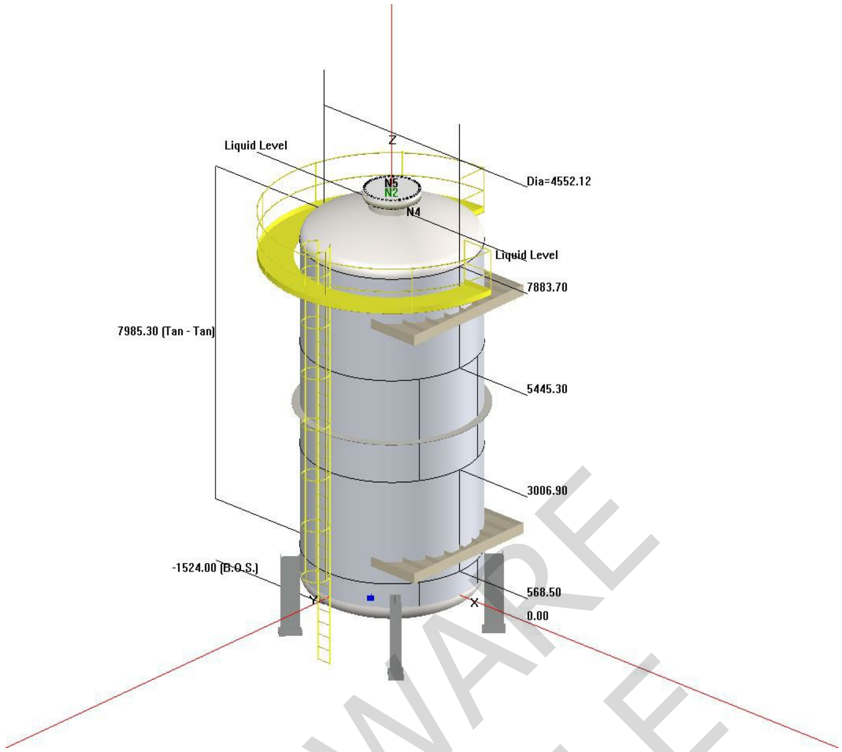
Elsewedy Electric



COMPRESS Pressure Vessel Design Calculations

Designer: CD

Date: Monday, February 14, 2022

Location:

Purchaser:

Name: Elsewedy Electric Example

Class: -

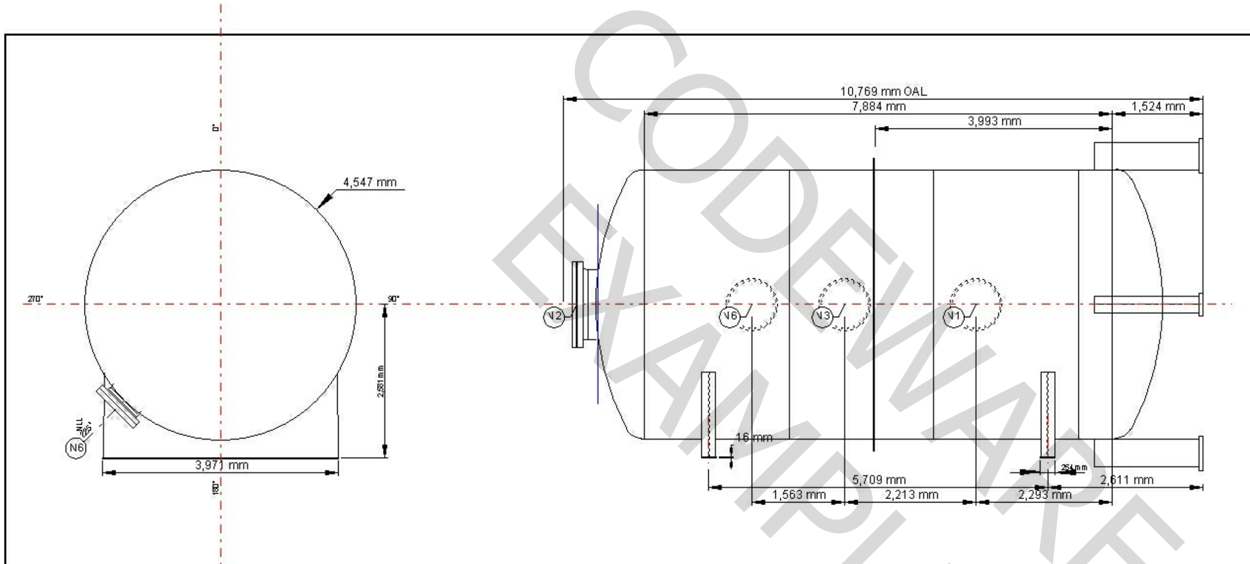
Service:

P.O. Number:

Tag Number:

Unit Number:

Table of Contents



DESIGN DATA

Design Pressure	7 bar
Vacuum Pressure	0.8 bar
Test Pressure (Shop)	0 bar
Design Temperature	40 °C
MDMT	5 °C
Corrosion Allowance	1.6 mm
Radiography	RT1
PWHT	None

Estimated Weights

Dry: 29,950 kg Wet: 168,778 kg

Materials

Cylinder(s):	Carbon Steel
Head(s):	SA-516 70
Transition(s):	
Support:	

NOZZLE SCHEDULE

MARK	NOZZLE	SIZE & SCH	FLANGE	MARK	NOZZLE	SIZE & SCH	FLANGE
N1	Nozzle #1	NPS 26 Sch 20 (XS) D	NPS 26 WN Class 150				
N3	Nozzle #3	NPS 26 Sch 20 (XS) D	NPS 26 WN Class 150				
N6	Nozzle #6	NPS 26 Sch 20 (XS) D	NPS 26 WN Class 150				
N5	Nozzle #5	NPS 10 (Thk = 0.438")					
N4	Nozzle #4	NPS 2 Sch 160 DN 50	NPS 2 WN Class 150				
N2	Nozzle #2	NPS 46 XS DN 1150	NPS 46 WN Class 150				

REVISIONS

REV	DATE	DESCRIPTION
0	02/14/2022	FOR APPROVAL

ABC Fabricators Inc.
2600 Washington Blvd.
Dallas, TX, 75204

DWN BY:
CHK BY:
DATE:

General Arrangement

DWG NO. 145685-1 Rev 0

Elsewedy Electric Example.CW7

Deficiencies Summary

Deficiencies for Bottom Head
UG-32(i): The inside knuckle radius (271.6 mm) is less than 6 percent of the head skirt outside diameter (0.06*4,530.72 mm = 271.84 mm). (Corroded)

Deficiencies for Cylinder #1
UCS-6(b)(3): Material thickness cannot exceed 16 mm.

Deficiencies for Legs #1
All available leg structures are too small.
WRC 537: The combined stress (PL+Pb+Q) is excessive
WRC 537: The local primary membrane stress (PL) is excessive

Deficiencies for Nozzle #5 (N5)
Nozzle MAWP (0 bar) is less than the design pressure (7 bar).
UG-39: Not adequately reinforced (MAWP)
UG-39: Not adequately reinforced (Internal Pressure)
Nozzle MAP (0 bar) is less than the design pressure (7 bar).
UG-39: Not adequately reinforced (MAP)
UG-39: Not adequately reinforced (External Pressure)
UG-37: Nozzle MAEP (0 bar) is less than the external design pressure (0.8 bar).

Deficiencies for Nozzle #6 (N6)
Nozzle MAWP (6.24 bar) is less than the design pressure (7 bar).
UG-37: Not adequately reinforced (Internal Pressure)

Deficiencies for Top Head
UG-32(i): The inside knuckle radius (271.6 mm) is less than 6 percent of the head skirt outside diameter (0.06*4,530.72 mm = 271.84 mm). (Corroded)

Deficiencies for Vacuum Ring
The rings in group 'Vacuum Ring' interfere with nozzle 'Nozzle #3 (N3) + pad' at elevation 3,992.65 mm.

Warnings Summary

Warnings for Nozzle #4 (N4)
The attached ASME B16.5 flange limits the nozzle MAP. (warning)

Warnings for Vessel
Changes to steelmaking practices have increased the risk of brittle fracture at temperatures higher than the ASME impact test exemption temperatures. It is highly recommended that the following supplemental requirements be applied for SA-105, SA-106 B, SA-53 seamless, and SA-234: material composition should have a minimum Mn:C ratio of 5, and SA-105 flanges should require a grain size of 7 or finer. (warning)

Warnings for Wind Code
Basic Wind Speed (38.00 m/s) is less than the minimum basic wind speed of 40.00 m/s specified as per Fig. 26.5-1B (warning)

ASME B16.5 / B16.47 Flange Warnings Summary

Flange	Applicable Warnings
Nozzle #4 (N4)	1
Nozzle #2 (N2)	2
Nozzle #6 (N6)	2
Nozzle #3 (N3)	2
Nozzle #1 (N1)	2

No.	Warning
1	For Class 150 flanges, ASME B16.5 para. 5.4.3 recommends gaskets to be in accordance with Nonmandatory Appendix B, Table B1, Group No. I.
2	For Class 150 flanges, ASME B16.47 para. 5.4.3 recommends gaskets to be in accordance with Nonmandatory Appendix B, Table B1, Group No. Ia or Ib.

Nozzle Schedule

Specifications									
Nozzle mark	**Identifier**	**Size**	**Materials**		**Impact Tested**	**Normalized**	**Fine Grain**	**Flange**	**Blind**
N1	Nozzle #1	NPS 26 Sch 20 (XS) DN 650	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 26 Class 150 WN A105 Series A	NPS 26 Class 150 A105 Series A
			Pad	SA-516 70	No	No	No		
N2	Nozzle #2	NPS 46 XS DN 1150	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 46 Class 150 WN A105 Series A	SA-516 70
			Pad	SA-516 70	No	No	No		
N3	Nozzle #3	NPS 26 Sch 20 (XS) DN 650	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 26 Class 150 WN A105 Series A	NPS 26 Class 150 A105 Series A
			Pad	SA-516 70	No	No	No		
N4	Nozzle #4	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 150 WN A105	No
N5	Nozzle #5	NPS 10 (Thk = 0.438") DN 250	Nozzle	SA-106 B Smls Pipe	No	No	No	N/A	No
N6	Nozzle #6	NPS 26 Sch 20 (XS) DN 650	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 26 Class 150 WN A105 Series A	NPS 26 Class 150 A105 Series A
			Pad	SA-516 70	No	No	No		

Nozzle Summary

Dimensions												
Nozzle mark	OD (mm)	t_n (mm)	Req t_n (mm)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (mm)	A_a/A_r (%)
						Nom t (mm)	Design t (mm)	User t (mm)	Width (mm)	t_{pad} (mm)		
N1	660.4	12.7	11.34	Yes	Yes	18	15.14		180	18	1.59	100.0
N2	1,168.4	12.7	11.34	Yes	Yes	23.64*	13.58		100	11.82	1.59	100.0
N3	660.4	12.7	11.34	Yes	Yes	18	15.14		180	18	1.59	100.0
N4	60.33	8.74	5.73	Yes	Yes	12.7	N/A		N/A	N/A	1.59	Exempt
N5	273.05	11.13	11.09	Yes	Yes	68	64.36		N/A	N/A	1.59	**21.0****
N6	660.4	12.7	11.34	Yes	Yes	18	15.37		180	18	1.59	100.0

*Head minimum thickness after forming
**The nozzle does not have sufficient reinforcement.

Definitions	
t_n	Nozzle thickness
Req t_n	Nozzle thickness required per UG-45/UG-16 Increased for pipe to account for 12.5% pipe thickness tolerance
Nom t	Vessel wall thickness
Design t	Required vessel wall thickness due to pressure + corrosion allowance per UG-37
User t	Local vessel wall thickness (near opening)
A_a	Area available per UG-37, governing condition
A_r	Area required per UG-37, governing condition
Corr	Corrosion allowance on nozzle wall

Pressure Summary

Component Summary

Identifier	P Design (bar)	T Design (°C)	MAWP (bar)	MAP (bar)	MAEP (bar)	T_e external (°C)	MDMT (°C)	MDMT Exemption	Impact Tested
Top Head	7	40	7	8.18	2.53	40	-105	Note 1	No
Straight Flange on Top Head	7	40	8.33	10.38	1	40	-105	Note 2	No
Cylinder #1	7	40	7.13	9.08	1.16	40	-105	Note 3	No
Cylinder #2	7	40	8.47	10.99	1.13	40	-105	Note 4	No
Cylinder #3	7	40	8.23	10.99	1.13	40	-105	Note 5	No
Cylinder #4	7	40	7.57	10.38	0.97	40	-105	Note 6	No
Straight Flange on Bottom Head	7	40	7.57	10.38	0.97	40	-105	Note 8	No
Bottom Head	7	40	7	9.02	3.17	40	-105	Note 7	No
Vacuum Ring	N/A	N/A	N/A	N/A	1.13	40	-105	Note 9	No
Legs #1	7	40	7	N/A	N/A	N/A	N/A	N/A	N/A
Nozzle #1 (N1)	7	40	7.14	9.25	1.13	40	-29	Nozzle: Note 10 Pad: Note 11	No No
Nozzle #2 (N2)	7	40	7.07	8.32	1	40	-48	Nozzle: Note 12 Pad: Note 13	No No
Bolted Cover #3	7	40	10.39	10.89	15.14	40	-29	Note 14	No
Nozzle #3 (N3)	7	40	7.35	9.25	1.13	40	-29	Nozzle: Note 10 Pad: Note 11	No No
Nozzle #4 (N4)	7	40	19.42	19.6	1	40	-29	Note 15	No
Nozzle #5 (N5)	7	40	0	0	0	40	-105	Note 16	No
Nozzle #6 (N6)	7	40	6.24	7.76	1.16	40	-29	Nozzle: Note 17 Pad: Note 11	No No

Chamber Summary

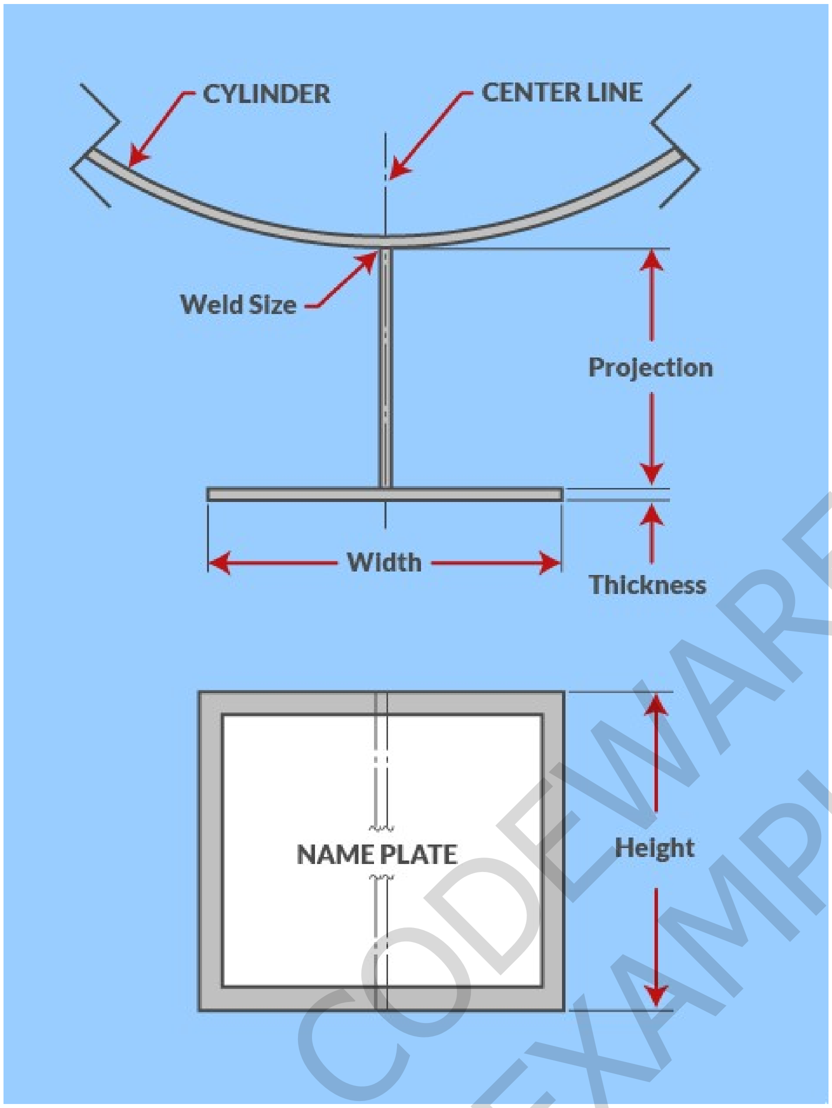
Design MDMT	5 °C
Rated MDMT	5 °C @ 0 bar
MAWP hot & corroded	0 bar @ 40 °C
MAP cold & new	0 bar @ 21.11 °C
MAEP	0 bar @ 40 °C

(1) The rated MDMT is limited to the design MDMT based on the setting in the Calculations tab of the Set Mode dialog.

Notes for MDMT Rating		
Note #	Exemption	Details
1.	Straight Flange governs MDMT	
2.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0089)	
3.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0414)	
4.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0601)	
5.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.086)	
6.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0987)	
7.	Straight Flange governs MDMT	
8.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0993)	
9.	Ring is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0601)	
10.	Nozzle is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.2218).	
11.	Pad is impact test exempt per UG-20(f)	UCS-66 governing thickness = 18 mm.
12.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -24.98°C Fig UCS-66.1M MDMT reduction = 69.6°C, (coincident ratio = 0.362) Rated MDMT of -94.58°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 11.11 mm.
13.	Pad impact test exemption temperature from Fig UCS-66M Curve B = -23.65°C Fig UCS-66.1M MDMT reduction = 25.7°C, (coincident ratio = 0.566) Rated MDMT of -49.35°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 11.82 mm.
14.	Bolted cover is impact test exempt per UG-20(f)	UCS-66 governing thickness = 17 mm
15.	Flange rating governs: Flange rated MDMT per UG-20(f) = -29°C Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
16.	Nozzle is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0827).	
17.	Nozzle is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.1857).	

Nameplate Summary

Geometry	



Orientation	Longitudinal
Projection	76.2 mm
Height	127 mm
Width	177.8 mm
Thickness	6.35 mm
Weld Size	4.76 mm
Material	
Attached To	Cylinder #4 (175 mm from bottom end)
Angle	60°

Nameplate Content	
National Board Number	NB Number
Certification Mark Designator	U
Manufacturer’s Serial Number	Manf. Serial No.
Certified by	Codeware Example
Notes	Nameplate Notes
Construction Type	W
Special Service	
Non Destructive Examination	RT1
PWHT	None
MAWP	0 bar @ 40 °C
MDMT	5 °C @ 0 bar
MAEP	0 bar @ 40 °C

Revision History

Revisions			
No.	Date	Operator	Notes
0	2/14/2022	christian.dionisio	New vessel created with Vessel Wizard, ASME Section VIII Division 1 [COMPRESS 2022 Build 8200]

Settings Summary

COMPRESS 2022 Build 8200	
ASME Section VIII Division 1, 2021 Edition Metric	
Units	MKS
Datum Line Location	0.00 mm from bottom seam
Vessel Design Mode	Design Mode
Minimum thickness	1.5 mm per UG-16(b)
Design for cold shut down only	No
Design for lethal service (full radiography required)	No
Design nozzles for	Design P only
Corrosion weight loss	100% of theoretical loss
UG-23 Stress Increase	1.00
Skirt/legs stress increase	1.0
Minimum nozzle projection	152.4 mm
Juncture calculations for α > 30 only	Yes
Preheat P-No 1 Materials > 1.25" and <= 1.50" thick	No
UG-37(a) shell tr calculation considers longitudinal stress	No
Cylindrical shells made from pipe are entered as minimum thickness	No
Nozzles made from pipe are entered as minimum thickness	No
ASME B16.9 fittings are entered as minimum thickness	No
Butt welds	Tapered per Figure UCS-66.3(a)
Disallow Appendix 1-5, 1-8 calculations under 15 psi	No
Hydro/Pneumatic Test	
Shop Hydrotest Pressure	1.3 times vessel MAWP [UG-99(b)]
Test liquid specific gravity	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
UG-116(e) Radiography	RT1
UG-116(f) Postweld heat treatment	None
Code Cases\Interpretations	
Use Appendix 46	No
Use UG-44(b)	No
Apply interpretation VIII-1-83-66	Yes
Apply interpretation VIII-1-86-175	Yes
Apply interpretation VIII-1-01-37	Yes
Apply interpretation VIII-1-01-150	Yes
Apply interpretation VIII-1-07-50	Yes
Apply interpretation VIII-1-16-85	No
No UCS-66.1 MDMT reduction	No
No UCS-68(c) MDMT reduction	No
Disallow UG-20(f) exemptions	No
UG-22 Loadings	
UG-22(a) Internal or External Design Pressure	Yes
UG-22(b) Weight of the vessel and normal contents under operating or test conditions	Yes
UG-22(c) Superimposed static reactions from weight of attached equipment (external loads)	No
UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs	Yes
UG-22(f) Wind reactions	Yes
UG-22(f) Seismic reactions	Yes
UG-22(j) Test pressure and coincident static head acting during the test:	No
Note: UG-22(b),(c) and (f) loads only considered when supports are present.	

Note 2: UG-22(d)(1),(e),(f)-snow,(g),(h),(i) are not considered. If these loads are present, additional calculations must be performed.

License Information	
Company Name	Codeware, Inc.
License	Commercial
License Key ID	23740
Support Expires	July 03, 2022

Radiography Summary

UG-116 Radiography							
Component	Longitudinal Seam		Top Circumferential Seam		Bottom Circumferential Seam		Mark
	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	Category (Fig UW-3)	Radiography / Joint Type	
Top Head	N/A	Seamless No RT	N/A	N/A	B	Full UW-11(a) / Type 2	RT1
Bolted Cover #3	N/A	Seamless No RT	N/A	N/A / Gasketed	N/A	N/A	N/A
Cylinder #1	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 2	B	Full UW-11(a) / Type 2	RT1
Cylinder #2	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 2	B	Full UW-11(a) / Type 2	RT1
Cylinder #3	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 2	B	Full UW-11(a) / Type 2	RT1
Cylinder #4	A	Full UW-11(a) / Type 1	B	Full UW-11(a) / Type 2	B	Full UW-11(a) / Type 2	RT1
Bottom Head	N/A	Seamless No RT	B	Full UW-11(a) / Type 2	N/A	N/A	RT1
Nozzle	Longitudinal Seam		Nozzle to Vessel Circumferential Seam		Nozzle free end Circumferential Seam		
Nozzle #2 (N2)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
Nozzle #4 (N4)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Nozzle #6 (N6)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
Nozzle #3 (N3)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
Nozzle #1 (N1)	N/A	Seamless No RT	D	N/A / Type 7	C	Full UW-11(a) / Type 1	RT1
Nozzle Flange	Longitudinal Seam		Flange Face		Nozzle to Flange Circumferential Seam		
ASME B16.5/16.47 flange attached to Nozzle #2 (N2)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to Nozzle #4 (N4)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
ASME B16.5/16.47 flange attached to Nozzle #6 (N6)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to Nozzle #3 (N3)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
ASME B16.5/16.47 flange attached to Nozzle #1 (N1)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Full UW-11(a) / Type 1	RT1
UG-116(e) Required Marking: **RT1**							

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (mm)	Length (mm)	Nominal t (mm)	Design t (mm)	Total Corrosion (mm)	Joint E	Load
Top Head	SA-516 70	4,500 ID	785.66	23.64*	23.64	3.24	1.00	Internal
Straight Flange on Top Head	SA-516 70	4,500 ID	50.8	17	15.81	3.24	1.00	External
Cylinder #1	SA-36	4,500 ID	2,438.4	18	17.73	3.24	1.00	Internal
Cylinder #2	SA-516 70	4,500 ID	2,438.4	18	15.93	3.24	1.00	External
Cylinder #3	SA-516 70	4,500 ID	2,438.4	18	15.97	3.24	1.00	Internal
Cylinder #4	SA-516 70	4,500 ID	568.5	17	16.06	3.24	1.00	Internal
Straight Flange on Bottom Head	SA-516 70	4,500 ID	50.8	17	16.07	3.24	1.00	Internal
Bottom Head	SA-516 70	4,500 ID	788.08	26.06*	26.06	3.24	1.00	Internal
Bolted Cover #3	SA-516 70	1,454.15 OD	68	68	67.31	1.59	1.00	Internal
*Head minimum thickness after forming								

Definitions	
Nominal t	Vessel wall nominal thickness
Design t	Required vessel thickness due to governing loading + corrosion
Joint E	Longitudinal seam joint efficiency
Load	
Internal	Circumferential stress due to internal pressure governs
External	External pressure governs
Wind	Combined longitudinal stress of pressure + weight + wind governs
Seismic	Combined longitudinal stress of pressure + weight + seismic governs

Weight Summary

Weight (kg) Contributed by Vessel Elements											
Component	Metal New*	Metal Corroded	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid		Surface Area m^2
							New	Corroded	New	Corroded	
Top Head	3,437.2	2,960.8	0	0	0	0	8,003.4	8,032.6	8,307.2	8,341.1	19.63
Cylinder #1	4,831.5	3,961.5	0	0	0	0	37,984.3	38,039	38,759.5	38,815.3	34.41
Cylinder #2	4,831.5	3,961.8	0	0	0	0	37,984.3	38,039	38,759.5	38,815.3	34.41
Cylinder #3	4,831.5	3,961.5	0	0	0	0	37,984.3	38,039	38,759.5	38,815.3	34.41
Cylinder #4	1,074.3	869.5	0	0	0	0	8,853.4	8,866	9,034	9,046.9	8.1
Bottom Head	4,004.3	3,500	0	0	0	0	8,018.5	8,049.2	8,182.2	8,213.5	20.77
Legs #1	1,547.3	1,547.3	0	0	0	0	0	0	0	0	16.27
TOTAL:	**24,557.5**	**20,762.5**	**0**	**0**	**0**	**0**	**138,828.3**	**139,064.7**	**141,802.1**	**142,047.4**	**167.98**
*Shells with attached nozzles have weight reduced by material cut out for opening.											

Weight (kg) Contributed by Attachments											
Component	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms*	Trays	Tray Supports	Rings & Clips	Vertical Loads	Surface Area m^2
	New	Corroded	New	Corroded							
Top Head	0	0	2,104.2	1,910.4	0	200.6	0	0	0	0	4.05
Cylinder #1	0	0	558.5	555.6	0	773.1	0	0	0	0	1.43
Cylinder #2	0	0	558.5	555.6	0	65.3	0	0	451.4	0	8.05
Cylinder #3	0	0	558.5	555.6	0	65.3	0	0	0	0	1.43
Cylinder #4	0	0	0	0	0	15.2	0	0	1.6	0	0
Bottom Head	0	0	0	0	0	40.2	0	0	0	0	0
Legs #1	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	**0**	**0**	**3,779.6**	**3,577.2**	**0**	**1,159.8**	**0**	**0**	**453**	**0**	**14.97**
* Platforms and ladders are not included in surface area.											

Vessel Totals		
	New	Corroded
Operating Weight (kg)	168,778	165,017
Empty Weight (kg)	29,950	25,952
Test Weight (kg)	171,752	168,000
Surface Area (m^2)	182.94	-
Capacity** (liters)	141,763	142,004
**The vessel capacity does not include volume of nozzle, piping or other attachments.		

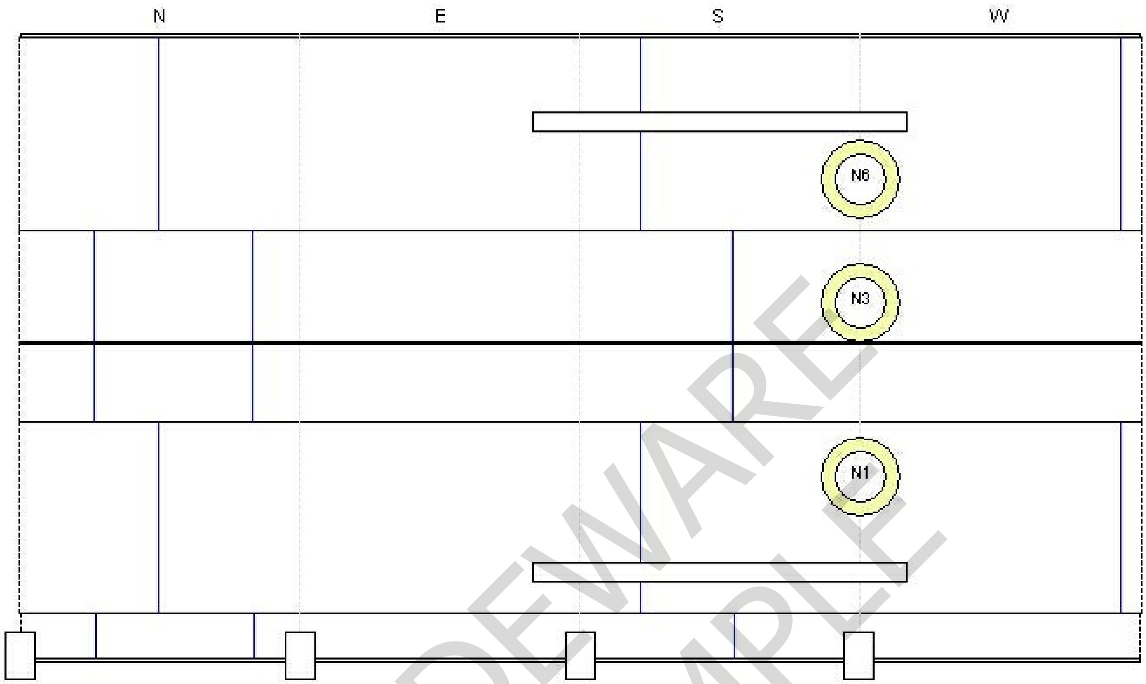
Vessel Lift Condition	
Vessel Lift Weight, New (kg)	29,975
Center of Gravity from Datum (mm)	3,947.32

Long Seam Summary

Shell Long Seam Angles			
Component	**Seam 1**	**Seam 2**	**Seam 3**
Cylinder #1	0°	154.6834°	309.3668°
Cylinder #2	30°	184.6834°	339.3668°
Cylinder #3	0°	154.6834°	309.3668°
Cylinder #4	30°	184.6491°	339.2983°

Shell Plate Lengths				
Component	**Starting Angle**	**Plate 1**	**Plate 2**	**Plate 3**
Cylinder #1	0°	6,098.7 mm	6,098.7 mm	1,996.31 mm
Cylinder #2	30°	6,098.7 mm	6,098.7 mm	1,996.31 mm
Cylinder #3	0°	6,098.7 mm	6,098.7 mm	1,996.31 mm
Cylinder #4	30°	6,096 mm	6,096 mm	1,998.57 mm

Notes
1) Plate Lengths use the circumference of the vessel based on the mid diameter of the components. 2) North is located at 0°



Shell Rollout

Hydrostatic Test

Horizontal shop hydrostatic test based on MAWP per UG-99(b)

Gauge pressure at 21.11°C $= 1.3 \cdot MAWP \cdot LSR$

$= 1.3 \cdot 0 \cdot 1$

$= 0 \;\; \text{bar}$

Horizontal shop hydrostatic test				
Identifier	**Local test pressure (bar)**	**Test liquid static head (bar)**	**UG-99(b) stress ratio**	**UG-99(b) pressure factor**
Top Head (1)	0.44	0.44	1	1.30
Straight Flange on Top Head	0.44	0.44	1	1.30
Cylinder #1	0.44	0.44	1	1.30
Cylinder #2	0.44	0.44	1	1.30
Cylinder #3	0.44	0.44	1	1.30
Cylinder #4	0.44	0.44	1	1.30
Straight Flange on Bottom Head	0.44	0.44	1	1.30
Bottom Head	0.44	0.44	1	1.30
Bolted Cover #3	0.28	0.28	1	1.30
Nozzle #1 (N1)	0.41	0.41	1	1.30
Nozzle #2 (N2)	0.28	0.28	1	1.30
Nozzle #3 (N3)	0.41	0.41	1	1.30
Nozzle #4 (N4)	0.16	0.16	1	1.30
Nozzle #5 (N5)	0.23	0.23	1	1.30
Nozzle #6 (N6)	0.41	0.41	1	1.30

(1) Top Head limits the UG-99(b) stress ratio.
(2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.
(3) UG-99(i): Custom flange assemblies shall be tested with gaskets having identical geometries and gasket factors, and bolting having identical allowable stress at room temperature as used in the design calculations.

The field test condition has not been investigated.

The test temperature of 21.11 °C is warmer than the minimum recommended temperature of -12 °C so the brittle fracture provision of UG-99(h) has been met.

Vacuum Summary

Largest Unsupported Length Le			
Component	**Line of Support**	**Elevation above Datum (mm)**	**Length Le (mm)**
Top Head	-	8,720.16	N/A
-	1/3 depth of Top Head	8,189.04	N/A
Straight Flange on Top Head Top	-	7,934.5	4,196.39
Straight Flange on Top Head Bottom	-	7,883.7	4,196.39
Cylinder #1 Top	-	7,883.7	4,196.39
Cylinder #1 Bottom	-	5,445.3	4,196.39
Cylinder #2 Top	-	5,445.3	4,297.99
-	Vacuum Ring	3,992.65	4,247.19
Cylinder #2 Bottom	-	3,006.9	4,297.99
Cylinder #3 Top	-	3,006.9	4,297.99
Cylinder #3 Bottom	-	568.5	4,297.99
Cylinder #4 Top	-	568.5	4,297.99
Cylinder #4 Bottom	-	0	4,297.99
Straight Flange on Bottom Head Top	-	0	4,297.99
Straight Flange on Bottom Head Bottom	-	-50.8	4,297.99
-	1/3 depth of Bottom Head	-305.34	N/A
Bottom Head	-	-838.88	N/A
For Rings, the listed value of length Le is Ls per UG-29.			

Foundation Load Summary

Legs #1: Total Loading at Base				
Load	Vessel Condition	Base Shear (kg_f)	Base Moment (kg_f-m)	Vertical Force (kg_f)
Weight	Operating, Corroded	0	4,119.2	165,218.9
Weight	Operating, New	0	4,140	169,008
Wind	Operating, Corroded	1,749.6	15,268.3	165,218.9
Wind	Operating, New	1,749.5	15,288.9	169,008
Wind	Empty, Corroded	1,749.6	15,268.3	26,154.2
Wind	Empty, New	1,749.5	15,288.9	30,179.7
Wind	External Pressure, Corroded	1,749.6	15,268.3	165,218.9
Seismic	Operating, Corroded	33,043.8	226,860.2	185,045.2
Seismic	Operating, New	33,801.6	232,321.1	189,288.9
Seismic	Empty, Corroded	5,230.8	42,458.3	29,292.7
Seismic	Empty, New	6,035.9	48,229.7	33,801.2
Seismic	External Pressure, Corroded	33,043.8	226,860.2	185,045.2

Shear and moment values reported above are presented without applicable load combination factors.

Vertical Force values in the Seismic case include the 1 + 0.2 * S_{DS} dead load factor (compressive) as described in the Seismic Code report. This excludes the 0.7 load combination factor as well.

Support Information	
Support Type	Legs
Number of Support Elements (Base Plates)	4
Base Plate Length	584.2 mm
Base Plate Width	381 mm
Base Plate Thickness	57 mm
Number of Anchor Bolts Per Base Plate	1
Bolt Circle Diameter	4,584.8 mm
Bolt Size and Type	1-7/8" series 8 bolt
Bolt Hole Clearance	9.52 mm
Center of Gravity (Distance from Support Base)	5,471.32 mm

Bill of Materials

Heads / Covers						
Item #	Type	Material	Thk [mm]	Dia. [mm]	Wt. [kg] (ea.)	Qty
H1	F&D Head	SA-516 70	23.64 (min.)	4,500 ID	3,635.7	1
H2	F&D Head	SA-516 70	26.06 (min.)	4,500 ID	4,004.3	1
H3	Bolted Cover	SA-516 70	68	1,454.15 OD	884.6	1
H4	ASME B16.5/B16.47 Blind NPS 26 Class 150	A105	68.33	869.95 OD	337	3

Shells							
Item #	Type	Material	Thk [mm]	Dia. [mm]	Length [mm]	Wt. [kg] (ea.)	Qty
S1	Cylinder	SA-36	18	4,500 ID	2,438	4,879.8	1
S2	Cylinder	SA-516 70	18	4,500 ID	2,438	4,879.8	2
S3	Cylinder	SA-516 70	17	4,500 ID	569	1,074.3	1

Rings / Legs						
Item #	Type	Material	Thk [mm]	Length [mm]	Wt. [kg]	Qty
R1	3/4x8 Flat Bar	SA-516 70	19.05	14,889	451.4	1
L1	W 18x106	Leg material	23.88	1,829	386.8	4

Nozzles							
Item #	Type	Material	NPS	Thk [mm]	Dia. [mm]	Length [mm]	Wt. [kg]
Noz1	Nozzle	SA-106 B Smls Pipe	NPS 46 XS DN 1150	12.7	1,168.4 OD	1,976	750.6
Noz2	Nozzle	SA-106 B Smls Pipe	NPS 2 Sch 160 DN 50	8.74	60.33 OD	102	1.1
Noz3	Nozzle	SA-106 B Smls Pipe	NPS 10 (Thk = 0.438") DN 250	11.13	273.05 OD	220	15.8
Noz4	Nozzle	SA-106 B Smls Pipe	NPS 26 Sch 20 (XS) DN 650	12.7	660.4 OD	272	256.1

Flanges						
Item #	Type	Material	NPS	Dia. [mm]	Wt. [kg] (ea.)	Qty
AF1	ASME B16.5 Welding Neck - Class 150	A105	2	152.4 x 52.58	2.7	1
AF2	ASME B16.47 Welding Neck - Class 150 - Series A	A105	46	1,454.15 x 1,150.92	480.8	1
AF3	ASME B16.47 Welding Neck - Class 150 - Series A	A105	26	869.95 x 647.7	136.1	3

Gaskets				
Item #	Type	Size [mm]	Thk [mm]	Qty
G1	Corrugated metal Iron or soft steel / Mineral Fiber (Corrugated Metal)	1,160 x 1,155	4.44	1
There are 4 flanges that do not include gasket information.				

Fasteners				
Item #	Description	Material	Length [mm]	Qty
FB1	5/8" coarse bolt	SA-193 B7 Bolt <= 64	70	4
FB2	1-1/2" series 8 bolt	SA-193 B7 Bolt <= 64	260	40
FB3	1-1/4" series 8 bolt	SA-193 B7 Bolt <= 64	184	72
SB1	1-7/8" series 8 bolt	Support Leg bolt material	-	4
All listed flange bolts require associated nuts and washers in accordance with Division 1, UCS-11.				

Platform and Ladders						
Item #	Pl. Area [m^2]	Pl. Wt. [kg]	Lad. Len. [mm]	Lad. Wt. [kg]	Rail Len. [mm]	Rail Wt. [kg]
PL-1	12.4	605.4	9,000	241.1	17,544	313.3

Plates				
Item #	**Material**	**Thk [mm]**	**Wt. [kg]**	**Qty [m^2]**
Plate1	SA-516 70	11.82	292.6	1.47
Plate1 - Note: Applies to nozzle pad				
Plate2	SA-516 70	18	488.1	2.45
Plate2 - Note: Applies to nozzle pad				
Plate3	Unspecified material	57	397.5	0.89
Plate3 - Note: Applies to support leg base plates				
Plate4	Carbon steel	15.88	870.8	7
Plate4 - Note: Applies to shipping saddle base plate, shipping saddle web plate				
Plate5	Carbon steel	12.7	313.6	3.15
Plate5 - Note: Applies to shipping saddle rib plate				
Plate6	Unspecified material	6.35	1.6	0.0323
Plate6 - Note: Applies to nameplate front, nameplate projection				

Liquid Level

ASME Section VIII Division 1, 2021 Edition Metric	
Location from Datum (mm)	8,663.5
Operating Liquid Specific Gravity	0.98

Wind Code

Building Code: ASCE 7-16		
Elevation of base above grade		0.00 ft (0.00 m)
Increase effective outer diameter by		0.00 ft (0.00 m)
Wind Force Coefficient, Cf		0.7000
Risk Category (Table 1.5-1)		II
Basic Wind Speed, V		85.00 mph (37.9984 m/s)
Exposure Category		B
Wind Directionality Factor, Kd		0.9500
Ground Elevation Factor, Ke		1.0000
Top Deflection Limit		6.00 mm per m.
Topographic Factor, Kzt		1.0000
Enforce min. loading of 0.77 kPa		No
Hazardous, toxic, or explosive contents		No
Vessel Characteristics		
Height, h		33.6094 ft (10.2442 m)
Effective Width, b	Operating, Corroded	14.2688 ft (4.3491 m)
	Empty, Corroded	14.2688 ft (4.3491 m)
Fundamental Frequency, n_1	Operating, Corroded	6.5524 Hz
	Empty, Corroded	16.6341 Hz
	Vacuum, Corroded	6.5524 Hz
Damping coefficient, β	Operating, Corroded	0.0250
	Empty, Corroded	0.0200
	Vacuum, Corroded	0.0250

Vortex Shedding Calculations
Table Lookup Values

2.4.1 Basic Load Combinations for Allowable Stress Design	
Load combinations considered in accordance with ASCE section 2.4.1:	
5.	$D + P + P_s + 0.6W$
7.	$0.6D + P + P_s + 0.6W$
Parameter Description	
D	= Dead load
P	= Internal or external pressure load
P_s	= Static head load
W	= Wind load

Wind Deflection Reports:

Operating, Corroded
Empty, Corroded
Vacuum, Corroded

Wind Pressure Calculations

Wind Deflection Report: Operating, Corroded

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	9,407.7	4.54	2,051,670.3	*	0	69.3	26.6	0.05
Cylinder #1	6,969.3	4.54	2,051,670.3	0.5345	215.9	528.1	2,506.6	0.05
Cylinder #2	4,530.9	4.54	2,051,670.3	0.5345	215.9	750.1	5,312	0.04
Cylinder #3	2,092.5	4.54	2,051,670.3	0.5345	215.9	950.5	8,693.4	0.04
Cylinder #4 (top)	1,524	4.53	2,051,670.3	0.498	215.9	995.1	9,228.4	0.03
Legs #1	0	0	2,038,903.0	0.001773	0	1,049.7	10,808.6	0.03
Cylinder #4 (bottom)	1,524	4.53	2,051,670.3	0.498	0	54.7	19.6	0.03
Bottom Head	1,524	4.54	2,051,670.3	*	0	52.6	18.2	0.03

*Moment of Inertia I varies over the length of the component

Wind Deflection Report: Empty, Corroded

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	9,407.7	4.54	2,062,603.9	*	0	69.3	26.6	0.05
Cylinder #1	6,969.3	4.54	2,062,603.9	0.5345	215.9	528.1	2,506.6	0.05
Cylinder #2	4,530.9	4.54	2,062,603.9	0.5345	215.9	750.1	5,312	0.04
Cylinder #3	2,092.5	4.54	2,062,603.9	0.5345	215.9	950.5	8,693.4	0.04
Cylinder #4 (top)	1,524	4.53	2,062,603.9	0.498	215.9	995.1	9,228.4	0.03
Legs #1	0	0	2,038,903.0	0.001773	0	1,049.7	10,808.6	0.03
Cylinder #4 (bottom)	1,524	4.53	2,062,603.9	0.498	0	54.7	19.6	0.03
Bottom Head	1,524	4.54	2,062,603.9	*	0	52.6	18.2	0.03

*Moment of Inertia I varies over the length of the component

Wind Deflection Report: Vacuum, Corroded

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	9,407.7	4.54	2,051,670.3	*	0	69.3	26.6	0.05
Cylinder #1	6,969.3	4.54	2,051,670.3	0.5345	215.9	528.1	2,506.6	0.05
Cylinder #2	4,530.9	4.54	2,051,670.3	0.5345	215.9	750.1	5,312	0.04
Cylinder #3	2,092.5	4.54	2,051,670.3	0.5345	215.9	950.5	8,693.4	0.04
Cylinder #4 (top)	1,524	4.53	2,051,670.3	0.498	215.9	995.1	9,228.4	0.03
Legs #1	0	0	2,038,903.0	0.001773	0	1,049.7	10,808.6	0.03
Cylinder #4 (bottom)	1,524	4.53	2,051,670.3	0.498	0	54.7	19.6	0.03
Bottom Head	1,524	4.54	2,051,670.3	*	0	52.6	18.2	0.03

*Moment of Inertia I varies over the length of the component

Wind Pressure (WP) Calculations

Gust Factor (G) Calculations

$$Kz = 2.01 \cdot \left(\frac{Z}{Z_g}\right)^{\frac{2}{\alpha}}$$

$$= 2.01 \cdot \left(\frac{Z}{365.76}\right)^{0.2857}$$

$$qz = 0.613 \cdot Kz \cdot Kzt \cdot Kd \cdot Ke \cdot V^2$$

$$= 0.613 \cdot Kz \cdot 1.0000 \cdot 0.9500 \cdot 1.0000 \cdot 37.9984^{\ 2}$$

$$= 840.8426 \cdot Kz$$

$$WP = 0.6 \cdot qz \cdot G \cdot Cf$$

$$= 0.6 \cdot qz \cdot G \cdot 0.7000$$

Design Wind Pressures							
Height Z (m)	Kz	qz (bar)	WP (bar)				
			Operating	Empty	Hydrotest New	Hydrotest Corroded	Vacuum
4.6	0.5747	0.0048	0.0018	0.0018	N.A.	N.A.	0.0018
6.1	0.6240	0.0052	0.0019	0.0019	N.A.	N.A.	0.0019
7.6	0.6650	0.0056	0.0021	0.0021	N.A.	N.A.	0.0021
9.1	0.7006	0.0059	0.0022	0.0022	N.A.	N.A.	0.0022
12.2	0.7606	0.0064	0.0024	0.0024	N.A.	N.A.	0.0024
Design Wind Force determined from: F = Pressure * Af , where Af is the projected area.							

Vortex Shedding Calculations			
Calculations based on NBC 1995 building code, Structural Commentaries (Part 4).			
Average diameter of vessel, upper third, D	13.9210 ft (4243.11 mm)		
Aspect ratio, Ar	2.4143		
	Operating, Corroded	Empty, Corroded	Vacuum, Corroded
Vortex shedding factor, C_1	N.A.	N.A.	N.A.
Vortex shedding factor, C_2	N.A.	N.A.	N.A.
Weight per foot of vessel, upper third, M	11,620.2939 lb/ft (172.9290 kg/cm)	2,130.0129 lb/ft (31.6981 kg/cm)	11,620.2939 lb/ft (172.9290 kg/cm)
Strouhal number, S	0.2000	0.2000	0.2000

Critical wind speed at top of vessel, V_h = (n*D/S)*(3600/5280) mph

Operating, Corroded: $V_h = \left(6.5524 \cdot \frac{13.9210}{0.2000}\right) \cdot \left(\frac{3600}{5280}\right) = 310.9609 \text{ mph}$ (139.0120 m/s)

Empty, Corroded: $V_h = \left(16.6341 \cdot \frac{13.9210}{0.2000}\right) \cdot \left(\frac{3600}{5280}\right) = 789.4170 \text{ mph}$ (352.9010 m/s)

Vacuum, Corroded: $V_h = \left(6.5524 \cdot \frac{13.9210}{0.2000}\right) \cdot \left(\frac{3600}{5280}\right) = 310.9609 \text{ mph}$ (139.0120 m/s)

Reference wind speed corresponding to critical wind speed, V_{Ref}

Operating, Corroded: $V_{Ref} = 310.1491$ mph $(138.6491$ m/s $)$

Empty, Corroded: $V_{Ref} = 787.3560$ mph $(351.9796$ m/s$)$

Vacuum, Corroded: $V_{Ref} = 310.1491$ mph $(138.6491$ m/s$)$

Corresponding reference wind speed, V_{Ref}

Operating, Corroded: $V_{Ref} = 85.0000$ mph $(37.9984$ m/s$)$

Empty, Corroded: $V_{Ref} = 85.0000$ mph $(37.9984$ m/s$)$

Vacuum, Corroded: $V_{Ref} = 85.0000$ mph$(37.9984$ m/s$)$

Speed for operating, corroded condition which produces vortex shedding is greater than reference speed. No further vortex shedding computations were done for this condition.
Speed for empty, corroded condition which produces vortex shedding is greater than reference speed. No further vortex shedding computations were done for this condition.
Speed for vacuum, corroded condition which produces vortex shedding is greater than reference speed. No further vortex shedding computations were done for this condition.

Corresponding pressure at top of vessel, $q_h = 0.00256 * V_h^2$

Equivalent static loading, $FL = \dfrac{q_h \cdot C_1 \cdot D}{\sqrt{Ar} \cdot \sqrt{\beta - \left(C_2 \cdot R0 \cdot \frac{D^2}{M}\right)}}$

Static loading FL is applied throughout the top third of the vessel

Gust Factor Calculations

- Operating, Corroded
- Empty, Corroded
- Vacuum, Corroded

Gust Factor Calculations: Operating, Corroded

Vessel is considered a rigid structure as n_1 = 6.5524 Hz ≥ 1 Hz.

$$z^{-} = \max[0.60 \cdot h, z_{\min}]$$

$$= \max[0.60 \cdot 33.6094, 30.0000]$$

$$= 30.0000$$

$$I_{z^{-}} = c \cdot \left(\frac{33}{z^{-}}\right)^{\frac{1}{6}}$$

$$= 0.3000 \cdot \left(\frac{33}{30.0000}\right)^{\frac{1}{6}}$$

$$= 0.3048$$

$$L_{z^{-}} = l \cdot \left(\frac{z^{-}}{33}\right)^{ep}$$

$$= 320.0000 \cdot \left(\frac{30.0000}{33}\right)^{0.3333}$$

$$= 309.9934$$

$$Q = \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{b+h}{L_{z^{-}}}\right)^{0.63}}}$$

$$= \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{14.2688+33.6094}{309.9934}\right)^{0.63}}}$$

$$= 0.9151$$

$$G = 0.925 \cdot \frac{1 + 1.7 \cdot g_Q \cdot I_{z^{-}} \cdot Q}{1 + 1.7 \cdot g_v \cdot I_{z^{-}}}$$

$$= 0.925 \cdot \frac{1 + 1.7 \cdot 3.40 \cdot 0.3048 \cdot 0.9151}{1 + 1.7 \cdot 3.40 \cdot 0.3048}$$

$$= 0.8749$$

Gust Factor Calculations: Empty, Corroded

Vessel is considered a rigid structure as n_1 = 16.6341 Hz ≥ 1 Hz.

z^{-} $= \max[0.60 \cdot h, z_{\min}]$

$= \max[0.60 \cdot 33.6094, 30.0000]$

$= 30.0000$

$I_{z^{-}}$ $= c \cdot \left(\frac{33}{z^{-}}\right)^{\frac{1}{6}}$

$= 0.3000 \cdot \left(\frac{33}{30.0000}\right)^{\frac{1}{6}}$

$= 0.3048$

$L_{z^{-}}$ $= l \cdot \left(\frac{z^{-}}{33}\right)^{ep}$

$= 320.0000 \cdot \left(\frac{30.0000}{33}\right)^{0.3333}$

$= 309.9934$

Q $= \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{b+h}{L_{z^{-}}}\right)^{0.63}}}$

$= \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{14.2688+33.6094}{309.9934}\right)^{0.63}}}$

$= 0.9151$

G $= 0.925 \cdot \frac{1 + 1.7 \cdot g_Q \cdot I_{z^{-}} \cdot Q}{1 + 1.7 \cdot g_v \cdot I_{z^{-}}}$

$= 0.925 \cdot \frac{1 + 1.7 \cdot 3.40 \cdot 0.3048 \cdot 0.9151}{1 + 1.7 \cdot 3.40 \cdot 0.3048}$

$= 0.8749$

Gust Factor Calculations: Vacuum, Corroded

Vessel is considered a rigid structure as n_1 = 6.5524 Hz ≥ 1 Hz.

$z^{-} = \max[0.60 \cdot h, z_{\min}]$

$= \max[0.60 \cdot 33.6094, 30.0000]$

$= 30.0000$

$I_{z^{-}} = c \cdot \left(\frac{33}{z^{-}}\right)^{\frac{1}{6}}$

$= 0.3000 \cdot \left(\frac{33}{30.0000}\right)^{\frac{1}{6}}$

$= 0.3048$

$L_{z^{-}} = l \cdot \left(\frac{z^{-}}{33}\right)^{ep}$

$= 320.0000 \cdot \left(\frac{30.0000}{33}\right)^{0.3333}$

$= 309.9934$

$Q = \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{b+h}{L_{z^{-}}}\right)^{0.63}}}$

$= \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{14.2688+33.6094}{309.9934}\right)^{0.63}}}$

$= 0.9151$

$G = 0.925 \cdot \frac{1 + 1.7 \cdot g_Q \cdot I_{z^{-}} \cdot Q}{1 + 1.7 \cdot g_v \cdot I_{z^{-}}}$

$= 0.925 \cdot \frac{1 + 1.7 \cdot 3.40 \cdot 0.3048 \cdot 0.9151}{1 + 1.7 \cdot 3.40 \cdot 0.3048}$

$= 0.8749$

Table Lookup Values	
α = 7.0000, z_g = 365.76 m	[Table 26.11-1, page 269]
c = 0.3000, l = 320.0000, ep = 0.3333	[Table 26.11-1, page 269]
a¯ = 0.2500, b¯ = 0.4500	[Table 26.11-1, page 269]
z_{min} = 30.0000 ft	[Table 26.11-1, page 269]
g_Q = 3.40	[26.11.4 page 269]
g_v = 3.40	[26.11.4 page 269]

Seismic Code

Building Code: ASCE 7-16 ground supported	
Site Class	C
Importance Factor, I_e	1.0000
Spectral Response Acceleration at short period (% g), S_s	75.00%
Spectral Response Acceleration at period of 1 sec (% g), S_1	75.00%
Response Modification Coefficient from Table 15.4-2, R	3.0000
Acceleration-based Site Coefficient, F_a	1.2000
Velocity-based Site Coefficient, F_v	1.4000
Long-period Transition Period, T_L	12.0000
Redundancy factor, ρ	1.0000
Risk Category (Table 1.5-1)	II
User Defined Vertical Accelerations Considered	No
Hazardous, toxic, or explosive contents	No

Vessel Characteristics		
Height		33.6094 ft (10.24 m)
Weight	Operating, Corroded	363,801 lb (165,017 kg)
	Empty, Corroded	57,215 lb (25,952 kg)
	Vacuum, Corroded	363,801 lb (165,017 kg)
Period of Vibration Calculation		
Fundamental Period, T	Operating, Corroded	0.153 sec (f = 6.6 Hz)
	Empty, Corroded	0.060 sec (f = 16.6 Hz)
	Vacuum, Corroded	0.153 sec (f = 6.6 Hz)

The fundamental period of vibration T (above) is calculated using the Rayleigh method of approximation

$$T = 2 \cdot \pi \cdot \sqrt{\frac{\sum(W_i \cdot y_i^2)}{g \cdot \sum(W_i \cdot y_i)}}$$,where

W_i is the weight of the i^{th} lumped mass, and
y_i is its deflection when the system is treated as a cantilever beam.

12.4 Basic Load Combinations for Allowable Stress Design			
Load combinations considered in accordance with ASCE section 2.4.5:			
8.	$D + P + P_s + 0.7E$	$= (1.0 + 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$	
10.	$0.6D + P + P_s + 0.7E$	$= (0.6 - 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$	
Parameter description			
D	= Dead load		
P	= Internal or external pressure load		
P_s	= Static head load		
E	= Seismic load	$= E_h$ +/- E_v	$= \rho Q_E$ +/- $0.2S_{DS}D$

Seismic Shear Reports:

Operating, Corroded
Empty, Corroded
Vacuum, Corroded

Base Shear Calculations

Seismic Shear Report: Operating, Corroded					
Component	Elevation of Bottom above Base (mm)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Seismic Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)
Top Head	9,407.7	2,051,670.3	*	3,218.2	1,025.7
Cylinder #1	6,969.3	2,051,670.3	0.5345	12,271.1	22,131.4
Cylinder #2	4,530.9	2,051,670.3	0.5345	18,539.1	61,475
Cylinder #3	2,092.5	2,051,670.3	0.5345	22,105.7	112,893
Cylinder #4 (top)	1,524	2,051,670.3	0.4980	22,530.8	125,019.9
Legs #1	0	2,038,903.0	0.2054	23,130.7	160,037.9
Cylinder #4 (bottom)	1,524	2,051,670.3	0.4980	569.5	210
Bottom Head	1,524	2,051,670.3	*	552.5	195.7
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Empty, Corroded					
Component	Elevation of Bottom above Base (mm)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Seismic Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)
Top Head	9,407.7	2,062,603.9	*	1,206.6	434.8
Cylinder #1	6,969.3	2,062,603.9	0.5345	2,333.1	6,488.7
Cylinder #2	4,530.9	2,062,603.9	0.5345	3,044.5	14,344
Cylinder #3	2,092.5	2,062,603.9	0.5345	3,422.2	23,610.6
Cylinder #4 (top)	1,524	2,062,603.9	0.4980	3,459.7	25,479.9
Legs #1	0	2,038,903.0	0.2054	3,661.6	30,956.6
Cylinder #4 (bottom)	1,524	2,062,603.9	0.4980	172.5	81.2
Bottom Head	1,524	2,062,603.9	*	171	76.8
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Vacuum, Corroded					
Component	Elevation of Bottom above Base (mm)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Seismic Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)
Top Head	9,407.7	2,051,670.3	*	3,218.2	1,025.7
Cylinder #1	6,969.3	2,051,670.3	0.5345	12,271.1	22,131.4
Cylinder #2	4,530.9	2,051,670.3	0.5345	18,539.1	61,475
Cylinder #3	2,092.5	2,051,670.3	0.5345	22,105.7	112,893
Cylinder #4 (top)	1,524	2,051,670.3	0.4980	22,530.8	125,019.9
Legs #1	0	2,038,903.0	0.2054	23,130.7	160,037.9
Cylinder #4 (bottom)	1,524	2,051,670.3	0.4980	569.5	210
Bottom Head	1,524	2,051,670.3	*	552.5	195.7
*Moment of Inertia I varies over the length of the component					

11.4.4: Maximum considered earthquake spectral response acceleration

The maximum considered earthquake spectral response acceleration at short period, S_{MS}

$$S_{MS} = F_a \cdot S_s = 1.2000 \cdot 75.00/100 = 0.9000$$

The maximum considered earthquake spectral response acceleration at 1 s period, S_{M1}

$$S_{M1} = F_v \cdot S_1 = 1.4000 \cdot 75.00/100 = 1.0500$$

11.4.5: Design spectral response acceleration parameters

Design earthquake spectral response acceleration at short period, S_{DS}

$$S_{DS} = \frac{2}{3} \cdot S_{MS} = \frac{2}{3} \cdot 0.9000 = 0.6000$$

Design earthquake spectral response acceleration at 1 s period, S_{D1}

$$S_{D1} = \frac{2}{3} \cdot S_{M1} = \frac{2}{3} \cdot 1.0500 = 0.7000$$

11.6 Seismic Design Category

The Risk Category is II.
The mapped spectral response acceleration parameter at 1-s period, S_1 is 75.00.
This vessel is assigned to Seismic Design Category E.

12.4: Seismic Load Combinations: Vertical Term

Factor is applied to dead load.

Compressive Side: $= 1.0 + 0.14 \cdot S_{DS} = 1.0 + 0.14 \cdot 0.6000 = 1.0840$

Tensile Side: $= 0.6 - 0.14 \cdot S_{DS} = 0.6 - 0.14 \cdot 0.6000 = 0.5160$

Base Shear Calculations

Operating, Corroded
Empty, Corroded
Vacuum, Corroded

Base Shear Calculations: Operating, Corroded

Paragraph 15.4.4: Period Determination

Fundamental Period is taken from the Rayleigh method listed previously in this report.

$T = 0.1526\ \text{sec}$.

12.8.1: Calculation of Seismic Response Coefficient

C_s is the value computed below, bounded by C_sMin and C_sMax:
C_sMin is calculated with equation 15.4-1 and shall not be less than 0.03; in addition, if S_1 >= 0.6g, C_sMin shall not be less than eqn 15.4-2.
C_sMax calculated with 12.8-3 because (T = 0.1526) <= (T_L = 12.0000)

$$C_s = \frac{S_{DS}}{\frac{R}{I_e}} = \frac{0.6000}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Min} = 0.8 \cdot \frac{S_1}{\frac{R}{I_e}} = 0.8 \cdot \frac{0.7500}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Max} = \frac{S_{D1}}{T \cdot \left(\frac{R}{I_e}\right)} = \frac{0.7000}{0.1526 \cdot \left(\frac{3.0000}{1.0000}\right)} = 1.5289$$

$$C_s = 0.2000$$

12.8.1: Calculation of Base Shear

$$V = C_s \cdot W = 0.2000 \cdot 363{,}800.5938 = 72{,}760.12\ \text{lb}(33{,}003.43\ \text{kg})$$

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = V$

$E_h = 0.7 \cdot \rho \cdot Q_E$ (Only 70% of seismic load considered as per Section 2.4.5)

$= 0.7 \cdot 1.0000 \cdot 72{,}760.12$

$= 50{,}932.08\ \text{lb}(23{,}102.40\ \text{kg})$

Base Shear Calculations: Empty, Corroded

Paragraph 15.4.4: Period Determination

Fundamental Period is taken from the Rayleigh method listed previously in this report.

$T = 0.0601 \sec.$

12.8.1: Calculation of Seismic Response Coefficient

C_s is the value computed below, bounded by C_sMin and C_sMax:
C_sMin is calculated with equation 15.4-1 and shall not be less than 0.03; in addition, if S_1 >= 0.6g, C_sMin shall not be less than eqn 15.4-2.
C_sMax calculated with 12.8-3 because (T = 0.0601) <= (T_L = 12.0000)

$$C_s = \frac{S_{DS}}{\frac{R}{I_e}} = \frac{0.6000}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Min} = 0.8 \cdot \frac{S_1}{\frac{R}{I_e}} = 0.8 \cdot \frac{0.7500}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Max} = \frac{S_{D1}}{T \cdot \left(\frac{R}{I_e}\right)} = \frac{0.7000}{0.0601 \cdot \left(\frac{3.0000}{1.0000}\right)} = 3.8813$$

$$C_s = 0.2000$$

12.8.1: Calculation of Base Shear

$$V = C_s \cdot W = 0.2000 \cdot 57{,}215.3477 = 11{,}443.07 \ \text{lb}(5{,}190.49 \ \text{kg})$$

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = V$

$E_h = 0.7 \cdot \rho \cdot Q_E$ (Only 70% of seismic load considered as per Section 2.4.5)

$= 0.7 \cdot 1.0000 \cdot 11{,}443.07$

$= 8{,}010.15 \ \text{lb}(3{,}633.34 \ \text{kg})$

Base Shear Calculations: Vacuum, Corroded

Paragraph 15.4.4: Period Determination

Fundamental Period is taken from the Rayleigh method listed previously in this report.

$T = 0.1526 \sec.$

12.8.1: Calculation of Seismic Response Coefficient

C_s is the value computed below, bounded by C_sMin and C_sMax:
C_sMin is calculated with equation 15.4-1 and shall not be less than 0.03; in addition, if S_1 >= 0.6g, C_sMin shall not be less than eqn 15.4-2.
C_sMax calculated with 12.8-3 because (T = 0.1526) <= (T_L = 12.0000)

$$C_s = \frac{S_{DS}}{\frac{R}{I_e}} = \frac{0.6000}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Min} = 0.8 \cdot \frac{S_1}{\frac{R}{I_e}} = 0.8 \cdot \frac{0.7500}{\frac{3.0000}{1.0000}} = 0.2000$$

$$C_s\text{Max} = \frac{S_{D1}}{T \cdot \left(\frac{R}{I_e}\right)} = \frac{0.7000}{0.1526 \cdot \left(\frac{3.0000}{1.0000}\right)} = 1.5289$$

$C_s = 0.2000$

12.8.1: Calculation of Base Shear

$V = C_s \cdot W = 0.2000 \cdot 363{,}800.5938 = 72{,}760.12 \text{ lb}(33{,}003.43 \text{ kg})$

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = V$

$E_h = 0.7 \cdot \rho \cdot Q_E$ (Only 70% of seismic load considered as per Section 2.4.5)

$= 0.7 \cdot 1.0000 \cdot 72{,}760.12$

$= 50{,}932.08 \text{ lb}(23{,}102.40 \text{ kg})$

Top Head

ASME Section VIII Division 1, 2021 Edition Metric					
Component		F&D Head			
Material		SA-516 70 (II-D Metric p. 20, ln. 45)			
Attached To		Cylinder #1			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
No	No	No	No	No	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		7	40	5	
External		0.8	40		
Static Liquid Head					
Condition		**P_s (bar)**	**H_s (mm)**	**SG**	
Operating		0.07	729	0.98	
Test horizontal		0.44	4,500	1	
Dimensions					
Inner Diameter		4,500 mm			
Crown Radius L		4,500 mm			
Knuckle Radius r		270 mm			
Minimum Thickness		23.64 mm			
Corrosion	**Inner**	1.6 mm			
	Outer	1.64 mm			
Length L_{sf}		50.8 mm			
Nominal Thickness t_{sf}		17 mm			
Weight and Capacity					
		Weight (kg)[1]		**Capacity (liters)[1]**	
New		3,437.18		8,189.03	
Corroded		2,960.82		8,220.36	
Radiography					
Category A joints		Seamless No RT			
Head to shell seam		Full UW-11(a) Type 2			

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	23.64 mm
Design thickness due to external pressure (t_e)	14.69 mm
Maximum allowable working pressure (MAWP)	7 bar
Maximum allowable pressure (MAP)	8.18 bar
Maximum allowable external pressure (MAEP)	2.53 bar
Straight Flange governs MDMT	-105°C

Note: Endnote 88 used to determine allowable stress.

Factor M		
$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r}\right)^{\frac{1}{2}}\right]$		
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{4{,}501.6}{271.6}\right)^{\frac{1}{2}}\right]$	1.7678
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{4{,}500}{270}\right)^{\frac{1}{2}}\right]$	1.7706

Design thickness for internal pressure, (Corroded at 40 °C) Appendix 1-4(d)

$$t = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} + \text{Corrosion} = \frac{7.07 \cdot 4{,}501.6 \cdot 1.7678}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7.07} + 3.24 = 23.64 \text{ mm}$$

Maximum allowable working pressure, (Corroded at 40 °C) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 1{,}380 \cdot 1 \cdot 20.4}{4{,}501.6 \cdot 1.7678 + 0.2 \cdot 20.4} - 0.07 = 7 \text{ bar}$$

Maximum allowable pressure, (New at 21.11 °C) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 1{,}380 \cdot 1 \cdot 23.64}{4{,}500 \cdot 1.7706 + 0.2 \cdot 23.64} - 0 = 8.18 \text{ bar}$$

Design thickness for external pressure, (Corroded at 40 °C) UG-33(e)

Equivalent outside spherical radius
$R_o = \text{Outside crown radius} = 4{,}522 \text{ mm}$

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{4{,}522 \ / \ 11.45} = 0.000317$$

From Table CS-2 Metric: B = 322.1081 kg_f/cm^2

$$P_a = \frac{B}{R_o \ / \ t} = \frac{315.8801}{4{,}522 \ / \ 11.45} = 0.8 \text{ bar}$$

$$t = 11.45 \text{ mm} + \text{Corrosion} = 11.45 \text{ mm} + 3.24 \text{ mm} = 14.69 \text{ mm}$$

The head external pressure design thickness (t_e) is 14.69 mm.

Maximum Allowable External Pressure, (Corroded at 40 °C) UG-33(e)

Equivalent outside spherical radius
$R_o = \text{Outside crown radius} = 4{,}522 \text{ mm}$

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{4{,}522 \ / \ 20.4} = 0.000564$$

From Table CS-2 Metric: B = 572.6195 kg_f/cm^2

$$P_a = \frac{B}{R_o \ / \ t} = \frac{561.5479}{4{,}522 \ / \ 20.4} = 2.533 \text{ bar}$$

The maximum allowable external pressure (MAEP) is 2.53 bar.

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 17}{278.5}\right) \cdot \left(1 - \frac{278.5}{\infty}\right) = 4.5781\,\%$$

The extreme fiber elongation does not exceed 5%.

Straight Flange on Top Head

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		7	40	5
External		0.8	40	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.07	779.8	0.98
Test horizontal		0.44	4,500	1
Dimensions				
Inner Diameter		4,500 mm		
Length		50.8 mm		
Nominal Thickness		17 mm		
Corrosion	**Inner**	1.6 mm		
	Outer	1.64 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		95.99		807.94
Corroded		77.7		809.09
Radiography				
Longitudinal seam		Seamless No RT		
Bottom Circumferential seam		Full UW-11(a) Type 2		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	14.82 mm
Design thickness due to external pressure (t_e)	15.81 mm
Design thickness due to combined loadings + corrosion	9.57 mm
Maximum allowable working pressure (MAWP)	8.33 bar
Maximum allowable pressure (MAP)	10.38 bar
Maximum allowable external pressure (MAEP)	1 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \frac{0.07 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.07} =$	0.12 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.12 \cdot 1}{17 - 3.24} =$	0.0089
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.07 \cdot 2{,}251.6}{1{,}380 \cdot 1.00 - 0.60 \cdot 7.07} + 3.24 = \underline{14.82} \text{ mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}380 \cdot 1.00 \cdot 13.76}{2{,}251.6 + 0.60 \cdot 13.76} - 0.07 = \underline{8.33} \text{ bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}380 \cdot 1.00 \cdot 17}{2{,}250 + 0.60 \cdot 17} = \underline{10.38} \text{ bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}196.39}{4{,}534} = 0.9255$$

$$\frac{D_o}{t} = \frac{4{,}534}{12.57} = 360.6878$$

From table G: $A = 0.000217$

From table CS-2 Metric: $B = 220.6799 \text{ kg/cm}^2 (216.41 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 216.41}{3 \cdot (4{,}534/12.57)} = 0.8 \text{ bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.57 + 3.24 = \underline{15.81} \text{ mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}196.39}{4{,}534} = 0.9255$$

$$\frac{D_o}{t} = \frac{4{,}534}{13.76} = 329.5058$$

From table G: $A = 0.000247$

From table CS-2 Metric: $B = 251.3806 \text{ kg/cm}^2 (246.5197 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 246.52}{3 \cdot (4{,}534/13.76)} = \underline{1} \text{ bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 17}{2{,}258.5}\right) \cdot \left(1 - \frac{2{,}258.5}{\infty}\right) = 0.3764\,\%$$

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	7	1,407.2	769.8	40	3.24	Wind	6.32	6.31
						Seismic	6.33	6.3
Operating, Hot & New	7	1,407.2	843.3	40	0	Wind	6.32	6.3
						Seismic	6.32	6.29
Hot Shut Down, Corroded	0	1,407.2	769.8	40	3.24	Wind	0.03	0.04
						Seismic	0.01	0.06
Hot Shut Down, New	0	1,407.2	843.3	40	0	Wind	0.03	0.05
						Seismic	0.02	0.06
Empty, Corroded	0	1,407.2	769.8	21.11	3.24	Wind	0.03	0.04
						Seismic	0.02	0.05
Empty, New	0	1,407.2	843.3	21.11	0	Wind	0.03	0.05
						Seismic	0.02	0.05
Vacuum	-0.8	1,407.2	769.8	40	3.24	Wind	1.22	1.24
						Seismic	1.21	1.25
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,407.2	769.8	40	3.24	Weight	0.04	0.04

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \quad kg/cm^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \quad kg/cm^2$$

$$S_{cHC} = \min(B, S) = 769.8 \ kg/cm^2$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \quad kg/cm^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \quad kg/cm^2$$

$$S_{cHN} = \min(B, S) = 843.3 \ kg/cm^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \quad kg/cm^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$S_{cCN} = \min(B, S) =$ 843.3 kg/cm²

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \text{ kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$S_{cC} = \min(B, S) =$ 769.8 kg/cm²

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \text{ kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$S_{cVC} = \min(B, S) =$ 769.8 kg/cm²

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 26.6 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.02 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.34 + 0 - (0.02)$

= 6.32 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.03 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (0.03) - (6.34)|$

= 6.31 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (13.76 - 0 + (0.02))}{2{,}251.6 - 0.40 \cdot (13.76 - 0 + (0.02))}$

= 15.24 bar

Operating, Hot & New, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 26.8 \dfrac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 5,541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.02 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.33 + 0 - (0.02)$

= 6.32 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{5,541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.03 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (0.03) - (6.33)|$

= 6.3 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (17 - 0 + (0.02))}{2{,}250 - 0.40 \cdot (17 - 0 + (0.02))}$

= 18.85 bar

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{26.6}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot 4,871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.03 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.03)|$

= 0.03 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{4,871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.04 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.04) - (0)$

= 0.04 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 26.8 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 5{,}541.4 \frac{}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$

= 0.03 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.03)|$

= 0.03 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.05) - (0)$

= 0.05 mm

Empty, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 26.6 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 4,871.2 \frac{}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.03 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.03)|$

= 0.03 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{4,871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.04 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.04) - (0)$

= 0.04 mm

Empty, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 26.8 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 5{,}541.4 \frac{}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$

= 0.03 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.03)|$

= 0.03 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.05) - (0)$

= 0.05 mm

Vacuum, Wind, Bottom Seam

t_p = $\frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

= $\frac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

= $\frac{26.6}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

t_w = $0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $0.60 \cdot \frac{4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.03 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|-1.19 + 0 - (0.03)|$

= 1.22 mm

$t_{w\,c}$ = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $\frac{4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.04 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0 + (0.04) - (-1.19)$

= 1.24 mm

Maximum Allowable External Pressure, Longitudinal Stress

P = $\frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

= $\frac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0 - 0.04)}{2{,}251.6 - 0.40 \cdot (13.76 - 0 - 0.04)}$

= 9.22 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 2.7 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 4{,}871.2 \frac{}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.04 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.04)|$

= 0.04 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.04) - (0)$

= 0.04 mm

Operating, Hot & Corroded, Seismic, Bottom Seam

t_p = $\frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $\frac{1{,}025.7}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.01 mm

t_w = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.52 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.01 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.34 + 0.01 - (0.01)$

= 6.33 mm

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{1.08 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.03 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.01 + (0.03) - (6.34)|$

= 6.3 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (13.76 - 0.01 + (0.01))}{2{,}251.6 - 0.40 \cdot (13.76 - 0.01 + (0.01))}$

= 15.23 bar

Operating, Hot & New, Seismic, Bottom Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $1{,}089.3 \dfrac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.01 mm

t_w = $\dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.52 \cdot 5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.02 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.33 + 0.01 - (0.02)$

= 6.32 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.03 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.01 + (0.03) - (6.33)|$

= 6.29 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (17 - 0.01 + (0.02))}{2{,}250 - 0.40 \cdot (17 - 0.01 + (0.02))}$

= 18.84 bar

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{1{,}025.7}{\pi \cdot 2{,}258.48^{\;2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0.01 mm

$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.02 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.01 - (0.02)|$

= 0.01 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.01 + (0.05) - (0)$

= 0.06 mm

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 1,089.3 \frac{}{\pi \cdot 2{,}258.5^{\ 2} \cdot 826.96 \cdot 1.00} \cdot 98066.5$$

= 0.01 mm

$$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= 0.52 \cdot 5,541.4 \frac{}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.02 mm

$$t_t = |t_p + t_m - t_w| \quad \text{(total, net compressive)}$$

$$= |0 + 0.01 - (0.02)|$$

= 0.02 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot 5,541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.05 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.01 + (0.05) - (0)$$

= 0.06 mm

Empty, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{434.8}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.02 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.02)|$

= 0.02 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.05) - (0)$

= 0.05 mm

Empty, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{499.9}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot 5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.02 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0 - (0.02)|$$

= 0.02 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot 5{,}541.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.05 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0 + (0.05) - (0)$$

= 0.05 mm

Vacuum, Seismic, Bottom Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (bending)

= $1{,}025.7 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0.01 mm

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (Weight)

= $0.52 \cdot 4{,}871.2 \dfrac{}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.02 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $| -1.19 + 0.01 - (0.02)|$

= 1.21 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 4{,}871.2}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.01 + (0.05) - (-1.19)$

= 1.25 mm

Maximum Allowable External Pressure, Longitudinal Stress

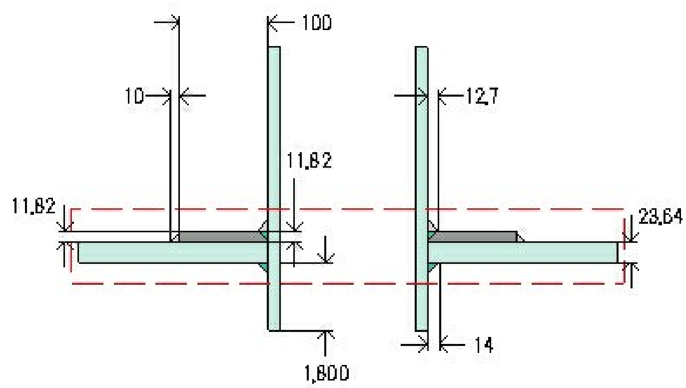
P = $\dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

= $\dfrac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0.01 - 0.05)}{2{,}251.6 - 0.40 \cdot (13.76 - 0.01 - 0.05)}$

= 9.21 bar

Nozzle #2 (N2)

ASME Section VIII Division 1, 2021 Edition Metric



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	0°
End of nozzle to datum line	9,020.35 mm
Calculated as hillside	No
Distance to head center, R	0 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 46 XS DN 1150
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	1,143 mm
Pipe nominal wall thickness	12.7 mm
Pipe minimum wall thickness[1]	11.11 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	152.4 mm
Internal projection, h_{new}	1,800 mm
Projection available outside vessel to flange face, Lf	338.07 mm
Local vessel minimum thickness	23.64 mm
Liquid static head included	0 bar

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 20, ln. 45)
Diameter, D_p	1,368.4 mm
Thickness, t_e	11.82 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	12.7 mm
Outer fillet, Leg_{42}	10 mm
Lower fillet, Leg_{43}	14 mm
Pad groove weld	11.82 mm

Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Full UW-11(a) Type 1

[1]Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.47-2017 Flange	
Description	NPS 46 Class 150 WN A105 Series A
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 410, ln. 32)
Blind included	Yes
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	19.53 bar @ 40°C
MAP rating	19.6 bar @ 21.11°C
Hydrotest rating	30 bar @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Bore diameter, B (specified by purchaser)	1,150.92 mm
Gasket	
Type	Corrugated Metal
Description	Corrugated metal Iron or soft steel / Mineral Fiber
Factor, m	3
Seating Stress, y	316.381 kg_f/cm^2
Thickness, T	4.45 mm
Inner Diameter	1,155 mm
Outer Diameter	1,160 mm
Notes	
Flange and blind rated MDMT per UCS-66(b)(1)(b) = -48°C (Coincident ratio = 0.361) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
Governing thickness, t_g =	11.11 mm
Exemption temperature from Fig UCS-66M Curve B =	-24.98°C
$t_r = \dfrac{7.07 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.07} =$	3.45 mm
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{3.45 \cdot 1}{11.11 - 1.59} =$	0.362
Reduction in MDMT, T_R from Fig UCS-66.1M =	69.6°C
$MDMT = \max\left[MDMT - T_R, -48\right] = \max\left[-24.98 - 69.6, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	11.82 mm
Exemption temperature from Fig UCS-66M Curve B =	-23.65°C
$t_r = \frac{7.07 \cdot 4{,}501.6 \cdot 1}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7.07} =$	11.55 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{11.55 \cdot 1}{23.64 - 3.24} =$	0.566
Reduction in MDMT, T_R from Fig UCS-66.1M =	25.7°C
$MDMT = \max\left[MDMT - T_R, -48\right] = \max\left[-23.65 - 25.7, -48\right] =$	-48°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
131.2942	134.1416	102.5727	4.9993	3.8688	20.0234	2.6774	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
42,817	37,328	283,639	20,877	464,711	49,879	240,250

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	5.09	5.36 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[1{,}146.18,\ 573.09 + (12.7 - 1.59) + (23.64 - 3.24)\right]$$

$$= 1{,}146.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 10.18\right]$$

$$= 37.96 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[1{,}798.4,\ 2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 23.78 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7}$$

$$= 3.41 \text{ mm}$$

Required thickness t_r from UG-37(a)(a)

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P}$$

$$= \frac{7 \cdot 4{,}501.6 \cdot 1}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7}$$

$$= 11.42 \ \ \text{mm}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} = \frac{7 \cdot 4{,}501.6 \cdot 1.7678}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7} = 20.19 \ \ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (1{,}146.18 \cdot 11.42 \cdot 1 + 2 \cdot 11.11 \cdot 11.42 \cdot 1 \cdot (1 - 0.8551))/100$$

= 131.2942 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 102.5727 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (1{,}146.18 \cdot (1 \cdot 20.4 - 1 \cdot 11.42) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.42) \cdot (1 - 0.8551))/100$$

$$= 102.5727 \ \ \text{cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (20.4 + 11.11) \cdot (1 \cdot 20.4 - 1 \cdot 11.42) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.42) \cdot (1 - 0.8551))/100$$

$$= 5.3664 \ \ \text{cm}^2$$

A_2 = smaller of the following= 4.9993 cm^2

$$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$$

$$= (5 \cdot (11.11 - 3.41) \cdot 0.8551 \cdot 20.4)/100$$

$$= 6.7161 \ \ \text{cm}^2$$

$= 2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

$= (2 \cdot (11.11 - 3.41) \cdot (2.5 \cdot 11.11 + 10.18) \cdot 0.8551)/100$

$= 4.9993 \text{ cm}^2$

A_3 = smaller of the following= 3.8688 cm^2

$= 5 \cdot t \cdot t_i \cdot f_{r2}$

$= (5 \cdot 20.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 8.2957 cm^2

$= 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= (5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

$=$ 3.8688 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 1{,}798.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 292.5687 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 0.8551)/100$

$=$ 0.9174 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (7.66^2 \cdot 1)/100$

$=$ 0.5865 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 0.8551)/100$

$=$ 1.1735 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}365.12 - 1{,}146.18 - 2 \cdot 11.11) \cdot 10.18 \cdot 1)/100$

$=$ 20.0234 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 102.5727 + 4.9993 + 3.8688 + 0.9174 + 0.5865 + 1.1735 + 20.0234$

$=$ 134.1416 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\left[19 \text{ mm}, t_n, t_e\right] =$ 10.18 mm

$t_{c(\min)} = \min\left[6 \text{ mm}, 0.7 \cdot t_{\min}\right] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\left[19 \text{ mm}, t_e, t\right] =$ 10.18 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = 5.09 \text{ mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 7.66 = 5.36 \text{ mm}$

Lower fillet: $t_{\min} = \min\left[19 \text{ mm}, t_n, t\right] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = 7.78 \text{ mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2 \text{ mm}$

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7} + 1.59$$

$$= 5 \text{ mm}$$

$$t_a = \max\left[t_{a\text{UG-27}}, t_{a\text{UG-22}}\right]$$

$$= \max\left[5, 0\right]$$

$$= 5 \text{ mm}$$

t_{b1} = 23.43 mm

$$t_{b1} = \max\left[t_{b1}, t_{b\text{UG16}}\right]$$

$$= \max\left[23.43, 3.09\right]$$

$$= 23.43 \text{ mm}$$

$$t_b = \min\left[t_{b3}, t_{b1}\right]$$

$$= \min\left[9.92, 23.43\right]$$

$$= 9.92 \text{ mm}$$

$$t_{\text{UG-45}} = \max\left[t_a, t_b\right]$$

$$= \max\left[5, 9.92\right]$$

$$= 9.92 \text{ mm}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 10.36 \cdot 589.6$ = 112,075.03 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}368.4 \cdot 7.66 \cdot 689.532$ = 113,489.12 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 1{,}157.29 \cdot 11.11 \cdot 842.286$ = 170,150.15 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 11.71 \cdot 589.6$ = 126,760.72 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 11.82 \cdot 1{,}041.334$ = 225,875.11 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$
= $(13{,}129.42 - 10{,}257.27 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 20.4 - 1 \cdot 11.42)) \cdot 1{,}407.208$
= 42,817.12 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$
= $(499.9345 + 2{,}002.3381 + 91.7418 + 58.645) \cdot 1{,}407.208$
= 37,328.45 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= $(499.9345 + 386.88 + 91.7418 + 117.3546 + 2 \cdot 11.11 \cdot 20.4 \cdot 0.8551) \cdot 1{,}407.208$
= 20,876.67 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= $(499.9345 + 386.88 + 2{,}002.3381 + 91.7418 + 58.645 + 117.3546 + 2 \cdot 11.11 \cdot 20.4 \cdot 0.8551) \cdot 1{,}407.208$
= 49,879 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 37,328.45 kg_f
Path 1-1 through (2) & (3) = 113,489.12 + 170,150.15 = 283,639.27 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 20,876.67 kg_f
Path 2-2 through (1), (5), (6) = 112,075.03 + 126,760.72 + 225,875.11 = 464,710.85 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 42,817.12 kg_f
Path 3-3 through (2), (5) = 113,489.12 + 126,760.72 = 240,249.84 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.07 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
132.6984	132.721	101.1766	4.9748	3.8688	20.0234	2.6774	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
46,725	37,294	283,639	20,842	464,711	49,845	240,250

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	5.09	5.36 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.07 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[1{,}146.18,\ 573.09 + (12.7 - 1.59) + (23.64 - 3.24)\right]$$

$$= 1{,}146.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 10.18\right]$$

$$= 37.96 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[1{,}798.4,\ 2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 23.78 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.0749 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.0749}$$

$$= 3.45 \text{ mm}$$

Required thickness t_r from UG-37(a)(a)

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P}$$

$$= \frac{7.0749 \cdot 4{,}501.6 \cdot 1}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7.0749}$$

$$= 11.55 \text{ mm}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} = \frac{7.07 \cdot 4{,}501.6 \cdot 1.7678}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7.07} = 20.41 \text{ mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (1{,}146.18 \cdot 11.55 \cdot 1 + 2 \cdot 11.11 \cdot 11.55 \cdot 1 \cdot (1 - 0.8551))/100$$

= 132.6984 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 101.1766 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (1{,}146.18 \cdot (1 \cdot 20.4 - 1 \cdot 11.55) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.55) \cdot (1 - 0.8551))/100$$

$$= 101.1766 \text{ cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (20.4 + 11.11) \cdot (1 \cdot 20.4 - 1 \cdot 11.55) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.55) \cdot (1 - 0.8551))/100$$

$$= 5.2935 \text{ cm}^2$$

A_2 = smaller of the following= 4.9748 cm^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $(5 \cdot (11.11 - 3.45) \cdot 0.8551 \cdot 20.4)/100$

= $6.6832 \ \text{cm}^2$

= $2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

= $(2 \cdot (11.11 - 3.45) \cdot (2.5 \cdot 11.11 + 10.18) \cdot 0.8551)/100$

= $4.9748 \ \text{cm}^2$

A_3 = smaller of the following= 3.8688 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 20.4 \cdot 9.51 \cdot 0.8551)/100$

= 8.2957 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 1{,}798.4 \cdot 9.51 \cdot 0.8551)/100$

= 292.5687 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 0.8551)/100$

= 0.9174 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(7.66^2 \cdot 1)/100$

= 0.5865 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 0.8551)/100$

= 1.1735 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}365.12 - 1{,}146.18 - 2 \cdot 11.11) \cdot 10.18 \cdot 1)/100$

= 20.0234 cm^2

$Area$ = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

= $101.1766 + 4.9748 + 3.8688 + 0.9174 + 0.5865 + 1.1735 + 20.0234$

= 132.721 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t_e] =$ 10.18 mm

$t_{c(\min)} = \min[6 \text{ mm}, 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm}, t_e, t] =$ 10.18 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 5.09 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 7.66 = 5.36$ mm

Lower fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.0749 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.0749} + 1.59$$

$$= 5.04 \text{ mm}$$

$$t_a = \max[t_{a\text{UG-27}}, t_{a\text{UG-22}}]$$

$$= \max[5.04, 0]$$

$$= 5.04 \text{ mm}$$

$$t_{b1} = 23.65 \text{ mm}$$

$$t_{b1} = \max[t_{b1}, t_{b\text{UG16}}]$$

$$= \max[23.65, 3.09]$$

$$= 23.65 \text{ mm}$$

$$t_b = \min[t_{b3}, t_{b1}]$$

$$= \min[9.92, 23.65]$$

$$= 9.92 \text{ mm}$$

$$t_{\text{UG-45}} = \max[t_a, t_b]$$

$$= \max[5.04, 9.92]$$

$$= 9.92 \text{ mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 10.36 \cdot 589.6$ = 112,075.03 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}368.4 \cdot 7.66 \cdot 689.532$ = 113,489.12 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 1{,}157.29 \cdot 11.11 \cdot 842.286$ = 170,150.15 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 11.71 \cdot 589.6$ = 126,760.72 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 11.82 \cdot 1{,}041.334$ = 225,875.11 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(13{,}269.84 - 10{,}117.66 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 20.4 - 1 \cdot 11.55)) \cdot 1{,}407.208$

= 46,725.18 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(497.4829 + 2{,}002.3381 + 91.7418 + 58.645) \cdot 1{,}407.208$

= 37,293.95 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(497.4829 + 386.88 + 91.7418 + 117.3546 + 2 \cdot 11.11 \cdot 20.4 \cdot 0.8551) \cdot 1{,}407.208$

= 20,842.17 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(497.4829 + 386.88 + 2{,}002.3381 + 91.7418 + 58.645 + 117.3546 + 2 \cdot 11.11 \cdot 20.4 \cdot 0.8551) \cdot 1{,}407.208$

= 49,844.5 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 37,293.95 kg_f
Path 1-1 through (2) & (3) = 113,489.12 + 170,150.15 = 283,639.27 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 20,842.17 kg_f
Path 2-2 through (1), (5), (6) = 112,075.03 + 126,760.72 + 225,875.11 = 464,710.85 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 46,725.18 kg_f
Path 3-3 through (2), (5) = 113,489.12 + 126,760.72 = 240,249.84 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 8.32 bar @ 21.11 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
155.668	155.6717	114.6353	6.4477	6.896	23.6372	4.0555	8.33	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
60,817	45,684	342,404	30,302	514,797	64,971	299,708

Calculations for internal pressure 8.32 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[1{,}143,\ 571.5 + (12.7 - 0) + (23.64 - 0)\right]$$

$$= 1{,}143 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (23.64 - 0),\ 2.5 \cdot (12.7 - 0) + 11.82\right]$$

$$= 43.57 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[1{,}800,\ 2.5 \cdot (23.64 - 0),\ 2.5 \cdot (12.7 - 0 - 0)\right]$$

$$= 31.75 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{8.3213 \cdot 571.5}{1{,}180 \cdot 1 - 0.6 \cdot 8.3213}$$

$$= 4.05 \text{ mm}$$

Required thickness t_r from UG-37(a)(a)

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P}$$

$$= \frac{8.3213 \cdot 4{,}500 \cdot 1}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 8.3213}$$

$$= 13.58 \text{ mm}$$

Required thickness t_r per Interpretation VIII-1-07-50

$$t_r = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} = \frac{8.32 \cdot 4{,}500 \cdot 1.7706}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 8.32} = 24.04 \ \ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

= $(1{,}143 \cdot 13.58 \cdot 1 + 2 \cdot 12.7 \cdot 13.58 \cdot 1 \cdot (1 - 0.8551))/100$

= 155.668 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 114.6353 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(1{,}143 \cdot (1 \cdot 23.64 - 1 \cdot 13.58) - 2 \cdot 12.7 \cdot (1 \cdot 23.64 - 1 \cdot 13.58) \cdot (1 - 0.8551))/100$

= $114.6353 \ \ \text{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (23.64 + 12.7) \cdot (1 \cdot 23.64 - 1 \cdot 13.58) - 2 \cdot 12.7 \cdot (1 \cdot 23.64 - 1 \cdot 13.58) \cdot (1 - 0.8551))/100$

= $6.9419 \ \ \text{cm}^2$

A_2 = smaller of the following= 6.4477 cm^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $(5 \cdot (12.7 - 4.05) \cdot 0.8551 \cdot 23.64)/100$

= $8.7458 \ \ \text{cm}^2$

= $2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

= $(2 \cdot (12.7 - 4.05) \cdot (2.5 \cdot 12.7 + 11.82) \cdot 0.8551)/100$

= $6.4477 \ \ \text{cm}^2$

A_3 = smaller of the following= 6.896 cm^2

	=	$5 \cdot t \cdot t_i \cdot f_{r2}$
	=	$(5 \cdot 23.64 \cdot 12.7 \cdot 0.8551)/100$
	=	12.8347 cm^2
	=	$5 \cdot t_i \cdot t_i \cdot f_{r2}$
	=	$(5 \cdot 12.7 \cdot 12.7 \cdot 0.8551)/100$
	=	6.896 cm^2
	=	$2 \cdot h \cdot t_i \cdot f_{r2}$
	=	$(2 \cdot 1{,}800 \cdot 12.7 \cdot 0.8551)/100$
	=	390.9517 cm^2
A_{41}	=	$Leg^2 \cdot f_{r3}$
	=	$(12.7^2 \cdot 0.8551)/100$
	=	1.3794 cm^2
A_{42}	=	$Leg^2 \cdot f_{r4}$
	=	$(10^2 \cdot 1)/100$
	=	1 cm^2
A_{43}	=	$Leg^2 \cdot f_{r2}$
	=	$(14^2 \cdot 0.8551)/100$
	=	1.6761 cm^2
A_5	=	$(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$
	=	$((1{,}368.4 - 1{,}143 - 2 \cdot 12.7) \cdot 11.82 \cdot 1)/100$
	=	23.6372 cm^2
$Area$	=	$A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
	=	$114.6353 + 6.4477 + 6.896 + 1.3794 + 1 + 1.6761 + 23.6372$
	=	155.6717 cm^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{8.3213 \cdot 571.5}{1{,}180 \cdot 1 - 0.6 \cdot 8.3213} + 0$$

$$= 4.05 \text{ mm}$$

$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$

$= \max\left[4.05,\ 0\right]$

$= 4.05\ \text{mm}$

$t_{b1} =$ 24.04 mm

$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$

$= \max\left[24.04,\ 1.5\right]$

$= 24.04\ \text{mm}$

$t_b = \min\left[t_{b3},\ t_{b1}\right]$

$= \min\left[8.33,\ 24.04\right]$

$= 8.33\ \text{mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[4.05,\ 8.33\right]$

$=$ 8.33 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 12.7 \cdot 589.6$ = 137,427.17 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}368.4 \cdot 10 \cdot 689.532$ = 148,213.4 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 1{,}155.7 \cdot 12.7 \cdot 842.286$ = 194,190.57 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 14 \cdot 589.6$ = 151,494.52 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 1{,}168.4 \cdot 11.82 \cdot 1{,}041.334$ = 225,875.11 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(15{,}566.8 - 11{,}463.53 + 2 \cdot 12.7 \cdot 0.8551 \cdot (1 \cdot 23.64 - 1 \cdot 13.58)) \cdot 1{,}407.208$

= 60,816.94 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(644.7729 + 2{,}363.724 + 137.9352 + 99.9998) \cdot 1{,}407.208$

= 45,684.07 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(644.7729 + 689.5954 + 137.9352 + 167.6126 + 2 \cdot 12.7 \cdot 23.64 \cdot 0.8551) \cdot 1{,}407.208$

= 30,301.51 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(644.7729 + 689.5954 + 2{,}363.724 + 137.9352 + 99.9998 + 167.6126 + 2 \cdot 12.7 \cdot 23.64 \cdot 0.8551) \cdot 1{,}407.208$

= 64,971.24 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 45,684.07 kg_f
Path 1-1 through (2) & (3) = 148,213.4 + 194,190.57 = 342,403.97 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 30,301.51 kg_f
Path 2-2 through (1), (5), (6) = 137,427.17 + 151,494.52 + 225,875.11 = 514,796.79 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 60,816.94 kg_f
Path 3-3 through (2), (5) = 148,213.4 + 151,494.52 = 299,707.92 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
65.8412	134.6616	102.1869	5.9051	3.8688	20.0234	2.6774	5.55	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	5.09	5.36 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[1{,}146.18,\ 573.09 + (12.7 - 1.59) + (23.64 - 3.24)\right]$$
$$= 1{,}146.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 10.18\right]$$
$$= 37.96 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[1{,}798.4,\ 2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$
$$= 23.78 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 2.02 mm

From UG-37(d)(1) required thickness t_r = 11.46 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (1{,}146.18 \cdot 11.46 \cdot 1 + 2 \cdot 11.11 \cdot 11.46 \cdot 1 \cdot (1 - 0.8551)))/100$

= 65.8412 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 102.1869 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(1{,}146.18 \cdot (1 \cdot 20.4 - 1 \cdot 11.46) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.46) \cdot (1 - 0.8551))/100$

= $102.1869\ cm^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (20.4 + 11.11) \cdot (1 \cdot 20.4 - 1 \cdot 11.46) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 11.46) \cdot (1 - 0.8551))/100$

= $5.3464\ cm^2$

A_2 = smaller of the following= 5.9051 cm^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $(5 \cdot (11.11 - 2.02) \cdot 0.8551 \cdot 20.4)/100$

= $7.9329\ cm^2$

= $2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

= $(2 \cdot (11.11 - 2.02) \cdot (2.5 \cdot 11.11 + 10.18) \cdot 0.8551)/100$

= $5.9051\ cm^2$

A_3 = smaller of the following= 3.8688 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 20.4 \cdot 9.51 \cdot 0.8551)/100$

= 8.2957 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 1{,}798.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 292.5687 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 0.8551)/100$

$=$ 0.9174 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (7.66^2 \cdot 1)/100$

$=$ 0.5865 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 0.8551)/100$

$=$ 1.1735 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}365.12 - 1{,}146.18 - 2 \cdot 11.11) \cdot 10.18 \cdot 1)/100$

$=$ 20.0234 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 102.1869 + 5.9051 + 3.8688 + 0.9174 + 0.5865 + 1.1735 + 20.0234$

$=$ 134.6616 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t_e] =$ 10.18 mm

$t_{c(\min)} = \min[6 \text{ mm}, 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm}, t_e, t] =$ 10.18 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 5.09 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 7.66 = 5.36$ mm

Lower fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\text{UG-28}} \quad = \quad 3.6 \ \ \text{mm}$

$t_a \quad = \quad \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$

$\quad = \quad \max\left[3.6,\ \ 0\right]$

$\quad = \quad 3.6 \ \ \text{mm}$

$t_{b2} \quad = \quad$ 5.55 mm

$t_{b2} \quad = \quad \max\left[t_{b2},\ \ t_{b\text{UG16}}\right]$

$\quad = \quad \max\left[5.55,\ \ 3.09\right]$

$\quad = \quad 5.55 \ \ \text{mm}$

$t_b \quad = \quad \min\left[t_{b3},\ \ t_{b2}\right]$

$\quad = \quad \min\left[9.92,\ \ 5.55\right]$

$\quad = \quad 5.55 \ \ \text{mm}$

$t_{\text{UG-45}} \quad = \quad \max\left[t_a,\ \ t_b\right]$

$\quad = \quad \max\left[3.6,\ \ 5.55\right]$

$\quad = \quad$ 5.55 $\ \text{mm}$

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{338.07}{1{,}168.4} = 0.2893$$

$$\frac{D_o}{t} = \frac{1{,}168.4}{2.02} = 579.5594$$

From table G: $A = 0.000349$

From table CS-2 Metric: $B = 354.5898 \ \ \text{kg/cm}^{2} (347.73 \ \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 347.73}{3 \cdot (1{,}168.4/2.02)} = 0.8 \ \ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 2.02 + 1.59 = $ 3.6 mm

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
73.5355	119.2417	86.8843	5.7877	3.8688	20.0234	2.6774	6.12	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	5.09	5.36 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 1 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[1{,}146.18,\ 573.09 + (12.7 - 1.59) + (23.64 - 3.24)\right]$$
$$= 1{,}146.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 10.18\right]$$
$$= 37.96\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[1{,}798.4,\ 2.5 \cdot (23.64 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$
$$= 23.78\ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 2.2 mm

From UG-37(d)(1) required thickness t_r = 12.8 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (1{,}146.18 \cdot 12.8 \cdot 1 + 2 \cdot 11.11 \cdot 12.8 \cdot 1 \cdot (1 - 0.8551)))/100$

= 73.5355 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 86.8843 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(1{,}146.18 \cdot (1 \cdot 20.4 - 1 \cdot 12.8) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 12.8) \cdot (1 - 0.8551))/100$

= $86.8843 \ \ cm^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (20.4 + 11.11) \cdot (1 \cdot 20.4 - 1 \cdot 12.8) - 2 \cdot 11.11 \cdot (1 \cdot 20.4 - 1 \cdot 12.8) \cdot (1 - 0.8551))/100$

= $4.5458 \ \ cm^2$

A_2 = smaller of the following= 5.7877 cm^2

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t$

= $(5 \cdot (11.11 - 2.2) \cdot 0.8551 \cdot 20.4)/100$

= $7.7755 \ \ cm^2$

= $2 \cdot (t_n - t_{rn}) \cdot (2.5 \cdot t_n + t_e) \cdot f_{r2}$

= $(2 \cdot (11.11 - 2.2) \cdot (2.5 \cdot 11.11 + 10.18) \cdot 0.8551)/100$

= $5.7877 \ \ cm^2$

A_3 = smaller of the following= 3.8688 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 20.4 \cdot 9.51 \cdot 0.8551)/100$

= 8.2957 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 1{,}798.4 \cdot 9.51 \cdot 0.8551)/100$

= 292.5687 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^{\,2} \cdot 0.8551)/100$

= 0.9174 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(7.66^{\,2} \cdot 1)/100$

= 0.5865 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^{\,2} \cdot 0.8551)/100$

= 1.1735 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}365.12 - 1{,}146.18 - 2 \cdot 11.11) \cdot 10.18 \cdot 1)/100$

= 20.0234 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 86.8843 + 5.7877 + 3.8688 + 0.9174 + 0.5865 + 1.1735 + 20.0234$

$=$ 119.2417 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\,[19 \;\text{mm},\; t_n,\; t_e] =$ 10.18 mm

$t_{c(\min)} = \min\,[6 \;\text{mm},\; 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\,[19 \;\text{mm},\; t_e,\; t] =$ 10.18 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 5.09 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 7.66 = 5.36$ mm

Lower fillet: $t_{\min} = \min\,[19 \;\text{mm},\; t_n,\; t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

Interpretation VIII-1-83-66 has been applied.

$t_{a\text{UG-28}} = 3.78$ mm

$t_a = \max[t_{a\text{UG-28}},\ t_{a\text{UG-22}}]$

$= \max[3.78,\ 0]$

$= 3.78\ \text{mm}$

$t_{b2} = 6.12$ mm

$t_{b2} = \max[t_{b2},\ t_{b\text{UG16}}]$

$= \max[6.12,\ 3.09]$

$= 6.12\ \text{mm}$

$t_b = \min[t_{b3},\ t_{b2}]$

$= \min[9.92,\ 6.12]$

$= 6.12\ \text{mm}$

$t_{\text{UG-45}} = \max[t_a,\ t_b]$

$= \max[3.78,\ 6.12]$

$=$ 6.12 mm

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{338.07}{1{,}168.4} = 0.2893$$

$$\frac{D_o}{t} = \frac{1{,}168.4}{2.2} = 531.8480$$

From table G: $A = 0.000399$

From table CS-2 Metric: $B = 405.7517\ \text{kg/cm}^2 (397.91\ \text{bar})$

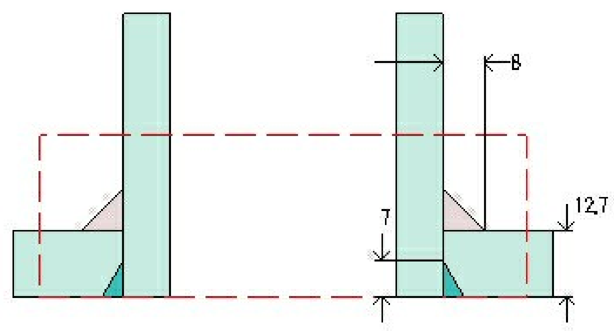
$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 397.91}{3 \cdot (1{,}168.4/2.2)} = 1\ \text{bar}$$

Design thickness for external pressure P_a = 1 bar

$t_a = t + \text{Corrosion} = 2.2 + 1.59 = 3.78$ mm

Nozzle #4 (N4)

ASME Section VIII Division 1, 2021 Edition Metric	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Nozzle #2 (N2)
Orientation	180°
Nozzle center line offset to face of parent nozzle	260.67 mm
End of nozzle to shell center	736.6 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	88.9 mm
Projection available outside vessel to flange face, Lf	152.4 mm
Local vessel minimum thickness	11.11 mm
Liquid static head included	0 bar
Welds	
Inner fillet, Leg_{41}	8 mm
Nozzle to vessel groove weld	7 mm
Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Full UW-11(a) Type 1

[1]Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.5-2017 Flange	
Description	NPS 2 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 410, ln. 32)
Blind included	No
Rated MDMT	-29°C
Liquid static head	0 bar
MAWP rating	19.53 bar @ 40°C
MAP rating	19.6 bar @ 21.11°C
Hydrotest rating	30 bar @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Notes	
Flange rated MDMT per UG-20(f) = -29°C Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
$t_r = \frac{19.42 \cdot 23.01}{1{,}180 \cdot 1 - 0.6 \cdot 19.42} =$	0.38 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.38 \cdot 1}{7.65 - 1.59} =$	0.0631
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7 bar @ 40 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							5	7.65

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	5.01	5.6	weld size is adequate
Combined weld check (t_1 + t_2)	8.94	11.01	weld size is adequate
Nozzle to shell groove (Lower)	5.01	5.41	weld size is adequate

Calculations for internal pressure 7 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ \ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[46.02,\ \ 23.01 + (8.74 - 1.59) + (11.11 - 1.59)\right]$$

$$= 46.02 \ \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ \ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (11.11 - 1.59),\ \ 2.5 \cdot (8.74 - 1.59) + 0\right]$$

$$= 17.88 \ \ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7 \cdot 23.01}{1{,}180 \cdot 1 - 0.6 \cdot 7}$$

$$= 0.14 \ \ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7}$$

$$= 3.41 \ \ \text{mm}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$t_{\min} = \min [19 \ \text{mm}, \ t_n, \ t] = 7.15 \ \text{mm}$

$t_{1(\min)}$ or $t_{2(\min)} = \min [6mm, \ 0.7 \cdot t_{\min}] = 5.01 \ \text{mm}$

$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 8 = 5.6 \ \text{mm}$

The weld size t_1 is satisfactory.

$t_{2(actual)} = 5.41 \ \text{mm}$

The weld size t_2 is satisfactory.

$t_1 + t_2 = 11.01 \geq 1.25 \cdot t_{\min} = 8.94$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7 \cdot 23.01}{1{,}180 \cdot 1 - 0.6 \cdot 7} + 1.59$$

$$= 1.72 \ \text{mm}$$

$$t_a = \max [t_{a\text{UG-27}}, \ t_{a\text{UG-22}}]$$

$$= \max [1.72, \ 0]$$

$$= 1.72 \ \text{mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 7} + 1.59$$

$$= 5 \ \text{mm}$$

$$t_{b1} = \max [t_{b1}, \ t_{b\text{UG16}}]$$

$$= \max [5, \ 3.09]$$

$$= 5 \ \text{mm}$$

$$t_b = \min [t_{b3}, \ t_{b1}]$$

$$= \min [5.01, \ 5]$$

$$= 5 \ \text{mm}$$

$$t_{\text{UG-45}} = \max [t_a, \ t_b]$$

$$= \max [1.72, \ 5]$$

$$= 5 \ \text{mm}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 8.74$ = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAWP

The vessel wall thickness governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 19.42 bar @ 40 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							5.01	7.65

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	5.01	5.6	weld size is adequate
Combined weld check (t_1 + t_2)	8.94	11.01	weld size is adequate
Nozzle to shell groove (Lower)	5.01	5.41	weld size is adequate

Calculations for internal pressure 19.42 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[46.02,\ 23.01 + (8.74 - 1.59) + (11.11 - 1.59)\right]$$

$$= 46.02 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (11.11 - 1.59),\ 2.5 \cdot (8.74 - 1.59) + 0\right]$$

$$= 17.88 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{19.4184 \cdot 23.01}{1{,}180 \cdot 1 - 0.6 \cdot 19.4184}$$

$$= 0.38 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{19.4184 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 19.4184}$$

$$= 9.52 \text{ mm}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$t_{\min} = \min\left[19 \ \text{mm}, \ t_n, \ t\right] = 7.15 \ \text{mm}$

$t_{1(\min)} \ \text{or} \ t_{2(\min)} = \min\left[6mm, \ 0.7 \cdot t_{\min}\right] = \underline{5.01} \ \text{mm}$

$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 8 = 5.6 \ \text{mm}$

The weld size t_1 is satisfactory.

$t_{2(actual)} = 5.41 \ \text{mm}$

The weld size t_2 is satisfactory.

$t_1 + t_2 = 11.01 \geq 1.25 \cdot t_{\min} = \underline{8.94}$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{19.4184 \cdot 23.01}{1{,}180 \cdot 1 - 0.6 \cdot 19.4184} + 1.59$$

$$= 1.97 \ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}}, \ t_{a\text{UG-22}}\right]$$

$$= \max\left[1.97, \ 0\right]$$

$$= 1.97 \ \text{mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{19.4184 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 19.4184} + 1.59$$

$$= 11.11 \ \text{mm}$$

$$t_{b1} = \max\left[t_{b1}, \ t_{b\text{UG16}}\right]$$

$$= \max\left[11.11, \ 3.09\right]$$

$$= 11.11 \ \text{mm}$$

$$t_b = \min\left[t_{b3}, \ t_{b1}\right]$$

$$= \min\left[5.01, \ 11.11\right]$$

$$= 5.01 \ \text{mm}$$

$$t_{\text{UG-45}} = \max\left[t_a, \ t_b\right]$$

$$= \max\left[1.97, \ 5.01\right]$$

$$= \underline{5.01} \ \text{mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 8.74 = 7.65$ mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

The attached ASME B16.5 flange limits the nozzle MAP.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 19.6 bar @ 21.11 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

Calculations for internal pressure 19.6 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[42.85,\ 21.42 + (8.74 - 0) + (11.11 - 0)\right]$$

$$= 42.85\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (11.11 - 0),\ 2.5 \cdot (8.74 - 0) + 0\right]$$

$$= 21.84\ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{19.6 \cdot 21.42}{1{,}180 \cdot 1 - 0.6 \cdot 19.6}$$

$$= 0.36\ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{19.6 \cdot 571.5}{1{,}180 \cdot 1 - 0.6 \cdot 19.6}$$

$$= 9.59\ \text{mm}$$

This opening does not require reinforcement per UG-36(c)(3)(a)

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{19.6 \cdot 21.42}{1{,}180 \cdot 1 - 0.6 \cdot 19.6} + 0$$

$$= 0.36\ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$
$$= \max\left[0.36,\ 0\right]$$
$$= 0.36 \text{ mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$
$$= \frac{19.6 \cdot 571.5}{1{,}180 \cdot 1 - 0.6 \cdot 19.6} + 0$$
$$= 9.59 \text{ mm}$$

$$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$$
$$= \max\left[9.59,\ 1.5\right]$$
$$= 9.59 \text{ mm}$$

$$t_b = \min\left[t_{b3},\ t_{b1}\right]$$
$$= \min\left[3.42,\ 9.59\right]$$
$$= 3.42 \text{ mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$
$$= \max\left[0.36,\ 3.42\right]$$
$$= 3.42 \text{ mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 8.74 = 7.65$ mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for External Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.09	7.65

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	5.01	5.6	weld size is adequate
Combined weld check (t_1 + t_2)	8.94	11.01	weld size is adequate
Nozzle to shell groove (Lower)	5.01	5.41	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[46.02,\ 23.01 + (8.74 - 1.59) + (11.11 - 1.59)\right]$$

$$= 46.02\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (11.11 - 1.59),\ 2.5 \cdot (8.74 - 1.59) + 0\right]$$

$$= 17.88\ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.26 mm

From UG-37(d)(1) required thickness t_r = 2.02 mm

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$$t_{\min} = \min\left[19\ \text{mm},\ t_n,\ t\right] = 7.15\ \text{mm}$$

$$t_{1(\min)}\ \text{or}\ t_{2(\min)} = \min\left[6mm,\ 0.7 \cdot t_{\min}\right] = 5.01\ \text{mm}$$

$$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 8 = 5.6\ \text{mm}$$

The weld size t_1 is satisfactory.

$$t_{2(actual)} = 5.41\ \text{mm}$$

The weld size t_2 is satisfactory.

$$t_1 + t_2 = 11.01 \geq 1.25 \cdot t_{\min} = 8.94$$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$t_{aUG\text{-}28}$ = 1.84 mm

t_a = $\max\left[t_{aUG\text{-}28},\ t_{aUG\text{-}22}\right]$

= $\max\left[1.84,\ 0\right]$

= 1.84 mm

t_{b2} = $\dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\dfrac{0.8 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 0.8} + 1.59$

= 1.98 mm

t_{b2} = $\max\left[t_{b2},\ t_{bUG16}\right]$

= $\max\left[1.98,\ 3.09\right]$

= 3.09 mm

t_b = $\min\left[t_{b3},\ t_{b2}\right]$

= $\min\left[5.01,\ 3.09\right]$

= 3.09 mm

$t_{UG\text{-}45}$ = $\max\left[t_a,\ t_b\right]$

= $\max\left[1.84,\ 3.09\right]$

= 3.09 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 8.74$ = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{153.18}{60.33} = 2.5392$$

$$\frac{D_o}{t} = \frac{60.33}{0.26} = 235.5862$$

From table G: $A = 0.000141$

From table CS-2 Metric: $B = 144.1362\ \text{kg/cm}^2 (141.35\ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 141.35}{3 \cdot (60.33/0.26)} = 0.8\ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 0.26 + 1.59 = 1.84$ mm

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1 bar @ 40 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.09	7.65

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	5.01	5.6	weld size is adequate
Combined weld check (t_1 + t_2)	8.94	11.01	weld size is adequate
Nozzle to shell groove (Lower)	5.01	5.41	weld size is adequate

Calculations for external pressure 1 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[46.02,\ 23.01 + (8.74 - 1.59) + (11.11 - 1.59)\right]$$
$$= 46.02 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (11.11 - 1.59),\ 2.5 \cdot (8.74 - 1.59) + 0\right]$$
$$= 17.88 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.28 mm

From UG-37(d)(1) required thickness t_r = 2.2 mm

This opening does not require reinforcement per UG-36(c)(3)(a)

UW-16(d) Weld Check

$$t_{\min} = \min\left[19 \text{ mm},\ t_n,\ t\right] = 7.15 \text{ mm}$$
$$t_{1(\min)} \text{ or } t_{2(\min)} = \min\left[6mm,\ 0.7 \cdot t_{\min}\right] = 5.01 \text{ mm}$$
$$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 8 = 5.6 \text{ mm}$$

The weld size t_1 is satisfactory.

$$t_{2(actual)} = 5.41 \text{ mm}$$

The weld size t_2 is satisfactory.

$$t_1 + t_2 = 11.01 \geq 1.25 \cdot t_{\min} = 8.94$$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 1.87 \text{ mm}$

$$t_a = \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$$
$$= \max\left[1.87,\ 0\right]$$
$$= 1.87 \text{ mm}$$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$
$$= \frac{0.9975 \cdot 573.09}{1{,}180 \cdot 1 - 0.6 \cdot 0.9975} + 1.59$$
$$= 2.07 \text{ mm}$$

$$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$$
$$= \max\left[2.07,\ 3.09\right]$$
$$= 3.09 \text{ mm}$$

$$t_b = \min\left[t_{b3},\ t_{b2}\right]$$
$$= \min\left[5.01,\ 3.09\right]$$
$$= 3.09 \text{ mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$
$$= \max\left[1.87,\ 3.09\right]$$
$$= 3.09 \text{ mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 8.74 = 7.65$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{153.18}{60.33} = 2.5392$$

$$\frac{D_o}{t} = \frac{60.33}{0.28} = 215.5924$$

From table G: $A = 0.000161$

From table CS-2 Metric: $B = 164.4858 \text{ kg/cm}^2 (161.31 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 161.31}{3 \cdot (60.33/0.28)} = 1 \text{ bar}$$

Design thickness for external pressure P_a = 1 bar

$t_a = t + \text{Corrosion} = 0.28 + 1.59 = 1.87$ mm

Bolted Cover #3

ASME Section VIII Division 1, 2021 Edition Metric					
Component		Bolted Cover			
Material		SA-516 70 (II-D Metric p. 20, ln. 45)			
Attached To		ASME B16.5/16.47 flange attached to Nozzle #2 (N2)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
No	No	No	No	No	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		7	40	5	
External		0.8	40		
Static Liquid Head					
Condition		**P_s (bar)**	**H_s (mm)**	**SG**	
Test horizontal		0.28	2,825.46	1	
Dimensions					
Outer Diameter		1,454.15 mm			
Bolt Circle, BC		1,365.25 mm			
Nominal Thickness		68 mm			
Corrosion	**Inner**	1.59 mm			
	Outer	0 mm			
Weight and Capacity					
		Weight (kg)		**Capacity (liters)**	
New		853.41		0	
Corroded		833.48		0	
Radiography					
Category A joints		Seamless No RT			

Results Summary	
Governing condition	gasket seating
Minimum thickness per UG-16	1.5 mm + 1.59 mm = 3.09 mm
Design thickness due to internal pressure (t)	56.1 mm
Design thickness due to external pressure (t_e)	16.85 mm
Design thickness due to gasket seating	67.31 mm
Maximum allowable working pressure (MAWP)	10.39 bar
Maximum allowable pressure (MAP)	10.89 bar
Maximum allowable external pressure (MAEP)	15.14 bar
Rated MDMT	-29°C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	17 mm
MDMT =	-29°C
Material is exempt from impact testing per UG-20(f) at the Design MDMT of 5°C.	

Figure UG-34 Diameter

$d = BC - 2 \cdot h_G = 1{,}365.25 - 2 \cdot 103.88$ = 1,157.5 mm

Design thickness, (at 40 °C) UG-34(c)(2), flange operating

$$t = d \cdot \sqrt{\frac{C \cdot P}{S \cdot E} + \frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3}} + \text{Corrosion}$$

$$= 1{,}157.5 \cdot \sqrt{\frac{0.3 \cdot 7.14}{1{,}407.208 \cdot 1} + \frac{100 \cdot 1.9 \cdot 77{,}019.81 \cdot 103.88}{1{,}407.208 \cdot 1 \cdot 1{,}157.5^{\ 3}}} + 1.59$$

$= \underline{56.1}$ mm

Design thickness, (at 21.11 °C) UG-34(c)(2), gasket seating

$$t = d \cdot \sqrt{\frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3}} + \text{Corrosion}$$

$$= 10 \cdot 1{,}157.5 \cdot \sqrt{\frac{1.9 \cdot 356{,}476.56 \cdot 103.88}{1{,}407.208 \cdot 1 \cdot 1{,}157.5^{\ 3}}} + 1.59$$

$= \underline{67.31}$ mm

Maximum allowable working pressure, (at 40 °C)

$$P = \frac{S \cdot E}{C} \cdot \left(\left(\frac{t}{d} \right)^2 - \frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3} \right) - P_s$$

$$= \frac{\frac{1{,}407.208}{1.02} \cdot 1}{0.3} \cdot \left(\left(\frac{66.41}{1{,}157.5} \right)^2 - \frac{1.9 \cdot 100 \cdot 114{,}299.34 \cdot 103.88}{1{,}407.208 \cdot 1 \cdot 1{,}157.5^{\ 3}} \right) - 0$$

$= \underline{10.39}$ bar

Maximum allowable pressure, (at 21.11 °C)

$$P = \frac{S \cdot E}{C} \cdot \left(\left(\frac{t}{d} \right)^2 - \frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3} \right)$$

$$= \frac{\frac{1{,}407.208}{1.02} \cdot 1}{0.3} \cdot \left(\left(\frac{68}{1{,}157.5} \right)^2 - \frac{1.9 \cdot 100 \cdot 119{,}828.94 \cdot 103.88}{1{,}407.208 \cdot 1 \cdot 1{,}157.5^{\ 3}} \right)$$

$= \underline{10.89}$ bar

Design thickness for external pressure, (at 40 °C) U-2(g)

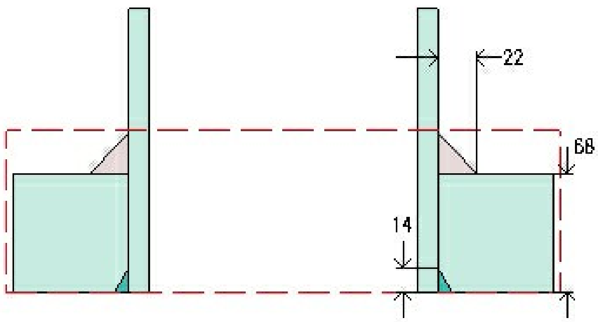
$$t = d \cdot \sqrt{\frac{C \cdot P_a}{S \cdot E}} + \text{Corrosion} = 1{,}157.5 \cdot \sqrt{\frac{0.3 \cdot 0.82}{1{,}407.208 \cdot 1}} + 1.59 = \underline{16.85} \ \text{mm}$$

Maximum allowable external pressure, (at 40 °C) U-2(g)

$$P_a = \frac{S \cdot E}{C} \cdot \left(\frac{t}{d} \right)^2 = \frac{\frac{1{,}407.208}{1.02} \cdot 1}{0.3} \cdot \left(\frac{66.41}{1{,}157.5} \right)^2 = \underline{15.14} \ \text{bar}$$

Nozzle #5 (N5)

ASME Section VIII Division 1, 2021 Edition Metric	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bolted Cover #3
Orientation	90°
Distance to head center, R	0 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 10 (Thk = 0.438") DN 250
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	250.8 mm
Pipe nominal wall thickness	11.13 mm
Pipe minimum wall thickness[1]	9.73 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	152.4 mm
Local vessel minimum thickness	68 mm
Liquid static head included	0 bar
Welds	
Inner fillet, Leg_{41}	22 mm
Nozzle to vessel groove weld	14 mm
Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Spot UW-11(a)(5)(b) only Type 1

[1]Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

UCS-66 Material Toughness Requirements Nozzle	
$t_r = \frac{6.24 \cdot 126.99}{1{,}180 \cdot 1 - 0.6 \cdot 6.24} =$	0.67 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.67 \cdot 1}{9.73 - 1.59} =$	0.0827
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7 bar @ 40 °C *The opening is NOT adequately reinforced*							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
84.3662	9.4555	1.7361	3.5806	–	–	4.1387	9.7	9.73

UG-41 Weld Failure Path Analysis Summary (kg_f)				
All failure paths are stronger than the applicable weld loads				
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength
116,436	10,863	88,887	26,107	111,073

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate
Combined weld check (t_1 + t_2)	11.92	27.81	weld size is adequate
Nozzle to shell groove (Lower)	6	12.41	weld size is adequate

Calculations for internal pressure 7 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[253.97,\ 126.99 + (11.13 - 1.59) + (68 - 1.59)\right]$$

$$= 253.97 \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (68 - 1.59),\ 2.5 \cdot (11.13 - 1.59) + 0\right]$$

$$= 23.84 \ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7 \cdot 126.99}{1{,}180 \cdot 1 - 0.6 \cdot 7}$$

$$= 0.76 \ \text{mm}$$

Required thickness t_r from UG-34

The static head of liquid has not been included in the total design load because the vessel is supported below the flange.

$$W = 0.785 \cdot G^2 \cdot P + 2 \cdot b \cdot 3.14 \cdot G \cdot m \cdot P$$

$$= 0.785 \cdot 1{,}157.5^{\ 2} \cdot \frac{7.138}{100} + 2 \cdot 1.25 \cdot 3.14 \cdot 1{,}157.5 \cdot 3 \cdot \frac{7.138}{1007.138} / 100$$

$$= 77{,}019.81 \ \text{kg}_f$$

t_r = $d \cdot \sqrt{\frac{C \cdot P}{S \cdot E} + \frac{1.9 \cdot W \cdot h_g}{S \cdot E \cdot d^3}}$

= $1{,}157.5 \cdot \sqrt{\frac{0.3 \cdot 7.138}{1{,}407.208 \cdot 1} + \frac{1.9 \cdot 77{,}019.81 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5^{\ 3}}}$

= $54.52\ \ \text{mm}$

Gasket seating

t_r = $d \cdot \sqrt{\frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3}}$

= $1{,}157.5 \cdot \sqrt{\frac{1.9 \cdot 356{,}476.56 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5^{\ 3}}}$

= $65.72\ \ \text{mm}$

Area required per UG-39

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

A = $0.5 \cdot d \cdot t_r + t_r \cdot t_n \cdot (1 - f_{r1})$

= $(0.5 \cdot 253.97 \cdot 65.72 + 65.72 \cdot 9.54 \cdot (1 - 0.8551))/100$

= 84.3662 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.7361 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(253.97 \cdot (1 \cdot 66.41 - 1 \cdot 65.72) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 65.72) \cdot (1 - 0.8551))/100$

= $1.7361\ \ \text{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (66.41 + 9.54) \cdot (1 \cdot 66.41 - 1 \cdot 65.72) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 65.72) \cdot (1 - 0.8551))/100$

= $1.0303\ \ \text{cm}^2$

A_2 = smaller of the following= 3.5806 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (9.54 - 0.76) \cdot 0.8551 \cdot 152.4)/100$

= $22.8858\ \ \text{cm}^2$

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$= (5 \cdot (9.54 - 0.76) \cdot 0.8551 \cdot 9.54)/100$

$= 3.5806 \ \text{cm}^2$

$A_{41} = Leg^2 \cdot f_{r2}$

$= (22^2 \cdot 0.8551)/100$

= 4.1387 cm^2

$Area = A_1 + A_2 + A_{41}$

$= 1.7361 + 3.5806 + 4.1387$

= 9.4555 cm^2

***** As Area < A the reinforcement is NOT adequate. *****

UW-16(d) Weld Check

$t_{\min} = \min\,[19 \ \text{mm}, \ t_n, \ t] = 9.54 \ \text{mm}$

$t_{1(\min)}$ or $t_{2(\min)} = \min\,[6mm, \ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 22 = 15.4 \ \text{mm}$

The weld size t_1 is satisfactory.

$t_{2(actual)} = 12.41 \ \text{mm}$

The weld size t_2 is satisfactory.

$t_1 + t_2 = 27.81 \geq 1.25 \cdot t_{\min} =$ 11.92

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7 \cdot 126.99}{1{,}180 \cdot 1 - 0.6 \cdot 7} + 1.59$$

$$= 2.34 \ \text{mm}$$

$$t_a = \max\,[t_{a\text{UG-27}}, \ t_{a\text{UG-22}}]$$

$$= \max\,[2.34, \ 0]$$

$$= 2.34 \ \text{mm}$$

$$t_{b1} = 67.31 \text{ mm}$$

$$t_{b1} = \max\,[t_{b1}, \ t_{b\text{UG16}}]$$

$$= \max\,[67.31, \ 3.09]$$

$$= 67.31 \ \text{mm}$$

$t_b \quad = \quad \min\left[t_{b3},\ t_{b1}\right]$

$= \quad \min\left[9.7,\ 67.31\right]$

$= \quad 9.7 \ \text{mm}$

$t_{\text{UG-45}} \quad = \quad \max\left[t_a,\ t_b\right]$

$= \quad \max\left[2.34,\ 9.7\right]$

$= \quad 9.7 \ \text{mm}$

Available nozzle wall thickness new, t_n = $0.875 \cdot 11.13$ = 9.73 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	$0.74 \cdot 1{,}407.208$	=	1,041.334 kg_f/cm^2
Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$	=	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$	=	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 273.05 \cdot 22 \cdot 589.6$ = 55,634.24 kg_f

(3) Nozzle wall in shear

$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 263.51 \cdot 9.54 \cdot 842.286$ = 33,252.46 kg_f

(4) Groove weld in tension

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 273.05 \cdot 12.41 \cdot 1{,}041.334$ = 55,438.5 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}436.6217 - 173.6126 + 2 \cdot 9.54 \cdot 0.8551 \cdot (1 \cdot 66.41 - 1 \cdot 65.72)) \cdot 1{,}407.208$

= 116,436.38 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(358.0638 + 0 + 413.8701 + 0) \cdot 1{,}407.208$

= 10,862.72 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(358.0638 + 0 + 413.8701 + 0 + 2 \cdot 9.54 \cdot 66.41 \cdot 0.8551) \cdot 1{,}407.208$

= 26,106.72 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 10,862.72 kg_f
Path 1-1 through (1) & (3) = 55,634.24 + 33,252.46 = 88,886.71 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 26,106.72 kg_f
Path 2-2 through (1), (4) = 55,634.24 + 55,438.5 = 111,072.75 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Reinforcement Calculations for MAWP

Available reinforcement per UG-39 governs the MAWP of this nozzle.

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 0 bar @ 40 °C *The opening is NOT adequately reinforced*							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
80.5745	17.1838	9.1561	3.889	–	–	4.1387	9.7	9.73

UG-41 Weld Failure Path Analysis Summary (kg_f)				
All failure paths are stronger than the applicable weld loads				
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength
101,337	11,297	88,887	26,541	111,073

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate
Combined weld check (t_1 + t_2)	11.92	27.81	weld size is adequate
Nozzle to shell groove (Lower)	6	12.41	weld size is adequate

Calculations for internal pressure 0 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[253.97,\ 126.99 + (11.13 - 1.59) + (68 - 1.59)\right]$$

$$= 253.97 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (68 - 1.59),\ 2.5 \cdot (11.13 - 1.59) + 0\right]$$

$$= 23.84 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{0 \cdot 126.99}{1{,}180 \cdot 1 - 0.6 \cdot 0}$$

$$= 0 \text{ mm}$$

Required thickness t_r from UG-34

The static head of liquid has not been included in the total design load because the vessel is supported below the flange.

W = $0.785 \cdot G^2 \cdot P + 2 \cdot b \cdot 3.14 \cdot G \cdot m \cdot P$

= $0.785 \cdot 1{,}157.5\ ^2 \cdot \frac{0}{100} + 2 \cdot 1.25 \cdot 3.14 \cdot 1{,}157.5 \cdot 3 \cdot \frac{0}{1000} / 100$

= $0\ \ \mathrm{kg}_f$

t_r = $d \cdot \sqrt{\frac{C \cdot P}{S \cdot E} + \frac{1.9 \cdot W \cdot h_g}{S \cdot E \cdot d^3}}$

= $1{,}157.5 \cdot \sqrt{\frac{0.3 \cdot 0}{1{,}407.208 \cdot 1} + \frac{1.9 \cdot 0 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5\ ^3}}$

= $0.0094\ \ \mathrm{mm}$

Gasket seating

t_r = $d \cdot \sqrt{\frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3}}$

= $1{,}157.5 \cdot \sqrt{\frac{1.9 \cdot 325{,}153.55 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5\ ^3}}$

= $62.77\ \ \mathrm{mm}$

Area required per UG-39

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

A = $0.5 \cdot d \cdot t_r + t_r \cdot t_n \cdot (1 - f_{r1})$

= $(0.5 \cdot 253.97 \cdot 62.77 + 62.77 \cdot 9.54 \cdot (1 - 0.8551))/100$

= 80.5745 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 9.1561 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(253.97 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

= $9.1561\ \ \mathrm{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (66.41 + 9.54) \cdot (1 \cdot 66.41 - 1 \cdot 62.77) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

= $5.4355\ \ \mathrm{cm}^2$

A_2 = smaller of the following= 3.889 cm^2

$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

$= (2 \cdot (9.54 - 0) \cdot 0.8551 \cdot 152.4)/100$

$= 24.8587 \ \ \text{cm}^2$

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$= (5 \cdot (9.54 - 0) \cdot 0.8551 \cdot 9.54)/100$

$= 3.889 \ \ \text{cm}^2$

$A_{41} = Leg^2 \cdot f_{r2}$

$= (22^2 \cdot 0.8551)/100$

$= 4.1387$ cm^2

$Area = A_1 + A_2 + A_{41}$

$= 9.1561 + 3.889 + 4.1387$

$= 17.1838$ cm^2

***** As Area < A the reinforcement is NOT adequate. *****

UW-16(d) Weld Check

$t_{\min} = \min\left[19 \ \ \text{mm}, \ \ t_n, \ \ t\right] = 9.54 \ \ \text{mm}$

$t_{1(\min)} \ \ \text{or} \ \ t_{2(\min)} = \min\left[6mm, \ \ 0.7 \cdot t_{\min}\right] = 6 \ \ \text{mm}$

$t_{1(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 22 = 15.4 \ \ \text{mm}$

The weld size t_1 is satisfactory.

$t_{2(actual)} = 12.41 \ \ \text{mm}$

The weld size t_2 is satisfactory.

$t_1 + t_2 = 27.81 \geq 1.25 \cdot t_{\min} = 11.92$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{0 \cdot 126.99}{1{,}180 \cdot 1 - 0.6 \cdot 0} + 1.59$$

$$= 1.59 \ \ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}}, \ \ t_{a\text{UG-22}}\right]$$

$$= \max\left[1.59, \ \ 0\right]$$

$$= 1.59 \ \ \text{mm}$$

$t_{b1} = 64.36$ mm

t_{b1} $= \max\left[t_{b1},\ t_{bUG16}\right]$

$= \max\left[64.36,\ 3.09\right]$

$= 64.36\ \text{mm}$

t_b $= \min\left[t_{b3},\ t_{b1}\right]$

$= \min\left[9.7,\ 64.36\right]$

$= 9.7\ \text{mm}$

$t_{\text{UG-45}}$ $= \max\left[t_a,\ t_b\right]$

$= \max\left[1.59,\ 9.7\right]$

$= 9.7\ \text{mm}$

Available nozzle wall thickness new, t_n = $0.875 \cdot 11.13$ = 9.73 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 273.05 \cdot 22 \cdot 589.6$ = 55,634.24 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 263.51 \cdot 9.54 \cdot 842.286$ = 33,252.46 kg_f

(4) Groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 273.05 \cdot 12.41 \cdot 1{,}041.334$ = 55,438.5 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}057.4488 - 915.6111 + 2 \cdot 9.54 \cdot 0.8551 \cdot (1 \cdot 66.41 - 1 \cdot 62.77)) \cdot 1{,}407.208$

= 101,337.16 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(388.9024 + 0 + 413.8701 + 0) \cdot 1{,}407.208$

= 11,296.68 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(388.9024 + 0 + 413.8701 + 0 + 2 \cdot 9.54 \cdot 66.41 \cdot 0.8551) \cdot 1{,}407.208$

= 26,540.68 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 11,296.68 kg_f
Path 1-1 through (1) & (3) = 55,634.24 + 33,252.46 = 88,886.71 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 26,540.68 kg_f
Path 2-2 through (1), (4) = 55,634.24 + 55,438.5 = 111,072.75 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Reinforcement Calculations for MAP

Available reinforcement per UG-39 governs the MAP of this nozzle.

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 0 bar @ 21.11 °C *The opening is NOT adequately reinforced*							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
79.7224	22.3845	12.9542	5.2916	–	–	4.1387	8.11	9.73

UG-41 Weld Failure Path Analysis Summary (kg_f)				
All failure paths are stronger than the applicable weld loads				
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength
95,358	13,270	94,188	31,477	118,163

Calculations for internal pressure 0 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[250.8,\ 125.4 + (11.13 - 0) + (68 - 0)\right]$$

$$= 250.8 \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (68 - 0),\ 2.5 \cdot (11.13 - 0) + 0\right]$$

$$= 27.81 \ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{0 \cdot 125.4}{1{,}180 \cdot 1 - 0.6 \cdot 0}$$

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

Required thickness t_r from UG-34

The static head of liquid has not been included in the total design load because the vessel is supported below the flange.

$$W = 0.785 \cdot G^2 \cdot P + 2 \cdot b \cdot 3.14 \cdot G \cdot m \cdot P$$

$$= 0.785 \cdot 1{,}157.5^{\ 2} \cdot \frac{0}{100} + 2 \cdot 1.25 \cdot 3.14 \cdot 1{,}157.5 \cdot 3 \cdot \frac{0}{1000} / 100$$

$$= 0 \ \text{kg}_f$$

$t_r = d \cdot \sqrt{\frac{C \cdot P}{S \cdot E} + \frac{1.9 \cdot W \cdot h_g}{S \cdot E \cdot d^3}}$

$= 1{,}157.5 \cdot \sqrt{\frac{0.3 \cdot 0}{1{,}407.208 \cdot 1} + \frac{1.9 \cdot 0 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5^{\ 3}}}$

$= 0.0094 \text{ mm}$

Gasket seating

$t_r = d \cdot \sqrt{\frac{1.9 \cdot W \cdot h_G}{S \cdot E \cdot d^3}}$

$= 1{,}157.5 \cdot \sqrt{\frac{1.9 \cdot 325{,}153.55 \cdot 103.88}{\frac{1{,}407.208}{100} \cdot 1 \cdot 1{,}157.5^{\ 3}}}$

$= 62.77 \text{ mm}$

Area required per UG-39

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

A $= 0.5 \cdot d \cdot t_r + t_r \cdot t_n \cdot (1 - f_{r1})$

$= (0.5 \cdot 250.8 \cdot 62.77 + 62.77 \cdot 11.13 \cdot (1 - 0.8551))/100$

= 79.7224 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 12.9542 cm^2

$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= (250.8 \cdot (1 \cdot 68 - 1 \cdot 62.77) - 2 \cdot 11.13 \cdot (1 \cdot 68 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

$= 12.9542 \text{ cm}^2$

$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

$= (2 \cdot (68 + 11.13) \cdot (1 \cdot 68 - 1 \cdot 62.77) - 2 \cdot 11.13 \cdot (1 \cdot 68 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

$= 8.1116 \text{ cm}^2$

A_2 = smaller of the following= 5.2916 cm^2

$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

$= (2 \cdot (11.13 - 0) \cdot 0.8551 \cdot 152.4)/100$

$= 28.9961 \text{ cm}^2$

$= 5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

$= (5 \cdot (11.13 - 0) \cdot 0.8551 \cdot 11.13)/100$

$= 5.2916 \ \text{cm}^2$

$A_{41} = Leg^2 \cdot f_{r2}$

$= (22^2 \cdot 0.8551)/100$

$=$ 4.1387 cm^2

$Area = A_1 + A_2 + A_{41}$

$= 12.9542 + 5.2916 + 4.1387$

$=$ 22.3845 cm^2

***** As Area < A the reinforcement is NOT adequate. *****

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{0 \cdot 125.4}{1{,}180 \cdot 1 - 0.6 \cdot 0} + 0$$

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

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[0,\ 0\right]$$

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

$t_{b1} =$ 62.77 mm

$$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$$

$$= \max\left[62.77,\ 1.5\right]$$

$$= 62.77 \ \text{mm}$$

$$t_b = \min\left[t_{b3},\ t_{b1}\right]$$

$$= \min\left[8.11,\ 62.77\right]$$

$$= 8.11 \ \text{mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$

$$= \max\left[0,\ 8.11\right]$$

$=$ 8.11 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 11.13$ = 9.73 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension: $0.74 \cdot 1{,}407.208$ = 1,041.334 kg_f/cm^2

Nozzle wall in shear: $0.7 \cdot 1{,}203.265$ = 842.286 kg_f/cm^2

Inner fillet weld in shear: $0.49 \cdot 1{,}203.265$ = 589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 273.05 \cdot 22 \cdot 589.6$ = 55,634.24 kg_f

(3) Nozzle wall in shear

$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 261.92 \cdot 11.13 \cdot 842.286$ = 38,553.49 kg_f

(4) Groove weld in tension

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 273.05 \cdot 14 \cdot 1{,}041.334$ = 62,528.83 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(7{,}972.2434 - 1{,}295.4168 + 2 \cdot 11.13 \cdot 0.8551 \cdot (1 \cdot 68 - 1 \cdot 62.77)) \cdot 1{,}407.208$

= 95,357.77 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(529.1602 + 0 + 413.8701 + 0) \cdot 1{,}407.208$

= 13,270.4 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(529.1602 + 0 + 413.8701 + 0 + 2 \cdot 11.13 \cdot 68 \cdot 0.8551) \cdot 1{,}407.208$

= 31,476.72 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 13,270.4 kg_f
Path 1-1 through (1) & (3) = 55,634.24 + 38,553.49 = 94,187.74 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 31,476.72 kg_f
Path 2-2 through (1), (4) = 55,634.24 + 62,528.83 = 118,163.07 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Reinforcement Calculations for External Pressure

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C *The opening is NOT adequately reinforced*							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
80.5745	16.9322	9.1561	3.6374	–	–	4.1387	9.7	9.73

UG-41 Weld Failure Path Analysis Summary (kg_f)				
All failure paths are stronger than the applicable weld loads				
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength
101,337	10,943	88,887	26,187	111,073

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	15.4	weld size is adequate
Combined weld check (t_1 + t_2)	11.92	27.81	weld size is adequate
Nozzle to shell groove (Lower)	6	12.41	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[253.97,\ 126.99 + (11.13 - 1.59) + (68 - 1.59)\right]$$

$$= 253.97 \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (68 - 1.59),\ 2.5 \cdot (11.13 - 1.59) + 0\right]$$

$$= 23.84 \ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.62 mm

From UG-34 required thickness t_r = 62.77 mm

Area required per UG-39

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (253.97 \cdot 62.77 \cdot 1 + 2 \cdot 9.54 \cdot 62.77 \cdot 1 \cdot (1 - 0.8551)))/100$

= 80.5745 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 9.1561 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(253.97 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

= $9.1561 \quad cm^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (66.41 + 9.54) \cdot (1 \cdot 66.41 - 1 \cdot 62.77) - 2 \cdot 9.54 \cdot (1 \cdot 66.41 - 1 \cdot 62.77) \cdot (1 - 0.8551))/100$

= $5.4355 \quad cm^2$

A_2 = smaller of the following= 3.6374 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (9.54 - 0.62) \cdot 0.8551 \cdot 152.4)/100$

= $23.2477 \quad cm^2$

= $5 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot t_n$

= $(5 \cdot (9.54 - 0.62) \cdot 0.8551 \cdot 9.54)/100$

= $3.6374 \quad cm^2$

A_{41} = $Leg^2 \cdot f_{r2}$

= $(22^2 \cdot 0.8551)/100$

= 4.1387 cm^2

$Area = A_1 + A_2 + A_{41}$

$= 9.1561 + 3.6374 + 4.1387$

$=$ 16.9322 cm^2

***** As Area < A the reinforcement is NOT adequate. *****

UW-16(d) Weld Check

$t_{\min} = \min[19 \quad mm, \ t_n, \ t] = 9.54 \quad mm$

$t_{1(\min)}$ or $t_{2(\min)} = \min[6mm, \ 0.7 \cdot t_{\min}] = 6 \quad mm$

$t_{1(actual)} = 0.7 \cdot Leg = 0.7 \cdot 22 = 15.4 \quad mm$

The weld size t_1 is satisfactory.

$t_{2(actual)} = 12.41 \quad mm$

The weld size t_2 is satisfactory.

$t_1 + t_2 = 27.81 \geq 1.25 \cdot t_{\min} = 11.92$

The combined weld sizes for t_1 and t_2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.21 \text{ mm}$

$t_a = \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$

$= \max\left[2.21,\ 0\right]$

$= 2.21 \text{ mm}$

$t_{b2} = 64.36 \text{ mm}$

$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$

$= \max\left[64.36,\ 3.09\right]$

$= 64.36 \text{ mm}$

$t_b = \min\left[t_{b3},\ t_{b2}\right]$

$= \min\left[9.7,\ 64.36\right]$

$= 9.7 \text{ mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[2.21,\ 9.7\right]$

$=$ 9.7 mm

Available nozzle wall thickness new, $t_n = 0.875 \cdot 11.13 = 9.73$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 273.05 \cdot 22 \cdot 589.6 = 55{,}634.24\ kg_f$

(3) Nozzle wall in shear

$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 263.51 \cdot 9.54 \cdot 842.286 = 33{,}252.46\ kg_f$

(4) Groove weld in tension

$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 273.05 \cdot 12.41 \cdot 1{,}041.334 = 55{,}438.5\ kg_f$

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}057.4488 - 915.6111 + 2 \cdot 9.54 \cdot 0.8551 \cdot (1 \cdot 66.41 - 1 \cdot 62.77)) \cdot 1{,}407.208$

= 101,337.16 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(363.7412 + 0 + 413.8701 + 0) \cdot 1{,}407.208$

= 10,942.61 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(363.7412 + 0 + 413.8701 + 0 + 2 \cdot 9.54 \cdot 66.41 \cdot 0.8551) \cdot 1{,}407.208$

= 26,186.61 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 10,942.61 kg_f
Path 1-1 through (1) & (3) = 55,634.24 + 33,252.46 = 88,886.71 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 26,186.61 kg_f
Path 2-2 through (1), (4) = 55,634.24 + 55,438.5 = 111,072.75 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{152.4}{273.05} = 0.5581$$

$$\frac{D_o}{t} = \frac{273.05}{0.62} = 441.8706$$

From table G: $A = 0.000266$

From table CS-2 Metric: $B = 270.3425 \text{ kg/cm}^2 (265.11 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 265.11}{3 \cdot (273.05/0.62)} = 0.8 \text{ bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 0.62 + 1.59 =$ 2.21 mm

Cylinder #1

ASME Section VIII Division 1, 2021 Edition Metric					
Component		Cylinder			
Material		SA-36 (II-D Metric p. 12, ln. 19)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
No	No	No	No	No	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		7	40	5	
External		0.8	40		
Static Liquid Head					
Condition		**P_s (bar)**	**H_s (mm)**	**SG**	
Operating		0.31	3,218.2	0.98	
Test horizontal		0.44	4,500	1	
Dimensions					
Inner Diameter		4,500 mm			
Length		2,438.4 mm			
Nominal Thickness		18 mm			
Corrosion	**Inner**	1.6 mm			
	Outer	1.64 mm			
Weight and Capacity					
		Weight (kg)		**Capacity (liters)**	
New		4,831.5		38,781.08	
Corroded		3,961.52		38,836.26	
Radiography					
Longitudinal seam		Full UW-11(a) Type 1			
Top Circumferential seam		Full UW-11(a) Type 2			
Bottom Circumferential seam		Full UW-11(a) Type 2			

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	17.73 mm
Design thickness due to external pressure (t_e)	15.81 mm
Design thickness due to combined loadings + corrosion	11.01 mm
Maximum allowable working pressure (MAWP)	7.13 bar
Maximum allowable pressure (MAP)	9.08 bar
Maximum allowable external pressure (MAEP)	1.16 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \frac{0.31 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 0.31} =$	0.61 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.61 \cdot 1}{18 - 3.24} =$	0.0414
$\text{Stress ratio} longitud \in al = \frac{6.755 \cdot 0.9}{1{,}162.477 \cdot 0.9} =$	0.0058
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.31 \cdot 2{,}251.6}{1{,}140 \cdot 1.00 - 0.60 \cdot 7.31} + 3.24 = \underline{17.73} \text{ mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}140 \cdot 1.00 \cdot 14.76}{2{,}251.6 + 0.60 \cdot 14.76} - 0.31 = \underline{7.13} \text{ bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}140 \cdot 1.00 \cdot 18}{2{,}250 + 0.60 \cdot 18} = \underline{9.08} \text{ bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}196.39}{4{,}536} = 0.9251$$

$$\frac{D_o}{t} = \frac{4{,}536}{12.57} = 360.7504$$

From table G: $A = 0.000217$

From table CS-2 Metric: $B = 220.7183 \text{ kg/cm}^2 (216.45 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 216.45}{3 \cdot (4{,}536/12.57)} = 0.8 \text{ bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.57 + 3.24 = \underline{15.81} \text{ mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}196.39}{4{,}536} = 0.9251$$

$$\frac{D_o}{t} = \frac{4{,}536}{14.76} = 307.3387$$

From table G: $A = 0.000268$

From table CS-2 Metric: $B = 273.324 \text{ kg/cm}^2 (268.0388 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 268.04}{3 \cdot (4{,}536/14.76)} = 1.16 \text{ bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 18}{2{,}259}\right) \cdot \left(1 - \frac{2{,}259}{\infty}\right) = 0.3984\,\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{10 \cdot 10,548.1}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 2,506.6 \frac{}{\pi \cdot 2{,}258.98\ ^2} = 8.9951 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{8.9951}{0.8 \cdot 4{,}536} = 0.0243$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4,196.39}{4,536}\right)^2} = 1.4371$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.4371 + 1.4371 \cdot 0.0243}{7^2 - 1 + 1.4371} = 1.0007$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1.0007 \cdot 0.8 = 0.8) \leq 1.16$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.08 \cdot 10 \cdot 10,548.1}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 22,131.4 \frac{}{\pi \cdot 2{,}258.98\ ^2} = 21.8607 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{21.8607}{0.8 \cdot 4{,}536} = 0.0591$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4,196.39}{4,536}\right)^2} = 1.4371$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.4371 + 1.4371 \cdot 0.0591}{7^2 - 1 + 1.4371} = 1.0017$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1.0017 \cdot 0.8 = 0.8) \leq 1.16$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	7	1,162.5	805.5	40	3.24	Wind	7.64	7.58
						Seismic	7.77	7.46
Operating, Hot & New	7	1,162.5	862	40	0	Wind	7.63	7.57
						Seismic	7.76	7.44
Hot Shut Down, Corroded	0	1,162.5	805.5	40	3.24	Wind	0.04	0.11
						Seismic	0.1	0.27
Hot Shut Down, New	0	1,162.5	862	40	0	Wind	0.04	0.12
						Seismic	0.09	0.27
Empty, Corroded	0	1,162.5	805.5	21.11	3.24	Wind	0.04	0.11
						Seismic	0	0.15
Empty, New	0	1,162.5	862	21.11	0	Wind	0.04	0.12
						Seismic	0	0.16
Vacuum	-0.8	1,162.5	805.5	40	3.24	Wind	1.18	1.25
						Seismic	1.02	1.41
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,162.5	805.5	40	3.24	Weight	0.08	0.1

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}162.5}{1.00} = 1{,}162.5 \quad \text{kg/cm}^2$$

$$S_{cHC} = \min(B, S) = 805.5 \text{ kg/cm}^2$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}162.5}{1.00} = 1{,}162.5 \quad \text{kg/cm}^2$$

$$S_{cHN} = \min(B, S) = 862 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}162.5}{1.00} = 1{,}162.5 \ \ \text{kg/cm}^2$$

$$S_{cCN} = \min(B,S) = 862 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}162.5}{1.00} = 1{,}162.5 \ \ \text{kg/cm}^2$$

$$S_{cC} = \min(B,S) = 805.5 \text{ kg/cm}^2$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}162.5}{1.00} = 1{,}162.5 \ \ \text{kg/cm}^2$$

$$S_{cVC} = \min(B,S) = 805.5 \text{ kg/cm}^2$$

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = $\frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 7.67 mm

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $2{,}506.6 \frac{}{\pi \cdot 2{,}258.98^{\ 2} \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.01 mm

t_w = $\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.60 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $7.67 + 0.01 - (0.04)$

= 7.64 mm

$t_{w\,c}$ = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.07 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.01 + (0.07) - (7.67)|$

= 7.58 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\frac{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.01 + (0.04))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.01 + (0.04))}$

= 13.51 bar

Operating, Hot & New, Wind, Bottom Seam

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

$$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$$

= 7.66 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 2{,}512.7 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.01 mm

$$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot 12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.05 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 7.66 + 0.01 - (0.05)$$

= 7.63 mm

$$t_{wc} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.08 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}|$$ (total, net tensile)

$$= |0.01 + (0.08) - (7.66)|$$

= 7.57 mm

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.01 + (0.05))}{2{,}250 - 0.40 \cdot (18 - 0.01 + (0.05))}$$

= 16.5 bar

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 2,506.6 \dfrac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.02 mm

$t_w = 0.6 \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 10,548.1 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.06 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.02 - (0.06)|$

= 0.04 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{10,548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.09 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.02 + (0.09) - (0)$

= 0.11 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{2,512.7}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$$

= 0.02 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot 12,091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.06 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.02 - (0.06)|$$

= 0.04 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{12,091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.1 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.02 + (0.1) - (0)$$

= 0.12 mm

Empty, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{2,506.6}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$$

= 0.02 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot 10,548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.06 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.02 - (0.06)|$$

= 0.04 mm

$$t_{wc} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{10,548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.09 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.02 + (0.09) - (0)$$

= 0.11 mm

Empty, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 2,512.7 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.02 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 12,091.1 \frac{}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.06 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.02 - (0.06)|$

= 0.04 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{12,091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.1 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.02 + (0.1) - (0)$

= 0.12 mm

Vacuum, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.9 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.14 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 2{,}506.6 \dfrac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.02 mm

$t_w = 0.6 \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 10{,}548.1 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.06 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-1.14 + 0.02 - (0.06)|$

= 1.18 mm

$t_{wc} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.09 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.02 + (0.09) - (-1.14)$

= 1.25 mm

Maximum Allowable External Pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

$= \dfrac{2 \cdot 789.9 \cdot 1.00 \cdot (14.76 - 0.02 - 0.09)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.02 - 0.09)}$

= 10.3 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{1,568.6}{\pi \cdot 2,258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$$

= 0.01 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{10,548.1}{2 \cdot \pi \cdot 2,258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.09 mm

$$t_t = |t_p + t_m - t_w| \quad \text{(total, net compressive)}$$

$$= |0 + 0.01 - (0.09)|$$

= 0.08 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.01 + (0.09) - (0)$$

= 0.1 mm

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 7.67 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 22{,}131.4 \dfrac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.13 mm

$t_w = \dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.52 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 7.67 + 0.13 - (0.04)$

= 7.77 mm

$t_{w\,c} = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.08 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.13 + (0.08) - (7.67)|$

= 7.46 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.13 + (0.04))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.13 + (0.04))}$

= 13.4 bar

Operating, Hot & New, Seismic, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 7.66 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \dfrac{22{,}794.5}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.14 mm

$t_w = \dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.52 \cdot 12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 7.66 + 0.14 - (0.04)$

= 7.76 mm

$t_{w\,c} = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot 12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.09 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.14 + (0.09) - (7.66)|$

= 7.44 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.14 + (0.04))}{2{,}250 - 0.40 \cdot (18 - 0.14 + (0.04))}$

= 16.38 bar

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{22,131.4}{\pi \cdot 2{,}258.98^{\ 2} \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.13 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.52 \cdot 10,548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.04 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0.13 - (0.04)$$

= 0.1 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{22,131.4}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$$

= 0.17 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot 10,548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.1 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.17 + (0.1) - (0)$$

= 0.27 mm

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 22{,}794.5 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.14 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.14 - (0.04)$

= 0.09 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 22{,}794.5 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.16 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 12{,}091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.16 + (0.11) - (0)$

= 0.27 mm

Empty, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 6{,}488.7 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.04 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.04 - (0.04)$

= 0 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 6{,}488.7 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.05 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.1 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.05 + (0.1) - (0)$

= 0.15 mm

Empty, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 7,178.6 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.04 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 12,091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}140 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.04 - (0.04)$

= 0 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 7,178.6 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.05 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 12,091.1}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.05 + (0.11) - (0)$

= 0.16 mm

Vacuum, Seismic, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.9 \cdot 1.00 + 0.40 \cdot |0.8|}$

$= -1.14 \text{ mm}$

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 22{,}131.4 \dfrac{}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$

$= 0.17$ mm

$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.52 \cdot 10{,}548.1 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

$= 0.05$ mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-1.14 + 0.17 - (0.05)|$

= 1.02 mm

$t_{w\,c} = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot 10{,}548.1}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

$= 0.1$ mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.17 + (0.1) - (-1.14)$

= 1.41 mm

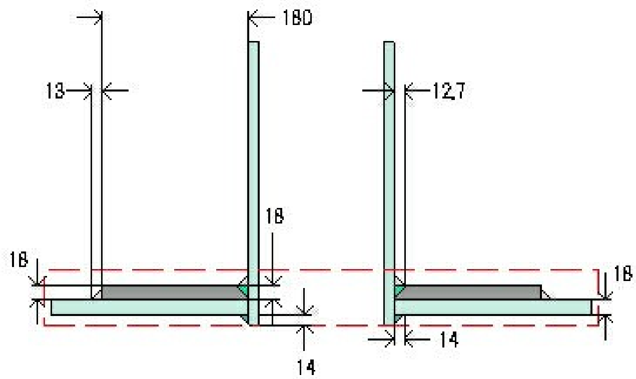
Maximum Allowable External Pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

$= \dfrac{2 \cdot 789.9 \cdot 1.00 \cdot (14.76 - 0.17 - 0.1)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.17 - 0.1)}$

= 10.19 bar

Nozzle #6 (N6)

ASME Section VIII Division 1, 2021 Edition Metric	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Cylinder #1
Orientation	225°
Nozzle center line offset to datum line	6,070.3 mm
End of nozzle to shell center	2,423 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 26 Sch 20 (XS) DN 650
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	635 mm
Pipe nominal wall thickness	12.7 mm
Pipe minimum wall thickness[1]	11.11 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	34.35 mm
Internal projection, h_{new}	14 mm
Projection available outside vessel to flange face, Lf	155 mm
Local vessel minimum thickness	18 mm
Liquid static head included	0.28 bar
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 20, ln. 45)
Diameter, D_p	1,020.4 mm
Thickness, t_e	18 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	12.7 mm
Outer fillet, Leg_{42}	13 mm
Lower fillet, Leg_{43}	14 mm
Pad groove weld	18 mm
Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Full UW-11(a) Type 1

[1]Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.47-2017 Flange	
Description	NPS 26 Class 150 WN A105 Series A
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 410, ln. 32)
Blind included	Yes
Rated MDMT	-48°C
Liquid static head	0.25 bar
MAWP rating	19.53 bar @ 40°C
MAP rating	19.6 bar @ 21.11°C
Hydrotest rating	30 bar @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Bore diameter, B (specified by purchaser)	647.7 mm
Notes	
Flange and blind rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.331) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
$t_r = \frac{6.52 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 6.52} =$	1.77 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{1.77 \cdot 1}{11.11 - 1.59} =$	0.1857
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	18 mm
MDMT =	-29°C
Material is exempt from impact testing per UG-20(f) at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.28 bar @ 40 °C *The opening is NOT adequately reinforced*							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
92.1081	72.6519	2.08	6.2768	2.359	58.3561	3.58	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
104,740	77,701	192,750	16,694	326,998	85,851	166,506

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.28 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4\ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.2795 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.2795}$$

$$= 1.98\ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.2795 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 7.2795}$$

$$= 14.43 \ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,162.477, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 14.43 \cdot 1 + 2 \cdot 11.11 \cdot 14.43 \cdot 1 \cdot (1 - 1))/100$$

= 92.1081 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 2.08 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 14.43) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.43) \cdot (1 - 1))/100$$

$$= 2.08 \ \text{cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 14.43) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.43) \cdot (1 - 1))/100$$

$$= 0.1684 \ \text{cm}^2$$

A_2 = smaller of the following= 6.2768 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 1.98) \cdot 1 \cdot 34.35)/100$$

$$= 6.2768 \ \text{cm}^2$$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.98) \cdot 1 \cdot 34.35)/100$

= 6.2768 cm^2

A_3 = smaller of the following= 2.359 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 1)/100$

= 7.0196 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 1)/100$

= 4.5242 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 1)/100$

= 2.359 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 1)/100$

= 1.0723 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(10.66^2 \cdot 1)/100$

= 1.1355 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 1)/100$

= 1.3723 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area$ = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

= $2.08 + 6.2768 + 2.359 + 1.0723 + 1.1355 + 1.3723 + 58.3561$

= 72.6519 cm^2

***** As Area < A the reinforcement is NOT adequate. *****

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19\ \text{mm},\ t_n,\ t_e] =$ 11.11 mm

$t_{c(\min)} = \min[6\ \text{mm},\ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19\ \text{mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = 7.38\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \text{mm}$

Lower fillet: $t_{\min} = \min[19\ \text{mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = 7.78\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.2795 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.2795} + 1.59$$

$$= 3.56\ \text{mm}$$

$$t_a = \max[t_{a\text{UG-27}},\ t_{a\text{UG-22}}]$$

$$= \max[3.56,\ 0]$$

$$= 3.56\ \text{mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.2795 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 7.2795} + 3.24$$

$$= 17.67\ \text{mm}$$

$$t_{b1} = \max[t_{b1},\ t_{b\text{UG16}}]$$

$$= \max[17.67,\ 3.09]$$

$$= 17.67\ \text{mm}$$

$$t_b = \min[t_{b3},\ t_{b1}]$$

$$= \min[9.92,\ 17.67]$$

$$= 9.92\ \text{mm}$$

$$t_{\text{UG-45}} = \max[t_a,\ t_b]$$

$$= \max[3.56,\ 9.92]$$

$$= 9.92\ \text{mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,339.41 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 569.614$ = 97,288.72 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 569.614$ = 69,216.95 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(9{,}210.8066 - 207.9996 + 2 \cdot 11.11 \cdot 1 \cdot (1 \cdot 14.76 - 1 \cdot 14.43)) \cdot 1{,}162.477$

= 104,739.73 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(627.6762 + 5{,}835.6121 + 107.2256 + 113.5482) \cdot 1{,}162.477$

= 77,700.66 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(627.6762 + 235.9012 + 107.2256 + 137.2255 + 2 \cdot 11.11 \cdot 14.76 \cdot 1) \cdot 1{,}162.477$

= 16,693.7 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(627.6762 + 235.9012 + 5{,}835.6121 + 107.2256 + 113.5482 + 137.2255 + 2 \cdot 11.11 \cdot 14.76 \cdot 1) \cdot 1{,}162.477$

= 85,851.3 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 77,700.66 kg_f
Path 1-1 through (2) & (3) = 97,288.72 + 95,461.47 = 192,750.19 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 16,693.7 kg_f
Path 2-2 through (1), (5), (6) = 63,339.41 + 69,216.95 + 194,441.8 = 326,998.16 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 85,851.3 kg_f
Path 3-3 through (2), (5) = 97,288.72 + 69,216.95 = 166,505.68 kg_f
Path 3-3 is stronger than W_{3-3} so it is acceptable per UG-41(b)(1).

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 6.52 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
82.4471	82.4557	11.7406	6.42	2.359	58.3561	3.58	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
82,670	77,867	192,750	16,860	326,998	86,018	166,506

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 6.52 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{6.5186 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 6.5186}$$

$$= 1.77 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{6.5186 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 6.5186}$$

$$= 12.92 \text{ mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,162.477, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 12.92 \cdot 1 + 2 \cdot 11.11 \cdot 12.92 \cdot 1 \cdot (1 - 1))/100$$

= 82.4471 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 11.7406 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.92) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.92) \cdot (1 - 1))/100$$

$$= 11.7406 \text{ cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.92) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.92) \cdot (1 - 1))/100$$

$$= 0.9523 \text{ cm}^2$$

A_2 = smaller of the following= 6.42 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 1.77) \cdot 1 \cdot 34.35)/100$$

$$= 6.42 \text{ cm}^2$$

$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

$= (2 \cdot (11.11 - 1.77) \cdot 1 \cdot 34.35)/100$

$= 6.42 \text{ cm}^2$

A_3 = smaller of the following= 2.359 cm^2

$= 5 \cdot t \cdot t_i \cdot f_{r2}$

$= (5 \cdot 14.76 \cdot 9.51 \cdot 1)/100$

= 7.0196 cm^2

$= 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= (5 \cdot 9.51 \cdot 9.51 \cdot 1)/100$

= 4.5242 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 12.4 \cdot 9.51 \cdot 1)/100$

= 2.359 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 1)/100$

= 1.0723 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (10.66^2 \cdot 1)/100$

= 1.1355 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 1)/100$

= 1.3723 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 11.7406 + 6.42 + 2.359 + 1.0723 + 1.1355 + 1.3723 + 58.3561$

= 82.4557 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t_e] =$ 11.11 mm

$t_{c(\min)} = \min[6 \text{ mm}, 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\left[19 \text{ mm},\ t_e,\ t\right] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = \underline{7.38} \text{ mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46 \text{ mm}$

Lower fillet: $t_{\min} = \min\left[19 \text{ mm},\ t_n,\ t\right] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = \underline{7.78} \text{ mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2 \text{ mm}$

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{6.5186 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 6.5186} + 1.59$$

$$= 3.36 \text{ mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[3.36,\ 0\right]$$

$$= 3.36 \text{ mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{6.5186 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 6.5186} + 3.24$$

$$= 16.16 \text{ mm}$$

$$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$$

$$= \max\left[16.16,\ 3.09\right]$$

$$= 16.16 \text{ mm}$$

$$t_b = \min\left[t_{b3},\ t_{b1}\right]$$

$$= \min\left[9.92,\ 16.16\right]$$

$$= 9.92 \text{ mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$

$$= \max\left[3.36,\ 9.92\right]$$

$$= \underline{9.92} \text{ mm}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,339.41 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 569.614$ = 97,288.72 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 569.614$ = 69,216.95 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}244.7117 - 1{,}174.0622 + 2 \cdot 11.11 \cdot 1 \cdot (1 \cdot 14.76 - 1 \cdot 12.92)) \cdot 1{,}162.477$

= 82,669.97 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(641.9987 + 5{,}835.6121 + 107.2256 + 113.5482) \cdot 1{,}162.477$

= 77,867.15 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(641.9987 + 235.9012 + 107.2256 + 137.2255 + 2 \cdot 11.11 \cdot 14.76 \cdot 1) \cdot 1{,}162.477$

= 16,860.2 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(641.9987 + 235.9012 + 5{,}835.6121 + 107.2256 + 113.5482 + 137.2255 + 2 \cdot 11.11 \cdot 14.76 \cdot 1) \cdot 1{,}162.477$

= 86,017.8 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 77,867.15 kg_f
Path 1-1 through (2) & (3) = 97,288.72 + 95,461.47 = 192,750.19 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 16,860.2 kg_f
Path 2-2 through (1), (5), (6) = 63,339.41 + 69,216.95 + 194,441.8 = 326,998.16 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 82,669.97 kg_f
Path 3-3 through (2), (5) = 97,288.72 + 69,216.95 = 166,505.68 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.76 bar @ 21.11 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
97.5998	97.6043	16.7	7.2851	3.556	64.8	5.2632	8.33	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load $W_{1\text{-}1}$	Path 1-1 strength	Weld load $W_{2\text{-}2}$	Path 2-2 strength	Weld load $W_{3\text{-}3}$	Path 3-3 strength
94,821	87,637	227,522	22,071	354,843	99,364	201,415

Calculations for internal pressure 7.76 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[635,\ 317.5 + (12.7 - 0) + (18 - 0)\right]$$

$$= 635 \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0) + 18\right]$$

$$= 45 \ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[14,\ 2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0 - 0)\right]$$

$$= 14 \ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7557 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 7.7557}$$

$$= 2.1 \ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7557 \cdot 2{,}250}{1{,}140 \cdot 1 - 0.6 \cdot 7.7557}$$

$$= 15.37 \ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,162.477, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

= $(635 \cdot 15.37 \cdot 1 + 2 \cdot 12.7 \cdot 15.37 \cdot 1 \cdot (1 - 1))/100$

= 97.5998 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 16.7 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(635 \cdot (1 \cdot 18 - 1 \cdot 15.37) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.37) \cdot (1 - 1))/100$

= 16.7 cm^2

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (18 + 12.7) \cdot (1 \cdot 18 - 1 \cdot 15.37) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.37) \cdot (1 - 1))/100$

= 1.6148 cm^2

A_2 = smaller of the following= 7.2851 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.1) \cdot 1 \cdot 34.35)/100$

= 7.2851 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.1) \cdot 1 \cdot 34.35)/100$

= 7.2851 cm^2

A_3 = smaller of the following= 3.556 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 18 \cdot 12.7 \cdot 1)/100$

= 11.43 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 12.7 \cdot 12.7 \cdot 1)/100$

= 8.0645 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 14 \cdot 12.7 \cdot 1)/100$

= 3.556 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(12.7^2 \cdot 1)/100$

= 1.6129 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(13^2 \cdot 1)/100$

= 1.6903 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(14^2 \cdot 1)/100$

= 1.96 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}020.4 - 635 - 2 \cdot 12.7) \cdot 18 \cdot 1)/100$

= 64.8 cm^2

$Area$ = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

= $16.7 + 7.2851 + 3.556 + 1.6129 + 1.6903 + 1.96 + 64.8$

= 97.6043 cm^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.7557 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 7.7557} + 0$$

$$= 2.1 \text{ mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[2.1,\ 0\right]$$

$$= 2.1 \text{ mm}$$

t_{b1} = $\dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\dfrac{7.7557 \cdot 2{,}250}{1{,}140 \cdot 1 - 0.6 \cdot 7.7557} + 0$

= 15.37 mm

$t_{b1} = \max[t_{b1},\ t_{bUG16}]$

$= \max[15.37,\ 1.5]$

$= 15.37 \text{ mm}$

$t_b = \min[t_{b3},\ t_{b1}]$

$= \min[8.33,\ 15.37]$

$= 8.33 \text{ mm}$

$t_{\text{UG-45}} = \max[t_a,\ t_b]$

$= \max[2.1,\ 8.33]$

= 8.33 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}162.477$ =	569.614 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 12.7 \cdot 589.6$ = 77,676.23 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 13 \cdot 569.614$ = 118,689.96 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 647.7 \cdot 12.7 \cdot 842.286$ = 108,832.08 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 14 \cdot 569.614$ = 82,724.71 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

$$W = (A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$$

$$= (9{,}759.9805 - 1{,}669.9967 + 2 \cdot 12.7 \cdot 1 \cdot (1 \cdot 18 - 1 \cdot 15.37)) \cdot 1{,}162.477$$

= 94,820.71 kg_f

$$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$$

$$= (728.5147 + 6{,}480 + 161.29 + 169.0319) \cdot 1{,}162.477$$

= 87,637.21 kg_f

$$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$$

$$= (728.5147 + 355.6 + 161.29 + 195.9996 + 2 \cdot 12.7 \cdot 18 \cdot 1) \cdot 1{,}162.477$$

= 22,070.83 kg_f

$$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$$

$$= (728.5147 + 355.6 + 6{,}480 + 161.29 + 169.0319 + 195.9996 + 2 \cdot 12.7 \cdot 18 \cdot 1) \cdot 1{,}162.477$$

= 99,364.27 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 87,637.21 kg_f
Path 1-1 through (2) & (3) = 118,689.96 + 108,832.08 = 227,522.03 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 22,070.83 kg_f
Path 2-2 through (1), (5), (6) = 77,676.23 + 82,724.71 + 194,441.8 = 354,842.74 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = 94,820.71 kg_f
Path 3-3 through (2), (5) = 118,689.96 + 82,724.71 = 201,414.67 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
40.1213	85.1106	13.9451	6.8703	2.359	58.3561	3.58	4.82	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ \ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ \ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18 \ \ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ \ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ \ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9 \ \ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ \ 2.5 \cdot (t - C),\ \ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ \ 2.5 \cdot (18 - 3.24),\ \ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4 \ \ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.11 mm

From UG-37(d)(1) required thickness t_r = 12.57 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,162.477, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 12.57 \cdot 1 + 2 \cdot 11.11 \cdot 12.57 \cdot 1 \cdot (1 - 1)))/100$

= 40.1213 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 13.9451 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) \cdot (1 - 1))/100$

= $13.9451 \ \ cm^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.57) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) \cdot (1 - 1))/100$

= $1.131 \ \ cm^2$

A_2 = smaller of the following= 6.8703 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 1 \cdot 34.35)/100$

= $6.8703 \ \ cm^2$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 1 \cdot 34.35)/100$

= $6.8703 \ \ cm^2$

A_3 = smaller of the following= 2.359 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 1)/100$

= 7.0196 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 1)/100$

= 4.5242 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 12.4 \cdot 9.51 \cdot 1)/100$

$=$ 2.359 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 1)/100$

$=$ 1.0723 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (10.66^2 \cdot 1)/100$

$=$ 1.1355 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 1)/100$

$=$ 1.3723 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

$=$ 58.3561 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 13.9451 + 6.8703 + 2.359 + 1.0723 + 1.1355 + 1.3723 + 58.3561$

$=$ 85.1106 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t_e] =$ 11.11 mm

$t_{c(\min)} = \min[6 \text{ mm}, 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm}, t_e, t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46$ mm

Lower fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.7$ mm

$t_a = \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$

$= \max\left[2.7,\ 0\right]$

$= 2.7\ \text{mm}$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{0.8 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 0.8} + 3.24$$

$= 4.82\ \text{mm}$

$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$

$= \max\left[4.82,\ 3.09\right]$

$= 4.82\ \text{mm}$

$t_b = \min\left[t_{b3},\ t_{b2}\right]$

$= \min\left[9.92,\ 4.82\right]$

$= 4.82\ \text{mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[2.7,\ 4.82\right]$

$=$ 4.82 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{179.17}{660.4} = 0.2713$$

$$\frac{D_o}{t} = \frac{660.4}{1.11} = 593.9318$$

From table G: $A = 0.000357$

From table CS-2 Metric: $B = 363.3769\ \text{kg/cm}^2 (356.35\ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 356.35}{3 \cdot (660.4/1.11)} = 0.8\ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 1.11 + 1.59 =$ 2.7 mm

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.16 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
47.0939	71.0454	–	6.7503	2.359	58.3561	3.58	5.54	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 1.16 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$
$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$
$$= 638.18 \ \ \mathrm{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$
$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$
$$= 36.9 \ \ \mathrm{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$
$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$
$$= 12.4 \ \ \mathrm{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.29 mm

From UG-37(d)(1) required thickness t_r = 14.76 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,162.477, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 1

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 1

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 14.76 \cdot 1 + 2 \cdot 11.11 \cdot 14.76 \cdot 1 \cdot (1 - 1)))/100$

= 47.0939 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) \cdot (1 - 1))/100$

= $0 \ \text{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 14.76) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) \cdot (1 - 1))/100$

= $0 \ \text{cm}^2$

A_2 = smaller of the following= 6.7503 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.29) \cdot 1 \cdot 34.35)/100$

= $6.7503 \ \text{cm}^2$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.29) \cdot 1 \cdot 34.35)/100$

= $6.7503 \ \text{cm}^2$

A_3 = smaller of the following= 2.359 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 1)/100$

= 7.0196 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 1)/100$

= 4.5242 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 1)/100$

= 2.359 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^{\,2} \cdot 1)/100$

= 1.0723 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(10.66^{\,2} \cdot 1)/100$

= 1.1355 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^{\,2} \cdot 1)/100$

= 1.3723 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area$ = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

= $0 + 6.7503 + 2.359 + 1.0723 + 1.1355 + 1.3723 + 58.3561$

= 71.0454 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\text{min}} = \min\,[19\ \text{mm},\ t_n,\ t_e] =$ 11.11 mm

$t_{c(\text{min})} = \min\,[6\ \text{mm},\ 0.7 \cdot t_{\text{min}}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\text{min}} = \min\,[19\ \text{mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\text{min})} = 0.5 \cdot t_{\text{min}} = 7.38\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \text{mm}$

Lower fillet: $t_{\text{min}} = \min\,[19\ \text{mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\text{min})} = 0.7 \cdot t_{\text{min}} = 7.78\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.87\ \text{mm}$

$t_a = \max\,[t_{a\text{UG-28}},\ t_{a\text{UG-22}}]$

$= \max\,[2.87,\ 0]$

$= 2.87\ \text{mm}$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{1.1628 \cdot 2{,}251.6}{1{,}140 \cdot 1 - 0.6 \cdot 1.1628} + 3.24$$

$$= 5.54 \ \text{mm}$$

$$t_{b2} = \max\left[t_{b2}, \ t_{b\text{UG16}}\right]$$

$$= \max\left[5.54, \ 3.09\right]$$

$$= 5.54 \ \text{mm}$$

$$t_b = \min\left[t_{b3}, \ t_{b2}\right]$$

$$= \min\left[9.92, \ 5.54\right]$$

$$= 5.54 \ \text{mm}$$

$$t_{\text{UG-45}} = \max\left[t_a, \ t_b\right]$$

$$= \max\left[2.87, \ 5.54\right]$$

$$= 5.54 \ \text{mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{179.17}{660.4} = 0.2713$$

$$\frac{D_o}{t} = \frac{660.4}{1.29} = 513.1493$$

From table G: $A = 0.000449$

From table CS-2 Metric: $B = 456.3599 \ \text{kg/cm}^2 (447.54 \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 447.54}{3 \cdot (660.4/1.29)} = 1.16 \ \text{bar}$$

Design thickness for external pressure P_a = 1.16 bar

$t_a = t + \text{Corrosion} = 1.29 + 1.59 = 2.87$ mm

Platform/Ladder #1

Platform	
Distance from Base to Datum	7,500 mm
Attached To	Cylinder #1
Start Angle	0.00 degrees
End Angle	270.00 degrees
Shell Clearance, L_c	152.4 mm
Width, W	914.4 mm (0.91 m)
Projected Length, L	2,133.6 mm (2.13 m)
Wind Force Coefficient, C_f	2.00
Floor Grating	
Unit Weight	48.82 kg/m²
Area	12.40 m²
Railing	
Height, h	1,066.8 mm (1.07 m)
Length	17543.67 mm (17.54 m)
Unit Weight	17.86 kg/m
Ladder	
Distance from Start to Datum	-1,500 mm
Angle	90.00 degrees
Unit Weight	26.79 kg/m
Length	9,000 mm (9.00 m)
Allow Cage on Ladder	Yes
Weight	
Platform & Railing Weight	918.70 kg
Ladder Weight	241.08 kg
Total Weight	1159.78 kg
Included in Vessel Lift & Shipping Weight	No
Present When Vessel is Empty	Yes
Present During Test	Yes

Platform Wind Shear Calculation

Method and assumptions taken from *Wind Loads and Anchor Bolt Design for Petrochemical Facilities*, ASCE, 1997.

Platform depth: $H_p = 152.4$ mm

Railing effective height: $H_r = 243.84$ mm

Angle subtended by ends of platform: $\text{Angle} = 270.00\ ^\circ$

Length from vessel center line to platform outer edge: $R = 3{,}334.8$ mm

Platform projected length: $L_{eP} = 2 \cdot R = 2 \cdot 3{,}334.8 = 6{,}669.6$ mm

Front Railing projected length: $L_{eFR} = L_{eP} = 6{,}669.6$ mm

Rear Railing projected length: $L_{\text{e RR}} = L_{eFR} - 2 \cdot R \cdot \sin\left(\frac{360 - \text{angle}}{2}\right) + W \cdot \sin\left(\frac{360 - \text{angle}}{2}\right) \cdot 2 = 6{,}669.6 - 2 \cdot 3{,}334.8 \cdot \sin\left(\frac{360 - 270.00}{2}\right) + 914.4 \cdot \sin\left(\frac{360 - 270.00}{2}\right) \cdot 2 =$ 3,246.64 mm

Platform projected area: $A_{eP} = H_p \cdot L_{eP} = 152.4 \cdot 6{,}669.6 = 10{,}164.47\ \ \text{cm}^2$

Front Railing projected area: $A_{eFR} = H_r \cdot L_{eFR} = 243.84 \cdot 6{,}669.6 = 16{,}263.15\ \ \text{cm}^2$

Rear Railing projected area: $A_{\text{e RR}} = H_r \cdot L_{\text{e RR}} = 243.84 \cdot 3{,}246.64 = 7{,}916.6\ \ \text{cm}^2$

Total projected area: $A_e = A_{eP} + A_{eFR} + A_{\text{e RR}} = 10{,}164.47 + 16{,}263.15 + 7{,}916.6 = 34{,}344.22\ \ \text{cm}^2$

Local wind pressure: $P_w = 0.6 \cdot \text{qz} \cdot G = 0.6 \cdot 587.2 \cdot 0.8749 = 308.24 Pa$

Wind shear: $V_p = P_w \cdot C_f \cdot A_e \cdot \text{MetricFactor} = 308.24 \cdot 2.00 \cdot 34{,}344.22 \cdot 0.101972 = 215.90\ \ \text{kg}f$

Cylinder #2

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		7	40	5
External		0.8	40	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.54	5,656.6	0.98
Test horizontal		0.44	4,500	1
Dimensions				
Inner Diameter		4,500 mm		
Length		2,438.4 mm		
Nominal Thickness		18 mm		
Corrosion	**Inner**	1.6 mm		
	Outer	1.64 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		4,831.5		38,781.08
Corroded		3,961.8		38,836.25
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Full UW-11(a) Type 2		
Bottom Circumferential seam		Full UW-11(a) Type 2		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	15.59 mm
Design thickness due to external pressure (t_e)	15.93 mm
Design thickness due to combined loadings + corrosion	9.84 mm
Maximum allowable working pressure (MAWP)	8.47 bar
Maximum allowable pressure (MAP)	10.99 bar
Maximum allowable external pressure (MAEP)	1.13 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \dfrac{0.54 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.54} =$	0.89 mm
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{0.89 \cdot 1}{18 - 3.24} =$	0.0601
$\text{Stress ratio} longitud \in al = \dfrac{22.158 \cdot 0.9}{1{,}407.208 \cdot 0.9} =$	0.0157
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.54 \cdot 2{,}251.6}{1{,}380 \cdot 1.00 - 0.60 \cdot 7.54} + 3.24 = 15.59 \text{ mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}380 \cdot 1.00 \cdot 14.76}{2{,}251.6 + 0.60 \cdot 14.76} - 0.54 = 8.47 \text{ bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}380 \cdot 1.00 \cdot 18}{2{,}250 + 0.60 \cdot 18} = 10.99 \text{ bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{12.69} = 357.3338$$

From table G: $A = 0.000215$

From table CS-2 Metric: $B = 218.6278 \ \text{kg/cm}^2 (214.4 \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 214.4}{3 \cdot (4{,}536/12.69)} = 0.8 \ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.69 + 3.24 = 15.93 \text{ mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{14.76} = 307.3171$$

From table G: $A = 0.000262$

From table CS-2 Metric: $B = 266.6019 \ \text{kg/cm}^2 (261.4467 \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 261.45}{3 \cdot (4{,}536/14.76)} = \underline{1.13} \text{ bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 18}{2{,}259}\right) \cdot \left(1 - \frac{2{,}259}{\infty}\right) = 0.3984\,\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{10 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 5{,}312 \frac{}{\pi \cdot 2{,}258.98^{\ 2}} = 14.2458 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{14.2458}{0.8 \cdot 4{,}536} = 0.0385$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}536}\right)^2} = 1.37$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.37 + 1.37 \cdot 0.0385}{7^2 - 1 + 1.37} = 1.0011$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0011 \cdot 0.8 = 0.8) \le 1.13$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.08 \cdot 10 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 61{,}475 \frac{}{\pi \cdot 2{,}258.98^{\ 2}} = 50.1970 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{50.197}{0.8 \cdot 4{,}536} = 0.1357$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}536}\right)^2} = 1.37$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.37 + 1.37 \cdot 0.1357}{7^2 - 1 + 1.37} = 1.0038$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0038 \cdot 0.8 = 0.8) \le 1.13$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	7	1,407.2	805.5	40	3.24	Wind	6.31	6.23
						Seismic	6.6	5.94
Operating, Hot & New	7	1,407.2	862	40	0	Wind	6.3	6.21
						Seismic	6.59	5.91
Hot Shut Down, Corroded	0	1,407.2	805.5	40	3.24	Wind	0.04	0.18
						Seismic	0.26	0.62
Hot Shut Down, New	0	1,407.2	862	40	0	Wind	0.05	0.19
						Seismic	0.26	0.62
Empty, Corroded	0	1,407.2	805.5	21.11	3.24	Wind	0.04	0.18
						Seismic	0.03	0.26
Empty, New	0	1,407.2	862	21.11	0	Wind	0.05	0.19
						Seismic	0.03	0.27
Vacuum	-0.8	1,407.2	805.5	40	3.24	Wind	1.18	1.32
						Seismic	0.73	1.76
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,407.2	805.5	40	3.24	Weight	0.11	0.16

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \quad \text{kg/cm}^2$$

$$S_{cHC} = \min(B, S) = 805.5 \text{ kg/cm}^2$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \quad \text{kg/cm}^2$$

$$S_{cHN} = \min(B, S) = 862 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \quad \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cCN} = \min(B, S) = 862 \ \text{kg/cm}^2$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cC} = \min(B, S) = 805.5 \ \text{kg/cm}^2$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cVC} = \min(B, S) = 805.5 \ \text{kg/cm}^2$$

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = $$\frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

= $$\frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$$

= 6.34 mm

t_m = $$\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

= $$5{,}312 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.03 mm

t_w = $$\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{0.60 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.05 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.34 + 0.03 - (0.05)$

= 6.31 mm

$t_{w\,c}$ = $$\frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.09 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.03 + (0.09) - (6.34)|$

= 6.23 mm

Maximum allowable working pressure, Longitudinal Stress

P = $$\frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

= $$\frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.03 + (0.05))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.03 + (0.05))}$$

= 16.35 bar

Operating, Hot & New, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 5,325.5 \dfrac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.03 mm

$t_w = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.06 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.33 + 0.03 - (0.06)$

= 6.3 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.1 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.03 + (0.1) - (6.33)|$

= 6.21 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.03 + (0.06))}{2{,}250 - 0.40 \cdot (18 - 0.03 + (0.06))}$

= 19.97 bar

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{5,312}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$

= 0.04 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot 15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.08 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.04 - (0.08)|$

= 0.04 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.14 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.04 + (0.14) - (0)$

= 0.18 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{5,325.5}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$$

= 0.04 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot 17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.09 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.04 - (0.09)|$$

= 0.05 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.15 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.04 + (0.15) - (0)$$

= 0.19 mm

Empty, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= 5,312 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.91 \cdot 1.00} \cdot 98066.5$$

= 0.04 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= 0.60 \cdot 15,516.9 \frac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$$

= 0.08 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.04 - (0.08)|$$

= 0.04 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$$

= 0.14 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.04 + (0.14) - (0)$$

= 0.18 mm

Empty, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 5,325.5 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.04 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.60 \cdot 17,932.5 \frac{}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.09 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.04 - (0.09)|$

= 0.05 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.15 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.04 + (0.15) - (0)$

= 0.19 mm

Vacuum, Wind, Bottom Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.14 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

= $5{,}312 \dfrac{}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$

= 0.04 mm

t_w = $0.6 \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $0.60 \cdot 15{,}516.9 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.08 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|-1.14 + 0.04 - (0.08)|$

= 1.18 mm

$t_{w\,c}$ = $\dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.14 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.04 + (0.14) - (-1.14)$

= 1.32 mm

Maximum Allowable External Pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

= $\dfrac{2 \cdot 789.91 \cdot 1.00 \cdot (14.76 - 0.04 - 0.14)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.04 - 0.14)}$

= 10.26 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 2{,}811.1 \frac{}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$

= 0.02 mm

$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 15{,}516.9 \frac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.14 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.02 - (0.14)|$

= 0.11 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.02 + (0.14) - (0)$

= 0.16 mm

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 61{,}475 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.3 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.34 + 0.3 - (0.04)$

= 6.6 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.09 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.3 + (0.09) - (6.34)|$

= 5.94 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.3 + (0.04))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.3 + (0.04))}$

= 16.04 bar

Operating, Hot & New, Seismic, Bottom Seam

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

$$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$$

= 6.33 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 63{,}077.9 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.31 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot 17{,}932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.05 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 6.33 + 0.31 - (0.05)$$

= 6.59 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot 17{,}932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.11 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}|$$ (total, net tensile)

$$= |0.31 + (0.11) - (6.33)|$$

= 5.91 mm

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.31 + (0.05))}{2{,}250 - 0.40 \cdot (18 - 0.31 + (0.05))}$$

= 19.65 bar

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{61,475}{\pi \cdot 2{,}258.98^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.3 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot 15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.04 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.3 - (0.04)$

= 0.26 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{61,475}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$$

= 0.48 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot 15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$$

= 0.15 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.48 + (0.15) - (0)$

= 0.62 mm

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{63,077.9}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.31 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.05 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.31 - (0.05)$

= 0.26 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{63,077.9}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.46 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 17,932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.16 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.46 + (0.16) - (0)$

= 0.62 mm

Empty, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{14,344}{\pi \cdot 2{,}258.98^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.07 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.52 \cdot 15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.04 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0.07 - (0.04)$$

= 0.03 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{14,344}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$$

= 0.11 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot 15,516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$$

= 0.15 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.11 + (0.15) - (0)$$

= 0.26 mm

Empty, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 16{,}026.3 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.08 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 17{,}932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.05 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.08 - (0.05)$

= 0.03 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 16{,}026.3 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.12 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 17{,}932.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.16 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.12 + (0.16) - (0)$

= 0.27 mm

Vacuum, Seismic, Bottom Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.14 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (bending)

= $61{,}475 \dfrac{}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.91 \cdot 1.00} \cdot 98066.5$

= 0.48 mm

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (Weight)

= $0.52 \cdot 15{,}516.9 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.07 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|-1.14 + 0.48 - (0.07)|$

= 0.73 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \mathrm{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 15{,}516.9}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.91 \cdot 1.00} \cdot 98.0665$

= 0.15 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.48 + (0.15) - (-1.14)$

= 1.76 mm

Maximum Allowable External Pressure, Longitudinal Stress

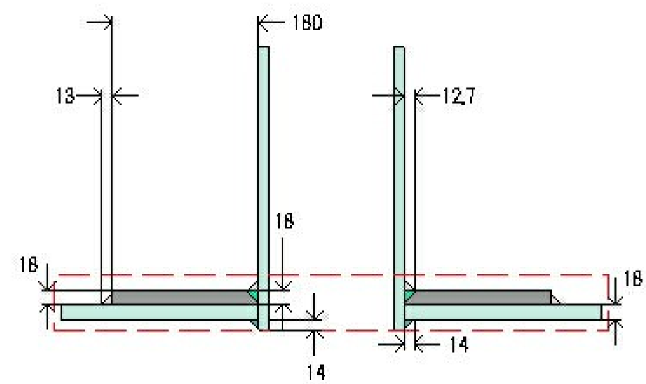
P = $\dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

= $\dfrac{2 \cdot 789.91 \cdot 1.00 \cdot (14.76 - 0.48 - 0.15)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.48 - 0.15)}$

= 9.94 bar

Nozzle #3 (N3)

ASME Section VIII Division 1, 2021 Edition Metric



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Cylinder #2
Orientation	225°
Nozzle center line offset to datum line	4,506.9 mm
End of nozzle to shell center	2,423 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 26 Sch 20 (XS) DN 650
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	635 mm
Pipe nominal wall thickness	12.7 mm
Pipe minimum wall thickness[1]	11.11 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	34.35 mm
Internal projection, h_{new}	14 mm
Projection available outside vessel to flange face, Lf	155 mm
Local vessel minimum thickness	18 mm
Liquid static head included	0.43 bar

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 20, ln. 45)
Diameter, D_p	1,020.4 mm
Thickness, t_e	18 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	12.7 mm
Outer fillet, Leg_{42}	13 mm
Lower fillet, Leg_{43}	14 mm
Pad groove weld	18 mm

Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Full UW-11(a) Type 1

[1] Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.47-2017 Flange	
Description	NPS 26 Class 150 WN A105 Series A
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 410, ln. 32)
Blind included	Yes
Rated MDMT	-48°C
Liquid static head	0.4 bar
MAWP rating	19.53 bar @ 40°C
MAP rating	19.6 bar @ 21.11°C
Hydrotest rating	30 bar @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Bore diameter, B (specified by purchaser)	647.7 mm
Notes	
Flange and blind rated MDMT per UCS-66(b)(1)(b) = -48°C (Coincident ratio = 0.3955) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
$t_r = \dfrac{7.78 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.78} =$	2.11 mm
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{2.11 \cdot 1}{11.11 - 1.59} =$	0.2218
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	18 mm
MDMT =	-29°C
Material is exempt from impact testing per UG-20(f) at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.43 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
78.0034	85.4456	16.4993	5.3432	2.0173	58.3594	3.2264	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
87,244	92,532	213,245	17,247	329,436	100,969	189,431

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.43 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.4296 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.4296}$$

$$= 2.02 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.4296 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.4296}$$

$$= 12.16 \quad \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 12.16 \cdot 1 + 2 \cdot 11.11 \cdot 12.16 \cdot 1 \cdot (1 - 0.8551))/100$$

= 78.0034 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 16.4993 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.16) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.16) \cdot (1 - 0.8551))/100$$

$$= 16.4993 \quad cm^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.16) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.16) \cdot (1 - 0.8551))/100$$

$$= 1.2606 \quad cm^2$$

A_2 = smaller of the following= 5.3432 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 2.02) \cdot 0.8551 \cdot 34.35)/100$$

$$= 5.3432 \quad cm^2$$

$= \quad 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

$= \quad (2 \cdot (11.11 - 2.02) \cdot 0.8551 \cdot 34.35)/100$

$= \quad 5.3432 \ \text{cm}^2$

A_3 = smaller of the following= 2.0173 cm^2

$= \quad 5 \cdot t \cdot t_i \cdot f_{r2}$

$= \quad (5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

$=$ 6.003 cm^2

$= \quad 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= \quad (5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

$=$ 3.8688 cm^2

$= \quad 2 \cdot h \cdot t_i \cdot f_{r2}$

$= \quad (2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 2.0173 cm^2

$A_{41} \quad = \quad Leg^2 \cdot f_{r3}$

$= \quad (10.36^2 \cdot 0.8551)/100$

$=$ 0.9174 cm^2

$A_{42} \quad = \quad Leg^2 \cdot f_{r4}$

$= \quad (10.66^2 \cdot 1)/100$

$=$ 1.1355 cm^2

$A_{43} \quad = \quad Leg^2 \cdot f_{r2}$

$= \quad (11.71^2 \cdot 0.8551)/100$

$=$ 1.1735 cm^2

$A_5 \quad = \quad (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= \quad ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

$=$ 58.3594 cm^2

$Area \quad = \quad A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= \quad 16.4993 + 5.3432 + 2.0173 + 0.9174 + 1.1355 + 1.1735 + 58.3594$

$=$ 85.4456 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} \quad = \min[19 \ \text{mm}, \ t_n, \ t_e] =$ 11.11 mm

$t_{c(\min)} \quad = \min[6 \ \text{mm}, \ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} \quad = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm}, t_e, t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46 \text{ mm}$

Lower fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2 \text{ mm}$

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.4296 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.4296} + 1.59$$

$$= 3.6 \text{ mm}$$

$$t_a = \max[t_{a\text{UG-27}}, t_{a\text{UG-22}}]$$

$$= \max[3.6, 0]$$

$$= 3.6 \text{ mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.4296 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.4296} + 3.24$$

$$= 15.4 \text{ mm}$$

$$t_{b1} = \max[t_{b1}, t_{b\text{UG16}}]$$

$$= \max[15.4, 3.09]$$

$$= 15.4 \text{ mm}$$

$$t_b = \min[t_{b3}, t_{b1}]$$

$$= \min[9.92, 15.4]$$

$$= 9.92 \text{ mm}$$

$$t_{\text{UG-45}} = \max[t_a, t_b]$$

$$= \max[3.6, 9.92]$$

$$= 9.92 \text{ mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,346.75 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 689.532$ = 117,783.82 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 589.6$ = 71,647.36 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(7{,}800.343 - 1{,}649.9322 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 14.76 - 1 \cdot 12.16)) \cdot 1{,}407.208$

= 87,244.03 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(534.3215 + 5{,}835.9392 + 91.7418 + 113.5482) \cdot 1{,}407.208$

= 92,531.71 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(534.3215 + 201.7266 + 91.7418 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 17,247.48 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(534.3215 + 201.7266 + 5{,}835.9392 + 91.7418 + 113.5482 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 100,969.18 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 87,244.03 kg_f
Path 1-1 through (2) & (3) = 117,783.82 + 95,461.47 = 213,245.29 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 17,247.48 kg_f
Path 2-2 through (1), (5), (6) = 63,346.75 + 71,647.36 + 194,441.8 = 329,435.91 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 87,244.03 kg_f
Path 3-3 through (2), (5) = 117,783.82 + 71,647.36 = 189,431.19 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.78 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
81.713	81.7166	12.8271	5.2864	2.0173	58.3594	3.2264	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
97,477	92,452	213,245	17,168	329,436	100,889	189,431

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.78 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7818 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.7818}$$

$$= 2.11 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7818 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.7818}$$

$$= 12.74 \text{ mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 12.74 \cdot 1 + 2 \cdot 11.11 \cdot 12.74 \cdot 1 \cdot (1 - 0.8551))/100$$

= 81.713 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 12.8271 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) \cdot (1 - 0.8551))/100$$

$$= 12.8271 \text{ cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.74) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) \cdot (1 - 0.8551))/100$$

$$= 0.98 \text{ cm}^2$$

A_2 = smaller of the following= 5.2864 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 2.11) \cdot 0.8551 \cdot 34.35)/100$$

$$= 5.2864 \text{ cm}^2$$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 2.11) \cdot 0.8551 \cdot 34.35)/100$

= 5.2864 cm^2

A_3 = smaller of the following= 2.0173 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.003 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

= 2.0173 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 0.8551)/100$

= 0.9174 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(10.66^2 \cdot 1)/100$

= 1.1355 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 0.8551)/100$

= 1.1735 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3594 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 12.8271 + 5.2864 + 2.0173 + 0.9174 + 1.1355 + 1.1735 + 58.3594$

= 81.7166 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\left[19 \text{ mm}, t_n, t_e\right] =$ 11.11 mm

$t_{c(\min)} = \min\left[6 \text{ mm}, 0.7 \cdot t_{\min}\right] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\left[19\ \ \text{mm},\ t_e,\ t\right] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = \underline{7.38}\ \ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \ \text{mm}$

Lower fillet: $t_{\min} = \min\left[19\ \ \text{mm},\ t_n,\ t\right] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = \underline{7.78}\ \ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.7818 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.7818} + 1.59$$

$$= 3.7\ \ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[3.7,\ \ 0\right]$$

$$= 3.7\ \ \text{mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.7818 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.7818} + 3.24$$

$$= 15.98\ \ \text{mm}$$

$$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$$

$$= \max\left[15.98,\ \ 3.09\right]$$

$$= 15.98\ \ \text{mm}$$

$$t_b = \min\left[t_{b3},\ t_{b1}\right]$$

$$= \min\left[9.92,\ \ 15.98\right]$$

$$= 9.92\ \ \text{mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$

$$= \max\left[3.7,\ \ 9.92\right]$$

$$= \underline{9.92}\ \ \text{mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,346.75 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 689.532$ = 117,783.82 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 589.6$ = 71,647.36 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}171.2992 - 1{,}282.7071 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 14.76 - 1 \cdot 12.74)) \cdot 1{,}407.208$

= 97,477.1 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(528.6441 + 5{,}835.9392 + 91.7418 + 113.5482) \cdot 1{,}407.208$

= 92,451.82 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(528.6441 + 201.7266 + 91.7418 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 17,167.59 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(528.6441 + 201.7266 + 5{,}835.9392 + 91.7418 + 113.5482 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 100,889.29 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 92,451.82 kg_f
Path 1-1 through (2) & (3) = 117,783.82 + 95,461.47 = 213,245.29 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 17,167.59 kg_f
Path 2-2 through (1), (5), (6) = 63,346.75 + 71,647.36 + 194,441.8 = 329,435.91 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 97,477.1 kg_f
Path 3-3 through (2), (5) = 117,783.82 + 71,647.36 = 189,431.19 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 9.25 bar @ 21.11 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
96.6649	96.6652	18.0864	5.9922	3.0407	64.8	4.7458	8.33	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
111,452	103,939	252,509	22,512	357,745	116,078	229,305

Calculations for internal pressure 9.25 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[635,\ 317.5 + (12.7 - 0) + (18 - 0)\right]$$

$$= 635 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0) + 18\right]$$

$$= 45 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[14,\ 2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0 - 0)\right]$$

$$= 14 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{9.2455 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 9.2455}$$

$$= 2.5 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{9.2455 \cdot 2{,}250}{1{,}380 \cdot 1 - 0.6 \cdot 9.2455}$$

$$= 15.14 \text{ mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

= $(635 \cdot 15.14 \cdot 1 + 2 \cdot 12.7 \cdot 15.14 \cdot 1 \cdot (1 - 0.8551))/100$

= 96.6649 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 18.0864 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(635 \cdot (1 \cdot 18 - 1 \cdot 15.14) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.14) \cdot (1 - 0.8551))/100$

= 18.0864 cm^2

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (18 + 12.7) \cdot (1 \cdot 18 - 1 \cdot 15.14) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.14) \cdot (1 - 0.8551))/100$

= 1.6535 cm^2

A_2 = smaller of the following= 5.9922 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.5) \cdot 0.8551 \cdot 34.35)/100$

= 5.9922 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.5) \cdot 0.8551 \cdot 34.35)/100$

= 5.9922 cm^2

A_3 = smaller of the following= 3.0407 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 18 \cdot 12.7 \cdot 0.8551)/100$

= 9.7738 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 12.7 \cdot 12.7 \cdot 0.8551)/100$

= 6.896 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 14 \cdot 12.7 \cdot 0.8551)/100$

= 3.0407 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(12.7^{\,2} \cdot 0.8551)/100$

= 1.3794 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(13^2 \cdot 1)/100$

= 1.6903 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(14^2 \cdot 0.8551)/100$

= 1.6761 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}020.4 - 635 - 2 \cdot 12.7) \cdot 18 \cdot 1)/100$

= 64.8 cm^2

$Area$ = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

= $18.0864 + 5.9922 + 3.0407 + 1.3794 + 1.6903 + 1.6761 + 64.8$

= 96.6652 cm^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{9.2455 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 9.2455} + 0$$

$$= 2.5 \ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[2.5,\ 0\right]$$

$$= 2.5 \ \text{mm}$$

t_{b1} = $\frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\frac{9.2455 \cdot 2{,}250}{1{,}380 \cdot 1 - 0.6 \cdot 9.2455} + 0$

= 15.14 mm

$t_{b1} = \max\left[t_{b1},\ t_{bUG16}\right]$

$= \max\left[15.14,\ 1.5\right]$

$= 15.14 \text{ mm}$

$t_b = \min\left[t_{b3},\ t_{b1}\right]$

$= \min\left[8.33,\ 15.14\right]$

$= 8.33 \text{ mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[2.5,\ 8.33\right]$

$=$ 8.33 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 12.7 \cdot 589.6$ = 77,676.23 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 13 \cdot 689.532$ = 143,677.32 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 647.7 \cdot 12.7 \cdot 842.286$ = 108,832.08 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 14 \cdot 589.6$ = 85,627.34 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(9{,}666.4914 - 1{,}808.6415 + 2 \cdot 12.7 \cdot 0.8551 \cdot (1 \cdot 18 - 1 \cdot 15.14)) \cdot 1{,}407.208$

= 111,451.96 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(599.2246 + 6{,}480 + 137.9352 + 169.0319) \cdot 1{,}407.208$

= 103,939.12 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(599.2246 + 304.0736 + 137.9352 + 167.6126 + 2 \cdot 12.7 \cdot 18 \cdot 0.8551) \cdot 1{,}407.208$

= 22,512.49 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(599.2246 + 304.0736 + 6{,}480 + 137.9352 + 169.0319 + 167.6126 + 2 \cdot 12.7 \cdot 18 \cdot 0.8551) \cdot 1{,}407.208$

= 116,078.23 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 103,939.12 kg_f
Path 1-1 through (2) & (3) = 143,677.32 + 108,832.08 = 252,509.39 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 22,512.49 kg_f
Path 2-2 through (1), (5), (6) = 77,676.23 + 85,627.34 + 194,441.8 = 357,745.36 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 111,451.96 kg_f
Path 3-3 through (2), (5) = 143,677.32 + 85,627.34 = 229,304.66 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
40.3238	83.3598	13.8819	5.8748	2.0173	58.3594	3.2264	4.55	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4\ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.11 mm

From UG-37(d)(1) required thickness t_r = 12.57 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 12.57 \cdot 1 + 2 \cdot 11.11 \cdot 12.57 \cdot 1 \cdot (1 - 0.8551)))/100$

= 40.3238 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 13.8819 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) \cdot (1 - 0.8551))/100$

= 13.8819 cm^2

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.57) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.57) \cdot (1 - 0.8551))/100$

= 1.0606 cm^2

A_2 = smaller of the following= 5.8748 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 0.8551 \cdot 34.35)/100$

= 5.8748 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 0.8551 \cdot 34.35)/100$

= 5.8748 cm^2

A_3 = smaller of the following= 2.0173 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.003 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 2.0173 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 0.8551)/100$

$=$ 0.9174 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (10.66^2 \cdot 1)/100$

$=$ 1.1355 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 0.8551)/100$

$=$ 1.1735 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

$=$ 58.3594 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 13.8819 + 5.8748 + 2.0173 + 0.9174 + 1.1355 + 1.1735 + 58.3594$

$=$ 83.3598 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_n,\ t_e] =$ 11.11 mm

$t_{c(\min)} = \min\,[6\ \text{mm},\ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46$ mm

Lower fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.7$ mm

$$t_a = \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[2.7,\ 0\right]$$

$$= 2.7 \text{ mm}$$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{0.8 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.8} + 3.24$$

$$= 4.55 \text{ mm}$$

$$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$$

$$= \max\left[4.55,\ 3.09\right]$$

$$= 4.55 \text{ mm}$$

$$t_b = \min\left[t_{b3},\ t_{b2}\right]$$

$$= \min\left[9.92,\ 4.55\right]$$

$$= 4.55 \text{ mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$

$$= \max\left[2.7,\ 4.55\right]$$

$$= 4.55 \text{ mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{179.17}{660.4} = 0.2713$$

$$\frac{D_o}{t} = \frac{660.4}{1.11} = 593.9318$$

From table G: $A = 0.000357$

From table CS-2 Metric: $B = 363.3769 \text{ kg/cm}^2 (356.35 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 356.35}{3 \cdot (660.4/1.11)} = 0.8 \text{ bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 1.11 + 1.59 = 2.7$ mm

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.13 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
46.7809	70.4799	1.0968	5.78	2.0173	58.3594	3.2264	5.09	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 1.13 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$

$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$

$= 638.18\ \text{mm}$

Outer Normal Limit of reinforcement per UG-40

$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$

$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$

$= 36.9\ \text{mm}$

Inner Normal Limit of reinforcement per UG-40

$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$

$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$

$= 12.4\ \text{mm}$

Nozzle required thickness per UG-28 t_{rn} = 1.27 mm

From UG-37(d)(1) required thickness t_r = 14.59 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 14.59 \cdot 1 + 2 \cdot 11.11 \cdot 14.59 \cdot 1 \cdot (1 - 0.8551)))/100$

= 46.7809 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 1.0968 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 14.59) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.59) \cdot (1 - 0.8551))/100$

= $1.0968 \ \ \mathrm{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 14.59) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.59) \cdot (1 - 0.8551))/100$

= $0.0839 \ \ \mathrm{cm}^2$

A_2 = smaller of the following= 5.78 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.27) \cdot 0.8551 \cdot 34.35)/100$

= $5.78 \ \ \mathrm{cm}^2$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.27) \cdot 0.8551 \cdot 34.35)/100$

= $5.78 \ \ \mathrm{cm}^2$

A_3 = smaller of the following= 2.0173 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.003 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8688 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

= 2.0173 cm^2

A$_{41}$ = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 0.8551)/100$

= 0.9174 cm^2

A$_{42}$ = $Leg^2 \cdot f_{r4}$

= $(10.66^2 \cdot 1)/100$

= 1.1355 cm^2

A$_{43}$ = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 0.8551)/100$

= 1.1735 cm^2

A$_5$ = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3594 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 1.0968 + 5.78 + 2.0173 + 0.9174 + 1.1355 + 1.1735 + 58.3594$

= 70.4799 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19\ \text{mm},\ t_n,\ t_e] =$ 11.11 mm

$t_{c(\min)} = \min[6\ \text{mm},\ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19\ \text{mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = 7.38\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \text{mm}$

Lower fillet: $t_{\min} = \min[19\ \text{mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = 7.78\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.86\ \text{mm}$

$t_a = \max[t_{a\text{UG-28}},\ t_{a\text{UG-22}}]$

$= \max[2.86,\ 0]$

$= 2.86\ \text{mm}$

t_{b2} = $\dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

= $\dfrac{1.1343 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 1.1343} + 3.24$

= 5.09 mm

$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$

$= \max\left[5.09,\ 3.09\right]$

$= 5.09 \text{ mm}$

$t_b = \min\left[t_{b3},\ t_{b2}\right]$

$= \min\left[9.92,\ 5.09\right]$

$= 5.09 \text{ mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[2.86,\ 5.09\right]$

$=$ 5.09 mm

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{179.17}{660.4} = 0.2713$$

$$\frac{D_o}{t} = \frac{660.4}{1.27} = 518.6947$$

From table G: $A = 0.000443$

From table CS-2 Metric: $B = 449.979 \text{ kg/cm}^2 (441.28 \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 441.28}{3 \cdot (660.4/1.27)} = 1.13 \text{ bar}$$

Design thickness for external pressure P_a = 1.13 bar

$t_a = t + \text{Corrosion} = 1.27 + 1.59 = 2.86$ mm

Vacuum Ring

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Stiffening Ring		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Attached To		Cylinder #2		
Impact Tested	Normalized	Fine Grain Practice	PWHT	
No	No	No	No	
		Design Pressure (bar)	Design Temperature (°C)	Design MDMT (°C)
Internal		7	40	5
External		0.8	40	
Ring Properties				
Ring type		Flat bar		
Description		3/4x8 Flat Bar		
Corrosion allowance		0 mm		
Distance from ring neutral axis to datum		3,992.65 mm		
Distance to previous support		4,196.39 mm		
Distance to next support		4,297.99 mm		
Internal ring		No		
Max depth to thickness ratio		12		
Ring distance to centroid		101.6 mm		
Ring area		38.7096 cm^2		
Ring inertia		1,331.9405 cm^4		
Welds				
Weld configuration		Staggered intermittent		
Fillet weld leg size		6.93 mm		
Length of individual weld segments		76.2 mm		
Spacing between toes of weld segments		76.2 mm		
Vessel thickness at weld location, new		18 mm		
Vessel corrosion allowance at weld location		3.24 mm		
Stiffener thickness at weld location		19.05 mm		

UCS-66 Material Toughness Requirements	
$t_r = \frac{0.54 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.54} =$	0.89 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{0.89 \cdot 1}{18 - 3.24} =$	0.0601
$\text{Stress ratio}longitud \in al = \frac{22.158 \cdot 0.9}{1{,}407.208 \cdot 0.9} =$	0.0157
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

External Pressure, (Corroded & at 40°C) UG-29(a)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{12.69} = 357.3262$$

From Table G: $A = 2.1461E\text{-}04$

From Table CS-2 Metric: $B = 218.64 \ \ kg_f/cm^2$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o \ / \ t)} = \frac{4 \cdot 214.41}{3 \cdot (4{,}536 \ / \ 12.69)} = 0.8 \ \ bar$$

$$B = \frac{3}{4} \cdot \left(\frac{P \cdot D_o}{t + A_s \ / \ L_s} \right) = \frac{3}{4} \cdot \left(\frac{0.8 \cdot 4{,}536}{12.69 + 3{,}870.96 \ / \ 4{,}247.19} \cdot 1.02 \right) = 203.969 \ kg_f/cm^2$$

From Table CS-2 Metric: $A = 0.00020017$ (ring, 40°C)

$$I_s' = \frac{D_o^2 \cdot L_s \cdot (t + A_s \ / \ L_s) \cdot A}{10.9}$$

$$= \frac{4{,}536^{\ 2} \cdot 4{,}247.19 \cdot (12.69 + 3{,}870.96 \ / \ 4{,}247.19) \cdot 0.00020017}{10.9} / 10000$$

$$= 2{,}183.53 \ \ cm^4$$

I' for the composite corroded shell-ring cross section is 3,732.27 cm^4

As *I'* >= I_s' a 3/4x8 Flat Bar stiffener is adequate for an external pressure of 0.8 bar.

Check the stiffener ring attachment welds per UG-30

UG-30(f) minimum weld size $= \min\left[6{,}18 - 1.6 - 1.64{,}19.05\right] + 0 = 6 \ \ mm$

The fillet weld size of 6.93 mm is adequate per UG-30(f).

Radial pressure load, $P \cdot L_s = 0.8 \cdot \frac{4{,}247.19}{10} = 346.47 \ \ kg_f/cm$

Radial shear load, $V = 0.01 \cdot P \cdot L_s \cdot D_o = 0.01 \cdot 0.8 \cdot 1.02 \cdot 4{,}247.19 \cdot \frac{4{,}536}{100} = 1{,}571.61 \ \ kg_f$

First moment of area, $Q = 42.01 \cdot 5.23 = 219.5544 \ \ cm^3$

Weld shear flow, $q = \frac{V \cdot Q}{I'} = 92.4514 \ \ kg_f/cm$

Combined weld load, $f_w = \sqrt{346.4747^{\ 2} + 92.4514^{\ 2}} = 358.6 \ \ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55 \cdot S = 0.55 \cdot 1{,}407.208 = 773.965 \ \ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$t_w = \frac{f_w \cdot (d_{\text{weld segment}} + d_{\text{toe}})}{S_w \cdot d_{\text{weld total}}} + \text{corrosion} = \frac{10 \cdot 358.6 \cdot (76.2 + 76.2)}{773.965 \cdot 152.4} + 0 = 4.63 \ \ mm$$

The fillet weld size of 6.93 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 40°C) UG-29(a)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{14.76} = 307.3173$$

From Table G: $A = 2.6186E\text{-}04$

From Table CS-2 Metric: $B = 266.6 \ \ kg_f/cm^2$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o \ / \ t)} = \frac{4 \cdot 261.45}{3 \cdot (4{,}536 \ / \ 14.76)} = 1.13 \ \text{bar}$$

$$B = \frac{3}{4} \cdot \left(\frac{P \cdot D_o}{t + A_s \ / \ L_s} \right) = \frac{3}{4} \cdot \left(\frac{1.13 \cdot 4{,}536}{14.76 + 3{,}870.96 \ / \ 4{,}247.19} \cdot 1.02 \right) = 251.097 \ \text{kg}_f/\text{cm}^2$$

From Table CS-2 Metric: $A = 0.00024659$ (ring, 40°C)

$$I_s' = \frac{D_o^2 \cdot L_s \cdot (t + A_s \ / \ L_s) \cdot A}{10.9}$$

$$= \frac{4{,}536^{\ 2} \cdot 4{,}247.19 \cdot (14.76 + 3{,}870.96 \ / \ 4{,}247.19) \cdot 0.00024659}{10.9} / 10000$$

$$= 3{,}098.1 \ \text{cm}^4$$

I' for the composite corroded shell-ring cross section is 3,732.27 cm^4

As $I' >= I_s'$ a 3/4x8 Flat Bar stiffener is adequate for an external pressure of 1.13 bar.

Check the stiffener ring attachment welds per UG-30

UG-30(f) minimum weld size = $\min\left[6{,}18 - 1.6 - 1.64{,}19.05\right] + 0 = 6 \ \text{mm}$

The fillet weld size of 6.93 mm is adequate per UG-30(f).

Radial pressure load, $P \cdot L_s = 1.13 \cdot \frac{4{,}247.19}{10} = 491.26 \ \text{kg}_f/\text{cm}$

Radial shear load, $V = 0.01 \cdot P \cdot L_s \cdot D_o = 0.01 \cdot 1.13 \cdot 1.02 \cdot 4{,}247.19 \cdot \frac{4{,}536}{100} = 2{,}228.38 \ \text{kg}_f$

First moment of area, $Q = 42.01 \cdot 5.23 = 219.5544 \ \text{cm}^3$

Weld shear flow, $q = \frac{V \cdot Q}{I'} = 131.0862 \ \text{kg}_f/\text{cm}$

Combined weld load, $f_w = \sqrt{491.2643^{\ 2} + 131.0862^{\ 2}} = 508.45 \ \text{kg}_f/\text{cm}$

Allowable weld stress per UW-18(d) $S_w = 0.55 \cdot S = 0.55 \cdot 1{,}407.208 = 773.965 \ \text{kg}_f/\text{cm}^2$

Fillet weld size required to resist radial pressure and shear

$$t_w = \frac{f_w \cdot (d_{\text{weld segment}} + d_{\text{toe}})}{S_w \cdot d_{\text{weld total}}} + \text{corrosion} = \frac{10 \cdot 508.45 \cdot (76.2 + 76.2)}{773.965 \cdot 152.4} + 0 = 6.57 \ \text{mm}$$

The fillet weld size of 6.93 mm is adequate to resist radial pressure and shear.

Cylinder #3

ASME Section VIII Division 1, 2021 Edition Metric					
Component		Cylinder			
Material		SA-516 70 (II-D Metric p. 20, ln. 45)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
No	No	No	No	No	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		7	40	5	
External		0.8	40		
Static Liquid Head					
Condition		**P_s (bar)**	**H_s (mm)**	**SG**	
Operating		0.78	8,095	0.98	
Test horizontal		0.44	4,500	1	
Dimensions					
Inner Diameter		4,500 mm			
Length		2,438.4 mm			
Nominal Thickness		18 mm			
Corrosion	**Inner**	1.6 mm			
	Outer	1.64 mm			
Weight and Capacity					
		Weight (kg)		**Capacity (liters)**	
New		4,831.5		38,781.08	
Corroded		3,961.52		38,836.26	
Radiography					
Longitudinal seam		Full UW-11(a) Type 1			
Top Circumferential seam		Full UW-11(a) Type 2			
Bottom Circumferential seam		Full UW-11(a) Type 2			

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	15.97 mm
Design thickness due to external pressure (t_e)	15.94 mm
Design thickness due to combined loadings + corrosion	10.08 mm
Maximum allowable working pressure (MAWP)	8.23 bar
Maximum allowable pressure (MAP)	10.99 bar
Maximum allowable external pressure (MAEP)	1.13 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \frac{0.78 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.78} =$	1.27 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{1.27 \cdot 1}{18 - 3.24} =$	0.086
$\text{Stress ratio} longitud \in al = \frac{42.778 \cdot 0.9}{1{,}407.208 \cdot 0.9} =$	0.0304
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.78 \cdot 2{,}251.6}{1{,}380 \cdot 1.00 - 0.60 \cdot 7.78} + 3.24 = \underline{15.97}\ \text{mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}380 \cdot 1.00 \cdot 14.76}{2{,}251.6 + 0.60 \cdot 14.76} - 0.78 = \underline{8.23}\ \text{bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}380 \cdot 1.00 \cdot 18}{2{,}250 + 0.60 \cdot 18} = \underline{10.99}\ \text{bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{12.69} = 357.3338$$

From table G: $A = 0.000215$

From table CS-2 Metric: $B = 218.6278\ \text{kg/cm}^2 (214.4\ \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 214.4}{3 \cdot (4{,}536/12.69)} = 0.8\ \ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.69 + 3.24 = \underline{15.94}\ \text{mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}536} = 0.9475$$

$$\frac{D_o}{t} = \frac{4{,}536}{14.76} = 307.3387$$

From table G: $A = 0.000262$

From table CS-2 Metric: $B = 266.5812\ \text{kg/cm}^2 (261.4263\ \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 261.43}{3 \cdot (4{,}536/14.76)} = \underline{1.13} \text{ bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 18}{2{,}259}\right) \cdot \left(1 - \frac{2{,}259}{\infty}\right) = 0.3984\,\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{10 \cdot 20{,}034}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 8{,}693.4 \frac{}{\pi \cdot 2{,}258.98\ ^2} = 19.5375 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{19.5375}{0.8 \cdot 4{,}536} = 0.0528$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}536}\right)^2} = 1.37$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.37 + 1.37 \cdot 0.0528}{7^2 - 1 + 1.37} = 1.0015$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0015 \cdot 0.8 = 0.8) \le 1.13$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.08 \cdot 10 \cdot 20{,}034}{2 \cdot \pi \cdot 2{,}258.98} + 10000 \cdot 112{,}893 \frac{}{\pi \cdot 2{,}258.98\ ^2} = 85.7199 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{85.7199}{0.8 \cdot 4{,}536} = 0.2317$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}536}\right)^2} = 1.37$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.37 + 1.37 \cdot 0.2317}{7^2 - 1 + 1.37} = 1.0064$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0064 \cdot 0.8 = 0.81) \le 1.13$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm²)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	7	1,407.2	805.5	40	3.24	Wind	6.31	6.18
						Seismic	6.84	5.66
Operating, Hot & New	7	1,407.2	862	40	0	Wind	6.3	6.16
						Seismic	6.84	5.62
Hot Shut Down, Corroded	0	1,407.2	805.5	40	3.24	Wind	0.04	0.24
						Seismic	0.5	1.06
Hot Shut Down, New	0	1,407.2	862	40	0	Wind	0.05	0.25
						Seismic	0.5	1.04
Empty, Corroded	0	1,407.2	805.5	21.11	3.24	Wind	0.04	0.24
						Seismic	0.06	0.37
Empty, New	0	1,407.2	862	21.11	0	Wind	0.05	0.25
						Seismic	0.06	0.4
Vacuum	-0.8	1,407.2	805.5	40	3.24	Wind	1.18	1.38
						Seismic	0.36	2.2
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,407.2	805.5	40	3.24	Weight	0.14	0.21

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cHC} = \min(B, S) = 805.5 \text{ kg/cm}^2$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cHN} = \min(B, S) = 862 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/18} = 0.000992$$

$$B = 862 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \text{kg/cm}^2$$

$$S_{cCN} = \min(B,S) = 862 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \text{kg/cm}^2$$

$$S_{cC} = \min(B,S) = 805.5 \text{ kg/cm}^2$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}268/14.76} = 0.000813$$

$$B = 805.5 \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \text{kg/cm}^2$$

$$S_{cVC} = \min(B,S) = 805.5 \text{ kg/cm}^2$$

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \dfrac{8{,}693.4}{\pi \cdot 2{,}258.98^{\,2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.04 mm

$t_w = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 20{,}034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.07 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.34 + 0.04 - (0.07)$

= 6.31 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{20{,}034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.11 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.04 + (0.11) - (6.34)|$

= 6.18 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.04 + (0.07))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.04 + (0.07))}$

= 16.35 bar

Operating, Hot & New, Wind, Bottom Seam

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|} \quad \text{(Pressure)}$$

$$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$$

= 6.33 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 8{,}714.1 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.04 mm

$$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot 23{,}322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.08 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 6.33 + 0.04 - (0.08)$$

= 6.3 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{23{,}322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.13 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0.04 + (0.13) - (6.33)|$$

= 6.16 mm

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.04 + (0.08))}{2{,}250 - 0.40 \cdot (18 - 0.04 + (0.08))}$$

= 19.97 bar

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{8,693.4}{\pi \cdot 2{,}258.98^{\;2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$$

= 0.07 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.11 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.07 - (0.11)|$$

= 0.04 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.18 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.07 + (0.18) - (0)$$

= 0.24 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{8,714.1}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.06 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.06 - (0.11)|$

= 0.05 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.19 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.06 + (0.19) - (0)$

= 0.25 mm

Empty, Corroded, Wind, Bottom Seam

t_p	=	0 mm	(Pressure)
t_m	=	$\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$	(bending)
	=	$\frac{8,693.4}{\pi \cdot 2{,}258.98^{\;2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$	
	=	0.07 mm	
t_w	=	$0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$	(Weight)
	=	$\frac{0.60 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$	
	=	0.11 mm	
t_t	=	$\lvert t_p + t_m - t_w \rvert$	(total, net compressive)
	=	$\lvert 0 + 0.07 - (0.11) \rvert$	
	=	0.04 mm	
$t_{w\,c}$	=	$\frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$	(Weight)
	=	$\frac{20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$	
	=	0.18 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	$0.07 + (0.18) - (0)$	
	=	0.24 mm	

Empty, New, Wind, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{8,714.1}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$$

= 0.06 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.11 mm

$$t_t = |t_p + t_m - t_w| \quad \text{(total, net compressive)}$$

$$= |0 + 0.06 - (0.11)|$$

= 0.05 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.19 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.06 + (0.19) - (0)$$

= 0.25 mm

Vacuum, Wind, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.9 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.14 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \dfrac{8{,}693.4}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.07 mm

$t_w = 0.6 \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 20{,}034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-1.14 + 0.07 - (0.11)|$

= 1.18 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{20{,}034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.18 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.07 + (0.18) - (-1.14)$

= 1.38 mm

Maximum Allowable External Pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

$= \dfrac{2 \cdot 789.9 \cdot 1.00 \cdot (14.76 - 0.07 - 0.18)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.07 - 0.18)}$

= 10.21 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{4,119.2}{\pi \cdot 2{,}258.98^{\ 2} \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.03 mm

$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.18 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.03 - (0.18)|$

= 0.14 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.03 + (0.18) - (0)$

= 0.21 mm

Operating, Hot & Corroded, Seismic, Bottom Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $112,893 \dfrac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.56 mm

t_w = $\dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.52 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.06 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.34 + 0.56 - (0.06)$

= 6.84 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.12 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.56 + (0.12) - (6.34)|$

= 5.66 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (14.76 - 0.56 + (0.06))}{2{,}251.6 - 0.40 \cdot (14.76 - 0.56 + (0.06))}$

= 15.77 bar

Operating, Hot & New, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \mathrm{MetricFactor}$ (bending)

$= 115{,}651 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.57 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \mathrm{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 23{,}322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.07 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.33 + 0.57 - (0.07)$

= 6.84 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \mathrm{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 23{,}322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.14 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.57 + (0.14) - (6.33)|$

= 5.62 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (18 - 0.57 + (0.07))}{2{,}250 - 0.40 \cdot (18 - 0.57 + (0.07))}$

= 19.38 bar

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 112,893 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.56 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.06 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.56 - (0.06)$

= 0.5 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= 112,893 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$$

= 0.87 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$$

= 0.19 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.87 + (0.19) - (0)$

= 1.06 mm

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 115,651 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0.57 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= 0.07 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 0 + 0.57 - (0.07)$$

= 0.5 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= 115,651 \frac{}{\pi \cdot 2{,}259^{\ 2} \cdot 845.38 \cdot 1.00} \cdot 98066.5$$

= 0.84 mm

$$t_{wc} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$$

= 0.21 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.84 + (0.21) - (0)$$

= 1.04 mm

Empty, Corroded, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 23,610.6 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.12 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.06 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.12 - (0.06)$

= 0.06 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 23,610.6 \frac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.18 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 20,034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.19 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.18 + (0.19) - (0)$

= 0.37 mm

Empty, New, Seismic, Bottom Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 26,518.8 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0.13 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= 0.07 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.13 - (0.07)$

= 0.06 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 26,518.8 \frac{}{\pi \cdot 2{,}259\ ^2 \cdot 845.38 \cdot 1.00} \cdot 98066.5$

= 0.19 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 23,322.5}{2 \cdot \pi \cdot 2{,}259 \cdot 845.38 \cdot 1.00} \cdot 98.0665$

= 0.21 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.19 + (0.21) - (0)$

= 0.4 mm

Vacuum, Seismic, Bottom Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 789.9 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.14 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 112{,}893 \dfrac{}{\pi \cdot 2{,}258.98\ ^2 \cdot 789.9 \cdot 1.00} \cdot 98066.5$

= 0.87 mm

$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= 0.52 \cdot 20{,}034 \dfrac{}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.09 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-1.14 + 0.87 - (0.09)|$

= 0.36 mm

$t_{w\,c} = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot 20{,}034}{2 \cdot \pi \cdot 2{,}258.98 \cdot 789.9 \cdot 1.00} \cdot 98.0665$

= 0.19 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.87 + (0.19) - (-1.14)$

= 2.2 mm

Maximum Allowable External Pressure, Longitudinal Stress

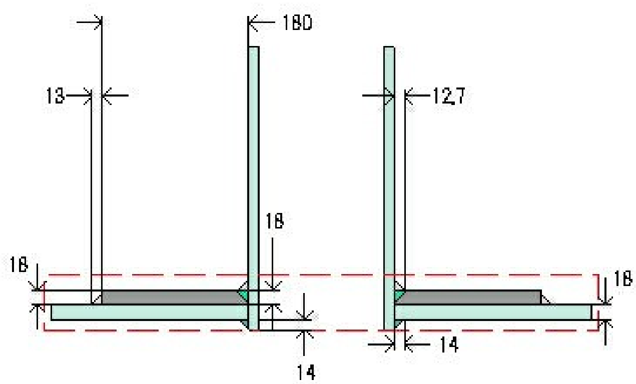
$P = \dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

$= \dfrac{2 \cdot 789.9 \cdot 1.00 \cdot (14.76 - 0.87 - 0.19)}{2{,}251.6 - 0.40 \cdot (14.76 - 0.87 - 0.19)}$

= 9.63 bar

Nozzle #1 (N1)

ASME Section VIII Division 1, 2021 Edition Metric	



Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Cylinder #3
Orientation	225°
Nozzle center line offset to datum line	2,293.5 mm
End of nozzle to shell center	2,423 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 26 Sch 20 (XS) DN 650
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 16, ln. 16)
Inside diameter, new	635 mm
Pipe nominal wall thickness	12.7 mm
Pipe minimum wall thickness[1]	11.11 mm
Corrosion allowance	1.59 mm
Projection available outside vessel, Lpr	34.35 mm
Internal projection, h_{new}	14 mm
Projection available outside vessel to flange face, Lf	155 mm
Local vessel minimum thickness	18 mm
Liquid static head included	0.64 bar
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 20, ln. 45)
Diameter, D_p	1,020.4 mm
Thickness, t_e	18 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	12.7 mm
Outer fillet, Leg_{42}	13 mm
Lower fillet, Leg_{43}	14 mm
Pad groove weld	18 mm
Radiography	
Longitudinal seam	Seamless No RT
Circumferential seam	Full UW-11(a) Type 1

[1]Pipe minimum thickness = nominal thickness times pipe tolerance factor of 0.875.

ASME B16.47-2017 Flange	
Description	NPS 26 Class 150 WN A105 Series A
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 410, ln. 32)
Blind included	Yes
Rated MDMT	-48°C
Liquid static head	0.61 bar
MAWP rating	19.53 bar @ 40°C
MAP rating	19.6 bar @ 21.11°C
Hydrotest rating	30 bar @ 21.11°C
PWHT performed	No
Produced to Fine Grain Practice and Supplied in Heat Treated Condition	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Bore diameter, B (specified by purchaser)	647.7 mm
Notes	
Flange and blind rated MDMT per UCS-66(b)(1)(b) = -48°C (Coincident ratio = 0.3954) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
$t_r = \frac{7.78 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.78} =$	2.11 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{2.11 \cdot 1}{11.11 - 1.59} =$	0.2218
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	18 mm
MDMT =	-29°C
Material is exempt from impact testing per UG-20(f) at the Design MDMT of 5°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.64 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
80.2419	83.1849	14.2767	5.309	2.0172	58.3561	3.2258	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
93,428	92,478	213,232	17,198	329,427	100,915	189,416

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.64 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4\ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.6422 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.6422}$$

$$= 2.08\ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.6422 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.6422}$$

$$= 12.51 \text{ mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 12.51 \cdot 1 + 2 \cdot 11.11 \cdot 12.51 \cdot 1 \cdot (1 - 0.8551))/100$$

= 80.2419 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 14.2767 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.51) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.51) \cdot (1 - 0.8551))/100$$

$$= 14.2767 \text{ cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.51) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.51) \cdot (1 - 0.8551))/100$$

$$= 1.091 \text{ cm}^2$$

A_2 = smaller of the following= 5.309 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 2.08) \cdot 0.8551 \cdot 34.35)/100$$

$$= 5.309 \text{ cm}^2$$

$= \quad 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

$= \quad (2 \cdot (11.11 - 2.08) \cdot 0.8551 \cdot 34.35)/100$

$= \quad 5.309 \;\; cm^2$

A_3 = smaller of the following= 2.0172 cm^2

$= \quad 5 \cdot t \cdot t_i \cdot f_{r2}$

$= \quad (5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.0024 cm^2

$= \quad 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= \quad (5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8686 cm^2

$= \quad 2 \cdot h \cdot t_i \cdot f_{r2}$

$= \quad (2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

= 2.0172 cm^2

$A_{41} \quad = \quad Leg^2 \cdot f_{r3}$

$= \quad (10.36^{\,2} \cdot 0.8551)/100$

= 0.9168 cm^2

$A_{42} \quad = \quad Leg^2 \cdot f_{r4}$

$= \quad (10.66^{\,2} \cdot 1)/100$

= 1.1355 cm^2

$A_{43} \quad = \quad Leg^2 \cdot f_{r2}$

$= \quad (11.71^{\,2} \cdot 0.8551)/100$

= 1.1735 cm^2

$A_5 \quad = \quad (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= \quad ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area \quad = \quad A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= \quad 14.2767 + 5.309 + 2.0172 + 0.9168 + 1.1355 + 1.1735 + 58.3561$

= 83.1849 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} \quad = \min\left[19 \;\; \text{mm}, \;\; t_n, \;\; t_e\right] =$ 11.11 mm

$t_{c(\min)} \quad = \min\left[6 \;\; \text{mm}, \;\; 0.7 \cdot t_{\min}\right] =$ 6 mm

$t_{c(actual)} \quad = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\left[19\ \text{mm},\ t_e,\ t\right] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \text{mm}$

Lower fillet: $t_{\min} = \min\left[19\ \text{mm},\ t_n,\ t\right] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.6422 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.6422} + 1.59$$

$$= 3.66\ \text{mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[3.66,\ 0\right]$$

$$= 3.66\ \text{mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.6422 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.6422} + 3.24$$

$$= 15.75\ \text{mm}$$

$$t_{b1} = \max\left[t_{b1},\ t_{b\text{UG16}}\right]$$

$$= \max\left[15.75,\ 3.09\right]$$

$$= 15.75\ \text{mm}$$

$$t_b = \min\left[t_{b3},\ t_{b1}\right]$$

$$= \min\left[9.92,\ 15.75\right]$$

$$= 9.92\ \text{mm}$$

$$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$$

$$= \max\left[3.66,\ 9.92\right]$$

$$= 9.92\ \text{mm}$$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,339.41 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 689.532$ = 117,770.56 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 589.6$ = 71,645.62 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}024.1874 - 1{,}427.6746 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 14.76 - 1 \cdot 12.51)) \cdot 1{,}407.208$

= 93,428 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(530.9022 + 5{,}835.6121 + 91.6772 + 113.5482) \cdot 1{,}407.208$

= 92,478.08 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(530.9022 + 201.7191 + 91.6772 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 17,198.08 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(530.9022 + 201.7191 + 5{,}835.6121 + 91.6772 + 113.5482 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 100,915.17 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 92,478.08 kg_f
Path 1-1 through (2) & (3) = 117,770.56 + 95,461.47 = 213,232.03 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 17,198.08 kg_f
Path 2-2 through (1), (5), (6) = 63,339.41 + 71,645.62 + 194,441.8 = 329,426.83 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 93,428 kg_f
Path 3-3 through (2), (5) = 117,770.56 + 71,645.62 = 189,416.18 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAWP

Available reinforcement per UG-37 governs the MAWP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 7.78 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
81.7016	81.7171	12.8316	5.2864	2.0172	58.3561	3.2258	9.92	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
97,455	92,446	213,232	17,166	329,427	100,883	189,416

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for internal pressure 7.78 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4 \text{ mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7808 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.7808}$$

$$= 2.11 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{7.7808 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.7808}$$

$$= 12.74 \ \ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

$$= (638.18 \cdot 12.74 \cdot 1 + 2 \cdot 11.11 \cdot 12.74 \cdot 1 \cdot (1 - 0.8551))/100$$

= 81.7016 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 12.8316 cm^2

$$= d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) \cdot (1 - 0.8551))/100$$

$$= 12.8316 \ \ \text{cm}^2$$

$$= 2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$$

$$= (2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.74) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.74) \cdot (1 - 0.8551))/100$$

$$= 0.9806 \ \ \text{cm}^2$$

A_2 = smaller of the following= 5.2864 cm^2

$$= 2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$$

$$= (2 \cdot (11.11 - 2.11) \cdot 0.8551 \cdot 34.35)/100$$

$$= 5.2864 \ \ \text{cm}^2$$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 2.11) \cdot 0.8551 \cdot 34.35)/100$

= $5.2864 \ \text{cm}^2$

A_3 = smaller of the following= 2.0172 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.0024 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8686 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

= 2.0172 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 0.8551)/100$

= 0.9168 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(10.66^2 \cdot 1)/100$

= 1.1355 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 0.8551)/100$

= 1.1735 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 12.8316 + 5.2864 + 2.0172 + 0.9168 + 1.1355 + 1.1735 + 58.3561$

= 81.7171 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\left[19 \ \text{mm}, \ t_n, \ t_e\right] =$ 11.11 mm

$t_{c(\min)} = \min\left[6 \ \text{mm}, \ 0.7 \cdot t_{\min}\right] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46$ mm

Lower fillet: $t_{\min} = \min[19 \text{ mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.7808 \cdot 319.09}{1{,}180 \cdot 1 - 0.6 \cdot 7.7808} + 1.59$$

$$= 3.7 \text{ mm}$$

$$t_a = \max[t_{a\text{UG-27}},\ t_{a\text{UG-22}}]$$

$$= \max[3.7,\ 0]$$

$$= 3.7 \text{ mm}$$

$$t_{b1} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{7.7808 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 7.7808} + 3.24$$

$$= 15.98 \text{ mm}$$

$$t_{b1} = \max[t_{b1},\ t_{b\text{UG16}}]$$

$$= \max[15.98,\ 3.09]$$

$$= 15.98 \text{ mm}$$

$$t_b = \min[t_{b3},\ t_{b1}]$$

$$= \min[9.92,\ 15.98]$$

$$= 9.92 \text{ mm}$$

$$t_{\text{UG-45}} = \max[t_a,\ t_b]$$

$$= \max[3.7,\ 9.92]$$

$$= 9.92 \text{ mm}$$

Available nozzle wall thickness new, t_n = $0.875 \cdot 12.7$ = 11.11 mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 10.36 \cdot 589.6$ = 63,339.41 kg_f

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 10.66 \cdot 689.532$ = 117,770.56 kg_f

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 649.29 \cdot 11.11 \cdot 842.286$ = 95,461.47 kg_f

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 11.71 \cdot 589.6$ = 71,645.62 kg_f

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334$ = 194,441.8 kg_f

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(8{,}170.1588 - 1{,}283.1587 + 2 \cdot 11.11 \cdot 0.8551 \cdot (1 \cdot 14.76 - 1 \cdot 12.74)) \cdot 1{,}407.208$

= 97,454.9 kg_f

$W_{1\text{-}1}$ = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(528.6441 + 5{,}835.6121 + 91.6772 + 113.5482) \cdot 1{,}407.208$

= 92,446.3 kg_f

$W_{2\text{-}2}$ = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(528.6441 + 201.7191 + 91.6772 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 17,166.3 kg_f

$W_{3\text{-}3}$ = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(528.6441 + 201.7191 + 5{,}835.6121 + 91.6772 + 113.5482 + 117.3546 + 2 \cdot 11.11 \cdot 14.76 \cdot 0.8551) \cdot 1{,}407.208$

= 100,883.39 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = 92,446.3 kg_f
Path 1-1 through (2) & (3) = 117,770.56 + 95,461.47 = 213,232.03 kg_f
Path 1-1 is stronger than $W_{1\text{-}1}$ so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = 17,166.3 kg_f
Path 2-2 through (1), (5), (6) = 63,339.41 + 71,645.62 + 194,441.8 = 329,426.83 kg_f
Path 2-2 is stronger than $W_{2\text{-}2}$ so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 97,454.9 kg_f
Path 3-3 through (2), (5) = 117,770.56 + 71,645.62 = 189,416.18 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAP

Available reinforcement per UG-37 governs the MAP of this nozzle.

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 9.25 bar @ 21.11 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
96.6649	96.6652	18.0864	5.9922	3.0407	64.8	4.7458	8.33	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
111,452	103,939	252,509	22,512	357,745	116,078	229,305

Calculations for internal pressure 9.25 bar @ 21.11 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[635,\ 317.5 + (12.7 - 0) + (18 - 0)\right]$$

$$= 635\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0) + 18\right]$$

$$= 45\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[14,\ 2.5 \cdot (18 - 0),\ 2.5 \cdot (12.7 - 0 - 0)\right]$$

$$= 14\ \text{mm}$$

Nozzle required thickness per UG-27(c)(1)

$$t_{rn} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P}$$

$$= \frac{9.2455 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 9.2455}$$

$$= 2.5\ \text{mm}$$

Required thickness t_r from UG-37(a)

$$t_r = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$$

$$= \frac{9.2455 \cdot 2{,}250}{1{,}380 \cdot 1 - 0.6 \cdot 9.2455}$$

$$= 15.14\ \text{mm}$$

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

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

= $(635 \cdot 15.14 \cdot 1 + 2 \cdot 12.7 \cdot 15.14 \cdot 1 \cdot (1 - 0.8551))/100$

= 96.6649 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 18.0864 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(635 \cdot (1 \cdot 18 - 1 \cdot 15.14) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.14) \cdot (1 - 0.8551))/100$

= $18.0864 \ \ cm^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (18 + 12.7) \cdot (1 \cdot 18 - 1 \cdot 15.14) - 2 \cdot 12.7 \cdot (1 \cdot 18 - 1 \cdot 15.14) \cdot (1 - 0.8551))/100$

= $1.6535 \ \ cm^2$

A_2 = smaller of the following= 5.9922 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.5) \cdot 0.8551 \cdot 34.35)/100$

= $5.9922 \ \ cm^2$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (12.7 - 2.5) \cdot 0.8551 \cdot 34.35)/100$

= $5.9922 \ \ cm^2$

A_3 = smaller of the following= 3.0407 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 18 \cdot 12.7 \cdot 0.8551)/100$

= 9.7738 cm^2

$= 5 \cdot t_i \cdot t_i \cdot f_{r2}$

$= (5 \cdot 12.7 \cdot 12.7 \cdot 0.8551)/100$

= 6.896 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 14 \cdot 12.7 \cdot 0.8551)/100$

= 3.0407 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (12.7^2 \cdot 0.8551)/100$

= 1.3794 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (13^2 \cdot 1)/100$

= 1.6903 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (14^2 \cdot 0.8551)/100$

= 1.6761 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}020.4 - 635 - 2 \cdot 12.7) \cdot 18 \cdot 1)/100$

= 64.8 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 18.0864 + 5.9922 + 3.0407 + 1.3794 + 1.6903 + 1.6761 + 64.8$

= 96.6652 cm^2

As Area >= A the reinforcement is adequate.

UG-45 Nozzle Neck Thickness Check

$$t_{a\text{UG-27}} = \frac{P \cdot R_n}{S_n \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{9.2455 \cdot 317.5}{1{,}180 \cdot 1 - 0.6 \cdot 9.2455} + 0$$

$$= 2.5 \text{ mm}$$

$$t_a = \max\left[t_{a\text{UG-27}},\ t_{a\text{UG-22}}\right]$$

$$= \max\left[2.5,\ 0\right]$$

$$= 2.5 \text{ mm}$$

$t_{b1} = \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

$= \dfrac{9.2455 \cdot 2{,}250}{1{,}380 \cdot 1 - 0.6 \cdot 9.2455} + 0$

$= 15.14 \ \text{mm}$

$t_{b1} = \max\left[t_{b1}, \ t_{b\text{UG16}}\right]$

$= \max\left[15.14, \ 1.5\right]$

$= 15.14 \ \text{mm}$

$t_b = \min\left[t_{b3}, \ t_{b1}\right]$

$= \min\left[8.33, \ 15.14\right]$

$= 8.33 \ \text{mm}$

$t_{\text{UG-45}} = \max\left[t_a, \ t_b\right]$

$= \max\left[2.5, \ 8.33\right]$

$=$ 8.33 mm

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

Allowable stresses in joints UG-45 and UW-15(c)

Nozzle wall in shear:	$0.7 \cdot 1{,}203.265$ =	842.286 kg_f/cm^2
Inner fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2
Outer fillet weld in shear:	$0.49 \cdot 1{,}407.208$ =	689.532 kg_f/cm^2
Upper groove weld in tension:	$0.74 \cdot 1{,}407.208$ =	1,041.334 kg_f/cm^2
Lower fillet weld in shear:	$0.49 \cdot 1{,}203.265$ =	589.6 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_i = \frac{\pi}{2} \cdot 660.4 \cdot 12.7 \cdot 589.6 = 77{,}676.23 \ kg_f$

(2) Outer fillet weld in shear
$\frac{\pi}{2} \cdot \text{Pad OD} \cdot \text{Leg} \cdot S_o = \frac{\pi}{2} \cdot 1{,}020.4 \cdot 13 \cdot 689.532 = 143{,}677.32 \ kg_f$

(3) Nozzle wall in shear
$\frac{\pi}{2} \cdot \text{Mean nozzle dia} \cdot t_n \cdot S_n = \frac{\pi}{2} \cdot 647.7 \cdot 12.7 \cdot 842.286 = 108{,}832.08 \ kg_f$

(5) Lower fillet weld in shear
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot \text{Leg} \cdot S_l = \frac{\pi}{2} \cdot 660.4 \cdot 14 \cdot 589.6 = 85{,}627.34 \ kg_f$

(6) Upper groove weld in tension
$\frac{\pi}{2} \cdot \text{Nozzle OD} \cdot t_w \cdot S_g = \frac{\pi}{2} \cdot 660.4 \cdot 18 \cdot 1{,}041.334 = 194{,}441.8 \ kg_f$

Loading on welds per UG-41(b)(1)

W = $(A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$

= $(9{,}666.4914 - 1{,}808.6415 + 2 \cdot 12.7 \cdot 0.8551 \cdot (1 \cdot 18 - 1 \cdot 15.14)) \cdot 1{,}407.208$

= 111,451.96 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$

= $(599.2246 + 6{,}480 + 137.9352 + 169.0319) \cdot 1{,}407.208$

= 103,939.12 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(599.2246 + 304.0736 + 137.9352 + 167.6126 + 2 \cdot 12.7 \cdot 18 \cdot 0.8551) \cdot 1{,}407.208$

= 22,512.49 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$

= $(599.2246 + 304.0736 + 6{,}480 + 137.9352 + 169.0319 + 167.6126 + 2 \cdot 12.7 \cdot 18 \cdot 0.8551) \cdot 1{,}407.208$

= 116,078.23 kg_f

Load for path 1-1 lesser of W or W_{1-1} = 103,939.12 kg_f
Path 1-1 through (2) & (3) = 143,677.32 + 108,832.08 = 252,509.39 kg_f
Path 1-1 is stronger than W_{1-1} so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W_{2-2} = 22,512.49 kg_f
Path 2-2 through (1), (5), (6) = 77,676.23 + 85,627.34 + 194,441.8 = 357,745.36 kg_f
Path 2-2 is stronger than W_{2-2} so it is acceptable per UG-41(b)(1).

Load for path 3-3 lesser of W or W_{3-3} = 111,451.96 kg_f
Path 3-3 through (2), (5) = 143,677.32 + 85,627.34 = 229,304.66 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 0.8 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
40.7091	82.5862	13.1122	5.8748	2.0172	58.3561	3.2258	4.55	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 0.8 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4\ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.11 mm

From UG-37(d)(1) required thickness t_r = 12.69 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 12.69 \cdot 1 + 2 \cdot 11.11 \cdot 12.69 \cdot 1 \cdot (1 - 0.8551)))/100$

= 40.7091 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 13.1122 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 12.69) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.69) \cdot (1 - 0.8551))/100$

= 13.1122 cm^2

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 12.69) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 12.69) \cdot (1 - 0.8551))/100$

= 1.0019 cm^2

A_2 = smaller of the following= 5.8748 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 0.8551 \cdot 34.35)/100$

= 5.8748 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.11) \cdot 0.8551 \cdot 34.35)/100$

= 5.8748 cm^2

A_3 = smaller of the following= 2.0172 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.0024 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8686 cm^2

$= 2 \cdot h \cdot t_i \cdot f_{r2}$

$= (2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

$=$ 2.0172 cm^2

$A_{41} = Leg^2 \cdot f_{r3}$

$= (10.36^2 \cdot 0.8551)/100$

$=$ 0.9168 cm^2

$A_{42} = Leg^2 \cdot f_{r4}$

$= (10.66^2 \cdot 1)/100$

$=$ 1.1355 cm^2

$A_{43} = Leg^2 \cdot f_{r2}$

$= (11.71^2 \cdot 0.8551)/100$

$=$ 1.1735 cm^2

$A_5 = (D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

$= ((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

$=$ 58.3561 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 13.1122 + 5.8748 + 2.0172 + 0.9168 + 1.1355 + 1.1735 + 58.3561$

$=$ 82.5862 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t_e] =$ 11.11 mm

$t_{c(\min)} = \min[6 \text{ mm}, 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min[19 \text{ mm}, t_e, t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} =$ 7.38 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46$ mm

Lower fillet: $t_{\min} = \min[19 \text{ mm}, t_n, t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} =$ 7.78 mm

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2$ mm

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.7$ mm

$t_a = \max\left[t_{a\text{UG-28}},\ t_{a\text{UG-22}}\right]$

$= \max\left[2.7,\ 0\right]$

$= 2.7\ \text{ mm}$

$$t_{b2} = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$$

$$= \frac{0.8 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.8} + 3.24$$

$= 4.55\ \text{ mm}$

$t_{b2} = \max\left[t_{b2},\ t_{b\text{UG16}}\right]$

$= \max\left[4.55,\ 3.09\right]$

$= 4.55\ \text{ mm}$

$t_b = \min\left[t_{b3},\ t_{b2}\right]$

$= \min\left[9.92,\ 4.55\right]$

$= 4.55\ \text{ mm}$

$t_{\text{UG-45}} = \max\left[t_a,\ t_b\right]$

$= \max\left[2.7,\ 4.55\right]$

$=$ 4.55 mm

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{179.17}{660.4} = 0.2713$$

$$\frac{D_o}{t} = \frac{660.4}{1.11} = 593.9318$$

From table G: $A = 0.000357$

From table CS-2 Metric: $B = 363.3769\ \text{ kg/cm}^2 (356.35\ \text{ bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 356.35}{3 \cdot (660.4/1.11)} = 0.8\ \text{ bar}$$

Design thickness for external pressure P_a = 0.8 bar

$t_a = t + \text{Corrosion} = 1.11 + 1.59 = 2.7$ mm

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.13 bar @ 40 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
47.3315	69.3791	–	5.78	2.0172	58.3561	3.2258	5.09	11.11

UG-41 Weld Failure Path Analysis Summary
Weld strength calculations are not required for external pressure

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	7.25 (corroded)	weld size is adequate
Pad to shell fillet (Leg_{42})	7.38	7.46 (corroded)	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	7.78	8.2 (corroded)	weld size is adequate

Calculations for external pressure 1.13 bar @ 40 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \max\left[d,\ R_n + (t_n - C_n) + (t - C)\right]$$

$$= \max\left[638.18,\ 319.09 + (12.7 - 1.59) + (18 - 3.24)\right]$$

$$= 638.18\ \text{mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \min\left[2.5 \cdot (t - C),\ 2.5 \cdot (t_n - C_n) + t_e\right]$$

$$= \min\left[2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59) + 16.36\right]$$

$$= 36.9\ \text{mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = \min\left[h,\ 2.5 \cdot (t - C),\ 2.5 \cdot (t_i - C_n - C)\right]$$

$$= \min\left[12.4,\ 2.5 \cdot (18 - 3.24),\ 2.5 \cdot (12.7 - 1.59 - 1.6)\right]$$

$$= 12.4\ \text{mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.27 mm

From UG-37(d)(1) required thickness t_r = 14.76 mm

Area required per UG-37(d)(1)

Allowable stresses: S_n = 1,203.265, S_v = 1,407.208, S_p = 1,407.208 kg_f/cm^2

f_{r1} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r2} = lesser of 1 or $\frac{S_n}{S_v}$ = 0.8551

f_{r3} = lesser of f_{r2} or $\frac{S_p}{S_v}$ = 0.8551

f_{r4} = lesser of 1 or $\frac{S_p}{S_v}$ = 1

A = $0.5 \cdot (d \cdot t_r \cdot F + 2 \cdot t_n \cdot t_r \cdot F \cdot (1 - f_{r1}))$

= $(0.5 \cdot (638.18 \cdot 14.76 \cdot 1 + 2 \cdot 11.11 \cdot 14.76 \cdot 1 \cdot (1 - 0.8551)))/100$

= 47.3315 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

= $d \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(638.18 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) \cdot (1 - 0.8551))/100$

= $0 \ \text{cm}^2$

= $2 \cdot (t + t_n) \cdot (E_1 \cdot t - F \cdot t_r) - 2 \cdot t_n \cdot (E_1 \cdot t - F \cdot t_r) \cdot (1 - f_{r1})$

= $(2 \cdot (14.76 + 11.11) \cdot (1 \cdot 14.76 - 1 \cdot 14.76) - 2 \cdot 11.11 \cdot (1 \cdot 14.76 - 1 \cdot 14.76) \cdot (1 - 0.8551))/100$

= $0 \ \text{cm}^2$

A_2 = smaller of the following= 5.78 cm^2

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.27) \cdot 0.8551 \cdot 34.35)/100$

= $5.78 \ \text{cm}^2$

= $2 \cdot (t_n - t_{rn}) \cdot f_{r2} \cdot L_{pr}$

= $(2 \cdot (11.11 - 1.27) \cdot 0.8551 \cdot 34.35)/100$

= $5.78 \ \text{cm}^2$

A_3 = smaller of the following= 2.0172 cm^2

= $5 \cdot t \cdot t_i \cdot f_{r2}$

= $(5 \cdot 14.76 \cdot 9.51 \cdot 0.8551)/100$

= 6.0024 cm^2

= $5 \cdot t_i \cdot t_i \cdot f_{r2}$

= $(5 \cdot 9.51 \cdot 9.51 \cdot 0.8551)/100$

= 3.8686 cm^2

= $2 \cdot h \cdot t_i \cdot f_{r2}$

= $(2 \cdot 12.4 \cdot 9.51 \cdot 0.8551)/100$

= 2.0172 cm^2

A_{41} = $Leg^2 \cdot f_{r3}$

= $(10.36^2 \cdot 0.8551)/100$

= 0.9168 cm^2

A_{42} = $Leg^2 \cdot f_{r4}$

= $(10.66^2 \cdot 1)/100$

= 1.1355 cm^2

A_{43} = $Leg^2 \cdot f_{r2}$

= $(11.71^2 \cdot 0.8551)/100$

= 1.1735 cm^2

A_5 = $(D_p - d - 2 \cdot t_n) \cdot t_e \cdot f_{r4}$

= $((1{,}017.12 - 638.18 - 2 \cdot 11.11) \cdot 16.36 \cdot 1)/100$

= 58.3561 cm^2

$Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$

$= 0 + 5.78 + 2.0172 + 0.9168 + 1.1355 + 1.1735 + 58.3561$

$=$ 69.3791 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_n,\ t_e] =$ 11.11 mm

$t_{c(\min)} = \min\,[6\ \text{mm},\ 0.7 \cdot t_{\min}] =$ 6 mm

$t_{c(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.36 = 7.25$ mm

Outer fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_e,\ t] =$ 14.76 mm

$t_{w(\min)} = 0.5 \cdot t_{\min} = 7.38\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 10.66 = 7.46\ \text{mm}$

Lower fillet: $t_{\min} = \min\,[19\ \text{mm},\ t_n,\ t] =$ 11.11 mm

$t_{w(\min)} = 0.7 \cdot t_{\min} = 7.78\ \text{mm}$

$t_{w(actual)} = 0.7 \cdot \text{Leg} = 0.7 \cdot 11.71 = 8.2\ \text{mm}$

UG-45 Nozzle Neck Thickness Check

$t_{a\text{UG-28}} = 2.86\ \text{mm}$

$t_a = \max\,[t_{a\text{UG-28}},\ t_{a\text{UG-22}}]$

$= \max\,[2.86,\ 0]$

$= 2.86\ \text{mm}$

$t_{b2} = \dfrac{P \cdot R}{S \cdot E - 0.6 \cdot P} + \text{Corrosion}$

$= \dfrac{1.1342 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 1.1342} + 3.24$

$= 5.09 \text{ mm}$

$t_{b2} = \max[t_{b2},\ t_{bUG16}]$

$= \max[5.09,\ 3.09]$

$= 5.09 \text{ mm}$

$t_b = \min[t_{b3},\ t_{b2}]$

$= \min[9.92,\ 5.09]$

$= 5.09 \text{ mm}$

$t_{\text{UG-45}} = \max[t_a,\ t_b]$

$= \max[2.86,\ 5.09]$

$= 5.09 \text{ mm}$

Available nozzle wall thickness new, $t_n = 0.875 \cdot 12.7 = 11.11$ mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 40 °C) UG-28(c)

$\dfrac{L}{D_o} = \dfrac{179.17}{660.4} = 0.2713$

$\dfrac{D_o}{t} = \dfrac{660.4}{1.27} = 518.7274$

From table G: $A = 0.000443$

From table CS-2 Metric: $B = 449.9414 \text{ kg/cm}^2 (441.24 \text{ bar})$

$P_a = \dfrac{4 \cdot B}{3 \cdot (D_o/t)} = \dfrac{4 \cdot 441.24}{3 \cdot (660.4/1.27)} = 1.13 \text{ bar}$

Design thickness for external pressure P_a = 1.13 bar

$t_a = t + \text{Corrosion} = 1.27 + 1.59 = 2.86$ mm

Shipping Saddle

ASME Section VIII Division 1, 2021 Edition Metric	
Saddle Material	Carbon steel
Saddle Construction	Centered web
Saddle Allowable Stress, S_s	1,406 kg_f/cm^2
Saddle Yield Stress, S_y	2,672 kg_f/cm^2
Dimensions	
Shipping saddle angular position	0°
Right saddle distance to datum	1,087.23 mm
Tangent To Tangent Length, L	7,985.3 mm
Saddle separation, L_s	5,709.24 mm
Vessel Radius, R	2,268 mm
Tangent Distance Left, A_l	1,138.03 mm
Tangent Distance Right, A_r	1,138.03 mm
Saddle Height, H_s	2,580.86 mm
Saddle Contact Angle, θ	120°
Web Plate Thickness, t_s	15.88 mm
Base Plate Length, E	3,970.87 mm
Base Plate Width, F	254 mm
Base Plate Thickness, t_b	15.88 mm
Number of Stiffening Ribs, n	9
Largest Stiffening Rib Spacing, d_i	491.6 mm
Stiffening Rib Thickness, t_w	12.7 mm
Saddle Width, b	228.6 mm
Weight	
	Empty, New
Weight on Left Saddle	14,544.44 kg
Weight on Right Saddle	14,245.52 kg
Weight of Saddle Pair	1,184.78 kg

Shipping Load Cases	
	Road
K_L	1
K_T	0.5
K_V	1.5
Include Vertical Coincident with Horizontal	✔
Include Wind	✘
Wind Pressure, bar	✘
Check Saddle Plates	✘

Notes
(1) Saddle calculations are based on the method presented in "Stresses in Large Cylindrical Pressure Vessels on Two Saddle Supports" by L.P. Zick.

Stress Summary										
Load	Condition	Saddle	Bending + pressure between saddles (kg_f/cm^2)				Bending + pressure at the saddle (kg_f/cm^2)			
			S_1 (+)	allow (+)	S_1 (-)	allow (-)	S_2 (+)	allow (+)	S_2 (-)	allow (-)
Road	Empty & New	Right Saddle	15.012	2,164.042	15.012	862.047	2.972	2,404.491	2.972	862.047
		Left Saddle					2.9	2,276.007	2.9	862.047

Stress Summary										
Load	Condition	Saddle	Tangential shear (kg_f/cm^2)		Circumferential stress (kg_f/cm^2)		Stress over saddle (kg_f/cm^2)		Splitting (kg_f/cm^2)	
			S_3	allow	S_4 (horns)	allow (+/-)	S_5	allow	S_6	allow
Road	Empty & New	Right Saddle	101.852	1,923.593	-806.939	2,404.491	620.41	2,404.491	209.896	2,404.498
		Left Saddle	104.041	1,820.805	-819.34	2,276.007	629.944	2,276.007	213.122	2,404.498

Saddle reactions due to shipping
Shipping load longitudinal reaction, Q_l
Shipping load transverse reaction, Q_t
Shipping load vertical reaction, Q_v

Equations

$$Q_v = \frac{K_V \cdot W \cdot L_{COG}}{L_s}$$

If consider vertical coincident, $V_v = Q_v$

$$Q_t = \frac{K_T \cdot W \cdot H_s}{R_o \cdot \text{Sin}(\theta \ / \ 2)} + V_v$$

$$Q_l = \frac{K_L \cdot W \cdot H_s}{L_s} + V_v$$

$$Q = W + \max\ [Q_t, Q_l]$$

Road

Empty & New	Right Saddle	$V_v = Q_v = \frac{1.5 \cdot 28{,}789.96 \cdot 2{,}824.98}{5{,}709.24}$	21,368.26 kg_f
		$Q_t = \frac{0.5 \cdot 14{,}245.52 \cdot 2{,}580.86}{2{,}268 \cdot \text{Sin}(120 \ / \ 2)} + 21{,}368.26$	30,727.47 kg_f
		$Q_l = \frac{1 \cdot 28{,}789.96 \cdot 2{,}580.86}{5{,}709.24} + 21{,}368.26$	34,382.76 kg_f
		$Q = 14{,}245.52 + \max\ [30{,}727.47, 34{,}382.76]$	48,628.28 kg_f
	Left Saddle	$V_v = Q_v = \frac{1.5 \cdot 28{,}789.96 \cdot 2{,}884.26}{5{,}709.24}$	21,816.68 kg_f
		$Q_t = \frac{0.5 \cdot 14{,}544.44 \cdot 2{,}580.86}{2{,}268 \cdot \text{Sin}(120 \ / \ 2)} + 21{,}816.68$	31,372.28 kg_f
		$Q_l = \frac{1 \cdot 28{,}789.96 \cdot 2{,}580.86}{5{,}709.24} + 21{,}816.68$	34,831.18 kg_f
		$Q = 14{,}544.44 + \max\ [31{,}372.28, 34{,}831.18]$	49,375.62 kg_f

Load Case 1: Road, Empty & New

Longitudinal stress between saddles (Road, Empty & New, left saddle loading and geometry govern)

$$S_1 = \pm \frac{3 \cdot K_1 \cdot Q \cdot (L \ / \ 12)}{\pi \cdot R^2 \cdot t} = \frac{300 \cdot 0.4395 \cdot 49{,}375.62 \cdot (7{,}985.3 \ / \ 12)}{\pi \cdot 2{,}259^{\ 2} \cdot 18} = 15.012 \ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Tensile stress is acceptable $\left(\leq 0.9 \cdot S_y \cdot E = 2{,}164.042 \ \ \mathrm{kg}_f/\mathrm{cm}^2 \right)$

Compressive stress is acceptable $\left(\leq S_c = 862.047 \ \ \mathrm{kg}_f/\mathrm{cm}^2 \right)$

Longitudinal stress at the right saddle (Road, Empty & New)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 785.66}{3} + 7{,}985.3 + \frac{2 \cdot 788.08}{3} = 9{,}034.46 \ \ \mathrm{mm}$$

$$w = \frac{W_t \cdot (1 + K_V)}{L_e} = \frac{28{,}789.96 \cdot (1 + 1.5) \cdot 10}{9{,}034.46} = 79.67 \ \ \mathrm{kg}_f/\mathrm{cm}$$

Bending moment at the right saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_r \cdot A_r}{3} + \frac{A_r^2}{2} - \frac{R^2 - H_r^2}{4} \right)$$
$$= \frac{79.67}{10000} \cdot \left(\frac{2 \cdot 788.08 \cdot 1{,}138.03}{3} + \frac{1{,}138.03^{\ 2}}{2} - \frac{2{,}268^{\ 2} - 788.08^{\ 2}}{4} \right)$$
$$= 914.4 kg_f - m$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{914.4 \cdot 1e5 \cdot 9.3799}{\pi \cdot 2{,}259^{\ 2} \cdot 18} = 2.972 \ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Tensile stress is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}404.491 \ \ \mathrm{kg}_f/\mathrm{cm}^2 \right)$

Compressive stress is acceptable $\left(\leq S_c = 862.047 \ \ \mathrm{kg}_f/\mathrm{cm}^2 \right)$

Tangential shear stress in the shell (right saddle, Road, Empty & New)

$$Q_{shear} = Q - w \cdot \left(A_r + \frac{2 \cdot H_r}{3} \right) = 48{,}628.28 - 7.97 \cdot \left(1{,}138.03 + \frac{2 \cdot 788.08}{3} \right) = 35{,}376.32 \ \ \mathrm{kg}_f$$

$$S_3 = \frac{K_{2.2} \cdot Q_{shear}}{R \cdot t} = \frac{1.1707 \cdot 100 \cdot 35{,}376.32}{2{,}259 \cdot 18} = 101.852 \ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot (0.9 \cdot S_y) = 1{,}923.593 \ \ \mathrm{kg}_f/\mathrm{cm}^2$)

Circumferential stress at the right saddle horns (Road, Empty & New)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{12 \cdot K_3 \cdot Q \cdot R}{L \cdot t^2}$$
$$= \frac{-100 \cdot 48{,}628.28}{4 \cdot 18 \cdot \left(228.6 + 1.56 \cdot \sqrt{2{,}268 \cdot 18}\right)} - \frac{12 \cdot 0.0134 \cdot 100 \cdot 48{,}628.28 \cdot 2{,}259}{7{,}985.3 \cdot 18^2}$$
$$= -806.939 \ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Circumferential stress at saddle horns is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}404.491 \ \ \mathrm{kg}_f/\mathrm{cm}^2 \right)$

Ring compression in shell over right saddle (Road, Empty & New)

$$S_5 = \frac{K_5 \cdot Q}{t \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{100 \cdot 0.7603 \cdot 48{,}628.28}{18 \cdot \left(15.88 + 1.56 \cdot \sqrt{2{,}268 \cdot 18}\right)}$$

$$= \underline{620.41} \quad kg_f/cm^2$$

Ring compression in shell is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}404.491 \quad kg_f/cm^2 \right)$

Saddle splitting load (right, Road, Empty & New)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 29.6985 \cdot 1.5875 + 0 \cdot 0$ = 47.1464 cm^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{100 \cdot 0.2035 \cdot 48{,}628.28}{4{,}714.6432} = \underline{209.896} \quad kg_f/cm^2$$

Stress in saddle is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}404.498 \quad kg_f/cm^2 \right)$

Longitudinal stress at the left saddle (Road, Empty & New)

$$L_e = \frac{2 \cdot H_l}{3} + L + \frac{2 \cdot H_r}{3} = \frac{2 \cdot 785.66}{3} + 7{,}985.3 + \frac{2 \cdot 788.08}{3} = 9{,}034.46 \quad mm$$

$$w = \frac{W_t \cdot (1 + K_V)}{L_e} = \frac{28{,}789.96 \cdot (1 + 1.5) \cdot 10}{9{,}034.46} = 79.67 \quad kg_f/cm$$

Bending moment at the left saddle:

$$M_q = w \cdot \left(\frac{2 \cdot H_l \cdot A_l}{3} + \frac{A_l^2}{2} - \frac{R^2 - H_l^2}{4} \right)$$

$$= \frac{79.67}{10000} \cdot \left(\frac{2 \cdot 785.66 \cdot 1{,}138.03}{3} + \frac{1{,}138.03^{\ 2}}{2} - \frac{2{,}268^{\ 2} - 785.66^{\ 2}}{4} \right)$$

$$= 892.1 kg_f - m$$

$$S_2 = \pm \frac{M_q \cdot K_1{}'}{\pi \cdot R^2 \cdot t} = \frac{892.1 \cdot 1e5 \cdot 9.3799}{\pi \cdot 2{,}259^{\ 2} \cdot 18} = 2.9 \quad kg_f/cm^2$$

Tensile stress is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}276.007 \quad kg_f/cm^2 \right)$

Compressive stress is acceptable $\left(\leq S_c = 862.047 \quad kg_f/cm^2 \right)$

Tangential shear stress in the shell (left saddle, Road, Empty & New)

$$Q_{shear} = Q - w \cdot \left(A_l + \frac{2 \cdot H_l}{3} \right) = 49{,}375.62 - 7.97 \cdot \left(1{,}138.03 + \frac{2 \cdot 785.66}{3} \right) = 36{,}136.53 \quad kg_f$$

$$S_3 = \frac{K_{2.2} \cdot Q_{shear}}{R \cdot t} = \frac{1.1707 \cdot 100 \cdot 36{,}136.53}{2{,}259 \cdot 18} = \underline{104.041} \quad kg_f/cm^2$$

Tangential shear stress is acceptable ($\leq 0.8 \cdot (0.9 \cdot S_y) = 1{,}820.805 \quad kg_f/cm^2$)

Circumferential stress at the left saddle horns (Road, Empty & New)

$$S_4 = \frac{-Q}{4 \cdot t \cdot \left(b + 1.56 \cdot \sqrt{R_o \cdot t}\right)} - \frac{12 \cdot K_3 \cdot Q \cdot R}{L \cdot t^2}$$

$$= \frac{-100 \cdot 49{,}375.62}{4 \cdot 18 \cdot \left(228.6 + 1.56 \cdot \sqrt{2{,}268 \cdot 18}\right)} - \frac{12 \cdot 0.0134 \cdot 100 \cdot 49{,}375.62 \cdot 2{,}259}{7{,}985.3 \cdot 18^2}$$

$= \underline{-819.34}\ \ \mathrm{kg}_f/\mathrm{cm}^2$

Circumferential stress at saddle horns is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}276.007\ \ \mathrm{kg}_f/\mathrm{cm}^2\right)$

Ring compression in shell over left saddle (Road, Empty & New)

$$S_5 = \frac{K_5 \cdot Q}{t \cdot \left(t_s + 1.56 \cdot \sqrt{R_o \cdot t_c}\right)}$$

$$= \frac{100 \cdot 0.7603 \cdot 49{,}375.62}{18 \cdot \left(15.88 + 1.56 \cdot \sqrt{2{,}268 \cdot 18}\right)}$$

$$= \underline{629.944}\ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Ring compression in shell is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}276.007\ \ \mathrm{kg}_f/\mathrm{cm}^2\right)$

Saddle splitting load (left, Road, Empty & New)

Area resisting splitting force = Web area + wear plate area

$A_e = H_{eff} \cdot t_s + t_p \cdot W_p = 29.6985 \cdot 1.5875 + 0 \cdot 0$ = 47.1464 cm^2

$$S_6 = \frac{K_8 \cdot Q}{A_e} = \frac{100 \cdot 0.2035 \cdot 49{,}375.62}{4{,}714.6432} = \underline{213.122}\ \ \mathrm{kg}_f/\mathrm{cm}^2$$

Stress in saddle is acceptable $\left(\leq 0.9 \cdot S_y = 2{,}404.498\ \ \mathrm{kg}_f/\mathrm{cm}^2\right)$

Cylinder #4

ASME Section VIII Division 1, 2021 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		7	40	5
External		0.8	40	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.83	8,663.5	0.98
Test horizontal		0.44	4,500	1
Dimensions				
Inner Diameter		4,500 mm		
Length		568.5 mm		
Nominal Thickness		17 mm		
Corrosion	**Inner**	1.6 mm		
	Outer	1.64 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		1,074.26		9,041.6
Corroded		869.51		9,054.47
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Full UW-11(a) Type 2		
Bottom Circumferential seam		Full UW-11(a) Type 2		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	16.06 mm
Design thickness due to external pressure (t_e)	15.93 mm
Design thickness due to combined loadings + corrosion	9.72 mm
Maximum allowable working pressure (MAWP)	7.57 bar
Maximum allowable pressure (MAP)	10.38 bar
Maximum allowable external pressure (MAEP)	0.97 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \frac{0.83 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.83} =$	1.36 mm
$\text{Stress ratio} = \frac{t_r \cdot E^*}{t_n - c} = \frac{1.36 \cdot 1}{17 - 3.24} =$	0.0987
$\text{Stress ratio} longitud \in al = \frac{79.262 \cdot 1}{1{,}407.208 \cdot 1} =$	0.0563
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.83 \cdot 2{,}251.6}{1{,}380 \cdot 1.00 - 0.60 \cdot 7.83} + 3.24 = 16.06 \text{ mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}380 \cdot 1.00 \cdot 13.76}{2{,}251.6 + 0.60 \cdot 13.76} - 0.83 = 7.57 \text{ bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}380 \cdot 1.00 \cdot 17}{2{,}250 + 0.60 \cdot 17} = 10.38 \text{ bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}534} = 0.9479$$

$$\frac{D_o}{t} = \frac{4{,}534}{12.69} = 357.2703$$

From table G: $A = 0.000215$

From table CS-2 Metric: $B = 218.5894 \ \text{kg/cm}^2 (214.36 \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 214.36}{3 \cdot (4{,}534/12.69)} = 0.8 \ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.69 + 3.24 = 15.93 \text{ mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}534} = 0.9479$$

$$\frac{D_o}{t} = \frac{4{,}534}{13.76} = 329.5058$$

From table G: $A = 0.000241$

From table CS-2 Metric: $B = 245.2108 \ \text{kg/cm}^2 (240.4692 \ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 240.47}{3 \cdot (4{,}534/13.76)} = 0.97 \text{ bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 17}{2{,}258.5}\right) \cdot \left(1 - \frac{2{,}258.5}{\infty}\right) = 0.3764\,\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{10 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48} + 10000 \cdot 9{,}228.4 \frac{}{\pi \cdot 2{,}258.48\ ^2} = 20.4634 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{20.4634}{0.8 \cdot 4{,}534} = 0.0553$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}534}\right)^2} = 1.3688$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.3688 + 1.3688 \cdot 0.0553}{7^2 - 1 + 1.3688} = 1.0015$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1.0015 \cdot 0.8 = 0.8) \leq 0.97$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Wind Loading Check at Bottom Seam (Bergman, ASME paper 54-A-104)

$$P_v = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{0.60 \cdot 10 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48} + 10000 \cdot 19.6 \frac{}{\pi \cdot 2{,}258.48\ ^2} = -60.2834 \quad \text{kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot - \frac{60.2834}{0.8 \cdot 4{,}534} = -0.163$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4{,}297.99}{4{,}534}\right)^2} = 1.3688$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.3688 + 1.3688 \cdot -0.163}{7^2 - 1 + 1.3688} = 1$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1 \cdot 0.8 = 0.8) \leq 0.97$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.08 \cdot 10 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48} + 10000 \cdot 125,019.9 \frac{}{\pi \cdot 2{,}258.48\ ^2} = 93.9580 \text{ kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot \frac{93.958}{0.8 \cdot 4{,}534} = 0.254$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4,297.99}{4,534}\right)^2} = 1.3688$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.3688 + 1.3688 \cdot 0.254}{7^2 - 1 + 1.3688} = 1.007$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1.007 \cdot 0.8 = 0.81) \leq 0.97$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check at Bottom Seam(Bergman, ASME paper 54-A-104)

$$P_v = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{0.52 \cdot 10 \cdot \text{-}142,603.6}{2 \cdot \pi \cdot 2{,}258.48} + 10000 \cdot \frac{210}{\pi \cdot 2{,}258.48\ ^2} = -51.7232 \text{ kg/cm}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = 9.803 \cdot - \frac{51.7232}{0.8 \cdot 4{,}534} = -0.1398$$

$$n = 7$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{4,297.99}{4,534}\right)^2} = 1.3688$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{7^2 - 1 + 1.3688 + 1.3688 \cdot -0.1398}{7^2 - 1 + 1.3688} = 1$$

$$RatioP_e \cdot P_e \leq \text{MAEP}$$

$$(1 \cdot 0.8 = 0.8) \leq 0.97$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads									
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Location	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c						
Operating, Hot & Corroded	7	1,407.2	769.8	40	3.24	Top	Wind	5.68	5.56
							Seismic	6.21	5.04
						Bottom	Wind	6.42	6.13
							Seismic	6.48	6.07
Operating, Hot & New	7	1,407.2	843.3	40	0	Top	Wind	5.67	5.54
							Seismic	6.21	5
						Bottom	Wind	6.42	6.13
							Seismic	6.48	6.07
Hot Shut Down, Corroded	0	1,407.2	769.8	40	3.24	Top	Wind	0.04	0.27
							Seismic	0.5	1.22
						Bottom	Wind	0.71	0.43
							Seismic	0.78	0.37
Hot Shut Down, New	0	1,407.2	843.3	40	0	Top	Wind	0.05	0.27
							Seismic	0.5	1.17
						Bottom	Wind	0.72	0.43
							Seismic	0.78	0.37
Empty, Corroded	0	1,407.2	769.8	21.11	3.24	Top	Wind	0.04	0.27
							Seismic	0.06	0.41
						Bottom	Wind	0.02	0.01
							Seismic	0.02	0.01
Empty, New	0	1,407.2	843.3	21.11	0	Top	Wind	0.05	0.27
							Seismic	0.06	0.43
						Bottom	Wind	0.02	0.01
							Seismic	0.02	0.01
Vacuum	-0.8	1,407.2	769.8	40	3.24	Top	Wind	1.23	1.46
							Seismic	0.28	2.41
						Bottom	Wind	0.06	0.41
							Seismic	0.12	0.52
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,407.2	769.8	40	3.24	Top	Weight	0.16	0.22
						Bottom	Weight	0.71	0.71

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \ \ \mathrm{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \mathrm{kg/cm}^2$$

$$S_{cHC} = \min(B, S) = 769.8 \ \mathrm{kg/cm^2}$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cHN} = \min(B, S) = 843.3 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cCN} = \min(B, S) = 843.3 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cC} = \min(B, S) = 769.8 \text{ kg/cm}^2$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cVC} = \min(B, S) = 769.8 \text{ kg/cm}^2$$

Operating, Hot & Corroded, Wind, Above Support Point

t_p = $$\frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

= $$\frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$$

= 5.7 mm

t_m = $$\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

= $$9,228.4 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0.04 mm

t_w = $$\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{0.60 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= 0.06 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $5.7 + 0.04 - (0.06)$

= 5.68 mm

$t_{w\,c}$ = $$\frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= 0.1 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.04 + (0.1) - (5.7)|$

= 5.56 mm

Maximum allowable working pressure, Longitudinal Stress

P = $$\frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

= $$\frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (13.76 - 0.04 + (0.06))}{2{,}251.6 - 0.40 \cdot (13.76 - 0.04 + (0.06))}$$

= 16.94 bar

Operating, Hot & New, Wind, Above Support Point

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$

= 5.7 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 9{,}249.1 \dfrac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.04 mm

$t_w = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot 24{,}350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.07 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 5.7 + 0.04 - (0.07)$

= 5.67 mm

$t_{w\,c} = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{24{,}350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.12 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0.04 + (0.12) - (5.7)|$

= 5.54 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (17 - 0.04 + (0.07))}{2{,}250 - 0.40 \cdot (17 - 0.04 + (0.07))}$

= 20.96 bar

Hot Shut Down, Corroded, Wind, Above Support Point

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{9,228.4}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0.07 mm

$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.07 - (0.11)|$

= 0.04 mm

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.19 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.07 + (0.19) - (0)$

= 0.27 mm

Hot Shut Down, New, Wind, Above Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 9,249.1 \frac{}{\pi \cdot 2,258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$$

= 0.07 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= 0.60 \cdot 24,350.4 \frac{}{2 \cdot \pi \cdot 2,258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.12 mm

$$t_t = |t_p + t_m - t_w| \quad \text{(total, net compressive)}$$

$$= |0 + 0.07 - (0.12)|$$

= 0.05 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{24,350.4}{2 \cdot \pi \cdot 2,258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.2 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.07 + (0.2) - (0)$$

= 0.27 mm

Empty, Corroded, Wind, Above Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= 9,228.4 \frac{}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$$

= 0.07 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= 0.60 \cdot 20,866.3 \frac{}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$$

= 0.11 mm

$$t_t = |t_p + t_m - t_w|$$ (total, net compressive)

$$= |0 + 0.07 - (0.11)|$$

= 0.04 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$$

= 0.19 mm

$$t_c = t_{mc} + t_{wc} - t_{pc}$$ (total required, compressive)

$$= 0.07 + (0.19) - (0)$$

= 0.27 mm

Empty, New, Wind, Above Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 9,249.1 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$$

= 0.07 mm

$$t_w = 0.6 \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= 0.60 \cdot 24,350.4 \frac{}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.12 mm

$$t_t = |t_p + t_m - t_w| \quad \text{(total, net compressive)}$$

$$= |0 + 0.07 - (0.12)|$$

= 0.05 mm

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.2 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.07 + (0.2) - (0)$$

= 0.27 mm

Vacuum, Wind, Above Support Point

t_p = $\dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

= $\dfrac{9{,}228.4}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0.07 mm

t_w = $0.6 \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.60 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|-1.19 + 0.07 - (0.11)|$

= 1.23 mm

t_{wc} = $\dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.19 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.07 + (0.19) - (-1.19)$

= 1.46 mm

Maximum Allowable External Pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

= $\dfrac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0.07 - 0.19)}{2{,}251.6 - 0.40 \cdot (13.76 - 0.07 - 0.19)}$

= 9.07 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Above Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{4,119.2}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$$

= 0.03 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$$

= 0.19 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0.03 - (0.19)|$

= 0.16 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.03 + (0.19) - (0)$

= 0.22 mm

Operating, Hot & Corroded, Wind, Below Support Point

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$

= 5.7 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 19.6 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{\text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.71 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 5.7 + 0 - (-0.71)$

= 6.42 mm

$t_{w\,c} = \dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.60 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.43 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.43) - (5.7)|$

= 6.13 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (13.76 - 0 + (-0.71))}{2{,}251.6 - 0.40 \cdot (13.76 - 0 + (-0.71))}$

= 16.03 bar

Operating, Hot & New, Wind, Below Support Point

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|} \quad \text{(Pressure)}$$

$$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$$

= 5.7 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{19.6}{\pi \cdot 2{,}258.5^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{\text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.72 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 5.7 + 0 - (-0.72)$$

= 6.42 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot \text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.43 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.43) - (5.7)|$$

= 6.13 mm

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (17 - 0 + (-0.72))}{2{,}250 - 0.40 \cdot (17 - 0 + (-0.72))}$$

= 20.03 bar

Hot Shut Down, Corroded, Wind, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{19.6}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{\text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.71 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0 - (-0.71)$$

= 0.71 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.43 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.43) - (0)|$$

= 0.43 mm

Hot Shut Down, New, Wind, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{19.6}{\pi \cdot 2{,}258.5^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{-142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.72 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0 - (-0.72)$$

= 0.72 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot -142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.43 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.43) - (0)|$$

= 0.43 mm

Empty, Corroded, Wind, Below Support Point

t_p = 0 mm (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $\frac{19.6}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0 mm

t_w = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{-3{,}538.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.02 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0 - (-0.02)$

= 0.02 mm

$t_{w\,c}$ = $\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.60 \cdot -3{,}538.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.01 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.01) - (0)|$

= 0.01 mm

Empty, New, Wind, Below Support Point

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 19.6 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{-4{,}052.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.02 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.02)$

= 0.02 mm

$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot -4{,}052.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.01 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.01) - (0)|$

= 0.01 mm

Vacuum, Wind, Below Support Point

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|} \quad \text{(Pressure)}$$

$$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |0.8|}$$

= -0.65 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{19.6}{\pi \cdot 2{,}258.48^{\;2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{-142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.71 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= -0.65 + 0 - (-0.71)$$

= 0.06 mm

$$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|} \quad \text{(Pressure)}$$

$$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$$

= -1.19 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{19.6}{\pi \cdot 2{,}258.48^{\;2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_{wc} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot -142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$$

= -0.78 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0 + (-0.78) - (-1.19)$$

= 0.41 mm

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0 - - 0.78)}{2{,}251.6 - 0.40 \cdot (13.76 - 0 - - 0.78)}$$

= 9.78 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{0}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{-142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.71 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.71)$

= 0.71 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.71) - (0)|$

= 0.71 mm

Operating, Hot & Corroded, Seismic, Above Support Point

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$

= 5.7 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $125{,}019.9 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.55 mm

t_w = $\dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.52 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $5.7 + 0.55 - (0.05)$

= 6.21 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.11 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.55 + (0.11) - (5.7)|$

= 5.04 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (13.76 - 0.55 + (0.05))}{2{,}251.6 - 0.40 \cdot (13.76 - 0.55 + (0.05))}$

= 16.29 bar

Operating, Hot & New, Seismic, Above Support Point

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$

= 5.7 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $128,051.2 \dfrac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.57 mm

t_w = $\dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.52 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.06 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $5.7{+}0.57 - (0.06)$

= 6.21 mm

$t_{w\,c}$ = $\dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{1.08 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.13 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0.57 + (0.13) - (5.7)|$

= 5 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (17 - 0.57 + (0.06))}{2{,}250{-}0.40 \cdot (17 - 0.57 + (0.06))}$

= 20.29 bar

Hot Shut Down, Corroded, Seismic, Above Support Point

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{125,019.9}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.55 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.55 - (0.05)$

= 0.5 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{125,019.9}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 1.01 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.21 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 1.01 + (0.21) - (0)$

= 1.22 mm

Hot Shut Down, New, Seismic, Above Support Point

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 128,051.2 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.57 mm

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.06 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.57 - (0.06)$

= 0.5 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 128,051.2 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$

= 0.95 mm

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$

= 0.22 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.95 + (0.22) - (0)$

= 1.17 mm

Empty, Corroded, Seismic, Above Support Point

t_p = 0 mm (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $25,479.9 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0.11 mm

t_w = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.52 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= 0.05 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.11 - (0.05)$

= 0.06 mm

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

= $25,479.9 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0.21 mm

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

= $\frac{1.08 \cdot 20,866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.21 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.21 + (0.21) - (0)$

= 0.41 mm

Empty, New, Seismic, Above Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 28,678.7 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0.13 mm

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.52 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= 0.06 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0.13 - (0.06)$$

= 0.06 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 28,678.7 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 826.96 \cdot 1.00} \cdot 98066.5$$

= 0.21 mm

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot 24,350.4}{2 \cdot \pi \cdot 2{,}258.5 \cdot 826.96 \cdot 1.00} \cdot 98.0665$$

= 0.22 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \quad \text{(total required, compressive)}$$

$$= 0.21 + (0.22) - (0)$$

= 0.43 mm

Vacuum, Seismic, Above Support Point

$t_p = \dfrac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \dfrac{125{,}019.9}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 1.01 mm

$t_w = (0.6 - 0.14 \cdot S_{DS}) \cdot \dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.52 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.1 mm

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |-1.19 + 1.01 - (0.1)|$

= 0.28 mm

$t_{w\,c} = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot 20{,}866.3}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= 0.21 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 1.01 + (0.21) - (-1.19)$

= 2.41 mm

Maximum Allowable External Pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$

$= \dfrac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 1.01 - 0.21)}{2{,}251.6 - 0.40 \cdot (13.76 - 1.01 - 0.21)}$

= 8.43 bar

Operating, Hot & Corroded, Seismic, Below Support Point

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

$$= \frac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$$

= 5.7 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{210}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.77 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 5.7 + 0 - (-0.77)$$

= 6.48 mm

$$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.37 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}|$$ (total, net tensile)

$$= |0 + (-0.37) - (5.7)|$$

= 6.07 mm

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (13.76 - 0 + (-0.77))}{2{,}251.6 - 0.40 \cdot (13.76 - 0 + (-0.77))}$$

= 15.95 bar

Operating, Hot & New, Seismic, Below Support Point

t_p = $$\frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$$ (Pressure)

= $$\frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |7|}$$

= 5.7 mm

t_m = $$\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

= $$\frac{221}{\pi \cdot 2{,}258.5^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

t_w = $$\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{1.08 \cdot \text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.78 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $5.7 + 0 - (- 0.78)$

= 6.48 mm

$t_{w\,c}$ = $$\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

= $$\frac{0.52 \cdot \text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.37 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (- 0.37) - (5.7)|$

= 6.07 mm

Maximum allowable working pressure, Longitudinal Stress

P = $$\frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

= $$\frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 \cdot (17 - 0 + (- 0.78))}{2{,}250 - 0.40 \cdot (17 - 0 + (- 0.78))}$$

= 19.96 bar

Hot Shut Down, Corroded, Seismic, Below Support Point

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{210}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}142,603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.77 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.77)$

= 0.78 mm

$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}142,603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.37 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.37) - (0)|$

= 0.37 mm

Hot Shut Down, New, Seismic, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= \frac{221}{\pi \cdot 2{,}258.5^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot \text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.78 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.78)$

= 0.78 mm

$$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.52 \cdot \text{-}142{,}880.6}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.37 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.37) - (0)|$

= 0.37 mm

Empty, Corroded, Seismic, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 81.2 \frac{}{\pi \cdot 2{,}258.48^{\;2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{1.08 \cdot \text{-}3{,}538.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.02 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 0 + 0 - (-0.02)$$

= 0.02 mm

$$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.52 \cdot \text{-}3{,}538.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.01 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}|$$ (total, net tensile)

$$= |0 + (-0.01) - (0)|$$

= 0.01 mm

Empty, New, Seismic, Below Support Point

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 92.6 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{1.08 \cdot \text{-}4{,}052.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.02 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0 - (-0.02)$$

= 0.02 mm

$$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.52 \cdot \text{-}4{,}052.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$$

= -0.01 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.01) - (0)|$$

= 0.01 mm

Vacuum, Seismic, Below Support Point

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -0.65 mm

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{210}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 1.00} \cdot 98.0665$

= -0.77 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.65 + 0 - (-0.77)$

= 0.12 mm

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= \frac{210}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_{wc} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}142{,}603.6}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= -0.67 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (-0.67) - (-1.19)$

= 0.52 mm

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0 - -0.67)}{2{,}251.6 - 0.40 \cdot (13.76 - 0 - -0.67)}$$

$= \underline{9.7}$ bar

Legs #1

Inputs	
Leg material	
Leg description	W 18x106 (Flange out)
Number of legs, N	4
Overall length	1,828.8 mm
Base to girth seam length	1,524 mm
Effective length coefficient, K	1.5
Coefficient, C_m	0.85
Leg yield stress, F_y	2,531.05 kg_f/cm^2
Leg elastic modulus, E	2,038,901.782 kg_f/cm^2
Anchor Bolts	
Anchor bolt size	1.875" series 8 threaded
Anchor bolt material	
Bolt circle, BC	4,584.8 mm
Anchor bolts/leg, n	1
Anchor bolt allowable stress, S_b	1,406.139 kg_f/cm^2
Anchor bolt corrosion allowance	0 mm
Anchor bolt hole clearance	9.53 mm
Base Plate	
Base plate length	584.2 mm
Base plate width	381 mm
Base plate thickness	57 mm (19.58 mm required)
Base plate allowable stress	1,687.367 kg_f/cm^2
Foundation allowable bearing stress	116.569 kg_f/cm^2
Welds	
Leg to shell fillet weld	60 mm (58.77 mm required)
Legs braced	No

Note: The support attachment point is assumed to be 25.4 mm up from the cylinder circumferential seam.

Wind operating corroded, Moment = 9,208.8 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	22,519.7	470.7	112.237	181.025	0	0.1731	0.1823
	90	40,917.9	54.2	203.932	291.225	12.406	0.3019	0.3160
	180	42,949.0	470.7	214.055	326.427	0	0.3207	0.3364
	270	40,917.9	54.2	203.932	291.225	12.406	0.3019	0.3160
45	0	22,519.7	262.4	112.237	168.459	42.465	0.1885	0.2002
	90	22,519.7	262.4	112.237	168.459	42.465	0.1885	0.2002
	180	42,949.0	262.4	214.055	313.86	42.465	0.3364	0.3543
	270	42,949.0	262.4	214.055	313.86	42.465	0.3364	0.3543
32	0	22,519.7	353.7	112.237	173.501	42.893	0.1913	0.2034
	90	22,519.7	171.2	112.237	164.277	33.215	0.1816	0.1921
	180	42,949.0	353.7	214.055	318.903	42.893	0.3392	0.3575
	270	42,949.0	171.2	214.055	309.678	33.215	0.3294	0.3462

Wind operating new, Moment = 9,229.6 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	23,083.5	470.7	115.046	185.038	0	0.1771	0.1865
	90	41,865.2	54.2	208.653	297.967	12.405	0.3087	0.3232
	180	43,900.8	470.7	218.799	333.201	0	0.3276	0.3435
	270	41,865.2	54.2	208.653	297.967	12.405	0.3087	0.3232
45	0	23,083.5	262.4	115.046	172.471	42.464	0.1926	0.2044
	90	23,083.5	262.4	115.046	172.471	42.464	0.1926	0.2044
	180	43,900.8	262.4	218.799	320.634	42.464	0.3433	0.3614
	270	43,900.8	262.4	218.799	320.634	42.464	0.3433	0.3614
32	0	23,083.5	353.7	115.046	177.514	42.892	0.1954	0.2077
	90	23,083.5	171.2	115.046	168.29	33.215	0.1857	0.1964
	180	43,900.8	353.7	218.799	325.677	42.892	0.3461	0.3647
	270	43,900.8	171.2	218.799	316.453	33.215	0.3363	0.3534

Wind empty corroded, Moment = 9,208.8 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	1,660.0	470.7	8.273	32.561	0	0.0225	0.0249
	90	6,151.7	54.2	30.66	43.784	12.406	0.0507	0.0538
	180	8,182.8	470.7	40.783	78.986	0	0.0696	0.0741
	270	6,151.7	54.2	30.66	43.784	12.406	0.0507	0.0538
45	0	1,660.0	262.4	8.273	19.994	42.465	0.0378	0.0428
	90	1,660.0	262.4	8.273	19.994	42.465	0.0378	0.0428
	180	8,182.8	262.4	40.783	66.419	42.465	0.0849	0.0920
	270	8,182.8	262.4	40.783	66.419	42.465	0.0849	0.0920
32	0	1,660.0	353.7	8.273	25.037	42.893	0.0405	0.0461
	90	1,660.0	171.2	8.273	15.812	33.215	0.0309	0.0348
	180	8,182.8	353.7	40.783	71.462	42.893	0.0877	0.0953
	270	8,182.8	171.2	40.783	62.237	33.215	0.0780	0.0840

Wind empty new, Moment = 9,229.6 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	2,259.2	470.7	11.26	36.826	0	0.0269	0.0295
	90	7,158.1	54.2	35.675	50.946	12.405	0.0580	0.0614
	180	9,193.7	470.7	45.821	86.18	0	0.0769	0.0818
	270	7,158.1	54.2	35.675	50.946	12.405	0.0580	0.0614
45	0	2,259.2	262.4	11.26	24.259	42.464	0.0421	0.0474
	90	2,259.2	262.4	11.26	24.259	42.464	0.0421	0.0474
	180	9,193.7	262.4	45.821	73.614	42.464	0.0922	0.0997
	270	9,193.7	262.4	45.821	73.614	42.464	0.0922	0.0997
32	0	2,259.2	353.7	11.26	29.302	42.892	0.0449	0.0506
	90	2,259.2	171.2	11.26	20.077	33.215	0.0352	0.0393
	180	9,193.7	353.7	45.821	78.657	42.892	0.0950	0.1029
	270	9,193.7	171.2	45.821	69.432	33.215	0.0853	0.0916

Wind vacuum corroded, Moment = 9,208.8 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	22,519.7	470.7	112.237	181.025	0	0.1731	0.1823
	90	40,917.9	54.2	203.932	291.225	12.406	0.3019	0.3160
	180	42,949.0	470.7	214.055	326.427	0	0.3207	0.3364
	270	40,917.9	54.2	203.932	291.225	12.406	0.3019	0.3160
45	0	22,519.7	262.4	112.237	168.459	42.465	0.1885	0.2002
	90	22,519.7	262.4	112.237	168.459	42.465	0.1885	0.2002
	180	42,949.0	262.4	214.055	313.86	42.465	0.3364	0.3543
	270	42,949.0	262.4	214.055	313.86	42.465	0.3364	0.3543
32	0	22,519.7	353.7	112.237	173.501	42.893	0.1913	0.2034
	90	22,519.7	171.2	112.237	164.277	33.215	0.1816	0.1921
	180	42,949.0	353.7	214.055	318.903	42.893	0.3392	0.3575
	270	42,949.0	171.2	214.055	309.678	33.215	0.3294	0.3462

Seismic operating corroded, Moment = 124,809.8 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	-6,413.9	10,370.8	-31.966	502.787	0	0.2327	0.2799
	90	44,355.0	1,194.5	221.062	315.688	273.355	0.4626	0.4982
	180	71,882.6	10,370.8	358.258	968.746	0	0.7531	0.8158
	270	44,355.0	1,194.5	221.062	315.688	273.355	0.4626	0.4982
45	0	-6,413.9	5,782.7	-31.966	225.888	935.705	0.5664	0.6743
	90	-6,413.9	5,782.7	-31.966	225.888	935.705	0.5664	0.6743
	180	71,882.6	5,782.7	358.258	691.848	935.705	1.1057	1.2102
	270	71,882.6	5,782.7	358.258	691.848	935.705	1.1057	1.2102
32	0	-6,413.9	7,794.0	-31.966	336.999	945.135	0.6277	0.7465
	90	-6,413.9	3,771.4	-31.966	133.743	731.888	0.4162	0.4971
	180	71,882.6	7,794.0	358.258	802.958	945.135	1.1675	1.2824
	270	71,882.6	3,771.4	358.258	599.702	731.888	0.9510	1.0330

Governing Condition : Seismic operating new, Moment = 127,830.2 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	-6,591.3	10,608.6	-32.851	514.533	0	0.2380	0.2864
	90	45,381.9	1,221.9	226.18	322.996	279.624	0.4733	0.5097
	180	73,575.6	10,608.6	366.696	991.28	0	0.7707	0.8349
	270	45,381.9	1,221.9	226.18	322.996	279.624	0.4733	0.5097
45	0	-6,591.3	5,915.3	-32.851	231.284	957.164	0.5794	0.6898
	90	-6,591.3	5,915.3	-32.851	231.284	957.164	0.5794	0.6898
	180	73,575.6	5,915.3	366.696	708.031	957.164	1.1319	1.2383
	270	73,575.6	5,915.3	366.696	708.031	957.164	1.1319	1.2383
32	0	-6,591.3	7,972.7	-32.851	344.943	966.81	0.6421	0.7636
	90	-6,591.3	3,857.9	-32.851	137.026	748.673	0.4257	0.5086
	180	73,575.6	7,972.7	366.696	821.69	966.81	1.1951	1.3121
	270	73,575.6	3,857.9	366.696	613.772	748.673	0.9735	1.0571

Seismic empty corroded, Moment = 25,398.7 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	-2,427.5	1,641.7	-12.099	89.642	0	0.0369	0.0457
	90	6,668.5	189.1	33.235	47.462	43.272	0.0702	0.0762
	180	12,270.3	1,641.7	61.154	159.696	0	0.1254	0.1359
	270	6,668.5	189.1	33.235	47.462	43.272	0.0702	0.0762
45	0	-2,427.5	915.4	-12.099	45.809	148.122	0.0899	0.1081
	90	-2,427.5	915.4	-12.099	45.809	148.122	0.0899	0.1081
	180	12,270.3	915.4	61.154	115.863	148.122	0.1789	0.1983
	270	12,270.3	915.4	61.154	115.863	148.122	0.1789	0.1983
32	0	-2,427.5	1,233.8	-12.099	63.398	149.615	0.0996	0.1195
	90	-2,427.5	597.0	-12.099	31.223	115.858	0.0661	0.0801
	180	12,270.3	1,233.8	61.154	133.452	149.615	0.1886	0.2097
	270	12,270.3	597.0	61.154	101.277	115.858	0.1549	0.1703

Seismic empty new, Moment = 28,586.0 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	-2,611.2	1,894.4	-13.014	102.088	0	0.0426	0.0525
	90	7,759.4	218.2	38.672	55.226	49.932	0.0815	0.0884
	180	14,064.2	1,894.4	70.095	183.602	0	0.1440	0.1561
	270	7,759.4	218.2	38.672	55.226	49.932	0.0815	0.0884
45	0	-2,611.2	1,056.3	-13.014	51.508	170.92	0.1037	0.1246
	90	-2,611.2	1,056.3	-13.014	51.508	170.92	0.1037	0.1246
	180	14,064.2	1,056.3	70.095	133.022	170.92	0.2058	0.2281
	270	14,064.2	1,056.3	70.095	133.022	170.92	0.2058	0.2281
32	0	-2,611.2	1,423.7	-13.014	71.804	172.643	0.1149	0.1378
	90	-2,611.2	688.9	-13.014	34.676	133.69	0.0762	0.0922
	180	14,064.2	1,423.7	70.095	153.318	172.643	0.2170	0.2413
	270	14,064.2	688.9	70.095	116.19	133.69	0.1782	0.1957

Seismic vacuum corroded, Moment = 124,809.8 kg_f-m								
Force attack angle °	Leg position °	Axial end load kg_f	Shear resisted kg_f	Axial f_a kg_f/cm^2	Bending f_{bx} kg_f/cm^2	Bending f_{by} kg_f/cm^2	Ratio H_{1-1}	Ratio H_{1-2}
0	0	-6,413.9	10,370.8	-31.966	502.787	0	0.2327	0.2799
	90	44,355.0	1,194.5	221.062	315.688	273.355	0.4626	0.4982
	180	71,882.6	10,370.8	358.258	968.746	0	0.7531	0.8158
	270	44,355.0	1,194.5	221.062	315.688	273.355	0.4626	0.4982
45	0	-6,413.9	5,782.7	-31.966	225.888	935.705	0.5664	0.6743
	90	-6,413.9	5,782.7	-31.966	225.888	935.705	0.5664	0.6743
	180	71,882.6	5,782.7	358.258	691.848	935.705	1.1057	1.2102
	270	71,882.6	5,782.7	358.258	691.848	935.705	1.1057	1.2102
32	0	-6,413.9	7,794.0	-31.966	336.999	945.135	0.6277	0.7465
	90	-6,413.9	3,771.4	-31.966	133.743	731.888	0.4162	0.4971
	180	71,882.6	7,794.0	358.258	802.958	945.135	1.1675	1.2824
	270	71,882.6	3,771.4	358.258	599.702	731.888	0.9510	1.0330

Leg Calculations (AISC manual ninth edition)

Axial end load, P_1 (Based on vessel total bending moment acting at leg attachment elevation)

$$P_1 = (1 + 0.14 \cdot S_{DS}) \cdot \frac{W_t}{N} + \frac{4 \cdot M_t}{N \cdot D} = (1 + 0.14 \cdot 0.6) \cdot \frac{167{,}460.71}{4} + \frac{4 \cdot 1e3 \cdot 127{,}830.2}{4 \cdot 4{,}534} = 73{,}575.56 \quad kg_f$$

Allowable axial compressive stress, F_a (AISC chapter E)

$$C_c = \sqrt{\frac{2 \cdot \pi^2 \cdot E}{F_y}} = \sqrt{\frac{2 \cdot \pi^2 \cdot 2{,}038{,}902}{2{,}531.05}} = 126.0993$$

$$\frac{K \cdot l}{r} = \frac{1.5 \cdot 1{,}473.2}{67.56} = 32.7106$$

$$F_a = \frac{1 \cdot \left(1 - \frac{(K \cdot l/r)^2}{2 \cdot C_c^2}\right) \cdot F_y}{\frac{5}{3} + \frac{3}{8} \cdot \frac{K \cdot l/r}{C_c} - \frac{(K \cdot l/r)^3}{8 \cdot C_c^3}} = \frac{1 \cdot \left(1 - \frac{(32.7106)^2}{2 \cdot 126.0993^2}\right) \cdot 2{,}531.05}{\frac{5}{3} + \frac{3}{8} \cdot \frac{32.7106}{126.0993} - \frac{(32.7106)^3}{8 \cdot 126.0993^3}} = 1{,}388.323 \quad kg_f/cm^2$$

Allowable axial compression and bending (AISC chapter H)

$$F'_{ex} = \frac{1 \cdot 12 \cdot \pi^2 \cdot E}{23 \cdot (K \cdot l/r)^2} = \frac{1 \cdot 12 \cdot \pi^2 \cdot 2{,}038{,}902}{23 \cdot (11.1015)^2} = 85{,}189.081 \ \ \text{kg}_f/\text{cm}^2$$

$$F'_{ey} = \frac{1 \cdot 12 \cdot \pi^2 \cdot E}{23 \cdot (K \cdot l/r)^2} = \frac{1 \cdot 12 \cdot \pi^2 \cdot 2{,}038{,}902}{23 \cdot (32.7106)^2} = 9{,}812.355 \ \ \text{kg}_f/\text{cm}^2$$

$$F_b = 1 \cdot 0.66 \cdot F_y = 1 \cdot 0.66 \cdot 2{,}531.05 = 1{,}670.493 \ \ \text{kg}_f/\text{cm}^2$$

Compressive axial stress

$$f_a = \frac{P_1}{A} = \frac{73{,}575.56}{200.6448} = 366.696 \ \ \text{kg}_f/\text{cm}^2$$

Bending stresses

$$f_{bx} = \frac{F \cdot \cos(\alpha) \cdot L}{I_x/C_x} + \frac{P_1 \cdot E_{cc}}{I_x/C_x} = \frac{7{,}972.71 \cdot \cos(32) \cdot 1{,}473.2}{100 \cdot 79{,}500.2/237.87} + \frac{73{,}575.56 \cdot 237.87}{100 \cdot 79{,}500.2/237.87} = 821.69 \ \ \text{kg}_f/\text{cm}^2$$

$$f_{by} = \frac{F \cdot \sin(\alpha) \cdot L}{I_y/C_y} = \frac{7{,}972.71 \cdot \sin(32) \cdot 1{,}473.2}{100 \cdot 9{,}157.09/142.24} = 966.81 \ \ \text{kg}_f/\text{cm}^2$$

AISC equation H_{1-1}

$$H_{1-1} = \frac{f_a}{F_a} + \frac{C_{mx} \cdot f_{bx}}{(1 - f_a/F'_{ex}) \cdot F_{bx}} + \frac{C_{my} \cdot f_{by}}{(1 - f_a/F'_{ey}) \cdot F_{by}}$$

$$= \frac{366.696}{1{,}388.323} + \frac{0.85 \cdot 821.69}{(1 - 366.696/85{,}189.081) \cdot 1{,}670.493} + \frac{0.85 \cdot 966.81}{(1 - 366.696/9{,}812.355) \cdot 1{,}670.493}$$

$$= 1.1951$$

AISC equation H_{1-2}

$$H_{1-2} = \frac{f_a}{0.6 \cdot 1 \cdot F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = \frac{366.696}{0.6 \cdot 1 \cdot 2{,}531.05} + \frac{821.69}{1{,}670.493} + \frac{966.81}{1{,}670.493} = 1.3121$$

Warning! 4, W 18x106 legs are NOT adequate.

Anchor bolts - Seismic operating new condition governs

Tensile loading per leg (1 bolt per leg)

$$R = \frac{4 \cdot M}{N \cdot BC} - \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{N} = \frac{4 \cdot 163{,}866.7}{4 \cdot 4.5848} - \frac{(0.6 - 0.14 \cdot 0.6) \cdot 169{,}007.99}{4} = 13{,}939.28 \ \ \text{kg}_f$$

Required area per bolt

$$A_b = \frac{R}{S_b \cdot n} = \frac{13{,}939.28}{1{,}406.139 \cdot 1} = 9.9132 \ \ \text{cm}^2$$

Area of a 1.875" series 8 threaded bolt (corroded) = 14.8645 cm^2

1.875" series 8 threaded bolts are satisfactory.

Check the leg to vessel fillet weld, Bednar 10.3, Seismic operating new governs

Note: continuous welding is assumed for all support leg fillet welds.

$$Z_w = \frac{2 \cdot b \cdot d + d^2}{3} = \frac{2 \cdot 28.448 \cdot 35.56 + 35.56^2}{3} = 1{,}095.9118 \ \ \text{cm}^2$$

$$J_w = \frac{(b + 2 \cdot d)^3}{12} - \frac{d^2 \cdot (b + d)^2}{b + 2 \cdot d}$$

$$= \frac{(28.448 + 2 \cdot 35.56)^{3}}{12} - \frac{35.56^{2} \cdot (28.448 + 35.56)^{2}}{28.448 + 2 \cdot 35.56}$$

$= 30{,}225.79 \ \ \mathrm{cm}^{3}$

$$E = \frac{d^2}{b + 2 \cdot d} = \frac{355.6^{2}}{284.48 + 2 \cdot 355.6} = 127 \ \ \mathrm{mm}$$

Governing weld load $f_x = \mathrm{Cos}(0) \cdot 10{,}608.62 = 10{,}608.62 \ \ \mathrm{kg}_f$

Governing weld load $f_y = \mathrm{Sin}(0) \cdot 10{,}608.62 = 0 \ \ \mathrm{kg}_f$

$$f_1 = \frac{P_1}{L_{\mathrm{weld}}} = \frac{73{,}575.56}{99.568} = 738.95 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (V_L direct shear)

$$f_2 = \frac{f_y \cdot L_{\mathrm{leg}} \cdot 0.5 \cdot b}{J_w} = \frac{0 \cdot 147.32 \cdot 0.5 \cdot 28.448}{30{,}225.7866} = 0 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (V_L torsion shear)

$$f_3 = \frac{f_y}{L_{\mathrm{weld}}} = \frac{0}{99.568} = 0 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (V_c direct shear)

$$f_4 = \frac{f_y \cdot L_{\mathrm{leg}} \cdot E}{J_w} = \frac{0 \cdot 147.32 \cdot 12.7}{30{,}225.7866} = 0 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (V_c torsion shear)

$$f_5 = \frac{f_x \cdot L_{\mathrm{leg}} + P_1 \cdot E_{\mathrm{cc}}}{Z_w} = \frac{10{,}608.62 \cdot 147.32 + 73{,}575.56 \cdot 23.7871}{1{,}095.9118} = 3{,}023.06 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (M_L bending)

$$f_6 = \frac{f_x}{L_{\mathrm{weld}}} = \frac{10{,}608.62}{99.568} = 106.55 \ \ \mathrm{kg}_f/\mathrm{cm}$$ (Direct outward radial shear)

$$f = \sqrt{(f_1 + f_2)^{2} + (f_3 + f_4)^{2} + (f_5 + f_6)^{2}}$$

$$= \sqrt{(738.95 + 0)^{2} + (0 + 0)^{2} + (3{,}023.06 + 106.55)^{2}}$$

$= 3{,}215.66 \ \ \mathrm{kg}_f/\mathrm{cm}$ (Resultant shear load)

Required leg to vessel fillet weld leg size **(welded both sides + top)**

$$t_w = \frac{f}{0.707 \cdot 0.55 \cdot S_a} = 100 \cdot \frac{321.57}{0.707 \cdot 0.55 \cdot 1{,}407.208} = 58.77 \ \ \mathrm{mm}$$

The 60 mm leg to vessel attachment fillet weld size is adequate.

Base plate thickness check, AISC 3-106

$$f_p = \frac{P}{B \cdot N} = 100 \cdot \frac{81{,}542.48}{381 \cdot 584.2} = 36.635 \ \ \mathrm{kg}_f/\mathrm{cm}^{2}$$

$$m = \frac{N - 0.95 \cdot d}{2} = \frac{584.2 - 0.95 \cdot 475.74}{2} = 66.12 \ \ \mathrm{mm}$$

$$n = \frac{B - 0.8 \cdot b}{2} = \frac{381 - 0.8 \cdot 284.48}{2} = 76.71 \ \ \mathrm{mm}$$

$$L = \frac{0.5 \cdot (d + b)}{2} - \sqrt{\frac{(0.5 \cdot (d + b))^{2}}{4} - \frac{P}{4 \cdot F_p}}$$

$$= \frac{0.5 \cdot (475.74 + 284.48)}{2} - \sqrt{\frac{(0.5 \cdot (475.74 + 284.48))^{2}}{4} - 100 \cdot \frac{81{,}542.48}{4 \cdot 116.569}}$$

$= 53.55 \ \ \mathrm{mm}$

$$t_b = \max(m, n, L) \cdot \sqrt{\frac{3 \cdot f_p}{S_b}} = 76.71 \cdot \sqrt{\frac{3 \cdot 36.635}{1{,}687.367}} = 19.58 \text{ mm}$$

The base plate thickness is adequate.

Check the leg to vessel attachment stresses, WRC 537 (Seismic vacuum corroded governs)

Applied Loads	
Radial load, P_r	10,370.79 kg_f
Circumferential moment, M_c	0 kg_f-m
Circumferential shear, V_c	0 kg_f
Longitudinal moment, M_L	32,376.9 kg_f-m
Longitudinal shear, V_L	71,882.56 kg_f
Torsion moment, M_t	0 kg_f-m
Internal pressure, P	-0.8 bar
Mean shell radius, R_m	2,258.48 mm
Local shell thickness, T	13.76 mm
Design factor	3

Maximum stresses due to the applied loads at the leg edge (includes pressure)

$$\gamma = \frac{R_m}{T} = \frac{2{,}258.48}{13.76} = 164.1337$$

$$C_1 = 142.24, C_2 = 282.24 \text{ mm}$$

Local circumferential pressure stress $= \dfrac{P \cdot R_i}{T} = -133.513 \text{ kg}_f/\text{cm}^2$

Local longitudinal pressure stress $= \dfrac{P \cdot R_i}{2 \cdot T} = -66.792 \text{ kg}_f/\text{cm}^2$

Maximum combined stress $(P_L + P_b + Q) = -24{,}906.87 \text{ kg}_f/\text{cm}^2$

Allowable combined stress $(P_L + P_b + Q) = \pm 3 \cdot S = \pm 4{,}221.63 \text{ kg}_f/\text{cm}^2$

WRC 537: The combined stress (P_L+P_b+Q) is excessive

Maximum local primary membrane stress $(P_L) = -7{,}738.55 \text{ kg}_f/\text{cm}^2$

Allowable local primary membrane stress $(P_L) = \pm 1.5 \cdot S = \pm 2{,}110.81 \text{ kg}_f/\text{cm}^2$

WRC 537: The local primary membrane stress (P_L) is excessive

Stresses at the leg edge per WRC Bulletin 537

Figure	Y	β	A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	10.6851	0.1169	0	0	0	0	-356.597	-356.597	-356.597	-356.597
4C*	25.1974	0.1005	-840.871	-840.871	-840.871	-840.871	0	0	0	0
1C	0.0782	0.0817	0	0	0	0	-2,569.649	2,569.649	-2,569.649	2,569.649
2C-1	0.0521	0.0817	-1,713.662	1,713.662	-1,713.662	1,713.662	0	0	0	0
3A*	5.9051	0.0791	0	0	0	0	0	0	0	0
1A	0.0883	0.0813	0	0	0	0	0	0	0	0
3B*	18.1165	0.0995	-6,764.162	-6,764.162	6,764.162	6,764.162	0	0	0	0
1B-1	0.0291	0.0855	-15,454.665	15,454.665	15,454.665	-15,454.665	0	0	0	0
Pressure stress*			-133.513	-133.513	-133.513	-133.513	-133.513	-133.513	-133.513	-133.513
Total circumferential stress			-24,906.873	9,429.78	19,530.781	-7,951.225	-3,059.759	2,079.539	-3,059.759	2,079.539
Primary membrane circumferential stress*			-7,738.546	-7,738.546	5,789.778	5,789.778	-490.11	-490.11	-490.11	-490.11
3C*	12.5689	0.1005	-419.451	-419.451	-419.451	-419.451	0	0	0	0
4C*	24.0721	0.1169	0	0	0	0	-803.327	-803.327	-803.327	-803.327
1C-1	0.063	0.1034	-2,070.681	2,070.681	-2,070.681	2,070.681	0	0	0	0
2C	0.0375	0.1034	0	0	0	0	-1,231.426	1,231.426	-1,231.426	1,231.426
4A*	10.3252	0.0791	0	0	0	0	0	0	0	0
2A	0.0363	0.0966	0	0	0	0	0	0	0	0
4B*	6.6778	0.0995	-3,904.989	-3,904.989	3,904.989	3,904.989	0	0	0	0
2B-1	0.0315	0.1013	-14,107.161	14,107.161	14,107.161	-14,107.161	0	0	0	0
Pressure stress*			-66.792	-66.792	-66.792	-66.792	-66.792	-66.792	-66.792	-66.792
Total longitudinal stress			-20,569.074	11,786.61	15,455.227	-8,617.735	-2,101.545	361.307	-2,101.545	361.307
Primary membrane longitudinal stress*			-4,391.232	-4,391.232	3,418.746	3,418.746	-870.119	-870.119	-870.119	-870.119
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0	0	0	0	0	0	0	0
Long shear from V_L			0	0	0	0	-462.76	-462.76	462.76	462.76
Total Shear stress			0	0	0	0	-462.76	-462.76	462.76	462.76
Combined stress (P_L+P_b+Q)			-24,906.873	11,786.61	19,530.781	-8,617.735	-3,246.775	2,196.249	-3,246.775	2,196.249

* denotes primary stress.

Straight Flange on Bottom Head

ASME Section VIII Division 1, 2021 Edition Metric					
Component		Cylinder			
Material		SA-516 70 (II-D Metric p. 20, ln. 45)			
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**	
No	No	No	No	No	
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**	
Internal		7	40	5	
External		0.8	40		
Static Liquid Head					
Condition		**P_s (bar)**	**H_s (mm)**	**SG**	
Operating		0.84	8,714.3	0.98	
Test horizontal		0.44	4,500	1	
Dimensions					
Inner Diameter		4,500 mm			
Length		50.8 mm			
Nominal Thickness		17 mm			
Corrosion	**Inner**	1.6 mm			
	Outer	1.64 mm			
Weight and Capacity					
		Weight (kg)		**Capacity (liters)**	
New		95.99		807.94	
Corroded		77.7		809.09	
Radiography					
Longitudinal seam		Seamless No RT			
Top Circumferential seam		Full UW-11(a) Type 2			

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	16.07 mm
Design thickness due to external pressure (t_e)	15.93 mm
Design thickness due to combined loadings + corrosion	10.44 mm
Maximum allowable working pressure (MAWP)	7.57 bar
Maximum allowable pressure (MAP)	10.38 bar
Maximum allowable external pressure (MAEP)	0.97 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
$t_r = \dfrac{0.84 \cdot 2{,}251.6}{1{,}380 \cdot 1 - 0.6 \cdot 0.84} =$	1.37 mm
$\text{Stress ratio} = \dfrac{t_r \cdot E^*}{t_n - c} = \dfrac{1.37 \cdot 1}{17 - 3.24} =$	0.0993
$\text{Stress ratio} longitud \in al = \dfrac{79.216 \cdot 0.9}{1{,}407.208 \cdot 0.9} =$	0.0563
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 5°C.	

Design thickness, (at 40 °C) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.84 \cdot 2{,}251.6}{1{,}380 \cdot 1.00 - 0.60 \cdot 7.84} + 3.24 = \underline{16.07}\ \text{mm}$$

Maximum allowable working pressure, (at 40 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{1{,}380 \cdot 1.00 \cdot 13.76}{2{,}251.6 + 0.60 \cdot 13.76} - 0.84 = \underline{7.57}\ \text{bar}$$

Maximum allowable pressure, (at 21.11 °C) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{1{,}380 \cdot 1.00 \cdot 17}{2{,}250 + 0.60 \cdot 17} = \underline{10.38}\ \text{bar}$$

External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}534} = 0.9479$$

$$\frac{D_o}{t} = \frac{4{,}534}{12.69} = 357.2703$$

From table G: $A = 0.000215$

From table CS-2 Metric: $B = 218.5894\ \text{kg/cm}^2 (214.36\ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 214.36}{3 \cdot (4{,}534/12.69)} = 0.8\ \text{bar}$$

Design thickness for external pressure P_a = 0.8 bar

$$t_a = t + \text{Corrosion} = 12.69 + 3.24 = \underline{15.93}\ \text{mm}$$

Maximum Allowable External Pressure, (Corroded & at 40 °C) UG-28(c)

$$\frac{L}{D_o} = \frac{4{,}297.99}{4{,}534} = 0.9479$$

$$\frac{D_o}{t} = \frac{4{,}534}{13.76} = 329.5058$$

From table G: $A = 0.000241$

From table CS-2 Metric: $B = 245.2108\ \text{kg/cm}^2 (240.4692\ \text{bar})$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 240.47}{3 \cdot (4{,}534/13.76)} = \underline{0.97}\ \text{bar}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 17}{2{,}258.5}\right) \cdot \left(1 - \frac{2{,}258.5}{\infty}\right) = 0.3764\,\%$$

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	7	1,407.2	769.8	40	3.24	Wind	7.13	6.81
						Seismic	7.2	6.75
Operating, Hot & New	7	1,407.2	843.3	40	0	Wind	7.13	6.81
						Seismic	7.2	6.74
Hot Shut Down, Corroded	0	1,407.2	769.8	40	3.24	Wind	0.79	0.48
						Seismic	0.86	0.41
Hot Shut Down, New	0	1,407.2	843.3	40	0	Wind	0.79	0.48
						Seismic	0.86	0.41
Empty, Corroded	0	1,407.2	769.8	21.11	3.24	Wind	0.02	0.01
						Seismic	0.02	0.01
Empty, New	0	1,407.2	843.3	21.11	0	Wind	0.02	0.01
						Seismic	0.02	0.01
Vacuum	-0.8	1,407.2	769.8	40	3.24	Wind	0.07	0.41
						Seismic	0.14	0.52
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	1,407.2	769.8	40	3.24	Weight	0.79	0.79

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cHC} = \min(B, S) = 769.8 \text{ kg/cm}^2$$

Allowable Compressive Stress, Hot and New- S_{cHN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \ \ \text{kg/cm}^2$$

$$S_{cHN} = \min(B, S) = 843.3 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/17} = 0.000937$$

$$B = 843.3 \ \ \text{kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$$S_{cCN} = \min(B, S) = 843.3 \text{ kg/cm}^2$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \text{ kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$$S_{cC} = \min(B, S) = 769.8 \text{ kg/cm}^2$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2 Metric)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{2{,}267/13.76} = 0.000759$$

$$B = 769.8 \text{ kg/cm}^2$$

$$S = \frac{1{,}407.2}{1.00} = 1{,}407.2 \text{ kg/cm}^2$$

$$S_{cVC} = \min(B, S) = 769.8 \text{ kg/cm}^2$$

Operating, Hot & Corroded, Wind, Top Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $18.2 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

t_w = $\dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{\text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.79 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.34 + 0 - (-0.79)$

= 7.13 mm

$t_{w\,c}$ = $\dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.60 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.48 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.48) - (6.34)|$

= 6.81 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (13.76 - 0 + (-0.79))}{2{,}251.6 - 0.40 \cdot (13.76 - 0 + (-0.79))}$

= 14.34 bar

Operating, Hot & New, Wind, Top Seam

t_p = $\dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

= $\dfrac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

t_m = $\dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $18.2 \dfrac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

t_w = $\dfrac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{\text{-}142,800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.79 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $6.33 + 0 - (-0.79)$

= 7.13 mm

$t_{w\,c}$ = $\dfrac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\dfrac{0.60 \cdot \text{-}142,800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.48 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.48) - (6.33)|$

= 6.81 mm

Maximum allowable working pressure, Longitudinal Stress

P = $\dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

= $\dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (17 - 0 + (-0.79))}{2{,}250 - 0.40 \cdot (17 - 0 + (-0.79))}$

= 17.94 bar

Hot Shut Down, Corroded, Wind, Top Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= 18.2 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{-142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.79 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0 - (-0.79)$

= 0.79 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{0.60 \cdot -142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.48 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.48) - (0)|$

= 0.48 mm

Hot Shut Down, New, Wind, Top Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 18.2 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{-142{,}800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.79 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.79)$

= 0.79 mm

$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.60 \cdot -142{,}800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.48 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.48) - (0)|$

= 0.48 mm

Empty, Corroded, Wind, Top Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 18.2 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{-3{,}500}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.02 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0 - (-0.02)$$

= 0.02 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot -3{,}500}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.01 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.01) - (0)|$$

= 0.01 mm

Empty, New, Wind, Top Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(bending)}$$

$$= 18.2 \frac{}{\pi \cdot 2{,}258.5^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{-4{,}004.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.02 mm

$$t_t = t_p + t_m - t_w \quad \text{(total required, tensile)}$$

$$= 0 + 0 - (-0.02)$$

= 0.02 mm

$$t_{w\,c} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \quad \text{(Weight)}$$

$$= \frac{0.60 \cdot -4{,}004.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.01 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}| \quad \text{(total, net tensile)}$$

$$= |0 + (-0.01) - (0)|$$

= 0.01 mm

Vacuum, Wind, Top Seam

$$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|} \qquad \text{(Pressure)}$$

$$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |0.8|}$$

= -0.73 mm

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \qquad \text{(bending)}$$

$$= 18.2 \frac{}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor} \qquad \text{(Weight)}$$

$$= \frac{\text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.79 mm

$$t_t = t_p + t_m - t_w \qquad \text{(total required, tensile)}$$

$$= -0.73 + 0 - (-0.79)$$

= 0.07 mm

$$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|} \qquad \text{(Pressure)}$$

$$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$$

= -1.19 mm

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \qquad \text{(bending)}$$

$$= 18.2 \frac{}{\pi \cdot 2{,}258.48^{\ 2} \cdot 754.91 \cdot 1.00} \cdot 98066.5$$

= 0 mm

$$t_{wc} = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor} \qquad \text{(Weight)}$$

$$= \frac{0.60 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$$

= -0.78 mm

$$t_c = t_{mc} + t_{wc} - t_{pc} \qquad \text{(total required, compressive)}$$

$$= 0 + (-0.78) - (-1.19)$$

= 0.41 mm

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0 - -0.78)}{2{,}251.6 - 0.40 \cdot (13.76 - 0 - -0.78)}$$

= 9.78 bar

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Top Seam

t_p = 0 mm (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (bending)

$$= \frac{0}{\pi \cdot 2{,}258.48^{\ 2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$$

= 0 mm

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$$ (Weight)

$$= \frac{\text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$$

= -0.79 mm

$$t_t = t_p + t_m - t_w$$ (total required, tensile)

$$= 0 + 0 - (-0.79)$$

= 0.79 mm

$$t_c = |t_{mc} + t_{wc} - t_{pc}|$$ (total, net tensile)

$$= |0 + (-0.79) - (0)|$$

= 0.79 mm

Operating, Hot & Corroded, Seismic, Top Seam

$t_p = \dfrac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \dfrac{7 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.34 mm

$t_m = \dfrac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 195.7 \dfrac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \dfrac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{1.08 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.86 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.34 + 0 - (-0.86)$

= 7.2 mm

$t_{w\,c} = \dfrac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \dfrac{0.52 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.41 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.41) - (6.34)|$

= 6.75 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \dfrac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \dfrac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (13.76 - 0 + (-0.86))}{2{,}251.6 - 0.40 \cdot (13.76 - 0 + (-0.86))}$

= 14.26 bar

Operating, Hot & New, Seismic, Top Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{7 \cdot 2{,}250}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |7|}$

= 6.33 mm

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{206.1}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}142,800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.86 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 6.33 + 0 - (-0.86)$

= 7.2 mm

$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}142,800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.41 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.41) - (6.33)|$

= 6.74 mm

Maximum allowable working pressure, Longitudinal Stress

$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$

$= \frac{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 \cdot (17 - 0 + (-0.86))}{2{,}250 - 0.40 \cdot (17 - 0 + (-0.86))}$

= 17.87 bar

Hot Shut Down, Corroded, Seismic, Top Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= \frac{195.7}{\pi \cdot 2{,}258.48^{\,2} \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.86 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.86)$

= 0.86 mm

$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.41 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.41) - (0)|$

= 0.41 mm

Hot Shut Down, New, Seismic, Top Seam

t_p = 0 mm (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $206.1 \frac{}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

t_w = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{1.08 \cdot \text{-}142{,}800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.86 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0 - (-0.86)$

= 0.86 mm

$t_{w\,c}$ = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.52 \cdot \text{-}142{,}800.7}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.41 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.41) - (0)|$

= 0.41 mm

Empty, Corroded, Seismic, Top Seam

t_p = 0 mm (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 76.8 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}3,500}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.02 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0 - (-0.02)$

= 0.02 mm

$t_{w\,c} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}3,500}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.01 mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

$= |0 + (-0.01) - (0)|$

= 0.01 mm

Empty, New, Seismic, Top Seam

t_p = 0 mm (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

= $\frac{87.7}{\pi \cdot 2{,}258.5\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

t_w = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{1.08 \cdot \text{-}4{,}004.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.02 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0 - (-0.02)$

= 0.02 mm

$t_{w\ c}$ = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

= $\frac{0.52 \cdot \text{-}4{,}004.3}{2 \cdot \pi \cdot 2{,}258.5 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.01 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)

= $|0 + (-0.01) - (0)|$

= 0.01 mm

Vacuum, Seismic, Top Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90 + 0.40 \cdot |0.8|}$

= -0.73 mm

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (bending)

$= 195.7 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98066.5$

= 0 mm

$t_w = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c} \cdot \text{MetricFactor}$ (Weight)

$= \frac{1.08 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 1{,}380 \cdot 1.00 \cdot 0.90} \cdot 98.0665$

= -0.86 mm

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.73 + 0 - (-0.86)$

= 0.14 mm

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.8 \cdot 2{,}251.6}{2 \cdot 754.91 \cdot 1.00 + 0.40 \cdot |0.8|}$

= -1.19 mm

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (bending)

$= 195.7 \frac{}{\pi \cdot 2{,}258.48\ ^2 \cdot 754.91 \cdot 1.00} \cdot 98066.5$

= 0 mm

$t_{wc} = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s} \cdot \text{MetricFactor}$ (Weight)

$= \frac{0.52 \cdot \text{-}142{,}530.9}{2 \cdot \pi \cdot 2{,}258.48 \cdot 754.91 \cdot 1.00} \cdot 98.0665$

= -0.67 mm

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (-0.67) - (-1.19)$

= 0.52 mm

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 754.91 \cdot 1.00 \cdot (13.76 - 0 - -0.67)}{2{,}251.6 - 0.40 \cdot (13.76 - 0 - -0.67)}$$

= 9.7 bar

Bottom Head

ASME Section VIII Division 1, 2021 Edition Metric				
Component		F&D Head		
Material		SA-516 70 (II-D Metric p. 20, ln. 45)		
Attached To		Cylinder #4		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		7	40	5
External		0.8	40	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.91	9,477.92	0.98
Test horizontal		0.44	4,500	1
Dimensions				
Inner Diameter		4,500 mm		
Crown Radius L		4,500 mm		
Knuckle Radius r		270 mm		
Minimum Thickness		26.06 mm		
Corrosion	**Inner**	1.6 mm		
	Outer	1.64 mm		
Length L_{sf}		50.8 mm		
Nominal Thickness t_{sf}		17 mm		
Weight and Capacity				
		Weight (kg)[1]		**Capacity (liters)[1]**
New		4,004.32		8,189.03
Corroded		3,500.02		8,220.36
Radiography				
Category A joints		Seamless No RT		
Head to shell seam		Full UW-11(a) Type 2		

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	1.5 mm + 3.24 mm = 4.74 mm
Design thickness due to internal pressure (t)	26.06 mm
Design thickness due to external pressure (t_e)	14.7 mm
Maximum allowable working pressure (MAWP)	7 bar
Maximum allowable pressure (MAP)	9.02 bar
Maximum allowable external pressure (MAEP)	3.17 bar
Straight Flange governs MDMT	-105°C

Note: Endnote 88 used to determine allowable stress.

Factor M		
$M = \frac{1}{4} \cdot \left[3 + \left(\frac{L}{r}\right)^{\frac{1}{2}}\right]$		
Corroded	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{4{,}501.6}{271.6}\right)^{\frac{1}{2}}\right]$	1.7678
New	$M = \frac{1}{4} \cdot \left[3 + \left(\frac{4{,}500}{270}\right)^{\frac{1}{2}}\right]$	1.7706

Design thickness for internal pressure, (Corroded at 40 °C) Appendix 1-4(d)

$$t = \frac{P \cdot L \cdot M}{2 \cdot S \cdot E - 0.2 \cdot P} + \text{Corrosion} = \frac{7.91 \cdot 4{,}501.6 \cdot 1.7678}{2 \cdot 1{,}380 \cdot 1 - 0.2 \cdot 7.91} + 3.24 = 26.06 \text{ mm}$$

Maximum allowable working pressure, (Corroded at 40 °C) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 1{,}380 \cdot 1 \cdot 22.82}{4{,}501.6 \cdot 1.7678 + 0.2 \cdot 22.82} - 0.91 = 7 \text{ bar}$$

Maximum allowable pressure, (New at 21.11 °C) Appendix 1-4(d)

$$P = \frac{2 \cdot S \cdot E \cdot t}{L \cdot M + 0.2 \cdot t} - P_s = \frac{2 \cdot 1{,}380 \cdot 1 \cdot 26.06}{4{,}500 \cdot 1.7706 + 0.2 \cdot 26.06} - 0 = 9.02 \text{ bar}$$

Design thickness for external pressure, (Corroded at 40 °C) UG-33(e)

Equivalent outside spherical radius
$R_o = \text{Outside crown radius} = 4{,}524.42 \text{ mm}$

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{4{,}524.42 \ / \ 11.46} = 0.000317$$

From Table CS-2 Metric: B = 322.1082 kg_f/cm^2

$$P_a = \frac{B}{R_o \ / \ t} = \frac{315.8802}{4{,}524.42 \ / \ 11.46} = 0.8 \text{ bar}$$

$$t = 11.46 \text{ mm} + \text{Corrosion} = 11.46 \text{ mm} + 3.24 \text{ mm} = 14.7 \text{ mm}$$

The head external pressure design thickness (t_e) is 14.7 mm.

Maximum Allowable External Pressure, (Corroded at 40 °C) UG-33(e)

Equivalent outside spherical radius
$R_o = \text{Outside crown radius} = 4{,}524.42 \text{ mm}$

$$A = \frac{0.125}{R_o \ / \ t} = \frac{0.125}{4{,}524.42 \ / \ 22.82} = 0.00063$$

From Table CS-2 Metric: B = 640.072 kg_f/cm^2

$$P_a = \frac{B}{R_o \ / \ t} = \frac{627.6962}{4{,}524.42 \ / \ 22.82} = 3.166 \text{ bar}$$

The maximum allowable external pressure (MAEP) is 3.17 bar.

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{75 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{75 \cdot 17}{278.5}\right) \cdot \left(1 - \frac{278.5}{\infty}\right) = 4.5781\,\%$$

The extreme fiber elongation does not exceed 5%.