad N_{1,Rd} = \frac{355 \times 3114.9}{\sqrt{3} \times \sin 45^{\circ}} / 1.0$$

$$N_{1,Rd} = 903 \ \text{kN}$$

and $\mathbf{N_{2,Rd} = N_{1,Rd}}$ as same brace and angle dimensions

903kN > 150 kN ∴PASS

<u>Bracing Effective Width</u>;

$$N_{i,Rd} = 2 \times f_{yi} \times t_i \times p_{eff,i} / \gamma_{M5}$$ 5.7.4

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

$g / t_f \leq 20 - 28\beta$

165.8 / 14.0 ≤ 20 – 28 (100+100+100+100/4 x 125.3)

11.8 ≤ -2.4 ∴ **Check Effective Width**;

where… $p_{eff,i} = t_w + 2r + 7t_f \times (f_{y0} / f_{yi})$ 5.7.2

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

$p_{eff,1}$ = 9.0 + 2 x 8.9 + 7 x 14.0 x (355/355)

but ≤ 100 + 100 – 2 x 6.3

$p_{eff,1}$ = **124.8 but ≤ 187.4**

and $\mathbf{p_{eff,2} = p_{eff,1}}$ as same brace and angle dimensions

$$N_{1,Rd} = 2 \times 355 \times 6.3 \times 124.8 \div 1.0$$

558kN > 150kN ∴PASS

and $\mathbf{N_{2,Rd} = N_{1,Rd}}$ as same brace and angle dimensions

<u>Chord Axial Force Resistance in gap</u>;

$$N_{0,gap,Rd} = \left[\left(A_0 - A_{v,0}\right) \times f_{y0} + A_{v,0} \times f_{y0} \times \sqrt{1 - \left(\frac{V_{0,Ed}}{V_{pl,0,Rd}}\right)} \right] / \gamma_{M5}$$ 5.7.4

where… $V_{0,Ed} = \max\left(\left|N_{1,Ed}\right| \times \sin\theta_1 , \left|N_{2,Ed}\right| \times \sin\theta_2\right)$ 5.7.4

$$V_{0,Ed} = \max\left(\left|150\right| \times \sin 45^{\circ}, \left|-150\right| \times \sin 45^{\circ}\right)$$

Reference

$V_{o,Ed}$ = 106.1kN

where…

$$V_{pl,0,Rd} = \frac{A_{v,0}\left(f_{y0} / \sqrt{3}\right)}{\gamma_{M0}} = \frac{3141.8 \times \left(355 / \sqrt{3}\right)}{1.0}$$

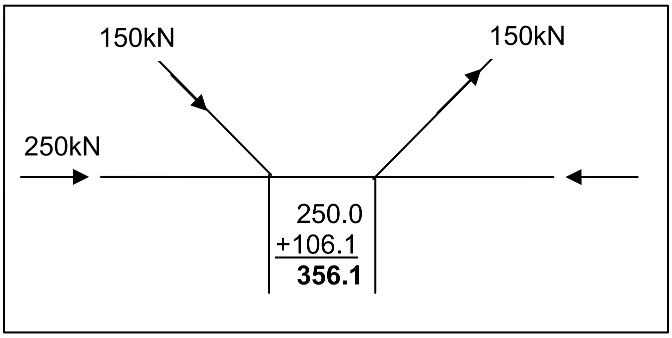
5.7.4

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

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

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

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



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

2077kN ≥ 356.1kN ∴PASS

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