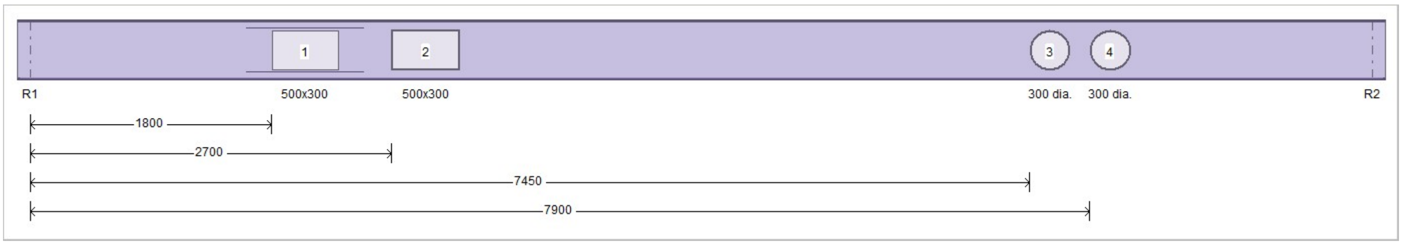
Web Opening Analysis

Beam: SCI Web Openings book example p.87 457x191x74 S355 Span: 10.00m.

SECTION SIZE : 457 x 191 x 74 UKB S355

Dimensions (mm): D: 457.0 B: 190.4 T: 14.5 t: 9.0 d: 407.6 CSA: 94.6 cm^2

Openings: 1. 500 x 300mm at 1.800m. from R1
2. 500 x 300mm at 2.700m.
3. 300mm dia.at 7.450m.
4. 300mm dia.at 7.900m.



Web opening 1: 500mm x 300mm deep, 1.80 - 2.30 m from R1, vertically centered about N.A.

Upper and lower tee depths = 64.0/78.5 mm excluding/including flange
Single-sided 80 x 10 stiffeners, top and bottom, 10 mm clear of opening *(user-selected size)*

Check opening position and size [P355 2.7]

Max height of opening (300 mm) <= 0.7h (320 mm) OK
Stiffened opening length (500 mm) <= $4.0h_o$ (1,200 mm) OK
Stiffened opening length (500 mm) in high shear area <= $2.5h_o$ (750 mm) OK
Opening corners to be predrilled to a minimum radius of 18 mm
Check R1 end post width (1800 mm) >= h (457 mm) and >= l_o (500 mm) OK
Check no point loads within 0.5h (229 mm) of opening: N/A

Top and bottom tee section classifications

Top and bottom stiffened tee sections are Class 2, compact (stiffener outstands <= 10te)

Check moment resistance at opening

Moment at centre of opening = 134.2kNm (6.10)

As < $0.75M_{Ed,max}$, take M_{Ed} as $0.75M_{Ed,max}$ = 0.75 x 205.9 = 154.4 kNm [P355 3.1.3]

Areas of top and bottom tees = 3,380 mm^2
Stiffener area = 1 x 10 x 80 = 800 mm^2
Stiffened tee areas = 4,180 mm^2

Tee elastic axes from outer faces of flanges, z_{el}: 23.6 mm

Tee elastic axis centres = 457.0 - (23.6 + 23.6) = 409.8 mm

Compression/tension forces in tees arising from moment = 154.4 x 1000/409.8 = 327 kN

Compression resistance of top tee = $A.f_y$/1.0 = 4,180 x 355/(1.0 x 1000) = 1,484 kN OK
Tensile resistance of bottom tee = $A.f_y$/1.0 = 4,180 x 355/(1.0 x 1000) = 1,484 kN OK

Check shear resistance at opening

Use shear at R1 end of opening, V_{Ed} = 52.7 kN (6.10)
As V_{Ed} >= $0.25V_{Ed,max}$ (0.25 x -82.3 = -20.6 kN), use 52.7 kN as design value [P355 3.1.3]

Shear is divided between top and bottom tees in proportion to their bending resistances

Top/bottom tee shear, V_{Ed} = 0.500/0.500 x 52.70 = 26.35/26.35 kN

Shear areas of tees $A_{v.t}/A_{v.b}$ = (4,365 - (300 x 9.0))/2 = 832/832 mm^2 *Stiffener area ignored* [P355 5.2.6]
Shear resistances of tees $V_{Rd} = (A_v f_y/\sqrt{3})/g_{M0}$ = (832 x 355/√3)/(1.0 x 1000) = 170.6 kN OK

Calculate tee moment resistance

Full thickness of web can be considered when calculating bending resistance if $V_{Ed} <= 0.5V_{Rd}$
otherwise effective web thickness, $t_{w,eff} = t_w(1 - (2m-1)^2)$ where $m = V_{Ed}/V_{Rd}$ [P355 3.4.3/5.2.6]
Top tee: V_{Ed} = 26.4 kN; V_{Rd} = 170.6kN; $t_{w,eff} = t_w$ = 9.0 mm
Bottom tee: V_{Ed} = 26.4 kN; V_{Rd} = 170.6kN; $t_{w,eff} = t_w$ = 9.0 mm

Tee $W_{pl,y} = A_w(0.5h_w + t_f - z_{pl}) + (A_f(0.5h_f - z_{pl} + z_{pl}^2/t_f)$

Top tee plastic modulus, $W_{pl,y,t}$ = 75.1 cm^3 (z_{pl} = 10.9 mm)
Moment resistance, $M_{pl,Rd} = f_y.W_{pl,y,t}/g_{M0}$ = 355 x 75.1/(1000 x 1.0) = 26.7 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (327/1,484) = 0.779 [P355 5.2.5 (60)]

Net moment resistance, $M_{pl,N,Rd}$ = 0.779 x 26.7 = 20.8 kNm

Bottom tee plastic modulus, $W_{pl,y,b}$ = 75.1 cm^3 (z_{pl} = 10.9 mm)
Moment resistance, $M_{pl,Rd} = f_y.W_{pl,y,b}/g_{M0}$ = 355 x 75.1/(1000 x 1.0) = 26.7 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (327/1,484) = 0.779 [P355 5.2.5 (60)]

Net moment resistance, $M_{pl,N,Rd}$ = 0.779 x 26.7 = 20.8 kNm

Ratio of moment capacities top/bottom = 0.500/0.500

Vierendeel moment resulting from shear

Vierendeel moment = $V_{Ed}.l_e$ = 52.7 x 500/1000 = 26.4 kNm

Vierendeel resistance = $2M_{pl,t} + 2M_{pl,b}$ = 2 x 20.8 + 2 x 20.8 = 83.1 kNm OK

Stiffener anchorage length, l_v

Use 6 mm fillet welds: throat size, a = 0.7 x 6 = 4.2 mm
Fillet weld design shear strength $f_{vw,d} = (f_u/\sqrt{3})/(B_w.g_{M2})$ = (470/√3)/(0.90 x 1.25) = 241 N/mm^2 [EC3-1-8 4.5.3.3]
Stiffener design force, $F_r = A_r.f_{yr}/g_{Mo}$ = 800 x 355/(1000 x 1.0) = 284 kN

Determine minimum anchorage length considering ... [P355 5.2.2 (55)]
a. ... weld shear resistance, min $l_v = F_r/(2.n.a.f_{vw,d})$ = 284 x 1000/(2 x 1 x 4.2 x 241) = 140 mm
b. ... stiffener shear resistance, min $l_v = F_r/(n.t_f.f_{y,t}/(g_{M0}\sqrt{3}))$ = 284 x 1000/(1 x 10 x 355/(1.0 √3)) = 139 mm
c. ... web shear resistance, min $l_v = F_r/(2.n.t_w.f_{y,t}/(g_{M0}\sqrt{3}))$ = 284 x 1000/(2 x 1 x 9.0 x 355/(1.0 √3)) = 77.0 mm
... or 150mm, $0.25l_o$ (125 mm) or $2b_r$ (160 mm)
... or $2b_r.t_r/(0.96 \times t_w)$ = 2 x 80 x 10/(0.96 x 9.0) = 185 mm [P355 5.2.3 (56)]

Required minimum stiffener anchorage length = 185 mm, say 200 mm; min O/A stiffener length = 880 mm

Additional check for single sided stiffeners

Check (t_r/t_w) (1.11) <= $0.96l_v/2b_r$ (1.14) and <= 1.0 FAIL [P355 (56)]

Web opening 2: 500mm x 300mm deep, 2.70 - 3.20 m from R1, vertically centered about N.A.

Upper and lower tee depths = 64.0/78.5 mm excluding/including flange
Opening is unstiffened

Check opening position and size [P355 2.7]

Max height of opening (300 mm) <= 0.7h (320 mm) OK
Depth of unstiffened top tee (78.5 mm) >= 0.1 l_o (50.0 mm) OK
Unstiffened opening length (500 mm) <= $2.5h_o$ (750 mm) OK
Opening corners to be predrilled to a minimum radius of 18 mm
Check no point loads within h (457 mm) of opening: N/A

Top and bottom tee section classifications

Top and bottom tee sections are Class 2, compact

Check moment resistance at opening

Moment at centre of opening = 171.3kNm (6.10)

As >= $0.75M_{Ed,max}$, 0.75 x 205.9 = 51.5 kNm, use 171.3 kNm as design value [P355 3.1.3]

Areas of top and bottom tees = 3,380 mm^2

Tee elastic axes from outer faces of flanges, z_{el}: 14.0 mm

Tee elastic axis centres = 457.0 - (14.0 + 14.0) = 428.9 mm

Compression/tension forces in tees arising from moment = 171.3 x 1000/428.9 = 399 kN

Compression resistance of top tee = $A.f_y/1.0$ = 3,380 x 355/(1.0 x 1000) = 1,200 kN OK
Tensile resistance of bottom tee = $A.f_y/1.0$ = 3,380 x 355/(1.0 x 1000) = 1,200 kN OK

Check shear resistance at opening

Use shear at R1 end of opening, V_{Ed} = 37.9 kN (6.10)
As $V_{Ed} >= 0.25V_{Ed,max}$ (0.25 x -82.3 = -20.6 kN), use 37.9 kN as design value [P355 3.1.3]

Shear is divided between top and bottom tees in proportion to their bending resistances

Top/bottom tee shear, V_{Ed} = 0.500/0.500 x 37.88 = 18.94/18.94 kN

Shear areas of tees $A_{v.t}/A_{v.b}$ = (4,365 - (300 x 9.0))/2 = 832/832 mm^2
Shear resistances of tees $V_{Rd} = (A_v f_y/\sqrt{3})/g_{M0}$ = (832 x 355/$\sqrt{3}$)/(1.0 x 1000) = 170.6 kN OK

Calculate tee moment resistance

Full thickness of web can be considered when calculating bending resistance if $V_{Ed} <= 0.5V_{Rd}$
otherwise effective web thickness, $t_{w,eff} = t_w(1 - (2m-1)^2)$ where $m = V_{Ed}/V_{Rd}$ [P355 3.4.3]
Top tee: V_{Ed} = 18.9 kN; V_{Rd} = 170.6kN; $t_{w,eff} = t_w$ = 9.0 mm
Bottom tee: V_{Ed} = 18.9 kN; V_{Rd} = 170.6kN; $t_{w,eff} = t_w$ = 9.0 mm

Tee $W_{pl,y} = A_w(0.5h_w + t_f - z_{pl}) + (A_f(0.5h_f - z_{pl} + z_{pl}^2/t_f)$

Top tee plastic modulus, $W_{pl,y,t}$ = 32.2 cm^3 (z_{pl} = 8.76 mm)
Moment resistance, $M_{pl,Rd} = f_y.W_{pl,y,t}/g_{M0}$ = 355 x 32.2/(1000 x 1.0) = 11.4 kNm
Reduction factor to allow for axial forces = $1 - N_{T,Ed}/N_{Rd}$ = 1 - $(399/1,200)^2$ = 0.889 [P355 3.4.4 (20)]

Net moment resistance, $M_{pl,N,Rd}$ = 0.889 x 11.4 = 10.2 kNm

Bottom tee plastic modulus, $W_{pl,y,b}$ = 32.2 cm^3 (z_{pl} = 8.76 mm)
Moment resistance, $M_{pl,Rd} = f_y.W_{pl,y,b}/g_{M0}$ = 355 x 32.2/(1000 x 1.0) = 11.4 kNm
Reduction factor to allow for axial forces = $1 - N_{T,Ed}/N_{Rd}$ = 1 - $(399/1,200)^2$ = 0.889 [P355 3.4.4 (20)]

Net moment resistance, $M_{pl,N,Rd}$ = 0.889 x 11.4 = 10.2 kNm

Ratio of moment capacities top/bottom = 0.500/0.500

Vierendeel moment resulting from shear

Vierendeel moment = $V_{Ed}.l_e$ = 37.9 x 500/1000 = 18.9 kNm

Vierendeel resistance = $2M_{pl,t} + 2M_{pl,b}$ = 2 x 10.2 + 2 x 10.2 = 40.6 kNm OK

Web opening 3: 300mm dia, 7.45 - 7.75 m from R1, vertically centered about N.A.

Upper and lower tee depths = 64.0/78.5 mm excluding/including flange
Take circular opening height as $0.9h_o$: tee depths taken as 79.0/93.5 mm
Opening is unstiffened

Check opening position and size [P355 2.7]

Diameter of opening (300 mm) <= 0.8h (366 mm) OK
Depth of tee stems (64.0 mm) >= 30 mm OK
Check no point loads within 0.5h (229 mm) of opening: N/A

Top and bottom tee section classifications

Top and bottom tee sections are Class 3, semi-compact

Check moment resistance at opening

Moment at centre of opening = 150.2kNm (6.10)

As < $0.75M_{Ed,max}$, take M_{Ed} as $0.75M_{Ed,max}$ = 0.75 x 205.9 = 154.4 kNm [P355 3.1.3]

Areas of top and bottom tees = 3,515 mm^2

Tee elastic axes from outer faces of flanges, z_{el}: 16.8 mm

Tee elastic axis centres = 457.0 - (16.8 + 16.8) = 423.4 mm

Compression/tension forces in tees arising from moment = 154.4 x 1000/423.4 = 355 kN

Compression resistance of top tee = $A.f_y/1.0$ = 3,515 x 355/(1.0 x 1000) = 1,248 kN OK
Tensile resistance of bottom tee = $A.f_y/1.0$ = 3,515 x 355/(1.0 x 1000) = 1,248 kN OK

Check shear resistance at opening

Use shear at R2 end of opening, V_{Ed} = 45.3 kN (6.10)
As V_{Ed} >= $0.25V_{Ed,max}$ (0.25 x -82.3 = -20.6 kN), use 45.3 kN as design value [P355 3.1.3]

Shear is divided between top and bottom tees in proportion to their bending resistances

Top/bottom tee shear, V_{Ed} = 0.500/0.500 x 45.29 = 22.65/22.65 kN

Shear areas of tees $A_{v.t}/A_{v.b}$ = (4,365 - (300 x 9.0))/2 = 967/967 mm^2
Shear resistances of tees $V_{Rd} = (A_v f_y/\sqrt{3})/g_{M0}$ = (967 x 355/$\sqrt{3}$)/(1.0 x 1000) = 198.3 kN OK

Calculate tee moment resistance

Full thickness of web can be considered when calculating bending resistance if $V_{Ed} <= 0.5V_{Rd}$
otherwise effective web thickness, $t_{w,eff} = t_w(1 - (2m-1)^2)$ where $m = V_{Ed}/V_{Rd}$ [P355 3.4.3]
Top tee: V_{Ed} = 22.6 kN; V_{Rd} = 198.3kN; $t_{w,eff} = t_w$ = 9.0 mm
Bottom tee: V_{Ed} = 22.6 kN; V_{Rd} = 198.3kN; $t_{w,eff} = t_w$ = 9.0 mm

Top tee elastic modulus, $W_{el,y,t}$ = 21.6 cm^3 (z_{el} = 16.8 mm)
Bending resistance, $M_{el,Rd} = f_y.W_{el,y,t}/g_{M0}$ = 355 x 21.6/(1000 x 1.0) = 7.66 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (355/1,248) = 0.919 [P355 3.4.5 (23)]
Reduced elastic bending resistance, $M_{el,N,Rd}$ = 0.919 x 7.66 = 7.04 kNm

Bottom tee elastic modulus, $W_{el,y,b}$ = 21.6 cm^3 (z_{el} = 16.8 mm)
Bending resistance, $M_{el,Rd} = f_y.W_{el,y,b}/g_{M0}$ = 355 x 21.6/(1000 x 1.0) = 7.66 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (355/1,248) = 0.919 [P355 3.4.5 (23)]
Reduced elastic bending resistance, $M_{el,N,Rd}$ = 0.919 x 7.66 = 7.04 kNm

Ratio of moment capacities top/bottom = 0.500/0.500

Vierendeel moment resulting from shear

Vierendeel moment = $V_{Ed}.l_e$ = 45.3 x 135/1000 = 6.11 kNm ($l_e = 0.45h_o$) [P355 3.1.4]

Vierendeel resistance = $2M_{el,t} + 2M_{el,b}$ = 2 x 7.04 + 2 x 7.04 = 28.2 kNm OK

Web opening 4: 300mm dia, 7.90 - 8.20 m from R1, vertically centered about N.A.

Upper and lower tee depths = 64.0/78.5 mm excluding/including flange
Take circular opening height as $0.9h_o$: tee depths taken as 79.0/93.5 mm
Opening is unstiffened

Check opening position and size [P355 2.7]

Diameter of opening (300 mm) <= 0.8h (366 mm) OK
Depth of tee stems (64.0 mm) >= 30 mm OK
Check R2 end post width (1800 mm) >= $0.5h_o$ (150 mm) OK

Check no point loads within 0.5h (229 mm) of opening: N/A

Top and bottom tee section classifications

Top and bottom tee sections are Class 3, semi-compact

Check moment resistance at opening

Moment at centre of opening = 129.3kNm (6.10)

As < $0.75M_{Ed,max}$, take M_{Ed} as $0.75M_{Ed,max}$ = 0.75 x 205.9 = 154.4 kNm [P355 3.1.3]

Areas of top and bottom tees = 3,515 mm^2

Tee elastic axes from outer faces of flanges, z_{el}: 16.8 mm

Tee elastic axis centres = 457.0 - (16.8 + 16.8) = 423.4 mm

Compression/tension forces in tees arising from moment = 154.4 x 1000/423.4 = 305 kN

Compression resistance of top tee = $A.f_y/1.0$ = 3,515 x 355/(1.0 x 1000) = 1,248 kN OK
Tensile resistance of bottom tee = $A.f_y/1.0$ = 3,515 x 355/(1.0 x 1000) = 1,248 kN OK

Check shear resistance at opening

Use shear at R2 end of opening, V_{Ed} = 52.7 kN (6.10)
As $V_{Ed} >= 0.25V_{Ed,max}$ (0.25 x -82.3 = -20.6 kN), use 52.7 kN as design value [P355 3.1.3]

Shear is divided between top and bottom tees in proportion to their bending resistances

Top/bottom tee shear, V_{Ed} = 0.500/0.500 x 52.70 = 26.35/26.35 kN

Shear areas of tees $A_{v.t}/A_{v.b}$ = (4,365 - (300 x 9.0))/2 = 967/967 mm^2
Shear resistances of tees $V_{Rd} = (A_v f_y/\sqrt{3})/g_{M0}$ = (967 x 355/$\sqrt{3}$)/(1.0 x 1000) = 198.3 kN OK

Calculate tee moment resistance

Full thickness of web can be considered when calculating bending resistance if $V_{Ed} <= 0.5V_{Rd}$
otherwise effective web thickness, $t_{w,eff} = t_w(1 - (2m-1)^2)$ where $m = V_{Ed}/V_{Rd}$ [P355 3.4.3]
Top tee: V_{Ed} = 26.4 kN; V_{Rd} = 198.3kN; $t_{w,eff} = t_w$ = 9.0 mm
Bottom tee: V_{Ed} = 26.4 kN; V_{Rd} = 198.3kN; $t_{w,eff} = t_w$ = 9.0 mm

Top tee elastic modulus, $W_{el,y,t}$ = 21.6 cm^3 (z_{el} = 16.8 mm)
Bending resistance, $M_{el,Rd} = f_y.W_{el,y,t}/g_{M0}$ = 355 x 21.6/(1000 x 1.0) = 7.66 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (305/1,248) = 0.940 [P355 3.4.5 (23)]
Reduced elastic bending resistance, $M_{el,N,Rd}$ = 0.940 x 7.66 = 7.20 kNm

Bottom tee elastic modulus, $W_{el,y,b}$ = 21.6 cm^3 (z_{el} = 16.8 mm)
Bending resistance, $M_{el,Rd} = f_y.W_{el,y,b}/g_{M0}$ = 355 x 21.6/(1000 x 1.0) = 7.66 kNm
Reduction factor to allow for axial forces = 1 - $N_{T,Ed}/N_{Rd}$ = 1 - (305/1,248) = 0.940 [P355 3.4.5 (23)]
Reduced elastic bending resistance, $M_{el,N,Rd}$ = 0.940 x 7.66 = 7.20 kNm

Ratio of moment capacities top/bottom = 0.500/0.500

Vierendeel moment resulting from shear

Vierendeel moment = $V_{Ed}.l_e$ = 52.7 x 135/1000 = 7.12 kNm ($l_e = 0.45h_o$) [P355 3.1.4]

Vierendeel resistance = $2M_{el,t} + 2M_{el,b}$ = 2 x 7.20 + 2 x 7.20 = 28.8 kNm OK

Check web post dimensions [P355 2.7]

	Min	mm	Act mm		$V_{wp,Ed}$	$V_{wp,Rd}$	
1-2	$0.5l_o$	250	400	OK	88.4	246.0	OK
2-3	$0.5l_o$	250	4250	OK	415.1	2613.2	OK
3-4	$0.3h_o$	90	150	OK	48.8	92.2	OK

$V_{wp,Ed}/V_{wp,Rd}$ Web post longtitudinal shear/shear resistance [P355 3.5.1, 3.5.4]