

ASME BPVC VIII-1 2021

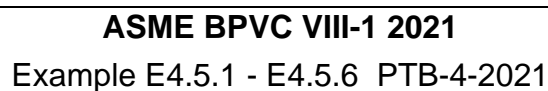
Example E4.5.1 - E4.5.6 PTB-4-2021

Table of contents

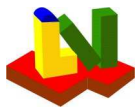
Table of contents	1
Summary.....	2
E4.3.1 - Thickness of cylindrical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2021.....	3
E4.3.2 - Cone without knuckle under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021	6
E4.3.3 - Thickness of spherical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2021	8
E4.3.4 - Torispherical heads (Kloeppe, Korbogen, Semi-spherical) under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021	10
E4.3.5 - Elliptical heads under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021.....	13

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		10.0.92	
Developed by Lauterbach Verfahrenstechnik GmbH							
Certified per DIN EN ISO 9001:2015		Certificate Number 01 100 044763					
		LV Soft		ASME		Diff [%]	
Example E4.3.1 - Cylinder Shell							
	Required thickness t_c [in]	20.62 mm	0.81 in	0.81 in		0.00%	
	Required thickness t_{long} [in]	10.16 mm	0.40 in	0.40 in		0.00%	
Example E4.3.2 - Conical Shell							
	Required thickness t [in]	39.92 mm	1.57 in	1.57 in		0.11%	
Example E4.3.3 - spherical Shell							
	Required thickness t [in]	94.65 mm	3.73 in	3.73 in		0.00%	
Example E4.3.4 - Torispherical Head					in		
	Allowable Pressure P [psi]	9.34 bar	135.42 Psi	135.30 in		0.09%	
Example E4.3.5 - Elliptical Head							
	Allowable Pressure P [psi]	30.51 bar	442.57 Psi	442.23 in		0.08%	



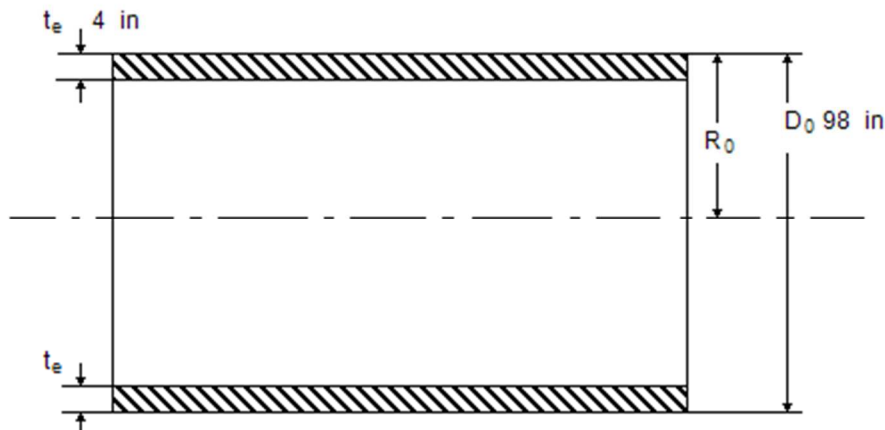
ASME BPVC VIII-1 2021

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

E4.3.1 - Thickness of cylindrical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2021

Cylindrical shells

Design pressure	P_D	356 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	P_0	356 psi
Calculation temperature	T_0	300 °F



Outside diameter	D_0	98 in
Design wall thickness	t_e	4 in
Wall thickness allowance	c_1	0.125 in
Allowance (corrosion)	c_2	0 in
Weld joint efficiency (or Cast Quality Factor)	E	1
Circumferential weld joint efficiency for Eq. 2	E_c	1

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

Allowable stress	S	20000 psi
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Results

Outside radius	R_0	49 in
Effective thickness	t_0	3.875 in

Calculation as thin shell is applicable

Required thickness	$t(R_0)$	Yes
thin shell acc. UG-27	0.866 in	$t(R)$
thick shell (not applicable)	0.8645 in	0.8119 in
Minimum wall thickness without condition acc. UG-16		0.8104 in
Minimum wall thickness acc. UG-16		20.62 mm
Required wall thickness for circumferential seam		0.05906 in
$t = \text{Max}\{\text{Min}[t_R; t_{R0}], t_{UG-16}\}$		0.4002 in
with allowances		0.8119 in
		$t + c_1 + c_2$
		0.9369 in

Allowable excess pressure	P	1633 psi
Allowable excess pressure for longitudinal stress for Eq. (2)	P_{long}	3557 psi
Allowable excess pressure without hydrostatic head	MAWP	1633 psi

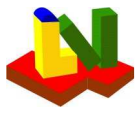
Remark

For calculation of openings according to UG-37

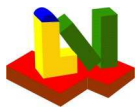
Required thickness	$t(E=1)$	0.8119 in
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Allowable unreinforced opening diameter d for welded, brazed, and flued connections acc. UG 36(c)3

$d \leq 89 \text{ mm}$ for $t \leq 10 \text{ mm}$	or	$d \leq 3 \frac{1}{2} \text{ in}$ for $t \leq \frac{3}{8} \text{ in}$
$d \leq 60 \text{ mm}$ for $t > 10 \text{ mm}$	or	$d \leq 2 \frac{3}{8} \text{ in}$ for $t > \frac{3}{8} \text{ in}$



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



ASME BPVC VIII-1 2021

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

Equations

$$R_0 = \frac{D_0}{2} = \frac{2489 \text{ mm}}{2} = 1245 \text{ mm}$$

$$t+c_1+c_2=t+c_1+c_2=20.62 \text{ mm}+3.175 \text{ mm}+0 \text{ mm}=23.8 \text{ mm}$$

corroded inside radius $R=R_0-t_0=1245 \text{ mm}-98.42 \text{ mm}=1146 \text{ mm}$

1) Thin shell For $P_0 \leq 0.385 \cdot S \cdot E \Leftrightarrow 24.55 \text{ bar} \leq 53.09 \text{ N/mm}^2$

and
with the inside radius R

$$t_e \leq \frac{(R_0 - t_e)}{2} \Leftrightarrow 101.6 \text{ mm} \leq 571.5 \text{ mm}$$

$$t(R) = \frac{P_0 \cdot R}{S \cdot E - 0.6 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1146 \text{ mm}}{137.9 \text{ N/mm}^2 \cdot 1 - 0.6 \cdot 24.55 \text{ bar}} = 20.62 \text{ mm} \quad \text{UG-27 (1)}$$

$$P(R) = \frac{S \cdot E \cdot t_0}{R + 0.6 \cdot t_0} = \frac{137.9 \text{ N/mm}^2 \cdot 1 \cdot 98.42 \text{ mm}}{1146 \text{ mm} + 0.6 \cdot 98.42 \text{ mm}} = 11.26 \text{ MPa} \quad \text{UG-27 (1)}$$

or with the outside radius R_0

$$t(R_0) = \frac{P_0 \cdot R_0}{S \cdot E + 0.4 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1245 \text{ mm}}{137.9 \text{ N/mm}^2 \cdot 1 + 0.4 \cdot 24.55 \text{ bar}} = 22 \text{ mm} \quad \text{App. 1-1 (1)}$$

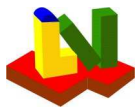
$$P(R_0) = \frac{S \cdot E \cdot t_0}{R_0 - 0.4 \cdot t_0} = \frac{137.9 \text{ N/mm}^2 \cdot 1 \cdot 98.42 \text{ mm}}{1245 \text{ mm} - 0.4 \cdot 98.42 \text{ mm}} = 11.26 \text{ MPa} \quad \text{App. 1-1 (1)}$$

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

Longitudinal Stress (Circumferential Joints)

$$t_{long} = \frac{P_0 \cdot R}{2 \cdot S \cdot E_c + 0.4 \cdot P_0} = \frac{24.55 \text{ bar} \cdot 1146 \text{ mm}}{2 \cdot 137.9 \text{ N/mm}^2 \cdot 1 + 0.4 \cdot 24.55 \text{ bar}} = 10.16 \text{ mm} \quad \text{UG-27 (2)}$$

$$P_{long} = \frac{2 \cdot S \cdot E_c \cdot t_0}{R - 0.4 \cdot t_0} = \frac{2 \cdot 137.9 \text{ N/mm}^2 \cdot 1 \cdot 98.42 \text{ mm}}{1146 \text{ mm} - 0.4 \cdot 98.42 \text{ mm}} = 24.53 \text{ MPa} \quad \text{UG-27 (2)}$$



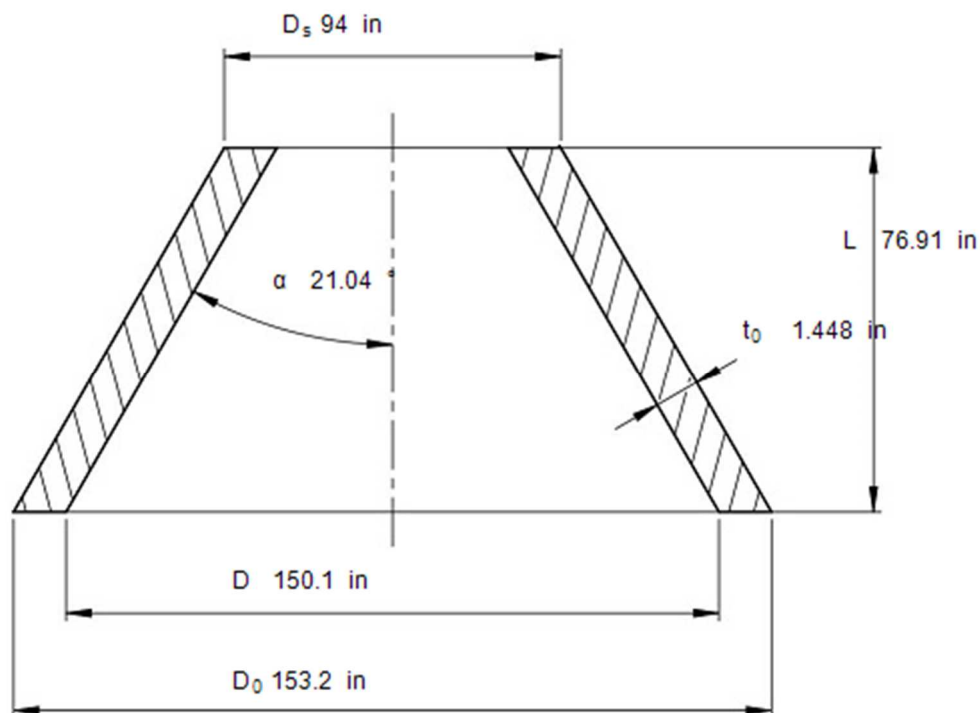
ASME BPVC VIII-1 2021

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

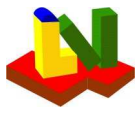
E4.3.2 - Cone without knuckle under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021

Conical sections without knuckle acc. to UG-32(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	1.573 in
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Effective thickness without allowances	t_0	1.448 in



Half-apex angle ($\leq 30^\circ$ without knuckle)	α	21.04 °
Outside diameter at the large end	D_0	153.2 in
Inside diameter at the large end	D	150.1 in
Outside diameter at the small end	D_s	94 in
Cone length	L	76.91 in
Weld joint efficiency (or Cast Quality Factor)	E	1
Material		
Allowable stress	S	20000 psi



ASME BPVC VIII-1 2021

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

Calculation

Required thickness		t	1.446 in
incl. allowances (t _e)	1.573 in	t+	1.571 in
Allowable excess pressure incl. hydrost. head		P	356.4 psi
Allowable excess pressure without hydrostatic Head		MAWP	356.4 psi

Remark

Geometrical conditions

valid

Strength condition

Wall thickness acceptable

For calculation of openings according to UG-37(a) in nomenclature for t_r

Design diameter according to UG-37(a):tr(b)	D ₁	in
Required thickness	t(E=1)	in

Equations according to UG-32(g)

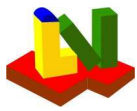
$$\cos(\alpha) = \cos(\alpha) \Leftrightarrow \cos(21.04^\circ) = 0.9333$$

$$D = D_0 - 2 \cdot \frac{t_0}{\cos(\alpha)} = 3891 \text{ mm} - 2 \cdot \frac{36.78 \text{ mm}}{0.9333} = 3812 \text{ mm}$$

$$t = \frac{P_0 \cdot D}{2 \cdot \cos(\alpha) \cdot (S \cdot E - 0.6 \cdot P_0)} = \frac{24.55 \text{ bar} \cdot 3812 \text{ mm}}{2 \cdot 0.9333 \cdot (137.9 \text{ N/mm}^2 \cdot 1 - 0.6 \cdot 24.55 \text{ bar})} = 36.74 \text{ mm}$$

$$P = \frac{2 \cdot S \cdot E \cdot t_0 \cdot \cos(\alpha)}{D + 1.2 \cdot t_0 \cdot \cos(\alpha)} = \frac{2 \cdot 137.9 \text{ N/mm}^2 \cdot 1 \cdot 36.78 \text{ mm} \cdot 0.9333}{3812 \text{ mm} + 1.2 \cdot 36.78 \text{ mm} \cdot 0.9333} = 2.457 \text{ MPa}$$

Rem.: App.1-5(d) or (e) indicates if a reinforcement ring is required.



ASME BPVC VIII-1 2021

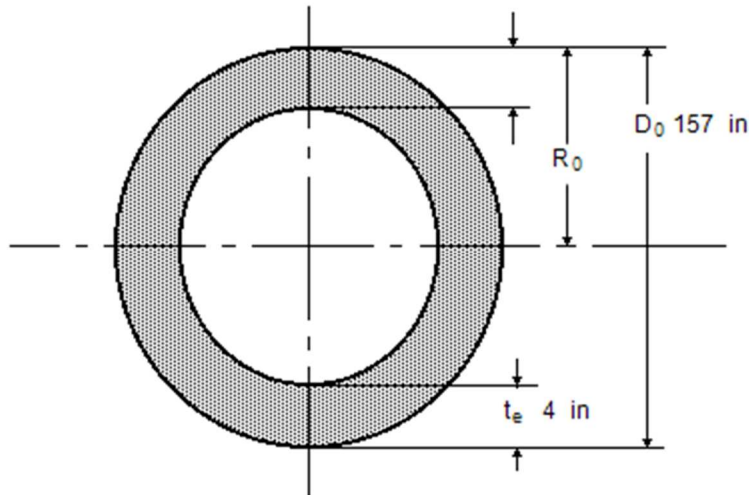
Example E4.5.1 - E4.5.6 PTB-4-2021

E4.3.3 - Thickness of spherical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2021

Spherical shells

Design pressure
Hydrostatic head
Calculation pressure
Calculation temperature

p_D 2080 psi
 D_p 0 psi
 P_0 **2080** psi
 T_0 850 °F



Outside diameter
Design wall thickness
Wall thickness allowance
Allowance (corrosion)
Weld joint efficiency (or Cast Quality Factor)

D_0 157 in
 t_e 4 in
 c_1 0 in
 c_2 0 in
 E 1 -

Material K31835-SA-542-D-Class:4a-Size:

Allowable stress

S **21000** psi

Results

Outside radius
Effective thickness

R_0 **78.5** in
 t_0 **4** in

Calculation as thin shell is applicable

Required thickness

thin shell acc. UG-27

thick shell (not applicable)

$t(R_0)$
3.739 in
3.793 in

Yes
 $t(R)$

3.726 in
3.782 in

Minimum wall thickness without condition acc. UG-16

Minimum wall thickness acc. UG-16

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

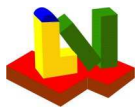
with allowances

Allowable excess pressure

Allowable excess pressure without hydrostatic head

t_{UG-27} **94.65** mm
 t_{UG-16} 0.05906 in
 t **3.726** in
 $t+c_1+c_2$ **3.726** in
 P **2231** psi
MAWP **2231** psi

Remark



ASME BPVC VIII-1 2021

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

For calculation of openings according to UG-37

Minimum required thickness for openings

$$t(E=1) \quad \mathbf{3.726 \text{ in}}$$

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

$$d \leq 89 \text{ mm for } t \leq 10 \text{ mm}$$

$$d \leq 60 \text{ mm for } t > 10 \text{ mm}$$

or

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

or

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

Equations

$$R_0 = \frac{D_0}{2} = \frac{3988 \text{ mm}}{2} = 1994 \text{ mm}$$

$$94.65 \text{ mm} = 94.65 \text{ mm} + 0 \text{ mm} + 0 \text{ mm}$$

corroded inside
radius

$$R = R_0 - t_0 = 1994 \text{ mm} - 101.6 \text{ mm} = 1892 \text{ mm}$$

1) Thin shell

For

$$P_0 \leq 0.665 \cdot S \cdot E \Leftrightarrow 143.4 \text{ bar} \leq 97.29 \text{ N/mm}^2$$

and

$$t_e \leq 0.356 \cdot (R_0 - t_e) \Leftrightarrow 101.6 \text{ mm} \leq 673.7 \text{ mm}$$

with the inside radius R

$$t(R) = \frac{P_0 \cdot R}{2 \cdot S \cdot E - 0.2 \cdot P_0} = \frac{143.4 \text{ bar} \cdot 1892 \text{ mm}}{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 - 0.2 \cdot 143.4 \text{ bar}} = 94.65 \text{ mm}$$

UG-27 (3)

$$P(R) = \frac{2 \cdot S \cdot E \cdot t_0}{R + 0.2 \cdot t_0} = \frac{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 \cdot 101.6 \text{ mm}}{1892 \text{ mm} + 0.2 \cdot 101.6 \text{ mm}} = 15.38 \text{ MPa}$$

UG-27 (3)

or with the outside radius R_0

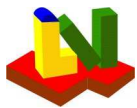
$$t(R_0) = \frac{P_0 \cdot R_0}{2 \cdot S \cdot E + 0.8 \cdot t_0} = \frac{143.4 \text{ bar} \cdot 1994 \text{ mm}}{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 + 0.8 \cdot 143.4 \text{ bar}} = 94.98 \text{ mm}$$

App. 1-1 (2)

$$P(R_0) = \frac{2 \cdot S \cdot E \cdot t_0}{R_0 - 0.8 \cdot t_0} = \frac{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 \cdot 101.6 \text{ mm}}{1994 \text{ mm} - 0.8 \cdot 101.6 \text{ mm}} = 15.38 \text{ MPa}$$

App. 1-1 (2)

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



E4.3.4 - Torispherical heads (Klopper, Korbogen, Semi-spherical) under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021

Type of head

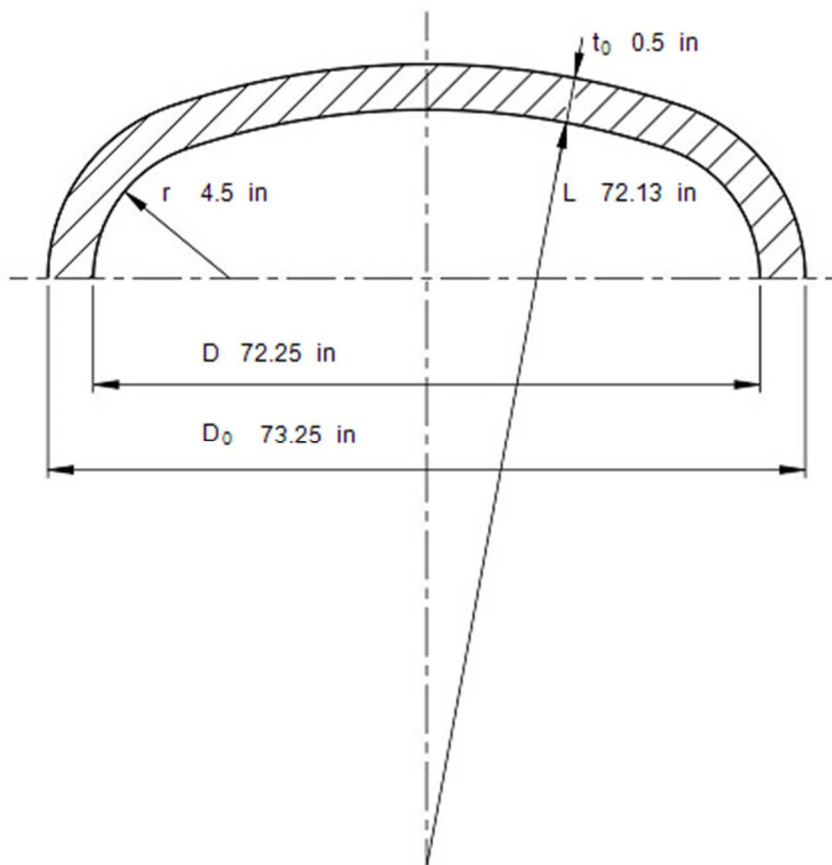
(1=Klopper-, 2=Korbogen-, 3=Torispherical, 4=Hemispherical, 5=Elliptical 2:1)

3

Torispherical

Design pressure	p_D	136 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	136 psi
Calculation temperature	T_0	650 °F

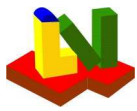
Final wall thickness	t_e	0.625 in
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Effective thickness without allowances	t_0	0.5 in



Outside diameter of cylindrical shell	D_0	73.25 in
Inside diameter of cylindrical shell	D	72.25 in
Outside crown radius	L_0	72.63 in
Outside crown radius with allowances	L_1	1848 mm
Inside crown radius	L	72.13 in
Knuckle radius	r	4.5 in
Weld joint efficiency (or Cast Quality Factor)	E	1

Material data

Material K11789-SA-387-11-Class:1-Size:



ASME BPVC VIII-1 2021

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

Elasticity modulus	E_T	2.66e+7	psi
Elastic limit	S_y	26948	psi
Reduce allowable*) stress for $R_{m20} > 485$ MPa?	Yes		(Yes/No)
Tensile strength at 20°C	R_{m20}	60190	psi
Allowable stress			
at working temperature acc. ASME-table	S_T	17114	psi
at 20°C	S_{20}	17100	psi
acc. UG-32(d) or endnote 90	S	17114	psi

) According to App. 1-4(c,d), the allowable stress must be reduced to $138 \cdot S_T / S_{20}$ (=20 ksi...) for $R_{m20} > 485$ MPa (70 ksi).

Calculation

Ratio	L/r	16.03
Factor	M	1.751
Required thickness without allowance	t	0.5021 in
incl. allowances (t_e 0.625 in $\geq t$)	t_+	0.6271 in
Allowable excess pressure incl. hydrost. head	P	135.4 psi
Allowable excess pressure without hydrostatic Head	MAWP	135.4 psi

Geometrical conditions
valid

Strength condition
Final wall thickness 15,875 < 15,9296 = required thickness

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

Using UG-32 with $E=1$	$t(E=1)$	0.5021 in
acc. section (a) in the crown region	$t_1(E=1)$	0.2868 in

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

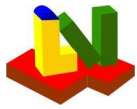
$d \leq 89$ mm (3.5 in.) for $t \leq 10$ mm (3/8 in.)
 $d \leq 60$ mm (2 3/8 in.) for $t > 10$ mm (3/8 in.)

Remark

Equations

$$t = \frac{P_0 \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P_0} = \frac{9.377 \text{ bar} \cdot 1832 \text{ mm} \cdot 1.751}{2 \cdot 118 \text{ N/mm}^2 \cdot 1 - 0.2 \cdot 9.377 \text{ bar}} = 12.75 \text{ mm}$$

$$P = \frac{2 \cdot S \cdot E \cdot t_0}{L \cdot M + 0.2 \cdot t_0} = \frac{2 \cdot 118 \text{ N/mm}^2 \cdot 1 \cdot 12.7 \text{ mm}}{1832 \text{ mm} \cdot 1.751 + 0.2 \cdot 12.7 \text{ mm}} = 0.9337 \text{ MPa}$$



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

For openings in the crown region with

Opening diameter

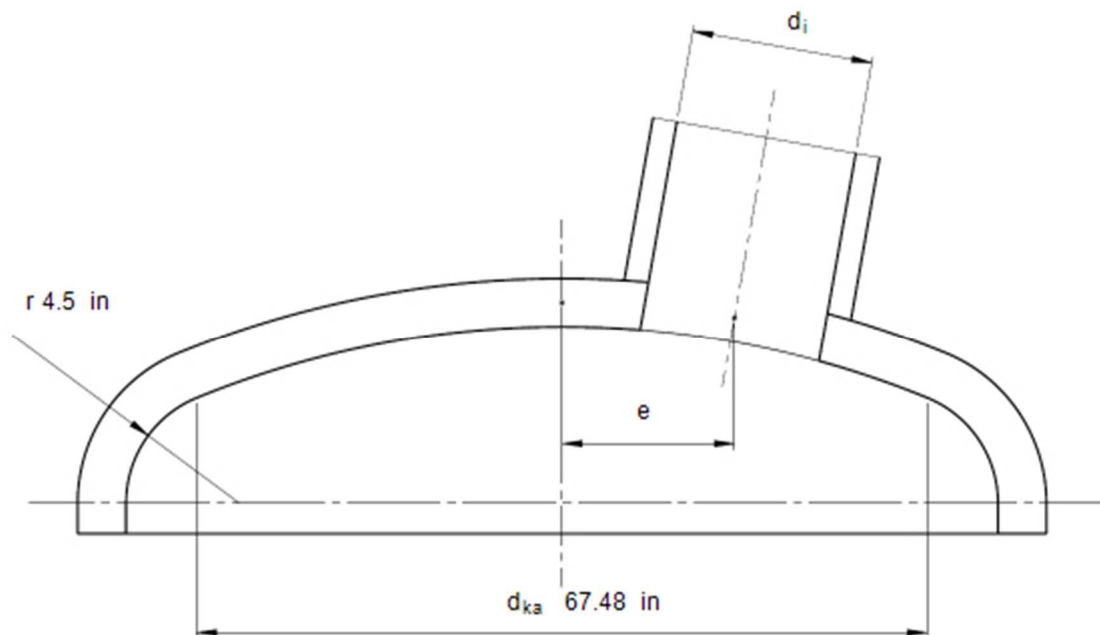
d_i

in

Distance between opening center and head center

e

in



Available reinforcement width acc. UG37

Available reinforcement width of the crown

b'

in

Diameter of the crown region

d_{ka}

67.48 in

Angle of the knuckle region

ϕ

62.24 °

Arc length of the knuckle region

b''

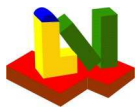
5.567 in

$$d_{ka} = (2 \cdot L + t_e) \cdot (D/2 - r) / (L - r)$$

$$\phi = \arccos((D/2 - r) / (L - r))$$

$$b' = (d_{ka} - d_i) / 2 - e$$

$$b'' = (r + t_e) \cdot \phi$$



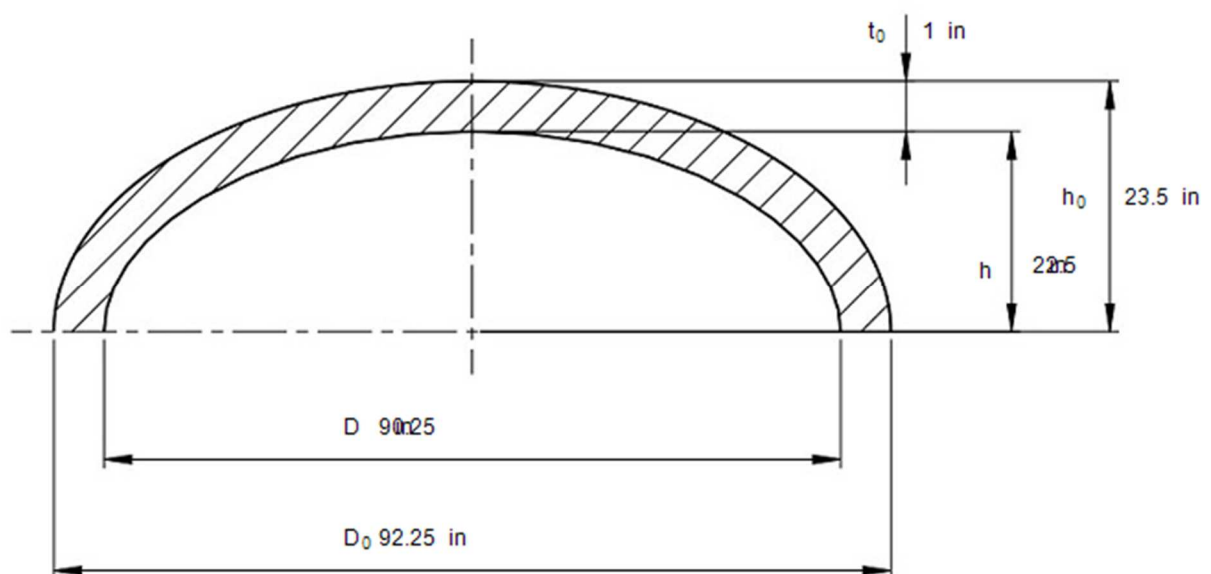
ASME BPVC VIII-1 2021

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

E4.3.5 - Elliptical heads under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2021

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

Design pressure	p_D	442.2 psi
Hydrostatic head	D_p	0 psi
Calculation pressure	p_0	442.2 psi
Calculation temperature	T_0	300 °F
Final wall thickness	t_e	1.125 in
Wall thickness allowance	c_1	0 in
Allowance (corrosion)	c_2	0.125 in
Effective thickness without allowances	t_0	1 in



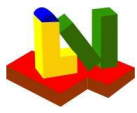
Outside diameter of cylindrical shell	D_0	92.25 in
Inside diameter of cylindrical shell ($= D_0 - 2t_0$)	D	90.25 in
Outer height of head	h_0	23.5 in
Inside depth of head (minor semi-axis $= h_0 - t_0$)	h	22.5 in
Weld joint efficiency (or Cast Quality Factor)	E	1

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		
at working temperature acc. ASME-table	S_T	20015 psi
at 20°C	S_{20}	20000 psi
acc. UG-32(c) or App. 1-4(c)	S	20015 psi
*) 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	0.9992 in
incl. allowances (t_e 1.125 in $\geq t+$)	$t+$	1.124 in
Allowable excess pressure incl. hydrostatic Head	P	442.6 psi
Allowable excess pressure without hydrostatic Head	MAWP	442.6 psi



ASME BPVC VIII-1 2021

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 $E=1$	$t(E=1)$	0.9992 in
Section (c) in the centre circle ($< 0.8 \cdot D$)	$t_1(E=1)$	0.8993 in
Equivalent spherical outside diameter	D_s	164.7 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

$$t = \frac{P_0 \cdot D \cdot K}{2 \cdot S \cdot E - 0.2 \cdot P_0} = \frac{30.49 \text{ bar} \cdot 2292 \text{ mm} \cdot 1}{2 \cdot 138 \text{ N/mm}^2 \cdot 1 - 0.2 \cdot 30.49 \text{ bar}} = 25.38 \text{ mm}$$

$$P = \frac{2 \cdot S \cdot E \cdot t_0}{K \cdot D + 0.2 \cdot t_0} = \frac{2 \cdot 138 \text{ N/mm}^2 \cdot 1 \cdot 25.4 \text{ mm}}{1 \cdot 2292 \text{ mm} + 0.2 \cdot 25.4 \text{ mm}} = 3.051 \text{ MPa}$$