Pressure Vessel Engineering

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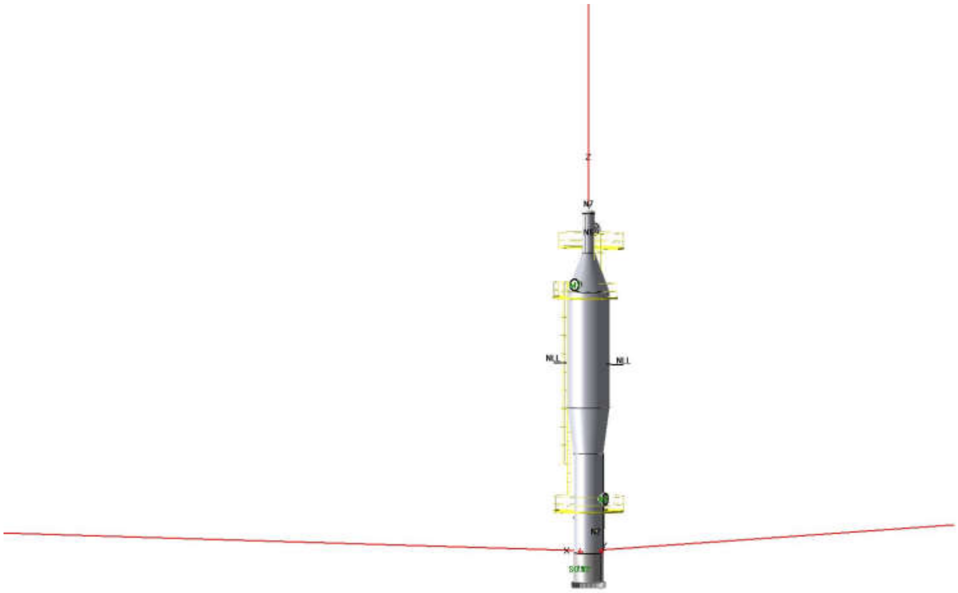

COMPRESS Pressure Vessel Design Calculations

Item: Tower: Sample #13
Drawing: 3602d-1 R0
Customer: T.B.D.
Document #: 3602c-1 R4
Designer: Brian Munn, C.E.T.
Date: Tuesday, October 18, 2016

Reviewed By: Laurence Brundrett, P.Eng.

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Warnings Summary

Warnings for Lower Cone

Due to the vessel geometry (vessel diameter above a bottom-supported converging cone is less than the diameter of the bottom end of the cone), additional loading may need to be applied to the small end cone juncture. COMPRESS accounts for the additional liquid load acting on the small end transition juncture by taking the total liquid weight at the point under consideration and subtracting the column of liquid above the small end transition diameter. In this situation, this assumption is unconservative. (warning)

Warnings for Platform/Ladder #3

The platform ladder interferes with one or more vessel components. (warning)

Nozzle Schedule

Specifications									
Nozzle mark	**Identifier**	**Size**	**Materials**		**Impact Tested**	**Normalized**	**Fine Grain**	**Flange**	**Blind**
M1	Manway	24 OD x 1	Nozzle	SA-516 70	No	No	No	NPS 24 Class 300 WN A105	NPS 24 Class 300 A105
			Pad	SA-516 70	No	No	No		
M2	Manway	24 OD x 1	Nozzle	SA-516 70	No	No	No	NPS 24 Class 300 WN A105	NPS 24 Class 300 A105
			Pad	SA-516 70	No	No	No		
M3	Manway	24 OD x 1	Nozzle	SA-516 70	No	No	No	NPS 24 Class 300 WN A105	NPS 24 Class 300 A105
			Pad	SA-516 70	No	No	No		
N1	Drain	NPS 8 Sch 80 (XS)	Nozzle	SA-106 B Smls pipe	No	No	No	N/A	No
			Pad	SA-516 70	No	No	No		
	Nozzle Pipe (N1)	NPS 8 Sch 40 (Std)	Nozzle Piping	SA-106 B Smls pipe	No	No	No	N/A	No
	Elbow (N1)	NPS 8 Sch 40 (Std)	B16.9 Elbow	SA-234 WPB	No	No	No	N/A	No
	Elbow Pipe (N1)	NPS 8 Sch 40 (Std)	Nozzle Piping	SA-106 B Smls pipe	No	No	No	NPS 8 Class 300 WN A105	No
N2	Process	NPS 6 Sch 160	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 6 Class 300 WN A105	No
N3	Process	NPS 2 Sch 160	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 2 Class 300 WN A105	No
N4	Process	NPS 4 XXS	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 4 Class 300 WN A105	No
N5	Process	NPS 2 Sch 160	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 2 Class 300 WN A105	No
N6	Process	NPS 4 Sch 80 (XS)	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 4 Class 300 WN A105	No
N7	Process	NPS 6 Sch 160	Nozzle	SA-106 B Smls pipe	No	No	No	NPS 6 Class 300 WN A105	No

Nozzle Summary

Dimensions

Nozzle mark	OD (in)	t_n (in)	Req t_n (in)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (in)	A_a/A_r (%)
						Nom t (in)	Design t (in)	User t (in)	Width (in)	t_{pad} (in)		
M1	24	1	0.2176	Yes	Yes	0.625	0.4757		2	0.625	0.125	103.3
M2	24	1	0.2101	Yes	Yes	0.875	0.5573		2.25	0.75	0.125	102.0
M3	24	1	0.2101	Yes	Yes	0.375	0.2646		2	0.375	0.125	167.7
N1	8.625	0.5	0.4649	Yes	Yes	0.625*	0.4486		2	0.5	0.125	152.1
N2	6.625	0.719	0.4229	Yes	Yes	0.625	0.4815		N/A	N/A	0.125	105.9
N3	2.375	0.344	0.2969	Yes	Yes	0.625	N/A		N/A	N/A	0.125	Exempt
N4	4.5	0.674	0.3799	Yes	Yes	0.875	0.5859		N/A	N/A	0.125	142.9
N5	2.375	0.344	0.2969	Yes	Yes	0.375	N/A		N/A	N/A	0.125	Exempt
N6	4.5	0.337	0.3024	Yes	Yes	0.375	0.3187		N/A	N/A	0.125	114.8
N7	6.625	0.719	0.3003	Yes	Yes	0.3125*	0.2493		N/A	N/A	0.125	119.1

*Head minimum thickness after forming

Definitions

tn	Nozzle thickness
Req tn	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 (psi)	T Design (°F)	MAEP (psi)	T_e external (°F)	MDMT (°F)	MDMT Exemption		Impact Tested
Top Head	150	550	49.6	550	-55	Note 1		No
Straight Flange on Top Head	150	550	27.85	550	-55	Note 2		No
Upper Shell	150	550	27.85	550	-55	Note 2		No
Upper Cone	150	550	15	550	-20	Note 3		No
Middle Shell	150	550	26.75	550	-20	Note 3		No
Lower Cone	150	550	15	550	-20	Note 3		No
Lower Shell	150	550	19.09	550	-24	Note 4		No
Straight Flange on Bottom Head	150	550	32.49	550	-41	Note 6		No
Bottom Head	150	550	59.15	550	-41	Note 5		No
Ring Upper Cone Small End	N/A	N/A	27.85	550	N/A	N/A		No
Ring Upper Cone Large End	N/A	N/A	22.17	550	N/A	N/A		No
Ring Lower Cone Large End	N/A	N/A	26.75	550	N/A	N/A		No
Clip #1	150	550	N/A	N/A	N/A	N/A		N/A
Ring Lower Cone Small End	N/A	N/A	19.09	550	N/A	N/A		No
Manway (M1)	150	550	17	550	-25.9	Nozzle	Note 7	No
						Pad	Note 8	No
Manway (M2)	150	550	15	550	-23	Nozzle	Note 9	No
						Pad	Note 10	No
Manway (M3)	150	550	27.44	550	-55	Nozzle	Note 11	No
						Pad	Note 12	No
Drain (N1)	150	550	32.49	550	-43.3	Nozzle	Note 13	No
						Pad	Note 14	No
Nozzle Pipe (N1)	150	550	412.19	550	-155	Note 15		No
Elbow (N1)	150	550	411.61	550	-155	Note 16		No
Elbow Pipe (N1)	150	550	411.61	550	-155	Note 16		No
Process (N2)	150	550	18.64	550	-24.8	Note 17		No
Process (N3)	150	550	19.09	550	-55	Note 18		No
Process (N4)	150	550	26.3	550	-55	Note 19		No
Process (N5)	150	550	27.85	550	-55	Note 19		No
Process (N6)	150	550	17.14	550	-55	Note 19		No
Process (N7)	150	550	27.85	550	-54.7	Note 20		No

Chamber Summary

Design MDMT	-20 °F
Rated MDMT	-20 °F @ 150 psi
MAWP hot & corroded	150 psi
MAEP	15 psi @ 550 °F

Notes for Maximum Pressure Rating	
Note #	**Details**
1.	Option to calculate MAP was not selected. See the Calculation->General tab of the Set Mode dialog.
2.	Option to calculate MAWP was not selected. See the Calculation->General tab of the Set Mode dialog.

Notes for MDMT Rating		
Note #	**Exemption**	**Details**
1.	Straight Flange governs MDMT	
2.	Material impact test exemption temperature from Fig UCS-66 Curve B = -20°F Fig UCS-66.1 MDMT reduction = 48.5°F, (coincident ratio = 0.55) Rated MDMT of -68.5°F is limited to -55°F by UCS-66(b)(2)	UCS-66 governing thickness = 0.375 in
3.	Material is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.875 in
4.	Material impact test exemption temperature from Fig UCS-66 Curve B = 5°F Fig UCS-66.1 MDMT reduction = 29°F, (coincident ratio = 0.71)	UCS-66 governing thickness = 0.625 in
5.	Straight Flange governs MDMT	
6.	Material impact test exemption temperature from Fig UCS-66 Curve B = 5°F Fig UCS-66.1 MDMT reduction = 46°F, (coincident ratio = 0.5681)	UCS-66 governing thickness = 0.625 in
7.	Nozzle impact test exemption temperature from Fig UCS-66 Curve B = 5°F Fig UCS-66.1 MDMT reduction = 30.9°F, (coincident ratio = 0.6908)	UCS-66 governing thickness = 0.625 in.
8.	Pad impact test exemption temperature from Fig UCS-66 Curve B = 5°F Fig UCS-66.1 MDMT reduction = 30.9°F, (coincident ratio = 0.6908)	UCS-66 governing thickness = 0.625 in.
9.	Nozzle impact test exemption temperature from Fig UCS-66 Curve B = 23°F Fig UCS-66.1 MDMT reduction = 46°F, (coincident ratio = 0.5678)	UCS-66 governing thickness = 0.875 in.
10.	Pad impact test exemption temperature from Fig UCS-66 Curve B = 15°F Fig UCS-66.1 MDMT reduction = 46°F, (coincident ratio = 0.5678)	UCS-66 governing thickness = 0.75 in.
11.	Nozzle impact test exemption temperature from Fig UCS-66 Curve B = -20°F Fig UCS-66.1 MDMT reduction = 48.5°F, (coincident ratio = 0.55) Rated MDMT of -68.5°F is limited to -55°F by UCS-66(b)(2)	UCS-66 governing thickness = 0.375 in.
12.	Pad impact test exemption temperature from Fig UCS-66 Curve B = -20°F Fig UCS-66.1 MDMT reduction = 48.5°F, (coincident ratio = 0.55) Rated MDMT of -68.5°F is limited to -55°F by UCS-66(b)(2)	UCS-66 governing thickness = 0.375 in.
13.	Nozzle is impact test exempt to -155°F per UCS-66(b)(3) (coincident ratio = 0.1249).	
14.	Pad impact test exemption temperature from Fig UCS-66 Curve B = -7°F Fig UCS-66.1 MDMT reduction = 36.3°F, (coincident ratio = 0.6375)	UCS-66 governing thickness = 0.5 in.
15.	Material is impact test exempt to -155°F per UCS-66(b)(3) (coincident ratio = 0.1505)	
16.	Material is impact test exempt to -155°F per UCS-66(b)(3) (coincident ratio = 0.151)	
17.	Nozzle impact test exemption temperature from Fig UCS-66 Curve B = 5°F Fig UCS-66.1 MDMT reduction = 29.8°F, (coincident ratio = 0.7022)	UCS-66 governing thickness = 0.625 in.
18.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2224) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
19.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	
20.	Nozzle impact test exemption temperature from Fig UCS-66 Curve B = -20°F Fig UCS-66.1 MDMT reduction = 34.7°F, (coincident ratio = 0.653)	UCS-66 governing thickness = 0.3125 in.

Settings Summary

COMPRESS 2016 Build 7600	
ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Units	U.S. Customary
Datum Line Location	0.00" from bottom seam
Vessel Design Mode	Get Pressure Rating and Calculate Required Thickness
Minimum thickness	0.0625" 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	1.20
Skirt/legs stress increase	1.0
Minimum nozzle projection	0.125"
Juncture calculations for $\alpha > 30$ 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
Test liquid specific gravity	1.00
Maximum stress during test	90% of yield
Required Marking - UG-116	
UG-116(e) Radiography	RT2
UG-116(f) Postweld heat treatment	None
Code Cases\Interpretations	
Use Code Case 2547	No
Apply interpretation VIII-1-83-66	Yes

Apply interpretation VIII-1-86-175	Yes
Apply interpretation VIII-1-83-115	Yes
Apply interpretation VIII-1-01-37	Yes
Apply interpretation VIII-1-01-150	Yes
Apply interpretation VIII-1-07-50	Yes
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:	Yes
Note: UG-22(b),(c) and (f) loads only considered when supports are present.	

License Information	
Company Name	Pressure Vessel Engineering Ltd.
License	Commercial
License Key ID	23429
Support Expires	March 01, 2017

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	Spot UW-11(a)(5)(b) / Type 1	RT2
Upper Shell	A	Full UW-11(a) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	RT2
Upper Cone	A	Full UW-11(a) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	RT2
Middle Shell	A	Full UW-11(a) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	RT2
Lower Cone	A	Full UW-11(a) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	RT2
Lower Shell	A	Full UW-11(a) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	B	Spot UW-11(a)(5)(b) / Type 1	RT2
Bottom Head	N/A	Seamless No RT	B	Spot UW-11(a)(5)(b) / Type 1	N/A	N/A	RT2
Nozzle	**Longitudinal Seam**		**Nozzle to Vessel Circumferential Seam**		**Nozzle free end Circumferential Seam**		
Process (N7)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Manway (M3)	A	User Defined (E = 1.00)	D	N/A / Type 7	C	Spot UW-11(a)(5)(b) / Type 1	RT2
Process (N6)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Process (N5)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Manway (M2)	A	User Defined (E = 1.00)	D	N/A / Type 7	C	Spot UW-11(a)(5)(b) / Type 1	RT2
Process (N4)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Manway (M1)	A	User Defined (E = 1.00)	D	N/A / Type 7	C	Spot UW-11(a)(5)(b) / Type 1	RT2
Process (N2)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Process (N3)	N/A	Seamless No RT	D	N/A / Type 7	C	UW-11(a)(4) exempt / Type 1	N/A
Drain (N1)	N/A	Seamless No RT	D	N/A / Type 7	B	UW-11(a)(4) exempt / Type 1	N/A
Nozzle Pipe (N1)	N/A	Seamless No RT	B	UW-11(a)(4) exempt / Type 1	B	UW-11(a)(4) exempt / Type 1	N/A
Elbow (N1)	N/A	Seamless No RT	B	UW-11(a)(4) exempt / Type 1	B	UW-11(a)(4) exempt / Type 1	N/A
Elbow Pipe (N1)	N/A	Seamless No RT	B	UW-11(a)(4) exempt / Type 1	C	UW-11(a)(4) exempt / Type 1	N/A
Nozzle Flange	**Longitudinal Seam**		**Flange Face**		**Nozzle to Flange Circumferential Seam**		
ASME B16.5/16.47 flange attached to Process (N7)	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 Manway (M3)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Spot UW-11(a)(5)(b) / Type 1	RT2
	N/A	Seamless No RT	N/A	N/A / Gasketed	C		N/A

ASME B16.5/16.47 flange attached to Process (N6)						UW-11(a)(4) exempt / Type 1	
ASME B16.5/16.47 flange attached to Process (N5)	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 Manway (M2)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Spot UW-11(a)(5)(b) / Type 1	RT2
ASME B16.5/16.47 flange attached to Process (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 Manway (M1)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	Spot UW-11(a)(5)(b) / Type 1	RT2
ASME B16.5/16.47 flange attached to Process (N2)	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 Process (N3)	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 right end of Elbow Pipe (N1)	N/A	Seamless No RT	N/A	N/A / Gasketed	C	UW-11(a)(4) exempt / Type 1	N/A
UG-116(e) Required Marking: **RT2**							

Thickness Summary

Component Data								
Component Identifier	**Material**	**Diameter (in)**	**Length (in)**	**Nominal t (in)**	**Design t (in)**	**Total Corrosion (in)**	**Joint E**	**Load**
Top Head	SA-516 70	36.25 ID	9.375	0.3125*	0.2629	0.125	1.00	Internal
Straight Flange on Top Head	SA-516 70	36.25 ID	1.5	0.375	0.3187	0.125	1.00	External
Upper Shell	SA-516 70	36.25 ID	104	0.375	0.3187	0.125	1.00	External
Upper Cone	SA-516 70	36.25 / 120.25 ID	100	0.875	0.6249	0.125	1.00	Internal
Middle Shell	SA-516 70	120.25 ID	304	0.875	0.7257	0.125	1.00	External
Lower Cone	SA-516 70	84 / 120.25 ID	120	0.875	0.6041	0.125	1.00	Internal
Lower Shell	SA-516 70	84 ID	255	0.625	0.582	0.125	1.00	Seismic
Straight Flange on Bottom Head	SA-516 70	84 ID	1.5	0.75	0.581	0.125	1.00	External
Bottom Head	SA-516 70	84 ID	21.625	0.625*	0.4843	0.125	1.00	Internal
Support Skirt	SA-516 70	84 ID	90.62	0.75	0.7266	0	0.55	Seismic
*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 (lb) Contributed by Vessel Elements											
Component	**Metal New***	**Metal Corroded**	**Insulation**	**Insulation Supports**	**Lining**	**Piping + Liquid**	**Operating Liquid**		**Test Liquid**		**Surface Area ft^2**
							New	**Corroded**	**New**	**Corroded**	
Top Head	152	93.2	0	0	0	0	0	0	288.7	296.5	12
Upper Shell	1,219.8	816.1	0	0	0	0	0	0	4,011.8	4,068.8	81
Upper Cone	6,570.5	5,641.7	0	0	0	0	0	0	19,169.6	19,293.4	187
Middle Shell	28,641.3	24,575	0	0	0	0	47,144.4	47,340.6	124,628.1	125,147.3	809
Lower Cone	9,725.3	8,346.2	0	0	0	0	35,854.5	36,030.4	35,854.5	36,030.4	275
Lower Shell	11,904.1	9,537.4	0	0	0	0	51,092.7	51,398.9	51,092.7	51,398.9	471
Bottom Head	1,539	1,238.4	0	0	0	0	3,214.8	3,250.1	3,214.8	3,250.1	64
Support Skirt	5,029.2	5,029.2	0	0	0	0	0	0	0	0	338
Skirt Base Ring	2,663	2,663	0	0	0	0	0	0	0	0	150
TOTAL:	**67,444.2**	**57,940.2**	**0**	**0**	**0**	**0**	**137,306.4**	**138,020.1**	**238,260.1**	**239,485.4**	**2,386**

*Shells with attached nozzles have weight reduced by material cut out for opening.

Weight (lb) Contributed by Attachments

Component	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms*	Trays	Tray Supports	Rings & Clips	Vertical Loads	Surface Area ft^2
	New	Corroded	New	Corroded							
Top Head	0	0	81.9	75.2	0	0	0	0	0	0	3
Upper Shell	0	0	1,853.5	1,812.3	0	1,587.4	0	0	26	0	29
Upper Cone	0	0	1,867.9	1,825.5	0	376	0	0	0	0	23
Middle Shell	0	0	52	47.5	0	1,311.1	0	0	709	0	70
Lower Cone	0	0	0	0	0	180	0	0	0	0	0
Lower Shell	0	0	1,756.1	1,730.5	0	2,255.6	0	0	202.3	0	46
Bottom Head	0	0	229.9	228.6	0	40.5	0	0	0	0	13
Support Skirt	0	0	287.6	287.6	0	0	0	0	0	0	0
TOTAL:	**0**	**0**	**6,128.9**	**6,007.1**	**0**	**5,750.6**	**0**	**0**	**937.3**	**0**	**184**

* Platforms and ladders are not included in surface area.

Vessel Totals

	New	Corroded
Operating Weight (lb)	217,567	208,655
Empty Weight (lb)	80,261	70,635
Test Weight (lb)	318,521	310,121
Surface Area (ft^2)	2,570	-
Capacity** (US gal)	28,515	28,661

**The vessel capacity does not include volume of nozzle, piping or other attachments.

Vessel Lift Condition

Vessel Lift Weight, New (lb)	74,510
Center of Gravity from Datum (in)	384.9918

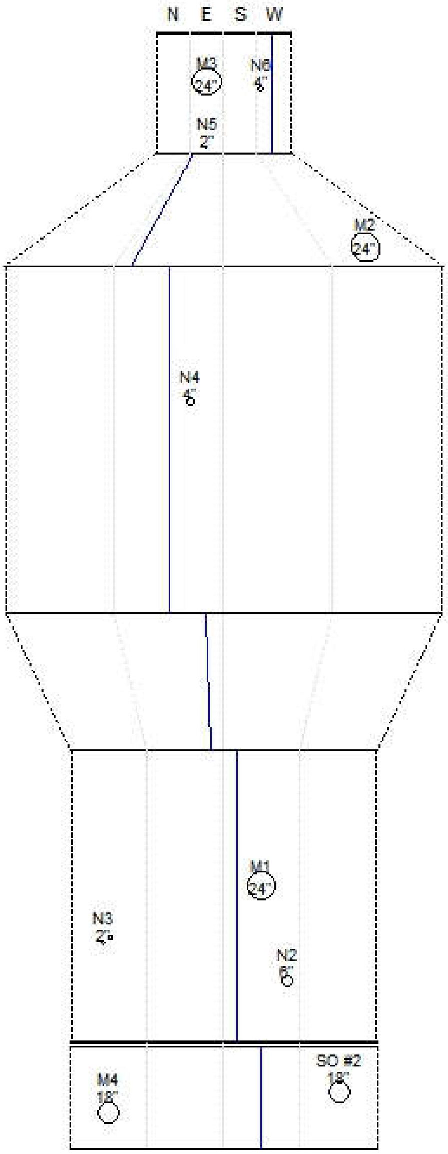
Long Seam Summary

Shell Long Seam Angles	
Component	**Seam 1**
Upper Shell	270°
Upper Cone	60°
Middle Shell	90°
Lower Cone	120°
Lower Shell	150°
Support Skirt	180°

Shell Plate Lengths		
Component	**Starting Angle**	**Plate 1**
Upper Shell	270°	115.0608"
Upper Cone	60°	380.758"
Middle Shell	90°	380.5254"
Lower Cone	120°	380.5566"
Lower Shell	150°	265.8573"
Support Skirt	180°	266.25"

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 70°F = 1.3*MAWP*LSR
= 1.3*150*1
= 195 psi

Horizontal shop hydrostatic test

Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test (psi)	Allowable test stress (psi)	Stress excessive?
Top Head	197.825	2.825	1.0152	1.30	10,326	34,200	No
Straight Flange on Top Head	197.825	2.825	1.0152	1.30	9,660	34,200	No
Upper Shell	197.825	2.825	1.0152	1.30	9,660	34,200	No
Upper Cone	199.341	4.341	1.0152	1.30	14,857	34,200	No
Middle Shell	199.341	4.341	1.0152	1.30	13,797	34,200	No
Lower Cone	199.341	4.341	1.0152	1.30	13,853	34,200	No
Lower Shell	198.686	3.686	1.0152	1.30	13,451	34,200	No
Straight Flange on Bottom Head	198.686	3.686	1.0152	1.30	11,225	34,200	No
Bottom Head	198.686	3.686	1.0152	1.30	12,017	34,200	No
Drain (N1) (1)	197.308	2.308	1	1.30	18,543	51,300	No
Elbow (N1)	197.314	2.314	1	1.30	2,892	31,500	No
Elbow Pipe (N1)	197.314	2.314	1	1.30	2,892	31,500	No
Manway (M1)	199.158	4.158	1.0152	1.30	22,210	51,300	No
Manway (M2)	197.567	2.567	1.0152	1.30	28,536	51,300	No
Manway (M3)	197.567	2.567	1.0152	1.30	14,331	51,300	No
Nozzle Pipe (N1)	197.314	2.314	1	1.30	2,892	31,500	No
Process (N2)	198.751	3.751	1	1.30	18,456	51,300	No
Process (N3)	195.651	0.651	1	1.30	20,234	51,300	No
Process (N4)	197.859	2.859	1	1.30	19,473	51,300	No
Process (N5)	197.201	2.201	1	1.30	12,860	51,300	No
Process (N6)	197.745	2.745	1	1.30	16,922	51,300	No
Process (N7)	197.264	2.264	1	1.30	13,228	51,300	No

(1) Drain (N1) limits the UG-99(b) stress ratio.
(2) P_L stresses at nozzle openings have been estimated using the method described in Division 2 Part 4.5.
(3) 1.5*0.9*S_y used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(4) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The field test condition has not been investigated.

The test temperature of 70 °F is warmer than the minimum recommended temperature of 10 °F 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 (in)**	**Length Le (in)**
Top Head	-	893.875	N/A
-	1/3 depth of Top Head	887.5625	N/A
Straight Flange on Top Head Top	-	884.5	108.0625
Straight Flange on Top Head Bottom	-	883	108.0625
Upper Shell Top	-	883	108.0625
-	Ring Upper Cone Small End	779.5	54.2813
Upper Shell Bottom	-	779	108.0625
Upper Cone Top	-	779	65.6155
-	Upper Cone Top	779	65.6155
-	Upper Cone Bottom	679	65.6155
Upper Cone Bottom	-	679	65.6155
Middle Shell Top	-	679	303
-	Ring Upper Cone Large End	678.5	151.75
-	Ring Lower Cone Large End	375.5	151.75
Middle Shell Bottom	-	375	303
Lower Cone Top	-	375	102.175
-	Lower Cone Top	375	102.175
-	Lower Cone Bottom	255	102.175
Lower Cone Bottom	-	255	102.175
Lower Shell Top	-	255	262.5417
-	Ring Lower Cone Small End	254	131.7708
Lower Shell Bottom	-	0	262.5417
Straight Flange on Bottom Head Top	-	0	262.5417
Straight Flange on Bottom Head Bottom	-	-1.5	262.5417
-	1/3 depth of Bottom Head	-8.5417	N/A
Bottom Head	-	-23.125	N/A
For Rings, the listed value of 'Le' is Ls per UG-29.			

Liquid Level bounded by Bottom Head

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Location from Datum (in)	490
Operating Liquid Specific Gravity	1

Top Head

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td colspan="2">Component</td><td colspan="3">Ellipsoidal Head</td></tr>
<tr><td colspan="2">Material</td><td colspan="3">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td colspan="2">Attached To</td><td colspan="3">Upper Shell</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Optimize MDMT/ Find MAWP</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (psi)</td><td>Design Temperature (°F)</td><td>Design MDMT (°F)</td></tr>
<tr><td colspan="2">Internal</td><td>150</td><td>550</td><td rowspan="2">-20</td></tr>
<tr><td colspan="2">External</td><td>15</td><td>550</td></tr>
<tr><td colspan="5">Static Liquid Head</td></tr>
<tr><td colspan="2">Condition</td><td>P_s (psi)</td><td>H_s (in)</td><td>SG</td></tr>
<tr><td colspan="2">Test horizontal</td><td>2.82</td><td>78.25</td><td>1</td></tr>
<tr><td colspan="5">Dimensions</td></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">36.25"</td></tr>
<tr><td colspan="2">Head Ratio</td><td colspan="3">2</td></tr>
<tr><td colspan="2">Minimum Thickness</td><td colspan="3">0.3125"</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">0.125"</td></tr>
<tr><td>Outer</td><td colspan="3">0"</td></tr>
<tr><td colspan="2">Length L_{sf}</td><td colspan="3">1.5"</td></tr>
<tr><td colspan="2">Nominal Thickness t_{sf}</td><td colspan="3">0.375"</td></tr>
<tr><td colspan="5">Weight and Capacity</td></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (lb)[1]</td><td>Capacity (US gal)[1]</td></tr>
<tr><td colspan="2">New</td><td colspan="2">152.04</td><td>33.69</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">93.19</td><td>34.54</td></tr>
<tr><td colspan="5">Radiography</td></tr>
<tr><td colspan="2">Category A joints</td><td colspan="3">Seamless No RT</td></tr>
<tr><td colspan="2">Head to shell seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
</table>

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.2629"
Design thickness due to external pressure (t_e)	0.2244"
Maximum allowable external pressure (MAEP)	49.6 psi
Straight Flange governs MDMT	-55°F

Factor K		
$K = (1/6)*[2 + (D / (2*h))^2]$		
Corroded	$K = (1/6)*[2 + (36.5 / (2*9.1875))^2]$	0.991
New	$K = (1/6)*[2 + (36.25 / (2*9.0625))^2]$	1

Design thickness for internal pressure, (Corroded at 550 °F) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 150*36.5*0.990961 / (2*19,700*1 - 0.2*150) + 0.125
= 0.2628"

Design thickness for external pressure, (Corroded at 550 °F) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.885*36.875
= 32.6344 in

A = 0.125 / (R_o / t)
= 0.125 / (32.6344 / 0.099387)
= 0.000381

From Table CS-2: B = 4,925.3336 psi

P_a = B / (R_o / t)
= 4,925.3336 / (32.6344 / 0.0994)
= 15 psi

t = 0.0994" + Corrosion = 0.0994" + 0.125" = 0.2244"
Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

t = $1.67*P_e*D*K / (2*S*E - 0.2*1.67*P_e)$ + Corrosion
= 1.67*15*36.5*0.990961 / (2*19,700*1 - 0.2*1.67*15) + 0.125
= 0.148"

The head external pressure design thickness (t_e) is 0.2244".

Maximum Allowable External Pressure, (Corroded at 550 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

R_o = K_o*D_o
= 0.885*36.875
= 32.6344 in

A = 0.125 / (R_o / t)
= 0.125 / (32.6344 / 0.1875)
= 0.000718

From Table CS-2: B = 8,632.7944 psi

P_a = B / (R_o / t)
= 8,632.7944 / (32.6344 / 0.1875)
= 49.5995 psi

Check the Maximum External Pressure, UG-33(a)(1) Appendix 1-4(c)

P = 2*S*E*t / ((K*D + 0.2*t)*1.67)
= 2*19,700*1*0.1875 / ((0.990961*36.5 +0.2*0.1875)*1.67)
= 122.17 psi

The maximum allowable external pressure (MAEP) is 49.6 psi.

% Extreme fiber elongation - UCS-79(d)

EFE = (75*t / R_f)*(1 - R_f / R_o)
= (75*0.375 / 6.35)*(1 - 6.35 / ∞)
= 4.4291%

The extreme fiber elongation does not exceed 5%.

Straight Flange on Top Head

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Cylinder		
Material		SA-516 70 (II-D p. 18, ln. 24)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal		2.82	78.25	1
Dimensions				
Inner Diameter		36.25"		
Length		1.5"		
Nominal Thickness		0.375"		
Corrosion	**Inner**	0.125"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		18.32		6.7
Corroded		12.25		6.79
Radiography				
Longitudinal seam		Seamless No RT		
Bottom Circumferential seam		Spot UW-11(a)(5)(b) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.2646"
Design thickness due to external pressure (t_e)	0.3187"
Design thickness due to combined loadings + corrosion	0.193"
Maximum allowable external pressure (MAEP)	27.85 psi
Rated MDMT	-55 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.375"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t_r = 150*18.25 / (20,000*1 - 0.6*150) =	0.1375"
Stress ratio = t_r*E^* / (t_n - c) = 0.1375*1 / (0.375 - 0.125) =	0.55
Reduction in MDMT, T_R from Fig UCS-66.1 =	48.5°F
MDMT = max[MDMT - T_R, -55] = max[-20 - 48.5 , -55] =	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 150*18.25 / (19,700*1.00 - 0.60*150) + 0.125
= 0.2646"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.1937 = 191.0372

From table G: A = 0.000167
From table CS-2: B = 2,149.169 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,149.17 / (3*(37 / 0.1937))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = t + Corrosion = 0.1937 + 0.125 = 0.3187"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.25 = 148.0000

From table G: A = 0.000240
From table CS-2: B = 3,091.0204 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,091.02 / (3*(37 / 0.25))
= 27.85 psi

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.375 / 18.3125)*(1 - 18.3125 / ∞)
= 1.0239%

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	19,700	10,515	550	0.125	Wind	150	0.068	0.0679
					Seismic	150	0.068	0.0679
Operating, Hot & New	19,700	11,412	550	0	Wind	150	0.0675	0.0674
					Seismic	150	0.0676	0.0674
Hot Shut Down, Corroded	19,700	10,515	550	0.125	Wind	0	0	0.0001
					Seismic	0	0	0.0002
Hot Shut Down, New	19,700	11,412	550	0	Wind	0	0.0001	0.0002
					Seismic	0	0	0.0003
Empty, Corroded	20,000	14,292	70	0.125	Wind	0	0	0.0001
					Seismic	0	0	0.0001
Empty, New	20,000	15,689	70	0	Wind	0	0	0.0001
					Seismic	0	0	0.0002
Vacuum	19,700	10,515	550	0.125	Wind	-15	0.0109	0.011
					Seismic	-15	0.0108	0.0111
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,515	550	0.125	Wind	0	0.0001	0.0001
					Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	14,292	70	0.125	Wind	0	0	0.0002

Upper Shell

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td colspan="2">Component</td><td colspan="3">Cylinder</td></tr>
<tr><td colspan="2">Material</td><td colspan="3">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Optimize MDMT/ Find MAWP</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (psi)</td><td>Design Temperature (°F)</td><td>Design MDMT (°F)</td></tr>
<tr><td colspan="2">Internal</td><td>150</td><td>550</td><td rowspan="2">-20</td></tr>
<tr><td colspan="2">External</td><td>15</td><td>550</td></tr>
<tr><td colspan="5">Static Liquid Head</td></tr>
<tr><td colspan="2">Condition</td><td>P_s (psi)</td><td>H_s (in)</td><td>SG</td></tr>
<tr><td colspan="2">Test horizontal</td><td>2.82</td><td>78.25</td><td>1</td></tr>
<tr><td colspan="5">Dimensions</td></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">36.25"</td></tr>
<tr><td colspan="2">Length</td><td colspan="3">104"</td></tr>
<tr><td colspan="2">Nominal Thickness</td><td colspan="3">0.375"</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">0.125"</td></tr>
<tr><td>Outer</td><td colspan="3">0"</td></tr>
<tr><td colspan="5">Weight and Capacity</td></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (lb)</td><td>Capacity (US gal)</td></tr>
<tr><td colspan="2">New</td><td colspan="2">1,219.76</td><td>464.65</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">816.06</td><td>471.08</td></tr>
<tr><td colspan="5">Radiography</td></tr>
<tr><td colspan="2">Longitudinal seam</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><td colspan="2">Top Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
<tr><td colspan="2">Bottom Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
</table>

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.2646"
Design thickness due to external pressure (t_e)	0.3187"
Design thickness due to combined loadings + corrosion	0.2056"
Maximum allowable external pressure (MAEP)	27.85 psi
Rated MDMT	-55 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.375"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t_r = 150*18.25 / (20,000*1 - 0.6*150) =	0.1375"
Stress ratio = t_r*E^* / (t_n - c) = 0.1375*1 / (0.375 - 0.125) =	0.55
Reduction in MDMT, T_R from Fig UCS-66.1 =	48.5°F
MDMT = max[MDMT - T_R, -55] = max[-20 - 48.5 , -55] =	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 150*18.25 / (19,700*1.00 - 0.60*150) + 0.125
= 0.2646"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.1937 = 191.0372

From table G: A = 0.000167
From table CS-2: B = 2,149.169 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,149.17 / (3*(37 / 0.1937))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = t + Corrosion = 0.1937 + 0.125 = 0.3187"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.25 = 148.0000

From table G: A = 0.000240
From table CS-2: B = 3,091.0204 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,091.02 / (3*(37 / 0.25))
= 27.85 psi

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*0.375 / 18.3125)*(1 - 18.3125 / ∞)
= 1.0239%

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

P_v = W / (2*π*R_m) + M / (π*R_m^2)
= 4,605.1 / (2*π*18.375) + 192,915 / (π*18.375^2)
= 221.7573 lb/in
α = P_v / (P_e*D_o)
= 221.7573 / (15*37)
= 0.3996
n = 3
m = 1.23 / (L / D_o)^2
= 1.23 / (108.0625 / 37)^2
= 0.1442
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (3^2 - 1 + 0.1442 + 0.1442*0.3996) / (3^2 - 1 + 0.1442)
= 1.0071
Ratio P_e * P_e ≤ MAEP
(1.0071 * 15 = 15.11) ≤ 27.85
Cylinder thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

P_v = (1 + 0.14*S_{DS})*W / (2*π*R_m) + M / (π*R_m^2)
= 1.19*4,605.1 / (2*π*18.375) + 273,441 / (π*18.375^2)
= 305.1187 lb/in
α = P_v / (P_e*D_o)
= 305.1187 / (15*37)
= 0.5498
n = 3
m = 1.23 / (L / D_o)^2
= 1.23 / (108.0625 / 37)^2
= 0.1442
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (3^2 - 1 + 0.1442 + 0.1442*0.5498) / (3^2 - 1 + 0.1442)
= 1.0097
Ratio P_e * P_e ≤ MAEP

(1.0097 * 15 = 15.15) ≤ 27.85

Cylinder thickness is satisfactory.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	19,700	10,515	550	0.125	Wind	150	0.0759	0.057
					Seismic	150	0.08	0.0528
Operating, Hot & New	19,700	11,412	550	0	Wind	150	0.0754	0.0562
					Seismic	150	0.0806	0.051
Hot Shut Down, Corroded	19,700	10,515	550	0.125	Wind	0	0.0079	0.0176
					Seismic	0	0.012	0.0242
Hot Shut Down, New	19,700	11,412	550	0	Wind	0	0.0078	0.0167
					Seismic	0	0.013	0.0243
Empty, Corroded	20,000	14,292	70	0.125	Wind	0	0.0077	0.0129
					Seismic	0	0.0109	0.0167
Empty, New	20,000	15,689	70	0	Wind	0	0.0077	0.0122
					Seismic	0	0.0118	0.0165
Vacuum	19,700	10,515	550	0.125	Wind	-15	0.001	0.0284
					Seismic	-15	0.0052	0.035
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,515	550	0.125	Wind	0	0.0051	0.0158
					Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	14,292	70	0.125	Wind	0	0.0155	0.0221

Upper Cone

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Cone		
Material		SA-516 70 (II-D p. 18, ln. 24)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Test horizontal	**Large**	4.34	120.25	1
	Small	2.82	78.25	
Dimensions				
Inner Diameter	**Large**	120.25"		
	Small	36.25"		
Length		100"		
Nominal Thickness		0.875"		
Corrosion	**Inner**	0.125"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		6,570.52		2,281.76
Corroded		5,641.68		2,296.21
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Spot UW-11(a)(5)(b) Type 1		
Bottom Circumferential seam		Spot UW-11(a)(5)(b) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.6249"
Design thickness due to external pressure (t_e)	0.4673"
Design thickness due to combined loadings + corrosion	0.3708"
Maximum allowable external pressure (MAEP)	15 psi
Rated MDMT	-20 °F
Design P and Design Pe are used for Appendix 1-5 and Appendix 1-8 calculations.	

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.875"
MDMT =	-20°F
Material is exempt from impact testing per UG-20(f) at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-32(g) (Large End)

$t = P*D / (2*\cos(\alpha)*(S*E - 0.60*P)) + \text{Corrosion}$
$= 150*120.5212 / (2*\cos(22.7824)*(19{,}700*1.00 - 0.60*150)) + 0.125$
$= 0.6249"$

Small End design thickness (t = 0.2765") does not govern.

External Pressure, (Corroded & at 550 °F) UG-33(f)

$D_L = 122.1481"$
$L_e = (L / 2)*(1 + D_s / D_L)$
$= (100 / 2)*(1 + 38.1481 / 122.1481)$
$= 65.6155"$

$t_e = t*\cos(\alpha) = 0.3423*\cos(22.7824) = 0.3156"$
$L_e / D_L = 65.6155 / 122.1481 = 0.5372$
$D_L / t_e = 122.1481 / 0.3156 = 387.0322$

From table G: A = 0.000337
From table CS-2: B = 4,354.1101 psi

$P_a = 4*B / (3*(D_L / t_e))$
$= 4*4{,}354.11 / (3*(122.1481 / 0.3156))$
$= 15$ psi

Design thickness for external pressure P_a = 15 psi

$t_a = t_e / \cos(\alpha) + \text{Corrosion} = 0.3156 / \cos(22.7824) + 0.125 = 0.4673"$

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-33(f)

$t_e = t*\cos(\alpha) = 0.75*\cos(22.7824) = 0.6915''$
$L_e / D_L = 65.6155 / 122.1481 = 0.5372$
$D_L / t_e = 122.1481 / 0.6915 = 176.646$

From table G: A = 0.001140
From table CS-2: B = 9,711.6736 psi

$P_a = 4*B / (3*(D_L / t_e))$
$= 4*9{,}711.67 / (3*(122.1481 / 0.6915))$
$= 73.3$ psi

% Extreme fiber elongation - UCS-79(d)

$EFE = (50*t / R_f)*(1 - R_f / R_o)$
$= (50*0.949 / 18.5995)*(1 - 18.5995 / \infty)$
$= 2.5513\%$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$P_v = [W / (2*\pi*R_m) + M / (\pi*R_m{}^2)] / \cos(\alpha)$
$= [12{,}072.3 / (2*\pi*60.6673) + 354{,}384 / (\pi*60.6673^2)] / \cos(22.7824)$
$= 67.5928$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 67.5928 / (15*122.1481)$
$= 0.0369$
$n = 7$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (65.6155 / 122.1481)^2$
$= 4.2625$
Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (7^2 - 1 + 4.2625 + 4.2625*0.0369) / (7^2 - 1 + 4.2625)$
$= 1.003$
Ratio $P_e * P_e \leq$ MAEP
$(1.003 * 15 = 15.05) \leq 73.3$
Transition thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$P_v = [(1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m{}^2)] / \cos(\alpha)$
$= [1.19*12{,}072.3 / (2*\pi*60.6673) + 627{,}325 / (\pi*60.6673^2)] / \cos(22.7824)$
$= 99.6077$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 99.6077 / (15*122.1481)$
$= 0.0544$
$n = 7$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (65.6155 / 122.1481)^2$

$= 4.2625$

$\text{Ratio } P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$

$= (7^2 - 1 + 4.2625 + 4.2625*0.0544) / (7^2 - 1 + 4.2625)$

$= 1.0044$

$\text{Ratio } P_e * P_e \leq \text{MAEP}$

$(1.0044 * 15 = 15.07) \leq 73.3$

Transition thickness is satisfactory.

Thickness Required Due to Pressure + External Loads										
Condition	**Allowable Stress Before UG-23 Stress Increase (psi)**		**Temperature (°F)**	**Corrosion C (in)**	**Location**	**Load**	**Pressure P (psi)**	**Req'd Thk Due to Tension (in)**	**Req'd Thk Due to Compression (in)**
	S_t	**S_c**							
Operating, Hot & Corroded	19,700	10,146	550	0.125	Top	Wind	150	0.0821	0.0622
						Seismic	150	0.0864	0.0578
					Bottom	Wind	150	0.2442	0.2402
						Seismic	150	0.2458	0.2386
Operating, Hot & New	19,700	10,467	550	0	Top	Wind	150	0.0815	0.0613
						Seismic	150	0.0869	0.0558
					Bottom	Wind	150	0.2435	0.2395
						Seismic	150	0.2455	0.2375
Hot Shut Down, Corroded	19,700	10,146	550	0.125	Top	Wind	0	0.0082	0.0192
						Seismic	0	0.0126	0.0264
					Bottom	Wind	0	0.0006	0.0056
						Seismic	0	0.0022	0.0082
Hot Shut Down, New	19,700	10,467	550	0	Top	Wind	0	0.0082	0.0192
						Seismic	0	0.0137	0.0279
					Bottom	Wind	0	0.0005	0.0057
						Seismic	0	0.0025	0.0089
Empty, Corroded	20,000	13,586	70	0.125	Top	Wind	0	0.0081	0.0143
						Seismic	0	0.0114	0.0185
					Bottom	Wind	0	0.0006	0.0041
						Seismic	0	0.0018	0.0056
Empty, New	20,000	14,199	70	0	Top	Wind	0	0.0081	0.0142
						Seismic	0	0.0123	0.0192
					Bottom	Wind	0	0.0005	0.0042
						Seismic	0	0.002	0.006
Vacuum	19,700	10,146	550	0.125	Top	Wind	-15	0.0008	0.0314

						Seismic	-15	0.0052	0.0386
					Bottom	Wind	-15	0.0392	0.0458
						Seismic	-15	0.0366	0.0484
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,146	550	0.125	Top	Wind	0	0.0054	0.0173
						Seismic	0	0	0
					Bottom	Wind	0	0.0033	0.0034
						Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	13,586	70	0.125	Top	Wind	0	0.0195	0.0294
					Bottom	Wind	0	0.0035	0.0084

Cone juncture large end calculations, P =150 psi
Appendix 1-5(d)

Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2) 1/2x5 Flat Bar	Status
Wind Corroded	No	No	11.68	4,530.43	0	3.69	2.5	OK
Wind New	No	No	9.24	4,518.62	0	5.85	2.5	OK
Seismic Corroded	No	No	41.23	4,559.98	0	3.69	2.5	OK
Seismic New	No	No	46.07	4,555.45	0	5.85	2.5	OK

Cone large end calculations per Appendix 1-5(d), wind + pressure, corroded

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*12,072.28 / (\pi*2*60.625) + 12*29,532 / (\pi*60.625^2)$
$= 11.68$ lb_f/in

$P*R_L / 2 = 4,518.75$ lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 150 / (19,700*1) = 0.007614$

From table 1-5.1 $\Delta = 27.92°$

As $\Delta >= \alpha$ no additional reinforcement is required.

Cone large end calculations per Appendix 1-5(d), wind + pressure, new

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*13,554.03 / (\pi*2*60.5625) + 12*29,396.4 / (\pi*60.5625^2)$
$= 9.24$ lb_f/in

$P*R_L / 2 = 4,509.38$ lb_f/in

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 150 / (19,700*1) = 0.007614$

From table 1-5.1 $\Delta = 27.92°$

As $\Delta >= \alpha$ no additional reinforcement is required.

Cone juncture small end calculations, P =150 psi
Appendix 1-5(e)

Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_2 (lbf/in)	Q_s (lbf/in)	A_{rs} (in2)	A_{es} (in2)	Ring area (in^2) 3/8x2 Flat Bar	Status
Wind Corroded	Yes	No	157.94	1,526.69	0.4	1.27	0.75	OK
Wind New	Yes	No	157.71	1,517.08	0.39	2.08	0.75	OK
Seismic Corroded	Yes	No	241.3	1,610.05	0.42	1.27	0.75	OK
Seismic New	Yes	No	261.58	1,620.95	0.42	2.08	0.75	OK

Cone small end calculations per Appendix 1-5(e), seismic + pressure, corroded

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m{}^2)$
$= -(0.6 - 0.14*1.3333)*4{,}605.14 / (\pi*2*18.375) + 12*22{,}786.7 / (\pi*18.375^2)$
$= 241.3\ lb_f/in$

$P*R_s / 2 = 1{,}368.75\ lb_f/in$

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 150 / (19{,}700*1) = 0.007614$

From table 1-5.2 $\Delta = 7.57°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 1{,}368.75 + 241.3$
$= 1{,}610.05\ lb_f/in$

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}610.05*18.25 / (19{,}700*1))*(1 - 7.57 / 22.7824)*\tan(22.7824)$
$= 0.4183\ in^2$

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(18.25*0.25)^{0.5}*[(0.25 - 0.1396) + (0.75 - 0.1514) / \cos(22.7824)]$
$= 1.2656\ in^2$

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Cone small end calculations per Appendix 1-5(e), seismic + pressure, new

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m{}^2)$
$= -(0.6 - 0.14*1.3333)*5{,}115.57 / (\pi*2*18.3125) + 12*24{,}578.1 / (\pi*18.3125^2)$
$= 261.58\ lb_f/in$

$P*R_s / 2 = 1{,}359.375\ lb_f/in$

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 150 / (19{,}700*1) = 0.007614$

From table 1-5.2 $\Delta = 7.57°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 1{,}359.38 + 261.58$
$= 1{,}620.95$ lb_f/in

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*1{,}620.95*18.125 / (19{,}700*1))*(1 - 7.57 / 22.7824)*\tan(22.7824)$
$= 0.4182$ in^2

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(18.125*0.375)^{0.5}*[(0.375 - 0.1386) + (0.875 - 0.1504) / \cos(22.7824)]$
$= 2.0789$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Cone large end calculations for external pressure of 15 psi Appendix 1-8(b)											
Loading	**Area check req'd** $\Delta < \alpha$	**U-2(g) analysis req'd**	**f_1** (lbf/in)	**Q_L** (lbf/in)	**A_{rL}** (in2)	**A_{eL}** (in2)	**Ring area (in^2) 1/2x5 Flat Bar**	**Area status**	**I'_s** (in^4)	**I'** (in^4)	**I status**
Wind Corroded	Yes	No	62.38	519.88	0.67	8.23	2.5	OK	26.9989	32.6292	OK
Seismic Corroded	Yes	No	91.94	549.44	0.7	8.23	2.5	OK	27.1188	32.6292	OK

Cone large end calculations per Appendix 1-8(b), seismic + external pressure

$f_1 = (1 + 0.14*S_{DS})*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= (1 + 0.14*1.3333)*12{,}072.28 / (\pi*2*60.625) + 12*52{,}277.1 / (\pi*60.625^2)$
$= 91.94\ lb_f/in$

$P*R_L / 2 = 457.5\ lb_f/in$

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 15 / (19{,}700*1) = 0.000761$

From table 1-8.1 $\Delta = 1.9°$

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 457.5 + 91.94$
$= 549.44\ lb_f/in$

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L-Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*549.44*61*\tan(22.7824) / (19{,}700*1))*[1 - 0.25*((15*61-549.44) / 549.44)*(1.9 / 22.7824)]$
$= 0.7046\ in^2$

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(122*0.75)^{0.5}*(0.75 + 0.75 / \cos(22.7824))$
$= 8.2255\ in^2$

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -61*\tan(22.7824) / 2 + 303.5 / 2 + (61^2 - 18.5^2) / (3*61*\tan(22.7824))$
$= 182.8998\ in$

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (100^2 + (61 - 18.5)^2)^{0.5}$
$= 108.6566\ in$

$A_{TL} = L_L*t_s / 2 + L_c * t_c / 2 + A_s$
$= 303.5*0.75 / 2 + 108.6566 * 0.75 / 2 + 2.5$
$= 157.0587\ in^2$

$F_L = P*M + f_1*\tan(\alpha)$

= 15*182.8998 + 91.94*tan(22.7824)
= 2,782.11 lb_f/in

B = 0.75*F_L*D_L / A_{TL}
= 0.75*2,782.11*122 / 157.0587
= 1,621 psi

From Table CS-2: A = 0.000126 (shell, 550°F)

I'_s = A*D_L^2*A_{TL} / 10.9
= 0.000126*122^2*157.0587 / 10.9
= 27.1188 in^4

The calculated I' for the combined ring-shell-cone cross section is 32.6292 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Cone small end calculations for external pressure of 15 psi Appendix 1-8(c)										
Loading	**U-2(g) analysis req'd**	**f_2 (lbf/in)**	**Q_s (lbf/in)**	**A_{rs} (in2)**	**A_{es} (in2)**	**Ring area (in^2) 3/8x2 Flat Bar**	**Area status**	**I'_s (in^4)**	**I' (in^4)**	**I status**
Wind Corroded	No	221.76	360.51	0.14	1.14	0.75	OK	0.5605	0.7887	OK
Seismic Corroded	No	305.12	443.87	0.18	1.14	0.75	OK	0.5699	0.7887	OK

Cone small end calculations per Appendix 1-8(c), seismic + external pressure

$f_2 = (1 + 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= (1 + 0.14*1.3333)*4,605.14 / (\pi*2*18.375) + 12*22,786.7 / (\pi*18.375^2)$
$= 305.12\ lb_f/in$

$P*R_s / 2 = 138.75\ lb_f/in$

$f_2 + P*R_s / 2$ is in compression so a U-2(g) analysis is not required.

$Q_s = P*R_s / 2 + f_2$
$= 138.75 + 305.12$
$= 443.87\ lb_f/in$

$A_{rs} = (k*Q_s*R_s*\tan(\alpha) / (S_s*E_1))$
$= (1*443.87*18.5*\tan(22.7824) / (19,700*1))$
$= 0.1751\ in^2$

$A_{es} = 0.55*(D_s*t_s)^{0.5}*((t_s - t) + (t_c - t_r) / \cos(\alpha))$
$= 0.55*(37*0.25)^{0.5}*((0.25 - 0.194) + (0.75 - 0.1737) / \cos(22.7824))$
$= 1.1393\ in^2$

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 18.5*\tan(22.7824) / 2 + 108.5625 / 2 + (61^2 - 18.5^2) / (6*18.5*\tan(22.7824))$
$= 130.6405$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (100^2 + (61 - 18.5)^2)^{0.5}$
$= 108.6566$ in

$A_{TS} = L_s*t_s / 2 + L_c * t_c / 2 + A_s$
$= 108.5625*0.25 / 2 + 108.6566 * 0.75 / 2 + 0.75$
$= 55.07$

$F_s = P*N + f_2*\tan(\alpha)$
$= 15*130.6405 + 305.12*\tan(22.7824)$
$= 2,087.76\ lb_f/in$

$B = 0.75*F_s*D_s / A_{TS}$
$= 0.75*2,087.76*37 / 55.0665$
$= 1,052$ psi

From Table CS-2: A = 0.000082 (shell, 550°F)

$I'_s = A*D_s^2*A_{TS} / 10.9$
$= 0.000082*37^2*55.0665 / 10.9$
$= 0.5699$ in^4

The calculated I' for the combined ring-shell-cone cross section is 0.7887 in^4

As $I' >= I'_s$ the small end is adequately stiffened per Appendix 1-8(c).

Middle Shell

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td colspan="2">Component</td><td colspan="3">Cylinder</td></tr>
<tr><td colspan="2">Material</td><td colspan="3">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Optimize MDMT/ Find MAWP</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (psi)</td><td>Design Temperature (°F)</td><td>Design MDMT (°F)</td></tr>
<tr><td colspan="2">Internal</td><td>150</td><td>550</td><td rowspan="2">-20</td></tr>
<tr><td colspan="2">External</td><td>15</td><td>550</td></tr>
<tr><td colspan="5">Static Liquid Head</td></tr>
<tr><td colspan="2">Condition</td><td>P_s (psi)</td><td>H_s (in)</td><td>SG</td></tr>
<tr><td colspan="2">Operating</td><td>4.15</td><td>115</td><td>1</td></tr>
<tr><td colspan="2">Test horizontal</td><td>4.34</td><td>120.25</td><td>1</td></tr>
<tr><td colspan="5">Dimensions</td></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">120.25"</td></tr>
<tr><td colspan="2">Length</td><td colspan="3">304"</td></tr>
<tr><td colspan="2">Nominal Thickness</td><td colspan="3">0.875"</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">0.125"</td></tr>
<tr><td>Outer</td><td colspan="3">0"</td></tr>
<tr><td colspan="5">Weight and Capacity</td></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (lb)</td><td>Capacity (US gal)</td></tr>
<tr><td colspan="2">New</td><td colspan="2">28,641.25</td><td>14,945.89</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">24,574.98</td><td>15,008.1</td></tr>
<tr><td colspan="5">Radiography</td></tr>
<tr><td colspan="2">Longitudinal seam</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><td colspan="2">Top Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
<tr><td colspan="2">Bottom Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
</table>

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.5987"
Design thickness due to external pressure (t_e)	0.7257"
Design thickness due to combined loadings + corrosion	0.3766"
Maximum allowable external pressure (MAEP)	26.75 psi
Rated MDMT	-20 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.875"
MDMT =	-20°F
Material is exempt from impact testing per UG-20(f) at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 154.15*60.25 / (19,700*1.00 - 0.60*154.15) + 0.125
= 0.5987"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 303 / 122 = 2.4836
D_o / t = 122 / 0.6007 = 203.1016

From table G: A = 0.000178
From table CS-2: B = 2,284.8943 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,284.89 / (3*(122 / 0.6007))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = t + Corrosion = 0.6007 + 0.125 = 0.7257"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 303 / 122 = 2.4836
D_o / t = 122 / 0.75 = 162.6667

From table G: A = 0.000253
From table CS-2: B = 3,263.9706 psi

P_a = 4*B / (3*(D_o / t))
= 4*3,263.97 / (3*(122 / 0.75))
= 26.75 psi

% Extreme fiber elongation - UCS-79(d)

$EFE = (50*t / R_f)*(1 - R_f / R_o)$
$= (50*0.875 / 60.5625)*(1 - 60.5625 / \infty)$
$= 0.7224\%$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$P_v = W / (2*\pi*R_m) + M / (\pi*R_m^2)$
$= 39{,}247 / (2*\pi*60.625) + 2{,}510{,}398 / (\pi*60.625^2)$
$= 320.4473$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 320.4473 / (15*122)$
$= 0.1751$
$n = 4$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (303 / 122)^2$
$= 0.1994$
Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (4^2 - 1 + 0.1994 + 0.1994*0.1751) / (4^2 - 1 + 0.1994)$
$= 1.0023$
Ratio $P_e * P_e \leq$ MAEP
$(1.0023 * 15 = 15.03) \leq 26.75$
Cylinder thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$P_v = (1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)$
$= 1.19*39{,}247 / (2*\pi*60.625) + 6{,}318{,}578 / (\pi*60.625^2)$
$= 669.4903$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 669.4903 / (15*122)$
$= 0.3658$
$n = 4$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (303 / 122)^2$
$= 0.1994$
Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (4^2 - 1 + 0.1994 + 0.1994*0.3658) / (4^2 - 1 + 0.1994)$
$= 1.0048$
Ratio $P_e * P_e \leq$ MAEP
$(1.0048 * 15 = 15.07) \leq 26.75$
Cylinder thickness is satisfactory.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	19,700	10,316	550	0.125	Wind	150	0.2323	0.2086
					Seismic	150	0.2497	0.1912
Operating, Hot & New	19,700	10,643	550	0	Wind	150	0.2314	0.2074
					Seismic	150	0.2516	0.1872
Hot Shut Down, Corroded	19,700	10,316	550	0.125	Wind	0	0.0077	0.0259
					Seismic	0	0.0251	0.0541
Hot Shut Down, New	19,700	10,643	550	0	Wind	0	0.0073	0.0263
					Seismic	0	0.0275	0.058
Empty, Corroded	20,000	13,910	70	0.125	Wind	0	0.0076	0.0192
					Seismic	0	0.0168	0.0304
Empty, New	20,000	14,538	70	0	Wind	0	0.0072	0.0192
					Seismic	0	0.0188	0.0328
Vacuum	19,700	10,316	550	0.125	Wind	-15	0.0239	0.0624
					Seismic	-15	0.0026	0.0906
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,316	550	0.125	Wind	0	0.0096	0.0104
					Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	13,910	70	0.125	Wind	0	0.0165	0.03

Lower Cone

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Cone		
Material		SA-516 70 (II-D p. 18, ln. 24)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating	**Large**	4.15	115	1
	Small	8.48	235	
Test horizontal	**Large**	4.34	120.25	1
	Small	3.69	102.125	
Dimensions				
Inner Diameter	**Large**	120.25"		
	Small	84"		
Length		120"		
Nominal Thickness		0.875"		
Corrosion	**Inner**	0.125"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		9,725.3		4,299.91
Corroded		8,346.2		4,321.01
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Spot UW-11(a)(5)(b) Type 1		
Bottom Circumferential seam		Spot UW-11(a)(5)(b) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.6041"
Design thickness due to external pressure (t_e)	0.5074"
Design thickness due to combined loadings + corrosion	0.3911"
Maximum allowable external pressure (MAEP)	15 psi
Rated MDMT	-20 °F
Design P and Design Pe are used for Appendix 1-5 and Appendix 1-8 calculations.	

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.875"
MDMT =	-20°F
Material is exempt from impact testing per UG-20(f) at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-32(g) (Large End)

t = $P*D / (2*\cos(\alpha)*(S*E - 0.60*P))$ + Corrosion
= 154.15*120.5028 / (2*cos(8.5891)*(19,700*1.00 - 0.60*154.15)) + 0.125
= 0.6041"

Small End design thickness (t = 0.4694") does not govern.

External Pressure, (Corroded & at 550 °F) UG-33(f)

D_L = 122.0198"
L_e = $(L / 2)*(1 + D_s / D_L)$
= (120 / 2)*(1 + 85.7699 / 122.0199)
= 102.175"

t_e = $t*\cos(\alpha)$ = 0.3824*cos(8.5891) = 0.3781"
L_e / D_L = 102.175 / 122.0198 = 0.8374
D_L / t_e = 122.0198 / 0.3781 = 322.7040

From table G: A = 0.000281
From table CS-2: B = 3,630.4154 psi

P_a = $4*B / (3*(D_L / t_e))$
= 4*3,630.42 / (3*(122.0198 / 0.3781))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = $t_e / \cos(\alpha)$ + Corrosion = 0.3781 / cos(8.5891) + 0.125 = 0.5074"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-33(f)

$t_e = t*\cos(\alpha) = 0.75*\cos(8.5891) = 0.7416"$
$L_e / D_L = 102.175 / 122.0199 = 0.8374$
$D_L / t_e = 122.0199 / 0.7416 = 164.538$

From table G: A = 0.000786
From table CS-2: B = 8,831.9911 psi

$P_a = 4*B / (3*(D_L / t_e))$
$= 4*8{,}831.99 / (3*(122.0199 / 0.7416))$
$= 71.57$ psi

% Extreme fiber elongation - UCS-79(d)

$EFE = (50*t / R_f)*(1 - R_f / R_o)$
$= (50*0.8849 / 42.4425)*(1 - 42.4425 / \infty)$
$= 1.0425\%$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$P_v = [W / (2*\pi*R_m) + M / (\pi*R_m^2)] / \cos(\alpha)$
$= [39{,}247 / (2*\pi*60.6307) + 2{,}510{,}398 / (\pi*60.6307^2)] / \cos(8.5891)$
$= 324.0311$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 324.0311 / (15*122.0198)$
$= 0.177$
$n = 6$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (102.175 / 122.0198)^2$
$= 1.7542$
$\text{Ratio } P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
$= (6^2 - 1 + 1.7542 + 1.7542*0.177) / (6^2 - 1 + 1.7542)$
$= 1.0084$
$\text{Ratio } P_e * P_e \leq \text{MAEP}$
$(1.0084 * 15 = 15.13) \leq 71.57$
Transition thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$P_v = [(1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)] / \cos(\alpha)$
$= [1.19*39{,}247 / (2*\pi*60.6307) + 6{,}318{,}578 / (\pi*60.6307^2)] / \cos(8.5891)$
$= 676.9689$ lb/in
$\alpha = P_v / (P_e*D_o)$
$= 676.9689 / (15*122.0198)$
$= 0.3699$
$n = 6$
$m = 1.23 / (L / D_o)^2$
$= 1.23 / (102.175 / 122.0198)^2$

$= 1.7542$

Ratio $P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$

$= (6^2 - 1 + 1.7542 + 1.7542*0.3699) / (6^2 - 1 + 1.7542)$

$= 1.0177$

Ratio $P_e * P_e \leq$ MAEP

$(1.0177 * 15 = 15.26) \leq 71.57$

Transition thickness is satisfactory.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Location	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c							
Operating, Hot & Corroded	19,700	10,292	550	0.125	Top	Wind	150	0.2349	0.211
						Seismic	150	0.2525	0.1934
					Bottom	Wind	150	0.1823	0.11
						Seismic	150	0.2588	0.0335
Operating, Hot & New	19,700	10,618	550	0	Top	Wind	150	0.234	0.2097
						Seismic	150	0.2544	0.1893
					Bottom	Wind	150	0.1812	0.1081
						Seismic	150	0.2661	0.0232
Hot Shut Down, Corroded	19,700	10,292	550	0.125	Top	Wind	0	0.0078	0.0262
						Seismic	0	0.0254	0.0548
					Bottom	Wind	0	0.0236	0.0794
						Seismic	0	0.1	0.2037
Hot Shut Down, New	19,700	10,618	550	0	Top	Wind	0	0.0074	0.0266
						Seismic	0	0.0278	0.0588
					Bottom	Wind	0	0.0229	0.0792
						Seismic	0	0.1078	0.2131
Empty, Corroded	20,000	13,865	70	0.125	Top	Wind	0	0.0077	0.0195
						Seismic	0	0.0169	0.0308
					Bottom	Wind	0	0.0272	0.0507
						Seismic	0	0.0548	0.0845
Empty, New	20,000	14,491	70	0	Top	Wind	0	0.0073	0.0195
						Seismic	0	0.0191	0.0333
					Bottom	Wind	0	0.0265	0.0502
						Seismic	0	0.0619	0.0916
Vacuum	19,700	10,292	550	0.125	Top	Wind	-15	0.0243	0.0632

						Seismic	-15	0.0027	0.0918
					Bottom	Wind	-15	0.0077	0.1052
						Seismic	-15	0.0841	0.2296
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,292	550	0.125	Top	Wind	0	0.0097	0.0105
						Seismic	0	0	0
					Bottom	Wind	0	0.0299	0.0316
						Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	13,865	70	0.125	Top	Wind	0	0.02	0.0366
					Bottom	Wind	0	0.0605	0.095

Cone juncture large end calculations, P =154.151 psi (MAWP = 150 psi)
Appendix 1-5(d)

Loading	Area check required ($\Delta < \alpha$)	U-2(g) analysis required	f_1 (lbf/in)	Q_L (lbf/in)	A_{rL} (in2)	A_{eL} (in2)	Ring area (in^2) 5/8x6 Flat Bar	Status
Wind Corroded	No	No	155.6	4,799.4	0	3.69	3.75	OK
Wind New	No	No	147.34	4,781.51	0	5.81	3.75	OK
Seismic Corroded	No	No	504.64	5,148.44	0	3.69	3.75	OK
Seismic New	No	No	552.4	5,186.57	0	5.81	3.75	OK

Cone large end calculations per Appendix 1-5(d), wind + pressure, corroded

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*39{,}246.95 / (\pi*2*60.625) + 12*209{,}199.8 / (\pi*60.625^2)$
$= 155.6\ lb_f/in$

$P*R_L / 2 = 4{,}643.8\ lb_f/in$

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 154.15 / (19{,}700*1) = 0.007825$

From table 1-5.1 $\Delta = 28.24°$

As $\Delta >= \alpha$ no additional reinforcement is required.

Cone large end calculations per Appendix 1-5(d), wind + pressure, new

$f_1 = -0.6*W_l / (\pi*2*R_m) + 12*M_l / (\pi*R_m^2)$
$= -0.6*44{,}799.49 / (\pi*2*60.5625) + 12*209{,}308.8 / (\pi*60.5625^2)$
$= 147.34\ lb_f/in$

$P*R_L / 2 = 4{,}634.17\ lb_f/in$

f_1 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 154.15 / (19{,}700*1) = 0.007825$

From table 1-5.1 $\Delta = 28.24°$

As $\Delta >= \alpha$ no additional reinforcement is required.

Cone juncture small end calculations, P =158.483 psi (MAWP = 150 psi) Appendix 1-5(e)								
Loading	**Area check required** ($\Delta < \alpha$)	**U-2(g) analysis required**	**f_2 (lbf/in)**	**Q_s (lbf/in)**	**A_{rs} (in2)**	**A_{es} (in2)**	**Ring area (in^2) 1/2x5 Flat Bar**	**Status**
Wind Corroded	Yes	No	471.46	3,809.5	0.11	2.04	2.5	OK
Wind New	Yes	No	457.92	3,786.06	0.11	3.29	2.5	OK
Seismic Corroded	Yes	No	1,999.6	5,337.64	0.15	2.04	2.5	OK
Seismic New	Yes	No	2,155	5,483.14	0.16	3.29	2.5	OK

Cone small end calculations per Appendix 1-5(e), seismic + pressure, corroded

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -(0.6 - 0.14*1.3333)*83{,}670.95 / (\pi*2*42.375) + 12*1{,}001{,}067.4 / (\pi*42.375^2)$
$= 1{,}999.6$ lb_f/in

$P*R_s / 2 = 3{,}338.0444$ lb_f/in

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 158.48 / (19{,}700*1) = 0.008045$

From table 1-5.2 $\Delta = 7.83°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 3{,}338.04 + 1{,}999.6$
$= 5{,}337.64$ lb_f/in

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*5{,}337.64*42.125 / (19{,}700*1))*(1 - 7.83 / 8.5891)*\tan(8.5891)$
$= 0.1524$ in^2

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(42.125*0.5)^{0.5}*[(0.5 - 0.3405) + (0.75 - 0.3444) / \cos(8.5891)]$
$= 2.0393$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Cone small end calculations per Appendix 1-5(e), seismic + pressure, new

$f_2 = -(0.6 - 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= -(0.6 - 0.14*1.3333)*90{,}513.88 / (\pi*2*42.3125) + 12*1{,}076{,}034.9 / (\pi*42.3125^2)$
$= 2{,}155$ lb_f/in

$P*R_s / 2 = 3{,}328.1392$ lb_f/in

f_2 is in tension so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 158.48 / (19,700*1) = 0.008045$

From table 1-5.2 $\Delta = 7.83°$

As $\Delta < \alpha$ reinforcement is required.

$Q_s = P*R_s / 2 + f_2$
$= 3,328.14 + 2,155$
$= 5,483.14$ lb_f/in

$A_{rs} = (k*Q_s*R_s / (S_s*E_1))*(1 - \Delta / \alpha)*\tan(\alpha)$
$= (1*5,483.14*42 / (19,700*1))*(1 - 7.83 / 8.5891)*\tan(8.5891)$
$= 0.156$ in^2

$A_{es} = 0.78*(R_s*t_s)^{0.5}*[(t_s - t) + (t_c - t_r) / \cos(\alpha)]$
$= 0.78*(42*0.625)^{0.5}*[(0.625 - 0.3395) + (0.875 - 0.3434) / \cos(8.5891)]$
$= 3.2895$ in^2

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

Cone large end calculations for external pressure of 15 psi Appendix 1-8(b)											
Loading	**Area check req'd** $\Delta < \alpha$	**U-2(g) analysis req'd**	**f_1 (lbf/in)**	**Q_L (lbf/in)**	**A_{rL} (in2)**	**A_{eL} (in2)**	**Ring area (in^2) 5/8x6 Flat Bar**	**Area status**	***I's* (in^4)**	***I'* (in^4)**	**I status**
Wind Corroded	Yes	No	320.45	777.95	0.36	7.94	3.75	OK	32.0203	44.6851	OK
Seismic Corroded	Yes	No	669.49	1,126.99	0.53	7.94	3.75	OK	32.5288	44.6851	OK

Cone large end calculations per Appendix 1-8(b), seismic + external pressure

$f_1 = (1 + 0.14*S_{DS})*W_I / (\pi*2*R_m) + 12*M_I / (\pi*R_m^2)$
$= (1 + 0.14*1.3333)*39{,}246.95 / (\pi*2*60.625) + 12*526{,}548.1 / (\pi*60.625^2)$
$= 669.49\ lb_f/in$

$P*R_L / 2 = 457.5\ lb_f/in$

$f_1 + P*R_L / 2$ is in compression so a U-2(g) analysis is not required.

$P / (S_s*E_1) = 15 / (19{,}700*1) = 0.000761$

From table 1-8.1 $\Delta = 1.9°$

As $\Delta < \alpha$ reinforcement is required.

$Q_L = P*R_L / 2 + f_1$
$= 457.5 + 669.49$
$= 1{,}126.99\ lb_f/in$

$A_{rL} = (k*Q_L*R_L*\tan(\alpha) / (S_s*E_1))*[1 - 0.25*((P*R_L-Q_L) / Q_L)*(\Delta / \alpha)]$
$= (1*1{,}126.99*61*\tan(8.5891) / (19{,}700*1))*[1 - 0.25*((15*61-1{,}126.99) / 1{,}126.99)*(1.9 / 8.5891)]$
$= 0.5326\ in^2$

$A_{eL} = 0.55*(D_L*t_s)^{0.5}*(t_s + t_c / \cos(\alpha))$
$= 0.55*(122*0.75)^{0.5}*(0.75 + 0.75 / \cos(8.5891))$
$= 7.9363\ in^2$

$A_{eL} >= A_{rL}$ therefore the large end juncture is adequately reinforced.

$M = -R_L*\tan(\alpha) / 2 + L_L / 2 + (R_L^2 - R_s^2) / (3*R_L*\tan(\alpha))$
$= -61*\tan(8.5891) / 2 + 303.5 / 2 + (61^2 - 42.625^2) / (3*61*\tan(8.5891))$
$= 216.0313\ in$

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (120^2 + (61 - 42.625)^2)^{0.5}$
$= 121.3987\ in$

$A_{TL} = L_L*t_s / 2 + L_c * t_c / 2 + A_s$
$= 303.5*0.75 / 2 + 121.3987 * 0.75 / 2 + 3.75$
$= 163.087\ in^2$

$F_L = P*M + f_1*\tan(\alpha)$

= 15*216.0313 + 669.49*tan(8.5891)
= 3,341.59 lb_f/in

B = 0.75*F_L*D_L / A_{TL}
= 0.75*3,341.59*122 / 163.087
= 1,875 psi

From Table CS-2: A = 0.000146 (shell, 550°F)

I'_s = A*D_L^2*A_{TL} / 10.9
= 0.000146*122^2*163.087 / 10.9
= 32.5288 in^4

The calculated I' for the combined ring-shell-cone cross section is 44.6851 in^4

As $I' >= I'_s$ the large end is adequately stiffened per Appendix 1-8(b).

Cone small end calculations for external pressure of 15 psi Appendix 1-8(c)										
Loading	**U-2(g) analysis req'd**	**f_2 (lbf/in)**	**Q_s (lbf/in)**	**A_{rs} (in2)**	**A_{es} (in2)**	**Ring area (in^2) 1/2x5 Flat Bar**	**Area status**	**I'_s (in^4)**	**I' (in^4)**	**I status**
Wind Corroded	No	974.27	1,293.96	0.42	1.75	2.5	OK	9.6821	16.2853	OK
Seismic Corroded	No	2,502.41	2,822.09	0.92	1.75	2.5	OK	10.4423	16.2853	OK

Cone small end calculations per Appendix 1-8(c), seismic + external pressure

$f_2 = (1 + 0.14*S_{DS})*W_s / (\pi*2*R_m) + 12*M_s / (\pi*R_m^2)$
$= (1 + 0.14*1.3333)*83{,}670.95 / (\pi*2*42.375) + 12*1{,}001{,}067.4 / (\pi*42.375^2)$
$= 2{,}502.41\ lb_f/in$

$P*R_s / 2 = 319.6875\ lb_f/in$

$f_2 + P*R_s / 2$ is in compression so a U-2(g) analysis is not required.

$Q_s = P*R_s / 2 + f_2$
$= 319.69 + 2{,}502.41$
$= 2{,}822.09\ lb_f/in$

$A_{rs} = (k*Q_s*R_s*\tan(\alpha) / (S_s*E_1))$
$= (1*2{,}822.09*42.625*\tan(8.5891) / (19{,}700*1))$
$= 0.9223\ in^2$

$A_{es} = 0.55*(D_s*t_s)^{0.5}*((t_s - t) + (t_c - t_r) / \cos(\alpha))$
$= 0.55*(85.25*0.5)^{0.5}*((0.5 - 0.4559) + (0.75 - 0.3126) / \cos(8.5891))$
$= 1.7468\ in^2$

$A_{es} >= A_{rs}$ therefore the small end juncture is adequately reinforced.

$N = R_s*\tan(\alpha) / 2 + L_s / 2 + (R_L^2 - R_s^2) / (6*R_s*\tan(\alpha))$
$= 42.625*\tan(8.5891) / 2 + 263.5417 / 2 + (61^2 - 42.625^2) / (6*42.625*\tan(8.5891))$
$= 184.2823$ in

$L_c = (L^2 + (R_L - R_s)^2)^{0.5}$
$= (120^2 + (61 - 42.625)^2)^{0.5}$
$= 121.3987$ in

$A_{TS} = L_s*t_s / 2 + L_c * t_c / 2 + A_s$
$= 263.5417*0.5 / 2 + 121.3987 * 0.75 / 2 + 2.5$
$= 113.91$

$F_s = P*N + f_2*\tan(\alpha)$
$= 15*184.2823 + 2{,}502.41*\tan(8.5891)$
$= 3{,}142.2\ lb_f/in$

$B = 0.75*F_s*D_s / A_{TS}$
$= 0.75*3{,}142.2*85.25 / 113.9099$
$= 1{,}764$ psi

From Table CS-2: A = 0.000137 (shell, 550°F)

I'_s = A*D_s^2*A_{TS} / 10.9
= 0.000137*85.25^2*113.9099 / 10.9
= 10.4423 in^4

The calculated I' for the combined ring-shell-cone cross section is 16.2853 in^4

As I' >= I'_s the small end is adequately stiffened per Appendix 1-8(c).

Lower Shell

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td colspan="2">Component</td><td colspan="3">Cylinder</td></tr>
<tr><td colspan="2">Material</td><td colspan="3">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Optimize MDMT/ Find MAWP</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (psi)</td><td>Design Temperature (°F)</td><td>Design MDMT (°F)</td></tr>
<tr><td colspan="2">Internal</td><td>150</td><td>550</td><td rowspan="2">-20</td></tr>
<tr><td colspan="2">External</td><td>15</td><td>550</td></tr>
<tr><td colspan="5">Static Liquid Head</td></tr>
<tr><td colspan="2">Condition</td><td>P_s (psi)</td><td>H_s (in)</td><td>SG</td></tr>
<tr><td colspan="2">Operating</td><td>17.69</td><td>490</td><td>1</td></tr>
<tr><td colspan="2">Test horizontal</td><td>3.69</td><td>102.125</td><td>1</td></tr>
<tr><td colspan="5">Dimensions</td></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">84"</td></tr>
<tr><td colspan="2">Length</td><td colspan="3">255"</td></tr>
<tr><td colspan="2">Nominal Thickness</td><td colspan="3">0.625"</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">0.125"</td></tr>
<tr><td>Outer</td><td colspan="3">0"</td></tr>
<tr><td colspan="5">Weight and Capacity</td></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (lb)</td><td>Capacity (US gal)</td></tr>
<tr><td colspan="2">New</td><td colspan="2">11,904.1</td><td>6,117.54</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">9,537.45</td><td>6,154.01</td></tr>
<tr><td colspan="5">Radiography</td></tr>
<tr><td colspan="2">Longitudinal seam</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><td colspan="2">Top Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
<tr><td colspan="2">Bottom Circumferential seam</td><td colspan="3">Spot UW-11(a)(5)(b) Type 1</td></tr>
</table>

Results Summary	
Governing condition	Vacuum
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.4855"
Design thickness due to external pressure (t_e)	0.5802"
Design thickness due to combined loadings + corrosion	0.582"
Maximum allowable external pressure (MAEP)	19.09 psi
Rated MDMT	-24 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.625"
Exemption temperature from Fig UCS-66 Curve B =	5°F
t_r = 167.69*42.125 / (20,000*1 - 0.6*167.69) =	0.355"
Stress ratio = t_r*E^* / (t_n - c) = 0.355*1 / (0.625 - 0.125) =	0.71
Reduction in MDMT, T_R from Fig UCS-66.1 =	29°F
MDMT = max[MDMT - T_R, -55] = max[5 - 29 , -55] =	-24°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 167.69*42.125 / (19,700*1.00 - 0.60*167.69) + 0.125
= 0.4855"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 262.5417 / 85.25 = 3.0797
D_o / t = 85.25 / 0.4552 = 187.2747

From table G: A = 0.000164
From table CS-2: B = 2,106.8346 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,106.83 / (3*(85.25 / 0.4552))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = t + Corrosion = 0.4552 + 0.125 = 0.5802"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 262.5417 / 85.25 = 3.0797
D_o / t = 85.25 / 0.5 = 170.5000

From table G: $A = 0.000190$
From table CS-2: $B = 2{,}440.8231$ psi

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*2{,}440.82 / (3*(85.25 / 0.5))$$
$$= 19.09 \text{ psi}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = (50*t / R_f)*(1 - R_f / R_o)$$
$$= (50*0.625 / 42.3125)*(1 - 42.3125 / \infty)$$
$$= 0.7386\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = W / (2*\pi*R_m) + M / (\pi*R_m^2)$$
$$= 97{,}266.2 / (2*\pi*42.375) + 6{,}944{,}927 / (\pi*42.375^2)$$
$$= 1{,}596.4335 \text{ lb/in}$$
$$\alpha = P_v / (P_e*D_o)$$
$$= 1{,}596.4335 / (15*85.25)$$
$$= 1.2484$$
$$n = 3$$
$$m = 1.23 / (L / D_o)^2$$
$$= 1.23 / (262.5417 / 85.25)^2$$
$$= 0.1297$$
$$\text{Ratio } P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$$
$$= (3^2 - 1 + 0.1297 + 0.1297*1.2484) / (3^2 - 1 + 0.1297)$$
$$= 1.0199$$
$$\text{Ratio } P_e * P_e \le \text{MAEP}$$
$$(1.0199 * 15 = 15.3) \le 19.09$$

Cylinder thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = (1 + 0.14*S_{DS})*W / (2*\pi*R_m) + M / (\pi*R_m^2)$$
$$= 1.19*97{,}266.2 / (2*\pi*42.375) + 27{,}385{,}691 / (\pi*42.375^2)$$
$$= 5{,}288.1228 \text{ lb/in}$$
$$\alpha = P_v / (P_e*D_o)$$
$$= 5{,}288.1228 / (15*85.25)$$
$$= 4.1354$$
$$n = 3$$
$$m = 1.23 / (L / D_o)^2$$
$$= 1.23 / (262.5417 / 85.25)^2$$
$$= 0.1297$$
$$\text{Ratio } P_e = (n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$$
$$= (3^2 - 1 + 0.1297 + 0.1297*4.1354) / (3^2 - 1 + 0.1297)$$
$$= 1.066$$
$$\text{Ratio } P_e * P_e \le \text{MAEP}$$

(1.066 * 15 = 15.99) ≤ 19.09

Cylinder thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	19,700	10,219	550	0.125	Wind	150	0.2074	0.0775
					Seismic	150	0.3911	0.1742
Operating, Hot & New	19,700	10,690	550	0	Wind	150	0.206	0.0751
					Seismic	150	0.4046	0.1935
Hot Shut Down, Corroded	19,700	10,219	550	0.125	Wind	0	0.0504	0.1302
					Seismic	0	0.2341	0.4312
Hot Shut Down, New	19,700	10,690	550	0	Wind	0	0.0495	0.1275
					Seismic	0	0.2481	0.4385
Empty, Corroded	20,000	13,724	70	0.125	Wind	0	0.0536	0.0887
					Seismic	0	0.1006	0.147
Empty, New	20,000	14,630	70	0	Wind	0	0.0527	0.0855
					Seismic	0	0.114	0.1566
Vacuum	19,700	10,219	550	0.125	Wind	-15	0.0346	0.1559
					Seismic	-15	0.2184	0.457
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,219	550	0.125	Wind	0	0.0331	0.0384
					Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	13,724	70	0.125	Wind	0	0.0861	0.129

Bottom Head

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Ellipsoidal Head		
Material		SA-516 70 (II-D p. 18, ln. 24)		
Attached To		Lower Shell		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		18.5	512.625	1
Test horizontal		3.69	102.125	1
Dimensions				
Inner Diameter		84"		
Head Ratio		2		
Minimum Thickness		0.625"		
Corrosion	**Inner**	0.125"		
	Outer	0"		
Length L_{sf}		1.5"		
Nominal Thickness t_{sf}		0.75"		
Weight and Capacity				
		Weight (lb)[1]		**Capacity (US gal)**[1]
New		1,538.96		371.85
Corroded		1,238.41		376.08
Radiography				
Category A joints		Seamless No RT		
Head to shell seam		Spot UW-11(a)(5)(b) Type 1		

[1] includes straight flange

Results Summary	
Governing condition	internal pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.4843"
Design thickness due to external pressure (t_e)	0.3553"
Maximum allowable external pressure (MAEP)	59.15 psi
Straight Flange governs MDMT	-41 °F

Factor K		
K = (1/6)*[2 + (D / (2*h))^2]		
Corroded	K = (1/6)*[2 + (84.25 / (2*21.125))^2]	0.9961
New	K = (1/6)*[2 + (84 / (2*21))^2]	1

Design thickness for internal pressure, (Corroded at 550 °F) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 168.5*84.25*0.996061 / (2*19,700*1 - 0.2*168.5) + 0.125
= 0.4842"

Design thickness for external pressure, (Corroded at 550 °F) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.887*85.25
= 75.6163 in

A = 0.125 / (R_o / t)
= 0.125 / (75.6163 / 0.230288)
= 0.000381

From Table CS-2: B = 4,925.3337 psi

P_a = B / (R_o / t)
= 4,925.3337 / (75.6163 / 0.2303)
= 15 psi

t = 0.2303" + Corrosion = 0.2303" + 0.125" = 0.3553"
Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

t = 1.67*P_e*D*K / (2*S*E - 0.2*1.67*P_e) + Corrosion
= 1.67*15*84.25*0.996061 / (2*19,700*1 - 0.2*1.67*15) + 0.125
= 0.1784"

The head external pressure design thickness (t_e) is 0.3553".

Maximum Allowable External Pressure, (Corroded at 550 °F) UG-33(d)

Equivalent outside spherical radius (R_o)

R_o = K_o*D_o
= 0.887*85.25
= 75.6163 in

A = 0.125 / (R_o / t)
= 0.125 / (75.6163 / 0.5)
= 0.000827

From Table CS-2: B = 8,944.9095 psi

P_a = B / (R_o / t)
= 8,944.9095 / (75.6163 / 0.5)
= 59.1467 psi

Check the Maximum External Pressure, UG-33(a)(1) Appendix 1-4(c)

P = 2*S*E*t / ((K*D + 0.2*t)*1.67)
= 2*19,700*1*0.5 / ((0.996061*84.25 +0.2*0.5)*1.67)
= 140.4 psi

The maximum allowable external pressure (MAEP) is 59.15 psi.

% Extreme fiber elongation - UCS-79(d)

EFE = (75*t / R_f)*(1 - R_f / R_o)
= (75*0.75 / 14.655)*(1 - 14.655 / ∞)
= 3.8383%

The extreme fiber elongation does not exceed 5%.

Straight Flange on Bottom Head

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Cylinder		
Material		SA-516 70 (II-D p. 18, ln. 24)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		17.74	491.5	1
Test horizontal		3.69	102.125	1
Dimensions				
Inner Diameter		84"		
Length		1.5"		
Nominal Thickness		0.75"		
Corrosion	**Inner**	0.125"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		84.77		35.99
Corroded		70.74		36.2
Radiography				
Longitudinal seam		Seamless No RT		
Top Circumferential seam		Spot UW-11(a)(5)(b) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0.125" = 0.1875"
Design thickness due to internal pressure (t)	0.4856"
Design thickness due to external pressure (t_e)	0.581"
Design thickness due to combined loadings + corrosion	0.5623"
Maximum allowable external pressure (MAEP)	32.49 psi
Rated MDMT	-41 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.625"
Exemption temperature from Fig UCS-66 Curve B =	5°F
t_r = 167.74*42.125 / (20,000*1 - 0.6*167.74) =	0.3551"
Stress ratio = t_r*E^* / (t_n - c) = 0.3551*1 / (0.75 - 0.125) =	0.5681
Reduction in MDMT, T_R from Fig UCS-66.1 =	46°F
MDMT = max[MDMT - T_R, -55] = max[5 - 46 , -55] =	-41°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) UG-27(c)(1)

t = P*R / (S*E - 0.60*P) + Corrosion
= 167.74*42.125 / (19,700*1.00 - 0.60*167.74) + 0.125
= 0.4856"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 262.5417 / 85.5 = 3.0707
D_o / t = 85.5 / 0.456 = 187.4841

From table G: A = 0.000164
From table CS-2: B = 2,109.1922 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,109.19 / (3*(85.5 / 0.456))
= 15 psi

Design thickness for external pressure P_a = 15 psi

t_a = t + Corrosion = 0.456 + 0.125 = 0.581"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 262.5417 / 85.5 = 3.0707
D_o / t = 85.5 / 0.625 = 136.8000

From table G: $A = 0.000259$
From table CS-2: $B = 3,333.5487$ psi

$P_a = 4*B / (3*(D_o / t))$
$= 4*3,333.55 / (3*(85.5 / 0.625))$
$=$ 32.49 psi

% Extreme fiber elongation - UCS-79(d)

$EFE = (50*t / R_f)*(1 - R_f / R_o)$
$= (50*0.75 / 42.375)*(1 - 42.375 / \infty)$
$= 0.885\%$

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads

Condition	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Pressure P (psi)	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
	S_t	S_c						
Operating, Hot & Corroded	19,700	10,684	550	0.125	Wind	150	0.2075	0.0774
					Seismic	150	0.3912	0.1668
Operating, Hot & New	19,700	11,086	550	0	Wind	150	0.2062	0.075
					Seismic	150	0.4047	0.1868
Hot Shut Down, Corroded	19,700	10,684	550	0.125	Wind	0	0.0505	0.1247
					Seismic	0	0.2342	0.4127
Hot Shut Down, New	19,700	11,086	550	0	Wind	0	0.0497	0.1232
					Seismic	0	0.2482	0.4231
Empty, Corroded	20,000	14,618	70	0.125	Wind	0	0.0537	0.0835
					Seismic	0	0.1006	0.1379
Empty, New	20,000	15,265	70	0	Wind	0	0.0529	0.0821
					Seismic	0	0.1139	0.15
Vacuum	19,700	10,684	550	0.125	Wind	-15	0.0348	0.1494
					Seismic	-15	0.2185	0.4373
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	19,700	10,684	550	0.125	Wind	0	0.0317	0.0367
					Seismic	0	0	0
Empty, Cold & Corroded, Vortex Shedding	20,000	14,618	70	0.125	Wind	0	0.0861	0.1211

Ring Upper Cone Small End

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Attached to	Upper Shell
Ring type	Flat bar
Description	3/8x2 Flat Bar
Material	SA-36 (II-D p. 10, ln. 18)
External design pressure	15 psi
External design temperature	550°F
Corrosion allowance	0"
Distance from ring neutral axis to datum	779.5"
Distance to previous support	108.0625"
Distance to next support	0.5"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.375"
Vessel thickness at weld location, new	0.375"
Vessel corrosion allowance at weld location	0.125"
Stiffener thickness at weld location	0.375"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	1"
Ring area	0.75 in^2
Ring inertia	0.25 in^4

External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.1937 = 191.022
From Table G: A = 1.674E-04
From Table CS-2: B = 2,149.49 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,149.49 / (3*(37 / 0.193695))
= 15 psi

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*15*37 / (0.1937 + 0.75 / 54.2813)
= 2,006 psi

From Table CS-2: A = 0.00015618 (ring, 550°F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[37^2 * 54.2813 * (0.1937 + 0.75 / 54.2813) * 0.00015618] / 10.9$
= 0.221 in^4

I' for the composite corroded shell-ring-cone cross section is 0.7887 in^4

As $I' >= I_s'$ a 3/8x2 Flat Bar stiffener is adequate for an external pressure of 15 psi.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.375 in is adequate per UG-30(f)(1).

Radial pressure load, $P * L_s = 15 * 54.2813 = 814.22$ lb_f/in
Radial shear load, $V = 0.01 * P * L_s * D_o = 0.01 * 15 * 54.2813 * 37 = 301.26$ lb_f
First moment of area, $Q = 1.78 * 0.5227 = 0.9297$ in^3

Weld shear flow, $q = V * Q / I' = 355.1367$ lb_f/in
Combined weld load, $f_w = \text{Sqr}(814.2188^2 + 355.1367^2) = 888.3$ lb_f/in

Allowable weld stress per UW-18(d) $S_w = 0.55 * S = 0.55 * 16{,}600 = 9{,}130$ psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w * (d_{\text{weld segment}} + d_{\text{toe}}) / (S_w * d_{\text{weld total}})$ + corrosion
= $888.3 * (1 + 0) / (9{,}130 * 2) + 0$
= 0.0486 in

The fillet weld size of 0.375 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 108.0625 / 37 = 2.9206
D_o / t = 37 / 0.25 = 148
From Table G: A = 2.3993E-04
From Table CS-2: B = 3,091.02 psi

P_a = $4 * B / (3 * (D_o / t))$
= $4 * 3{,}091.02 / (3 * (37 / 0.25))$
= 27.85 psi

B = $0.75 * P * D_o / (t + A_s / L_s)$
= $0.75 * 27.85 * 37 / (0.25 + 0.75 / 54.2813)$
= 2,929 psi

From Table CS-2: A = 0.00022728 (ring, 550°F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[37^2 * 54.2813 * (0.25 + 0.75 / 54.2813) * 0.00022728] / 10.9$
= 0.4088 in^4

I' for the composite corroded shell-ring-cone cross section is 0.7887 in^4

As $I' >= I_s'$ a 3/8x2 Flat Bar stiffener is adequate for an external pressure of 27.85 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.375 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 27.85*54.2813 = 1,511.57 lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*27.85*54.2813*37 = 559.28 lb_f
First moment of area, Q = 1.78*0.5227 = 0.9297 in^3

Weld shear flow, $q = V*Q / I'$ = 659.299 lb_f/in
Combined weld load, f_w = Sqr(1,511.5688^2 + 659.299^2) = 1,649.1 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 1{,}649.1*(1 + 0) / (9{,}130*2) + 0$$
$$= 0.0903 \text{ in}$$

The fillet weld size of 0.375 in is adequate to resist radial pressure and shear.

Ring Upper Cone Large End

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Attached to	Middle Shell
Ring type	Flat bar
Description	1/2x5 Flat Bar
Material	SA-36 (II-D p. 10, ln. 18)
External design pressure	15 psi
External design temperature	550°F
Corrosion allowance	0"
Distance from ring neutral axis to datum	678.5"
Distance to previous support	0.5"
Distance to next support	303"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.5"
Vessel thickness at weld location, new	0.875"
Vessel corrosion allowance at weld location	0.125"
Stiffener thickness at weld location	0.5"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	2.5"
Ring area	2.5 in^2
Ring inertia	5.2083 in^4

External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 303 / 122 = 2.4836
D_o / t = 122 / 0.6007 = 203.0886
From Table G: A = 1.7786E-04
From Table CS-2: B = 2,285.07 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,285.07 / (3*(122 / 0.600723))
= 15 psi

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*15*122 / (0.6007 + 2.5 / 151.75)
= 2,224 psi

From Table CS-2: A = 0.00017299 (ring, 550°F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[122^2 * 151.75 * (0.6007 + 2.5 / 151.75) * 0.00017299] / 10.9$
= 22.1235 in^4

I' for the composite corroded shell-ring-cone cross section is 32.6292 in^4

As *I'* >= I_s' a 1/2x5 Flat Bar stiffener is adequate for an external pressure of 15 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.5 in is adequate per UG-30(f)(1).

Radial pressure load, $P * L_s$ = 15*151.75 = 2,276.25 lb_f/in
Radial shear load, V = $0.01 * P * L_s * D_o$ = 0.01*15*151.75*122 = 2,777.03 lb_f
First moment of area, Q = 8.23*0.2293 = 1.886 in^3

Weld shear flow, *q* = V*Q / *I'* = 160.5143 lb_f/in
Combined weld load, f_w = Sqr($2{,}276.25^2 + 160.5143^2$) = 2,281.9 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w * (d_{weld\ segment} + d_{toe}) / (S_w * d_{weld\ total})$ + corrosion
= 2,281.9*(1 + 0) / (9,130*2) + 0
= 0.125 in

The fillet weld size of 0.5 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 303 / 122 = 2.4836
D_o / t = 122 / 0.6931 = 176.0129
From Table G: A = 2.2741E-04
From Table CS-2: B = 2,928.33 psi

P_a = $4 * B / (3 * (D_o / t))$
= 4*2,928.33 / (3*(122 / 0.693131))
= 22.18 psi

B = $0.75 * P * D_o / (t + A_s / L_s)$
= 0.75*22.17*122 / (0.6931 + 2.5 / 151.75)
= 2,859 psi

From Table CS-2: A = 0.00022192 (ring, 550°F)

I_s' = $[D_o^2 * L_s * (t + A_s / L_s) * A] / 10.9$
= $[122^2 * 151.75 * (0.6931 + 2.5 / 151.75) * 0.00022192] / 10.9$
= 32.6292 in^4

I' for the composite corroded shell-ring-cone cross section is 32.6292 in^4

As *I'* >= I_s' a 1/2x5 Flat Bar stiffener is adequate for an external pressure of 22.17 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.5 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 22.17*151.75 = 3,364.93 lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*22.17*151.75*122 = 4,105.21 lb_f
First moment of area, Q = 8.23*0.2293 = 1.886 in^3

Weld shear flow, *q* = V*Q / *I'* = 237.2846 lb_f/in
Combined weld load, f_w = Sqr(3,364.9294^2 + 237.2846^2) = 3,373.29 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 3{,}373.29*(1 + 0) / (9{,}130*2) + 0$$
$$= 0.1847 \text{ in}$$

The fillet weld size of 0.5 in is adequate to resist radial pressure and shear.

Ring Lower Cone Large End

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Attached to	Middle Shell
Ring type	Flat bar
Description	5/8x6 Flat Bar
Material	SA-36 (II-D p. 10, ln. 18)
External design pressure	15 psi
External design temperature	550°F
Corrosion allowance	0"
Distance from ring neutral axis to datum	375.5"
Distance to previous support	303"
Distance to next support	0.5"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.5"
Vessel thickness at weld location, new	0.875"
Vessel corrosion allowance at weld location	0.125"
Stiffener thickness at weld location	0.625"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	3"
Ring area	3.75 in^2
Ring inertia	11.25 in^4

External Pressure, (Corroded & at 550°F) UG-29(a)

$L / D_o = 303 / 122 = 2.4836$
$D_o / t = 122 / 0.6007 = 203.0886$
From Table G: $A = 1.7786E-04$
From Table CS-2: $B = 2,285.07$ psi

$P_a = 4*B / (3*(D_o / t))$
$= 4*2,285.07 / (3*(122 / 0.600723))$
$= 15$ psi

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*15*122 / (0.6007 + 3.75 / 151.75)$
$= 2,195$ psi

From Table CS-2: A = 0.00017073 (ring, 550°F)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[122^2*151.75*(0.6007 + 3.75 / 151.75)*0.00017073] / 10.9$
= 22.1262 in^4

I' for the composite corroded shell-ring-cone cross section is 44.6851 in^4

As $I' >= I_s'$ a 5/8x6 Flat Bar stiffener is adequate for an external pressure of 15 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.5 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 15*151.75 = 2{,}276.25 \text{ lb}_f\text{/in}$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*15*151.75*122 = 2{,}777.03 \text{ lb}_f$
First moment of area, $Q = 7.94*0.9473 = 7.5182 \text{ in}^3$

Weld shear flow, $q = V*Q / I' = 467.232 \text{ lb}_f\text{/in}$
Combined weld load, $f_w = \text{Sqr}(2{,}276.25^2 + 467.232^2) = 2{,}323.71 \text{ lb}_f\text{/in}$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*16{,}600 = 9{,}130$ psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w*(d_{\text{weld segment}} + d_{\text{toe}}) / (S_w*d_{\text{weld total}}) + \text{corrosion}$
= $2{,}323.71*(1 + 0) / (9{,}130*2) + 0$
= 0.1273 in

The fillet weld size of 0.5 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 303 / 122 = 2.4836
D_o / t = 122 / 0.75 = 162.6667
From Table G: A = 2.5323E-04
From Table CS-2: B = 3,263.97 psi

P_a = $4*B / (3*(D_o / t))$
= $4*3{,}263.97 / (3*(122 / 0.75))$
= 26.75 psi

B = $0.75*P*D_o / (t + A_s / L_s)$
= $0.75*26.75*122 / (0.75 + 3.75 / 151.75)$
= 3,160 psi

From Table CS-2: A = 0.00024501 (ring, 550°F)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[122^2*151.75*(0.75 + 3.75 / 151.75)*0.00024501] / 10.9$
= 39.332 in^4

I' for the composite corroded shell-ring-cone cross section is 44.6851 in^4

As *I'* >= I_s' a 5/8x6 Flat Bar stiffener is adequate for an external pressure of 26.75 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.5 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 26.75*151.75 = 4,059.89 lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*26.75*151.75*122 = 4,953.07 lb_f
First moment of area, Q = 7.94*0.9473 = 7.5182 in^3

Weld shear flow, *q* = V*Q / *I'* = 833.3489 lb_f/in
Combined weld load, $f_w = Sqr(4{,}059.8902^2 + 833.3489^2)$ = 4,144.54 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 4{,}144.54*(1 + 0) / (9{,}130*2) + 0$$
$$= 0.227 \text{ in}$$

The fillet weld size of 0.5 in is adequate to resist radial pressure and shear.

Ring Lower Cone Small End

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
Attached to	Lower Shell
Ring type	Flat bar
Description	1/2x5 Flat Bar
Material	SA-36 (II-D p. 10, ln. 18)
External design pressure	15 psi
External design temperature	550°F
Corrosion allowance	0"
Distance from ring neutral axis to datum	254"
Distance to previous support	1"
Distance to next support	262.5417"
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	0.375"
Vessel thickness at weld location, new	0.625"
Vessel corrosion allowance at weld location	0.125"
Stiffener thickness at weld location	0.5"
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	2.5"
Ring area	2.5 in^2
Ring inertia	5.2083 in^4

External Pressure, (Corroded & at 550°F) UG-29(a)

$L / D_o = 262.5417 / 85.25 = 3.0797$
$D_o / t = 85.25 / 0.4552 = 187.2676$
From Table G: A = 1.6412E-04
From Table CS-2: B = 2,106.97 psi

$P_a = 4*B / (3*(D_o / t))$
$= 4*2,106.97 / (3*(85.25 / 0.455231))$
$= 15$ psi

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*15*85.25 / (0.4552 + 2.5 / 131.7708)$
$= 2,023$ psi

From Table CS-2: A = 0.00015747 (ring, 550°F)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[85.25^2*131.7708*(0.4552 + 2.5 / 131.7708)*0.00015747] / 10.9$
= 6.5603 in^4

I' for the composite corroded shell-ring-cone cross section is 16.2853 in^4

As $I' >= I_s'$ a 1/2x5 Flat Bar stiffener is adequate for an external pressure of 15 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.375 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 15*131.7708 = 1,976.56 lb_f/in
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*15*131.7708*85.25 = 1,685.02 lb_f
First moment of area, Q = 4.52*1.0847 = 4.9019 in^3

Weld shear flow, $q = V*Q / I'$ = 507.1908 lb_f/in
Combined weld load, f_w = Sqr(1,976.5625^2 + 507.1908^2) = 2,040.6 lb_f/in

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

t_w = $f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total})$ + corrosion
= 2,040.6*(1 + 0) / (9,130*2) + 0
= 0.1118 in

The fillet weld size of 0.375 in is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 550°F) UG-29(a)

L / D_o = 262.5417 / 85.25 = 3.0797
D_o / t = 85.25 / 0.5 = 170.5
From Table G: A = 1.8987E-04
From Table CS-2: B = 2,440.82 psi

P_a = $4*B / (3*(D_o / t))$
= 4*2,440.82 / (3*(85.25 / 0.5))
= 19.09 psi

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*19.09*85.25 / (0.5 + 2.5 / 131.7708)
= 2,352 psi

From Table CS-2: A = 0.00018283 (ring, 550°F)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[85.25^2*131.7708*(0.5 + 2.5 / 131.7708)*0.00018283] / 10.9$
= 8.3365 in^4

I' for the composite corroded shell-ring-cone cross section is 16.2853 in^4

As *I'* >= I_s' a 1/2x5 Flat Bar stiffener is adequate for an external pressure of 19.09 psi.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 0.25 in

The fillet weld size of 0.375 in is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 19.09*131.7708 = 2,515.18 lb_f/in
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*19.09*131.7708*85.25 = 2,144.19 lb_f
First moment of area, Q = 4.52*1.0847 = 4.9019 in^3

Weld shear flow, *q* = V*Q / *I'* = 645.4002 lb_f/in
Combined weld load, f_w = Sqr($2,515.1755^2$ + 645.4002^2) = 2,596.66 lb_f/in

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*16,600 = 9,130 psi

Fillet weld size required to resist radial pressure and shear

$$\begin{aligned} t_w &= f_w*(d_{\text{weld segment}} + d_{\text{toe}}) / (S_w*d_{\text{weld total}}) + \text{corrosion} \\ &= 2{,}596.66*(1 + 0) / (9{,}130*2) + 0 \\ &= 0.1422 \text{ in} \end{aligned}$$

The fillet weld size of 0.375 in is adequate to resist radial pressure and shear.

Manway (M1)

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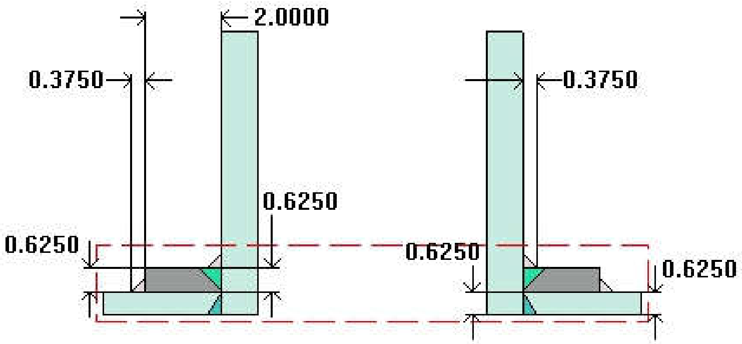

Note: round inside edges per UG-76(c)

Location and Orientation

Located on	Lower Shell
Orientation	180°
Nozzle center line offset to datum line	136"
End of nozzle to shell center	55.0625"
Passes through a Category A joint	No

Nozzle

Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, ln. 24)
Inside diameter, new	22"
Nominal wall thickness	1"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	5.8175"
Projection available outside vessel to flange face, Lf	12.4375"
Local vessel minimum thickness	0.625"
Liquid static head included	13.18 psi
Longitudinal joint efficiency	1

Reinforcing Pad

Material specification	SA-516 70 (II-D p. 18, ln. 24)
Diameter, D_p	28"
Thickness, t_e	0.625"

Is split	No
Welds	
Inner fillet, Leg_{41}	0.375"
Outer fillet, Leg_{42}	0.375"
Nozzle to vessel groove weld	0.625"
Pad groove weld	0.625"

ASME B16.5-2003 Flange	
Description	NPS 24 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	12.78 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(a)(5)(b) Type 1
Bore diameter, B (specified by purchaser)	22"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.22) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	0.625"
Exemption temperature from Fig UCS-66 Curve B =	5°F
t_r = 163.18*42.125 / (20,000*1 - 0.6*163.18) =	0.3454"
Stress ratio = t_r*E^* / (t_n - c) = 0.3454*1 / (0.625 - 0.125) =	0.6908
Reduction in MDMT, T_R from Fig UCS-66.1 =	30.9°F
MDMT = max[MDMT - T_R, -55] = max[5 - 30.9 , -55] =	-25.9°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 163.18*11.125 / (20,000*1 - 0.6*163.18) =	0.0912"
Stress ratio = t_r*E^* / (t_n - c) = 0.0912*1 / (1 - 0.125) =	0.1042
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	0.625"
Exemption temperature from Fig UCS-66 Curve B =	5°F
t_r = 163.18*42.125 / (20,000*1 - 0.6*163.18) =	0.3454"
Stress ratio = t_r*E^* / (t_n - c) = 0.3454*1 / (0.625 - 0.125) =	0.6908
Reduction in MDMT, T_R from Fig UCS-66.1 =	30.9°F
MDMT = max[MDMT - T_R, -55] = max[5 - 30.9 , -55] =	-25.9°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							**UG-45 Summary (in)**	
For P = 163.18 psi @ 550 °F 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}**
7.8022	8.06	3.3228	1.956	--	2.5	0.2812	0.2176	1

UG-41 Weld Failure Path Analysis Summary (lb_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
93,392.38	93,322.84	597,512.91	58,540.52	754,740.93	110,560.34	433,999.24

UW-16 Weld Sizing Summary			
Weld description	Required weld size (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.25	0.2625	weld size is adequate

% Extreme fiber elongation - UCS-79(d)

$$
\begin{aligned}
EFE &= (50*t / R_f)*(1 - R_f / R_o) \\
&= (50*1 / 11.5)*(1 - 11.5 / \infty) \\
&= 4.3478\%
\end{aligned}
$$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 17 psi @ 550 °F 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}
5.3085	5.3086	0.508	2.0194	--	2.5	0.2812	0.1922	1

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 (in)**	**Actual weld size (in)**	**Status**
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.25	0.2625	weld size is adequate

Manway (M2)

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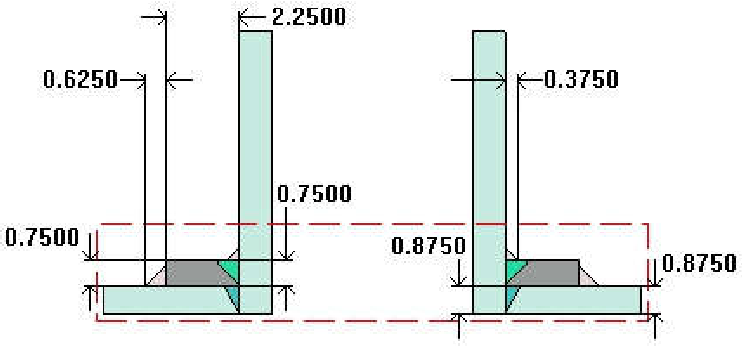


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Upper Cone
Orientation	270°
Nozzle center line offset to datum line	698.38"
End of nozzle to shell center	70"
Longitudinal axis is	perpendicular to the vessel longitudinal axis
Passes through a Category A joint	No
Nozzle	
Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, ln. 24)
Inside diameter, new	22"
Nominal wall thickness	1"
Corrosion allowance	0.125"
Opening chord length	24.1328"
Projection available outside vessel, Lpr	5.4056"
Projection available outside vessel to flange face, Lf	12.0256"
Local vessel minimum thickness	0.875"
User input radial limit of reinforcement	18"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	

Material specification	SA-516 70 (II-D p. 18, ln. 24)
Diameter, D_p	30.5309"
Thickness, t_e	0.75"
Is split	No
Welds	
Inner fillet, Leg_{41}	0.375"
Outer fillet, Leg_{42}	0.625"
Nozzle to vessel groove weld	0.875"
Pad groove weld	0.75"

ASME B16.5-2003 Flange	
Description	NPS 24 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(a)(5)(b) Type 1
Bore diameter, B (specified by purchaser)	22"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	0.875"
Exemption temperature from Fig UCS-66 Curve B =	23°F
t_r = 150*104.2208 / (2*cos(22.78)*(20,000*1 - 0.6*150)) =	0.4258"
Stress ratio = t_r*E^* / (t_n - c) = 0.4258*1 / (0.875 - 0.125) =	0.5678
Reduction in MDMT, T_R from Fig UCS-66.1 =	46°F
MDMT = max[MDMT - T_R, -55] = max[23 - 46 , -55] =	-23°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*11.125 / (20,000*1 - 0.6*150) =	0.0838"
Stress ratio = t_r*E^* / (t_n - c) = 0.0838*1 / (1 - 0.125) =	0.0958
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	0.75"
Exemption temperature from Fig UCS-66 Curve B =	15°F
t_r = 150*104.2208 / (2*cos(22.78)*(20,000*1 - 0.6*150)) =	0.4258"
Stress ratio = t_r*E^* / (t_n - c) = 0.4258*1 / (0.875 - 0.125) =	0.5678
Reduction in MDMT, T_R from Fig UCS-66.1 =	46°F
MDMT = max[MDMT - T_R, -55] = max[15 - 46 , -55] =	-31°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in²)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For P = 150 psi @ 550 °F
The opening is adequately reinforced</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A1</td><td>A2</td><td>A3</td><td>A5</td><td>A welds</td><td>treq</td><td>tmin</td></tr>
<tr><td>10.4333</td><td>10.6382</td><td>3.7699</td><td>2.9621</td><td>--</td><td>3.375</td><td>0.5312</td><td>0.2101</td><td>1</td></tr>
</table>

<table>
<tr><th colspan="7">UG-41 Weld Failure Path Analysis Summary (lbf)</th></tr>
<tr><td colspan="7">All failure paths are stronger than the applicable weld loads</td></tr>
<tr><td>Weld load W</td><td>Weld load W1-1</td><td>Path 1-1 strength</td><td>Weld load W2-2</td><td>Path 2-2 strength</td><td>Weld load W3-3</td><td>Path 3-3 strength</td></tr>
<tr><td>142,221.22</td><td>135,305.51</td><td>727,637.8</td><td>86,979.44</td><td>960,832.55</td><td>161,161.76</td><td>701,518.55</td></tr>
</table>

<table>
<tr><th colspan="4">UW-16 Weld Sizing Summary</th></tr>
<tr><td>Weld description</td><td>Required weld size (in)</td><td>Actual weld size (in)</td><td>Status</td></tr>
<tr><td>Nozzle to pad fillet (Leg41)</td><td>0.25</td><td>0.2625</td><td>weld size is adequate</td></tr>
<tr><td>Pad to shell fillet (Leg42)</td><td>0.375</td><td>0.4375</td><td>weld size is adequate</td></tr>
</table>

% Extreme fiber elongation - UCS-79(d)

$$
\begin{aligned}
\text{EFE} &= (50{*}t / R_f){*}(1 - R_f / R_o) \\
&= (50{*}1 / 11.5){*}(1 - 11.5 / \infty) \\
&= 4.3478\%
\end{aligned}
$$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

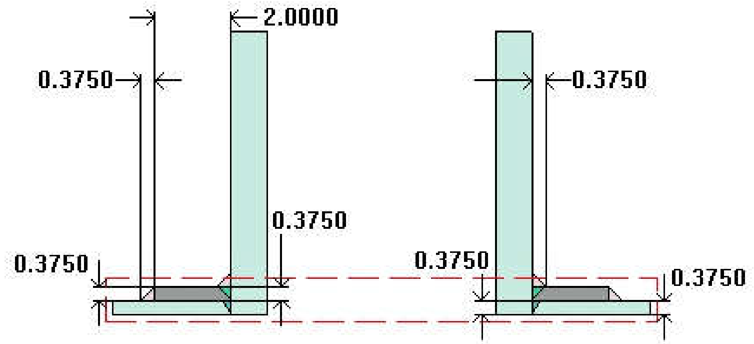
<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in²)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For Pe = 15 psi @ 550 °F
The opening is adequately reinforced</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A1</td><td>A2</td><td>A3</td><td>A5</td><td>A welds</td><td>treq</td><td>tmin</td></tr>
<tr><td>4.1304</td><td>11.7336</td><td>4.8381</td><td>2.9893</td><td>--</td><td>3.375</td><td>0.5312</td><td>0.2029</td><td>1</td></tr>
</table>

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 (in)**	**Actual weld size (in)**	**Status**
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.375	0.4375	weld size is adequate

Manway (M3)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda



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

Location and Orientation	
Located on	Upper Shell
Orientation	90°
Nozzle center line offset to datum line	841"
End of nozzle to shell center	35"
Passes through a Category A joint	No
Nozzle	
Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, ln. 24)
Inside diameter, new	22"
Nominal wall thickness	1"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	9.88"
Projection available outside vessel to flange face, Lf	16.5"
Local vessel minimum thickness	0.375"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D p. 18, ln. 24)
Diameter, D_p	28"
Thickness, t_e	0.375"

Is split	No
Welds	
Inner fillet, Leg_{41}	0.375"
Outer fillet, Leg_{42}	0.375"
Nozzle to vessel groove weld	0.375"
Pad groove weld	0.375"

ASME B16.5-2003 Flange	
Description	NPS 24 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(a)(5)(b) Type 1
Bore diameter, B (specified by purchaser)	22"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	0.375"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t_r = 150*18.25 / (20,000*1 - 0.6*150) =	0.1375"
Stress ratio = t_r*E^* / (t_n - c) = 0.1375*1 / (0.375 - 0.125) =	0.55
Reduction in MDMT, T_R from Fig UCS-66.1 =	48.5°F
MDMT = max[MDMT - T_R, -55] = max[-20 - 48.5 , -55] =	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*11.125 / (20,000*1 - 0.6*150) =	0.0838"
Stress ratio = t_r*E^* / (t_n - c) = 0.0838*1 / (1 - 0.125) =	0.0958
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	0.375"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t_r = 150*18.25 / (20,000*1 - 0.6*150) =	0.1375"
Stress ratio = t_r*E^* / (t_n - c) = 0.1375*1 / (0.375 - 0.125) =	0.55
Reduction in MDMT, T_R from Fig UCS-66.1 =	48.5°F
MDMT = max[MDMT - T_R, -55] = max[-20 - 48.5 , -55] =	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F 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}
3.1061	5.2094	2.4564	0.9874	--	1.5	0.2656	0.2101	1

UG-41 Weld Failure Path Analysis Summary (lb_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**
16,605.13	54,234.1	597,512.91	30,533.03	479,952.1	62,852.85	296,604.83

UW-16 Weld Sizing Summary			
Weld description	**Required weld size (in)**	**Actual weld size (in)**	**Status**
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.2625	weld size is adequate

Check Large Opening per Appendix 1-7(a)

Area required within 75 percent of the limits of reinforcement
= 2 / 3*A = (2 / 3)*3.1061 = 2.0707 in^2

L_R = MAX(0.75*d, R_n + (t_n - C_n) + (t - C))
= MAX(0.75*22.25, 11.125 + (1 - 0.125) + (0.375 - 0.125))
= 16.6875 in

A_1 = (2*L_R - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})
= (2*16.6875 - 22.25)*(1*0.25 - 1*0.1396) - 2*0.875*(1*0.25 - 1*0.1396)*(1 - 1)
= 1.2282 in^2

A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}
= (28 - 22.25 - 2*0.875)*0.375*1
= 1.5 in^2

Area = A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5
= 1.2282 + 0.9874 + 0 + 0.125 + 0.1406 + 0 + 1.5
= 3.9812 in^2

The area replacement requirements of Appendix 1-7(a) are satisfied.

Check Large Opening per Appendix 1-7(b)

1-7(b)(1)(a)	D_i = 36.5 in > 60 in	False
1-7(b)(1)(b)	d = 22.25 in > 40 in	False
1-7(b)(1)(b)	d = 22.25 in > 3.4*(18.25*0.25)$^{0.5}$ = 7.2624 in	True
1-7(b)(1)(c)	R_n / R = 11.125 / 18.25 = 0.6096 ≤ 0.7	True

The opening is not within the size range defined by 1-7(b)(1)(a) and (b) so it is exempt from the requirements of

1-7(b)(2),(3) and (4).

R_n / R = 0.6096 does not exceed 0.7 so a U-2(g) analysis is not required per 1-7(b)(1)(c).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*1 / 11.5)*(1 - 11.5 / \infty)$
= 4.3478%

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 27.44 psi @ 550 °F 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}
2.7669	2.7669	0.0287	0.9726	--	1.5	0.2656	0.2219	1

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 (in)	Actual weld size (in)	Status
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.125	0.2625	weld size is adequate

Check Large Opening per Appendix 1-7(a)

Area required within 75 percent of the limits of reinforcement
= 2 / 3*A = (2 / 3)*2.7669 = 1.8446 in^2

L_R = $MAX(0.75*d, R_n + (t_n - C_n) + (t - C))$
= MAX(0.75*22.25, 11.125 + (1 - 0.125) + (0.375 - 0.125))
= 16.6875 in

A_1 = $(2*L_R - d)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$

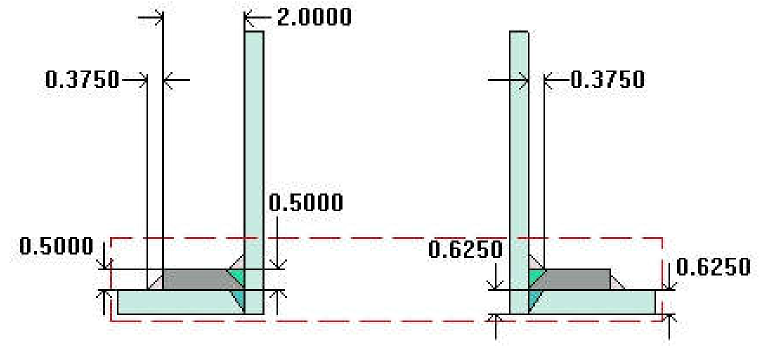
= (2*16.6875 - 22.25)*(1*0.25 - 1*0.2487) - 2*0.875*(1*0.25 - 1*0.2487)*(1 - 1)
= 0.0144 in^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= (28 - 22.25 - 2*0.875)*0.375*1
= 1.5 in^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 0.0144 + 0.9726 + 0 + 0.125 + 0.1406 + 0 + 1.5
= 2.7526 in^2

The area replacement requirements of Appendix 1-7(a) are satisfied.

Drain (N1)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Bottom Head
Orientation	0°
End of nozzle to datum line	-23.5141"
Calculated as hillside	No
Distance to head center, R	0"
Passes through a Category A joint	No
Nozzle	
Description	NPS 8 Sch 80 (XS)
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	7.625"
Pipe nominal wall thickness	0.5"
Pipe minimum wall thickness[1]	0.4375"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	0.5"
Local vessel minimum thickness	0.625"
Liquid static head included	18.51 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D p. 18, ln. 24)

Diameter, D_p	12.625"
Thickness, t_e	0.5"
Is split	No
Welds	
Inner fillet, Leg_{41}	0.375"
Outer fillet, Leg_{42}	0.375"
Nozzle to vessel groove weld	0.625"
Pad groove weld	0.5"

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

UCS-66 Material Toughness Requirements Nozzle	
t_r = 168.51*3.9375 / (17,100*1 - 0.6*168.51) =	0.039"
Stress ratio = t_r*E^* / (t_n - c) = 0.039*1 / (0.4375 - 0.125) =	0.1249
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	0.5"
Exemption temperature from Fig UCS-66 Curve B =	-7°F
t_r = 168.51*0.8973*84.25 / (2*20,000*1 - 0.2*168.51) =	0.3188"
Stress ratio = t_r*E^* / (t_n - c) = 0.3188*1 / (0.625 - 0.125) =	0.6375
Reduction in MDMT, T_R from Fig UCS-66.1 =	36.3°F
MDMT = max[MDMT - T_R, -55] = max[-7 - 36.3 , -55] =	-43.3°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in^2)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For P = 168.51 psi @ 550 °F
The opening is adequately reinforced</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A_1</td><td>A_2</td><td>A_3</td><td>A_5</td><td>A welds</td><td>t_{req}</td><td>t_{min}</td></tr>
<tr><td>2.5805</td><td>3.926</td><td>1.3716</td><td>0.2917</td><td>--</td><td>2</td><td>0.2627</td><td>0.4068</td><td>0.4375</td></tr>
</table>

<table>
<tr><th colspan="7">UG-41 Weld Failure Path Analysis Summary (lb_f)</th></tr>
<tr><td colspan="7">All failure paths are stronger than the applicable weld loads</td></tr>
<tr><td>Weld load W</td><td>Weld load W_{1-1}</td><td>Path 1-1 strength</td><td>Weld load W_{2-2}</td><td>Path 2-2 strength</td><td>Weld load W_{3-3}</td><td>Path 3-3 strength</td></tr>
<tr><td>26,076.81</td><td>50,321.68</td><td>129,956.86</td><td>14,564.21</td><td>240,074.35</td><td>56,734.03</td><td>170,539.07</td></tr>
</table>

<table>
<tr><th colspan="4">UW-16 Weld Sizing Summary</th></tr>
<tr><td>Weld description</td><td>Required weld size (in)</td><td>Actual weld size (in)</td><td>Status</td></tr>
<tr><td>Nozzle to pad fillet (Leg_{41})</td><td>0.25</td><td>0.2625</td><td>weld size is adequate</td></tr>
<tr><td>Pad to shell fillet (Leg_{42})</td><td>0.25</td><td>0.2625</td><td>weld size is adequate</td></tr>
</table>

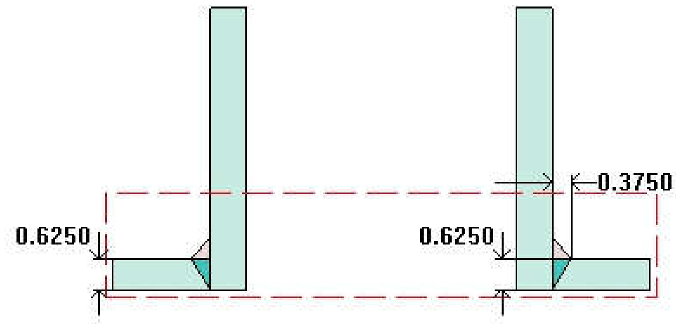
Reinforcement Calculations for MAEP

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in^2)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For Pe = 32.49 psi @ 550 °F
The opening is adequately reinforced</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A_1</td><td>A_2</td><td>A_3</td><td>A_5</td><td>A welds</td><td>t_{req}</td><td>t_{min}</td></tr>
<tr><td>1.3489</td><td>3.7632</td><td>1.2571</td><td>0.2434</td><td>--</td><td>2</td><td>0.2627</td><td>0.2196</td><td>0.4375</td></tr>
</table>

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 (in)**	**Actual weld size (in)**	**Status**
Nozzle to pad fillet (Leg_{41})	0.25	0.2625	weld size is adequate
Pad to shell fillet (Leg_{42})	0.25	0.2625	weld size is adequate

Process (N2)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Lower Shell
Orientation	210°
Nozzle center line offset to datum line	53"
End of nozzle to shell center	49.0625"
Passes through a Category A joint	No
Nozzle	
Description	NPS 6 Sch 160
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	5.187"
Pipe nominal wall thickness	0.719"
Pipe minimum wall thickness[1]	0.6291"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	2.5575"
Projection available outside vessel to flange face, Lf	6.4375"
Local vessel minimum thickness	0.625"
Liquid static head included	15.87 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.375"

Nozzle to vessel groove weld	0.625"

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

ASME B16.5-2003 Flange	
Description	NPS 6 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	15.77 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.224) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	0.625"
Exemption temperature from Fig UCS-66 Curve B =	5°F
t_r = 165.87*42.125 / (20,000*1 - 0.6*165.87) =	0.3511"
Stress ratio = t_r*E^* / (t_n - c) = 0.3511*1 / (0.625 - 0.125) =	0.7022
Reduction in MDMT, T_R from Fig UCS-66.1 =	29.8°F
MDMT = max[MDMT - T_R, -55] = max[5 - 29.8 , -55] =	-24.8°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 165.87*2.7185 / (17,100*1 - 0.6*165.87) =	0.0265"
Stress ratio = t_r*E^* / (t_n - c) = 0.0265*1 / (0.6291 - 0.125) =	0.0526
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 165.87 psi @ 550 °F 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}
1.9941	2.1114	0.7578	1.2315	--	--	0.1221	0.37	0.6291

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

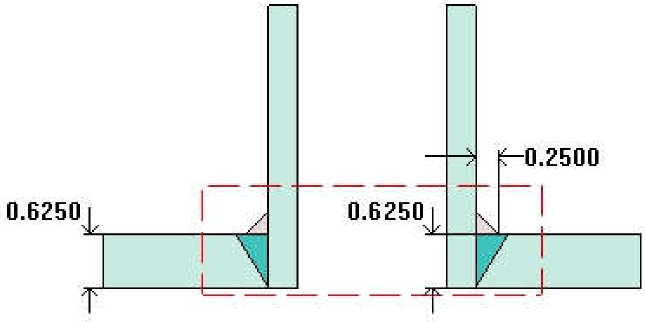
UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 18.64 psi @ 550 °F 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}
1.3847	1.3848	0.026	1.2367	--	--	0.1221	0.1875	0.6291

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 throat size (in)**	**Actual weld throat size (in)**	**Status**
Nozzle to shell fillet (Leg$_{41}$)	0.25	0.2625	weld size is adequate

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
 	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Lower Shell
Orientation	352°
Nozzle center line offset to datum line	86"
End of nozzle to shell center	49.0625"
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	1.687"
Pipe nominal wall thickness	0.344"
Pipe minimum wall thickness[1]	0.301"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.6875"
Projection available outside vessel to flange face, Lf	6.4375"
Local vessel minimum thickness	0.625"
Liquid static head included	14.61 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.25"

Nozzle to vessel groove weld	0.625"

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

ASME B16.5-2003 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	14.58 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2224) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 164.61*0.9685 / (17,100*1 - 0.6*164.61) =	0.0094"
Stress ratio = t_r*E^* / (t_n - c) = 0.0094*1 / (0.301 - 0.125) =	0.0533
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in^2)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For P = 164.61 psi @ 550 °F</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A_1</td><td>A_2</td><td>A_3</td><td>A_5</td><td>A welds</td><td>t_{req}</td><td>t_{min}</td></tr>
<tr><td colspan="7">This nozzle is exempt from area calculations per UG-36(c)(3)(a)</td><td>0.2598</td><td>0.301</td></tr>
</table>

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(2)

<table>
<tr><th colspan="4">UW-16 Weld Sizing Summary</th></tr>
<tr><td>Weld description</td><td>Required weld throat size (in)</td><td>Actual weld throat size (in)</td><td>Status</td></tr>
<tr><td>Nozzle to shell fillet (Leg_{41})</td><td>0.1533</td><td>0.175</td><td>weld size is adequate</td></tr>
</table>

This opening does not require reinforcement per UG-36(c)(3)(a)

Reinforcement Calculations for MAEP

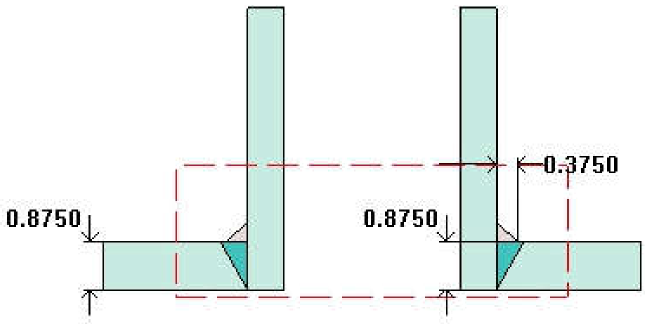
<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (in^2)</th><th colspan="2">UG-45 Summary (in)</th></tr>
<tr><td colspan="7">For Pe = 19.09 psi @ 550 °F</td><td colspan="2">The nozzle passes UG-45</td></tr>
<tr><td>A required</td><td>A available</td><td>A_1</td><td>A_2</td><td>A_3</td><td>A_5</td><td>A welds</td><td>t_{req}</td><td>t_{min}</td></tr>
<tr><td colspan="7">This nozzle is exempt from area calculations per UG-36(c)(3)(a)</td><td>0.1875</td><td>0.301</td></tr>
</table>

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 throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.175	weld size is adequate

This opening does not require reinforcement per UG-36(c)(3)(a)

Process (N4)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda	
	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Middle Shell
Orientation	90°
Nozzle center line offset to datum line	561"
End of nozzle to shell center	72"
Offset from center, Lo	17.5"
Passes through a Category A joint	No
Nozzle	
Description	NPS 4 XXS
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	3.152"
Pipe nominal wall thickness	0.674"
Pipe minimum wall thickness[1]	0.5898"
Corrosion allowance	0.125"
Opening chord length	3.5542"
Projection available outside vessel, Lpr	9.557"
Projection available outside vessel to flange face, Lf	12.937"
Local vessel minimum thickness	0.875"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Welds	
Inner fillet, Leg$_{41}$	0.375"
Nozzle to vessel groove weld	0.875"

---

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

ASME B16.5-2003 Flange	
Description	NPS 4 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*1.701 / (17,100*1 - 0.6*150) =	0.015"
Stress ratio = t_r*E^* / (t_n - c) = 0.015*1 / (0.5898 - 0.125) =	0.0323
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F 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}
0.8524	3.1658	1.7714	1.2723	--	--	0.1221	0.3324	0.5898

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Reinforcement check in the plane parallel to the longitudinal axis

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F 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}
1.6346	2.3361	0.9417	1.2723	--	--	0.1221	0.3324	0.5898

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 26.3 psi @ 550 °F 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$_{min}$
1.3763	1.3764	0.0195	1.2348	--	--	0.1221	0.2055	0.5898

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 throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg$_{41}$)	0.25	0.2625	weld size is adequate

Process (N5)

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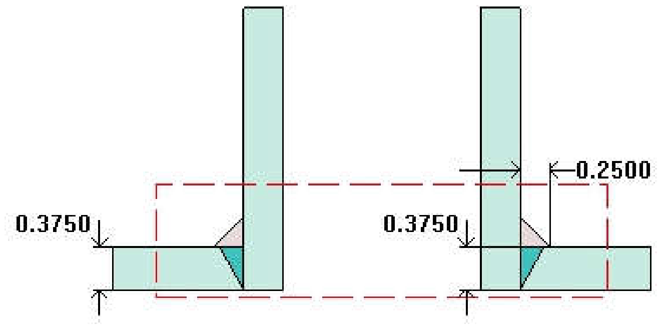

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Upper Shell
Orientation	90°
Nozzle center line offset to datum line	784"
End of nozzle to shell center	26.625"
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	1.687"
Pipe nominal wall thickness	0.344"
Pipe minimum wall thickness[1]	0.301"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	5.375"
Projection available outside vessel to flange face, Lf	8.125"
Local vessel minimum thickness	0.375"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	0.25"

Nozzle to vessel groove weld	0.375"

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

ASME B16.5-2003 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*0.9685 / (17,100*1 - 0.6*150) =	0.0085"
Stress ratio = t_r*E^* / (t_n - c) = 0.0085*1 / (0.301 - 0.125) =	0.0485
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F							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)							0.2598	0.301

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 throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1533	0.175	weld size is adequate

This opening does not require reinforcement per UG-36(c)(3)(a)

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 27.85 psi @ 550 °F							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)							0.1875	0.301

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 throat size (in)**	**Actual weld throat size (in)**	**Status**
Nozzle to shell fillet (Leg_{41})	0.1533	0.175	weld size is adequate

This opening does not require reinforcement per UG-36(c)(3)(a)

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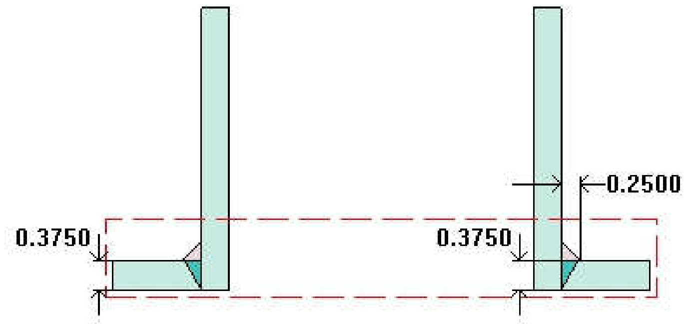

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Upper Shell
Orientation	235°
Nozzle center line offset to datum line	835"
End of nozzle to shell center	25"
Passes through a Category A joint	No
Nozzle	
Description	NPS 4 Sch 80 (XS)
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	3.826"
Pipe nominal wall thickness	0.337"
Pipe minimum wall thickness[1]	0.2949"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	3.12"
Projection available outside vessel to flange face, Lf	6.5"
Local vessel minimum thickness	0.375"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg$_{41}$	0.25"

Nozzle to vessel groove weld	0.375"

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

ASME B16.5-2003 Flange	
Description	NPS 4 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*2.038 / (17,100*1 - 0.6*150) =	0.018"
Stress ratio = t_r*E^* / (t_n - c) = 0.018*1 / (0.2949 - 0.125) =	0.1058
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F 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}
0.5768	0.6765	0.4438	0.1785	--	--	0.0542	0.2646	0.2949

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1484	0.175	weld size is adequate

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 17.14 psi @ 550 °F 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}
0.42	0.42	0.1879	0.1779	--	--	0.0542	0.1875	0.2949

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 throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1484	0.175	weld size is adequate

Process (N7)

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

Location and Orientation

Located on	Top Head
Orientation	0°
End of nozzle to datum line	907.8465"
Calculated as hillside	No
Distance to head center, R	0"
Passes through a Category A joint	No

Nozzle

Description	NPS 6 Sch 160
Access opening	No
Material specification	SA-106 B Smls pipe (II-D p. 14, ln. 5)
Inside diameter, new	5.187"
Pipe nominal wall thickness	0.719"
Pipe minimum wall thickness[1]	0.6291"
Corrosion allowance	0.125"
Projection available outside vessel, Lpr	10.244"
Projection available outside vessel to flange face, Lf	14.124"
Local vessel minimum thickness	0.3125"
Liquid static head included	0 psi
Longitudinal joint efficiency	1

Welds

Inner fillet, Leg$_{41}$	0.1875"
Nozzle to vessel groove weld	0.3125"

---

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

ASME B16.5-2003 Flange	
Description	NPS 6 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	None UW-11(c) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2027) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	0.3125"
Exemption temperature from Fig UCS-66 Curve B =	-20°F
t_r = 150*0.8939*36.5 / (2*20,000*1 - 0.2*150) =	0.1224"
Stress ratio = t_r*E^* / (t_n - c) = 0.1224*1 / (0.3125 - 0.125) =	0.653
Reduction in MDMT, T_R from Fig UCS-66.1 =	34.7°F
MDMT = max[MDMT - T_R, -55] = max[-20 - 34.7 , -55] =	-54.7°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 150*2.7185 / (17,100*1 - 0.6*150) =	0.024"
Stress ratio = t_r*E^* / (t_n - c) = 0.024*1 / (0.6291 - 0.125) =	0.0476
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For P = 150 psi @ 550 °F 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}
0.6954	0.828	0.3337	0.4638	--	--	0.0305	0.2628	0.6291

UG-41 Weld Failure Path Analysis Summary
The nozzle is exempt from weld strength calculations per UW-15(b)(1)

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (in^2)							UG-45 Summary (in)	
For Pe = 27.85 psi @ 550 °F 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}
0.3782	0.7584	0.276	0.4519	--	--	0.0305	0.1875	0.6291

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 throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.1312	0.1312	weld size is adequate

Seismic Code

Building Code: IBC 2006 ground supported (Seismic loads determined in accordance with ASCE 7-05)		
Site Class		B
Importance Factor, I		1.0000
Spectral Response Acceleration at short period (% g), S_s		200.00%
Spectral Response Acceleration at period of 1 sec (% g), S_1		100.00%
Response Modification Coeficient from Table 15.4-2, R		3.0000
Acceleration-based Site Coefficient, F_a		1.0000
Velocity-based Site Coefficient, F_v		1.0000
Long-period Transition Period, T_L		3.0000
Redundancy factor, ρ		1.0000
Occupancy Category (Table 1-1)		I
User Defined Vertical Accelerations Considered		No
Vessel Characteristics		
Height		82.4745 ft
Weight	Operating, Corroded	208,655 lb
	Empty, Corroded	70,635 lb
	Vacuum, Corroded	208,655 lb
Period of Vibration Calculation		
Fundamental Period, T	Operating, Corroded	0.465 sec (f = 2.2 Hz)
	Empty, Corroded	0.340 sec (f = 2.9 Hz)
	Vacuum, Corroded	0.465 sec (f = 2.2 Hz)

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

T = 2 * PI * Sqr({Sum(W_i * y_i^2)} / {g * Sum(W_i * 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.

12.4.2.3 Basic Load Combinations for Allowable Stress Design

Load combinations considered in accordance with ASCE section 2.4.1:

5.	$D + P + P_s + 0.7E$	$= (1.0 + 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$
8.	$0.6D + P + P_s + 0.7E$	$= (0.6 - 0.14S_{DS})D + P + P_s + 0.7\rho Q_E$

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 (in)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Seismic Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)
Top Head	978.8196	26.9	*	126	82
Upper Shell	874.8196	26.9	0.2350	3,063	22,787
Upper Cone	774.8196	26.9	*	7,865	52,277
Middle Shell	470.8196	26.9	25.3197	39,365	526,548
Lower Cone	350.8196	26.9	*	53,404	1,001,067
Lower Shell	95.8196	26.9	5.7642	64,384	2,282,141
Bottom Head (top)	90.62	26.9	*	64,477	2,310,059
Support Skirt	0	26.0	8.647	64,915	2,800,188

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

Seismic Shear Report: Empty, Corroded

Component	Elevation of Bottom above Base (in)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Seismic Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)
Top Head	978.8196	29.4	*	107	70
Upper Shell	874.8196	29.4	0.2350	2,615	21,082
Upper Cone	774.8196	29.4	*	6,714	44,697
Middle Shell	470.8196	29.4	25.3197	17,475	369,959
Lower Cone	350.8196	29.4	*	19,752	557,293
Lower Shell	95.8196	29.4	5.7642	21,723	1,009,523
Bottom Head (top)	90.62	29.4	*	21,741	1,018,939
Support Skirt	0	29.4	8.647	21,975	1,185,013

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

Seismic Shear Report: Vacuum, Corroded

Component	Elevation of Bottom above Base (in)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Seismic Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)
Top Head	978.8196	26.9	*	126	82
Upper Shell	874.8196	26.9	0.2350	3,063	22,787
Upper Cone	774.8196	26.9	*	7,865	52,277
Middle Shell	470.8196	26.9	25.3197	39,365	526,548
Lower Cone	350.8196	26.9	*	53,404	1,001,067
Lower Shell	95.8196	26.9	5.7642	64,384	2,282,141
Bottom Head (top)	90.62	26.9	*	64,477	2,310,059
Support Skirt	0	26.0	8.647	64,915	2,800,188

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

11.4.3: Maximum considered earthquake spectral response acceleration

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

$S_{MS} = F_a * S_s = 1.0000 * 200.00 / 100 = 2.0000$

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

$S_{M1} = F_v * S_1 = 1.0000 * 100.00 / 100 = 1.0000$

11.4.4: Design spectral response acceleration parameters

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

$S_{DS} = 2 / 3 * S_{MS} = 2 / 3 * 2.0000 = 1.3333$

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

$S_{D1} = 2 / 3 * S_{M1} = 2 / 3 * 1.0000 = 0.6667$

11.6 Seismic Design Category

The Occupancy Category is I.

The mapped spectral response acceleration parameter at 1-s period, S_1 is 100.00.

This vessel is assigned to Seismic Design Category E.

12.4.2.3: Seismic Load Combinations: Vertical Term

Factor is applied to dead load.

Compressive Side: $= 1.0 + 0.14 * S_{DS}$
$= 1.0 + 0.14 * 1.3333$
$= 1.1867$
Tensile Side: $= 0.6 - 0.14 * S_{DS}$
$= 0.6 - 0.14 * 1.3333$
$= 0.4133$

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.

$T = 0.4647$ 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 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 $(T = 0.4647) <= (T_L = 3.0000)$

$C_s = S_{DS} / (R / I) \quad = 1.3333 / (3.0000 / 1.0000) \quad = 0.4444$
$C_s\text{Min} = 0.8 * S_1 * I / R = 0.8 * 1.0000 * 1.0000 / 3.0000 \quad = 0.2667$
$C_s\text{Max} = S_{D1} / (T * (R / I)) \quad = 0.6667 / (0.4647 * (3.0000 / 1.0000)) \quad = 0.4782$
$C_s = 0.4444$

12.8.1: Calculation of Base Shear

$V = C_s * W$
$= 0.4444 * 208,655.3281$
$= 92,735.70$ lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

$Q_E = V$
$E_h = 0.7 * \rho * Q_E$ (Only 70% of seismic load considered as per Section 2.4.1)
$= 0.70 * 1.0000 * 92,735.70$

= 64,914.99 lb

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 = 0.3402 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 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 = 0.3402) <= (T_L = 3.0000)

C_s = S_{DS} / (R / I) = 1.3333 / (3.0000 / 1.0000) = 0.4444
C_sMin = 0.8 * S_1 * I / R = 0.8 * 1.0000 * 1.0000 / 3.0000 = 0.2667
C_sMax = S_{D1} / (T * (R / I)) = 0.6667 / (0.3402 * (3.0000 / 1.0000)) = 0.6532
C_s = 0.4444

12.8.1: Calculation of Base Shear

V = C_s * W
= 0.4444 * 70,635.2578
= 31,393.45 lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h
Q_E = V
E_h = 0.7 * ρ * Q_E (Only 70% of seismic load considered as per Section 2.4.1)
= 0.70 * 1.0000 * 31,393.45
= 21,975.41 lb

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 = 0.4647 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 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 = 0.4647) <= (T_L = 3.0000)

C_s = S_{DS} / (R / I) = 1.3333 / (3.0000 / 1.0000) = 0.4444
C_sMin = 0.8 * S_1 * I / R = 0.8 * 1.0000 * 1.0000 / 3.0000 = 0.2667
C_sMax = S_{D1} / (T * (R / I)) = 0.6667 / (0.4647 * (3.0000 / 1.0000)) = 0.4782

C_s = 0.4444

12.8.1: Calculation of Base Shear

V = C_s * W
= 0.4444 * 208,655.3281
= 92,735.70 lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h
Q_E = V
E_h = 0.7 * ρ * Q_E (Only 70% of seismic load considered as per Section 2.4.1)
= 0.70 * 1.0000 * 92,735.70
= 64,914.99 lb

Wind Code

Building Code: IBC 2006 **(Wind loads determined in accordance with ASCE 7-05)**		
Elevation of base above grade		0.00 ft
Increase effective outer diameter by		2.00 ft
Wind Force Coefficient, Cf		0.6100
Occupancy Category (Table 1-1)		I
Basic Wind Speed, V		90.00 mph
Importance Factor, I		1.1500
Exposure category		C
Wind Directionality Factor, Kd		1.0000
Topographic Factor, Kzt		1.0000
Enforce min. loading of 10 psf		Yes
Vessel Characteristics		
Height, h		82.4745 ft
Minimum Diameter, b	Operating, Corroded	7.1042 ft
	Empty, Corroded	7.1042 ft
Fundamental Frequency, n_1	Operating, Corroded	2.1521 Hz
	Empty, Corroded	2.9394 Hz
	Vacuum, Corroded	2.1521 Hz
Damping coefficient, β	Operating, Corroded	0.0240
	Empty, Corroded	0.0200
	Vacuum, Corroded	0.0240

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.	$D + P + P_s + W$
7.	$0.6D + P + P_s + W$
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
Empty, Corroded, Vortex Shedding
Wind Pressure Calculations
Wind Pressures at Critical Speed: Empty, Corroded

Wind Deflection Report: Operating, Corroded

Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb$_f$)	Total Wind Shear at Bottom (lb$_f$)	Bending Moment at Bottom (lb$_f$-ft)	Deflection at Top (in)
Top Head	978.8196	5.08	26.9	*	0	65	27	0.52
Upper Shell	874.8196	5.08	26.9	0.235	1,638	2,389	16,076	0.5123
Upper Cone	774.8196	8.68	26.9	*	1,638	3,487	29,532	0.4398
Middle Shell	470.8196	12.17	26.9	25.32	2,949	9,241	209,200	0.3744
Lower Cone	350.8196	10.66	26.9	*	2,949	10,663	310,271	0.1797
Lower Shell	95.8196	9.10	26.9	5.764	4,092	14,066	578,744	0.1071
Bottom Head (top)	90.62	9.11	26.9	*	4,092	14,109	586,232	0.0078
Support Skirt	0	9.13	26.0	8.647	4,092	14,860	695,613	0.007
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Empty, Corroded

Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	978.8196	5.08	29.4	*	0	65	27	0.4715
Upper Shell	874.8196	5.08	29.4	0.235	1,638	2,389	16,076	0.4645
Upper Cone	774.8196	8.68	29.4	*	1,638	3,487	29,532	0.3986
Middle Shell	470.8196	12.17	29.4	25.32	2,949	9,241	209,200	0.3392
Lower Cone	350.8196	10.66	29.4	*	2,949	10,663	310,271	0.1624
Lower Shell	95.8196	9.10	29.4	5.764	4,092	14,066	578,744	0.0966
Bottom Head (top)	90.62	9.11	29.4	*	4,092	14,109	586,232	0.0069
Support Skirt	0	9.13	29.4	8.647	4,092	14,860	695,613	0.0062

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

Wind Deflection Report: Vacuum, Corroded

Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	978.8196	5.08	26.9	*	0	65	27	0.52
Upper Shell	874.8196	5.08	26.9	0.235	1,638	2,389	16,076	0.5123
Upper Cone	774.8196	8.68	26.9	*	1,638	3,487	29,532	0.4398
Middle Shell	470.8196	12.17	26.9	25.32	2,949	9,241	209,200	0.3744
Lower Cone	350.8196	10.66	26.9	*	2,949	10,663	310,271	0.1797
Lower Shell	95.8196	9.10	26.9	5.764	4,092	14,066	578,744	0.1071
Bottom Head (top)	90.62	9.11	26.9	*	4,092	14,109	586,232	0.0078
Support Skirt	0	9.13	26.0	8.647	4,092	14,860	695,613	0.007

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

Wind Deflection Report: Empty, Corroded, Vortex Shedding

Component	Elevation of Bottom above Base (in)	Effective OD (ft)	Elastic Modulus E (10^6 psi)	Inertia I (ft^4)	Platform Wind Shear at Bottom (lb_f)	Total Wind Shear at Bottom (lb_f)	Bending Moment at Bottom (lb_f-ft)	Deflection at Top (in)
Top Head	978.8196	5.08	29.4	*	0	361	163	0.7556
Upper Shell	874.8196	5.08	29.4	0.235	704	4,522	29,997	0.7441
Upper Cone	774.8196	8.68	29.4	*	704	7,901	71,118	0.6358
Middle Shell	470.8196	12.17	29.4	25.32	1,268	14,262	383,238	0.5397
Lower Cone	350.8196	10.66	29.4	*	1,268	15,328	531,947	0.2551
Lower Shell	95.8196	9.10	29.4	5.764	1,759	17,754	890,421	0.1501
Bottom Head (top)	90.62	9.11	29.4	*	1,759	17,793	898,718	0.0103
Support Skirt	0	9.13	29.4	8.647	1,759	18,482	1,035,686	0.0092

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

Wind Pressure (WP) Calculations

Gust Factor ($\bar{G}$) Calculations

Kz $= 2.01 * (Z/Zg)^{2/\alpha}$

$= 2.01 * (Z/900.00)^{0.2105}$

qz $= 0.00256 * Kz * Kzt * Kd * V^2 * I$

$= 0.00256 * Kz * 1.0000 * 1.0000 * 90.0000^2 * 1.1500$

$= 23.8464 * Kz$

WP $= qz * G * Cf$ (Minimum 10 lb/ft^2)

$= qz * G * 0.6100$ (Minimum 10 lb/ft^2)

Design Wind Pressures							
Height Z (')	Kz	qz (psf)	WP (psf)				
			Operating	Empty	Hydrotest New	Hydrotest Corroded	Vacuum
15.0	0.8489	20.24	10.90	10.90	N.A.	N.A.	10.90
20.0	0.9019	21.51	11.58	11.58	N.A.	N.A.	11.58
25.0	0.9453	22.54	12.14	12.14	N.A.	N.A.	12.14
30.0	0.9823	23.42	12.61	12.61	N.A.	N.A.	12.61
40.0	1.0436	24.89	13.40	13.40	N.A.	N.A.	13.40
50.0	1.0938	26.08	14.04	14.04	N.A.	N.A.	14.04
60.0	1.1366	27.10	14.59	14.59	N.A.	N.A.	14.59
70.0	1.1741	28.00	15.07	15.07	N.A.	N.A.	15.07
80.0	1.2075	28.80	15.50	15.50	N.A.	N.A.	15.50
90.0	1.2379	29.52	15.89	15.89	N.A.	N.A.	15.89
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	6.4855 ft		
Aspect ratio, Ar	12.7167		
	Operating, Corroded	Empty, Corroded	Vacuum, Corroded
Vortex shedding factor, C_1	N.A.	2.6745	N.A.
Vortex shedding factor, C_2	N.A.	0.6000	N.A.
Weight per foot of vessel, upper third, M	N.A.	829.9277 lb/ft	N.A.
Strouhal number, S	N.A.	0.2000	N.A.

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

Empty, Corroded: V_h = (2.9394*6.4855/0.2000)*(3600/5280) = 64.9899 mph (104.5911 km/h)

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

Empty, Corroded: V_{Ref} = 59.0163 mph (94.9774 km/h)

Corresponding reference wind speed, V_{Ref}

Empty, Corroded: V_{Ref} = 90.0000 mph (144.8410 km/h)

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

Empty, Corroded: $q_h = 0.00256 * (64.9899)^2 = 10.8126$ psf

Equivalent static loading, FL = q_h*C_1*D / (SQR(Ar)*SQR(β - (C_2*R0*D^2/M)))

Empty, Corroded: FL = 10.8126*2.6745*6.4855 / (SQR(12.7167)*SQR(0.0200 - (0.6000*0.0765*$(6.4855)^2$/829.9277)))
= 395.6173 lb/ft

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

Wind Pressures at Critical Wind Speed: Empty, Corroded (V_h = 64.9899 mph)

Kz = 2.01 * $(Z/Zg)^{2/\alpha}$
= 2.01 * $(Z/900.00)^{0.2105}$

qz = 0.00256 * Kz * Kd * Kzt * Vh^2 * I
= 0.00256 * Kz * 1.0000 * 1.0000 * $(64.9899)^2$ * 1.1500
= 12.4345 * Kz

WP = qz * $\bar{G}$ * Cf
= qz * 0.8827 * 0.6100

Height Z(')	Kz	qz(psf)	WP(psf)
15.0	0.8489	10.5555	5.6833
20.0	0.9019	11.2145	6.0382
25.0	0.9453	11.7539	6.3286
30.0	0.9823	12.2139	6.5762
40.0	1.0436	12.9764	6.9868
50.0	1.0938	13.6006	7.3229
60.0	1.1366	14.1328	7.6094
70.0	1.1741	14.5990	7.8604
80.0	1.2075	15.0152	8.0845
90.0	1.2379	15.3922	8.2875

Gust Factor Calculations

Operating, Corroded
Empty, Corroded
Vacuum, Corroded
Empty, Corroded, Vortex Shedding

Gust Factor Calculations: Operating, Corroded

Vessel is considered a rigid structure as n_1 = 2.1521 Hz ≥ 1 Hz.

$\bar{z}$ = max (0.60 * h , z_{min})

$= \max(0.60 * 82.4745, 15.0000)$

$= 49.4847$

$I_{\bar{z}} = c * (33 / \bar{z})^{1/6}$

$= 0.2000 * (33 / 49.4847)^{1/6}$

$= 0.1869$

$L_{\bar{z}} = l * (\bar{z} / 33)^{ep}$

$= 500.0000 * (49.4847 / 33)^{0.2000}$

$= 542.2025$

$Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{\bar{z}})^{0.63}))$

$= Sqr(1 / (1 + 0.63 * ((7.1042 + 82.4745) / 542.2025)^{0.63}))$

$= 0.9119$

$G = 0.925 * (1 + 1.7 * g_Q * I_{\bar{z}} * Q) / (1 + 1.7 * g_v * I_{\bar{z}})$

$= 0.925 * (1 + 1.7 * 3.40* 0.1869 * 0.9119) / (1 + 1.7 * 3.40 * 0.1869)$

$= 0.8827$

Gust Factor Calculations: Empty, Corroded

Vessel is considered a rigid structure as $n_1 = 2.9394$ Hz ≥ 1 Hz.

$\bar{z} = \max(0.60 * h, z_{min})$

$= \max(0.60 * 82.4745, 15.0000)$

$= 49.4847$

$I_{\bar{z}} = c * (33 / \bar{z})^{1/6}$

$= 0.2000 * (33 / 49.4847)^{1/6}$

$= 0.1869$

$L_{\bar{z}} = l * (\bar{z} / 33)^{ep}$

$= 500.0000 * (49.4847 / 33)^{0.2000}$

$= 542.2025$

$Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{\bar{z}})^{0.63}))$

$= Sqr(1 / (1 + 0.63 * ((7.1042 + 82.4745) / 542.2025)^{0.63}))$

$= 0.9119$

$G = 0.925 * (1 + 1.7 * g_Q * I_{\bar{z}} * Q) / (1 + 1.7 * g_v * I_{\bar{z}})$

$= 0.925 * (1 + 1.7 * 3.40* 0.1869 * 0.9119) / (1 + 1.7 * 3.40 * 0.1869)$

$= 0.8827$

Gust Factor Calculations: Vacuum, Corroded

Vessel is considered a rigid structure as $n_1 = 2.1521$ Hz ≥ 1 Hz.

$\bar{z} = \max(0.60 * h, z_{min})$

$= \max(0.60 * 82.4745, 15.0000)$

$= 49.4847$

$I_{\bar{z}} = c * (33 / \bar{z})^{1/6}$

$= 0.2000 * (33 / 49.4847)^{1/6}$

$= 0.1869$

$L_{\bar{z}} = l * (\bar{z} / 33)^{ep}$
$= 500.0000 * (49.4847 / 33)^{0.2000}$
$= 542.2025$
$Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{\bar{z}})^{0.63}))$
$= Sqr(1 / (1 + 0.63 * ((7.1042 + 82.4745) / 542.2025)^{0.63}))$
$= 0.9119$
$G = 0.925 * (1 + 1.7 * g_Q * I_{\bar{z}} * Q) / (1 + 1.7 * g_v * I_{\bar{z}})$
$= 0.925 * (1 + 1.7 * 3.40 * 0.1869 * 0.9119) / (1 + 1.7 * 3.40 * 0.1869)$
$= 0.8827$

Gust Factor Calculations: Empty, Corroded, Vortex Shedding

Vessel is considered a rigid structure as $n_1 = 2.9394$ Hz ≥ 1 Hz.

$\bar{z} = max (0.60 * h , z_{min})$
$= max (0.60 * 82.4745 , 15.0000)$
$= 49.4847$
$I_{\bar{z}} = c * (33 / \bar{z})^{1/6}$
$= 0.2000 * (33 / 49.4847)^{1/6}$
$= 0.1869$
$L_{\bar{z}} = l * (\bar{z} / 33)^{ep}$
$= 500.0000 * (49.4847 / 33)^{0.2000}$
$= 542.2025$
$Q = Sqr(1 / (1 + 0.63 * ((b + h) / L_{\bar{z}})^{0.63}))$
$= Sqr(1 / (1 + 0.63 * ((7.1042 + 82.4745) / 542.2025)^{0.63}))$
$= 0.9119$
$G = 0.925 * (1 + 1.7 * g_Q * I_{\bar{z}} * Q) / (1 + 1.7 * g_v * I_{\bar{z}})$
$= 0.925 * (1 + 1.7 * 3.40 * 0.1869 * 0.9119) / (1 + 1.7 * 3.40 * 0.1869)$
$= 0.8827$

Table Lookup Values	
$\alpha = 9.5000$, $z_g = 900.00$ ft	[Table 6-2, page 78]
c = 0.2000, l = 500.0000, ep = 0.2000	[Table 6-2, page 78]
$\bar{a} = 0.1538$, $\bar{b} = 0.6500$	[Table 6-2, page 78]
$z_{min} = 15.0000$ ft	[Table 6-2, page 78]
$g_Q = 3.40$	[6.5.8.1 page 26]
$g_v = 3.40$	[6.5.8.1 page 26]

Support Skirt

ASME Section VIII Division 1, 2007 Edition, A08 Addenda		
Component		Support Skirt
Material		SA-516 70 (II-D p. 18, ln. 24)
Skirt is Attached To		Bottom Head
Skirt Attachment Offset		5.1996" down from the top seam
Design Temperature		
Internal		650°F
External		650°F
Dimensions		
Inner Diameter	**Top**	84"
	Botttom	84"
Length (includes base ring thickness)		90.62"
Nominal Thickness		0.75"
Corrosion	**Inner**	0"
	Outer	0"
Weight		
New		5,029.25 lb
Corroded		5,029.25 lb
Joint Efficiency		
Top		0.55
Bottom		0.8

Skirt design thickness, largest of the following + corrosion = 0.7266 in

The governing condition is due to seismic, compressive stress at the base, operating & new.

The skirt thickness of 0.75 in is adequate.

Results Summary

Loading	Condition	Tensile or Compressive Side	Governing Skirt Location	Temperature (°F)	Allowable Stress (psi)	Calculated Stress/E (psi)	Required thickness (in)
Wind	operating, corroded	Tensile	top	650	18,800	1,926.86	0.0769
		Compressive	bottom		9,966.68	3,004.5	0.2261
	operating, new	Tensile	top	650	18,800	1,878.96	0.075
		Compressive	bottom		9,966.68	3,049.57	0.2295
	empty, corroded	Tensile	top	70	20,000	2,680.87	0.1005
		Compressive	bottom		15,264.57	2,313.32	0.1137
	empty, new	Tensile	top	70	20,000	2,629.08	0.0986
		Compressive	bottom		15,264.57	2,361.96	0.1161
	vacuum, corroded	Tensile	top	650	18,800	1,926.86	0.0769
		Compressive	bottom		9,966.68	3,004.5	0.2261
Seismic	operating, corroded	Tensile	top	650	18,800	11,156.57	0.4451
		Compressive	bottom		9,966.68	9,166.25	0.6898
	operating, new	Tensile	top	650	18,800	11,808.44	0.4711
		Compressive	bottom		9,966.68	9,655.59	0.7266
	empty, corroded	Tensile	top	70	20,000	5,018.41	0.1882
		Compressive	bottom		15,264.57	3,764.94	0.185
	empty, new	Tensile	top	70	20,000	5,666.63	0.2125
		Compressive	bottom		15,264.57	4,262.74	0.2094
	vacuum, corroded	Tensile	top	650	18,800	11,156.57	0.4451
		Compressive	bottom		9,966.68	9,166.25	0.6898
Vortex shedding	empty, corroded	Tensile	top	70	20,000	4,292.33	0.161
		Compressive	bottom		15,264.57	3,277.87	0.1611

Loading due to seismic, operating & new

Tensile side

Required thickness, tensile stress at base:

$$\begin{aligned} t &= -(0.6 - 0.14*S_{DS})*W / (\pi*D*S_t*E) + 48*M / (\pi*D^2*S_t*E) \\ &= -(0.6 - 0.14*1.3333)*214{,}898.64 / (\pi*84.75*18{,}800*0.8) + 48*2{,}954{,}045.4 / (\pi*84.75^2*18{,}800*0.8) \\ &= 0.3956 \text{ in} \end{aligned}$$

Required thickness, tensile stress at the top:

$$\begin{aligned} t &= -(0.6 - 0.14*S_{DS})*W_t / (\pi*D_t*S_t*E) + 48*M_t / (\pi*D_t^2*S_t*E) \\ &= -(0.6 - 0.14*1.3333)*209{,}581.8 / (\pi*84.75*18{,}800*0.55) + 48*2{,}442{,}788.5 / (\pi*84.75^2*18{,}800*0.55) \\ &= 0.4711 \text{ in} \end{aligned}$$

Compressive side

Required thickness, compressive stress at base:

$t = (1 + 0.14*S_{DS})*W / (\pi*D*S_c*E_c) + 48*M / (\pi*D^2*S_c*E_c)$
$= (1 + 0.14*1.3333)*214{,}898.64 / (\pi*84.75*9{,}967*1) + 48*2{,}954{,}045.4 / (\pi*84.75^2*9{,}967*1)$
$= 0.7266$ in

Required thickness, compressive stress at the top:

$t = (1 + 0.14*S_{DS})*W_t / (\pi*D_t*S_c*E_c) + 48*M_t / (\pi*D_t^2*S_c*E_c)$
$= (1 + 0.14*1.3333)*209{,}581.8 / (\pi*84.75*9{,}967*1) + 48*2{,}442{,}788.5 / (\pi*84.75^2*9{,}967*1)$
$= 0.6151$ in

Skirt Base Ring

Inputs	
Base configuration	double base plate
Base plate material	SA-516 70
Base plate allowable stress, S_p	20,000 psi
Foundation compressive strength	20,000 psi
Concrete ultimate 28-day strength	20,000 psi
Bolt circle, BC	93.5"
Base plate inner diameter, D_i	81"
Base plate outer diameter, D_o	101"
Base plate thickness, t_b	1.625"
Gusset separation, w	5"
Gusset height, h	12"
Gusset thickness, t_g	0.375"
Compression ring width	7.75"
Compression ring thickness, t_c	1.625"
Anchor Bolts	
Material	SA-193 B7
Allowable stress, S_b	25,000 psi
Bolt size and type	3" series 8 threaded
Number of bolts, N	24
Corrosion allowance (applied to root radius)	0"
Anchor bolt clearance	0.125"
Bolt root area (corroded), A_b	6.32 in^2
Diameter of anchor bolt holes, d_b	3.125"
Initial bolt preload	0% (0 psi)
Bolt at 0°	No

Results Summary

Load	Vessel condition	Base V (lb$_f$)	Base M (lb$_f$-ft)	W (lb)	Required bolt area (in^2)	t_r Base (in)	Foundation bearing stress (psi)	t_r comp ring (in)	t_r gusset (in)
Wind	operating, corroded	14,859.9	695,612.9	208,655.3	0.3865	0.766	262.39	0.5755	0.2353
Wind	operating, new	14,859.9	695,766.8	217,567.5	0.3777	0.7706	265.55	0.5664	0.2349
Wind	empty, corroded	14,859.9	695,612.9	70,635.3	0.5245	0.6782	205.71	0.7087	0.2426
Wind	empty, new	14,859.9	695,766.8	80,261	0.515	0.6857	210.27	0.7001	0.2421
Wind	vacuum, corroded	14,859.9	695,612.9	208,655.3	0.3865	0.766	262.39	0.5755	0.2353
Seismic	operating, corroded	64,915	2,800,188	208,655.3	2.2521	1.3879	861.45	1.4984	0.3282
Seismic	operating, new	67,687.7	2,954,045.4	217,567.5	2.3776	1.4239	906.69	1.5396	0.3351
Seismic	empty, corroded	21,975.4	1,185,013.4	70,635.3	0.9653	0.8847	349.98	0.981	0.2633
Seismic	empty, new	24,970.1	1,340,357.6	80,261	1.0915	0.9412	396.17	1.0432	0.2692
Seismic	vacuum, corroded	64,915	2,800,188	208,655.3	2.2521	1.3879	861.45	1.4984	0.3282
Vortex shedding	empty, corroded	18,482.1	1,035,686.2	70,635.3	0.8155	0.8045	289.47	0.89	0.2555

Anchor bolt load (governing)

P = -(0.6 - 0.14*S_{DS})*W / N + 48 * M / (N*BC)
= -(0.6 - 0.14*1.3333)*217,567.46 / 24 + 48 * 2,954,045.4 / (24*93.5)
= 59,441.14 lb$_f$

Required area per bolt = P / S_b = 2.3776 in^2

The area provided (6.324 in^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, governing)

Base plate width, t_c: 10 in
Average base plate diameter, d: 91 in
Base plate elastic modulus, E_s: 28.8E+06 psi
Base plate yield stress, S_y: 38,000 psi

E_c = 57,000*Sqr(20,000) = 8,061,017 psi

n = E_s/E_c = 28.8E+06 / 8,061,017 = 3.5728

t_s = (N*A_b) / (π*d)
= (24*6.324) / (π*91)
= 0.5309 in

From table 12.4 for k = 0.29906:

K_1 = 2.4442, K_2 = 1.5067
L_1 = 18.2905, L_2 = 49.5274, L_3 = 21.5551

Total tensile force on bolting

$T = (12*M - (0.6 - 0.14*S_{DS})*W *(L_1 + L_3)) / (L_2 + L_3)$
$= (12*2,954,045.4 - (0.6 - 0.14*1.3333)*217,567.46 *(18.2905 + 21.5551)) / (49.5274 + 21.5551)$
$= 448,286.72$ lb_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 psi

$f_s = T / (t_s * (d / 2) * K_1)$
$= 448,286.72 / (0.5309 * (91 / 2) * 2.4442)$
$= 7,593$ psi

Total compressive load on foundation

$C_c = T + (1 + 0.14*S_{DS})*W +$ Bolt Preload
$= 448,286.72 + (1 + 0.14*1.3333)*217,567.46 + 0$
$= 706,466.77$ lb_f

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
$= 706,466.77 / (((10 - 0.5309) + 3.5728*0.5309)*(91 / 2)*1.5067)$
$= 907$ psi

As $f_c <= 20,000$ psi the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
$= 1 / (1 + 7,593 / (3.5728*907))$
$= 0.29906$

Base plate required thickness (governing)

From Brownell & Young, Table 10.3:, l / b = 1.55

$M_x = 0.1238*907*5^2 = 2,806.2$ lb_f

$M_y = -0.1241*907*7.75^2 = -6,758.3$ lb_f

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (6*6,758.28 / 20,000)^{0.5}$
$= 1.4239$ in

The base plate thickness is satisfactory.

Check the compression ring for bolt load (Jawad & Farr equation 12.13)

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (3.91*48,015.8 / (38,000*(2*7.75 / 5+5 / (2*4)-3.125*(2 / 5+1 / (2*4)))))^{0.5}$
$= 1.5396$ in

The compression ring thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
$= 0.289*0.375$
$= 0.1084$ in

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25)$
$= 0.375*(7.75 - 0.25)$
$= 2.8125$ in^2

Gusset allowable stress

$S_a = 17000 - 0.485*(h / r)^2$
$= 17000 - 0.485*(12 / 0.1084)^2$
= 11,054 psi

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
$= 48{,}015.8 / (2 * 2.8125)$
= 8,536 psi

The gusset plate thickness is satisfactory.

Check skirt thickness for bolt load reaction (Brownell & Young eq. 10.59)

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(48{,}015.8*4 / (11.1919*15.25*28{,}200))^{2/3}*(85.5 / 2)^{1/3}$
$= 0.7186$ in

The skirt thickness is satisfactory.

Elbow Pipe (N1)

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td colspan="2">Component</td><td colspan="3">Nozzle Pipe</td></tr>
<tr><td colspan="2">Material</td><td colspan="3">SA-106 B Smls pipe (II-D p. 14, ln. 5)</td></tr>
<tr><td colspan="2">Pipe NPS and Schedule</td><td colspan="3">NPS 8 Sch 40 (Std)</td></tr>
<tr><td colspan="2">Attached To</td><td colspan="3">Elbow (N1)</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Optimize MDMT/ Find MAWP</td></tr>
<tr><td>No</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (psi)</td><td>Design Temperature (°F)</td><td>Design MDMT (°F)</td></tr>
<tr><td colspan="2">Internal</td><td>150</td><td>550</td><td rowspan="2">-20</td></tr>
<tr><td colspan="2">External</td><td>15</td><td>550</td></tr>
<tr><th colspan="5">Static Liquid Head</th></tr>
<tr><td colspan="2">Condition</td><td>P_s (psi)</td><td>H_s (in)</td><td>SG</td></tr>
<tr><td colspan="2">Operating</td><td>19.33</td><td>535.5046</td><td>1</td></tr>
<tr><td colspan="2">Test horizontal</td><td>2.31</td><td>64.1155</td><td>1</td></tr>
<tr><th colspan="5">Dimensions</th></tr>
<tr><td colspan="2">Outer Diameter</td><td colspan="3">8.625"</td></tr>
<tr><td colspan="2">Length</td><td colspan="3">38"</td></tr>
<tr><td colspan="2">Pipe Nominal Thickness</td><td colspan="3">0.322"</td></tr>
<tr><td colspan="2">Pipe Minimum Thickness[1]</td><td colspan="3">0.2818"</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">0"</td></tr>
<tr><td>Outer</td><td colspan="3">0"</td></tr>
<tr><th colspan="5">Weight and Capacity</th></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (lb)</td><td>Capacity (US gal)</td></tr>
<tr><td colspan="2">New</td><td colspan="2">90.33</td><td>8.23</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">90.33</td><td>8.23</td></tr>
<tr><th colspan="5">Radiography</th></tr>
<tr><td colspan="2">Longitudinal seam</td><td colspan="3">None UW-11(c) Type 1</td></tr>
<tr><td colspan="2">Left Circumferential seam</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
</table>

Right Circumferential seam	Full UW-11(a) Type 1

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

ASME B16.5-2003 Flange	
Description	NPS 8 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	19.33 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2288) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0426"
Design thickness due to external pressure (t_e)	0.0966"
Maximum allowable external pressure (MAEP)	411.61 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
t_r = 169.33*4.3125 / (17,100*1 + 0.4*169.33) =	0.0425"
Stress ratio = t_r*E^* / (t_n - c) = 0.0425*1 / (0.2818 - 0) =	0.151
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) Appendix 1-1

$t = P*R_o / (S*E + 0.40*P) + \text{Corrosion}$
$= 169.33*4.3125 / (17{,}100*1.00 + 0.40*169.33) + 0$
$= 0.0426"$

External Pressure, (Corroded & at 550 °F) UG-28(c)

$L / D_o = 67.7296 / 8.625 = 7.8527$
$D_o / t = 8.625 / 0.0966 = 89.2694$

From table G: A = 0.000179
From table CS-2: B = 2,298.4631 psi

$P_a = 4*B / (3*(D_o / t))$
$= 4*2{,}298.46 / (3*(8.625 / 0.0966))$
$= 34.33$ psi

Design thickness for external pressure P_a = 34.33 psi

$t_a = t + \text{Corrosion} = 0.0966 + 0 = 0.0966"$

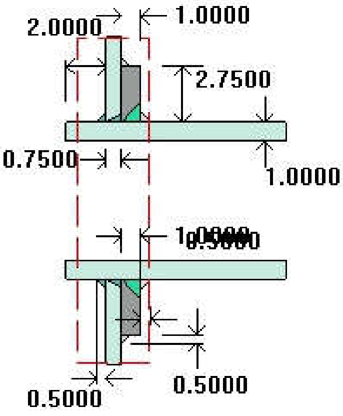
Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

$L / D_o = 67.7296 / 8.625 = 7.8527$
$D_o / t = 8.625 / (0.322*0.875) = 30.6122$

From table G: A = 0.001250
From table CS-2: B = 9,894.1434 psi

$P_a = 4*B / (3*(D_o / t)) - Pse$
$= 4*9{,}894.14 / (3*(8.625 / (0.322*0.875))) - 19.33$
$= 411.61$ psi

Skirt Opening: Manway (M4)

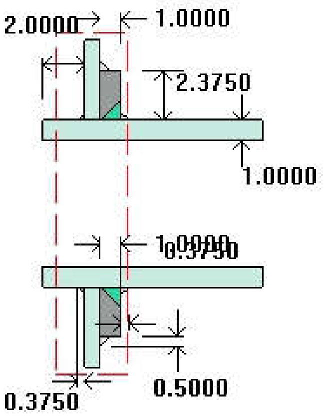
<table>
<tr><th colspan="3">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td>Component</td><td colspan="2">Skirt Opening</td></tr>
<tr><td>Description</td><td colspan="2">Skirt Opening: Manway</td></tr>
<tr><td>Drawing Mark</td><td colspan="2">M4</td></tr>
<tr><td>Sleeve Material</td><td colspan="2">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td>Pad Material</td><td colspan="2">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><th colspan="3">Location and Orientation</th></tr>
<tr><td>Attached to</td><td colspan="2">Support Skirt</td></tr>
<tr><td>Orientation</td><td colspan="2">radial</td></tr>
<tr><td>Offset, L</td><td colspan="2">32"</td></tr>
<tr><td>Angle, θ</td><td colspan="2">0°</td></tr>
<tr><td>Distance, r</td><td colspan="2">46"</td></tr>
<tr><td>Through a Category B Joint</td><td colspan="2">No</td></tr>
<tr><th colspan="3">Dimensions</th></tr>
<tr><td>Inside Diameter</td><td>16"</td><td rowspan="11"> </td></tr>
<tr><td>Nominal Wall Thickness</td><td>1"</td></tr>
<tr><td>Skirt Thickness</td><td>0.75"</td></tr>
<tr><td>Groove Weld, t_{w1}</td><td>0.75"</td></tr>
<tr><td>Pad Groove Weld, t_{w2}</td><td>1"</td></tr>
<tr><td>Leg_{41}</td><td>0.5"</td></tr>
<tr><td>Leg_{42}</td><td>0.5"</td></tr>
<tr><td>Leg_{43}</td><td>0.5"</td></tr>
<tr><td>Pad Width, W</td><td>2.75"</td></tr>
<tr><td>Pad Thickness, t_e</td><td>1"</td></tr>
<tr><td>External Projection Available, L_{pr1}</td><td>3.25"</td></tr>
</table>

Internal Projection, L_{pr2}		2"
Corrosion	**Inner**	0"
	Outer	0"

Skirt Opening Reinforcement Summary							
			Required Thickness t_r (in)	**A_T (in^2)**	**A_r (in^2)**	**Ratio**	**Status**
Operating Hot & Corroded	Wind	Tensile	0.0499	29.86	0.7978	37.4271	OK
		Compressive	0.2172	14.9694	3.4747	4.3082	OK
	Seismic	Tensile	0.2804	25.5434	4.4862	5.6937	OK
		Compressive	0.652	11.3086	10.4321	1.084	OK
Operating Hot & New	Wind	Tensile	0.0488	29.8797	0.781	38.2581	OK
		Compressive	0.2206	14.9409	3.5289	4.2338	OK
	Seismic	Tensile	0.2962	25.2469	4.7396	5.3268	OK
		Compressive	0.6872	11.0119	10.996	1.0014	OK
Empty Cold & Corroded	Wind	Tensile	0.0624	29.6249	0.9988	29.6612	OK
		Compressive	0.1078	15.8899	1.7253	9.2097	OK
	Seismic	Tensile	0.1147	28.6467	1.8346	15.6145	OK
		Compressive	0.1763	15.3136	2.8205	5.4294	OK
	Vortex shedding	Tensile	0.0976	28.967	1.5609	18.5576	OK
		Compressive	0.1539	15.5023	2.4619	6.2969	OK
Empty Cold & New	Wind	Tensile	0.0614	29.6449	0.9817	30.198	OK
		Compressive	0.1102	15.8697	1.7636	8.9986	OK
	Seismic	Tensile	0.1296	28.3672	2.0734	13.6813	OK
		Compressive	0.1996	15.1171	3.194	4.7329	OK
External Pressure Hot & Corroded	Wind	Tensile	0.0499	29.86	0.7978	37.4271	OK
		Compressive	0.2172	14.9694	3.4747	4.3082	OK
	Seismic	Tensile	0.2804	25.5434	4.4862	5.6937	OK
		Compressive	0.652	11.3086	10.4321	1.084	OK

Note: Skirt required thickness of zero on tensile side indicates load is compressive.

Skirt Opening #2 (SO #2)

<table>
<tr><th colspan="3">ASME Section VIII Division 1, 2007 Edition, A08 Addenda</th></tr>
<tr><td>Component</td><td colspan="2">Skirt Opening</td></tr>
<tr><td>Description</td><td colspan="2">Skirt Opening #2</td></tr>
<tr><td>Drawing Mark</td><td colspan="2">SO #2</td></tr>
<tr><td>Opening for Nozzle</td><td colspan="2">Drain (N1)</td></tr>
<tr><td>Sleeve Material</td><td colspan="2">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><td>Pad Material</td><td colspan="2">SA-516 70 (II-D p. 18, ln. 24)</td></tr>
<tr><th colspan="3">Location and Orientation</th></tr>
<tr><td>Attached to</td><td colspan="2">Support Skirt</td></tr>
<tr><td>Orientation</td><td colspan="2">radial</td></tr>
<tr><td>Offset, L</td><td colspan="2">50.6159"</td></tr>
<tr><td>Angle, θ</td><td colspan="2">270°</td></tr>
<tr><td>Distance, r</td><td colspan="2">46"</td></tr>
<tr><td>Through a Category B Joint</td><td colspan="2">No</td></tr>
<tr><th colspan="3">Dimensions</th></tr>
<tr><td>Inside Diameter</td><td>14.25"</td><td rowspan="11"> </td></tr>
<tr><td>Nominal Wall Thickness</td><td>1"</td></tr>
<tr><td>Skirt Thickness</td><td>0.75"</td></tr>
<tr><td>Pad Groove Weld, t_{w2}</td><td>1"</td></tr>
<tr><td>Leg_{41}</td><td>0.375"</td></tr>
<tr><td>Leg_{42}</td><td>0.5"</td></tr>
<tr><td>Leg_{43}</td><td>0.375"</td></tr>
<tr><td>Pad Width, W</td><td>2.375"</td></tr>
<tr><td>Pad Thickness, t_e</td><td>1"</td></tr>
<tr><td>External Projection Available, L_{pr1}</td><td>3.25"</td></tr>
<tr><td></td><td></td></tr>
</table>

Internal Projection, L_{pr2}		2"
Corrosion	**Inner**	0"
	Outer	0"

Skirt Opening Reinforcement Summary							
			Required Thickness t_r (in)	**A_T (in^2)**	**A_r (in^2)**	**Ratio**	**Status**
Operating Hot & Corroded	Wind	Tensile	0.0474	28.4096	0.6761	42.0184	OK
		Compressive	0.212	13.813	3.0206	4.5729	OK
	Seismic	Tensile	0.2691	24.4258	3.8344	6.3702	OK
		Compressive	0.63	10.2935	8.978	1.1465	OK
Operating Hot & New	Wind	Tensile	0.0464	28.4285	0.6611	42.9987	OK
		Compressive	0.2154	13.7845	3.069	4.4916	OK
	Seismic	Tensile	0.2844	24.1499	4.0531	5.9583	OK
		Compressive	0.6644	10.0045	9.4672	1.0568	OK
Empty Cold & Corroded	Wind	Tensile	0.0602	28.1812	0.8572	32.8772	OK
		Compressive	0.1044	14.7183	1.4883	9.8892	OK
	Seismic	Tensile	0.1111	27.2652	1.5834	17.2195	OK
		Compressive	0.1712	14.1561	2.4398	5.8021	OK
	Vortex shedding	Tensile	0.0947	27.5605	1.3492	20.4267	OK
		Compressive	0.1497	14.3374	2.1331	6.7215	OK
Empty Cold & New	Wind	Tensile	0.0591	28.2005	0.8419	33.4945	OK
		Compressive	0.1068	14.6982	1.5224	9.6547	OK
	Seismic	Tensile	0.1255	27.0058	1.789	15.0951	OK
		Compressive	0.1939	13.9651	2.7633	5.0538	OK
External Pressure Hot & Corroded	Wind	Tensile	0.0474	28.4096	0.6761	42.0184	OK
		Compressive	0.212	13.813	3.0206	4.5729	OK
	Seismic	Tensile	0.2691	24.4258	3.8344	6.3702	OK
		Compressive	0.63	10.2935	8.978	1.1465	OK

Note: Skirt required thickness of zero on tensile side indicates load is compressive.

Nozzle Pipe (N1)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Nozzle Pipe		
Material		SA-106 B Smls pipe (II-D p. 14, ln. 5)		
Pipe NPS and Schedule		NPS 8 Sch 40 (Std)		
Attached To		Drain (N1)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		18.75	519.5141	1
Test horizontal		2.31	64.1155	1
Dimensions				
Outer Diameter		8.625"		
Length		6"		
Pipe Nominal Thickness		0.322"		
Pipe Minimum Thickness[1]		0.2818"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		14.26		1.3
Corroded		14.26		1.3
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Left Circumferential seam		Full UW-11(a) Type 1		

Right Circumferential seam	Full UW-11(a) Type 1

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

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0424"
Design thickness due to external pressure (t_e)	0.096"
Maximum allowable external pressure (MAEP)	412.19 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
t_r = 168.75*4.3125 / (17,100*1 + 0.4*168.75) =	0.0424"
Stress ratio = t_r*E^* / (t_n - c) = 0.0424*1 / (0.2818 - 0) =	0.1505
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) Appendix 1-1

$$t = P*R_o / (S*E + 0.40*P) + \text{Corrosion}$$
$$= 168.75*4.3125 / (17,100*1.00 + 0.40*168.75) + 0$$
$$= 0.0424''$$

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / 0.096 = 89.8518

From table G: A = 0.000177
From table CS-2: B = 2,274.5657 psi

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*2,274.57 / (3*(8.625 / 0.096))$$
$$= 33.75 \text{ psi}$$

Design thickness for external pressure P_a = 33.75 psi

t_a = t + Corrosion = 0.096 + 0 = 0.096"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / (0.322*0.875) = 30.6122

From table G: A = 0.001250

From table CS-2: B = 9,894.1434 psi

P_a = 4*B / (3*(D_o / t)) - Pse
= 4*9,894.14 / (3*(8.625 / (0.322*0.875))) - 18.75
= 412.19 psi

Elbow (N1)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		ASME B16.9 Elbow		
Type		Long Radius 90-deg		
Material		SA-234 WPB (II-D p. 14, ln. 7)		
Pipe NPS and Schedule		NPS 8 Sch 40 (Std)		
Attached To		Nozzle Pipe (N1)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		19.33	535.5046	1
Test horizontal		2.31	64.1155	1
Dimensions				
Outer Diameter		8.625"		
Nominal Thickness		0.322"		
Minimum Thickness[1]		0.2818"		
Center-to-End, A		12"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		44.81		4.08
Corroded		44.81		4.08
Radiography				
Longitudinal seam		Seamless No RT		
Left Circumferential seam		Full UW-11(a) Type 1		

Right Circumferential seam	Full UW-11(a) Type 1

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

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0426"
Design thickness due to external pressure (t_e)	0.0966"
Maximum allowable external pressure (MAEP)	411.61 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
t_r = 169.33*4.3125 / (17,100*1 + 0.4*169.33) =	0.0425"
Stress ratio = t_r*E^* / (t_n - c) = 0.0425*1 / (0.2818 - 0) =	0.151
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 169.33*4.3125 / (17,100*1.00 + 0.40*169.33) + 0
= 0.0426"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / 0.0966 = 89.2694

From table G: A = 0.000179
From table CS-2: B = 2,298.4631 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,298.46 / (3*(8.625 / 0.0966))
= 34.33 psi

Design thickness for external pressure P_a = 34.33 psi

t_a = t + Corrosion = 0.0966 + 0 = 0.0966"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / (0.322*0.875) = 30.6122

From table G: A = 0.001250

From table CS-2: B = 9,894.1434 psi

P_a = 4*B / (3*(D_o / t)) - Pse
= 4*9,894.14 / (3*(8.625 / (0.322*0.875))) - 19.33
= 411.61 psi

Elbow Pipe (N1)

ASME Section VIII Division 1, 2007 Edition, A08 Addenda				
Component		Nozzle Pipe		
Material		SA-106 B Smls pipe (II-D p. 14, ln. 5)		
Pipe NPS and Schedule		NPS 8 Sch 40 (Std)		
Attached To		Elbow (N1)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Optimize MDMT/ Find MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		150	550	-20
External		15	550	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		19.33	535.5046	1
Test horizontal		2.31	64.1155	1
Dimensions				
Outer Diameter		8.625"		
Length		38"		
Pipe Nominal Thickness		0.322"		
Pipe Minimum Thickness[1]		0.2818"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)		**Capacity (US gal)**
New		90.33		8.23
Corroded		90.33		8.23
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Left Circumferential seam		Full UW-11(a) Type 1		

Right Circumferential seam	Full UW-11(a) Type 1

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

ASME B16.5-2003 Flange	
Description	NPS 8 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 348, ln. 33)
Blind included	No
Rated MDMT	-55°F
Liquid static head	19.33 psi
MAWP rating	587.5 psi @ 550°F
MAP rating	740 psi @ 70°F
Hydrotest rating	1,125 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2288) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0426"
Design thickness due to external pressure (t_e)	0.0966"
Maximum allowable external pressure (MAEP)	411.61 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
t_r = 169.33*4.3125 / (17,100*1 + 0.4*169.33) =	0.0425"
Stress ratio = t_r*E^* / (t_n - c) = 0.0425*1 / (0.2818 - 0) =	0.151
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 550 °F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 169.33*4.3125 / (17,100*1.00 + 0.40*169.33) + 0
= 0.0426"

External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / 0.0966 = 89.2694

From table G: A = 0.000179
From table CS-2: B = 2,298.4631 psi

P_a = 4*B / (3*(D_o / t))
= 4*2,298.46 / (3*(8.625 / 0.0966))
= 34.33 psi

Design thickness for external pressure P_a = 34.33 psi

t_a = t + Corrosion = 0.0966 + 0 = 0.0966"

Maximum Allowable External Pressure, (Corroded & at 550 °F) UG-28(c)

L / D_o = 67.7296 / 8.625 = 7.8527
D_o / t = 8.625 / (0.322*0.875) = 30.6122

From table G: A = 0.001250
From table CS-2: B = 9,894.1434 psi

P_a = 4*B / (3*(D_o / t)) - Pse
= 4*9,894.14 / (3*(8.625 / (0.322*0.875))) - 19.33
= 411.61 psi

Platform/Ladder #1

Platform	
Distance from Base to Datum	101"
Attached To	Lower Shell
Start Angle	90.00 degrees
End Angle	360.00 degrees
Shell Clearance, L_c	6"
Width, W	54.125" (4.51 ft)
Projected Length, L	120.25" (10.02 ft)
Wind Force Coefficient, C_f	2.00
Floor Grating	
Unit Weight	10.00 psf
Area	19304.71 in^2 (134.06 ft^2)
Railing	
Height, h	42" (3.50 ft)
Length	592.45" (49.37 ft)
Unit Weight	12.00 lb/ft
Ladder	
Distance from Start to Datum	-27"
Angle	90.00 degrees
Unit Weight	18.00 lb/ft
Length	128" (10.67 ft)
Weight	
Platform & Railing Weight	1933.05 lb
Ladder Weight	192.00 lb
Total Weight	2125.05 lb
Included in Vessel Lift 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 = 6"

Railing effective height: H_r = 9.6"

Angle subtended by ends of platform: Angle = 270.00°

Length from vessel center line to platform outer edge: R = 102.75"

Platform projected length: $L_{e\ P}$ = 2 * R
= 2 * 102.75
= 205.5"

Front Railing projected length: $L_{e\ FR}$ = $L_{e\ P}$
= 205.5"

Rear Railing projected length: $L_{e\ RR}$ = $L_{e\ FR}$ - 2 *R*sin((360 - angle) / 2) + W*sin((360 - angle) / 2)*2
= 205.5 - 2*102.75*sin((360 - 270.00) / 2) + 54.125*sin((360 - 270.00) / 2)*2
= 136.7339"

Platform projected area: $A_{e\ P}$ = H_p * $L_{e\ P}$
= 6 * 205.5
= 1,233 in^2

Front Railing projected area: $A_{e\ FR}$ = H_r * $L_{e\ FR}$
= 9.6 * 205.5
= 1,972.8001 in^2

Rear Railing projected area: $A_{e\ RR}$ = H_r * $L_{e\ RR}$
= 9.6 * 136.7339
= 1,312.6452 in^2

Total projected area: A_e = $A_{e\ P}$ + $A_{e\ FR}$ + $A_{e\ RR}$
= 1,233 + 1,972.8001 + 1,312.6452
= 4,518.4453 in^2

Local wind pressure: P_w = $(qz*G^{-})$ = 18.21 psf

Wind shear: V_p = P_w * C_f * A_e
= (18.21 / 144) * 2.00 * 4,518.4453
= 1142.59 lbf

Platform/Ladder #2

Platform	
Distance from Base to Datum	661"
Attached To	Middle Shell
Start Angle	180.00 degrees
End Angle	360.00 degrees
Shell Clearance, L_c	6"
Width, W	36" (3.00 ft)
Projected Length, L	84" (7.00 ft)
Wind Force Coefficient, C_f	2.00
Floor Grating	
Unit Weight	10.00 psf
Area	9613.27 in² (66.76 ft²)
Railing	
Height, h	42" (3.50 ft)
Length	395.58" (32.97 ft)
Unit Weight	12.00 lb/ft
Ladder	
Distance from Start to Datum	141"
Angle	360.00 degrees
Unit Weight	18.00 lb/ft
Length	520" (43.33 ft)
Weight	
Platform & Railing Weight	1063.17 lb
Ladder Weight	780.00 lb
Total Weight	1843.17 lb
Included in Vessel Lift 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 = 6"

Railing effective height: H_r = 9.6"

Angle subtended by ends of platform: Angle = 180.00°

Length from vessel center line to platform outer edge: R = 103"

Platform projected length: $L_{e\ P}$ = 2*R*sin(Angle / 2)

= 2*103*sin(180.00 / 2)

= 206"

Front Railing projected length: $L_{e\ FR}$ = $L_{e\ P}$

= 206"

Rear Railing projected length: $L_{e\ RR}$ = W*sin(Angle / 2)*2

= 36*sin(180.00 / 2)*2

= 72"

Platform projected area: $A_{e\ P}$ = $H_p * L_{e\ P}$

= 6 * 206

= 1,236 in^2

Front Railing projected area: $A_{e\ FR}$ = $H_r * L_{e\ FR}$

= 9.6 * 206

= 1,977.6001 in^2

Rear Railing projected area: $A_{e\ RR}$ = $H_r * L_{e\ RR}$

= 9.6 * 72

= 691.2 in^2

Total projected area: A_e = $A_{e\ P} + A_{e\ FR} + A_{e\ RR}$

= 1,236 + 1,977.6001 + 691.2

= 3,904.8001 in^2

Local wind pressure: P_w = $(qz*G^{-})$ = 24.18 psf

Wind shear: V_p = $P_w * C_f * A_e$

= (24.18 / 144) * 2.00 * 3,904.8001

= 1311.12 lbf

Platform/Ladder #3

Platform	
Distance from Base to Datum	789"
Attached To	Upper Shell
Start Angle	360.00 degrees
End Angle	180.00 degrees
Shell Clearance, L_c	6"
Width, W	78.5" (6.54 ft)
Projected Length, L	169" (14.08 ft)
Wind Force Coefficient, C_f	2.00
Floor Grating	
Unit Weight	10.00 psf
Area	15721.71 in^2 (109.18 ft^2)
Railing	
Height, h	42" (3.50 ft)
Length	480.58" (40.05 ft)
Unit Weight	12.00 lb/ft
Ladder	
Distance from Start to Datum	649"
Angle	180.00 degrees
Unit Weight	18.00 lb/ft
Length	140" (11.67 ft)
Weight	
Platform & Railing Weight	1572.37 lb
Ladder Weight	210.00 lb
Total Weight	1782.37 lb
Included in Vessel Lift 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 = 6"

Railing effective height: H_r = 9.6"

Angle subtended by ends of platform: Angle = 180.00°

Length from vessel center line to platform outer edge: R = 103"

Platform projected length: $L_{e\ P}$ = 2*R*sin(Angle / 2)
= 2*103*sin(180.00 / 2)
= 206"

Front Railing projected length: $L_{e\ FR}$ = $L_{e\ P}$
= 206"

Rear Railing projected length: $L_{e\ RR}$ = W*sin(Angle / 2)*2
= 78.5*sin(180.00 / 2)*2
= 157"

Platform projected area: $A_{e\ P}$ = $H_p * L_{e\ P}$
= 6 * 206
= 1,236 in^2

Front Railing projected area: $A_{e\ FR}$ = $H_r * L_{e\ FR}$
= 9.6 * 206
= 1,977.6001 in^2

Rear Railing projected area: $A_{e\ RR}$ = $H_r * L_{e\ RR}$
= 9.6 * 157
= 1,507.2001 in^2

Total projected area: A_e = $A_{e\ P} + A_{e\ FR} + A_{e\ RR}$
= 1,236 + 1,977.6001 + 1,507.2001
= 4,720.8001 in^2

Local wind pressure: P_w = $(qz*G^{-})$ = 24.98 psf

Wind shear: V_p = $P_w * C_f * A_e$
= (24.98 / 144) * 2.00 * 4,720.8001
= 1638.12 lbf

Clip #1

Geometry	
Height (radial)	6"
Width (circumferential)	0.5"
Length	2"
Fillet Weld Size:	0.375"
Located On	Lower Shell (90" from bottom end)
Location Angle	0.00°

Applied Loads	
Radial load, P_r	0 lb_f
Circumferential moment, M_c	0 lb_f-in
Circumferential shear, V_c	0 lb_f
Longitudinal moment, M_L	0 lb_f-in
Longitudinal shear, V_L	50,000 lb_f
Torsion moment, M_t	0 lb_f-in
Internal pressure, P	164.44 psi
Mean shell radius, R_m	42.375"
Design factor	3

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 42.375 / 0.5 = 84.75$

$C_1 = 0.625$, $C_2 = 1.375$ in

Local circumferential pressure stress = P^*R_i / T =13,854 psi

Local longitudinal pressure stress = $P^*R_i / (2^*T)$ =6,927 psi

Maximum combined stress (P_L+P_b+Q) = 37,018 psi
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±59,100 psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 13,854 psi
Allowable local primary membrane stress (P_L) = ±1.5*S = ±29,550 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the lug edge per WRC Bulletin 107

Figure	value	β	A_u	A_l	B_u	B_l	C_u	C_l	D_u	D_l
3C*	17.6489	0.0295	0	0	0	0	0	0	0	0
4C*	15.9108	0.0251	0	0	0	0	0	0	0	0
1C	0.2606	0.02	0	0	0	0	0	0	0	0
2C-1	0.2134	0.02	0	0	0	0	0	0	0	0
3A*	0.6171	0.0192	0	0	0	0	0	0	0	0
1A	0.1022	0.0206	0	0	0	0	0	0	0	0
3B*	3.2739	0.025	0	0	0	0	0	0	0	0
1B-1	0.0616	0.0222	0	0	0	0	0	0	0	0
Pressure stress*			13,854	13,854	13,854	13,854	13,854	13,854	13,854	13,854
Total circumferential stress			13,854	13,854	13,854	13,854	13,854	13,854	13,854	13,854
Primary membrane circumferential stress*			13,854	13,854	13,854	13,854	13,854	13,854	13,854	13,854
3C*	18.2436	0.0251	0	0	0	0	0	0	0	0
4C*	15.7658	0.0295	0	0	0	0	0	0	0	0
1C-1	0.2315	0.0259	0	0	0	0	0	0	0	0
2C	0.1854	0.0259	0	0	0	0	0	0	0	0
4A*	0.6991	0.0192	0	0	0	0	0	0	0	0
2A	0.0629	0.0253	0	0	0	0	0	0	0	0
4B*	0.893	0.025	0	0	0	0	0	0	0	0
2B-1	0.103	0.0271	0	0	0	0	0	0	0	0
Pressure stress*			6,927	6,927	6,927	6,927	6,927	6,927	6,927	6,927
Total longitudinal stress			6,927	6,927	6,927	6,927	6,927	6,927	6,927	6,927
Primary membrane longitudinal stress*			6,927	6,927	6,927	6,927	6,927	6,927	6,927	6,927
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	-18,182	-18,182	18,182	18,182
Total Shear stress			0	0	0	0	-18,182	-18,182	18,182	18,182
Combined stress (P_L+P_b+Q)			13,854	13,854	13,854	13,854	37,018	37,018	37,018	37,018

* denotes primary stress.