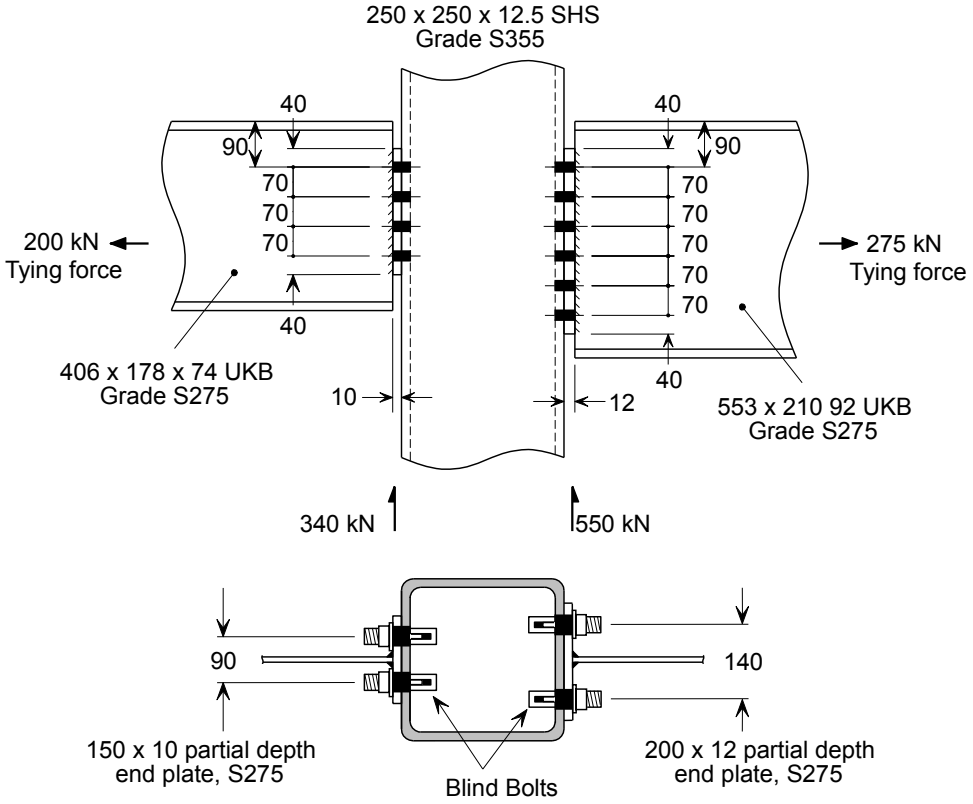
SCI Steel Knowledge ***CALCULATION SHEET*** BCSA	Job	*Joints in Steel Construction – Simple Joints*	*Sheet 1 of 11*
	Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	
	Client	*Blind Bolts*	
	Calcs by *CZK*	Checked by *DGB*	Date *December 2013*

DESIGN EXAMPLE 4

Check the following beam to hollow section column joint for the design forces shown using Blind Bolts to the column.

In this example the tie force is less than the shear force.

The connections should be checked independently for shear forces and tying forces and not for both forces acting at the same time.



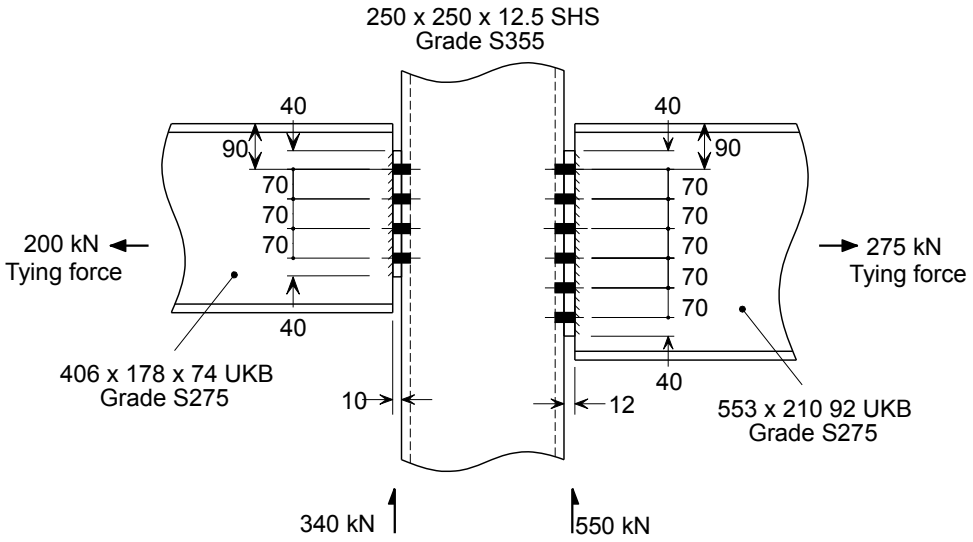
Design Information:

Bolts:	M20 Blind Bolts
Welds:	6 mm leg length fillet welds
Column:	S355
Beams:	S275
End plates:	S275

This worked example should be read in conjunction with P358: Joints in Steel Construction: Simple Joints to Eurocode 3

Title	*Example 4a – Partial depth end plates – Beam to hollow section column using Blind Bolts*	*Sheet 2 of 11*

CONNECTION DESIGN USING RESISTANCE TABLES



Although the connection resistance tables are based on ordinary bolts, they may be used to determine the vertical shear resistance of connections with Blind Bolts, because bolt shear resistance is generally not critical. The tables for ordinary bolts cannot be used to determine the connection tying resistance, as the bolt tension resistance has a significant influence on the tying resistance of the connection.

406 × 178 × 74 UKB, S275	**533 × 210 × 92 UKB, S275**
End plate, 150 × 10 S275	**End plate, 200 × 12 S275**
Welds 6 mm fillet	Welds 6 mm fillet
Bolts M20	Bolts M20
Bolts at 90 cross centres	Bolts at 140 cross centres
4 rows of bolts	6 rows of bolts
From Resistance Table G.4:	From Resistance Table G.4
Connection shear resistance = 394 kN > 340 kN	Connection shear resistance = 621 kN > 550 kN
Minimum support thickness in S355 = 3.2 mm < 12.5 mm	Minimum support thickness in S355 = 3.4 mm < 12.5 mm
Connection tying resistance *Table cannot be used*	Connection tying resistance *Table cannot be used*

Table G.4

Note:

(1) For connections using Blind Bolts, the tying resistance of the connection is the least of the values obtained from Checks 11, 12 & 13.

(2) The hollow section wall must also be checked as shown in Check 15.

Title *Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts* *Sheet 3 of 11*

SUMMARY OF FULL DESIGN CHECKS FOR EXAMPLE 4a

Notes:

(1) Checks 1 to 4 and 9 are as shown in Example 1.

(2) Tying forces are ignored when checking the shear resistance and shear is ignored calculating the tying resistance.

Sheet No.	CHECK		406 UKB (S275)		533 UKB (S275)		SHS Column, S355			
							406 UKB Side		533 UKB Side	
			Resist	Design force	Resist	Design force	Resist	Design force	Resist	Design force
	Check 1 Recommended detailing practice		All recommendations adopted							
	Check 2 Supported beam Welds (kN)		Full strength welds adopted – Not critical				Not applicable			
	Check 3		Not applicable							
	Check 4 Supported beam Web in shear	Shear resistance (kN)	394	340	621	550	Not applicable			
	Checks 5, 6, 7		Not applicable							
4	***Check 8*** Connection Bolt group	Bolt group (kN)	487	340	731	550	Not applicable			
	Check 9 Connection End plate in shear	Shear resistance (kN)	691	340	1195	550	Not applicable			
6	***Check 10*** Supporting column Shear and bearing	Shear and Bearing resistance (kN)	Not applicable				823	170	1196	275
8	***Check 11*** Tying resistance Plates and bolts	Tension (kN)	323	200	390	275	Not applicable			
10	***Check 12*** Structural Integrity Supported beam web	Tension (kN)	1027	200	1619	275	Not applicable			
10	***Check 13*** Structural Integrity Welds	Tension (kN)	Full strength welds adopted – not critical				Not applicable			
	Check 14		Not applicable							
11	***Check 15*** Structural Integrity Supporting column wall	Tension (kN)	Not applicable				431	200	850	275

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 4 of 11*

CONNECTION DESIGN FOLLOWING THE DESIGN PROCEDURES

Check 8: Connection – Bolt group

Basic requirement: $V_{Ed} \leq F_{Rd}$

The resistance of the bolt group, F_{Rd}, is as follows:

If $F_{b,Rd} \leq 0.8F_{v,Rd}$ then $F_{Rd} = nF_{b,Rd}$

if $F_{b,Rd} > 0.8F_{v,Rd}$ then $F_{Rd} = 0.8nF_{v,Rd}$

Shear resistance of a single bolt. For M20 Blind Bolts:

Conservatively asume the shear plane is over the slot:

$F_{v,Rd} = F_{v,Rd,slot} = 76.1$ kN — Table G.62

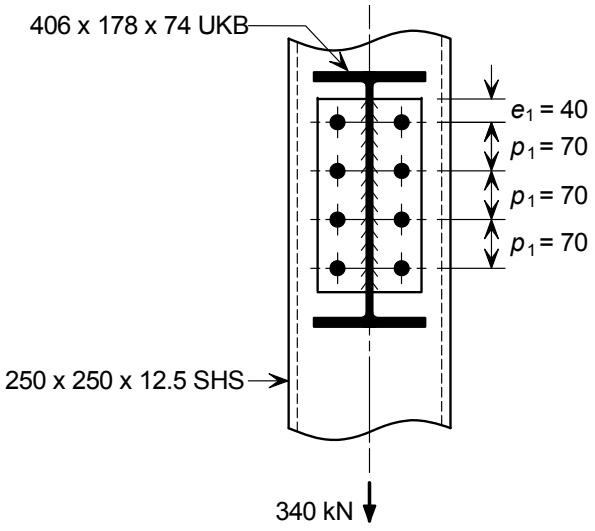
Bearing resistance of a single bolt:

$F_{b,Rd} = \min(F_{b,Rd,p};\ F_{b,Rd,2})$

$$F_{b,Rd,p} = \frac{k_{1,p}\alpha_{b,p}f_{u,p}dt_p}{\gamma_{M2}}$$

$$F_{b,Rd,2} = \frac{k_{1,2}\alpha_{b,2}f_{u,2}dt_2}{\gamma_{M2}}$$

406 × 178 × 74 UKB, S275



Since plate is 150 mm wide and p_3 = 90 mm then: e_2 = 30 mm — Appendix F

For an M20 Blind Bolt: d = 20 mm d_0 = 22 mm $f_{u,b}$ = 1000 N/mm^2

Bearing on the end plate:

$$k_{1,p} = \min\left(2.8\frac{e_2}{d_0} - 1.7;\ \ 1.4\frac{p_3}{d_0} - 1.7;\ \ 2.5\right)$$

$$= \min\left(2.8\times\frac{30}{22} - 1.7;\ \ 1.4\times\frac{90}{22} - 1.7;\ \ 2.5\right) = \min\left(2.1;\ 4.0;\ \ 2.5\right) = 2.1$$

$$\alpha_{b,p} = \min\left(\frac{e_1}{3d_0};\ \frac{p_1}{3d_0} - \frac{1}{4};\ \frac{f_{ub}}{f_{u,p}};\ 1.0\right) = \min\left(\frac{40}{3\times 22};\ \frac{70}{3\times 22} - 0.25;\ \frac{1000}{410};\ 1.0\right)$$

$= \min(0.61;\ \ 0.81;\ \ 2.44;\ \ 1.0) = 0.61$ — $f_{u,p}$ from Table 7 of EN 10025-2

$$F_{b,Rd,p} = \frac{2.1\times 0.61\times 410\times 20\times 10}{1.25}\times 10^{-3} = 84.0 \text{ kN}$$

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 5 of 11*

Bearing on the supporting column:

Since the hollow section wall is 12.5 mm thick and S355, clearly the end plate is critical.

Therefore can be assumed that:

$F_{b,Rd,2} > F_{b,Rd,p}$

$F_{b,Rd} = \min(F_{b,Rd,p};\ F_{b,Rd,2}) = 84.0$ kN

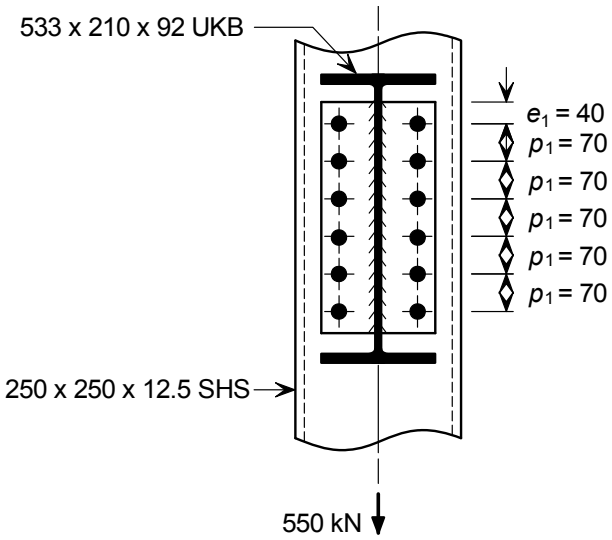
$0.8F_{v,Rd} = 0.8 \times 76.1 = 60.9$ kN

$\therefore F_{b,Rd} = 84.0$ kN > 60.9 kN

$\therefore F_{Rd} = 0.8nF_{v,Rd} = 0.8 \times 8 \times 76.1 = 487$ kN

$\therefore V_{Ed} = 340$ kN < 487 kN ∴ **O.K.**

533 × 210 × 92 UKB, S275



Since plate is 200 mm wide and $p_3 = 140$ mm then: $e_2 = 30$ mm

Bearing on the end plate:

$$k_{1,p} = \min\left(2.8\frac{e_2}{d_0} - 1.7;\ \ 1.4\frac{p_3}{d_0} - 1.7;\ \ 2.5\right)$$

$$= \min\left(2.8 \times \frac{30}{22} - 1.7;\ 1.4 \times \frac{140}{22} - 1.7;\ 2.5\right) = \min\left(2.1;\ 7.2;\ 2.5\right) = 2.1$$

$$\alpha_{b,p} = \min\left(\frac{e_1}{3d_0};\ \frac{p_1}{3d_0} - \frac{1}{4};\ \frac{f_{ub}}{f_{u,p}};\ 1.0\right) = \min\left(\frac{40}{3 \times 22};\ \frac{70}{3 \times 22} - 0.25;\ \frac{1000}{410};\ 1.0\right)$$

$$= \min(0.61;\ 0.81;\ 2.44;\ 1.0) = 0.61$$

$$F_{b,Rd,p} = \frac{2.1 \times 0.61 \times 410 \times 20 \times 12}{1.25} \times 10^{-3} = 100.8 \text{ kN}$$

Bearing on the supporting column:

Since the hollow section wall is 12.5 mm thick and S355, clearly the end plate is critical.

Therefore can be assumed that:

$F_{b,Rd,2} > F_{b,Rd,p}$

$F_{b,Rd} = \min(F_{b,Rd,p};\ F_{b,Rd,2}) = 100.8$ kN

$0.8F_{v,Rd} = 0.8 \times 76.1 = 60.9$ kN

$\therefore F_{b,Rd} = 100.8$ kN > 60.9 kN

$\therefore F_{Rd} = 0.8nF_{v,Rd} = 0.8 \times 12 \times 76.1 = 731$ kN

$\therefore V_{Ed} = 550$ kN < 731 kN ∴ **O.K.**

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 6 of 11*

Check 10: Supporting column – Shear and bearing

Local shear and bearing resistance of the hollow section column wall

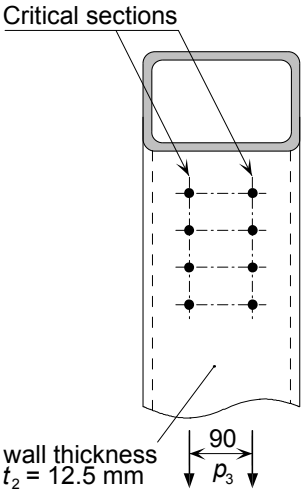
(i) Shear:

Basic requirement: $\frac{V_{Ed}}{2} \le V_{Rd,min}$

$$V_{Rd,min} = \min\left(\frac{A_v f_{y,2}}{\sqrt{3}\gamma_{M0}};\ \frac{A_{v,net} f_{u,2}}{\sqrt{3}\gamma_{M2}} \right)$$

406 × 178 × 74 UKB, S275

Critical sections



$\frac{V_{Ed}}{2}$ $\frac{V_{Ed}}{2}$ = 170 kN

Shear area of gross section: $A_v = t_2 (e_t + (n_1 - 1)p_1 + e_b)$

$$e_b = \min\left(e_{1,b};\frac{p_3}{2};\ 5d \right)$$

Since the connection is not near the bottom of the column $e_{1,b}$ is not applicable.

$$e_b = \min\left(\frac{p_3}{2};\ 5d \right) = \min\left(\frac{90}{2};\ 5 \times 20 \right) = 45 \text{ mm}$$

$$e_t = \min\left(e_{1,t};\ 5d \right)$$

Since the connection is not near the top of the column $e_{1,t}$ is not applicable.

$e_t = 5 \times 20 = 100$ mm

$\therefore A_v = 12.5 \times (100 + (4 - 1) \times 70 + 45) = 4438$ mm^2

$t_2 < 16$ mm, hence $f_{y,2} = 355$ N/mm^2

Therefore the resistance of the gross section is:

$$\therefore \frac{A_v f_{y,2}}{\sqrt{3}\gamma_{M0}} = \frac{4438 \times 355}{\sqrt{3} \times 1.0} \times 10^{-3} = 910 \text{ kN}$$

Shear area of net section: $A_{v,net} = A_v - n_1 d_0 t_2$

$\therefore A_{v,net} = 4438 - 4 \times 22 \times 12.5 = 3338$ mm^2

Therefore the resistance of the net section is:

$$\therefore \frac{A_{v,net} f_{u,2}}{\sqrt{3}\gamma_{M2}} = \frac{3338 \times 470}{\sqrt{3} \times 1.1} \times 10^{-3} = 823 \text{ kN}$$

$\therefore V_{Rd,min} = \min(910;\ 823) = 823$ kN

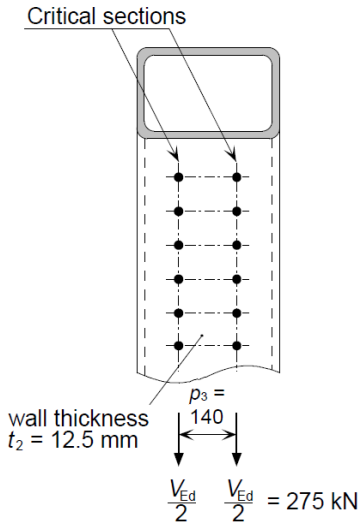
$\frac{V_{Ed}}{2}$ = 170 kN < 823 kN

$f_{u,2}$ for S355 from Table A.3 of EN 10210

$\therefore$ **O.K.**

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 7 of 11*

533 × 210 × 92 UKB, S275



Shear area of gross section: $A_v = t_2 (e_t + (n_1 - 1)p_1 + e_b)$

$e_b = \min\left(e_{1,b}; \frac{p_3}{2}; \quad 5d\right)$

Since the connection is not near the bottom of the column $e_{1,b}$ is not applicable.

$e_b = \min\left(\frac{p_3}{2}; \quad 5d\right) = \min\left(\frac{140}{2}; \quad 5 \times 20\right) = 70$ mm

$e_t = \min\left(e_{1,t}; \quad 5d\right)$

Since the connection is not near the top of column $e_{1,t}$ is not applicable.

$e_t = 5 \times 20 = 100$ mm

$\therefore A_v = 12.5 \times (100 + (6 - 1) \times 70 + 70) = 6500$ mm^2

Therefore the resistance of the gross section is:

$$\therefore \frac{A_v f_{y,2}}{\sqrt{3}\gamma_{M0}} = \frac{6500 \times 355}{\sqrt{3} \times 1.0} \times 10^{-3} = 1332 \text{ kN}$$

Shear area of net section: $A_{v,net} = A_v - n_1 d_0 t_2$

$\therefore A_{v,net} = 6500 - 6 \times 22 \times 12.5 = 4850$ mm^2

Therefore the resistance of the net section is:

$$\therefore \frac{A_{v,net} f_{u,2}}{\sqrt{3}\gamma_{M2}} = \frac{4850 \times 470}{\sqrt{3} \times 1.1} \times 10^{-3} = 1196 \text{ kN}$$

$\therefore V_{Rd,min} = \min(1332; \quad 1196) = 1196$ kN

$\frac{V_{Ed}}{2} = 275$ kN < 1196 kN **∴ O.K.**

(ii) Bearing resistance

Bearing resistance in the column wall will not be critical when compared to the bearing resistance in the end plates (see Check 8).

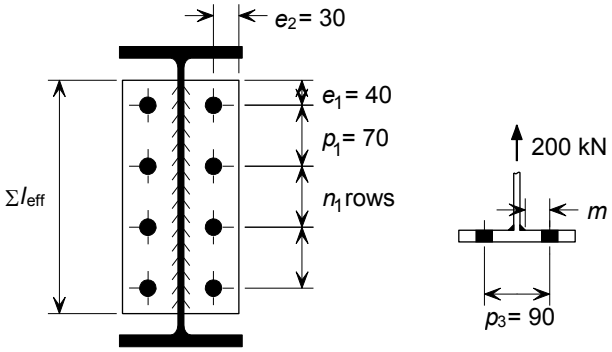
Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 8 of 11*

Check 11: Tying resistance – Plate and bolts

Resistance of end plate

Basic requirement: $F_{Ed} \le \min(F_{Rd,u,1};\ F_{Rd,u,2};\ F_{Rdu,3})$

406 × 178 × 74 UKB, S275



Mode 1:

$$F_{Rd,u,1} = \frac{(8n - 2e_w)M_{pl,1,Rd,u}}{2mn - e_w(m+n)}$$

Σl_{eff} is the effective length of the equivalent T-stub = h_p = 290 mm

$$M_{pl,1,Rd,u} = \frac{0.25\Sigma l_{eff} t_p^{\,2} f_{u,p}}{\gamma_{M,u}} = \frac{0.25\times 290\times 10^2 \times 410}{1.1}\times 10^{-6} = 2.7 \text{ kNm}$$

$a\sqrt{2}$ is the weld leg length = 6 mm

$$m = \frac{p_3 - t_{w,b1} - 2\times 0.8\times a\sqrt{2}}{2} = \frac{90 - 9.5 - 2\times 0.8\times 6}{2} = 35.5 \text{ mm}$$

$$e_w = \frac{d_w}{4} = \frac{37}{4} = 9.25 \text{ mm}$$

d_w from Table G.66

$$n = \min(e_2;\ 1.25m) = \min(30;\ 1.25\times 35.5) = 30 \text{ mm}$$

$$\therefore F_{Rd,u,1} = \frac{(8\times 30 - 2\times 9.25)\times 2.7\times 10^6}{2\times 35.5\times 30 - 9.25\times(35.5+30)}\times 10^{-3} = 392 \text{ kN}$$

Mode 2:

$$F_{Rd,u,2} = \frac{2M_{pl,2,Rd,u} + n\Sigma F_{t,Rd,u}}{m+n}$$

$M_{pl,2,Rd,u} = M_{pl,1,Rd,u}$ = 2.7 kNm

$F_{t,Rd,u}$ = 65.7 kN — Table G.63

$$F_{Rd,u,2} = \frac{2\times 2.7\times 10^6 + 30\times 8\times 65.7\times 10^3}{35.5+30}\times 10^{-3} = 323 \text{ kN}$$

Mode 3:

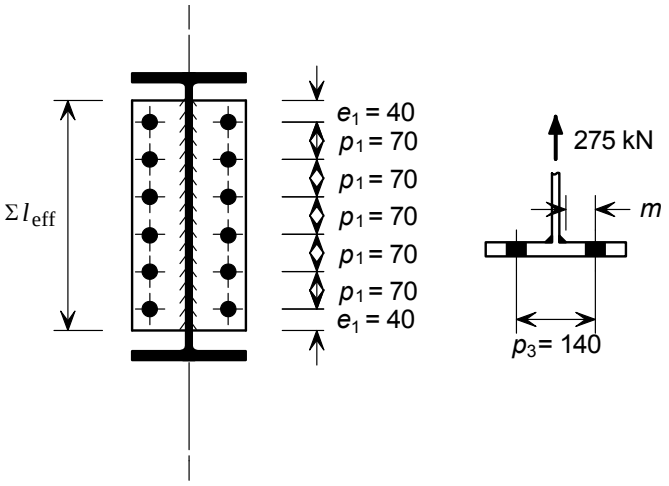
$F_{Rd,u,3} = \Sigma F_{t,Rd,u} = 8 \times 65.7 = 526$ kN

$\min(F_{Rd,u,1},\ F_{Rd,u,2},\ F_{Rd,u,3}) = \min(392,\ 323;\ 526) = 323$ kN

F_{Ed} = 200 kN < 323 kN — **∴ O.K.**

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 9 of 11*

533 × 210 × 92 UKB, S275



Mode 1:

$$F_{Rd,u,1} = \frac{(8n - 2e_w)M_{pl,1,Rd,u}}{2mn - e_w(m+n)}$$

Σl_{eff} is the effective length of the equivalent T-stub = h_p = 430 mm

$$M_{pl,1,Rd,u} = \frac{0.25\Sigma l_{eff} t_p^{\,2} f_{u,p}}{\gamma_{M,u}} = \frac{0.25 \times 430 \times 12^2 \times 410}{1.1} \times 10^{-6} = 5.77 \text{ kNm}$$

$a\sqrt{2}$ is the weld leg length = 6 mm

$$m = \frac{p_3 - t_{w,b1} - 2 \times 0.8 \times a\sqrt{2}}{2} = \frac{140 - 10.1 - 2 \times 0.8 \times 6}{2} = 60.15 \text{ mm}$$

$$e_w = \frac{d_w}{4} = \frac{37}{4} = 9.25 \text{ mm}$$ Table G.69

$$n = \min(e_2;\ 1.25m) = \min(30;\ 1.25 \times 60.15) = 30 \text{ mm}$$

$$\therefore F_{Rd,u,1} = \frac{(8 \times 30 - 2 \times 9.25) \times 5.77 \times 10^6}{2 \times 60.15 \times 30 - 9.25 \times (60.15 + 30)} \times 10^{-3} = 461 \text{ kN}$$

Mode 2:

$$F_{Rd,u,2} = \frac{2M_{pl,2,Rd,u} + n\Sigma F_{t,Rd,u}}{m+n}$$

$M_{pl,2,Rd,u} = M_{pl,1,Rd,u}$ = 5.77 kNm

$F_{t,Rd,u}$ = 65.7 kN Table G.63

$$F_{Rd,u,2} = \frac{2 \times 5.77 \times 10^6 + 30 \times 12 \times 65.7 \times 10^3}{60.15 + 30} \times 10^{-3} = 390 \text{ kN}$$

Mode 3:

$F_{Rd,u,3} = \Sigma F_{t,Rd,u} = 12 \times 65.7 = 788$ kN

$\min(F_{Rd,u,1},\ F_{Rd,u,2},\ F_{Rd,u,3}) = \min(461,\ 390;\ 788) = 390$ kN

F_{Ed} = 275 kN < 390 kN ∴ **O.K.**

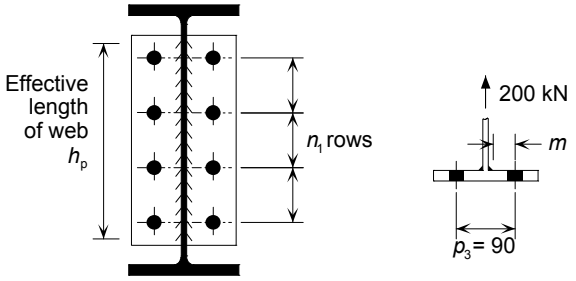
Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 10 of 11*

Check 12: Tying resistance – Supported beam web

Resistance of the beam web

Basic requirement: $F_{Ed} \le F_{Rd}$

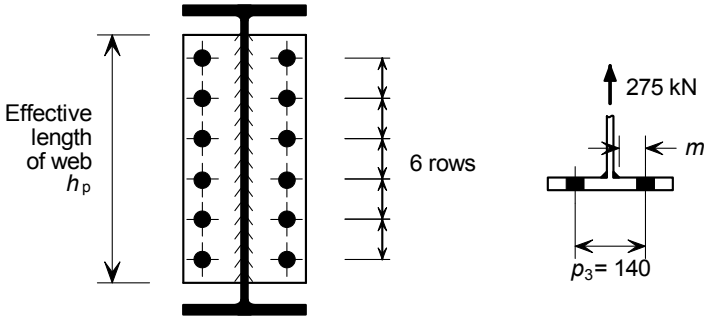
406 × 178 × 74 UKB, S275



$$F_{Rd} = \frac{t_{w,b1} h_p f_{u,b1}}{\gamma_{M,u}} = \frac{9.5 \times 290 \times 410}{1.1} \times 10^{-3} = 1027 \text{ kN}$$

F_{Ed} = 200 kN < 1027 kN ∴ **O.K.**

533 × 210 × 92 UKB, S275



$$F_{Rd} = \frac{t_{w,b1} h_p f_{u,b1}}{\gamma_{M,u}} = \frac{10.1 \times 430 \times 410}{1.1} \times 10^{-3} = 1619 \text{ kN}$$

F_{Ed} = 275 kN < 1619 kN ∴ **O.K.**

Check 13: Tying resistance – Welds

Basic requirement: $a \le 0.40\, t_{w,b1}$

406 × 178 × 74 UKB, S275

Throat thickness:

$$a = \frac{6}{\sqrt{2}} = 4.24 \text{ mm}$$

0.40 $t_{w,b1}$ = 0.40 × 9.5 = 3.8 mm

a = 4.24 mm ≥ 3.8 mm ∴ **O.K.**

533 × 210 × 92 UKB, S275

Throat thickness:

$$a = \frac{6}{\sqrt{2}} = 4.24 \text{ mm}$$

0.40 $t_{w,b1}$ = 0.40 × 10.1 = 4.04 mm

a = 4.24 mm ≥ 4.04 mm ∴ **O.K.**

Title	*Example 4a – Partial depth end plate – Beam to hollow section column using Blind Bolts*	*Sheet 11 of 11*

Check 15: Tying resistance – Supporting column wall

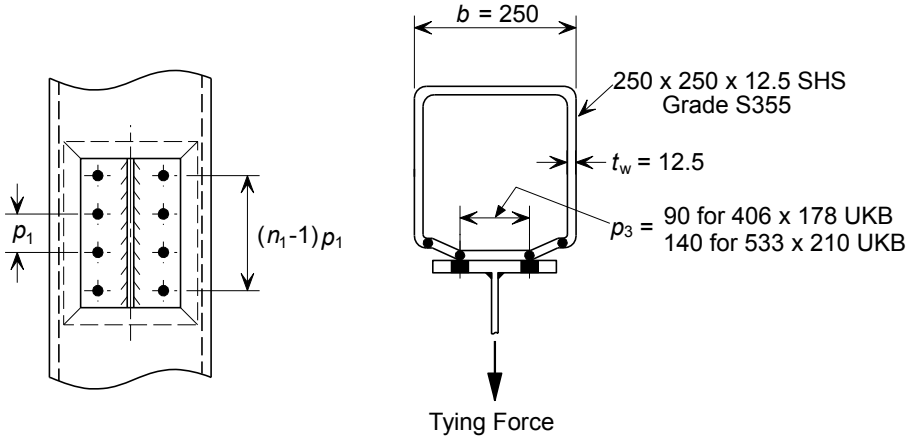
Resistance of hollow section wall

Basic requirement: $F_{Ed} \leq F_{Rd}$

$$F_{Rd} = \frac{8M_{pl,Rd,u}}{(1-\beta_1)}\left(\eta_1 + 1.5(1-\beta_1)^{0.5} \times (1-\gamma_1)^{0.5}\right)$$

$$M_{pl,Rd,u} = \frac{f_{u,c}\, t_2{}^2}{4\gamma_{M,u}}$$

406 × 178 × 74 UKB, S275



$$M_{pl,Rd,u} = \frac{470 \times 12.5^2}{4 \times 1.1} \times 10^{-3} = 16.7 \text{ kNm/mm}$$

$f_{u,c}$ for S355 from Table A.3 of EN 10210-1

$$\beta_1 = \frac{p_3}{b - 3t_2} = \frac{90}{250 - 3 \times 12.5} = 0.424$$

$$\gamma_1 = \frac{d_0}{b - 3t_2} = \frac{22}{250 - 3 \times 12.5} = 0.104$$

$$\eta_1 = \frac{(n_1 - 1)p_1 - \frac{n_1}{2}d_0}{b - 3t_2} = \frac{(4-1) \times 70 - \frac{4}{2} \times 22}{250 - 3 \times 12.5} = 0.781$$

$$F_{Rd,u} = \frac{8 \times 16.7}{(1-0.424)} \times \left(0.781 + 1.5 \times (1-0.424)^{0.5} \times (1-0.104)^{0.5}\right) = 431 \text{ kN}$$

F_{Ed} = 200 kN < 431 kN ∴ **O.K.**

533 × 210 × 92 UKB, S275

$$M_{pl,Rd,u} = \frac{470 \times 12.5^2}{4 \times 1.1} \times 10^{-3} = 16.7 \text{ kNm/mm}$$

$$\beta_1 = \frac{p_3}{b - 3t_2} = \frac{140}{250 - 3 \times 12.5} = 0.659$$

$$\gamma_1 = \frac{d_0}{b - 3t_2} = \frac{22}{250 - 3 \times 12.5} = 0.104$$

$$\eta_1 = \frac{(n_1 - 1)p_1 - \frac{n_1}{2}d_0}{b - 3t_2} = \frac{(6-1) \times 70 - \frac{6}{2} \times 22}{250 - 3 \times 12.5} = 1.34$$

$$F_{Rd,u} = \frac{8 \times 16.7}{(1-0.659)} \times \left(1.34 + 1.5 \times (1-0.659)^{0.5} \times (1-0.104)^{0.5}\right) = 850 \text{ kN}$$

F_{Ed} = 275 kN < 850 kN ∴ **O.K.**