

ASME BPVC VIII-1 2023

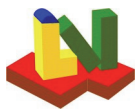
Example E4.3.1 - E4.3.5 PTB-4-2021

Table of contents

Table of contents	1
Summary.....	2
E 4.3.1 - Thickness of cylindrical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2023	3
E 4.3.2 - Cone without knuckle under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023	5
E 4.3.3 - Thickness of spherical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2023	7
E 4.3.4 - Torispherical heads (Kloepper, Korbogen, Semi-spherical) under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023	9
E 4.3.5 - Elliptical heads under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023.....	12

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

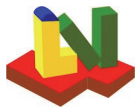


ASME BPVC VIII-1 2023
Example E4.3.1 - E4.3.5 PTB-4-2021

Summary

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 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							
	Allowable Pressure P [psi]	9,34 bar	135,42 Psi	135,30 Psi	0,09%	*	
Example E4.3.5 - Elliptical Head							
	Allowable Pressure P [psi]	30,51 bar	442,57 Psi	442,23 Psi	0,08%		

[illegible]



ASME BPVC VIII-1 2023

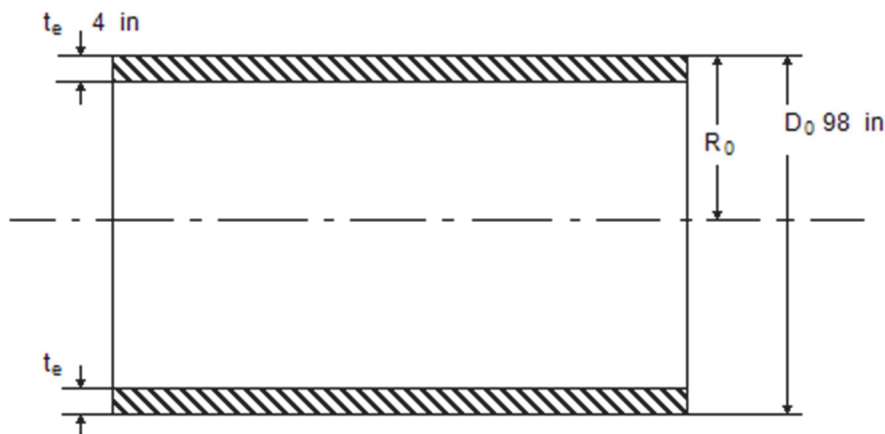
Example E4.3.1 - E4.3.5 PTB-4-2021

E 4.3.1 - 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 98 in
 t_e 4 in
 c_1 0.125 in
 c_2 0 in
 E 1
 E_c 1

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

Allowable stress

S 20000 psi

Results

Outside radius
Effective thickness

R_0 49 in
 t_0 3.875 in

Calculation as thin shell is applicable

Required thickness

$t(R_0)$ 0.866 in
0.8645 in

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

t_{UG-27} 20.62 mm
 t_{UG-16} 0.05906 in
 t_{long} 0.4002 in
 t 0.8119 in
 $t+c_1+c_2$ 0.9369 in

Allowable excess pressure

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

Allowable excess pressure without hydrostatic head

P 1633 psi
 P_{long} 3557 psi
MAWP 1633 psi

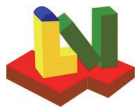
Remark

For calculation of openings according to UG-37

Required thickness

$t(E=1)$ 0.8119 in

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



ASME BPVC VIII-1 2023

Example E4.3.1 - E4.3.5 PTB-4-2021

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

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

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

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

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

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

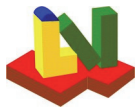
$$P(R_0) = \frac{S \cdot E \cdot t_0}{R_0 - 0.4 \cdot t_0} = \frac{137.9 \text{ N/mm}^2 \cdot 1 \cdot 98.42 \text{ mm}}{1245 \text{ mm} - 0.4 \cdot 98.42 \text{ mm}} = 11.26 \text{ MPa} \quad \text{App. 1-1 (1)}$$

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

Longitudinal Stress (Circumferential Joints)

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

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

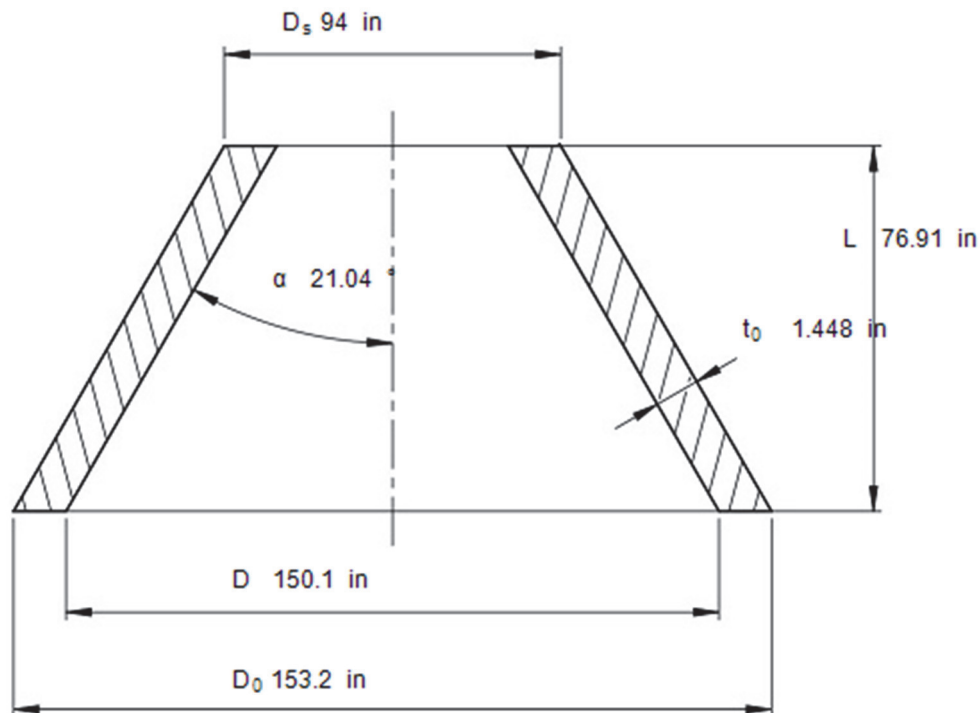


ASME BPVC VIII-1 2023
Example E4.3.1 - E4.3.5 PTB-4-2021

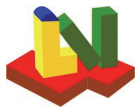
E 4.3.2 - Cone without knuckle under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023

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 2023

Example E4.3.1 - E4.3.5 PTB-4-2021

Calculation

Required thickness	t	1.446 in
incl. allowances (t _e 1.573 in ≥t+)	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)

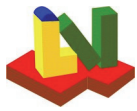
$$\cos(\alpha) = \cos(\alpha) \Leftrightarrow \cos(21.04^\circ) = 0.9333$$

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

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

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

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



ASME BPVC VIII-1 2023

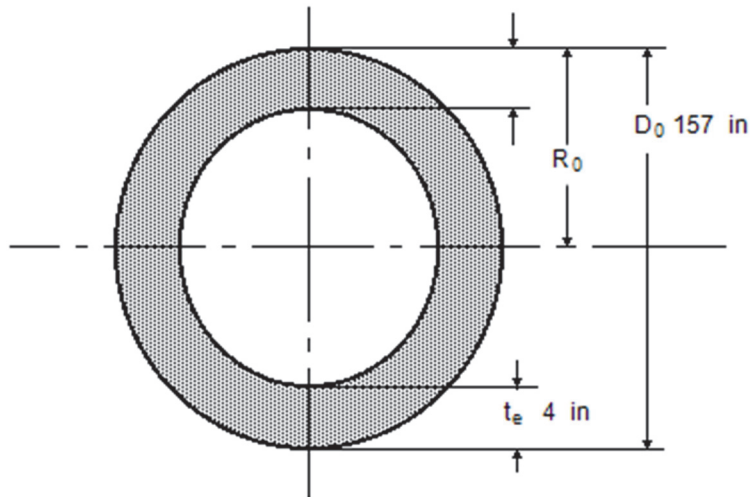
Example E4.3.1 - E4.3.5 PTB-4-2021

E 4.3.3 - Thickness of spherical shells under internal pressure - ASME BPVC VIII-1 UG-27 & Appendix-1: 2023

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
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

t_{UG-27} **94.65** mm

t_{UG-16} 0.05906 in

t **3.726** in

$t+c_1+c_2$ **3.726** in

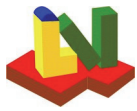
Allowable excess pressure

P **2231** psi

Allowable excess pressure without hydrostatic head

MAWP **2231** psi

Remark



ASME BPVC VIII-1 2023

Example E4.3.1 - E4.3.5 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

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

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

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

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

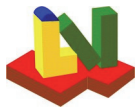
$$t(R_0) = \frac{P_0 \cdot R_0}{2 \cdot S \cdot E + 0.8 \cdot t_0} = \frac{143.4 \text{ bar} \cdot 1994 \text{ mm}}{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 + 0.8 \cdot 143.4 \text{ bar}} = 94.98 \text{ mm}$$

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)

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



ASME BPVC VIII-1 2023

Example E4.3.1 - E4.3.5 PTB-4-2021

E 4.3.4 - Torispherical heads (Kloepper, Korbogen, Semi-spherical) under internal pressure - ASME BPVC VIII-1 UG-32 & Appendix-1: 2023

Type of head

(1=Kloepper-, 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

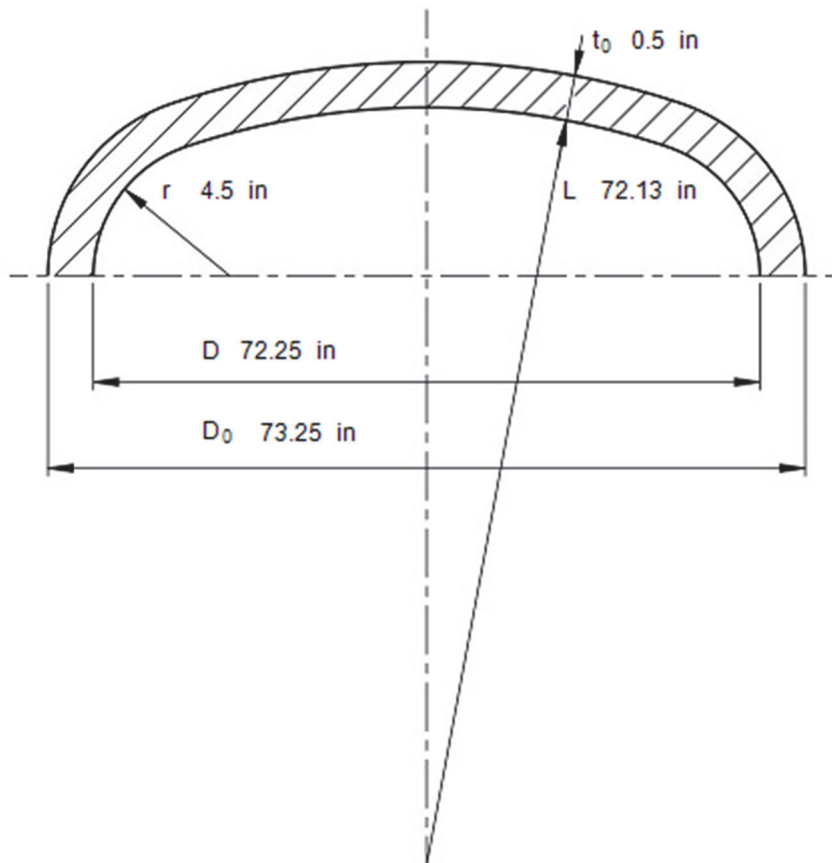
c_1 0 in

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

$(= D_0 - 2t_0)$ D 72.25 in

Outside crown radius

L_0 72.63 in

Outside crown radius with allowances

L_1 1848 mm

Inside crown radius

$(= L_0 - t_0)$ L 72.13 in

Knuckle radius

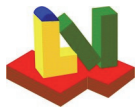
r 4.5 in

Weld joint efficiency (or Cast Quality Factor)

E 1

Material data

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



ASME BPVC VIII-1 2023

Example E4.3.1 - E4.3.5 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	17100 psi
at 20°C	S_{20}	17114 psi
acc. UG-32(d) or endnote 90	S	17100 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

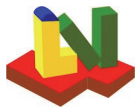
$d \leq 89$ mm (3.5 in.) for $t \leq 10$ mm (3/8 in.)
 $d \leq 60$ mm (2 3/8 in.) for $t > 10$ mm (3/8 in.)

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 2023 **Example E4.3.1 - E4.3.5 PTB-4-2021**

For openings in the crown region with

Opening diameter

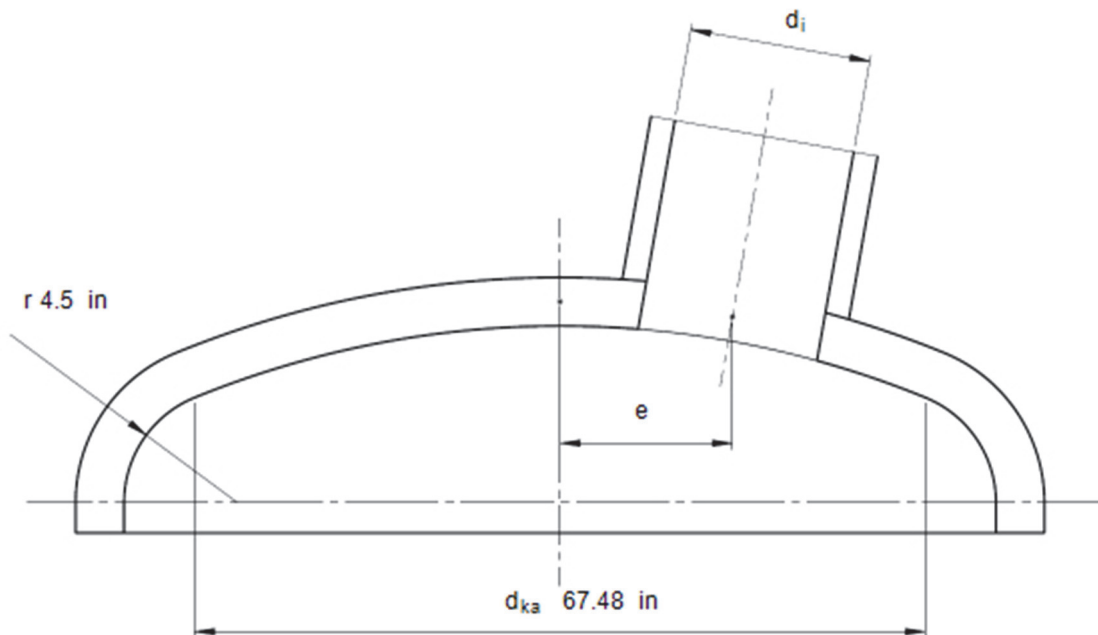
d_i

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''

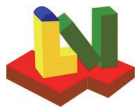
5.567 in

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

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

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

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



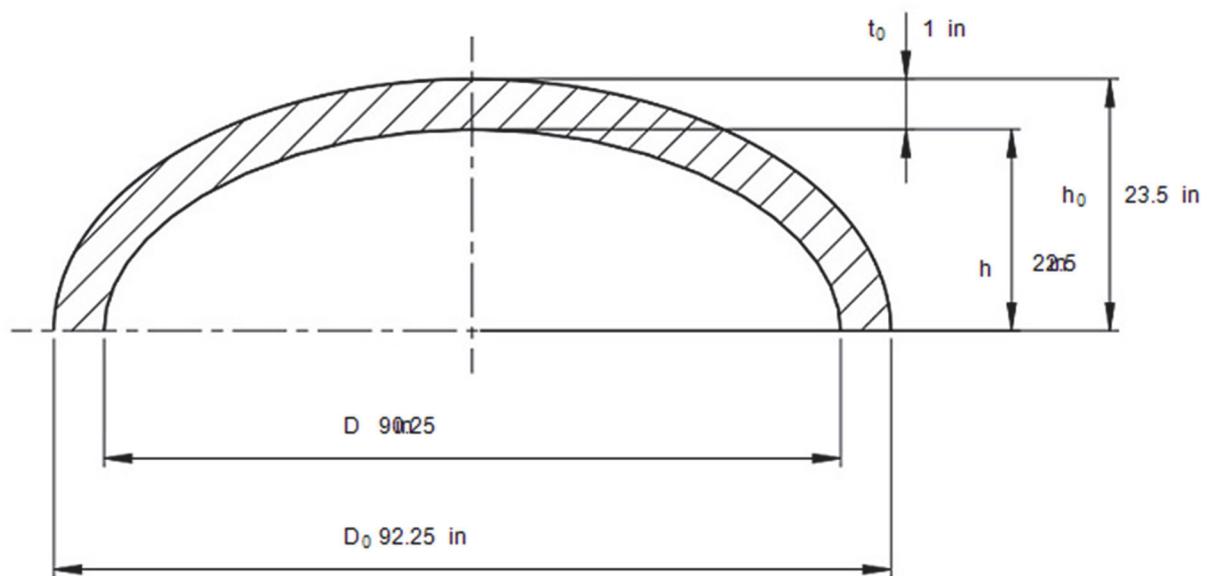
ASME BPVC VIII-1 2023

Example E4.3.1 - E4.3.5 PTB-4-2021

E 4.3.5 - 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	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



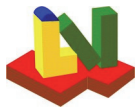
Outside diameter of cylindrical shell	D_0	92.25 in
Inside diameter of cylindrical shell ($= D_0 - 2t_0$)	D	90.25 in
Outer height of head	h_0	23.5 in
Inside depth of head (minor semi-axis $= h_0 - t_0$)	h	22.5 in
Weld joint efficiency (or Cast Quality Factor)	E	1

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 $138 * S_T / S_{20}$ ($= 20 \text{ ksi} * \dots$) 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_e	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 2023

Example E4.3.1 - E4.3.5 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 $2 \cdot (K_1 \cdot D + t_E)$	D_s	164.7 in

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

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

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