

ASME BPVC VIII-1 2023

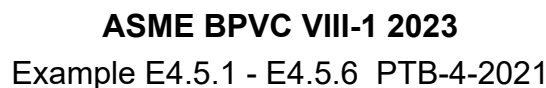
Example E4.5.1 - E4.5.6 PTB-4-2021

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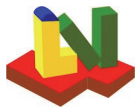
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Layout

Input values:	1.234	or	1.234
Calculated values:	1.234	or	1.234
Critical values:	1.234	or	1.234
Estimated values:	1.234	or	1.234



Strength Calculation Software			Program System ATLAS			Version		10.0.106	
Developed by Lauterbach Verfahrenstechnik GmbH									
Certified per DIN EN ISO 9001:2008			Certificate Number 01 100 044 763						
Example E4.5.1 - Radial Nozzle in Cylindrical Shell									
Required area A			14159,79	mm ²	21,95	in ²	21,97	in ²	0,08%
Available area A1			3531,71	mm ²	5,47	in ²	5,46	in ²	0,32%
Available area Aavl			28003,63	mm ²	43,41	in ²	43,39	in ²	0,04%
Example E4.5.2 - Hillside Nozzle in Cylindrical Shell									
Required area A			6863,13	mm ²	10,64	in ²	10,64	in ²	0,00%
Available area A1			1704,99	mm ²	2,64	in ²	2,64	in ²	0,00%
Available area Aavl			11453,94	mm ²	17,75	in ²	17,75	in ²	0,00%
Example E4.5.3 - Radial Nozzle in Cylindrical Shell									
Required area A			5429,32	mm ²	8,42	in ²	8,42	in ²	0,08%
Available area A1			1135,99	mm ²	1,76	in ²	1,75	in ²	0,40%
Available area Aavl			7014,28	mm ²	10,87	in ²	10,86	in ²	0,07%
Example E4.5.4 - Radial Nozzle in Cylindrical Shell									
Required area A			19037,86	mm ²	29,51	in ²	29,55	in ²	0,15%
Available area A1			1118,35	mm ²	1,73	in ²	1,69	in ²	2,69%
Available area Aavl			21735,78	mm ²	33,69	in ²	33,65	in ²	0,13%
Example E4.5.5 - Radial Nozzle in Cylindrical Shell									
Required area A			15075,45	mm ²	23,37	in ²	23,37	in ²	0,00%
Available area A1			1860,00	mm ²	2,88	in ²	2,88	in ²	0,00%
Available area Aavl			15080,66	mm ²	23,38	in ²	23,37	in ²	0,00%
Example E4.5.6 - Radial Nozzle in Cylindrical Shell									
Required area A			487,24	mm ²	0,76	in ²	0,76	in ²	0,01%
Available area A1			495,11	mm ²	0,77	in ²	0,77	in ²	0,02%
Available area Aavl			737,66	mm ²	1,14	in ²	1,14	in ²	0,16%



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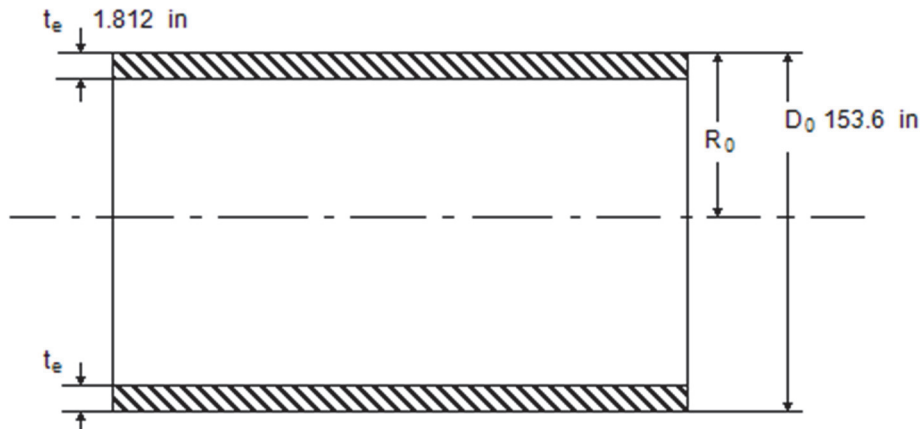
Example E4.5.1 - E4.5.6 PTB-4-2021

Thickness of cylindrical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2023

Cylindrical shells

Design pressure
Hydrostatic head
Calculation pressure
Calculation temperature

p_D 356 psi
 D_p 0 psi
 P_0 356 psi
 T_0 300 °F



Outside diameter
Design wall thickness
Wall thickness allowance
Allowance (corrosion)
Weld joint efficiency (or Cast Quality Factor)
Circumferential weld joint efficiency for Eq. 2

D_0 153.6 in
 t_e 1.812 in
 c_1 0 in
 c_2 0.125 in
 E 1
 E_c

Material K02700-SA-516-70-Class:-Size:

Allowable stress S 20015 psi

Results

Outside radius
Effective thickness

R_0 76.81 in
 t_0 1.687 in

Calculation as thin shell is applicable

Required thickness

$t(R_0)$

Yes
 $t(R)$

thin shell acc. UG-27

thick shell (not applicable)

Minimum wall thickness without condition acc. UG-16

Minimum wall thickness acc. UG-16

Required wall thickness for circumferential seam

$t = \text{Max}\{\text{Min}[t_R; t_{R0}], t_{UG-16}\}$

with allowances

1.351 in
1.348 in
1.351 in
0.05906 in
in
1.351 in
1.476 in

Allowable excess pressure

Allowable excess pressure for longitudinal stress for Eq. (2)

Allowable excess pressure without hydrostatic head

P 443.6 psi
 P_{long} psi
MAWP 443.6 psi

Remark

For calculation of openings according to UG-37

Required thickness

$t(E=1)$ 1.351 in

Allowable unreinforced opening diameter d for welded, brazed, and flued connections acc. UG 36(c)3

$d \leq 89$ mm for $t \leq 10$ mm

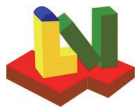
or

$d \leq 3 \frac{1}{2}$ in for $t \leq \frac{3}{8}$ in

$d \leq 60$ mm for $t > 10$ mm

or

$d \leq 2 \frac{3}{8}$ in for $t > \frac{3}{8}$ in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Equations

$$R_0 = \frac{D_0}{2} = \frac{3902 \text{ mm}}{2} = 1951 \text{ mm}$$

$$t+c_1+c_2=t+c_1+c_2=34.31 \text{ mm}+0 \text{ mm}+3.175 \text{ mm}=37.48 \text{ mm}$$

corroded inside radius $R=R_0-t_0=1951 \text{ mm}-42.86 \text{ mm}=1908 \text{ mm}$

1) Thin shell For $P_0 \leq 0.385 \cdot S \cdot E \Leftrightarrow 24.55 \text{ bar} \leq 53.13 \text{ N/mm}^2$

and
with the inside radius R

$$t_e \leq \frac{(R_0 - t_e)}{2} \Leftrightarrow 46.04 \text{ mm} \leq 952.5 \text{ mm}$$

$$t(R) = \frac{P_0 \cdot R}{S \cdot E - 0.6 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1908 \text{ mm}}{138 \text{ N/mm}^2 \cdot 1 - 0.6 \cdot 24.55 \text{ bar}} = 34.31 \text{ mm}$$

UG-27 (1)

$$P(R) = \frac{S \cdot E \cdot t_0}{R + 0.6 \cdot t_0} = \frac{138 \text{ N/mm}^2 \cdot 1 \cdot 42.86 \text{ mm}}{1908 \text{ mm} + 0.6 \cdot 42.86 \text{ mm}} = 3.059 \text{ MPa}$$

UG-27 (1)

or with the outside radius R_0

$$t(R_0) = \frac{P_0 \cdot R_0}{S \cdot E + 0.4 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1951 \text{ mm}}{138 \text{ N/mm}^2 \cdot 1 + 0.4 \cdot 24.55 \text{ bar}} = 34.46 \text{ mm}$$

App. 1-1 (1)

$$P(R_0) = \frac{S \cdot E \cdot t_0}{R_0 - 0.4 \cdot t_0} = \frac{138 \text{ N/mm}^2 \cdot 1 \cdot 42.86 \text{ mm}}{1951 \text{ mm} - 0.4 \cdot 42.86 \text{ mm}} = 3.059 \text{ MPa}$$

App. 1-1 (1)

$$\text{Log}(x) = \text{Ln}(x)$$

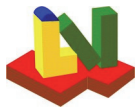
Longitudinal Stress (Circumferential Joints)

$$t_{long} = \frac{P_0 \cdot R}{2 \cdot S \cdot E_c + 0.4 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1908 \text{ mm}}{2 \cdot 138 \text{ N/mm}^2 \cdot E_c + 0.4 \cdot 24.55 \text{ bar}} = t_{long}$$

UG-27 (2)

$$P_{long} = \frac{2 \cdot S \cdot E_c \cdot t_0}{R - 0.4 \cdot t_0} = \frac{2 \cdot 138 \text{ N/mm}^2 \cdot E_c \cdot 42.86 \text{ mm}}{1908 \text{ mm} - 0.4 \cdot 42.86 \text{ mm}} = P_{long}$$

UG-27 (2)



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Example E4.5.1 - E4.5.6 PTB-4-2021

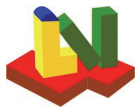
E 4.5.1 - Protruding nozzles without reinforcement - ASME BPVC VIII-1 UG-37: 2023

Protruding nozzle without reinforcement

Design pressure	p_D	356 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	356 psi
Calculation temperature	T_0	300 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

Shell

Shape of the shell	cylindrical	
Outside diameter	D_a	153.6 in
Nominal thickness without allowances	t	1.687 in
Available shell length for reinforcement	b_a	50 in
Joint efficiency factor (or Cast Quality Factor)	E_1	1
Material	<i>K02700-SA-516-70-Class:-Size:</i>	
Material strength	K	20015 psi
Safety factor	S	1
Allowable stress value	S_v	20015 psi
Wall thickness allowance	c_{1s}	0 in
Corrosion allowance	c_{2s}	0.125 in
Required thickness without allowances	t_r	1.351 in



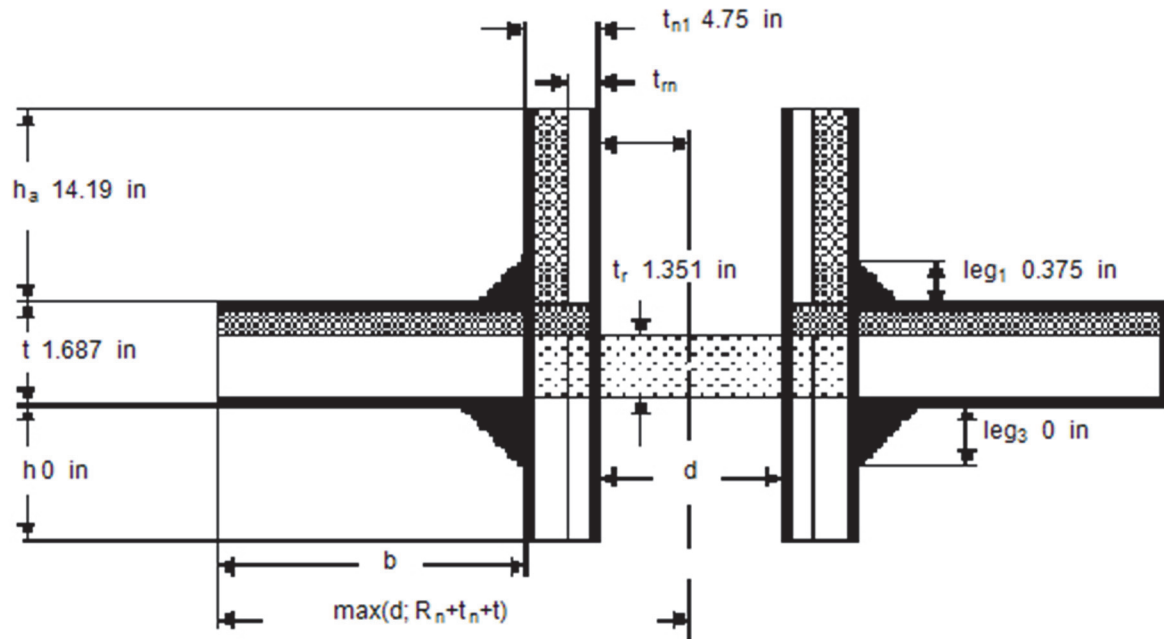
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Example E4.5.1 - E4.5.6 PTB-4-2021

Nozzle

Nº

1



Access opening

Outside diameter

Joint efficiency factor (or Cast Quality Factor)

Material K02700-SA-516-70-Class:-Size:

Material strength

Wall thickness allowance

Allowance (corrosion)

Safety factor

Allowable stress K_n/S

Nominal thickness with allowances

Required wall thickness acc. Table UG-45 with corrosion allowance

Nominal inside diameter = $d_a - 2 \cdot t_2$

Inside diameter, corroded = $d_a - 2 \cdot t_n$

External projection

Internal projection

Angle between the shell axis and the sectional plane through the opening center

Nominal thickness without allowances

Required nozzle neck thickness per UG-27

Required shell wall thickness where the nozzle neck attaches to the vessel

with joint efficiency $E=1.0$

Minimum nozzle neck thickness per UG-16

Required nozzle neck thickness per UG-45

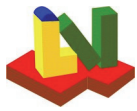
Fillet weld nozzle / shell outside

Fillet weld nozzle / shell inside

Groove weld nozzle / shell ($\leq t$)

No

d_a	25.5 in
E_n	1
K_n	20015 psi
c_1	0 in
c_2	0.125 in
S	1
S_n	20015 psi
t_{n1}	4.75 in
t_{b3}	0.4533 in
d_{iN}	16 in
d	16.25 in
h_a	14.19 in
h	0 in
Θ	0 °
t_n	4.625 in
t_a	0.2711 in
t_{b1}	1.476 in
t_{UG-16}	0.05906 in
t_{UG-45}	0.4533 in
leg_1	0.375 in
leg_3	0 in
leg_4	0 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)
 Reserve of shell
 Limit length of vessel acc. to UG-40(b)
 Limit length of nozzle outside, UG40(c)
 Limit length of nozzle inside, Fig.UG37
 Minimum required thickness of nozzle
 Required area for internal pressure
 Area of shell reserve
 Area of reinforcement (A_2 to A_5)
 Total available area ΣA
 Required area A/Γ
 Utilization
 Allowable pressure (approx.: p_D /utilization)

	UG-40	App.1-7
F	1	
$(E_1 \cdot t - F \cdot t_r)$	0.3369 in	
b	8.125 in	in
h'_a	4.219 in	4.219 in
h'_i	0 mm	0
t_{rn}	0.1461 in	0.1461 in
A	21.95 in ²	in ²
A_1	5.474 in ²	in ²
A_v	37.93 in ²	in ²
A_{avl}	43.41 in ²	in ²
A_{req}	21.95 in ²	in ²
A_{req}/A_{avl}	50.56 %	%
	704.1 psi	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	$= 392092$ lbf
W_{1-1}	$= [A_2 + A_{41}] \cdot S_v$	$= 759212$ lbf
W_{2-2}	$= [A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot f_{r1}] \cdot S_v$	$= 1071638$ lbf

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_v; S_n)$	$= 147316$ lbf
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_3 \cdot 0.49 \cdot \min(S_v; S_n)$	$= 0$ lbf
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.74 \cdot \min(S_v; S_n)$	$= 0$ lbf
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	$= 2124806$ lbf

Comparison of weld loads on path 1-1 and 2-2

1-1	147316 lbf	+	2124806 lbf	=	2272122 lbf
					≥ 392092 lbf
2-2	147316 lbf	+	0 lbf	+	0 lbf
					≥ 1915504 lbf
					≥ 392092 lbf

Equations according to UG-40 and App.1-7

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = 206.4 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{d}{t_n + t} \right\}$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

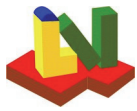
$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

Fig. UG-37.1

$$412.8 \text{ mm} \cdot 34.31 \text{ mm} \cdot 1 + 2 \cdot 117.5 \text{ mm} \cdot 34.31 \text{ mm} \cdot 1 \cdot (1 - 1) = 14160 \text{ mm}^2$$

Available shell thickness with allowances
 Required shell thickness with allowances
 Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	1.812 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	1.476 in
	t_{m+}	0.2711 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = 107.2 \text{ mm}$$

$$h'_n = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = 0 \text{ mm}$$

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} = 24.55 \text{ bar} \cdot \frac{\frac{412.8 \text{ mm}}{20}}{(138 \text{ N/mm}^2 - 0.06 \cdot 24.55 \text{ bar})} = 3.71 \text{ mm}$$

(internal pressure)

$$A_1 = \text{Max} \left\{ \begin{array}{l} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{array} \right\} =$$

$$\text{Max} \left\{ \begin{array}{l} 412.8 \text{ mm} \cdot 8.557 \text{ mm} - 2 \cdot 117.5 \text{ mm} \cdot 8.557 \text{ mm} \cdot (1 - 1) \\ 2 \cdot (42.86 \text{ mm} + 117.5 \text{ mm}) \cdot 8.557 \text{ mm} - 2 \cdot 117.5 \text{ mm} \cdot 8.557 \text{ mm} \cdot (1 - 1) \end{array} \right\} = 3532 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (117.5 \text{ mm} - 3.71 \text{ mm}) \cdot 1 \cdot 107.2 \text{ mm} = 24381 \text{ mm}^2$$

$$A_3 = 2 \cdot (t_n - c_2) \cdot f_{r2} \cdot h'_n = 2 \cdot (117.5 \text{ mm} - 3.175 \text{ mm}) \cdot 1 \cdot 0 \text{ mm} = 0 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r2} = (9.525 \text{ mm})^2 \cdot 1 = 90.73 \text{ mm}^2$$

$$A_{43} = (leg_3)^2 \cdot f_{r2} = (0 \text{ mm})^2 \cdot 1 = 0 \text{ mm}^2$$

$$A_v = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 24472 \text{ mm}^2$$

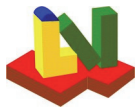
App.1-7 is additionally required acc. to UG-36(b) if

D_a	$3902 \leq 1520 \text{ mm (60 in.)}$	d_a	$647.7 > \text{Min [$	$3902/2; 508 \text{ mm (20 in.)}]$
D_a	$3902 > 1520 \text{ mm (60 in.)}$	d_a	$647.7 > \text{Min [$	$3902/3; 1000 \text{ mm (40 in.)}]$

Additional rules for cylindr. shells, App.1-7(b)

not required

Total available area		A_{avl}	in^2
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{nm}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	in^4
Material area acc. to Fig.1-7-1		A_s	in^2
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	l_m	in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = \text{ } > 1524 \text{ mm (60 in.)}$

(b) $2 \cdot R_n = \text{ } > 1016 \text{ mm (40 in.)}$ and

$$2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} = \text{ }$$

(c) $\frac{R_n}{R} = \frac{\text{ }}{\text{ }} = \text{ } \leq 0.7$

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$$S_m \leq S$$

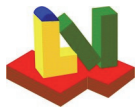
Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{42.86 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$



ASME BPVC VIII-1 2023 **Example E4.5.1 - E4.5.6 PTB-4-2021**

E 4.5.2 Step5 F=1 - Protruding nozzles without reinforcement - ASME BPVC VIII-1 UG-37: 2023

Protruding nozzle without reinforcement

Design pressure	p_D	356 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	356 psi
Calculation temperature	T_0	300 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

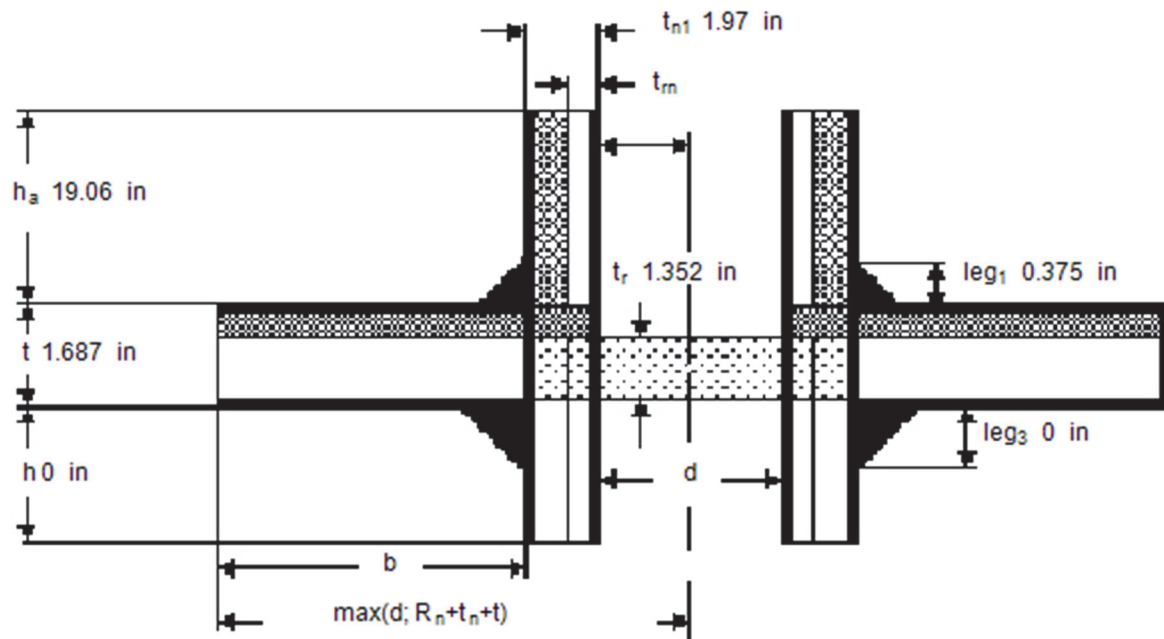
Shell

Shape of the shell	cylindrical	
Outside diameter	D_a	153.6 in
Nominal thickness without allowances	t	1.687 in
Available shell length for reinforcement	b_a	60 in
Joint efficiency factor (or Cast Quality Factor)	E_1	1
Material	<i>K02700-SA-516-70-Class:-Size:</i>	
Material strength	K	20015 psi
Safety factor	S	1
Allowable stress value	S_v	20015 psi
Wall thickness allowance	c_{1s}	0 in
Corrosion allowance	c_{2s}	0.125 in
Required thickness without allowances	t_r	1.352 in

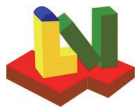
Nozzle

Nº

1



	No	
Access opening		
Outside diameter	d_a	11.56 in
Joint efficiency factor (or Cast Quality Factor)	E_n	1
Material	K02700-SA-516-70-Class:-Size:	
Material strength	K_n	20015 psi
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Safety factor	S	1
Allowable stress	K_n/S	20015 psi
Nominal thickness with allowances	t_{n1}	1.97 in
Required wall thickness acc. Table UG-45 with corrosion allowance	t_{b3}	0.4533 in
Nominal inside diameter = $d_a - 2 \cdot t_2$	d_{iN}	7.62 in
Inside diameter, corroded = $d_a - 2 \cdot t_n$	d	7.87 in
External projection	h_a	19.06 in
Internal projection	h	0 in
Angle between the shell axis and the sectional plane through the opening center	Θ	0 °
Nominal thickness without allowances	t_n	1.845 in
Required nozzle neck thickness per UG-27	t_a	0.1957 in
Required shell wall thickness where the nozzle neck attaches to the vessel	t_{b1}	1.475 in
with joint efficiency $E=1.0$		
Minimum nozzle neck thickness per UG-16	t_{UG-16}	0.05906 in
Required nozzle neck thickness per UG-45	t_{UG-45}	0.4533 in
Fillet weld nozzle / shell outside	leg_1	0.375 in
Fillet weld nozzle / shell inside	leg_3	0 in
Groove weld nozzle / shell ($\leq t$)	leg_4	0 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)
 Reserve of shell
 Limit length of vessel acc. to UG-40(b)
 Limit length of nozzle outside, UG40(c)
 Limit length of nozzle inside, Fig.UG37
 Minimum required thickness of nozzle
 Required area for internal pressure
 Area of shell reserve
 Area of reinforcement (A_2 to A_5)
 Total available area ΣA
 Required area A/Γ
 Utilization
 Allowable pressure (approx.: p_D /utilization)

	UG-40	1	App.1-7
F			
$(E_1 \cdot t - F \cdot t_r)$		0.3358 in	
b		3.935 in	
h'_a		4.219 in	4.219 in
h'_i		0 mm	0
t_{rn}		0.07075 in	0.07075 in
A		10.64 in ²	
A_1		2.643 in ²	
A_v		15.11 in ²	
A_{avl}		17.75 in ²	
A_{req}		10.64 in ²	
A_{req}/A_{avl}		59.92 %	%
		594.1 psi	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	$=$	184826 lbf
W_{1-1}	$= [A_2 + A_{41}] \cdot S_v$	$=$	302449 lbf
W_{2-2}	$= [A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot f_{r1}] \cdot S_v$	$=$	427082 lbf

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_v, S_n)$	$=$	66783 lbf
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_3 \cdot 0.49 \cdot \min(S_v, S_n)$	$=$	0 lbf
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.74 \cdot \min(S_v, S_n)$	$=$	0 lbf
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	$=$	394476 lbf

Comparison of weld loads on path 1-1 and 2-2

1-1	66783 lbf	+	394476 lbf	$=$	461259 lbf
				\geq	184826 lbf
2-2	66783 lbf	+	0 lbf	$=$	66783 lbf
				\geq	184826 lbf

Equations according to UG-40 and App.1-7

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = 99.95 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{d}{t_n + t} \right\}$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

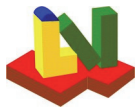
$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

Fig. UG-37.1

$$199.9 \text{ mm} \cdot 34.33 \text{ mm} \cdot 1 + 2 \cdot 46.86 \text{ mm} \cdot 34.33 \text{ mm} \cdot 1 \cdot (1 - 1) = 6863 \text{ mm}^2$$

Available shell thickness with allowances
 Required shell thickness with allowances
 Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	1.812 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	1.477 in
	t_{m+}	0.1957 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right. = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right. = 107.2 \text{ mm}$$

$$h'_n = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right. = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right. = 0 \text{ mm}$$

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} = 24.55 \text{ bar} \cdot \frac{\frac{199.9 \text{ mm}}{20}}{(138 \text{ N/mm}^2 - 0.06 \cdot 24.55 \text{ bar})} = 1.797 \text{ mm}$$

(internal pressure)

$$A_1 = \text{Max} \left\{ \begin{array}{l} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{array} \right. =$$

$$\text{Max} \left\{ \begin{array}{l} 199.9 \text{ mm} \cdot 8.529 \text{ mm} - 2 \cdot 46.86 \text{ mm} \cdot 8.529 \text{ mm} \cdot (1 - 1) \\ 2 \cdot (42.86 \text{ mm} + 46.86 \text{ mm}) \cdot 8.529 \text{ mm} - 2 \cdot 46.86 \text{ mm} \cdot 8.529 \text{ mm} \cdot (1 - 1) \end{array} \right. = 1705 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (46.86 \text{ mm} - 1.797 \text{ mm}) \cdot 1 \cdot 107.2 \text{ mm} = 9658 \text{ mm}^2$$

$$A_3 = 2 \cdot (t_n - c_2) \cdot f_{r2} \cdot h'_n = 2 \cdot (46.86 \text{ mm} - 3.175 \text{ mm}) \cdot 1 \cdot 0 \text{ mm} = 0 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r2} = (9.525 \text{ mm})^2 \cdot 1 = 90.73 \text{ mm}^2$$

$$A_{43} = (leg_3)^2 \cdot f_{r2} = (0 \text{ mm})^2 \cdot 1 = 0 \text{ mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 9749 \text{ mm}^2$$

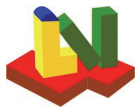
App.1-7 is additionally required acc. to UG-36(b) if

D_a	$3901 \leq 1520 \text{ mm (60in.)}$	d_a	$293.6 > \text{Min [$	$3901/2; 508 \text{ mm (20in.)}]$
D_a	$3901 > 1520 \text{ mm (60in.)}$	d_a	$293.6 > \text{Min [$	$3901/3; 1000 \text{ mm (40in.)}]$

Additional rules for cylindr. shells, App.1-7(b)

not required

Total available area	A_{avl}	in^2
Inside radius of shell	R	in
Inside radius of nozzle	R_n	in
Mean radius of shell	R_m	in
Mean radius of nozzle	R_{nm}	in
Allowable stress value	S	psi
Distance e	e	in
Moment of inertia	I	in^4
Material area acc. to Fig.1-7-1	A_s	in^2
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = \text{[redacted]} > 1524 \text{ mm (60 in.)}$

(b) $2 \cdot R_n = \text{[redacted]} > 1016 \text{ mm (40 in.)}$ and

$$2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} = \text{[redacted]}$$

(c) $\frac{R_n}{R} = \frac{\text{[redacted]}}{\text{[redacted]}} = \text{[redacted]} \leq 0.7$

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$$S_m \leq S$$

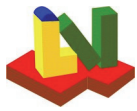
Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{42.86 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$



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Example E4.5.1 - E4.5.6 PTB-4-2021

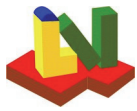
E 4.5.3 - Protruding nozzles without reinforcement - ASME BPVC VIII-1 UG-37: 2023

Protruding nozzle without reinforcement

Design pressure	p_D	356 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	356 psi
Calculation temperature	T_0	300 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

Shell

Shape of the shell	spherical	
Outside diameter	D_a	92 in
Nominal thickness without allowances	t	0.875 in
Available shell length for reinforcement	b_a	40 in
Joint efficiency factor (or Cast Quality Factor)	E_1	1
Material	<i>K02700-SA-516-70-Class:-Size:</i>	
Material strength	K	20015 psi
Safety factor	S	1
Allowable stress value	S_v	20015 psi
Wall thickness allowance	c_{1s}	0 in
Corrosion allowance	c_{2s}	0.125 in
Required thickness without allowances	t_r	0.7236 in



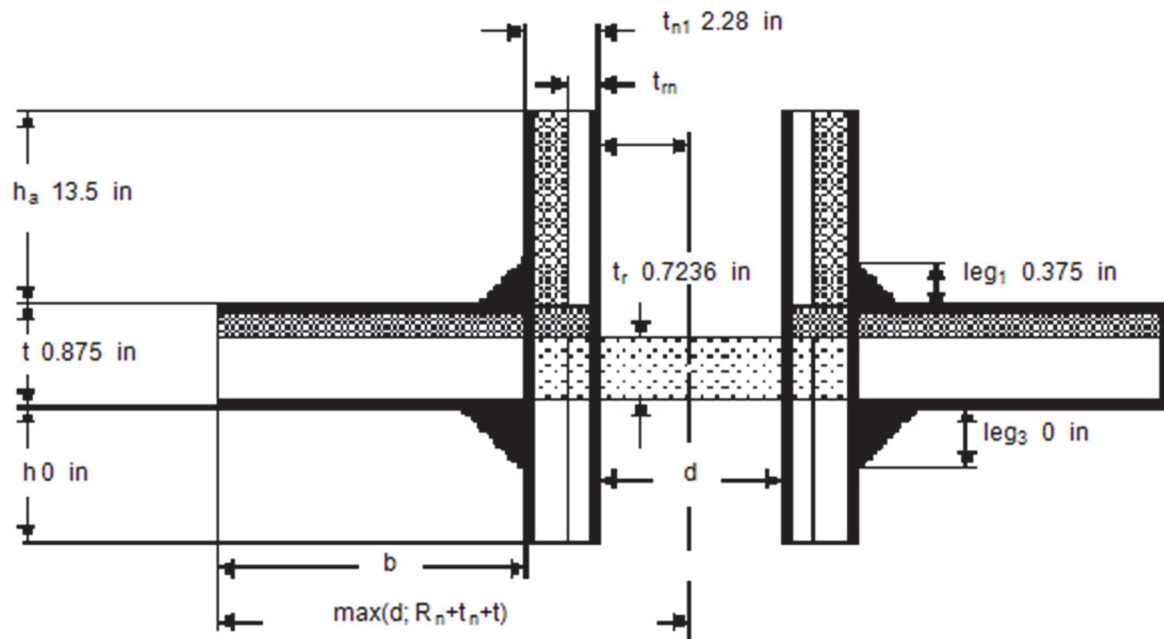
ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

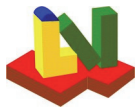
Nozzle

Nº

1



Access opening	No	
Outside diameter	d_a	15.94 in
Joint efficiency factor (or Cast Quality Factor)	E_n	1
Material	K02700-SA-516-70-Class:-Size:	
Material strength	K_n	20015 psi
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Safety factor	S	1
Allowable stress	K_n/S	20015 psi
Nominal thickness with allowances	t_{n1}	2.28 in
Required wall thickness acc. Table UG-45 with corrosion allowance	t_{b3}	0.4533 in
Nominal inside diameter = $d_a - 2 \cdot t_2$	d_{iN}	11.38 in
Inside diameter, corroded = $d_a - 2 \cdot t_n$	d	11.63 in
External projection	h_a	13.5 in
Internal projection	h	0 in
Angle between the shell axis and the sectional plane through the opening center	Θ	0 °
Nominal thickness without allowances	t_n	2.155 in
Required nozzle neck thickness per UG-27	t_a	0.2295 in
Required shell wall thickness where the nozzle neck attaches to the vessel	t_{b1}	0.527 in
with joint efficiency $E=1.0$		
Minimum nozzle neck thickness per UG-16	t_{UG-16}	0.05906 in
Required nozzle neck thickness per UG-45	t_{UG-45}	0.4533 in
Fillet weld nozzle / shell outside	leg_1	0.375 in
Fillet weld nozzle / shell inside	leg_3	0 in
Groove weld nozzle / shell ($\leq t$)	leg_4	0 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)
 Reserve of shell
 Limit length of vessel acc. to UG-40(b)
 Limit length of nozzle outside, UG40(c)
 Limit length of nozzle inside, Fig.UG37
 Minimum required thickness of nozzle
 Required area for internal pressure
 Area of shell reserve
 Area of reinforcement (A_2 to A_5)
 Total available area ΣA
 Required area A/Γ
 Utilization
 Allowable pressure (approx.: p_D /utilization)

	UG-40	App.1-7
F	1	
$(E_1 \cdot t - F \cdot t_r)$	0.1514 in	
b	5.815 in	in
h'_a	2.188 in	2.188 in
h'_i	0 mm	0
t_{rn}	0.1045 in	0.1045 in
A	8.415 in ²	in ²
A_1	1.761 in ²	in ²
A_v	9.111 in ²	in ²
A_{avl}	10.87 in ²	in ²
A_{req}	8.415 in ²	in ²
A_{req}/A_{avl}	77.4 %	%
	459.9 psi	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	$= 146256$ lbf
W_{1-1}	$= [A_2 + A_{41}] \cdot S_v$	$= 182367$ lbf
W_{2-2}	$= [A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot f_{r1}] \cdot S_v$	$= 257849$ lbf

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_v; S_n)$	$= 92087$ lbf
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_3 \cdot 0.49 \cdot \min(S_v; S_n)$	$= 0$ lbf
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.74 \cdot \min(S_v; S_n)$	$= 0$ lbf
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	$= 653785$ lbf

Comparison of weld loads on path 1-1 and 2-2

1-1	92087 lbf	+	653785 lbf	=	745872 lbf
					≥ 146256 lbf
2-2	92087 lbf	+	0 lbf	=	92087 lbf
					≥ 146256 lbf

Equations according to UG-40 and App.1-7

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = 147.7 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{d}{t_n + t} \right\}$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

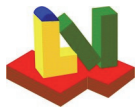
$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

Fig. UG-37.1

$$295.4 \text{ mm} \cdot 18.38 \text{ mm} \cdot 1 + 2 \cdot 54.74 \text{ mm} \cdot 18.38 \text{ mm} \cdot 1 \cdot (1 - 1) = 5429 \text{ mm}^2$$

Available shell thickness with allowances
 Required shell thickness with allowances
 Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	1 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	0.8486 in
	t_{m+}	0.2295 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = 55.56 \text{ mm}$$

$$h'_n = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = 0 \text{ mm}$$

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} = 24.55 \text{ bar} \cdot \frac{\frac{295.4 \text{ mm}}{20}}{(138 \text{ N/mm}^2 - 0.06 \cdot 24.55 \text{ bar})} = 2.655 \text{ mm} \quad (\text{internal pressure})$$

$$A_1 = \text{Max} \left\{ \begin{array}{l} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{array} \right\} =$$

$$\text{Max} \left\{ \begin{array}{l} 295.4 \text{ mm} \cdot 3.846 \text{ mm} - 2 \cdot 54.74 \text{ mm} \cdot 3.846 \text{ mm} \cdot (1 - 1) \\ 2 \cdot (22.23 \text{ mm} + 54.74 \text{ mm}) \cdot 3.846 \text{ mm} - 2 \cdot 54.74 \text{ mm} \cdot 3.846 \text{ mm} \cdot (1 - 1) \end{array} \right\} = 1136 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (54.74 \text{ mm} - 2.655 \text{ mm}) \cdot 1 \cdot 55.56 \text{ mm} = 5788 \text{ mm}^2$$

$$A_3 = 2 \cdot (t_n - c_2) \cdot f_{r2} \cdot h'_n = 2 \cdot (54.74 \text{ mm} - 3.175 \text{ mm}) \cdot 1 \cdot 0 \text{ mm} = 0 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r2} = (9.525 \text{ mm})^2 \cdot 1 = 90.73 \text{ mm}^2$$

$$A_{43} = (leg_3)^2 \cdot f_{r2} = (0 \text{ mm})^2 \cdot 1 = 0 \text{ mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 5878 \text{ mm}^2$$

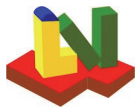
App.1-7 is additionally required acc. to UG-36(b) if

D_a	$2337 \leq 1520 \text{ mm (60in.)}$	d_a	$404.9 > \text{Min [$	$2337/2; 508 \text{ mm (20in.)}]$
D_a	$2337 > 1520 \text{ mm (60in.)}$	d_a	$404.9 > \text{Min [$	$2337/3; 1000 \text{ mm (40in.)}]$

Additional rules for cylindr. shells, App.1-7(b)

not required

Total available area		A_{avl}	in^2
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{nm}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	in^4
Material area acc. to Fig.1-7-1		A_s	in^2
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	l_m	in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = \text{[redacted]} > 1524 \text{ mm (60 in.)}$

(b) $2 \cdot R_n = \text{[redacted]} > 1016 \text{ mm (40 in.)}$ and

$$2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} = \text{[redacted]}$$

(c) $\frac{R_n}{R} = \frac{\text{[redacted]}}{\text{[redacted]}} = \text{[redacted]} \leq 0.7$

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$$S_m \leq S$$

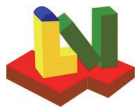
Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{22.23 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$



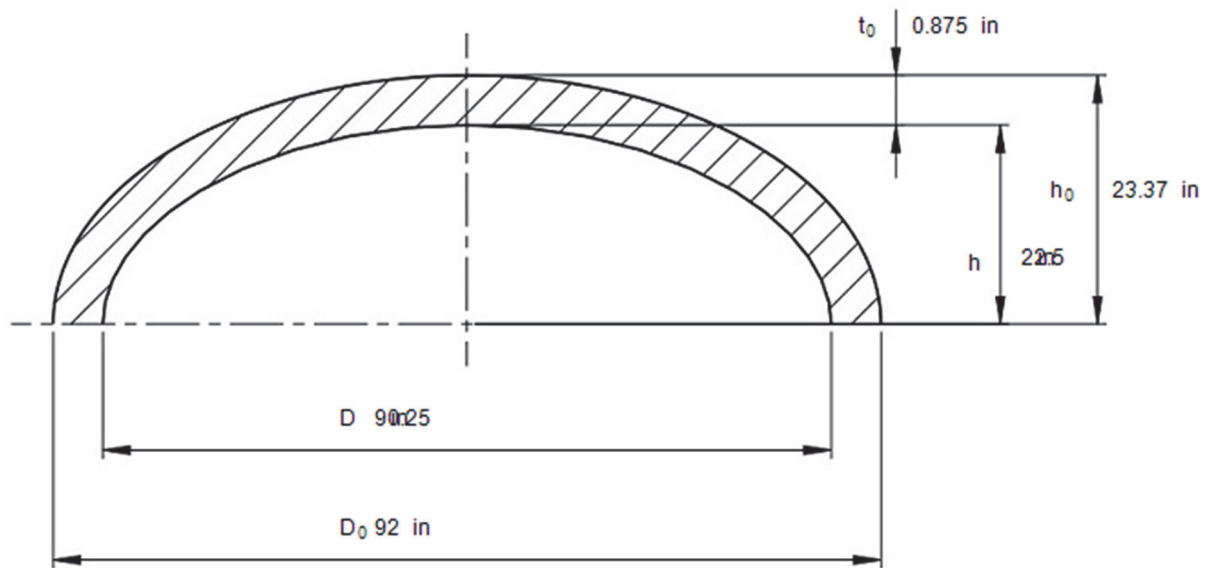
ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Elliptical heads under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023

Ellipsoidal heads acc. UG-32(c) and Appendix 1-4(f)

Design pressure	p_D	356 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	356 psi
Calculation temperature	T_0	300 °F
Final wall thickness	t_e	1 in
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Effective thickness without allowances	t_0	0.875 in



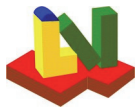
Outside diameter of cylindrical shell	D_0	92 in
Inside diameter of cylindrical shell (= $D_0 - 2t_0$)	D	90.25 in
Outer height of head	h_0	23.37 in
Inside depth of head (minor semi-axis = $h_0 - t_0$)	h	22.5 in
Weld joint efficiency (or Cast Quality Factor)	E	1

Material data

Material	K02700-SA-516-70-Class:-Size:	
Elasticity modulus	E_T	2.829e+7 psi
Elastic limit	S_y	33668 psi
Reduce allowable*) stress for $R_{m20} > 485$ MPa?	Yes	(Yes/No)
Tensile strength at 20°C	R_{m20}	70343 psi
Allowable stress	S_T	20015 psi
at working temperature acc. ASME-table	S_{20}	20015 psi
at 20°C	S	20015 psi
acc. UG-32(c) or App. 1-4(c)		
*) According to App. 1-4(c,d), the allowable stress must be reduced to $138 * S_T / S_{20}$ (=20 ksi*...) for $R_{m20} > 485$ MPa (70 ksi).		

Results

Ratio	$D/2h$	2
Factor	K	1
Factor K_1 acc. Table UG-37	K_1	0.9
Required thickness	t	0.804 in
incl. allowances (t_e 1 in $\geq t$)	t_+	0.929 in
Allowable excess pressure incl. hydrostatic Head	P	387.4 psi
Allowable excess pressure without hydrostatic Head	MAWP	387.4 psi



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Required thickness for openings acc. to UG-37(a) in nomenclature for t_r

Using UG-32 with $E=1$	$t(E=1)$	0.804 in
Section (c) in the centre circle ($< 0.8 \cdot D$)	$t_1(E=1)$	0.7236 in
Equivalent spherical outside diameter	D_s	164.5 in
$2 \cdot (K_1 \cdot D + t_E)$		

Geometrical conditions

valid

Strength

Wall thickness acceptable

Allowable unreinforced opening diameter d for welded, brazed, and flued connections acc. UG 36(c)3

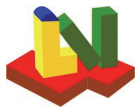
$d \leq 89 \text{ mm (3.5 in.)}$ for $t \leq 10 \text{ mm (3/8 in.)}$
 $d \leq 60 \text{ mm (2 3/8 in.)}$ for $t > 10 \text{ mm (3/8 in.)}$

Remark

Equations according to UG-32

$$t = \frac{P_0 \cdot D \cdot K}{2 \cdot S \cdot E - 0.2 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 2292 \text{ mm} \cdot 1}{2 \cdot 138 \text{ N/mm}^2 \cdot 1 - 0.2 \cdot 24.55 \text{ bar}} = 20.42 \text{ mm}$$

$$P = \frac{2 \cdot S \cdot E \cdot t_0}{K \cdot D + 0.2 \cdot t_0} = \frac{2 \cdot 138 \text{ N/mm}^2 \cdot 1 \cdot 22.23 \text{ mm}}{1 \cdot 2292 \text{ mm} + 0.2 \cdot 22.23 \text{ mm}} = 2.671 \text{ MPa}$$



ASME BPVC VIII-1 2023
Example E4.5.1 - E4.5.6 PTB-4-2021

E4.5.5 - Set-on nozzles with reinforcement - ASME BPVC VIII-1 UG-37: 2023

Set-on nozzle with reinforcement

Design pressure	p_D	500 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	500 psi
Calculation temperature	T_0	400 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

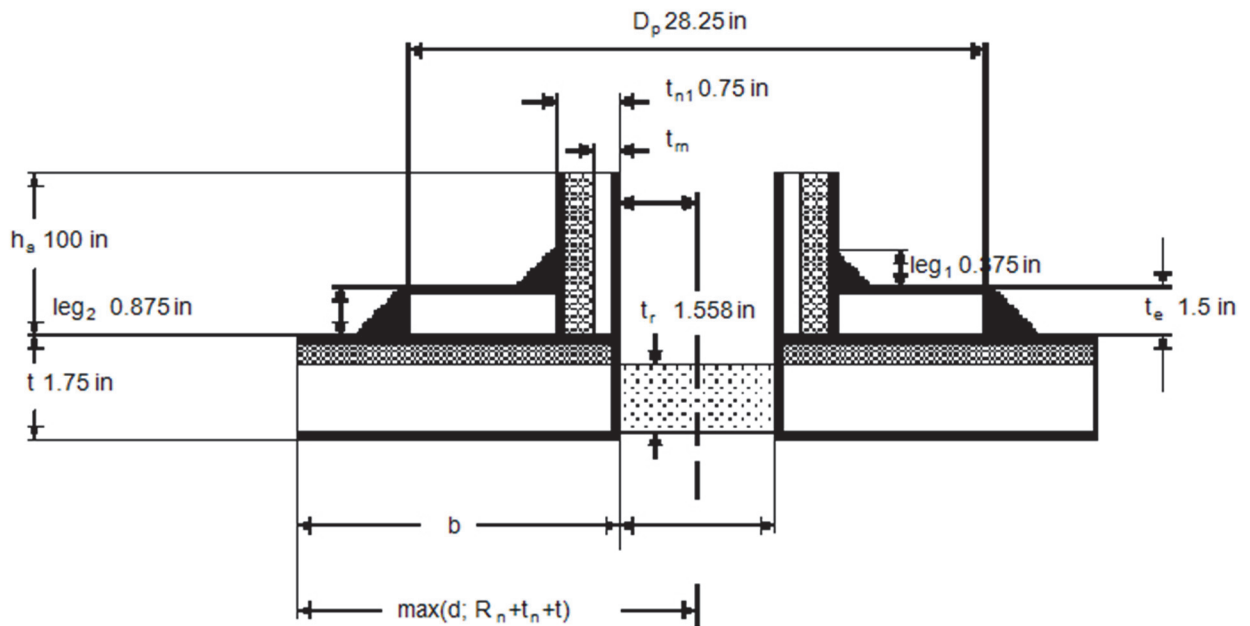
Shell

Shape of the shell	cylindrical	
Outside diameter	D_a	87 in
Nominal thickness without allowances	t	1.75 in
Available shell length for reinforcement	b_a	50 in
Joint efficiency factor (or Cast Quality Factor)	E_1	1
Material		
Material strength	K	psi
Safety factor	S	
Allowable stress value	S_v	13700 psi
Wall thickness allowance	c_{1s}	0 in
Corrosion allowance	c_{2s}	0.25 in
Required thickness without allowances	t_r	1.558 in

Nozzle

Nº

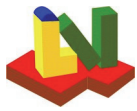
1



Access opening	No	
Outside diameter	d_a	16 in
Joint efficiency factor (or Cast Quality Factor)	E_n	1
Material		
Material strength	K_n	13700 psi
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.25 in
Safety factor	S	1
Allowable stress value	K_n/S	13700 psi
Nominal thickness with allowances	t_{n1}	0.75 in
Required wall thickness acc. Table UG-45 with corrosion allowance	t_{b3}	0.5783 in
Nominal inside diameter = $d_a - 2 \cdot t_2$	d_{iN}	14.5 in
Inside diameter, corroded = $d_a - 2 \cdot t_n$	d	15 in
External projection	h_a	100 in
Angle between the shell axis and the sectional plane through the opening center	Θ	0 °
Nominal thickness without allowances	t_n	0.5 in
Required nozzle neck thickness per UG-27	t_a	0.5299 in
Required shell wall thickness where the nozzle neck attaches to the vessel	t_{b1}	in
with joint efficiency $E=1.0$		
Minimum nozzle neck thickness per UG-16	t_{UG-16}	0.05906 in
Required nozzle neck thickness per UG-45	t_{UG-45}	in

Reinforcing element

Thickness	t_e	1.5 in
Outside diameter	D_p	28.25 in
Material		
Material strength	K_p	psi
Safety factor	S	
Allowable stress	S_p	1987007 psi
Fillet nozzle/ reinforcement outside	leg_1	0.375 in
Fillet of reinforcement / shell outside	leg_2	0.875 in
Groove nozzle / shell ($\leq t_n$)	leg_4	0.5 in
Groove reinforcement / nozzle ($\leq t_e$)	leg_5	0.5 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)

Reserve of shell

Limit length of vessel acc. to UG-40(b)

Limit length of nozzle outside, UG40(c)

Minimum required thickness of nozzle

Projected Area

Area of shell reserve

Area of reinforcement (A_2 to A_5)

Total available area ΣA

Required area A/Γ

Utilization

Allowable pressure (Approx.: pD/utilization)

UG-40

1

App.1-7

F		
$(E_1 \cdot t - F \cdot t_r)$	0.1922	in
b	7.5	in
h'_a	2.75	in
t_{rn}	0.2799	in
A	23.37	in ²
A_1	2.883	in ²
A_v	20.49	in ²
ΣA	23.38	in ²
A/H	23.37	in ²
A_{req}/A_{avl}	99.97	%
	500.2	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	= 280634	lbf
W_{1-1}	$= [A_2 + A_5 + A_{41} + A_{42}] \cdot S_v$	= 280744	lbf
W_{2-2}	$= [A_2 + A_{41}] \cdot S_v$	= 18515	lbf

Strength of fillet welds

Reinf./nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_p; S_n)$	63269	lbf
Reinf./shell	$\pi/2 \cdot D_p \cdot \text{leg}_2 \cdot 0.49 \cdot \min(S_p; S_v)$	260657	lbf

Groove weld

Shell /Nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.60 \cdot \min(S_v; S_n)$	100069	lbf
Reinf./nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_5 \cdot 0.74 \cdot \min(S_p; S_n)$	127400	lbf

Comparison of loads on path 1-1 and 2-2

1-1	260657 lbf	+	100069 lbf	=	360726 lbf
				\geq	280634 lbf
2-2	127400 lbf	+	63269 lbf	+	100069 lbf
				\geq	290738 lbf
					18515 lbf

Equations according to UG-40 and App.1-7

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = 190.5 \text{ mm}$$

App.1-7(a)(1)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{d}{t_n + t} \right\}$$

App.1-7(a)(1)

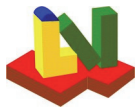
$$A = \frac{2}{3} \cdot d \cdot t_r \cdot F$$

Fig. UG-37.1

$$A = d \cdot t_r \cdot F = 381 \text{ mm} \cdot 39.57 \text{ mm} \cdot 1 = 15075 \text{ mm}^2$$

Available shell thickness with allowances
Required shell thickness with allowances
Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	2 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	1.808 in
	t_{m+}	0.5299 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \begin{cases} 2.5 \cdot t \\ 2.5 \cdot t_n + t_e = 69.85 \text{ mm} \\ h_a \end{cases}$$

(internal pressure)

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} =$$

$$34.47 \text{ bar} \cdot \frac{\frac{381 \text{ mm}}{20}}{(94.46 \text{ N/mm}^2 - 0.06 \cdot 34.47 \text{ bar})} = 7.108 \text{ mm}$$

$$A_1 = \text{Max} \begin{cases} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{cases} =$$

$$\text{Max} \begin{cases} 381 \text{ mm} \cdot 4.882 \text{ mm} - 2 \cdot 12.7 \text{ mm} \cdot 4.882 \text{ mm} \cdot (1 - f_{r1}) \\ 2 \cdot (44.45 \text{ mm} + 12.7 \text{ mm}) \cdot 4.882 \text{ mm} - 2 \cdot 12.7 \text{ mm} \cdot 4.882 \text{ mm} \cdot (1 - f_{r1}) \end{cases} = 1860 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (12.7 \text{ mm} - 7.108 \text{ mm}) \cdot 1 \cdot 69.85 \text{ mm} = 781.2 \text{ mm}^2$$

$$A_{41} = (\text{leg}_1)^2 \cdot f_{r3} = (9.525 \text{ mm})^2 \cdot 1 = 90.73 \text{ mm}^2$$

$$A_{42} = (\text{leg}_2)^2 \cdot f_{r4} = (22.23 \text{ mm})^2 \cdot 1 = 494 \text{ mm}^2$$

$$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4} = (717.5 \text{ mm} - 381 \text{ mm} - 2 \cdot 12.7 \text{ mm}) \cdot 38.1 \text{ mm} \cdot 1 = 11855 \text{ mm}^2$$

$$A_V = A_2 + A_{41} + A_{42} + A_5 = 781.2 + 90.73 + 494 + 11855 = 13221 \text{ mm}^2$$

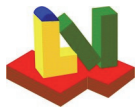
App.1-7 is additionally required according to UG-36(b), if

D_a	$2210 \leq 1520 \text{ mm (60in.)}$	d_a	$406.4 > \text{Min [$	$2210/2; 508 \text{ mm (20in.)}]$
D_a	$2210 > 1520 \text{ mm (60in.)}$	d_a	$406.4 > \text{Min [$	$2210/3; 1000 \text{ mm (40in.)}]$

Large cylinder opening acc. Appendix 1-7(b)

not required

Total available area		A_{avl}	in^2
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{nm}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	in^4
Material area acc. to Fig.1-7-1		A_s	in^2
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	l_m	in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = > 1524 \text{ mm} (60 \text{ in.})$

(b) $2 \cdot R_n = > 1016 \text{ mm} (40 \text{ in.})$ and $2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t}$

(c) $\frac{R_n}{R} = \frac{\text{[shaded box]}}{\text{[shaded box]}} = \text{[shaded box]} \leq 0.7$

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2} + \frac{(D_p - d_a)}{2} \cdot t_e \cdot f_{r4}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. App. 1-7(b)(4)

$$S_m \leq S$$

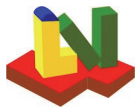
Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{44.45 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

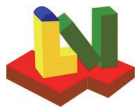
E.4.5.4 - Set-on nozzles with reinforcement - ASME BPVC VIII-1 UG-37: 2023

Set-on nozzle with reinforcement

Design pressure	p_D	425 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	425 psi
Calculation temperature	T_0	800 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

Shell

Shape of the shell	cylindrical	
Outside diameter	D_a	100 in
Nominal thickness without allowances	t	1.938 in
Available shell length for reinforcement	b_a	1000 in
Joint efficiency factor (or Cast Quality Factor)	E_1	1
Material	<i>K02700-SA-516-70-Class:-Size:</i>	
Material strength	K	11993 psi
Safety factor	S	1
Allowable stress value	S_v	11993 psi
Wall thickness allowance	c_{1s}	0 in
Corrosion allowance	c_{2s}	0.0625 in
Required thickness without allowances	t_r	1.83 in



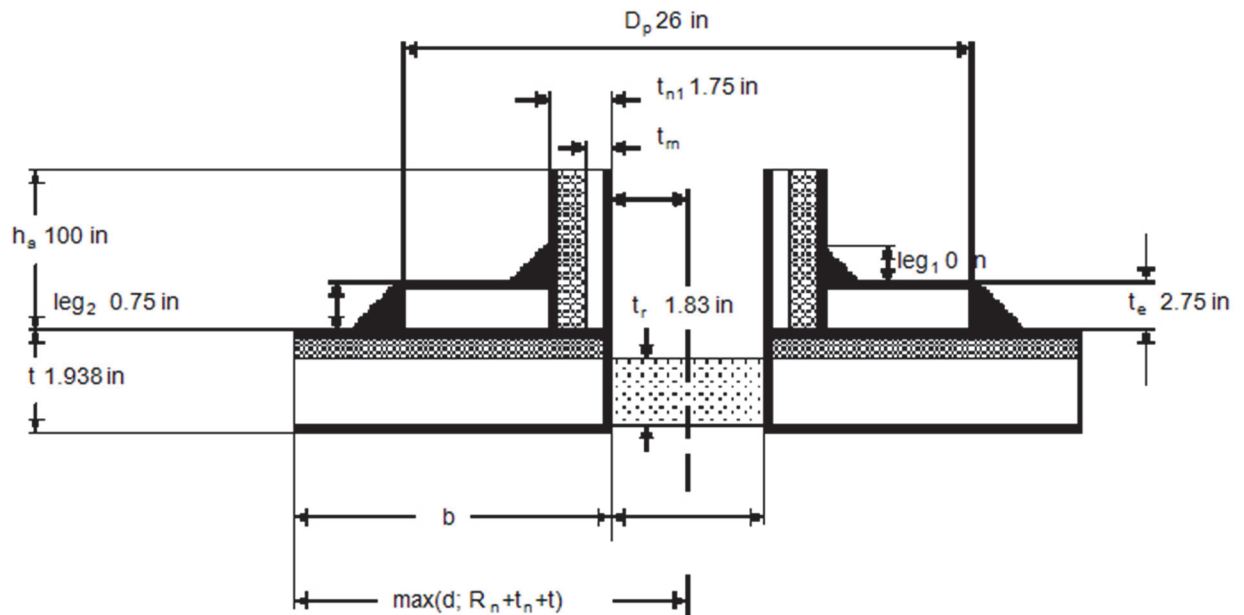
ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Nozzle

Nº

1



Access opening

Outside diameter

Joint efficiency factor (or Cast Quality Factor)

Material K02700-SA-516-70-Class:-Size:

Material strength

Wall thickness allowance

Allowance (corrosion)

Safety factor

Allowable stress value K_n/S

Nominal thickness with allowances

Required wall thickness acc. Table UG-45 with corrosion allowance

No

d_a 19.5 in

E_n 1

K_n 11993 psi

c_1 0 in

c_2 0.0625 in

S 1

S_n 11993 psi

t_{n1} 1.75 in

t_{b3} 0.3908 in

Nominal inside diameter = $d_a - 2 \cdot t_2$

Inside diameter, corroded = $d_a - 2 \cdot t_n$

External projection

Angle between the shell axis and the sectional plane through the opening center

d_{iN} 16 in

d 16.12 in

h_a 100 in

Θ 0 °

Nominal thickness without allowances

Required nozzle neck thickness per UG-27

Required shell wall thickness where the nozzle neck attaches to the vessel

with joint efficiency $E=1.0$

Minimum nozzle neck thickness per UG-16

Required nozzle neck thickness per UG-45

t_n 1.687 in

t_a 0.3544 in

t_{b1} 1.803 in

t_{UG-16} 0.05906 in

t_{UG-45} 0.3908 in

Reinforcing element

Thickness

Outside diameter

Material K02700-SA-516-70-Class:-Size:

Material strength

Safety factor

Allowable stress

t_e 2.75 in

D_p 26 in

K_p 11993 psi

S 1

S_p 11993 psi

Fillet nozzle/ reinforcement outside

Fillet of reinforcement / shell outside

Groove nozzle / shell ($\leq t_n$)

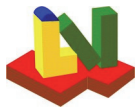
Groove reinforcement / nozzle ($\leq t_e$)

leg_1 0 in

leg_2 0.75 in

leg_4 0.812 in

leg_5 0 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)

Reserve of shell

Limit length of vessel acc. to UG-40(b)

Limit length of nozzle outside, UG40(c)

Minimum required thickness of nozzle

Projected Area

Area of shell reserve

Area of reinforcement (A_2 to A_5)

Total available area ΣA

Required area A/Γ

Utilization

Allowable pressure (Approx.: pD/utilization)

UG-40

1

App.1-7

F		
$(E_1 \cdot t - F \cdot t_r)$	0.1075 in	
b	8.062 in	in
h'_a	4.844 in	4.844 in
t_{rn}	0.2919 in	0.2919 in
A	29.51 in ²	in ²
A_1	1.733 in ²	in ²
A_v	31.96 in ²	in ²
ΣA	33.69 in ²	in ²
A/H	29.51 in ²	in ²
A_{req}/A_{avl}	87.59 %	%
	485.2 psi	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	= 333102 lbf
W_{1-1}	$= [A_2 + A_5 + A_{41} + A_{42}] \cdot S_v$	= 383253 lbf
W_{2-2}	$= [A_2 + A_{41}] \cdot S_v$	= 162137 lbf

Strength of fillet welds

Reinf./nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_p; S_n)$	0 lbf
Reinf./shell	$\pi/2 \cdot D_p \cdot \text{leg}_2 \cdot 0.49 \cdot \min(S_p; S_v)$	179999 lbf

Groove weld

Shell /Nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.60 \cdot \min(S_v; S_n)$	163483 lbf
Reinf./nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_5 \cdot 0.74 \cdot \min(S_p; S_n)$	0 lbf

Comparison of loads on path 1-1 and 2-2

1-1	179999 lbf	+	163483 lbf	=	343482 lbf
				\geq	333102 lbf
2-2	0 lbf	+	0 lbf	+	163483 lbf
				\geq	162137 lbf

Equations according to UG-40 and App.1-7

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{t_n + t}{2} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{t_n + t}{2} \right\} = 204.8 \text{ mm}$$

App.1-7(a)(1)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{t_n + t}{2} \right\}$$

App.1-7(a)(1)

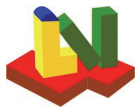
$$A = \frac{2}{3} \cdot d \cdot t_r \cdot F$$

Fig. UG-37.1

$$A = d \cdot t_r \cdot F = 409.6 \text{ mm} \cdot 46.48 \text{ mm} \cdot 1 = 19038 \text{ mm}^2$$

Available shell thickness with allowances
Required shell thickness with allowances
Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	2 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	1.893 in
	t_{m+}	0.3544 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \begin{cases} 2.5 \cdot t \\ 2.5 \cdot t_n + t_e = 123 \text{ mm} \\ h_a \end{cases}$$

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} = 29.3 \text{ bar} \cdot \frac{\frac{409.6 \text{ mm}}{20}}{(82.69 \text{ N/mm}^2 - 0.06 \cdot 29.3 \text{ bar})} = 7.415 \text{ mm}$$

(internal pressure)

$$A_1 = \text{Max} \begin{cases} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{cases} =$$

$$\text{Max} \begin{cases} 409.6 \text{ mm} \cdot 2.731 \text{ mm} - 2 \cdot 42.86 \text{ mm} \cdot 2.731 \text{ mm} \cdot (1 - f_{r1}) \\ 2 \cdot (49.21 \text{ mm} + 42.86 \text{ mm}) \cdot 2.731 \text{ mm} - 2 \cdot 42.86 \text{ mm} \cdot 2.731 \text{ mm} \cdot (1 - f_{r1}) \end{cases} = 1118 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (42.86 \text{ mm} - 7.415 \text{ mm}) \cdot 1 \cdot 123 \text{ mm} = 8722 \text{ mm}^2$$

$$A_{41} = (leg_1)^2 \cdot f_{r3} = (0 \text{ mm})^2 \cdot 1 = 0 \text{ mm}^2$$

$$A_{42} = (leg_2)^2 \cdot f_{r4} = (19.05 \text{ mm})^2 \cdot 1 = 362.9 \text{ mm}^2$$

$$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4} = (660.4 \text{ mm} - 409.6 \text{ mm} - 2 \cdot 42.86 \text{ mm}) \cdot 69.85 \text{ mm} \cdot 1 = 11532 \text{ mm}^2$$

$$A_V = A_2 + A_{41} + A_{42} + A_5 = A_2 + A_{41} + A_{42} + A_5 = 20617 \text{ mm}^2$$

App.1-7 is additionally required according to UG-36(b), if

$$\begin{array}{ll} D_a & 2540 \leq 1520 \text{ mm (60 in.):} \quad d_a & 495.3 > \text{Min} [& 2540/2; 508 \text{ mm (20 in.)}] \\ D_a & 2540 > 1520 \text{ mm (60 in.):} \quad d_a & 495.3 > \text{Min} [& 2540/3; 1000 \text{ mm (40 in.)}] \end{array}$$

Large cylinder opening acc. Appendix 1-7(b)

not required

Total available area		A_{avl}	in ²
Inside radius of shell		R	in
Inside radius of nozzle		R_n	in
Mean radius of shell		R_m	in
Mean radius of nozzle		R_{nm}	in
Allowable stress value		S	psi
Distance e		e	in
Moment of inertia		I	in ⁴
Material area acc. to Fig.1-7-1		A_s	in ²
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	l_{nm}	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	l_m	in

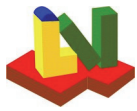
Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = > 1524 \text{ mm (60 in.)}$

(b) $2 \cdot R_n = > 1016 \text{ mm (40 in.) and}$

$$2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t}$$

(c) $\frac{R_n}{R} = \frac{\text{nozzle radius}}{\text{shell radius}} = \frac{\text{nozzle thickness}}{\text{shell thickness}} \leq 0.7$



ASME BPVC VIII-1 2023
Example E4.5.1 - E4.5.6 PTB-4-2021

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2} + \frac{(D_p - d_a)}{2} \cdot t_e \cdot f_{r4}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. App.1-7(b)(4)

$$S_m \leq S$$

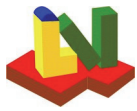
Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R_n \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{49.21 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$



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Example E4.5.1 - E4.5.6 PTB-4-2021

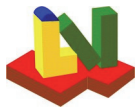
E.4.5.6 - Protruding nozzles without reinforcement - ASME BPVC VIII-1 UG-37: 2023

Protruding nozzle without reinforcement

Design pressure	p_D	150 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	150 psi
Calculation temperature	T_0	400 °F
Factor (1=internal pressure; 2=external pressure)	Γ	Internal pressure

Shell

Shape of the shell	spherical	
Outside diameter	D _a	24 in
Nominal thickness without allowances	t	0.1875 in
Available shell length for reinforcement	b _a	1000 in
Joint efficiency factor (or Cast Quality Factor)	E ₁	1
Material	S31651-SA-376-TP316N-Class:-Size:	
Material strength	K	17604 psi
Safety factor	S	1
Allowable stress value	S _v	17604 psi
Wall thickness allowance	c _{1s}	0 in
Corrosion allowance	c _{2s}	0 in
Required thickness without allowances	t _r	0.0912 in



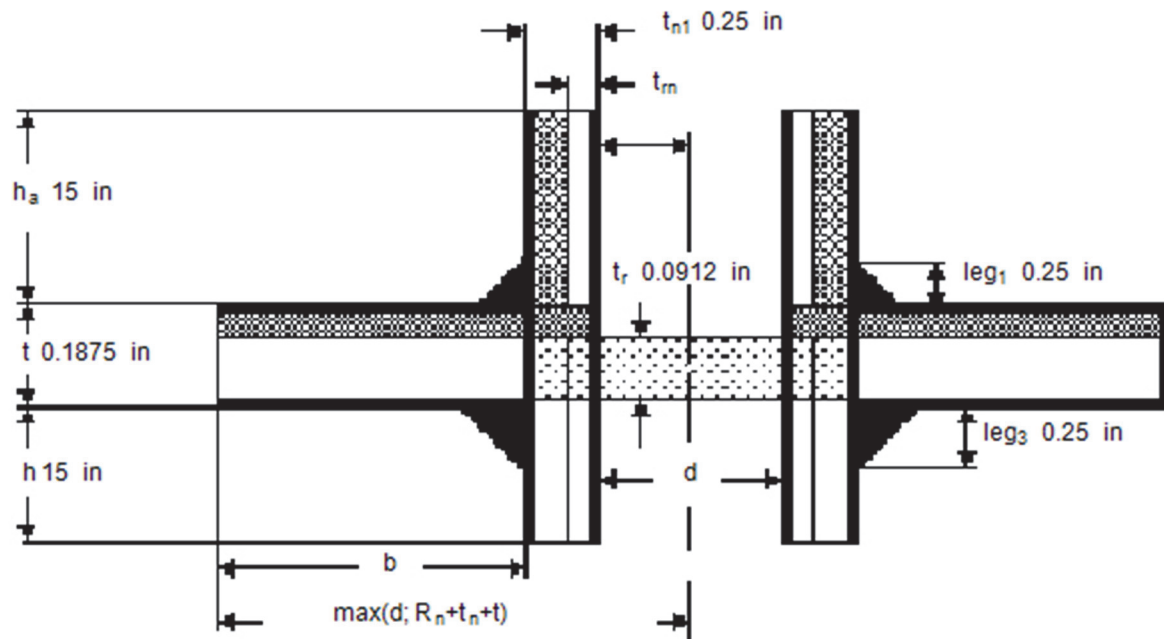
ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Nozzle

Nº

1



Access opening

Outside diameter

Joint efficiency factor (or Cast Quality Factor)

Material S31600-SA-249-TP316-Class:-Size:

Material strength

Wall thickness allowance

Allowance (corrosion)

Safety factor

Allowable stress K_n/S

Nominal thickness with allowances

Required wall thickness acc. Table UG-45 with corrosion allowance

Nominal inside diameter = $d_a - 2 \cdot t_2$

Inside diameter, corroded = $d_a - 2 \cdot t_n$

External projection

Internal projection

Angle between the shell axis and the sectional plane through the opening center

Nominal thickness without allowances

Required nozzle neck thickness per UG-27

Required shell wall thickness where the nozzle neck attaches to the vessel

with joint efficiency $E=1.0$

Minimum nozzle neck thickness per UG-16

Required nozzle neck thickness per UG-45

Fillet weld nozzle / shell outside

Fillet weld nozzle / shell inside

Groove weld nozzle / shell ($\leq t$)

No

d_a 8.625 in

E_n 1

K_n 12116 psi

c_1 0 in

c_2 0 in

S 1

S_n 12116 psi

t_{n1} 0.25 in

t_{b3} 0.2819 in

d_{iN} 8.125 in

d 8.125 in

h_a 15 in

h 15 in

Θ 0 °

t_n 0.25 in

t_a 0.05067 in

t_{b1} 0.05906 in

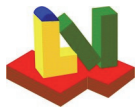
t_{UG-16} 0.05906 in

t_{UG-45} 0.05906 in

leg_1 0.25 in

leg_3 0.25 in

leg_4 0 in



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Example E4.5.1 - E4.5.6 PTB-4-2021

Calculation according to

Correction factor (Fig.UG-37, int. pres.)
 Reserve of shell
 Limit length of vessel acc. to UG-40(b)
 Limit length of nozzle outside, UG40(c)
 Limit length of nozzle inside, Fig.UG37
 Minimum required thickness of nozzle
 Required area for internal pressure
 Area of shell reserve
 Area of reinforcement (A_2 to A_5)
 Total available area ΣA
 Required area A/Γ
 Utilization
 Allowable pressure (approx.: p_D /utilization)

	UG-40	1	App.1-7
F			
$(E_1 \cdot t - F \cdot t_r)$		0.0963 in	
b		4.063 in	
h'_a		0.4688 in	0.4688 in
h'		11.91 mm	0
t_{rn}		0.05067 in	0.05067 in
A		0.7552 in ²	
A_1		0.7674 in ²	
A_v		0.376 in ²	
A_{avl}		1.143 in ²	
A_{req}		0.7552 in ²	
A_{req}/A_{avl}		66.05 %	%
		227.1 psi	psi

Weld loads according to UG-41

W	$= [A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)] \cdot S_v$	$=$	368.4 lbf
W_{1-1}	$= [A_2 + A_{41}] \cdot S_v$	$=$	3021 lbf
W_{2-2}	$= [A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot f_{r1}] \cdot S_v$	$=$	7754 lbf

Strength of nozzle wall, fillet and groove welds

Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_1 \cdot 0.49 \cdot \min(S_v, S_n)$	$=$	20109 lbf
Fillet shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_3 \cdot 0.49 \cdot \min(S_v, S_n)$	$=$	20109 lbf
Groove shell /nozzle	$\pi/2 \cdot d_a \cdot \text{leg}_4 \cdot 0.74 \cdot \min(S_v, S_n)$	$=$	0 lbf
Nozzle wall	$\pi/2 \cdot d_m \cdot t_n \cdot 0.70 \cdot S_n$	$=$	27894 lbf

Comparison of weld loads on path 1-1 and 2-2

1-1	20109 lbf	+	27894 lbf	$=$	48003 lbf
				\geq	368.4 lbf
2-2	20109 lbf	+	0 lbf	$=$	40217 lbf
				\geq	368.4 lbf

Equations according to UG-40 and App.1-7

$$b = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = \text{Max} \left\{ \frac{d}{2}, \frac{d}{t_n + t} \right\} = 103.2 \text{ mm}$$

Fig. UG-37.1, UG-40(b)

$$b = \text{Max} \left\{ \frac{3 \cdot d/2}{4}, \frac{d}{t_n + t} \right\}$$

App.1-7(a)(1)

$$A = \frac{2}{3} \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$$

App.1-7(a)(1)

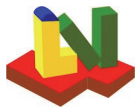
$$A = d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}) =$$

Fig. UG-37.1

$$206.4 \text{ mm} \cdot 2.316 \text{ mm} \cdot 1 + 2 \cdot 6.35 \text{ mm} \cdot 2.316 \text{ mm} \cdot 1 \cdot (1 - 0.6882) = 487.2 \text{ mm}^2$$

Available shell thickness with allowances
 Required shell thickness with allowances
 Required nozzle thickness with allowances

$t + C_{1s} + C_{2s}$	t_s	0.1875 in
$t_r + C_{1s} + C_{2s}$	t_{sr}	0.0912 in
	t_{m+}	0.05067 in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Areas according to UG-40

$$h'_a = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h_a \end{array} \right\} = 11.91 \text{ mm}$$

$$h' = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = \text{Min} \left\{ \begin{array}{l} 2.5 \cdot t \\ 2.5 \cdot t_n \\ h \end{array} \right\} = 11.91 \text{ mm}$$

(internal pressure)

$$t_m = p_0 \cdot \frac{\frac{d}{20}}{(S_n - 0.06 \cdot p_0)} =$$

$$10.34 \text{ bar} \cdot \frac{\frac{206.4 \text{ mm}}{20}}{(83.54 \text{ N/mm}^2 - 0.06 \cdot 10.34 \text{ bar})} = 1.287 \text{ mm}$$

$$A_1 = \text{Max} \left\{ \begin{array}{l} d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \\ 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1}) \end{array} \right\} =$$

$$\text{Max} \left\{ \begin{array}{l} 206.4 \text{ mm} \cdot 2.446 \text{ mm} - 2 \cdot 6.35 \text{ mm} \cdot 2.446 \text{ mm} \cdot (1 - 0.6882) \\ 2 \cdot (4.762 \text{ mm} + 6.35 \text{ mm}) \cdot 2.446 \text{ mm} - 2 \cdot 6.35 \text{ mm} \cdot 2.446 \text{ mm} \cdot (1 - 0.6882) \end{array} \right\} = 495.1 \text{ mm}^2$$

$$A_2 = 2 \cdot (t_n - t_m) \cdot f_{r2} \cdot h'_a = 2 \cdot (6.35 \text{ mm} - 1.287 \text{ mm}) \cdot 0.6882 \cdot 11.91 \text{ mm} = 82.98 \text{ mm}^2$$

$$A_3 = 2 \cdot (t_n - c_2) \cdot f_{r2} \cdot h' = 2 \cdot (6.35 \text{ mm} - 0 \text{ mm}) \cdot 0.6882 \cdot 11.91 \text{ mm} = 104.1 \text{ mm}^2$$

$$A_{41} = (\text{leg}_1)^2 \cdot f_{r2} = (6.35 \text{ mm})^2 \cdot 0.6882 = 27.75 \text{ mm}^2$$

$$A_{43} = (\text{leg}_3)^2 \cdot f_{r2} = (6.35 \text{ mm})^2 \cdot 0.6882 = 27.75 \text{ mm}^2$$

$$A_V = A_2 + A_3 + A_{41} + A_{43} = A_2 + A_3 + A_{41} + A_{43} = 242.5 \text{ mm}^2$$

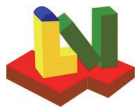
App.1-7 is additionally required acc. to UG-36(b) if

D_a	$609.6 \leq 1520 \text{ mm (60in.)}$	d_a	$219.1 > \text{Min [$	$609.6/2; 508 \text{ mm (20in.)}]$
D_a	$609.6 > 1520 \text{ mm (60in.)}$	d_a	$219.1 > \text{Min [$	$609.6/3; 1000 \text{ mm (40in.)}]$

Additional rules for cylindr. shells, App.1-7(b)

not required

Total available area	A_{avl}	in^2
Inside radius of shell	R	in
Inside radius of nozzle	R_n	in
Mean radius of shell	R_m	in
Mean radius of nozzle	R_{nm}	in
Allowable stress value	S	psi
Distance e	e	in
Moment of inertia	I	in^4
Material area acc. to Fig.1-7-1	A_s	in^2
Support length nozzle	$\text{Min}[h_a; t_e + (R_{nm} \cdot t_n)^{0.5}]$	in
Support length shell	$\text{Min}[b_a; (R_m \cdot t_e)^{0.5}]$	in



ASME BPVC VIII-1 2023

Example E4.5.1 - E4.5.6 PTB-4-2021

Conditions according to 1-7(b)(1) for radial nozzles

(a) $2 \cdot R = \text{[redacted]} > 1524 \text{ mm (60 in.)}$

(b) $2 \cdot R_n = \text{[redacted]} > 1016 \text{ mm (40 in.)}$ and

$$2 \cdot R_n > 3.4 \cdot \sqrt{R \cdot t} = \text{[redacted]}$$

(c) $\frac{R_n}{R} = \frac{\text{[redacted]}}{\text{[redacted]}} = \text{[redacted]} \leq 0.7$

Membrane stress S_m acc. App. 1-7(b)(2)

$$S_m = P \cdot \frac{[R \cdot (R_n + t_n + l_m) + R_n \cdot (t + l_{nm})]}{A_s}$$

$$A_s = l_m \cdot t + (t_n + l_{nm}) \cdot t_n \cdot f_{r2}$$

$$l_m = \text{Min} \left\{ \begin{array}{l} b_a \\ \sqrt{R_m \cdot t} \end{array} \right.$$

$$l_{nm} = \text{Min} \left\{ \begin{array}{l} h_a \\ t_e + \sqrt{R_{nm} \cdot t_n} \end{array} \right.$$

Reduction factors, only for f_{r2} or $f_{r4} < 0.8$ acc. to App.1-7(b)(4)

$$S_m \leq S$$

Bending stress S_b acc. to App. 1-7(b)(2)

$$M = \left(\frac{R_n^3}{6} + R \cdot R_n \cdot e \right) \cdot P$$

$$a = e + \frac{t}{2} = e + \frac{4.762 \text{ mm}}{2} = a$$

$$S_b = M \cdot \frac{a}{I}$$

$$(S_m + S_b) \leq 1.5 \cdot S$$