

ASME BPVC VIII-1 2023

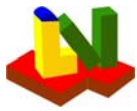
Example E4.3.1 - E4.3.5 PTB-4-2021

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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

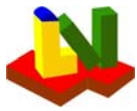


ASME BPVC VIII-1 2023
Example E4.3.1 - E4.3.5 PTB-4-2021

Summary

Strength Calculation Software		Program System ATLAS		Version		10.0.107	
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%	

*)	Anmerkung zum Berechnungswert gemäß ASME.
	Dieser Wert wurde durch Handrechnung ermittelt gemäß den Gleichungen im PTB-4 2021 Example E4.3.4 - Abschnitt b,c
	Handrechnung wurde angewendet da kein expliziter Berechnungswert angegeben wurde.
	Die Abweichung zwischen der Handrechnung und der Berechnungssoftware (LV Soft) beträgt 0,09%
	Die Validierung der Berechnungsformel in der Berechnungssoftware (LV Soft) konnte somit durchgeführt werden.
	Note on the calculation value according to ASME.
	This value was determined by hand calculation according to the equations in PTB-4 2021 Example E4.3.4 - Section b,c.
	Manual calculation was used as no explicit calculation value was given.
	The validation of the calculation formula in the calculation software (LV Soft) could therefore be carried out.



ASME BPVC VIII-1 2023

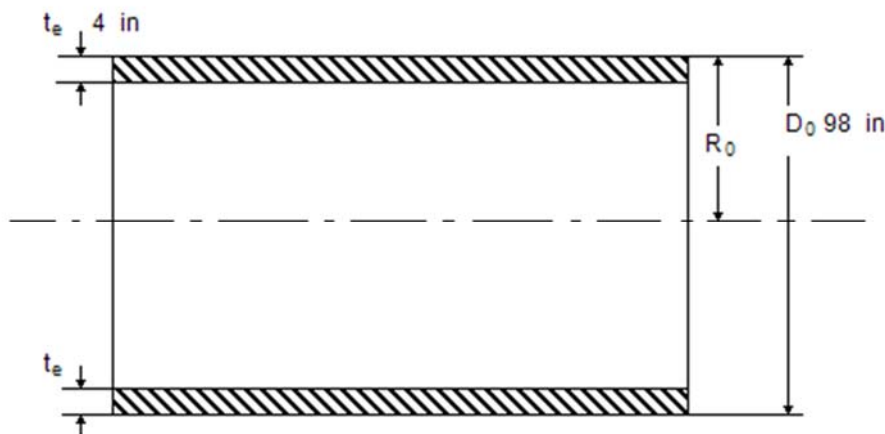
Example E4.3.1 - E4.3.5 PTB-4-2021

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

$t(R)$ 0.8119 in

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

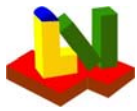
Remark

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

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

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

UG-27 (1)

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

UG-27 (1)

or with the outside radius R_0

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

App. 1-1 (1)

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

App. 1-1 (1)

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

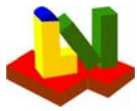
Longitudinal Stress (Circumferential Joints)

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

UG-27 (2)

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

UG-27 (2)

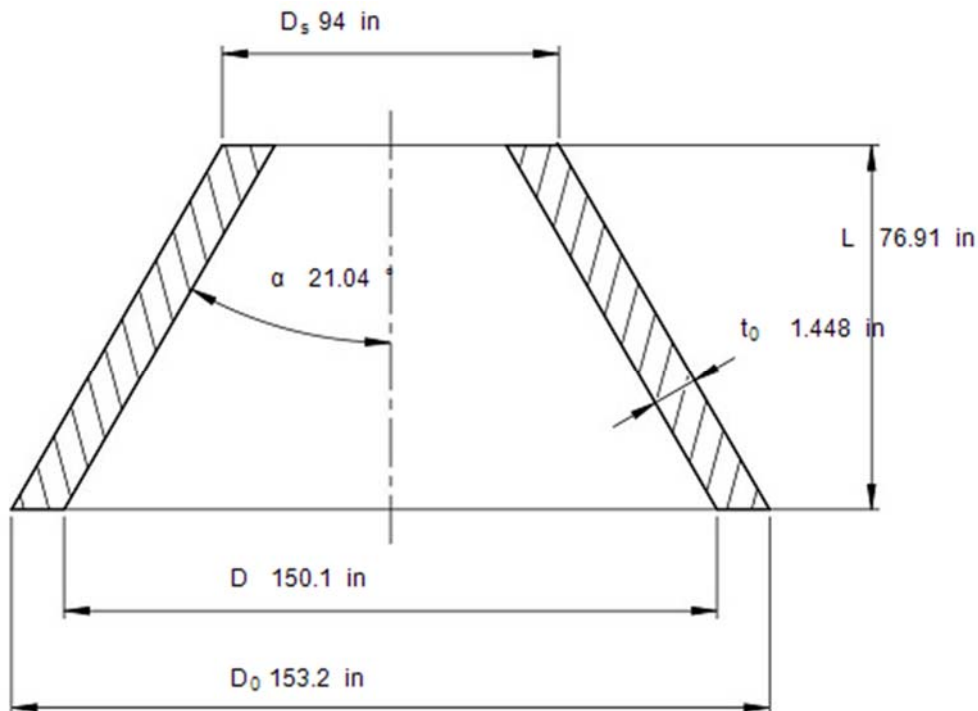


ASME BPVC VIII-1 2023
Example E4.3.1 - E4.3.5 PTB-4-2021

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)

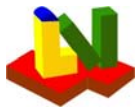
$$\cos(\alpha) = \cos(\alpha) \Leftrightarrow \cos(21.04^\circ) = 0.9333$$

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

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

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

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



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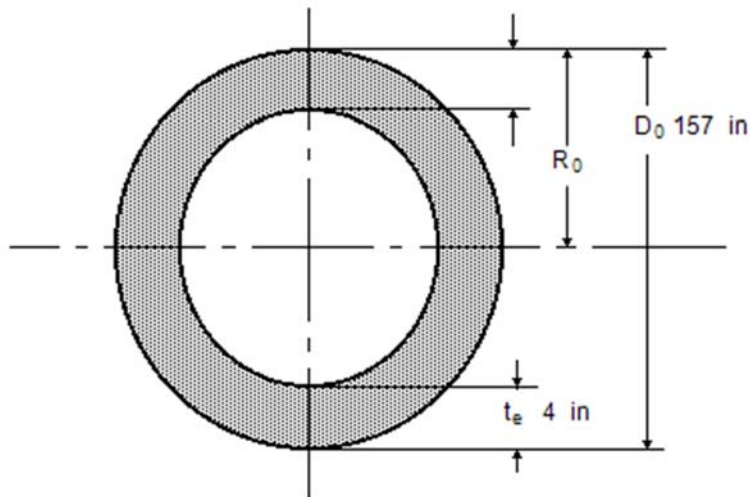
Example E4.3.1 - E4.3.5 PTB-4-2021

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

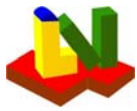
$$t(R_0) = \frac{P_0 \cdot R_0}{2 \cdot S \cdot E + 0.8 \cdot t_0} = \frac{143.4 \text{ bar} \cdot 1994 \text{ mm}}{2 \cdot 144.8 \text{ N/mm}^2 \cdot 1 + 0.8 \cdot 143.4 \text{ bar}} = 94.98 \text{ mm}$$

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

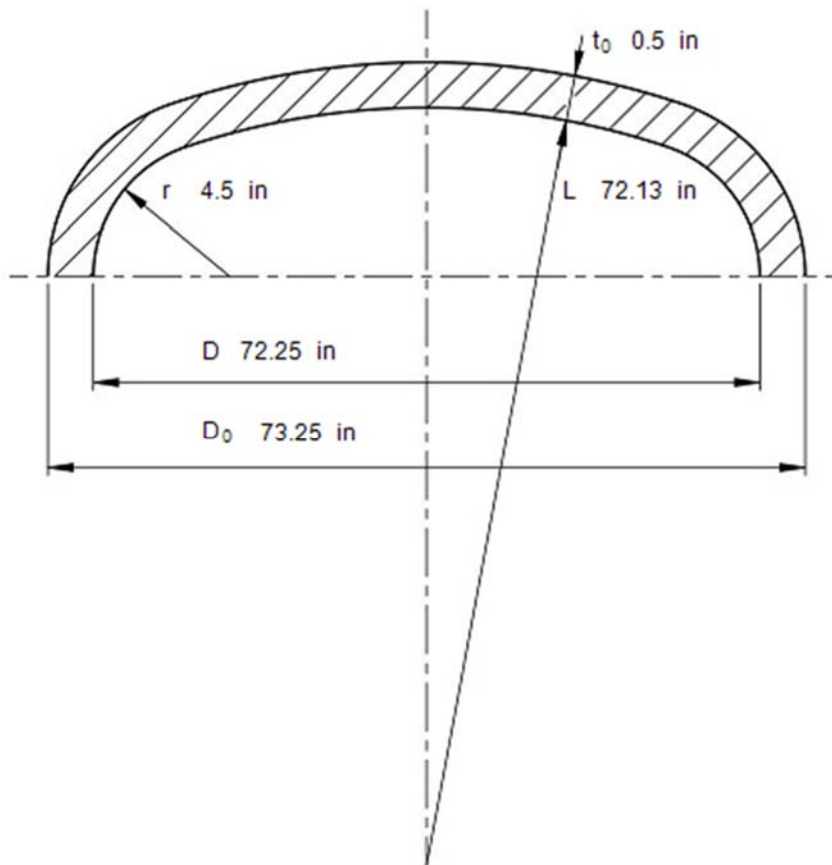
c_1 0 in

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

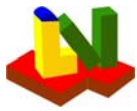
r 4.5 in

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

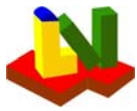
$d \leq 89$ mm (3.5 in.) for $t \leq 10$ mm (3/8 in.)
 $d \leq 60$ mm (2 3/8 in.) for $t > 10$ mm (3/8 in.)

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

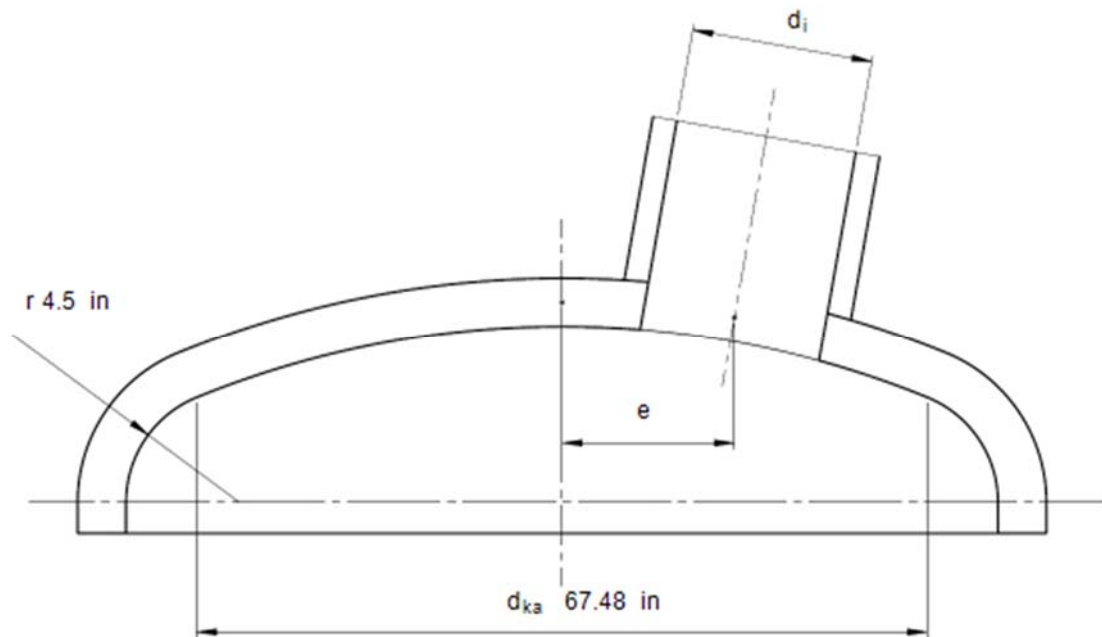
d_i

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

62.24 °

Arc length of the knuckle region

b''

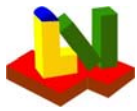
5.567 in

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

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

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

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



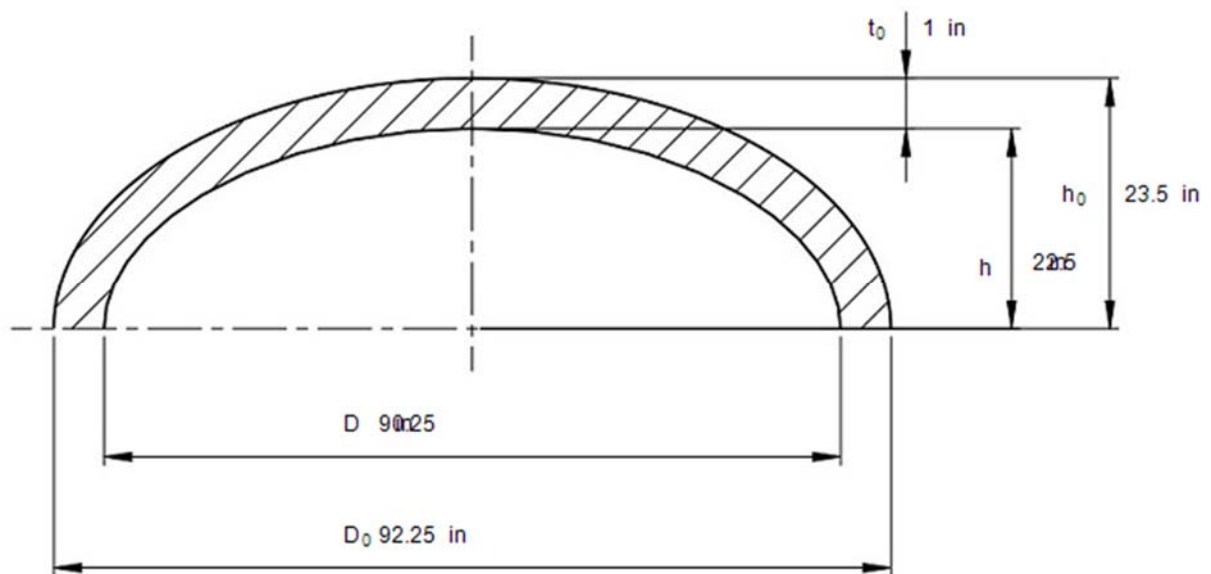
ASME BPVC VIII-1 2023

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



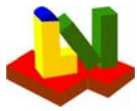
Outside diameter of cylindrical shell	D_0	92.25 in
Inside diameter of cylindrical shell (= $D_0 - 2t_0$)	D	90.25 in
Outer height of head	h_0	23.5 in
Inside depth of head (minor semi-axis= $h_0 - t_0$)	h	22.5 in
Weld joint efficiency (or Cast Quality Factor)	E	1

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	S_T	20015 psi	
at working temperature acc. ASME-table	S_{20}	20000 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 K1 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 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	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

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

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