PTT GLOBAL CHEMICAL PUBLIC COMPANY LIMITED

RECORD BOOK NO. -

SECTION -

SERVICE: 540-V5 STRIPPER COLUMN

DOCUMENT TITLE: CALCULATION SHEET FOR STRIPPER COLUMN 540-V5

PLANT: GC4

JOB NO.: A-P1-2018/051

REQUISITION NO.: N.A.

ITEM NO.: N.A.

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VENDOR NAME: UNIMIT ENGINEERING PUBLIC COMPANY LIMITED

TOTAL PAGES: 451

REV. 0

OWNER'S NAME	:	PTT GLOBAL CHEMICAL PUBLIC COMPANY LIMITED (PTTGC)
CLIENT'S NAME	:	PTT GLOBAL CHEMICAL PUBLIC COMPANY LIMITED (PTTGC)
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REV. NO.	DATE	DESCRIPTION	DESIGNED	CHECKED	REVIEWED	APPROVED
0	26-Feb-2019	FOR APPROVAL	P.PICHSINEE	S.NAKKARIN	S.NAKKARIN	P.RUNGROTE
1	21-Jun-2019	AS BUILT	P.PICHSINEE	S.NAKKARIN	S.NAKKARIN	P.RUNGROTE

UNIMIT ENGINEERING PUBLIC COMPANY LIMITED

CONTENT

CONTENT

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Nozzle Schedule

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Specifications									
Nozzle mark	Identifier	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange	Blind
AA	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 150 WN A105	No
AB	Nozzle	609.6 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 24 Class 150 WN A105	SA-105
			Pad	SA-516 70	No	No	No		
AC	Nozzle	406.4 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 16 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
AD	Nozzle	406.4 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 16 Class 150 WN A105	No
			Pad	SA-516 70	No	No	Yes		
BB	Nozzle	609.6 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 24 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
CB	Nozzle	609.6 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 24 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
CC	Nozzle	406.4 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 16 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
CD	Nozzle	NPS 8 Sch 80 (XS) DN 200	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 8 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
CF	Nozzle	812.8 OD x 13	Nozzle	SA-516 70	No	No	No	NPS 32 Class 150 WN A105 Series B	No
			Pad	SA-516 70	No	No	No		
CL1	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CL2	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CM1	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CM2	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CN	Nozzle	NPS 3 Sch 160 DN 80	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 3 Class 150 WN A105	No
			Pad	SA-516 70	No	No	No		
CO1	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO2	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO3	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO4	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO5	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		

CO6	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO7	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
CO8	Nozzle	NPS 2 Sch 160 DN 50	Nozzle	SA-106 B Smls Pipe	No	No	No	NPS 2 Class 300 WN A105	No
			Pad	SA-516 70	No	No	No		
DC	Nozzle	406.4 OD x 13	Nozzle	SA-516 70	No	No	No	N/A	No
			Pad	SA-516 70	No	No	No		
	B16.9 Elbow (DC)	NPS 16 (Thk = 0.562") DN 400	B16.9 Elbow	SA-234 WPB	No	No	No	N/A	No
	Nozzle Pipe (DC)	NPS 16 (Thk = 0.562") DN 400	Nozzle Pipe	SA-106 B Smls Pipe	No	No	No	NPS 16 Class 150 WN A105	No

Nozzle Summary

Dimensions												
Nozzle Identifier	OD (mm)	t_n (mm)	Req t_n (mm)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (mm)	A_a/A_r (%)
						Nom t (mm)	Design t (mm)	User t (mm)	Width (mm)	t_{pad} (mm)		
Nozzle	60.33	8.74	3.91	Yes	Yes	46.1	N/A		N/A	N/A		Exempt
Nozzle	406.4	13	7.37	Yes	Yes	12.4*	12.4		160.78	15	3	264.6
Nozzle	406.4	13	7.37	Yes	Yes	12.4*	12.4		176.66	15	3	326.8
Nozzle	609.6	13	7.38	Yes	Yes	14	14		270.2	14	3	254.2
Nozzle	219.08	12.7	5	Yes	Yes	14	11.75		90.46	14		306.4
Nozzle	812.8	13	4.38	Yes	Yes	14	11.75		156.1	15		159.8
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	609.6	13	4.65	Yes	Yes	14	14		270.2	14		209.0
Nozzle	406.4	13	4.66	Yes	Yes	14	14		186.8	14		219.2
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	88.9	11.13	5.36	Yes	Yes	14	14		45.55	14		269.9
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	60.33	8.74	3.91	Yes	Yes	14	N/A		44.85	14		Exempt
Nozzle	406.4	13	7.9	Yes	Yes	12.4*	12.4		186.8	15	3	324.4
Nozzle	609.6	13	7.37	Yes	Yes	12.4*	12.4		265.52	15	3	304.3
*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

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Component Summary								
Identifier	P Design (bar)	T Design (°C)	MAEP (bar)	T_e external (°C)	MDMT (°C)	MDMT Exemption		Impact Tested
Top Head	3.6	202	1.18	175	-48	Note 1		No
Straight Flange on Top Head	3.6	202	3.64	175	-48	Note 2		No
Top existing shell	3.6	202	1.81	175	-48	Note 3		No
New shell	3.6	202	8	175	-105	Note 4		No
Bottom existing shell	3.6	202	2.91	175	-105	Note 5		No
Straight Flange on Bottom Head	3.6	202	1.97	175	-48	Note 7		No
Bottom Head	3.6	202	1.18	175	-48	Note 6		No
Rings #6	N/A	N/A	1.9	175	N/A	N/A		No
Rings #7	N/A	N/A	1.6	175	N/A	N/A		No
Rings #8	N/A	N/A	1.52	175	N/A	N/A		No
Rings #9	N/A	N/A	1.83	175	N/A	N/A		No
Rings #11	N/A	N/A	1.71	175	N/A	N/A		No
Rings #12	N/A	N/A	2.05	175	N/A	N/A		No
Rings #13	N/A	N/A	1.6	175	N/A	N/A		No
Rings #14	N/A	N/A	1.78	175	N/A	N/A		No
Rings #5 (Ring #3 in Group)	N/A	N/A	1.71	175	N/A	N/A		No
Rings #5 (Ring #4 in Group)	N/A	N/A	1.71	175	N/A	N/A		No
Rings #5 (Ring #5 in Group)	N/A	N/A	1.71	175	N/A	N/A		No
Rings #10	N/A	N/A	1.49	175	N/A	N/A		No
Rings #4	N/A	N/A	2.91	175	N/A	N/A		No
Rings #5 (Ring #2 in Group)	N/A	N/A	2.58	175	N/A	N/A		No
Rings #5	N/A	N/A	2.91	175	N/A	N/A		No
PF clip#4	3.6	202	N/A	N/A	N/A	N/A		N/A
Rings #2	N/A	N/A	1.93	175	N/A	N/A		No
Rings #3	N/A	N/A	1.93	175	N/A	N/A		No
Rings #1	N/A	N/A	1.58	175	N/A	N/A		No
PF clip #3	3.6	202	N/A	N/A	N/A	N/A		N/A
Nozzle (AA)	3.6	202	21.98	175	-48	Note 8		No
Nozzle (AB)	3.6	202	1.18	175	-48	Nozzle	Note 9	No
						Pad	Note 10	No
Blind Flange (AB)	3.6	202	21.98	175	-105	Note 11		No
Nozzle (AC)	3.6	202	1.18	175	-48	Nozzle	Note 12	No
						Pad	Note 13	No
Nozzle (AD)	3.6	202	1.18	175	-48	Nozzle	Note 9	No
						Pad	Note 10	No
Nozzle (BB)	3.6	202	1.81	175	-48	Nozzle	Note 14	No
						Pad	Note 15	No
Nozzle (CB)	3.6	202	2.91	175	-48	Nozzle	Note 16	No
						Pad	Note 17	No
Nozzle (CC)	3.6	202	2.91	175	-48	Nozzle	Note 18	No
						Pad	Note 19	No
Nozzle (CD)	3.6	202	2.91	175	-48	Nozzle	Note 8	No
						Pad	Note 20	No

Nozzle (CF)	3.6	202	2.91	175	-48	Nozzle	Note 8	No
						Pad	Note 20	No
Nozzle (CL1)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CL2)	3.6	202	2.91	175	-48	Nozzle	Note 22	No
						Pad	Note 23	No
Nozzle (CM1)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CM2)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CN)	3.6	202	2.91	175	-48	Nozzle	Note 24	No
						Pad	Note 25	No
Nozzle (CO1)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CO2)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CO3)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CO4)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CO5)	3.6	202	2.91	175	-48	Nozzle	Note 21	No
						Pad	Note 20	No
Nozzle (CO6)	3.6	202	2.91	175	-48	Nozzle	Note 26	No
						Pad	Note 27	No
Nozzle (CO7)	3.6	202	2.91	175	-48	Nozzle	Note 28	No
						Pad	Note 29	No
Nozzle (CO8)	3.6	202	2.91	175	-48	Nozzle	Note 22	No
						Pad	Note 23	No
Nozzle (DC)	3.6	202	1.18	175	-48	Nozzle	Note 30	No
						Pad	Note 31	No
B16.9 Elbow (DC)	3.6	202	28.52	175	-105	Note 32		No
Nozzle Pipe (DC)	3.6	202	19.27	175	-105	Note 33		No

Chamber Summary	
Design MDMT	17 °C
Rated MDMT	-48 °C @ 3.6 bar
MAWP hot & corroded	3.6 bar
MAEP	1.18 bar @ 175 °C

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.	Material impact test exemption temperature from Fig UCS-66M Curve B = -22.56°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 36.2°C, (coincident ratio = 0.4647) Rated MDMT of -75.76°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 12.4 mm
2.	Material impact test exemption temperature from Fig UCS-66M Curve B = -16.69°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 67.7°C, (coincident ratio = 0.3653) Rated MDMT of -101.39°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15 mm
3.	Material impact test exemption temperature from Fig UCS-66M Curve B = -18.75°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 52.3°C, (coincident ratio = 0.3987) Rated MDMT of -88.05°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 14 mm
4.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.1993)	
5.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.336)	
6.	Material impact test exemption temperature from Fig UCS-66M Curve B = -22.56°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 30.5°C, (coincident ratio = 0.511) Rated MDMT of -70.06°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 12.4 mm
7.	Material impact test exemption temperature from Fig UCS-66M Curve B = -16.69°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 54.5°C, (coincident ratio = 0.3929) Rated MDMT of -88.19°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 15 mm
8.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
9.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 45.9°C, (coincident ratio = 0.4185) Rated MDMT of -84.15°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
10.	Pad impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 45.9°C, (coincident ratio = 0.4185) Rated MDMT of -84.15°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
11.	Bolted cover is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.2312)	
12.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 36.2°C, (coincident ratio = 0.4647) Rated MDMT of -74.45°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
13.	Pad impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 36.2°C, (coincident ratio = 0.4647) Rated MDMT of -74.45°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
14.	Nozzle is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.077).	
15.	Pad impact test exemption temperature from Fig UCS-66M Curve B = -18.75°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 52.3°C, (coincident ratio = 0.3986) Rated MDMT of -88.05°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 14 mm.
16.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1936) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
17.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3323).	
18.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1945) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
19.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3328).	
20.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3126).	
21.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
22.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0754) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

23.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3348).	
24.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1966) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
25.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3349).	
26.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.072) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
27.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3196).	
28.	Flange rating governs: Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0723) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	
29.	Pad is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.3212).	
30.	Nozzle impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 35.5°C, (coincident ratio = 0.4695) Rated MDMT of -73.75°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
31.	Pad impact test exemption temperature from Fig UCS-66M Curve B = -21.25°C 17°C MDMT reduction per UCS-68(c) applies. Fig UCS-66.1M MDMT reduction = 35.5°C, (coincident ratio = 0.4695) Rated MDMT of -73.75°C is limited to -48°C by UCS-66(b)(2)	UCS-66 governing thickness = 13 mm.
32.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.064)	
33.	Material is impact test exempt to -105°C per UCS-66(b)(3) (coincident ratio = 0.0763)	

Thickness Summary 1

Component Data								
Component Identifier	**Material**	**Diameter (mm)**	**Length (mm)**	**Nominal t (mm)**	**Design t (mm)**	**Total Corrosion (mm)**	**Joint E**	**Load**
Top Head	SA-516 70	3,350 ID	849.9	12.4*	11.78	3	1.00	External
Straight Flange on Top Head	SA-516 70	3,350 ID	38	15	10.03	3	1.00	External
Top existing shell	SA-516 70	3,350 ID	18,882	14	11.76	3	0.85	External
New shell	SA-516 70	3,350 ID	3,030	25	10.79	3	0.85	External
Bottom existing shell	SA-516 70	3,350 ID	6,372	14	9.28		0.85	External
Straight Flange on Bottom Head	SA-516 70	3,350 ID	38	15	12.2	3	1.00	External
Bottom Head	SA-516 70	3,350 ID	849.9	12.4*	11.78	3	1.00	External
Blind Flange (AB)	SA-105	812.8 OD	46.1	46.1	38.17		1.00	External
Support Skirt #1	SA-516 70	3,358 ID	976	10	6.99	1.6	0.60	Wind
Support Skirt #2	SA-285 C	3,358 ID	7,010	10	8.75	1.6	0.70	Wind
*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

Top Head 1

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2017 Edition Metric</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 Metric p. 18, ln. 33)</td></tr>
<tr><td colspan="2">Attached To</td><td colspan="3">Top existing shell</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Maximize MDMT/ No MAWP</td></tr>
<tr><td>No</td><td>No</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (bar)</td><td>Design Temperature (°C)</td><td>Design MDMT (°C)</td></tr>
<tr><td colspan="2">Internal</td><td>3.6</td><td>202</td><td rowspan="2">17</td></tr>
<tr><td colspan="2">External</td><td>1.03</td><td>175</td></tr>
<tr><th colspan="5">Static Liquid Head</th></tr>
<tr><td colspan="2">Condition</td><td>P_s (bar)</td><td>H_s (mm)</td><td>SG</td></tr>
<tr><td colspan="2">Test vertical</td><td>0.15</td><td>1,504.5</td><td>1</td></tr>
<tr><th colspan="5">Dimensions</th></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">3,350 mm</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">12.4 mm</td></tr>
<tr><td rowspan="2">Corrosion</td><td>Inner</td><td colspan="3">3 mm</td></tr>
<tr><td>Outer</td><td colspan="3">0 mm</td></tr>
<tr><td colspan="2">Length L_{sf}</td><td colspan="3">38 mm</td></tr>
<tr><td colspan="2">Nominal Thickness t_{sf}</td><td colspan="3">15 mm</td></tr>
<tr><th colspan="5">Weight and Capacity</th></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (kg)[1]</td><td>Capacity (liters)[1]</td></tr>
<tr><td colspan="2">New</td><td colspan="2">1,260.93</td><td>5,256.16</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">1,260.93</td><td>5,292.69</td></tr>
<tr><th colspan="5">Insulation</th></tr>
<tr><td colspan="2"></td><td>Thickness (mm)</td><td>Density (kg/m³)</td><td>Weight (kg)</td></tr>
<tr><td colspan="2">Insulation</td><td>75</td><td>150</td><td>146.9</td></tr>
<tr><td colspan="2"></td><td>Spacing(mm)</td><td>Individual Weight (kg)</td><td>Total Weight (kg)</td></tr>
<tr><td colspan="2">Insulation Supports</td><td>3,000</td><td>100</td><td>100</td></tr>
<tr><th colspan="5">Radiography</th></tr>
<tr><td colspan="2">Category A joints</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
<tr><td colspan="2">Head to shell seam</td><td colspan="3">Full UW-11(a) Type 1</td></tr>
</table>

[1] includes straight flange

Results Summary	
Governing condition	external pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	7.37 mm
Design thickness due to external pressure (t_e)	11.78 mm
Maximum allowable external pressure (MAEP)	1.18 bar
Rated MDMT	-48°C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	12.4 mm
Exemption temperature from Fig UCS-66M Curve B =	-22.56°C
t_r = 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6) =	4.37 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.37*1 / (12.4 - 3) =	0.4647
Reduction in MDMT, T_R from Fig UCS-66.1M =	36.2°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-22.56 - 36.2 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Factor K		
K = (1/6)*[2 + (D / (2*h))^2]		
Corroded	K = (1/6)*[2 + (3,356 / (2*840.5))^2]	0.9976
New	K = (1/6)*[2 + (3,350 / (2*837.5))^2]	1

Design thickness for internal pressure, (Corroded at 202 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6) + 3
= 7.37 mm

Design thickness for external pressure, (Corroded at 175 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8934*3,374.8
= 3,015.16 mm

A = 0.125 / (R_o / t)
= 0.125 / (3,015.16 / 8.77)
= 0.000364

From Table CS-2 Metric: B = 360.9567 kg_f/cm^2

P_a = B / (R_o / t)
= 353.9779 / (3,015.16 / 8.77)

= 1.03 bar

t = 8.77 mm + Corrosion = 8.77 mm + 3 mm = 11.77 mm

Check the external pressure per UG-33(a)(1) Appendix 1-4(c)

$t = 1.67*P_e*D*K / (2*S*E - 0.2*1.67*P_e) + Corrosion$
$= 1.67*1.03*3{,}356*0.997623 / (2*1{,}380*1 - 0.2*1.67*1.03) + 3$
$= 5.09$ mm

The head external pressure design thickness (t_e) is 11.77 mm.

Maximum Allowable External Pressure, (Corroded at 175 °C) UG-33(d)

Equivalent outside spherical radius (R_o)

$R_o = K_o*D_o$
$= 0.8934*3{,}374.8$
$= 3{,}015.16$ mm

$A = 0.125 / (R_o / t)$
$= 0.125 / (3{,}015.16 / 9.4)$
$= 0.00039$

From Table CS-2 Metric: B = 386.9029 kg_f/cm^2

$P_a = B / (R_o / t)$
$= 379.4224 / (3{,}015.16 / 9.4)$
$= 1.1829$ bar

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

$P = 2*S*E*t / ((K*D + 0.2*t)*1.67)$
$= 2*1{,}380*1*9.4 / ((0.997623*3{,}356 +0.2*9.4)*1.67)$
$= 4.64$ bar

The maximum allowable external pressure (MAEP) is 1.18 bar.

% Extreme fiber elongation - UCS-79(d)

$EFE = (75*t / R_f)*(1 - R_f / R_o)$
$= (75*15 / 577)*(1 - 577 / infinity)$
$= 1.9497\%$

The extreme fiber elongation does not exceed 5%.

Straight Flange on Top Head
1

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	Yes	Yes	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		3.6	202	17
External		1.03	175	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Test vertical		0.15	1,542.5	1
Dimensions				
Inner Diameter		3,350 mm		
Length		38 mm		
Nominal Thickness		15 mm		
Corrosion	**Inner**	3 mm		
	Outer	0 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		47.2		334.94
Corroded		47.2		336.14
Insulation				
		Thickness (mm)	**Density (kg/m³)**	**Weight (kg)**
Insulation		75	150	0
		Spacing(mm)	**Individual Weight (kg)**	**Total Weight (kg)**
Insulation Supports		0	0	0
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Bottom Circumferential seam		Full UW-11(a) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	7.39 mm
Design thickness due to external pressure (t_e)	10.03 mm
Design thickness due to combined loadings + corrosion	4.82 mm
Maximum allowable external pressure (MAEP)	3.64 bar
Rated MDMT	-48 °C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	15 mm
Exemption temperature from Fig UCS-66M Curve B =	-16.69°C
t_r = 3.6*1,678 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (15 - 3) =	0.3653
Reduction in MDMT, T_R from Fig UCS-66.1M =	67.7°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-16.69 - 67.7 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Design thickness, (at 202 °C) UG-27(c)(1)

t = P*R / (S*E - .60*P) + Corrosion
= 3.6*1,678 / (1,380*1.00 - .60*3.6) + 3
= 7.39 mm

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 1,180.17 / 3,380 = 0.3492
D_o / t = 3,380 / 7.03 = 480.5443

From table G: A = 0.000381
From table CS-2 Metric: B = 378.5413 kg/cm^2 (371.22 bar)

P_a = 4*B / (3*(D_o / t))
= 4*371.22 / (3*(3,380 / 7.03))
= 1.03 bar

Design thickness for external pressure P_a = 1.03 bar

t_a = t + Corrosion = 7.03 + 3 = 10.03 mm

Maximum Allowable External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 1,180.17 / 3,380 = 0.3492
D_o / t = 3,380 / 12 = 281.6606

From table G: A = 0.000866
From table CS-2 Metric: B = 784.1542 kg/cm^2 (768.9912 bar)

P_a = 4*B / (3*(D_o / t))
= 4*768.99 / (3*(3,380 / 12))
= 3.64 bar

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*15 / 1,682.5)*(1 - 1,682.5 / infinity)
= 0.4458%

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	3.6	1,407.2	751.6	202	3	Wind	1.82	1.76
Operating, Hot & New	3.6	1,407.2	803.8	202		Wind	1.82	1.76
Hot Shut Down, Corroded		1,407.2	751.6	202	3	Wind		.12
Hot Shut Down, New		1,407.2	803.8	202		Wind		.11
Empty, Corroded		1,407.2	826.6	13	3	Wind		.11
Empty, New		1,407.2	890.3	13		Wind		.1
Vacuum	-1.03	1,407.2	789.7	175	3	Wind	.93	1.04
Hot Shut Down, Corroded, Weight & Eccentric Moments Only		1,407.2	751.6	202	3	Weight	.04	.14
Operating, Hot & Corroded, Vortex Shedding	3.6	1,407.2	751.6	202	3	Wind	1.82	1.76
Empty, Cold & Corroded, Vortex Shedding		1,407.2	826.6	13	3	Wind		.11
Vacuum, Vortex Shedding	-1.03	1,407.2	789.7	175	3	Wind	.93	1.04

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888

B = 751.6 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHC} = min(B, S) = 751.6 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 15)
= 0.001109

B = 803.8 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHN} = min(B, S) = 803.8 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 15)
= 0.001109
B = 890.3 kg/cm^2
S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2
S_{cCN} = min(B, S) = 890.3 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888
B = 826.6 kg/cm^2
S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2
S_{cCC} = min(B, S) = 826.6 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888
B = 789.7 kg/cm^2
S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2
S_{cVC} = min(B, S) = 789.7 kg/cm^2

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^2*S_t*K_s*E_c) * MetricFactor (bending)
= 3,419.5 / (π*1,684^2*1,380*1.20*1.00) * 98066.5
= .02 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .02 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .02 - (.02)
= 1.82 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .04 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.02 + (.04) - (1.82)|

= 1.76 mm

Operating, Hot & New, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,675 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^2*S_t*K_s*E_c) * MetricFactor (bending)
= 3,419.5 / (π*1,682.5²*1,380*1.20*1.00) * 98066.5
= .02 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,682.5*1,380*1.20*1.00) * 98.0665
= .02 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .02 - (.02)
= 1.82 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,682.5*1,380*1.20*1.00) * 98.0665
= .04 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.02 + (.04) - (1.82)|
= 1.76 mm

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) * MetricFactor (bending)
= 3,419.5 / (π*1,684²*737.05*1.20) * 98066.5
= .04 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,684*737.05*1.20) * 98.0665
= .04 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= | + .04 - (.04)|
= mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*737.05*1.20) * 98.0665
= .07 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .04 + (.07) - ()
= .12 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = M / (π*R_m^2*S_c*K_s) * MetricFactor (bending)
= 3,419.5 / (π*1,682.5²*788.29*1.20) * 98066.5
= .04 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,682.5*788.29*1.20) * 98.0665
= .04 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= | + .04 - (.04)|
= mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,682.5*788.29*1.20) * 98.0665
= .07 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .04 + (.07) - ()
= .11 mm

Empty, Corroded, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = M / (π*R_m^{2}*S_c*K_s) * MetricFactor (bending)
= 3,419.5 / (π*1,684^2*810.65*1.20) * 98066.5
= .04 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,684*810.65*1.20) * 98.0665
= .04 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= | + .04 - (.04)|
= mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*810.65*1.20) * 98.0665
= .07 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .04 + (.07) - ()
= .11 mm

Empty, New, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = M / (π*R_m^{2}*S_c*K_s) * MetricFactor (bending)
= 3,419.5 / (π*1,682.5^2*873.07*1.20) * 98066.5
= .04 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,682.5*873.07*1.20) * 98.0665
= .04 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= | + .04 - (.04)|
= mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,682.5*873.07*1.20) * 98.0665
= .06 mm

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

= .04 + (.06) - ()
= .1 mm

Vacuum, Wind, Bottom Seam

t_p = P*R / (2*S_c*K_s + .40*|P|) (Pressure)
= -1.03*1,678 / (2*774.39*1.20 + .40*|1.03|)
= -.93 mm

t_m = M / (π*R_m^{2}*S_c*K_s) * MetricFactor (bending)
= 3,419.5 / (π*1,684^2*774.39*1.20) * 98066.5
= .04 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*7,116.2 / (2*π*1,684*774.39*1.20) * 98.0665
= .04 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-.93 + .04 - (.04)|
= .93 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*774.39*1.20) * 98.0665
= .07 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .04 + (.07) - (-.93)
= 1.04 mm

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

t_p = mm (Pressure)
t_m = M / (π*R_m^{2}*S_c*K_s) * MetricFactor (bending)
= 3,349.9 / (π*1,684^2*737.05*1.00) * 98066.5
= .05 mm

t_w = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*737.05*1.00) * 98.0665
= .09 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= | + .05 - (.09)|
= .04 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .05 + (.09) - ()
= .14 mm

Operating, Hot & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor (bending)
= 3,514.5 / (π*1,684^2*1,380*1.20*1.00) * 98066.5

= .02 mm

t_w = $0.6*W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$ (Weight)
= 0.60*7,116.2 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .02 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 1.82 + .02 - (.02)
= 1.82 mm

t_{wc} = $W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$ (Weight)
= 7,116.2 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .04 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |.02 + (.04) - (1.82)|
= 1.76 mm

Empty, Cold & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s) * MetricFactor$ (bending)
= 3,569.7 / (π*1,684²*810.65*1.20) * 98066.5
= .04 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s) * MetricFactor$ (Weight)
= 0.60*7,116.2 / (2*π*1,684*810.65*1.20) * 98.0665
= .04 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= | + .04 - (.04)|
= mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s) * MetricFactor$ (Weight)
= 7,116.2 / (2*π*1,684*810.65*1.20) * 98.0665
= .07 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .04 + (.07) - ()
= .11 mm

Vacuum, Vortex Shedding, Wind, Bottom Seam

t_p = $P*R / (2*S_c*K_s + .40*|P|)$ (Pressure)
= -1.03*1,678 / (2*774.39*1.20 + .40*|1.03|)
= -.93 mm

t_m = $M / (\pi*R_m^2*S_c*K_s) * MetricFactor$ (bending)
= 3,514.6 / (π*1,684²*774.39*1.20) * 98066.5
= .04 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s) * MetricFactor$ (Weight)
= 0.60*7,116.2 / (2*π*1,684*774.39*1.20) * 98.0665
= .04 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.93 + .04 - (.04)|

= .93 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 7,116.2 / (2*π*1,684*774.39*1.20) * 98.0665
= .07 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= .04 + (.07) - (-.93)
= 1.04 mm

Top existing shell

1

<table>
<tr><th colspan="5">ASME Section VIII Division 1, 2017 Edition Metric</th></tr>
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<tr><td colspan="2">Material</td><td colspan="3">SA-516 70 (II-D Metric p. 18, ln. 33)</td></tr>
<tr><td>Impact Tested</td><td>Normalized</td><td>Fine Grain Practice</td><td>PWHT</td><td>Maximize MDMT/ No MAWP</td></tr>
<tr><td>No</td><td>No</td><td>Yes</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="2"></td><td>Design Pressure (bar)</td><td>Design Temperature (°C)</td><td>Design MDMT (°C)</td></tr>
<tr><td colspan="2">Internal</td><td>3.6</td><td>202</td><td rowspan="2">17</td></tr>
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<tr><td colspan="2">Condition</td><td>P_s (bar)</td><td>H_s (mm)</td><td>SG</td></tr>
<tr><td colspan="2">Test vertical</td><td>2</td><td>20,424.5</td><td>1</td></tr>
<tr><th colspan="5">Dimensions</th></tr>
<tr><td colspan="2">Inner Diameter</td><td colspan="3">3,350 mm</td></tr>
<tr><td colspan="2">Length</td><td colspan="3">18,882 mm</td></tr>
<tr><td colspan="2">Nominal Thickness</td><td colspan="3">14 mm</td></tr>
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<tr><td>Outer</td><td colspan="3">0 mm</td></tr>
<tr><th colspan="5">Weight and Capacity</th></tr>
<tr><td colspan="2"></td><td colspan="2">Weight (kg)</td><td>Capacity (liters)</td></tr>
<tr><td colspan="2">New</td><td colspan="2">21,851.15</td><td>166,428.43</td></tr>
<tr><td colspan="2">Corroded</td><td colspan="2">21,851.15</td><td>167,025.07</td></tr>
<tr><th colspan="5">Insulation</th></tr>
<tr><td colspan="2"></td><td>Thickness (mm)</td><td>Density (kg/m^3)</td><td>Weight (kg)</td></tr>
<tr><td colspan="2">Insulation</td><td>75</td><td>150</td><td>2,304.34</td></tr>
<tr><td colspan="2"></td><td>Spacing(mm)</td><td>Individual Weight (kg)</td><td>Total Weight (kg)</td></tr>
<tr><td colspan="2">Insulation Supports</td><td>3,000</td><td>100</td><td>600</td></tr>
<tr><th colspan="5">Radiography</th></tr>
<tr><td colspan="2">Longitudinal seam</td><td colspan="3">Spot UW-11(b) Type 1</td></tr>
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</table>

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	8.16 mm
Design thickness due to external pressure (t_e)	11.76 mm
Design thickness due to combined loadings + corrosion	5.68 mm
Maximum allowable external pressure (MAEP)	1.81 bar
Rated MDMT	-48 °C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	14 mm
Exemption temperature from Fig UCS-66M Curve B =	-18.75°C
t_r = 3.6*1,678 / (1,380*.85 - 0.6*3.6) =	5.16 mm
Stress ratio = t_r*E^* / (t_n - c) = 5.16*0.85 / (14 - 3) =	0.3987
Reduction in MDMT, T_R from Fig UCS-66.1M =	52.3°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-18.75 - 52.3 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Design thickness, (at 202 °C) UG-27(c)(1)

t = P*R / (S*E - .60*P) + Corrosion
= 3.6*1,678 / (1,380*0.85 - .60*3.6) + 3
= 8.16 mm

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 8.76 = 385.5602

From table G: A = 0.000306
From table CS-2 Metric: B = 303.7181 kg/cm^2 (297.85 bar)

P_a = 4*B / (3*(D_o / t))
= 4*297.85 / (3*(3,378 / 8.76))
= 1.03 bar

Design thickness for external pressure P_a = 1.03 bar

t_a = t + Corrosion = 8.76 + 3 = 11.76 mm

Maximum Allowable External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 11 = 307.0837

From table G: A = 0.000428
From table CS-2 Metric: B = 425.3279 kg/cm^2 (417.1034 bar)

P_a = 4*B / (3*(D_o / t))
= 4*417.1 / (3*(3,378 / 11))
= 1.81 bar

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*14 / 1,682)*(1 - 1,682 / infinity)
= 0.4162%

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)
= 10*66,401.7 / (2*π*1,683.5) + 10000*51,607.6 / (π*$1,683.5^2$)
= 120.7362 kg/cm
α = P_v / (P_e*D_o)
= 9.803*120.7362 / (1.03*3,378)
= .3403
n = 8
m = 1.23 / (L / D_o)^2
= 1.23 / (2,000 / 3,378)^2
= 3.5088
Ratio P_e = (n^2 - 1 + m + m*α) / (n^2 - 1 + m)
= (8^2 - 1 + 3.5088 + 3.5088*.3403) / (8^2 - 1 + 3.5088)
= 1.018
Ratio P_e * P_e ≤ MAEP
(1.018 * 1.03 = 1.05) ≤ 1.81
Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	3.6	1,407.2	734.3	202	3	Wind	2.29	1.3
Operating, Hot & New	3.6	1,407.2	790.6	202		Wind	2.28	1.3
Hot Shut Down, Corroded		1,407.2	734.3	202	3	Wind	.14	1.37
Hot Shut Down, New		1,407.2	790.6	202		Wind	.14	1.27
Empty, Corroded		1,407.2	805.7	13	3	Wind	.19	1.12
Empty, New		1,407.2	873.4	13		Wind	.2	1.03
Vacuum	-1.03	1,407.2	770.5	175	3	Wind	.73	2.26
Hot Shut Down, Corroded, Weight & Eccentric Moments Only		1,407.2	734.3	202	3	Weight	.73	.98
Operating, Hot & Corroded, Vortex Shedding	3.6	1,407.2	734.3	202	3	Wind	2.56	1.03
Empty, Cold & Corroded, Vortex Shedding		1,407.2	805.7	13	3	Wind	.65	1.79
Vacuum, Vortex Shedding	-1.03	1,407.2	770.5	175	3	Wind	.31	2.69

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

$$
\begin{aligned}
A &= .125 / (R_o / t) \\
&= .125 / (1{,}689 / 11) \\
&= 0.000814 \\
B &= 734.3 \text{ kg/cm}^2 \\
S &= 1{,}407.2 / 1.00 = 1{,}407.2 \text{ kg/cm}^2 \\
S_{cHC} &= \min(B, S) = 734.3 \text{ kg/cm}^2
\end{aligned}
$$

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

$$
\begin{aligned}
A &= .125 / (R_o / t) \\
&= .125 / (1{,}689 / 14) \\
&= 0.001036 \\
B &= 790.6 \text{ kg/cm}^2 \\
S &= 1{,}407.2 / 1.00 = 1{,}407.2 \text{ kg/cm}^2 \\
S_{cHN} &= \min(B, S) = 790.6 \text{ kg/cm}^2
\end{aligned}
$$

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

$$
\begin{aligned}
A &= .125 / (R_o / t) \\
&= .125 / (1{,}689 / 14) \\
&= 0.001036 \\
B &= 873.4 \text{ kg/cm}^2 \\
S &= 1{,}407.2 / 1.00 = 1{,}407.2 \text{ kg/cm}^2 \\
S_{cCN} &= \min(B, S) = 873.4 \text{ kg/cm}^2
\end{aligned}
$$

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

$A = .125 / (R_o / t)$
$= .125 / (1{,}689 / 11)$
$= 0.000814$
$B = 805.7\ kg/cm^2$
$S = 1{,}407.2 / 1.00 = 1{,}407.2\ kg/cm^2$
$S_{cCC} = \min(B, S) =$ 805.7 kg/cm^2

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

$A = .125 / (R_o / t)$
$= .125 / (1{,}689 / 11)$
$= 0.000814$
$B = 770.5\ kg/cm^2$
$S = 1{,}407.2 / 1.00 = 1{,}407.2\ kg/cm^2$
$S_{cVC} = \min(B, S) =$ 770.5 kg/cm^2

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = P*R / (2*S_t*K_s*E_c + .40*|P|)$ (Pressure)
$= 3.6*1{,}678 / (2*1{,}380*1.20*0.85 + .40*|3.6|)$
$= 2.14$ mm

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c) * MetricFactor$ (bending)
$= 51{,}607.6 / (\pi*1{,}683.5^2*1{,}380*1.20*0.85) * 98066.5$
$= .4$ mm

$t_w = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$ (Weight)
$= 0.60*66{,}401.7 / (2*\pi*1{,}683.5*1{,}380*1.20*0.85) * 98.0665$
$= .26$ mm

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 2.14 + .4 - (.26)$
$=$ 2.29 mm

$t_{wc} = W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$ (Weight)
$= 66{,}401.7 / (2*\pi*1{,}683.5*1{,}380*1.20*0.85) * 98.0665$
$= .44$ mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |.4 + (.44) - (2.14)|$
$=$ 1.3 mm

Operating, Hot & New, Wind, Bottom Seam

$t_p = P*R / (2*S_t*K_s*E_c + .40*|P|)$ (Pressure)
$= 3.6*1{,}675 / (2*1{,}380*1.20*0.85 + .40*|3.6|)$
$= 2.14$ mm

$t_m = M / (\pi*R_m^2*S_t*K_s*E_c) * MetricFactor$ (bending)
$= 51{,}607.6 / (\pi*1{,}682^2*1{,}380*1.20*0.85) * 98066.5$
$= .4$ mm

$t_w = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$ (Weight)

= 0.60*66,401.7 / (2*π*1,682*1,380*1.20*0.85) * 98.0665
= .26 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 2.14 + .4 - (.26)
= 2.28 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 66,401.7 / (2*π*1,682*1,380*1.20*0.85) * 98.0665
= .44 mm

t_c = |$t_{mc} + t_{wc} - t_{pc}$| (total, net tensile)
= |.4 + (.44) - (2.14)|
= 1.3 mm

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	51,607.6 / (π*1,683.5^2*1,380*1.20*0.85) * 98066.5	
	=	.4 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*66,401.7 / (2*π*1,683.5*1,380*1.20*0.85) * 98.0665	
	=	.26 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .4 - (.26)	
	=	.14 mm	
t_{mc}	=	M / (π*R_m^{2}*S_c*K_s) * MetricFactor	(bending)
	=	51,607.6 / (π*1,683.5^2*720.1*1.20) * 98066.5	
	=	.66 mm	
t_{wc}	=	W / (2*π*R_m*S_c*K_s) * MetricFactor	(Weight)
	=	66,401.7 / (2*π*1,683.5*720.1*1.20) * 98.0665	
	=	.71 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.66 + (.71) - ()	
	=	1.37 mm	

Hot Shut Down, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	51,607.6 / (π*1,682^2*1,380*1.20*0.85) * 98066.5	
	=	.4 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*66,401.7 / (2*π*1,682*1,380*1.20*0.85) * 98.0665	
	=	.26 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .4 - (.26)	

	=	.14 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s) * MetricFactor$	(bending)
	=	$51,607.6 / (\pi*1,682^2*775.35*1.20) * 98066.5$	
	=	.61 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s) * MetricFactor$	(Weight)
	=	$66,401.7 / (2*\pi*1,682*775.35*1.20) * 98.0665$	
	=	.66 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.61 + (.66) - ()	
	=	1.27 mm	

Empty, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c) * MetricFactor$	(bending)
	=	$51,607.6 / (\pi*1,683.5^2*1,380*1.20*0.85) * 98066.5$	
	=	.4 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$	(Weight)
	=	$0.60*52,953.8 / (2*\pi*1,683.5*1,380*1.20*0.85) * 98.0665$	
	=	.21 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .4 - (.21)	
	=	.19 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s) * MetricFactor$	(bending)
	=	$51,607.6 / (\pi*1,683.5^2*790.09*1.20) * 98066.5$	
	=	.6 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s) * MetricFactor$	(Weight)
	=	$52,953.8 / (2*\pi*1,683.5*790.09*1.20) * 98.0665$	
	=	.52 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.6 + (.52) - ()	
	=	1.12 mm	

Empty, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c) * MetricFactor$	(bending)
	=	$51,607.6 / (\pi*1,682^2*1,380*1.20*0.85) * 98066.5$	
	=	.4 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c) * MetricFactor$	(Weight)
	=	$0.60*52,953.8 / (2*\pi*1,682*1,380*1.20*0.85) * 98.0665$	
	=	.21 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .4 - (.21)	
	=	.2 mm	

t_{mc} = $M / (\pi * R_m{}^2 * S_c * K_s)$ * MetricFactor (bending)
= 51,607.6 / (π*1,682²*856.48*1.20) * 98066.5
= .55 mm

t_{wc} = $W / (2*\pi * R_m * S_c * K_s)$ * MetricFactor (Weight)
= 52,953.8 / (2*π*1,682*856.48*1.20) * 98.0665
= .48 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .55 + (.48) - ()
= 1.03 mm

Vacuum, Wind, Bottom Seam

t_p = P*R / (2*S_c*K_s + .40*|P|) (Pressure)
= -1.03*1,678 / (2*755.63*1.20 + .40*|1.03|)
= -.95 mm

t_m = $M / (\pi * R_m{}^2 * S_c * K_s)$ * MetricFactor (bending)
= 51,607.6 / (π*1,683.5²*755.63*1.20) * 98066.5
= .63 mm

t_w = $0.6*W / (2*\pi * R_m * S_c * K_s)$ * MetricFactor (Weight)
= 0.60*66,401.7 / (2*π*1,683.5*755.63*1.20) * 98.0665
= .41 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.95 + .63 - (.41)|
= .73 mm

t_{wc} = $W / (2*\pi * R_m * S_c * K_s)$ * MetricFactor (Weight)
= 66,401.7 / (2*π*1,683.5*755.63*1.20) * 98.0665
= .68 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .63 + (.68) - (-.95)
= 2.26 mm

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

t_p = mm (Pressure)

t_m = $M / (\pi * R_m{}^2 * S_c * K_s)$ * MetricFactor (bending)
= 7,985.9 / (π*1,683.5²*720.1*1.00) * 98066.5
= .12 mm

t_w = $W / (2*\pi * R_m * S_c * K_s)$ * MetricFactor (Weight)
= 66,401.7 / (2*π*1,683.5*720.1*1.00) * 98.0665
= .85 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= | + .12 - (.85)|
= .73 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .12 + (.85) - ()

= .98 mm

Operating, Hot & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*0.85 + .40*|3.6|)
= 2.14 mm

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor (bending)
= 86,673.6 / (π*1,683.5^2*1,380*1.20*0.85) * 98066.5
= .68 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*66,401.7 / (2*π*1,683.5*1,380*1.20*0.85) * 98.0665
= .26 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 2.14 + .68 - (.26)
= 2.56 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 66,401.7 / (2*π*1,683.5*1,380*1.20*0.85) * 98.0665
= .44 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.68 + (.44) - (2.14)|
= 1.03 mm

Empty, Cold & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = mm (Pressure)

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor (bending)
= 109,243.9 / (π*1,683.5^2*1,380*1.20*0.85) * 98066.5
= .85 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*52,953.8 / (2*π*1,683.5*1,380*1.20*0.85) * 98.0665
= .21 mm

t_t = t_p + t_m - t_w (total required, tensile)
= + .85 - (.21)
= .65 mm

t_{mc} = M / (π*R_m^{2}*S_c*K_s) * MetricFactor (bending)
= 109,243.9 / (π*1,683.5^2*790.09*1.20) * 98066.5
= 1.27 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 52,953.8 / (2*π*1,683.5*790.09*1.20) * 98.0665
= .52 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 1.27 + (.52) - ()
= 1.79 mm

Vacuum, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_c*K_s + .40*|P|) (Pressure)
= -1.03*1,678 / (2*755.63*1.20 + .40*|1.03|)
= -.95 mm

t_m = M / (π*R_m^2*S_c*K_s) * MetricFactor (bending)
= 86,714.9 / (π*1,683.5^2*755.63*1.20) * 98066.5
= 1.05 mm

t_w = 0.6*W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 0.60*66,401.7 / (2*π*1,683.5*755.63*1.20) * 98.0665
= .41 mm

t_t = |t_p + t_m - t_w| (total, net compressive)
= |-.95 + 1.05 - (.41)|
= .31 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 66,401.7 / (2*π*1,683.5*755.63*1.20) * 98.0665
= .68 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 1.05 + (.68) - (-.95)
= 2.69 mm

New shell

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	Yes	Yes	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		3.6	202	17
External		1.03	175	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Test vertical		2.3	23,454.5	1
Dimensions				
Inner Diameter		3,350 mm		
Length		3,030 mm		
Nominal Thickness		25 mm		
Corrosion	**Inner**	3 mm		
	Outer	0 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		6,291.21		26,706.82
Corroded		6,291.21		26,802.56
Insulation				
		Thickness (mm)	**Density (kg/m^3)**	**Weight (kg)**
Insulation		75	150	372.13
		Spacing(mm)	**Individual Weight (kg)**	**Total Weight (kg)**
Insulation Supports		3,000	100	100
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Spot UW-11(b) Type 1		
Bottom Circumferential seam		Full UW-11(a) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	8.16 mm
Design thickness due to external pressure (t_e)	10.79 mm
Design thickness due to combined loadings + corrosion	5.71 mm
Maximum allowable external pressure (MAEP)	8 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
t_r = 3.6*1,678 / (1,380*.85 - 0.6*3.6) =	5.16 mm
Stress ratio = t_r*E^* / (t_n - c) = 5.16*0.85 / (25 - 3) =	0.1993
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Design thickness, (at 202 °C) UG-27(c)(1)

t = P*R / (S*E - .60*P) + Corrosion
= 3.6*1,678 / (1,380*0.85 - .60*3.6) + 3
= 8.16 mm

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 1,500 / 3,400 = 0.4412
D_o / t = 3,400 / 7.79 = 436.2676

From table G: A = 0.000346
From table CS-2 Metric: B = 343.6619 kg/cm^2 (337.02 bar)

P_a = 4*B / (3*(D_o / t))
= 4*337.02 / (3*(3,400 / 7.79))
= 1.03 bar

Design thickness for external pressure P_a = 1.03 bar

t_a = t + Corrosion = 7.79 + 3 = 10.79 mm

Maximum Allowable External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 1,500 / 3,400 = 0.4412
D_o / t = 3,400 / 22 = 154.5436

From table G: A = 0.001688
From table CS-2 Metric: B = 946.1129 kg/cm^2 (927.8182 bar)

P_a = 4*B / (3*(D_o / t))
= 4*927.82 / (3*(3,400 / 22))
= 8 bar

% Extreme fiber elongation - UCS-79(d)

EFE = $(50^*t / R_f)^*(1 - R_f / R_o)$
= (50*25 / 1,687.5)*(1 - 1,687.5 / infinity)
= 0.7407%

The extreme fiber elongation does not exceed 5%.

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

P_v = $W / (2^*\pi^*R_m) + M / (\pi^*R_m{}^2)$
= $10^*100{,}390.6 / (2^*\pi^*1{,}689) + 10000^*65{,}679.7 / (\pi^*1{,}689^2)$
= 167.8845 kg/cm
α = $P_v / (P_e{}^*D_o)$
= 9.803*167.8845 / (1.03*3,400)
= .4701
n = 8
m = $1.23 / (L / D_o)^2$
= $1.23 / (1{,}500 / 3{,}400)^2$
= 6.3195
Ratio P_e = $(n^2 - 1 + m + m^*\alpha) / (n^2 - 1 + m)$
= $(8^2 - 1 + 6.3195 + 6.3195^*.4701) / (8^2 - 1 + 6.3195)$
= 1.0429
Ratio P_e * P_e ≤ MAEP
(1.0429 * 1.03 = 1.07) ≤ 8

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm^2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	3.6	1,407.2	880.7	202	3	Wind	1.92	.83
Operating, Hot & New	3.6	1,407.2	908.4	202		Wind	1.92	.82
Hot Shut Down, Corroded		1,407.2	880.7	202	3	Wind	.1	1.59
Hot Shut Down, New		1,407.2	908.4	202		Wind	.1	1.54
Empty, Corroded		1,407.2	989.6	13	3	Wind	.15	1.29
Empty, New		1,407.2	1,025.8	13		Wind	.15	1.25
Vacuum	-1.03	1,407.2	935.7	175	3	Wind	.64	2.28
Hot Shut Down, Corroded, Weight & Eccentric Moments Only		1,407.2	880.7	202	3	Weight	.97	1.18
Operating, Hot & Corroded, Vortex Shedding	3.6	1,407.2	880.7	202	3	Wind	2.2	.55
Empty, Cold & Corroded, Vortex Shedding		1,407.2	989.6	13	3	Wind	.61	1.95
Vacuum, Vortex Shedding	-1.03	1,407.2	935.7	175	3	Wind	.21	2.71

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

A = .125 / (R_o / t)
= .125 / (1,700 / 22)
= 0.001618

B = 880.7 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHC} = min(B, S) = 880.7 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,700 / 25)
= 0.001838

B = 908.4 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHN} = min(B, S) = 908.4 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,700 / 25)
= 0.001838

B = 1,025.8 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cCN} = min(B, S) = 1,025.8 kg/cm^2

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

$A = .125 / (R_o / t)$
$= .125 / (1{,}700 / 22)$
$= 0.001618$

$B = 989.6\ kg/cm^2$

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

$S_{cCC} = \min(B, S) =$ 989.6 kg/cm^2

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

$A = .125 / (R_o / t)$
$= .125 / (1{,}700 / 22)$
$= 0.001618$

$B = 935.7\ kg/cm^2$

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

$S_{cVC} = \min(B, S) =$ 935.7 kg/cm^2

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = P*R / (2*S_t*K_s*E_c + .40*|P|)$ (Pressure)
$= 3.6*1{,}678 / (2*1{,}380*1.20*1.00 + .40*|3.6|)$
$= 1.82$ mm

$t_m = M / (\pi*R_m{}^2*S_t*K_s*E_c) *$ MetricFactor (bending)
$= 65{,}679.7 / (\pi*1{,}689^2*1{,}380*1.20*1.00) * 98066.5$
$= .43$ mm

$t_w = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c) *$ MetricFactor (Weight)
$= 0.60*100{,}390.6 / (2*\pi*1{,}689*1{,}380*1.20*1.00) * 98.0665$
$= .34$ mm

$t_t = t_p + t_m - t_w$ (total required, tensile)
$= 1.82 + .43 - (.34)$
$=$ 1.92 mm

$t_{wc} = W / (2*\pi*R_m*S_t*K_s*E_c) *$ MetricFactor (Weight)
$= 100{,}390.6 / (2*\pi*1{,}689*1{,}380*1.20*1.00) * 98.0665$
$= .56$ mm

$t_c = |t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
$= |.43 + (.56) - (1.82)|$
$=$ .83 mm

Operating, Hot & New, Wind, Bottom Seam

$t_p = P*R / (2*S_t*K_s*E_c + .40*|P|)$ (Pressure)
$= 3.6*1{,}675 / (2*1{,}380*1.20*1.00 + .40*|3.6|)$
$= 1.82$ mm

$t_m = M / (\pi*R_m{}^2*S_t*K_s*E_c) *$ MetricFactor (bending)
$= 65{,}679.7 / (\pi*1{,}687.5^2*1{,}380*1.20*1.00) * 98066.5$
$= .43$ mm

$t_w = 0.6*W / (2*\pi*R_m*S_t*K_s*E_c) *$ MetricFactor (Weight)

= 0.60*100,390.6 / (2*π*1,687.5*1,380*1.20*1.00) * 98.0665
= .34 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 1.82 + .43 - (.34)
= 1.92 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 100,390.6 / (2*π*1,687.5*1,380*1.20*1.00) * 98.0665
= .56 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |.43 + (.56) - (1.82)|
= .82 mm

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	65,679.7 / (π*1,689^2*1,380*1.20*1.00) * 98066.5	
	=	.43 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*100,390.6 / (2*π*1,689*1,380*1.20*1.00) * 98.0665	
	=	.34 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .43 - (.34)	
	=	.1 mm	
t_{mc}	=	M / (π*R_m^{2}*S_c*K_s) * MetricFactor	(bending)
	=	65,679.7 / (π*1,689^2*863.65*1.20) * 98066.5	
	=	.69 mm	
t_{wc}	=	W / (2*π*R_m*S_c*K_s) * MetricFactor	(Weight)
	=	100,390.6 / (2*π*1,689*863.65*1.20) * 98.0665	
	=	.9 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.69 + (.9) - ()	
	=	1.59 mm	

Hot Shut Down, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	65,679.7 / (π*1,687.5^2*1,380*1.20*1.00) * 98066.5	
	=	.43 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*100,390.6 / (2*π*1,687.5*1,380*1.20*1.00) * 98.0665	
	=	.34 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .43 - (.34)	

	=	.1 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor	(bending)
	=	65,679.7 / (π*1,687.5^2*890.79*1.20) * 98066.5	
	=	.67 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	100,390.6 / (2*π*1,687.5*890.79*1.20) * 98.0665	
	=	.87 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.67 + (.87) - ()	
	=	1.54 mm	

Empty, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	65,679.7 / (π*1,689^2*1,380*1.20*1.00) * 98066.5	
	=	.43 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	0.60*85,084.5 / (2*π*1,689*1,380*1.20*1.00) * 98.0665	
	=	.28 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .43 - (.28)	
	=	.15 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor	(bending)
	=	65,679.7 / (π*1,689^2*970.49*1.20) * 98066.5	
	=	.62 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	85,084.5 / (2*π*1,689*970.49*1.20) * 98.0665	
	=	.68 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	.62 + (.68) - ()	
	=	1.29 mm	

Empty, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	65,679.7 / (π*1,687.5^2*1,380*1.20*1.00) * 98066.5	
	=	.43 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	0.60*85,084.5 / (2*π*1,687.5*1,380*1.20*1.00) * 98.0665	
	=	.29 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .43 - (.29)	
	=	.15 mm	

t_{mc} = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= $65,679.7 / (\pi*1,687.5^2*1,005.92*1.20) * 98066.5$
= .6 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $85,084.5 / (2*\pi*1,687.5*1,005.92*1.20) * 98.0665$
= .65 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .6 + (.65) - ()
= 1.25 mm

Vacuum, Wind, Bottom Seam

t_p = $P*R / (2*S_c*K_s + .40*|P|)$ (Pressure)
= $-1.03*1,678 / (2*917.57*1.20 + .40*|1.03|)$
= -.78 mm

t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= $65,679.7 / (\pi*1,689^2*917.57*1.20) * 98066.5$
= .65 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $0.60*100,390.6 / (2*\pi*1,689*917.57*1.20) * 98.0665$
= .51 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.78 + .65 - (.51)|
= .64 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $100,390.6 / (2*\pi*1,689*917.57*1.20) * 98.0665$
= .84 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .65 + (.84) - (-.78)
= 2.28 mm

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

t_p = mm (Pressure)
t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= $7,985.9 / (\pi*1,689^2*863.65*1.00) * 98066.5$
= .1 mm

t_w = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $100,390.6 / (2*\pi*1,689*863.65*1.00) * 98.0665$
= 1.07 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= | + .1 - (1.07)|
= .97 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .1 + (1.07) - ()

= 1.18 mm

Operating, Hot & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*$R_m^{2*}S_t$*K_s*E_c) * MetricFactor (bending)
= 108,449.3 / (π*1,689²*1,380*1.20*1.00) * 98066.5
= .72 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*100,390.6 / (2*π*1,689*1,380*1.20*1.00) * 98.0665
= .34 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .72 - (.34)
= 2.2 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 100,390.6 / (2*π*1,689*1,380*1.20*1.00) * 98.0665
= .56 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.72 + (.56) - (1.82)|
= .55 mm

Empty, Cold & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*$R_m^{2*}S_t$*K_s*E_c) * MetricFactor	(bending)
	=	136,021.8 / (π*1,689²*1,380*1.20*1.00) * 98066.5	
	=	.9 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*85,084.5 / (2*π*1,689*1,380*1.20*1.00) * 98.0665	
	=	.28 mm	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	+ .9 - (.28)	
	=	.61 mm	
t_{mc}	=	M / (π*$R_m^{2*}S_c$*K_s) * MetricFactor	(bending)
	=	136,021.8 / (π*1,689²*970.49*1.20) * 98066.5	
	=	1.28 mm	
t_{wc}	=	W / (2*π*R_m*S_c*K_s) * MetricFactor	(Weight)
	=	85,084.5 / (2*π*1,689*970.49*1.20) * 98.0665	
	=	.68 mm	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	1.28 + (.68) - ()	
	=	1.95 mm	

Vacuum, Vortex Shedding, Wind, Bottom Seam

t_p = $P*R / (2*S_c*K_s + .40*|P|)$ (Pressure)
= -1.03*1,678 / (2*917.57*1.20 + .40*|1.03|)
= -.78 mm

t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= 108,499.8 / (π*1,689^2*917.57*1.20) * 98066.5
= 1.08 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= 0.60*100,390.6 / (2*π*1,689*917.57*1.20) * 98.0665
= .51 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.78 + 1.08 - (.51)|
= .21 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= 100,390.6 / (2*π*1,689*917.57*1.20) * 98.0665
= .84 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 1.08 + (.84) - (-.78)
= 2.71 mm

Bottom existing shell

1

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	Yes	Yes	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		3.6	202	17
External		1.06	175	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.27	2,562	1.065
Test vertical		2.92	29,826.5	1
Dimensions				
Inner Diameter		3,350 mm		
Length		6,372 mm		
Nominal Thickness		14 mm		
Corrosion	**Inner**	0 mm		
	Outer	0 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		7,273.08		55,962.64
Corroded		7,273.08		55,962.64
Insulation\Lining				
		Thickness (mm)	**Density (kg/m³)**	**Weight (kg)**
Lining		3	8,027	1,613.45
Insulation		75	150	777.63
		Spacing(mm)	**Individual Weight (kg)**	**Total Weight (kg)**
Insulation Supports		3,000	100	200
Radiography				
Longitudinal seam		Spot UW-11(b) Type 1		
Top Circumferential seam		Full UW-11(a) Type 1		
Bottom Circumferential seam		Full UW-11(a) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + mm = 1.5 mm
Design thickness due to internal pressure (t)	5.53 mm
Design thickness due to external pressure (t_e)	9.28 mm
Design thickness due to combined loadings + corrosion	3.82 mm
Maximum allowable external pressure (MAEP)	2.91 bar
Rated MDMT	-105 °C

UCS-66 Material Toughness Requirements	
t_r = 3.87*1,675 / (1,380*.85 - 0.6*3.87) =	5.53 mm
Stress ratio = t_r*E^* / (t_n - c) = 5.53*0.85 / (14 - 0) =	0.336
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Design thickness, (at 202 °C) UG-27(c)(1)

t = P*R / (S*E - .60*P) + Corrosion
= 3.87*1,675 / (1,380*0.85 - .60*3.87) +
= 5.53 mm

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,280.17 / 3,378 = 0.6750
D_o / t = 3,378 / 9.28 = 363.9740

From table G: A = 0.000296
From table CS-2 Metric: B = 293.6728 kg/cm^2 (287.99 bar)

P_a = 4*B / (3*(D_o / t))
= 4*287.99 / (3*(3,378 / 9.28))
= 1.05 bar

Design thickness for external pressure P_a = 1.05 bar

t_a = t + Corrosion = 9.28 + = 9.28 mm

Maximum Allowable External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,280.17 / 3,378 = 0.6750
D_o / t = 3,378 / 14 = 241.2857

From table G: A = 0.000541
From table CS-2 Metric: B = 537.7881 kg/cm^2 (527.389 bar)

P_a = 4*B / (3*(D_o / t))
= 4*527.39 / (3*(3,378 / 14))
= 2.91 bar

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*14 / 1,682)*(1 - 1,682 / infinity)
= 0.4162%

The extreme fiber elongation does not exceed 5%.

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

P_v = $W / (2*\pi*R_m) + M / (\pi*R_m^2)$
= $10*114{,}803.6 / (2*\pi*1{,}682) + 10000*103{,}236.4 / (\pi*1{,}682^2)$
= 224.7830 kg/cm
α = $P_v / (P_e*D_o)$
= 9.803*224.783 / (1.06*3,378)
= .6185
n = 8
m = $1.23 / (L / D_o)^2$
= $1.23 / (2{,}280.17 / 3{,}378)^2$
= 2.6995
Ratio P_e = $(n^2 - 1 + m + m*\alpha) / (n^2 - 1 + m)$
= $(8^2 - 1 + 2.6995 + 2.6995*.6185) / (8^2 - 1 + 2.6995)$
= 1.0254
Ratio $P_e * P_e$ ≤ MAEP
(1.0254 * 1.06 = 1.08) ≤ 2.91
Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	3.6	1,407.2	790.6	202		Wind	2.12	.49
Operating, Hot & New	3.6	1,407.2	790.6	202		Wind	2.12	.49
Hot Shut Down, Corroded		1,407.2	790.6	202		Wind	.3	2.37
Hot Shut Down, New		1,407.2	790.6	202		Wind	.3	2.37
Empty, Corroded		1,407.2	873.4	13		Wind	.35	2.01
Empty, New		1,407.2	873.4	13		Wind	.35	2.01
Vacuum	-1.06	1,407.2	832.6	175		Wind	.39	3.15
Hot Shut Down, Corroded, Weight & Eccentric Moments Only		1,407.2	790.6	202		Weight	1.23	1.51
Operating, Hot & Corroded, Vortex Shedding	3.6	1,407.2	790.6	202		Wind	2.51	.1
Empty, Cold & Corroded, Vortex Shedding		1,407.2	873.4	13		Wind	1	3.05
Vacuum, Vortex Shedding	-1.06	1,407.2	832.6	175		Wind	.16	3.82

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

$A = .125 / (R_o / t)$
$= .125 / (1,689 / 14)$
$= 0.001036$

$B = 790.6\ kg/cm^2$

$S = 1,407.2 / 1.00 = 1,407.2\ kg/cm^2$

$S_{cHC} = \min(B, S) = 790.6\ kg/cm^2$

Allowable Compressive Stress, Hot and New- S_{cHN}

$S_{cHN} = S_{cHC}$
$= 790.6\ kg/cm^2$

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

$A = .125 / (R_o / t)$
$= .125 / (1,689 / 14)$
$= 0.001036$

$B = 873.4\ kg/cm^2$

$S = 1,407.2 / 1.00 = 1,407.2\ kg/cm^2$

$S_{cCN} = \min(B, S) = 873.4\ kg/cm^2$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$S_{cCC} = S_{cCN}$
$= 873.4\ kg/cm^2$

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

A = .125 / (R_o / t)
= .125 / (1,689 / 14)
= 0.001036

B = 832.6 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cVC} = min(B, S) = 832.6 kg/cm^2

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,675 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor (bending)
= 103,236.4 / (π*1,682^2*1,380*1.20*1.00) * 98066.5
= .69 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .69 - (.39)
= 2.12 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .64 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.69 + (.64) - (1.82)|
= .49 mm

Operating, Hot & New, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,675 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor (bending)
= 103,236.3 / (π*1,682^2*1,380*1.20*1.00) * 98066.5
= .69 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .69 - (.39)
= 2.12 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .64 mm

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

= |.69 + (.64) - (1.82)|
= .49 mm

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	103,236.4 / (π*1,682^2*1,380*1.20*1.00) * 98066.5	
	=	.69 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665	
	=	.39 mm	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	+ .69 - (.39)	
	=	.3 mm	
t_{mc}	=	M / (π*R_m^{2}*S_c*K_s) * MetricFactor	(bending)
	=	103,236.4 / (π*1,682^2*775.35*1.20) * 98066.5	
	=	1.22 mm	
t_{wc}	=	W / (2*π*R_m*S_c*K_s) * MetricFactor	(Weight)
	=	114,803.6 / (2*π*1,682*775.35*1.20) * 98.0665	
	=	1.14 mm	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	1.22 + (1.14) - ()	
	=	2.37 mm	

Hot Shut Down, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor	(bending)
	=	103,236.3 / (π*1,682^2*1,380*1.20*1.00) * 98066.5	
	=	.69 mm	
t_w	=	0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor	(Weight)
	=	0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665	
	=	.39 mm	
t_t	=	t_p + t_m - t_w	(total required, tensile)
	=	+ .69 - (.39)	
	=	.3 mm	
t_{mc}	=	M / (π*R_m^{2}*S_c*K_s) * MetricFactor	(bending)
	=	103,236.3 / (π*1,682^2*775.35*1.20) * 98066.5	
	=	1.22 mm	
t_{wc}	=	W / (2*π*R_m*S_c*K_s) * MetricFactor	(Weight)
	=	114,803.6 / (2*π*1,682*775.35*1.20) * 98.0665	
	=	1.14 mm	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	1.22 + (1.14) - ()	

	=	2.37 mm	

Empty, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	103,236.4 / (π*1,682^2*1,380*1.20*1.00) * 98066.5	
	=	.69 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	0.60*99,497.4 / (2*π*1,682*1,380*1.20*1.00) * 98.0665	
	=	.33 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .69 - (.33)	
	=	.35 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor	(bending)
	=	103,236.4 / (π*1,682^2*856.48*1.20) * 98066.5	
	=	1.11 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	99,497.4 / (2*π*1,682*856.48*1.20) * 98.0665	
	=	.9 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.11 + (.9) - ()	
	=	2.01 mm	

Empty, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	103,236.3 / (π*1,682^2*1,380*1.20*1.00) * 98066.5	
	=	.69 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	0.60*99,497.4 / (2*π*1,682*1,380*1.20*1.00) * 98.0665	
	=	.33 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .69 - (.33)	
	=	.35 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor	(bending)
	=	103,236.3 / (π*1,682^2*856.48*1.20) * 98066.5	
	=	1.11 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	99,497.4 / (2*π*1,682*856.48*1.20) * 98.0665	
	=	.9 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.11 + (.9) - ()	
	=	2.01 mm	

Vacuum, Wind, Bottom Seam

t_p = $P*R / (2*S_c*K_s + .40*|P|)$ (Pressure)
= -1.06*1,675 / (2*816.47*1.20 + .40*|1.05|)
= -.9 mm

t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= 103,236.4 / (π*1,682^2*816.47*1.20) * 98066.5
= 1.16 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= 0.60*114,803.6 / (2*π*1,682*816.47*1.20) * 98.0665
= .65 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.9 + 1.16 - (.65)|
= .39 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= 114,803.6 / (2*π*1,682*816.47*1.20) * 98.0665
= 1.09 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 1.16 + (1.09) - (-.9)
= 3.15 mm

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

t_p = mm (Pressure)
t_m = $M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor (bending)
= 9,844.6 / (π*1,682^2*775.35*1.00) * 98066.5
= .14 mm

t_w = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= 114,803.6 / (2*π*1,682*775.35*1.00) * 98.0665
= 1.37 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= | + .14 - (1.37)|
= 1.23 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= .14 + (1.37) - ()
= 1.51 mm

Operating, Hot & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = $P*R / (2*S_t*K_s*E_c + .40*|P|)$ (Pressure)
= 3.6*1,675 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = $M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor (bending)
= 162,206.4 / (π*1,682^2*1,380*1.20*1.00) * 98066.5
= 1.08 mm

t_w = $0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor (Weight)
= 0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665

= .39 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 1.82 + 1.08 - (.39)
= 2.51 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .64 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |1.08 + (.64) - (1.82)|
= .1 mm

Empty, Cold & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = mm (Pressure)
t_m = M / (π*R_m^2*S_t*K_s*E_c) * MetricFactor (bending)
= 200,298.2 / (π*1,682²*1,380*1.20*1.00) * 98066.5
= 1.33 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*99,497.4 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .33 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= + 1.33 - (.33)
= 1 mm

t_{mc} = M / (π*R_m^2*S_c*K_s) * MetricFactor (bending)
= 200,298.2 / (π*1,682²*856.48*1.20) * 98066.5
= 2.15 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)
= 99,497.4 / (2*π*1,682*856.48*1.20) * 98.0665
= .9 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 2.15 + (.9) - ()
= 3.05 mm

Vacuum, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= -1.06*1,675 / (2*1,380*1.20*1.00 + .40*|1.05|)
= -.53 mm

t_m = M / (π*R_m^2*S_t*K_s*E_c) * MetricFactor (bending)
= 162,276.2 / (π*1,682²*1,380*1.20*1.00) * 98066.5
= 1.08 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*114,803.6 / (2*π*1,682*1,380*1.20*1.00) * 98.0665
= .39 mm

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

	=	-.53 + 1.08 - (.39)	
	=	.16 mm	
t_{pc}	=	$P*R / (2*S_c*K_s + .40*\|P\|)$	(Pressure)
	=	$-1.06*1{,}675 / (2*816.47*1.20 + .40*\|1.05\|)$	
	=	-.9 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s) * MetricFactor$	(bending)
	=	$162{,}276.2 / (\pi*1{,}682^2*816.47*1.20) * 98066.5$	
	=	1.83 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s) * MetricFactor$	(Weight)
	=	$114{,}803.6 / (2*\pi*1{,}682*816.47*1.20) * 98.0665$	
	=	1.09 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.83 + (1.09) - (-.9)	
	=	3.82 mm	

Bottom Head 1

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Ellipsoidal Head		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
Attached To		Bottom existing shell		
Impact Tested	Normalized	Fine Grain Practice	PWHT	Maximize MDMT/ No MAWP
No	No	Yes	Yes	No
		Design Pressure (bar)	Design Temperature (°C)	Design MDMT (°C)
Internal		3.6	202	17
External		1.03	175	
Static Liquid Head				
Condition		P_s (bar)	H_s (mm)	SG
Operating		0.36	3,440.5	1.065
Test vertical		3.01	30,702	1
Dimensions				
Inner Diameter		3,350 mm		
Head Ratio		2		
Minimum Thickness		12.4 mm		
Corrosion	Inner	3 mm		
	Outer	0 mm		
Length L_{sf}		38 mm		
Nominal Thickness t_{sf}		15 mm		
Weight and Capacity				
		Weight (kg)[1]		Capacity (liters)[1]
New		1,301.88		5,219.78
Corroded		1,301.88		5,219.78
Insulation\Lining				
		Thickness (mm)	Density (kg/m^3)	Weight (kg)
Lining		3	8,027	291.99
Insulation		75	150	146.9
		Spacing(mm)	Individual Weight (kg)	Total Weight (kg)
Insulation Supports		3,000	100	100
Radiography				
Category A joints		Full UW-11(a) Type 1		

Head to shell seam	Full UW-11(a) Type 1

[1] includes straight flange

Results Summary	
Governing condition	external pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	7.81 mm
Design thickness due to external pressure (t_e)	11.78 mm
Maximum allowable external pressure (MAEP)	1.18 bar
Rated MDMT	-48°C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	12.4 mm
Exemption temperature from Fig UCS-66M Curve B =	-22.56°C
t_r = 3.96*3,356*0.997623 / (2*1,380*1 - 0.2*3.96) =	4.8 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.8*1 / (12.4 - 3) =	0.511
Reduction in MDMT, T_R from Fig UCS-66.1M =	30.5°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-22.56 - 30.5 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Factor K		
K = (1/6)*[2 + (D / (2*h))^2]		
Corroded	K = (1/6)*[2 + (3,356 / (2*840.5))^2]	0.9976
New	K = (1/6)*[2 + (3,350 / (2*837.5))^2]	1

Design thickness for internal pressure, (Corroded at 202 °C) Appendix 1-4(c)

t = P*D*K / (2*S*E - 0.2*P) + Corrosion
= 3.96*3,356*0.997623 / (2*1,380*1 - 0.2*3.96) + 3
= 7.8 mm

Design thickness for external pressure, (Corroded at 175 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8934*3,374.8
= 3,015.16 mm

A = 0.125 / (R_o / t)
= 0.125 / (3,015.16 / 8.77)
= 0.000364

From Table CS-2 Metric: B = 360.9567 kg_f/cm^2

P_a = $B / (R_o / t)$
= 353.9779 / (3,015.16 / 8.77)
= 1.03 bar

t = 8.77 mm + Corrosion = 8.77 mm + 3 mm = 11.77 mm
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*1.03*3,356*0.997623 / (2*1,380*1 - 0.2*1.67*1.03) + 3
= 5.09 mm

The head external pressure design thickness (t_e) is 11.77 mm.

Maximum Allowable External Pressure, (Corroded at 175 °C) UG-33(d)

Equivalent outside spherical radius (R_o)
R_o = K_o*D_o
= 0.8934*3,374.8
= 3,015.16 mm

A = $0.125 / (R_o / t)$
= 0.125 / (3,015.16 / 9.4)
= 0.00039

From Table CS-2 Metric: B = 386.9029 kg_f/cm^2

P_a = $B / (R_o / t)$
= 379.4224 / (3,015.16 / 9.4)
= 1.1829 bar

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*1,380*1*9.4 / ((0.997623*3,356 +0.2*9.4)*1.67)
= 4.64 bar

The maximum allowable external pressure (MAEP) is 1.18 bar.

% Extreme fiber elongation - UCS-79(d)

EFE = $(75*t / R_f)*(1 - R_f / R_o)$
= (75*15 / 577)*(1 - 577 / infinity)
= 1.9497%

The extreme fiber elongation does not exceed 5%.

Straight Flange on Bottom Head 1

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Cylinder		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	Yes	Yes	No
		Design Pressure (bar)	**Design Temperature (°C)**	**Design MDMT (°C)**
Internal		3.6	202	17
External		1.03	175	
Static Liquid Head				
Condition		**P_s (bar)**	**H_s (mm)**	**SG**
Operating		0.27	2,600	1.065
Test vertical		2.93	29,864.5	1
Dimensions				
Inner Diameter		3,350 mm		
Length		38 mm		
Nominal Thickness		15 mm		
Corrosion	**Inner**	3 mm		
	Outer	0 mm		
Weight and Capacity				
		Weight (kg)		**Capacity (liters)**
New		47.2		333.74
Corroded		47.2		333.74
Insulation\Lining				
		Thickness (mm)	**Density (kg/m^3)**	**Weight (kg)**
Lining		3	8,027	0
Insulation		75	150	0
		Spacing(mm)	**Individual Weight (kg)**	**Total Weight (kg)**
Insulation Supports		0	0	0
Radiography				
Longitudinal seam		Full UW-11(a) Type 1		
Top Circumferential seam		Full UW-11(a) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	1.5 mm + 3 mm = 4.5 mm
Design thickness due to internal pressure (t)	7.72 mm
Design thickness due to external pressure (t_e)	12.2 mm
Design thickness due to combined loadings + corrosion	7 mm
Maximum allowable external pressure (MAEP)	1.97 bar
Rated MDMT	-48 °C

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	15 mm
Exemption temperature from Fig UCS-66M Curve B =	-16.69°C
t_r = 3.87*1,678 / (1,380*1 - 0.6*3.87) =	4.72 mm
Stress ratio = t_r*E* / (t_n - c) = 4.72*1 / (15 - 3) =	0.3929
Reduction in MDMT, T_R from Fig UCS-66.1M =	54.5°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-16.69 - 54.5 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Design thickness, (at 202 °C) UG-27(c)(1)

t = P*R / (S*E - .60*P) + Corrosion
= 3.87*1,678 / (1,380*1.00 - .60*3.87) + 3
= 7.72 mm

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,280.17 / 3,380 = 0.6746
D_o / t = 3,380 / 9.2 = 367.3097

From table G: A = 0.000292
From table CS-2 Metric: B = 289.3419 kg/cm^2 (283.75 bar)

P_a = 4*B / (3*(D_o / t))
= 4*283.75 / (3*(3,380 / 9.2))
= 1.03 bar

Design thickness for external pressure P_a = 1.03 bar

t_a = t + Corrosion = 9.2 + 3 = 12.2 mm

Maximum Allowable External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 2,280.17 / 3,380 = 0.6746
D_o / t = 3,380 / 12 = 281.6606

From table G: A = 0.000428
From table CS-2 Metric: B = 425.2207 kg/cm^2 (416.9983 bar)

P_a = 4*B / (3*(D_o / t))
= 4*417 / (3*(3,380 / 12))
= 1.97 bar

% Extreme fiber elongation - UCS-79(d)

EFE = (50*t / R_f)*(1 - R_f / R_o)
= (50*15 / 1,682.5)*(1 - 1,682.5 / infinity)
= 0.4458%

The extreme fiber elongation does not exceed 5%.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (bar)	Allowable Stress Before UG-23 Stress Increase (kg/cm2)		Temperature (°C)	Corrosion C (mm)	Load	Req'd Thk Due to Tension (mm)	Req'd Thk Due to Compression (mm)
		S_t	S_c					
Operating, Hot & Corroded	3.6	1,407.2	751.6	202	3	Wind	2.13	.49
Operating, Hot & New	3.6	1,407.2	803.8	202		Wind	2.12	.49
Hot Shut Down, Corroded		1,407.2	751.6	202	3	Wind	.3	2.49
Hot Shut Down, New		1,407.2	803.8	202		Wind	.3	2.33
Empty, Corroded		1,407.2	826.6	13	3	Wind	.35	2.12
Empty, New		1,407.2	890.3	13		Wind	.35	1.97
Vacuum	-1.03	1,407.2	789.7	175	3	Wind	.39	3.3
Hot Shut Down, Corroded, Weight & Eccentric Moments Only		1,407.2	751.6	202	3	Weight	1.3	1.59
Operating, Hot & Corroded, Vortex Shedding	3.6	1,407.2	751.6	202	3	Wind	2.52	.1
Empty, Cold & Corroded, Vortex Shedding		1,407.2	826.6	13	3	Wind	1	3.22
Vacuum, Vortex Shedding	-1.03	1,407.2	789.7	175	3	Wind	.17	4

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888

B = 751.6 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHC} = min(B, S) = 751.6 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 15)
= 0.001109

B = 803.8 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cHN} = min(B, S) = 803.8 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 15)
= 0.001109

B = 890.3 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cCN} = min(B, S) = 890.3 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888

B = 826.6 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cCC} = min(B, S) = 826.6 kg/cm^2

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

A = .125 / (R_o / t)
= .125 / (1,690 / 12)
= 0.000888

B = 789.7 kg/cm^2

S = 1,407.2 / 1.00 = 1,407.2 kg/cm^2

S_{cVC} = min(B, S) = 789.7 kg/cm^2

Operating, Hot & Corroded, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^2*S_t*K_s*E_c) * MetricFactor (bending)
= 103,514 / (π*1,684^2*1,380*1.20*1.00) * 98066.5
= .69 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .69 - (.39)
= 2.13 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .64 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.69 + (.64) - (1.82)|
= .49 mm

Operating, Hot & New, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|)   (Pressure)
= 3.6*1,675 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor   (bending)
= 103,514 / (π*1,682.5^2*1,380*1.20*1.00) * 98066.5
= .69 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor   (Weight)
= 0.60*114,850.8 / (2*π*1,682.5*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = t_p + t_m - t_w (total required, tensile)
= 1.82 + .69 - (.39)
= 2.12 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor   (Weight)
= 114,850.8 / (2*π*1,682.5*1,380*1.20*1.00) * 98.0665
= .64 mm

t_c = |t_{mc} + t_{wc} - t_{pc}| (total, net tensile)
= |.69 + (.64) - (1.82)|
= .49 mm

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = mm   (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor   (bending)
= 103,514 / (π*1,684^2*1,380*1.20*1.00) * 98066.5
= .69 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor   (Weight)
= 0.60*114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = t_p + t_m - t_w (total required, tensile)
= + .69 - (.39)
= .3 mm

t_{mc} = M / (π*R_m^{2}*S_c*K_s) * MetricFactor   (bending)
= 103,514 / (π*1,684^2*737.05*1.20) * 98066.5
= 1.29 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor   (Weight)
= 114,850.8 / (2*π*1,684*737.05*1.20) * 98.0665
= 1.2 mm

t_c = t_{mc} + t_{wc} - t_{pc} (total required, compressive)
= 1.29 + (1.2) - ()
= 2.49 mm

Hot Shut Down, New, Wind, Bottom Seam

t_p = mm   (Pressure)
t_m = M / (π*R_m^{2}*S_t*K_s*E_c) * MetricFactor   (bending)

	=	$103{,}514 / (\pi*1{,}682.5^2*1{,}380*1.20*1.00) * 98066.5$	
	=	.69 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	$0.60*114{,}850.8 / (2*\pi*1{,}682.5*1{,}380*1.20*1.00) * 98.0665$	
	=	.39 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .69 - (.39)	
	=	.3 mm	
t_{mc}	=	$M / (\pi*R_m^2*S_c*K_s)$ * MetricFactor	(bending)
	=	$103{,}514 / (\pi*1{,}682.5^2*788.29*1.20) * 98066.5$	
	=	1.21 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	$114{,}850.8 / (2*\pi*1{,}682.5*788.29*1.20) * 98.0665$	
	=	1.13 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.21 + (1.13) - ()	
	=	2.33 mm	

Empty, Corroded, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	$103{,}514 / (\pi*1{,}684^2*1{,}380*1.20*1.00) * 98066.5$	
	=	.69 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	$0.60*99{,}544.6 / (2*\pi*1{,}684*1{,}380*1.20*1.00) * 98.0665$	
	=	.33 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	+ .69 - (.33)	
	=	.35 mm	
t_{mc}	=	$M / (\pi*R_m^2*S_c*K_s)$ * MetricFactor	(bending)
	=	$103{,}514 / (\pi*1{,}684^2*810.65*1.20) * 98066.5$	
	=	1.17 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	$99{,}544.6 / (2*\pi*1{,}684*810.65*1.20) * 98.0665$	
	=	.95 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.17 + (.95) - ()	
	=	2.12 mm	

Empty, New, Wind, Bottom Seam

t_p	=	mm	(Pressure)
t_m	=	$M / (\pi*R_m^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	$103{,}514 / (\pi*1{,}682.5^2*1{,}380*1.20*1.00) * 98066.5$	

= .69 mm

t_w = $0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor (Weight)
= $0.60*99,544.6 / (2*\pi*1,682.5*1,380*1.20*1.00)$ * 98.0665
= .33 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= + .69 - (.33)
= .35 mm

t_{mc} = $M / (\pi*R_m^2*S_c*K_s)$ * MetricFactor (bending)
= $103,514 / (\pi*1,682.5^2*873.07*1.20)$ * 98066.5
= 1.09 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $99,544.6 / (2*\pi*1,682.5*873.07*1.20)$ * 98.0665
= .88 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 1.09 + (.88) - ()
= 1.97 mm

Vacuum, Wind, Bottom Seam

t_p = $P*R / (2*S_c*K_s + .40*|P|)$ (Pressure)
= $-1.03*1,678 / (2*774.39*1.20 + .40*|1.03|)$
= -.93 mm

t_m = $M / (\pi*R_m^2*S_c*K_s)$ * MetricFactor (bending)
= $103,514 / (\pi*1,684^2*774.39*1.20)$ * 98066.5
= 1.23 mm

t_w = $0.6*W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $0.60*114,850.8 / (2*\pi*1,684*774.39*1.20)$ * 98.0665
= .69 mm

t_t = $|t_p + t_m - t_w|$ (total, net compressive)
= |-.93 + 1.23 - (.69)|
= .39 mm

t_{wc} = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $114,850.8 / (2*\pi*1,684*774.39*1.20)$ * 98.0665
= 1.15 mm

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)
= 1.23 + (1.15) - (-.93)
= 3.3 mm

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

t_p = mm (Pressure)
t_m = $M / (\pi*R_m^2*S_c*K_s)$ * MetricFactor (bending)
= $9,844.6 / (\pi*1,684^2*737.05*1.00)$ * 98066.5
= .15 mm

t_w = $W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor (Weight)
= $114,850.8 / (2*\pi*1,684*737.05*1.00)$ * 98.0665

= 1.44 mm

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

= | + .15 - (1.44)|

= 1.3 mm

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

= .15 + (1.44) - ()

= 1.59 mm

Operating, Hot & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = P*R / (2*S_t*K_s*E_c + .40*|P|) (Pressure)
= 3.6*1,678 / (2*1,380*1.20*1.00 + .40*|3.6|)
= 1.82 mm

t_m = M / (π*$R_m{}^2$*S_t*K_s*E_c) * MetricFactor (bending)
= 162,597 / (π*1,684²*1,380*1.20*1.00) * 98066.5
= 1.08 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .39 mm

t_t = $t_p + t_m - t_w$ (total required, tensile)
= 1.82 + 1.08 - (.39)
= 2.52 mm

t_{wc} = W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .64 mm

t_c = $|t_{mc} + t_{wc} - t_{pc}|$ (total, net tensile)
= |1.08 + (.64) - (1.82)|
= .1 mm

Empty, Cold & Corroded, Vortex Shedding, Wind, Bottom Seam

t_p = mm (Pressure)

t_m = M / (π*$R_m{}^2$*S_t*K_s*E_c) * MetricFactor (bending)
= 200,762.1 / (π*1,684²*1,380*1.20*1.00) * 98066.5
= 1.33 mm

t_w = 0.6*W / (2*π*R_m*S_t*K_s*E_c) * MetricFactor (Weight)
= 0.60*99,544.6 / (2*π*1,684*1,380*1.20*1.00) * 98.0665
= .33 mm

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

= + 1.33 - (.33)

= 1 mm

t_{mc} = M / (π*$R_m{}^2$*S_c*K_s) * MetricFactor (bending)
= 200,762.1 / (π*1,684²*810.65*1.20) * 98066.5
= 2.27 mm

t_{wc} = W / (2*π*R_m*S_c*K_s) * MetricFactor (Weight)

	=	99,544.6 / (2*π*1,684*810.65*1.20) * 98.0665	
	=	.95 mm	
t_c	=	t_{mc} + t_{wc} - t_{pc}	(total required, compressive)
	=	2.27 + (.95) - ()	
	=	3.22 mm	

Vacuum, Vortex Shedding, Wind, Bottom Seam

t_p	=	$P*R / (2*S_t*K_s*E_c + .40*\|P\|)$	(Pressure)
	=	-1.03*1,678 / (2*1,380*1.20*1.00 + .40*|1.03|)	
	=	-.52 mm	
t_m	=	$M / (\pi*R_m{}^2*S_t*K_s*E_c)$ * MetricFactor	(bending)
	=	$162{,}666.9 / (\pi*1{,}684^2*1{,}380*1.20*1.00) * 98066.5$	
	=	1.08 mm	
t_w	=	$0.6*W / (2*\pi*R_m*S_t*K_s*E_c)$ * MetricFactor	(Weight)
	=	0.60*114,850.8 / (2*π*1,684*1,380*1.20*1.00) * 98.0665	
	=	.39 mm	
t_t	=	$t_p + t_m - t_w$	(total required, tensile)
	=	-.52 + 1.08 - (.39)	
	=	.17 mm	
t_{pc}	=	$P*R / (2*S_c*K_s + .40*\|P\|)$	(Pressure)
	=	-1.03*1,678 / (2*774.39*1.20 + .40*|1.03|)	
	=	-.93 mm	
t_{mc}	=	$M / (\pi*R_m{}^2*S_c*K_s)$ * MetricFactor	(bending)
	=	$162{,}666.9 / (\pi*1{,}684^2*774.39*1.20) * 98066.5$	
	=	1.93 mm	
t_{wc}	=	$W / (2*\pi*R_m*S_c*K_s)$ * MetricFactor	(Weight)
	=	114,850.8 / (2*π*1,684*774.39*1.20) * 98.0665	
	=	1.15 mm	
t_c	=	$t_{mc} + t_{wc} - t_{pc}$	(total required, compressive)
	=	1.93 + (1.15) - (-.93)	
	=	4 mm	

Nozzle (AA)

1

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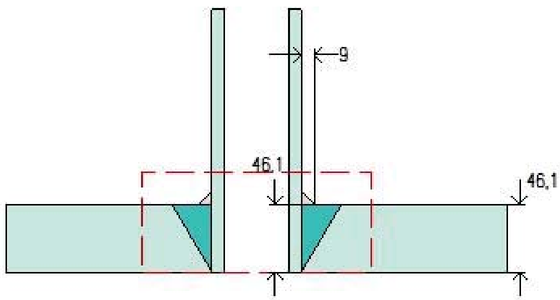

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Blind Flange (AB)
Orientation	45°
Distance to head center, R	180 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	70.4 mm
Projection available outside vessel to flange face, Lf	133.9 mm
Local vessel minimum thickness	46.1 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg_{41}	9 mm
Nozzle to vessel groove weld	46.1 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of -1.11°C.	

Reinforcement Calculations for Internal Pressure

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.3	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(42.85, 21.42 + (8.74 - 0) + (46.1 - 0))
= 76.26 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(46.1 - 0), 2.5*(8.74 - 0) + 0)
= 21.84 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 3.6*21.42 / (1,180*1 - 0.6*3.6)
= 0.066 mm

Required thickness t_r from UG-34

The static head of liquid has not been included in the total design load because the vessel is supported below the flange.

W = 0.785*G^2*P + 2*b*3.14*G*m*P
= 0.785*666.91^2*3.671/100 + 2*9.45*3.14*666.91*3*3.671/1003.671/100
= 17,173.93 kg_f

t_r = d*Sqr(C*P / (S*E) + 1.9*W*h_g / (S*E*d^3))
= 666.91*Sqr(0.3*3.671 / (1,407.207*1) + 1.9*17,173.93*41.2 / (1,407.207 / 100*1*666.91^3))

$= 22.17$ mm

Gasket seating

$t_r = d*Sqr(1.9*W*h_G / (S*E*d^3))$

$= 666.91*Sqr(1.9*174{,}659.56*41.2 / (1{,}407.207 / 100*1*666.91^3))$

$= 38.17$ mm

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

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27} = P*R_n / (S_n*E - 0.6*P) + Corrosion$

$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6) + 0$

$= 0.066$ mm

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

$= max[\ 0.066 , 0\ ]$

$= 0.066$ mm

$t_{b1} = 38.17$ mm

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

$= max[\ 38.17 , 1.5\ ]$

$= 38.17$ mm

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

$= min[\ 3.42 , 38.17\ ]$

$= 3.42$ mm

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

$= max[\ 0.066 , 3.42\ ]$

$= 3.42$ mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-39 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 21.98 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (mm)	Actual weld throat size (mm)	Status
Nozzle to shell fillet (Leg_{41})	6	6.3	weld size is adequate

Calculations for external pressure 21.98 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(42.85, 21.42 + (8.74 - 0) + (46.1 - 0))
= 76.26 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(46.1 - 0), 2.5*(8.74 - 0) + 0)
= 21.84 mm

Nozzle required thickness per UG-28 t_{rn} = 1.11 mm

From UG-34 required thickness t_r = 46.1 mm

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

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 19 mm or t_n or t = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 1.11 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[1.11 , 0]
= 1.11 mm

t_{b2} = 46.1 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[46.1 , 1.5]
= 46.1 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 46.1]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[1.11 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 133.9 / 60.33 = 2.2196
D_o / t = 60.33 / 1.11 = 54.1393

From table G: A = 0.001455
From table CS-2 Metric: B = 910.0732 kg/cm^2 (892.48 bar)

P_a = 4*B / (3*(D_o / t))
= 4*892.48 / (3*(60.33 / 1.11))
= 21.98 bar

Design thickness for external pressure P_a = 21.98 bar

t_a = t + Corrosion = 1.11 + = 1.11 mm

Nozzle (AB)

1

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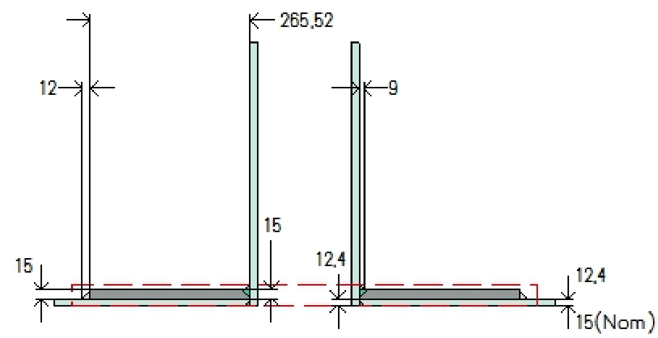


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	45°
End of nozzle to datum line	29,680 mm
Calculated as hillside	Yes
Distance to head center, R	550 mm
Passes through a Category A joint	No

Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	583.6 mm
Nominal wall thickness	13 mm
Corrosion allowance	3 mm
Opening chord length	598.79 mm
Projection available outside vessel, Lpr	326.72 mm
Projection available outside vessel to flange face, Lf	479.12 mm
Local vessel minimum thickness	12.4 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	1,150 mm
Thickness, t_e	15 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	12 mm
Nozzle to vessel groove weld	12.4 mm
Pad groove weld	15 mm

ASME B16.5-2013 Flange	
Description	NPS 24 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	Yes
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	583.6 mm
Gasket	
Type	Spiral-Wound
Description	Lamons Spiral Wound W 304 SS / Flexible Graphite
Factor, m	3
Seating Stress, y	703.069 kg_f/cm^2
Thickness, T	4.5 mm
Inner Diameter	628.7 mm
Outer Diameter	685.8 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6) =	3.93 mm
Stress ratio = t_r*E^* / (t_n - c) = 3.93*1 / (12.4 - 3) =	0.4185
Reduction in MDMT, T_R from Fig UCS-66.1M =	45.9°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 45.9 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*294.8 / (1,380*1 - 0.6*3.6) =	0.77 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.77*1 / (13 - 3) =	0.077
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6) =	3.93 mm
Stress ratio = t_r*E^* / (t_n - c) = 3.93*1 / (12.4 - 3) =	0.4185
Reduction in MDMT, T_R from Fig UCS-66.1M =	45.9°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 45.9 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
23.5545	118.9738	32.7328	4.3387	--	79.6545	2.2477	7.37	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-11,377	121,359	242,249	9,888	302,728	124,005	243,204

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(598.79, 299.39 + (13 - 3) + (12.4 - 3))$$
$$= 598.79 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)$$
$$= 23.5 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*294.8 / (1,380*1 - 0.6*3.6)$$
$$= 0.77 \text{ mm}$$

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

$$t_r = P*K_1*D / (2*S*E - 0.2*P)$$
$$= 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6)$$
$$= 3.93 \text{ mm}$$

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

t_r = P*D*K / (2*S*E - 0.2*P)
= 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6)
= 4.37 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (598.79*3.93*1 + 2*10*3.93*1*(1 - 1)) / 100
= 23.5545 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 32.7328 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (598.79*(1*9.4 - 1*3.93) - 2*10*(1*9.4 - 1*3.93)*(1 - 1)) / 100
= 32.7328 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(9.4 + 10)*(1*9.4 - 1*3.93) - 2*10*(1*9.4 - 1*3.93)*(1 - 1)) / 100
= 2.1213 cm^2

A_2 = smaller of the following= 4.3387 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10 - 0.77)*1*9.4) / 100
= 4.3387 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(10 - 0.77)*(2.5*10 + 15)*1) / 100
= 7.3845 cm^2

A_{41} = Leg^2*f_{r3}
= $(8.99^2*1) / 100$
= 0.8077 cm^2

(Part of the weld is outside of the limits)

A_{42} = Leg^2*f_{r4}
= $(12^2*1) / 100$
= 1.44 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((1,150 - 618.97)*15*1) / 100
= 79.6545 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 32.7328 + 4.3387 + 0.8077 + 1.44 + 79.6545
= 118.9738 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = $0.7*t_{min}$ = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}27}$ = $P*R_n / (S_n*E - 0.6*P)$ + Corrosion
= 3.6*294.8 / (1,380*1 - 0.6*3.6) + 3
= 3.77 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.77 , 0]
= 3.77 mm

t_{b1} = 7.37 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[7.37 , 4.5]
= 7.37 mm

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

= min[11.33 , 7.37]
= 7.37 mm

t_{UG-45} = max[t_a , t_b]
= max[3.77 , 7.37]
= 7.37 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*609.6*9*689.532 = 59,424 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*1,150*12*689.532 = 149,470.15 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*599.6*10*985.045 = 92,778.87 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*9.4*1,041.333 = 93,733.51 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*15*1,041.333 = 149,570.61 kg_f

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (2,355.4481 - 3,273.2838 + 2*10*1*(1*9.4 - 1*3.93))*1,407.207
= -11,377.3 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (433.8701 + 7,965.45 + 80.774 + 143.9997)*1,407.207
= 121,358.98 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (433.8701 + 0 + 80.774 + 0 + 2*10*9.4*1)*1,407.207
= 9,887.81 kg_f

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

= (433.8701 + 0 + 7,965.45 + 80.774 + 143.9997 + 0 + 2*10*9.4*1)*1,407.207
= 124,004.68 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -11,377.3 kg_f
Path 1-1 through (2) & (3) = 149,470.15 + 92,778.87 = 242,249.03 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -11,377.3 kg_f
Path 2-2 through (1), (4), (6) = 59,424 + 93,733.51 + 149,570.61 = 302,728.12 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -11,377.3 kg_f
Path 3-3 through (2), (4) = 149,470.15 + 93,733.51 = 243,203.66 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*13 / 298.3)*(1 - 298.3 / infinity)
= 2.179%

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.18 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
28.1429	85.6364	0.0013	3.7329	--	79.6545	2.2477	5.06	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for external pressure 1.18 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= \text{MAX}(d, R_n + (t_n - C_n) + (t - C)) \\
&= \text{MAX}(598.78, 299.39 + (13 - 3) + (12.4 - 3)) \\
&= 598.78 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= \text{MIN}(2.5*(12.4 - 3), 2.5*(13 - 3) + 15) \\
&= 23.5 \text{ mm}
\end{aligned}
$$

Nozzle required thickness per UG-28 t_{rn} = 2.06 mm

From UG-37(d)(1) required thickness t_r = 9.4 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or $S_p / S_v = 1$

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

$$A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$$
$$= (0.5*(598.78*9.4*1 + 2*10*9.4*1*(1 - 1))) / 100$$
$$= 28.1429 \text{ cm}^2$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.0013 cm^2

$$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (598.78*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100$$
$$= 0.0013 \text{ cm}^2$$

$$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (2*(9.4 + 10)*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100$$
$$= 0 \text{ cm}^2$$

A_2 = smaller of the following= 3.7329 cm^2

$$= 5*(t_n - t_{rn})*f_{r2}*t$$
$$= (5*(10 - 2.06)*1*9.4) / 100$$
$$= 3.7329 \text{ cm}^2$$

$$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$$
$$= (2*(10 - 2.06)*(2.5*10 + 15)*1) / 100$$
$$= 6.3542 \text{ cm}^2$$

$$A_{41} = Leg^2*f_{r3}$$
$$= (8.99^2*1) / 100$$
$$= 0.8077 \text{ cm}^2$$

(Part of the weld is outside of the limits)

$$A_{42} = Leg^2*f_{r4}$$
$$= (12^2*1) / 100$$
$$= 1.44 \text{ cm}^2$$

$$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$$
$$= ((1{,}150 - 618.97)*15*1) / 100$$
$$= 79.6545 \text{ cm}^2$$

$$\text{Area} = A_1 + A_2 + A_{41} + A_{42} + A_5$$
$$= 0.0013 + 3.7329 + 0.8077 + 1.44 + 79.6545$$
$$= 85.6364 \text{ cm}^2$$

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = 0.5*t_{min} = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = 0.7*t_{min} = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}28}$ = 5.06 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[5.06 , 0]
= 5.06 mm

t_{b2} = 4.43 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[4.43 , 4.5]
= 4.5 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.33 , 4.5]
= 4.5 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[5.06 , 4.5]
= 5.06 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 587.22 / 609.6 = 0.9633
D_o / t = 609.6 / 2.06 = 296.2265

From table G: A = 0.000271
From table CS-2 Metric: B = 267.9733 kg/cm^2 (262.79 bar)

P_a = 4*B / (3*(D_o / t))
= 4*262.79 / (3*(609.6 / 2.06))
= 1.18 bar

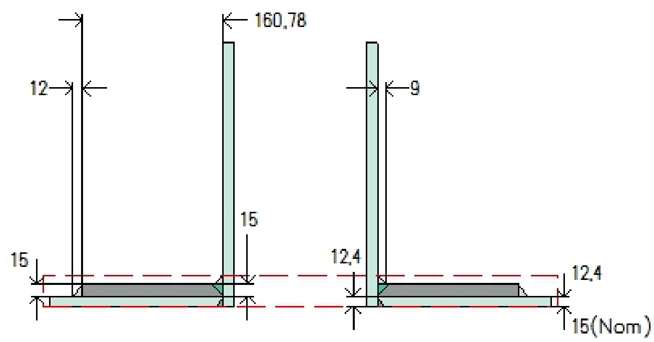
Design thickness for external pressure P_a = 1.18 bar

t_a = t + Corrosion = 2.06 + 3 = 5.06 mm

Nozzle (AC)

1

ASME Section VIII Division 1, 2017 Edition Metric



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

Location and Orientation

Located on	Top Head
Orientation	270°
End of nozzle to datum line	29,680 mm
Calculated as hillside	Yes
Distance to head center, R	1,200 mm
Passes through a Category A joint	No

Nozzle

Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	380.4 mm
Nominal wall thickness	13 mm
Corrosion allowance	3 mm
Opening chord length	436.76 mm
Projection available outside vessel, Lpr	507.24 mm
Projection available outside vessel to flange face, Lf	634.24 mm
Local vessel minimum thickness	12.4 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad

Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	780 mm
Thickness, t_e	15 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	12 mm
Nozzle to vessel groove weld	12.4 mm
Pad groove weld	15 mm

ASME B16.5-2013 Flange	
Description	NPS 16 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	380.4 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6) =	4.37 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.37*1 / (12.4 - 3) =	0.4647
Reduction in MDMT, T_R from Fig UCS-66.1M =	36.2°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 36.2 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*193.2 / (1,380*1 - 0.6*3.6) =	0.5 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.5*1 / (13 - 3) =	0.0505
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6) =	4.37 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.37*1 / (12.4 - 3) =	0.4647
Reduction in MDMT, T_R from Fig UCS-66.1M =	36.2°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 36.2 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
19.078	76.923	21.9787	4.4626	--	48.234	2.2477	7.37	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-2,666	77,318	162,717	10,062	201,819	79,964	163,869

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(436.76, 218.38 + (13 - 3) + (12.4 - 3))
= 436.76 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)
= 23.5 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 3.6*193.2 / (1,380*1 - 0.6*3.6)
= 0.51 mm

Required thickness t_r from UG-37(a)

t_r = P*D*K / (2*S*E - 0.2*P)
= 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6)
= 4.37 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

$$A = d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$$
$$= (436.76*4.37*1 + 2*10*4.37*1*(1 - 1)) / 100$$
$$= 19.078 \text{ cm}^2$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 21.9787 cm^2

$$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (436.76*(1*9.4 - 1*4.37) - 2*10*(1*9.4 - 1*4.37)*(1 - 1)) / 100$$
$$= 21.9787 \text{ cm}^2$$

$$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (2*(9.4 + 10)*(1*9.4 - 1*4.37) - 2*10*(1*9.4 - 1*4.37)*(1 - 1)) / 100$$
$$= 1.9523 \text{ cm}^2$$

A_2 = smaller of the following= 4.4626 cm^2

$$= 5*(t_n - t_{rn})*f_{r2}*t$$
$$= (5*(10 - 0.51)*1*9.4) / 100$$
$$= 4.4626 \text{ cm}^2$$

$$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$$
$$= (2*(10 - 0.51)*(2.5*10 + 15)*1) / 100$$
$$= 7.5961 \text{ cm}^2$$

$$A_{41} = Leg^2*f_{r3}$$
$$= (8.99^2*1) / 100$$
$$= 0.8077 \text{ cm}^2$$

(Part of the weld is outside of the limits)

$$A_{42} = Leg^2*f_{r4}$$
$$= (12^2*1) / 100$$
$$= 1.44 \text{ cm}^2$$

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((780 - 458.44)*15*1) / 100
= 48.234 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 21.9787 + 4.4626 + 0.8077 + 1.44 + 48.234
= 76.923 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = $0.7*t_{min}$ = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG-27}$ = $P*R_n / (S_n*E - 0.6*P)$ + Corrosion
= 3.6*193.2 / (1,380*1 - 0.6*3.6) + 3
= 3.51 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[3.51 , 0]
= 3.51 mm

t_{b1} = 7.37 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[7.37 , 4.5]
= 7.37 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.33 , 7.37]
= 7.37 mm

t_{UG-45} = max[t_a , t_b]
= max[3.51 , 7.37]
= 7.37 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*406.4*9*689.532 = 39,616 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*780*12*689.532 = 101,379.8 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*396.4*10*985.045 = 61,336.79 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*406.4*9.4*1,041.333 = 62,489.01 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*406.4*15*1,041.333 = 99,713.74 kg_f

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1,907.7981 - 2,197.8666 + 2*10*1*(1*9.4 - 1*4.37))*1,407.207
= -2,665.55 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (446.2572 + 4,823.4 + 80.774 + 143.9997)*1,407.207
= 77,318.1 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (446.2572 + 0 + 80.774 + 0 + 2*10*9.4*1)*1,407.207
= 10,062.12 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (446.2572 + 0 + 4,823.4 + 80.774 + 143.9997 + 0 + 2*10*9.4*1)*1,407.207
= 79,963.79 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -2,665.55 kg_f
Path 1-1 through (2) & (3) = 101,379.8 + 61,336.79 = 162,716.58 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -2,665.55 kg_f
Path 2-2 through (1), (4), (6) = 39,616 + 62,489.01 + 99,713.74 = 201,818.75 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -2,665.55 kg_f
Path 3-3 through (2), (4) = 101,379.8 + 62,489.01 = 163,868.8 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*13 / 196.7)*(1 - 196.7 / infinity)
= 3.3045%

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.18 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
20.5197	54.2991	0.0013	3.8161	--	48.234	2.2477	4.88	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for external pressure 1.18 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(436.59, 218.29 + (13 - 3) + (12.4 - 3))$$
$$= 436.59 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)$$
$$= 23.5 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.88 mm

From UG-37(d)(1) required thickness t_r = 9.4 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or $S_p / S_v = 1$

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

$$\begin{aligned} A &= 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})) \\ &= (0.5*(436.59*9.4*1 + 2*10*9.4*1*(1 - 1))) / 100 \\ &= \underline{20.5197}\ cm^2 \end{aligned}$$

Area available from FIG. UG-37.1

A_1 = larger of the following= $\underline{0.0013}$ cm^2

$$\begin{aligned} &= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= (436.59*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100 \\ &= 0.0013\ cm^2 \end{aligned}$$

$$\begin{aligned} &= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= (2*(9.4 + 10)*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100 \\ &= 0\ cm^2 \end{aligned}$$

A_2 = smaller of the following= $\underline{3.8161}$ cm^2

$$\begin{aligned} &= 5*(t_n - t_{rn})*f_{r2}*t \\ &= (5*(10 - 1.88)*1*9.4) / 100 \\ &= 3.8161\ cm^2 \end{aligned}$$

$$\begin{aligned} &= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2} \\ &= (2*(10 - 1.88)*(2.5*10 + 15)*1) / 100 \\ &= 6.4948\ cm^2 \end{aligned}$$

$$\begin{aligned} A_{41} &= Leg^2*f_{r3} \\ &= (8.99^2*1) / 100 \\ &= \underline{0.8077}\ cm^2 \end{aligned}$$

(Part of the weld is outside of the limits)

$$\begin{aligned} A_{42} &= Leg^2*f_{r4} \\ &= (12^2*1) / 100 \\ &= \underline{1.44}\ cm^2 \end{aligned}$$

$$\begin{aligned} A_5 &= (D_p - d - 2*t_n)*t_e*f_{r4} \\ &= ((780 - 458.44)*15*1) / 100 \\ &= \underline{48.234}\ cm^2 \end{aligned}$$

$$\begin{aligned} Area &= A_1 + A_2 + A_{41} + A_{42} + A_5 \\ &= 0.0013 + 3.8161 + 0.8077 + 1.44 + 48.234 \\ &= \underline{54.2991}\ cm^2 \end{aligned}$$

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = 0.5*t_{min} = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = 0.7*t_{min} = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}28}$ = 4.88 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[4.88 , 0]
= 4.88 mm

t_{b2} = 4.43 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[4.43 , 4.5]
= 4.5 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.33 , 4.5]
= 4.5 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[4.88 , 4.5]
= 4.88 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 847.96 / 406.4 = 2.0865
D_o / t = 406.4 / 1.88 = 215.9811

From table G: A = 0.000198
From table CS-2 Metric: B = 195.3787 kg/cm^2 (191.6 bar)

P_a = 4*B / (3*(D_o / t))
= 4*191.6 / (3*(406.4 / 1.88))
= 1.18 bar

Design thickness for external pressure P_a = 1.18 bar

t_a = t + Corrosion = 1.88 + 3 = 4.88 mm

Nozzle (AD)

1

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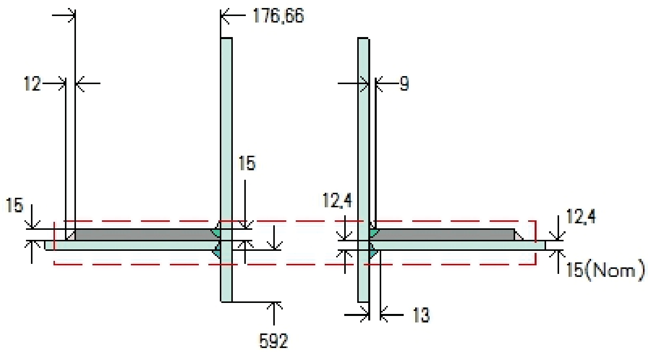

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Top Head
Orientation	315°
End of nozzle to datum line	29,680 mm
Calculated as hillside	Yes
Distance to head center, R	900 mm
Passes through a Category A joint	No

Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	380.4 mm
Nominal wall thickness	13 mm
Corrosion allowance	3 mm
Opening chord length	405.99 mm
Projection available outside vessel, Lpr	418.95 mm
Internal projection, h_{new}	592 mm
Projection available outside vessel to flange face, Lf	545.95 mm
Local vessel minimum thickness	12.4 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	780 mm
Thickness, t_e	15 mm

Is split	No
Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	12 mm
Lower fillet, Leg_{43}	13 mm
Nozzle to vessel groove weld	12.4 mm
Pad groove weld	15 mm

ASME B16.5-2013 Flange	
Description	NPS 16 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	380.4 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6) =	3.93 mm
Stress ratio = t_r*E^* / (t_n - c) = 3.93*1 / (12.4 - 3) =	0.4185
Reduction in MDMT, T_R from Fig UCS-66.1M =	45.9°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 45.9 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*193.2 / (1,380*1 - 0.6*3.6) =	0.5 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.5*1 / (13 - 3) =	0.0505
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6) =	3.93 mm
Stress ratio = t_r*E^* / (t_n - c) = 3.93*1 / (12.4 - 3) =	0.4185
Reduction in MDMT, T_R from Fig UCS-66.1M =	45.9°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 45.9 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
15.9703	85.1115	22.1935	4.4626	2.4504	52.998	3.0071	7.37	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-7,219	84,022	162,717	14,579	240,179	91,184	202,229

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	6	6.1 (corroded)	weld size is adequate
Nozzle to shell groove (Lower)	7	12.4	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(405.99, 202.99 + (13 - 3) + (12.4 - 3))$$
$$= 405.99 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)$$
$$= 23.5 \text{ mm}$$

Inner Normal Limit of reinforcement per UG-40

$$L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))$$
$$= MIN(589, 2.5*(12.4 - 3), 2.5*(13 - 3 - 3))$$
$$= 17.5 \text{ mm}$$

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 3.6*193.2 / (1,380*1 - 0.6*3.6)
= 0.51 mm

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

t_r = $P*K_1*D / (2*S*E - 0.2*P)$
= 3.6*0.8984*3,356 / (2*1,380*1 - 0.2*3.6)
= 3.93 mm

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

t_r = P*D*K / (2*S*E - 0.2*P)
= 3.6*3,356*0.997623 / (2*1,380*1 - 0.2*3.6)
= 4.37 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (405.99*3.93*1 + 2*10*3.93*1*(1 - 1)) / 100
= 15.9703 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 22.1935 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (405.99*(1*9.4 - 1*3.93) - 2*10*(1*9.4 - 1*3.93)*(1 - 1)) / 100
= 22.1935 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(9.4 + 10)*(1*9.4 - 1*3.93) - 2*10*(1*9.4 - 1*3.93)*(1 - 1)) / 100
= 2.1213 cm^2

A_2 = smaller of the following= 4.4626 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10 - 0.51)*1*9.4) / 100
= 4.4626 cm^2

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
$= (2*(10 - 0.51)*(2.5*10 + 15)*1) / 100$
$= 7.5961\ cm^2$

A_3 = smaller of the following= 2.4504 cm^2

$= 5*t*t_i*f_{r2}$
$= (5*9.4*7*1) / 100$
$= 3.2903\ cm^2$

$= 5*t_i*t_i*f_{r2}$
$= (5*7*7*1) / 100$
$= 2.4504\ cm^2$

$= 2*h*t_i*f_{r2}$
$= (2*589*7*1) / 100$
$= 82.4662\ cm^2$

$A_{41} = Leg^2*f_{r3}$
$= (8.99^2*1) / 100$
$= 0.8077\ cm^2$

(Part of the weld is outside of the limits)

$A_{42} = Leg^2*f_{r4}$
$= (12^2*1) / 100$
$= 1.44\ cm^2$

$A_{43} = Leg^2*f_{r2}$
$= (8.71^2*1) / 100$
$= 0.7594\ cm^2$

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((780 - 426.68)*15*1) / 100$
$= 52.998\ cm^2$

Area $= A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
$= 22.1935 + 4.4626 + 2.4504 + 0.8077 + 1.44 + 0.7594 + 52.998$
$= 85.1115\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = 0.5*t_{min} = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower fillet: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} or 0.7*h = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8.71 = 6.1 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = 0.7*t_{min} = 7 mm
$t_{w(actual)}$ = 12.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*193.2 / (1,380*1 - 0.6*3.6) + 3
= 3.51 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.51 , 0]
= 3.51 mm

t_{b1} = 7.37 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[7.37 , 4.5]
= 7.37 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.33 , 7.37]
= 7.37 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[3.51 , 7.37]
= 7.37 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2

Upper groove weld in tension: 0.74*1,407.207 = 1,041.333 kg_f/cm^2
Lower fillet weld in shear: 0.49*1,407.207 = 689.532 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*406.4*9*689.532 = 39,616 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*780*12*689.532 = 101,380.1 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*396.4*10*985.045 = 61,336.79 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*406.4*9.4*1,041.333 = 62,489.01 kg_f

(5) Lower fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_l = $(\pi / 2)$*406.4*8.71*689.532 = 38,359.98 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*406.4*15*1,041.333 = 99,713.74 kg_f

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

$W = (A - A_1 + 2 \cdot t_n \cdot f_{r1} \cdot (E_1 \cdot t - F \cdot t_r)) \cdot S_v$
= (1,597.0262 - 2,219.3504 + 2*10*1*(1*9.4 - 1*3.93))*1,407.207
= -7,218.84 kg_f

$W_{1\text{-}1} = (A_2 + A_5 + A_{41} + A_{42}) \cdot S_v$
= (446.2572 + 5,299.8 + 80.774 + 143.9997)*1,407.207
= 84,022.04 kg_f

$W_{2\text{-}2} = (A_2 + A_3 + A_{41} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= (446.2572 + 245.0364 + 80.774 + 75.9353 + 2*10*9.4*1)*1,407.207
= 14,578.86 kg_f

$W_{3\text{-}3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$
= (446.2572 + 245.0364 + 5,299.8 + 80.774 + 143.9997 + 75.9353 + 2*10*9.4*1)*1,407.207
= 91,184.48 kg_f

Load for path 1-1 lesser of W or $W_{1\text{-}1}$ = -7,218.84 kg_f
Path 1-1 through (2) & (3) = 101,380.1 + 61,336.79 = 162,716.89 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or $W_{2\text{-}2}$ = -7,218.84 kg_f
Path 2-2 through (1), (4), (5), (6) = 39,616 + 62,489.01 + 38,359.98 + 99,713.74 = 240,178.73 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or $W_{3\text{-}3}$ = -7,218.84 kg_f
Path 3-3 through (2), (4), (5) = 101,380.1 + 62,489.01 + 38,359.98 = 202,229.09 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$

= $(50*13 / 196.7)*(1 - 196.7 / \text{infinity})$

= 3.3045%

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.18 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
19.0801	62.3516	0.0006	3.8955	2.4504	52.998	3.0071	4.71	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to inside shell fillet (Leg_{43})	6	6.1 (corroded)	weld size is adequate
Nozzle to shell groove (Lower)	7	12.4	weld size is adequate

Calculations for external pressure 1.18 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(405.96, 202.98 + (13 - 3) + (12.4 - 3))
= 405.96 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)
= 23.5 mm

Inner Normal Limit of reinforcement per UG-40

L_I = MIN(h, 2.5*(t - C), 2.5*(t_i - C_n - C))
= MIN(589, 2.5*(12.4 - 3), 2.5*(13 - 3 - 3))
= 17.5 mm

Nozzle required thickness per UG-28 t_{rn} = 1.71 mm

From UG-37(d)(1) required thickness t_r = 9.4 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(405.96*9.4*1 + 2*10*9.4*1*(1 - 1))) / 100
= 19.0801 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.0006 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (405.96*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100
= 0.0006 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(9.4 + 10)*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100
= 0 cm^2

A_2 = smaller of the following= 3.8955 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10 - 1.71)*1*9.4) / 100
= 3.8955 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(10 - 1.71)*(2.5*10 + 15)*1) / 100
= 6.6303 cm^2

A_3 = smaller of the following= 2.4504 cm^2

= $5*t*t_i*f_{r2}$
= (5*9.4*7*1) / 100
= 3.2903 cm^2

= $5*t_i*t_i*f_{r2}$
= (5*7*7*1) / 100
= 2.4504 cm^2

= $2*h*t_i*f_{r2}$
= (2*589*7*1) / 100
= 82.4662 cm^2

A_{41} = Leg^2*f_{r3}
= $(8.99^2*1) / 100$
= 0.8077 cm^2

(Part of the weld is outside of the limits)

A_{42} = Leg^2*f_{r4}
= $(12^2*1) / 100$
= 1.44 cm^2

A_{43} = Leg^2*f_{r2}
= $(8.71^2*1) / 100$
= 0.7594 cm^2

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= $((780 - 426.68)*15*1) / 100$
= 52.998 cm^2

Area = $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5$
= 0.0006 + 3.8955 + 2.4504 + 0.8077 + 1.44 + 0.7594 + 52.998
= 62.3516 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower fillet: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ or 0.7*h = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*8.71 = 6.1 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = $0.7*t_{min}$ = 7 mm
$t_{w(actual)}$ = 12.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}28}$ = 4.71 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[4.71 , 0]
= 4.71 mm

t_{b2} = 4.43 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[4.43 , 4.5]
= 4.5 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.33 , 4.5]
= 4.5 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[4.71 , 4.5]
= 4.71 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 676.9 / 406.4 = 1.6656
D_o / t = 406.4 / 1.71 = 237.2647

From table G: A = 0.000217
From table CS-2 Metric: B = 214.6325 kg/cm^2 (210.48 bar)

P_a = 4*B / (3*(D_o / t))
= 4*210.48 / (3*(406.4 / 1.71))
= 1.18 bar

Design thickness for external pressure P_a = 1.18 bar

t_a = t + Corrosion = 1.71 + 3 = 4.71 mm

Nozzle (BB)

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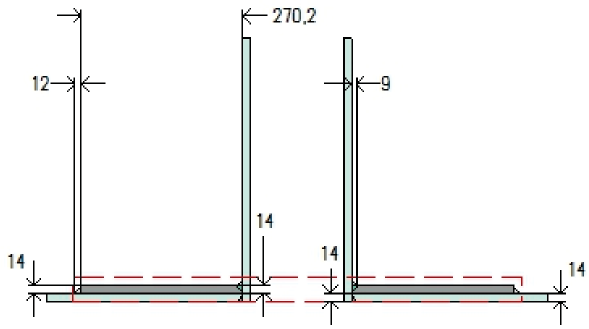
ASME Section VIII Division 1, 2017 Edition Metric



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

Location and Orientation	
Located on	Top existing shell
Orientation	0°
Nozzle center line offset to datum line	17,588 mm
End of nozzle to shell center	1,940 mm
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	583.6 mm
Nominal wall thickness	13 mm
Corrosion allowance	3 mm
Projection available outside vessel, Lpr	98.6 mm
Projection available outside vessel to flange face, Lf	251 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	1,150 mm
Thickness, t_e	14 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	9 mm

Outer fillet, Leg_{42}	12 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

ASME B16.5-2013 Flange	
Description	NPS 24 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	583.6 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*294.8 / (1,380*1 - 0.6*3.6) =	0.77 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.77*1 / (13 - 3) =	0.077
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	14 mm
Exemption temperature from Fig UCS-66M Curve B =	-18.75°C
t_r = 3.6*1,678 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 3) =	0.3986
Reduction in MDMT, T_R from Fig UCS-66.1M =	52.3°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-18.75 - 52.3 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
25.8498	121.9907	39.0077	5.0768	--	75.656	2.2503	7.38	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-16,654	116,775	242,249	11,380	308,711	119,871	259,158

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	5.5	8.4	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= \text{MAX}(d, R_n + (t_n - C_n) + (t - C)) \\
&= \text{MAX}(589.6, 294.8 + (13 - 3) + (14 - 3)) \\
&= 589.6 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= \text{MIN}(2.5*(14 - 3), 2.5*(13 - 3) + 14) \\
&= 27.5 \text{ mm}
\end{aligned}
$$

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

$$
\begin{aligned}
t_{rn} &= P*R_n / (S_n*E - 0.6*P) \\
&= 3.6*294.8 / (1{,}380*1 - 0.6*3.6) \\
&= 0.77 \text{ mm}
\end{aligned}
$$

Required thickness t_r from UG-37(a)

$$
\begin{aligned}
t_r &= P*R / (S*E - 0.6*P) \\
&= 3.6*1{,}678 / (1{,}380*1 - 0.6*3.6) \\
&= 4.38 \text{ mm}
\end{aligned}
$$

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

t_r = $P*R / (S*E - 0.6*P)$
= $3.6*1{,}678 / (1{,}380*0.85 - 0.6*3.6)$
= 5.16 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= $(589.6*4.38*1 + 2*10*4.38*1*(1 - 1)) / 100$
= 25.8498 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 39.0077 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(589.6*(1*11 - 1*4.38) - 2*10*(1*11 - 1*4.38)*(1 - 1)) / 100$
= 39.0077 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= $(2*(11 + 10)*(1*11 - 1*4.38) - 2*10*(1*11 - 1*4.38)*(1 - 1)) / 100$
= 2.7787 cm^2

A_2 = smaller of the following= 5.0768 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= $(5*(10 - 0.77)*1*11) / 100$
= 5.0768 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= $(2*(10 - 0.77)*(2.5*10 + 14)*1) / 100$
= 7.2 cm^2

A_{41} = Leg^2*f_{r3}
= $(9^2*1) / 100$
= 0.8103 cm^2

A_{42} = Leg^2*f_{r4}

$= (12^2*1) / 100$

$= \underline{1.44}\ cm^2$

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

$= ((1,150 - 589.6 - 2*10)*14*1) / 100$

$= \underline{75.656}\ cm^2$

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

$= 39.0077 + 5.0768 + 0.8103 + 1.44 + 75.656$

$= \underline{121.9907}\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm

$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min} = \underline{6}$ mm

$t_{c(actual)} = 0.7*Leg = 0.7*9 = 6.3$ mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 11 mm

$t_{w(min)} = 0.5*t_{min} = \underline{5.5}$ mm

$t_{w(actual)} = 0.7*Leg = 0.7*12 = 8.4$ mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27} = P*R_n / (S_n*E - 0.6*P) + Corrosion$

$= 3.6*294.8 / (1,380*1 - 0.6*3.6) + 3$

$= 3.77$ mm

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

$= max[\ 3.77\ ,\ 0\ ]$

$= 3.77$ mm

$t_{b1} = P*R / (S*E - 0.6*P) + Corrosion$

$= 3.6*1,678 / (1,380*1 - 0.6*3.6) + 3$

$= 7.38$ mm

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

$= max[\ 7.38\ ,\ 4.5\ ]$

$= 7.38$ mm

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

$= min[\ 11.33\ ,\ 7.38\ ]$

$= 7.38$ mm

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

$= max[\ 3.77\ ,\ 7.38\ ]$

= 7.38 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*609.6*9*689.532 = 59,424 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*1,150*12*689.532 = 149,469.82 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*599.6*10*985.045 = 92,778.87 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*11*1,041.333 = 109,687.71 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*609.6*14*1,041.333 = 139,599.24 kg_f

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

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (2,584.9775 - 3,900.7664 + 2*10*1*(1*11 - 1*4.38))*1,407.207
= -16,653.84 kg_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
= (507.6764 + 7,565.6 + 81.0321 + 143.9997)*1,407.207
= 116,774.5 kg_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (507.6764 + 0 + 81.0321 + 0 + 2*10*11*1)*1,407.207
= 11,380.37 kg_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (507.6764 + 0 + 7,565.6 + 81.0321 + 143.9997 + 0 + 2*10*11*1)*1,407.207
= 119,870.51 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -16,653.84 kg_f
Path 1-1 through (2) & (3) = 149,469.82 + 92,778.87 = 242,248.69 kg_f

Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -16,653.84 kg_f
Path 2-2 through (1), (4), (6) = 59,424 + 109,687.71 + 139,599.24 = 308,710.95 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -16,653.84 kg_f
Path 3-3 through (2), (4) = 149,469.82 + 109,687.71 = 259,157.52 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

$$\begin{aligned} EFE &= (50*t / R_f)*(1 - R_f / R_o) \\ &= (50*13 / 298.3)*(1 - 298.3 / \text{infinity}) \\ &= 2.179\% \end{aligned}$$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.81 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
32.4287	82.4386	--	4.5322	--	75.656	2.2503	5.2	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	5.5	8.4	weld size is adequate

Calculations for external pressure 1.81 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$\begin{aligned} L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\ &= MAX(589.6, 294.8 + (13 - 3) + (14 - 3)) \\ &= 589.6 \text{ mm} \end{aligned}$$

Outer Normal Limit of reinforcement per UG-40

$$\begin{aligned} L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\ &= MIN(2.5*(14 - 3), 2.5*(13 - 3) + 14) \\ &= 27.5 \text{ mm} \end{aligned}$$

Nozzle required thickness per UG-28 t_{rn} = 1.76 mm

From UG-37(d)(1) required thickness t_r = 11 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

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

$$A = 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$$
$$= (0.5*(589.6*11*1 + 2*10*11*1*(1 - 1))) / 100$$
$$= \underline{32.4287}\ cm^2$$

Area available from FIG. UG-37.1

A_1 = larger of the following= $\underline{0}$ cm^2

$$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (589.6*(1*11 - 1*11) - 2*10*(1*11 - 1*11)*(1 - 1)) / 100$$
$$= 0\ cm^2$$

$$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$$
$$= (2*(11 + 10)*(1*11 - 1*11) - 2*10*(1*11 - 1*11)*(1 - 1)) / 100$$
$$= 0\ cm^2$$

A_2 = smaller of the following= $\underline{4.5322}$ cm^2

$$= 5*(t_n - t_{rn})*f_{r2}*t$$
$$= (5*(10 - 1.76)*1*11) / 100$$
$$= 4.5322\ cm^2$$

$$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$$
$$= (2*(10 - 1.76)*(2.5*10 + 14)*1) / 100$$
$$= 6.4277\ cm^2$$

$$A_{41} = Leg^2*f_{r3}$$
$$= (9^2*1) / 100$$
$$= \underline{0.8103}\ cm^2$$

$$A_{42} = Leg^2*f_{r4}$$
$$= (12^2*1) / 100$$
$$= \underline{1.44}\ cm^2$$

$$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$$
$$= ((1{,}150 - 589.6 - 2*10)*14*1) / 100$$
$$= \underline{75.656}\ cm^2$$

$$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$$
$$= 0 + 4.5322 + 0.8103 + 1.44 + 75.656$$
$$= \underline{82.4386}\ cm^2$$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 11 mm
$t_{w(min)}$ = 0.5*t_{min} = 5.5 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 4.76 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[4.76 , 0]
= 4.76 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 1.811*1,678 / (1,380*1 - 0.6*1.811) + 3
= 5.2 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[5.2 , 4.5]
= 5.2 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.33 , 5.2]
= 5.2 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[4.76 , 5.2]
= 5.2 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 278.73 / 609.6 = 0.4572
D_o / t = 609.6 / 1.76 = 346.4015

From table G: A = 0.000483
From table CS-2 Metric: B = 479.7834 kg/cm^2 (470.51 bar)

P_a = 4*B / (3*(D_o / t))
= 4*470.51 / (3*(609.6 / 1.76))
= 1.81 bar

Design thickness for external pressure P_a = 1.81 bar

t_a = t + Corrosion = 1.76 + 3 = 4.76 mm

Nozzle (CB) 1

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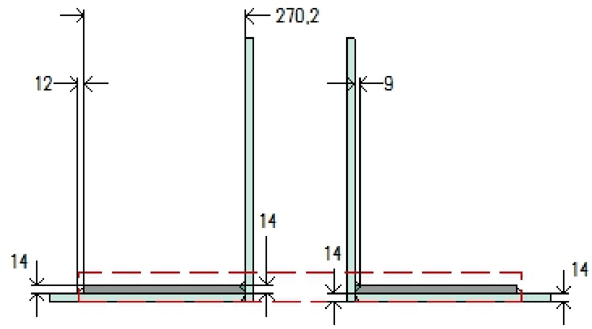


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	330°
Nozzle center line offset to datum line	728 mm
End of nozzle to shell center	1,940 mm
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	583.6 mm
Nominal wall thickness	13 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	98.6 mm
Projection available outside vessel to flange face, Lf	251 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.23 bar
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	1,150 mm
Thickness, t_e	14 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	9 mm

Outer fillet, Leg_{42}	12 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

ASME B16.5-2013 Flange	
Description	NPS 24 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.2 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	583.6 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1936) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.83*291.8 / (1,380*1 - 0.6*3.83) =	0.81 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.81*1 / (13 - 0) =	0.0623
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.83*1,675 / (1,380*1 - 0.6*3.83) =	4.65 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.65*1 / (14 - 0) =	0.3323
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.83 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
27.1462	140.8817	54.558	8.5329	--	75.656	2.1348	4.65	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-35,154	121,475	269,476	18,270	338,622	126,598	289,069

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	8.4	weld size is adequate

Calculations for internal pressure 3.83 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(583.6, 291.8 + (13 - 0) + (14 - 0))
= 583.6 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(14 - 0), 2.5*(13 - 0) + 14)
= 35 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 3.8258*291.8 / (1,380*1 - 0.6*3.8258)
= 0.81 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 3.8258*1,675 / (1,380*1 - 0.6*3.8258)
= 4.65 mm

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

t_r = $P*R / (S*E - 0.6*P)$
= 3.8258*1,675 / (1,380*0.85 - 0.6*3.8258)
= 5.47 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (583.6*4.65*1 + 2*13*4.65*1*(1 - 1)) / 100
= 27.1462 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 54.558 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (583.6*(1*14 - 1*4.65) - 2*13*(1*14 - 1*4.65)*(1 - 1)) / 100
= 54.558 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 13)*(1*14 - 1*4.65) - 2*13*(1*14 - 1*4.65)*(1 - 1)) / 100
= 5.0484 cm^2

A_2 = smaller of the following= 8.5329 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(13 - 0.81)*1*14) / 100
= 8.5329 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(13 - 0.81)*(2.5*13 + 14)*1) / 100
= 11.3368 cm^2

A_{41} = Leg^2*f_{r3}
= $(9^2*1) / 100$
= 0.8103 cm^2

A_{42} = Leg^2*f_{r4}

$= (11.51^2*1) / 100$
$= 1.3245\ cm^2$

(Part of the weld is outside of the limits)

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((1,150 - 583.6 - 2*13)*14*1) / 100$
$= 75.656\ cm^2$

Area $= A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 54.558 + 8.5329 + 0.8103 + 1.3245 + 75.656$
$= 140.8817\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27} = P*R_n / (S_n*E - 0.6*P) + Corrosion$
$= 3.8258*291.8 / (1,380*1 - 0.6*3.8258) + 0$
$= 0.81\ mm$

$t_a = max[\ t_{a\ UG\text{-}27}\ ,\ t_{a\ UG\text{-}22}\ ]$
$= max[\ 0.81\ ,\ 0\ ]$
$= 0.81\ mm$

$t_{b1} = P*R / (S*E - 0.6*P) + Corrosion$
$= 3.8258*1,675 / (1,380*1 - 0.6*3.8258) + 0$
$= 4.65\ mm$

$t_{b1} = max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$
$= max[\ 4.65\ ,\ 1.5\ ]$
$= 4.65\ mm$

$t_b = min[\ t_{b3}\ ,\ t_{b1}\ ]$
$= min[\ 8.33\ ,\ 4.65\ ]$
$= 4.65\ mm$

t_{UG-45} = max[t_a , t_b]
= max[0.81 , 4.65]
= 4.65 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*609.6*9*689.532 = 59,424 kg_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*1,150*12*689.532 = 149,469.82 kg_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*596.6*13*985.045 = 120,006 kg_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*609.6*14*1,041.333 = 139,599.24 kg_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*609.6*14*1,041.333 = 139,599.24 kg_f

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

W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v
= (2,714.6166 - 5,455.7955 + 2*13*1*(1*14 - 1*4.65))*1,407.207
= -35,153.73 kg_f

W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v
= (853.2886 + 7,565.6 + 81.0321 + 132.4513)*1,407.207
= 121,475.48 kg_f

W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v
= (853.2886 + 0 + 81.0321 + 0 + 2*13*14*1)*1,407.207
= 18,270.08 kg_f

W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v
= (853.2886 + 0 + 7,565.6 + 81.0321 + 132.4513 + 0 + 2*13*14*1)*1,407.207
= 126,597.71 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -35,153.73 kg_f
Path 1-1 through (2) & (3) = 149,469.82 + 120,006 = 269,475.82 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -35,153.73 kg_f
Path 2-2 through (1), (4), (6) = 59,424 + 139,599.24 + 139,599.24 = 338,622.48 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -35,153.73 kg_f
Path 3-3 through (2), (4) = 149,469.82 + 139,599.24 = 289,069.05 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

$$\begin{aligned} EFE &= (50*t / R_f)*(1 - R_f / R_o) \\ &= (50*13 / 298.3)*(1 - 298.3 / \text{infinity}) \\ &= 2.179\% \end{aligned}$$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
40.8519	85.3895	--	7.5987	--	75.656	2.1348	3.54	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	8.4	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(583.6, 291.8 + (13 - 0) + (14 - 0))
= 583.6 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(14 - 0), 2.5*(13 - 0) + 14)
= 35 mm

Nozzle required thickness per UG-28 t_{rn} = 2.14 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

$$
\begin{aligned}
A &= 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})) \\
&= (0.5*(583.6*14*1 + 2*13*14*1*(1 - 1))) / 100 \\
&= \underline{40.8519}\ cm^2
\end{aligned}
$$

Area available from FIG. UG-37.1

A_1 = larger of the following= $\underline{0}$ cm^2

$$
\begin{aligned}
&= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= (583.6*(1*14 - 1*14) - 2*13*(1*14 - 1*14)*(1 - 1)) / 100 \\
&= 0\ cm^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= (2*(14 + 13)*(1*14 - 1*14) - 2*13*(1*14 - 1*14)*(1 - 1)) / 100 \\
&= 0\ cm^2
\end{aligned}
$$

A_2 = smaller of the following= $\underline{7.5987}$ cm^2

$$
\begin{aligned}
&= 5*(t_n - t_{rn})*f_{r2}*t \\
&= (5*(13 - 2.14)*1*14) / 100 \\
&= 7.5987\ cm^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2} \\
&= (2*(13 - 2.14)*(2.5*13 + 14)*1) / 100 \\
&= 10.0955\ cm^2
\end{aligned}
$$

$$
\begin{aligned}
A_{41} &= Leg^2*f_{r3} \\
&= (9^2*1) / 100 \\
&= \underline{0.8103}\ cm^2
\end{aligned}
$$

$$
\begin{aligned}
A_{42} &= Leg^2*f_{r4} \\
&= (11.51^2*1) / 100 \\
&= \underline{1.3245}\ cm^2
\end{aligned}
$$

(Part of the weld is outside of the limits)

$$
\begin{aligned}
A_5 &= (D_p - d - 2*t_n)*t_e*f_{r4} \\
&= ((1{,}150 - 583.6 - 2*13)*14*1) / 100 \\
&= \underline{75.656}\ cm^2
\end{aligned}
$$

$$
\begin{aligned}
Area &= A_1 + A_2 + A_{41} + A_{42} + A_5 \\
&= 0 + 7.5987 + 0.8103 + 1.3245 + 75.656 \\
&= \underline{85.3895}\ cm^2
\end{aligned}
$$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-28}$ = 2.14 mm

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[2.14 , 0]
= 2.14 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[8.33 , 3.54]
= 3.54 mm

t_{UG-45} = max[t_a , t_b]
= max[2.14 , 3.54]
= 3.54 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 278.73 / 609.6 = 0.4572
D_o / t = 609.6 / 2.14 = 284.2856

From table G: A = 0.000636
From table CS-2 Metric: B = 633.6344 kg/cm² (621.38 bar)

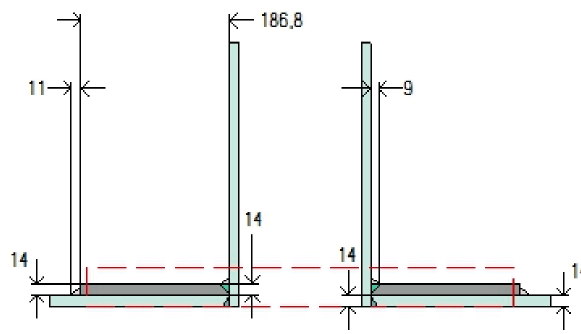
P_a = 4*B / (3*(D_o / t))
= 4*621.38 / (3*(609.6 / 2.14))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = 2.14 + = 2.14 mm

Nozzle (CC) 1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	135°
Nozzle center line offset to datum line	568 mm
End of nozzle to shell center	1,940 mm
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	380.4 mm
Nominal wall thickness	13 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	124 mm
Projection available outside vessel to flange face, Lf	251 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.23 bar
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	780 mm
Thickness, t_e	14 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	9 mm

Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

ASME B16.5-2013 Flange	
Description	NPS 16 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.21 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	380.4 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1945) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.83*190.2 / (1,380*1 - 0.6*3.83) =	0.53 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.53*1 / (13 - 0) =	0.0407
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.83*1,675 / (1,380*1 - 0.6*3.83) =	4.66 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.66*1 / (14 - 0) =	0.3328
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.83 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
17.7223	94.6901	35.5335	8.7303	--	49.616	0.8103	4.66	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-21,646	83,246	172,064	18,548	225,748	88,368	185,997

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.83 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= \text{MAX}(d, R_n + (t_n - C_n) + (t - C)) \\
&= \text{MAX}(380.4, 190.2 + (13 - 0) + (14 - 0)) \\
&= 380.4 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= \text{MIN}(2.5*(14 - 0), 2.5*(13 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

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

$$
\begin{aligned}
t_{rn} &= P*R_n / (S_n*E - 0.6*P) \\
&= 3.8319*190.2 / (1{,}380*1 - 0.6*3.8319) \\
&= 0.53 \text{ mm}
\end{aligned}
$$

Required thickness t_r from UG-37(a)

$$
\begin{aligned}
t_r &= P*R / (S*E - 0.6*P) \\
&= 3.8319*1{,}675 / (1{,}380*1 - 0.6*3.8319) \\
&= 4.66 \text{ mm}
\end{aligned}
$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.8319*1,675 / (1,380*0.85 - 0.6*3.8319)
= 5.48 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (380.4*4.66*1 + 2*13*4.66*1*(1 - 1)) / 100
= 17.7223 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 35.5335 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (380.4*(1*14 - 1*4.66) - 2*13*(1*14 - 1*4.66)*(1 - 1)) / 100
= 35.5335 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 13)*(1*14 - 1*4.66) - 2*13*(1*14 - 1*4.66)*(1 - 1)) / 100
= 5.0445 cm^2

A_2 = smaller of the following= 8.7303 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(13 - 0.53)*1*14) / 100
= 8.7303 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(13 - 0.53)*(2.5*13 + 14)*1) / 100
= 11.5987 cm^2

A_{41} = Leg^2*f_{r3}
= $(9^2*1) / 100$
= 0.8103 cm^2

A_{42} = Leg^2*f_{r4}

= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((760.8 - 380.4 - 2*13)*14*1) / 100
= 49.616 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 35.5335 + 8.7303 + 0.8103 + 0 + 49.616
= 94.6901 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = $P*R_n / (S_n*E - 0.6*P)$ + Corrosion
= 3.8319*190.2 / (1,380*1 - 0.6*3.8319) + 0
= 0.53 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.53 , 0]
= 0.53 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.8319*1,675 / (1,380*1 - 0.6*3.8319) + 0
= 4.66 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.66 , 1.5]
= 4.66 mm

t_b = min[t_{b3} , t_{b1}]
= min[8.33 , 4.66]
= 4.66 mm

t_{UG-45} = max[t_a , t_b]
= max[0.53 , 4.66]
= 4.66 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*406.4*9*689.532 = 39,616 kg_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*780*11*689.532 = 92,931.23 kg_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*393.4*13*985.045 = 79,132.35 kg_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*406.4*14*1,041.333 = 93,066.16 kg_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*406.4*14*1,041.333 = 93,066.16 kg_f

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (1,772.2334 - 3,553.3477 + 2*13*1*(1*14 - 1*4.66))*1,407.207
= -21,646.31 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (873.0305 + 4,961.6 + 81.0321 + 0)*1,407.207
= 83,245.71 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (873.0305 + 0 + 81.0321 + 0 + 2*13*14*1)*1,407.207
= 18,547.89 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (873.0305 + 0 + 4,961.6 + 81.0321 + 0 + 0 + 2*13*14*1)*1,407.207
= 88,367.95 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -21,646.31 kg_f
Path 1-1 through (2) & (3) = 92,931.23 + 79,132.35 = 172,063.59 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -21,646.31 kg_f
Path 2-2 through (1), (4), (6) = 39,616 + 93,066.16 + 93,066.16 = 225,748.32 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -21,646.31 kg_f
Path 3-3 through (2), (4) = 92,931.23 + 93,066.16 = 185,997.39 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

$$\begin{aligned} EFE &= (50*t / R_f)*(1 - R_f / R_o) \\ &= (50*13 / 196.7)*(1 - 196.7 / \text{infinity}) \\ &= 3.3045\% \end{aligned}$$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
26.6279	58.365	--	7.9387	--	49.616	0.8103	3.54	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(380.4, 190.2 + (13 - 0) + (14 - 0))$$
$$= 380.4 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(13 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.66 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A	=	$0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
	=	(0.5*(380.4*14*1 + 2*13*14*1*(1 - 1))) / 100
	=	26.6279 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

	=	$d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
	=	(380.4*(1*14 - 1*14) - 2*13*(1*14 - 1*14)*(1 - 1)) / 100
	=	0 cm^2
	=	$2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
	=	(2*(14 + 13)*(1*14 - 1*14) - 2*13*(1*14 - 1*14)*(1 - 1)) / 100
	=	0 cm^2

A_2 = smaller of the following= 7.9387 cm^2

	=	$5*(t_n - t_{rn})*f_{r2}*t$
	=	(5*(13 - 1.66)*1*14) / 100
	=	7.9387 cm^2
	=	$2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
	=	(2*(13 - 1.66)*(2.5*13 + 14)*1) / 100
	=	10.5471 cm^2

A_{41}	=	Leg^2*f_{r3}
	=	(9^2*1) / 100
	=	0.8103 cm^2
A_{42}	=	Leg^2*f_{r4}
	=	(0^2*1) / 100
	=	0 cm^2

(Part of the weld is outside of the limits)

A_5	=	$(D_p - d - 2*t_n)*t_e*f_{r4}$
	=	((760.8 - 380.4 - 2*13)*14*1) / 100
	=	49.616 cm^2

Area	=	$A_1 + A_2 + A_{41} + A_{42} + A_5$
	=	0 + 7.9387 + 0.8103 + 0 + 49.616
	=	58.365 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 1.66 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[1.66 , 0]
= 1.66 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[8.33 , 3.54]
= 3.54 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[1.66 , 3.54]
= 3.54 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 263.27 / 406.4 = 0.6478
D_o / t = 406.4 / 1.66 = 244.9884

From table G: A = 0.000549
From table CS-2 Metric: B = 546.0442 kg/cm^2 (535.49 bar)

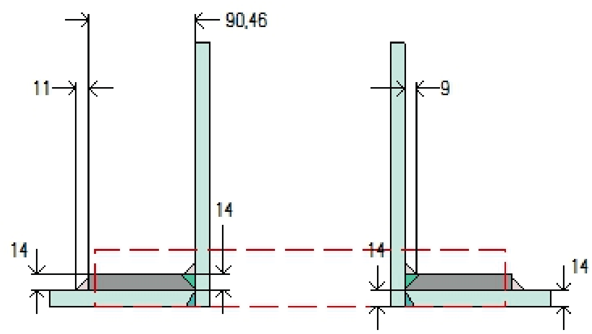
P_a = 4*B / (3*(D_o / t))
= 4*535.49 / (3*(406.4 / 1.66))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = 1.66 + = 1.66 mm

Nozzle (CD) 1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	200°
Nozzle center line offset to datum line	5,808 mm
End of nozzle to shell center	1,890 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 8 Sch 80 (XS) DN 200
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	193.68 mm
Pipe nominal wall thickness	12.7 mm
Pipe minimum wall thickness[1]	11.11 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	99.4 mm
Projection available outside vessel to flange face, Lf	201 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	400.01 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 8 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*96.84 / (1,180*1 - 0.6*3.6) =	0.3 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.3*1 / (11.11 - 0) =	0.0266
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
8.6371	49.9597	18.2845	7.4239	--	23.5585	0.6929	4.38	11.11

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-10,635	44,574	82,335	15,701	118,597	48,853	97,826

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(193.68, 96.84 + (12.7 - 0) + (14 - 0))$$
$$= 193.68 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(12.7 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*96.84 / (1,180*1 - 0.6*3.6)$$
$$= 0.3 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1,675 / (1,380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,203.264, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (193.68*4.38*1 + 2*12.7*4.38*1*(1 - 0.8551)) / 100
= 8.6371 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 18.2845 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (193.68*(1*14 - 1*4.38) - 2*12.7*(1*14 - 1*4.38)*(1 - 0.8551)) / 100
= 18.2845 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 12.7)*(1*14 - 1*4.38) - 2*12.7*(1*14 - 1*4.38)*(1 - 0.8551)) / 100
= 4.7845 cm^2

A_2 = smaller of the following= 7.4239 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(12.7 - 0.3)*0.8551*14) / 100
= 7.4239 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(12.7 - 0.3)*(2.5*12.7 + 14)*0.8551) / 100
= 9.7039 cm^2

A_{41} = Leg^2*f_{r3}
= $(9^2*0.8551) / 100$
= 0.6929 cm^2

A_{42} = Leg^2*f_{r4}

$= (0^2*1) / 100$
$= \underline{0}\ cm^2$

(Part of the weld is outside of the limits)

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((387.35 - 193.68 - 2*12.7)*14*1) / 100$
$= \underline{23.5585}\ cm^2$

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 18.2845 + 7.4239 + 0.6929 + 0 + 23.5585$
$= \underline{49.9597}\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 12.7 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = $\underline{6}$ mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = $0.5*t_{min}$ = $\underline{7}$ mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27} = P*R_n / (S_n*E - 0.6*P) + Corrosion$
$= 3.6*96.84 / (1,180*1 - 0.6*3.6) + 0$
$= 0.3$ mm

$t_a = max[\ t_{a\ UG-27}\ ,\ t_{a\ UG-22}\ ]$
$= max[\ 0.3\ ,\ 0\ ]$
$= 0.3$ mm

$t_{b1} = P*R / (S*E - 0.6*P) + Corrosion$
$= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0$
$= 4.38$ mm

$t_{b1} = max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$
$= max[\ 4.38\ ,\ 1.5\ ]$
$= 4.38$ mm

$t_b = min[\ t_{b3}\ ,\ t_{b1}\ ]$
$= min[\ 7.16\ ,\ 4.38\ ]$
$= 4.38$ mm

t_{UG-45} = max[t_a , t_b]
= max[0.3 , 4.38]
= 4.38 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,203.264 =	842.285 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,203.264 =	589.599 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*219.08*9*589.599 = 18,260.5 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*400.01*11*689.532 = 47,657.64 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*206.38*12.7*842.285 = 34,676.89 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*14*1,041.333 = 50,168.48 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*219.08*14*1,041.333 = 50,168.48 kg_f

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

W = $(A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
= (863.7104 - 1,828.448 + 2*12.7*0.8551*(1*14 - 1*4.38))*1,407.207
= -10,634.53 kg_f

W_{1-1} = $(A_2 + A_5 + A_{41} + A_{42})*S_v$
= (742.3856 + 2,355.85 + 69.2902 + 0)*1,407.207
= 44,573.69 kg_f

W_{2-2} = $(A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (742.3856 + 0 + 69.2902 + 0 + 2*12.7*14*0.8551)*1,407.207
= 15,700.92 kg_f

W_{3-3} = $(A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
= (742.3856 + 0 + 2,355.85 + 69.2902 + 0 + 0 + 2*12.7*14*0.8551)*1,407.207
= 48,852.64 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -10,634.53 kg_f
Path 1-1 through (2) & (3) = 47,657.64 + 34,676.89 = 82,334.53 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -10,634.53 kg_f
Path 2-2 through (1), (4), (6) = 18,260.5 + 50,168.48 + 50,168.48 = 118,597.45 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -10,634.53 kg_f
Path 3-3 through (2), (4) = 47,657.64 + 50,168.48 = 97,826.11 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
11.5902	35.5146	4.2832	6.98	--	23.5585	0.6929	3.54	11.11

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(193.68, 96.84 + (12.7 - 0) + (14 - 0))$$
$$= 193.68 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(12.7 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 1.04 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

Allowable stresses: S_n = 1,203.264, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
= (0.5*(193.68*11.75*1 + 2*12.7*11.75*1*(1 - 0.8551))) / 100
= 11.5902 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 4.2832 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (193.68*(1*14 - 1*11.75) - 2*12.7*(1*14 - 1*11.75)*(1 - 0.8551)) / 100
= 4.2832 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 12.7)*(1*14 - 1*11.75) - 2*12.7*(1*14 - 1*11.75)*(1 - 0.8551)) / 100
= 1.1206 cm^2

A_2 = smaller of the following= 6.98 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(12.7 - 1.04)*0.8551*14) / 100
= 6.98 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(12.7 - 1.04)*(2.5*12.7 + 14)*0.8551) / 100
= 9.1239 cm^2

A_{41} = Leg^2*f_{r3}
= $(9^2*0.8551)$ / 100
= 0.6929 cm^2

A_{42} = Leg^2*f_{r4}
= (0^2*1) / 100
= 0 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((387.35 - 193.68 - 2*12.7)*14*1) / 100
= 23.5585 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 4.2832 + 6.98 + 0.6929 + 0 + 23.5585
= 35.5146 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 12.7 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 1.04 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[1.04 , 0]
= 1.04 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[7.16 , 3.54]
= 3.54 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[1.04 , 3.54]
= 3.54 mm

Available nozzle wall thickness new, t_n = 0.875*12.7 = 11.11 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 204.56 / 219.08 = 0.9337
D_o / t = 219.08 / 1.04 = 210.7936

From table G: A = 0.000473
From table CS-2 Metric: B = 469.8193 kg/cm^2 (460.73 bar)

P_a = 4*B / (3*(D_o / t))
= 4*460.73 / (3*(219.08 / 1.04))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = 1.04 + = 1.04 mm

Nozzle (CF)

1

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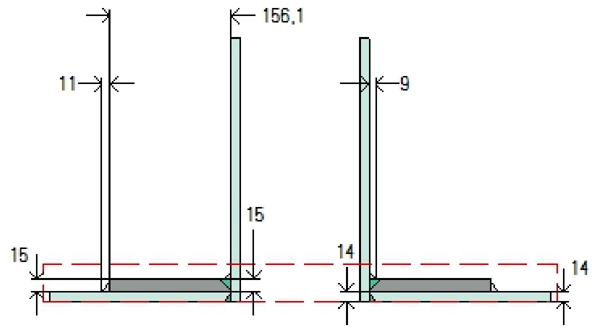

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	45°
Nozzle center line offset to datum line	5,808 mm
End of nozzle to shell center	1,940 mm
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	786.8 mm
Nominal wall thickness	13 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	143.05 mm
Projection available outside vessel to flange face, Lf	251 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	1,125 mm
Thickness, t_e	15 mm
Is split	No
Welds	
Inner fillet, Leg_{41}	9 mm

Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	15 mm

ASME B16.47-2011 Flange	
Description	NPS 32 Class 150 WN A105 Series B
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	786.8 mm
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1837) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*393.4 / (1,380*1 - 0.6*3.6) =	1.03 mm
Stress ratio = t_r*E^* / (t_n - c) = 1.03*1 / (13 - 0) =	0.0791
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
34.4337	132.9492	75.7186	8.38	--	46.83	2.0206	4.38	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-54,575	80,535	294,915	18,055	464,792	85,658	320,168

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, $R_n + (t_n - C_n) + (t - C)$)
= MAX(786.8, 393.4 + (13 - 0) + (14 - 0))
= 786.8 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*($t_n - C_n$) + t_e)
= MIN(2.5*(14 - 0), 2.5*(13 - 0) + 15)
= 35 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 3.6*393.4 / (1,380*1 - 0.6*3.6)
= 1.03 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*1 - 0.6*3.6)
= 4.38 mm

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (786.8*4.38*1 + 2*13*4.38*1*(1 - 1)) / 100
= 34.4337 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 75.7186 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (786.8*(1*14 - 1*4.38) - 2*13*(1*14 - 1*4.38)*(1 - 1)) / 100
= 75.7186 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 13)*(1*14 - 1*4.38) - 2*13*(1*14 - 1*4.38)*(1 - 1)) / 100
= 5.1968 cm^2

A_2 = smaller of the following= 8.38 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(13 - 1.03)*1*14) / 100
= 8.38 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(13 - 1.03)*(2.5*13 + 15)*1) / 100
= 11.3729 cm^2

A_{41} = Leg^2*f_{r3}
= (9^2*1) / 100
= 0.8103 cm^2

A_{42} = Leg^2*f_{r4}

$= (11^2*1) / 100$
$= \underline{1.2103}\ cm^2$

$A_5 = (D_p - d - 2*t_n)*t_e*f_{r4}$
$= ((1,125 - 786.8 - 2*13)*15*1) / 100$
$= \underline{46.83}\ cm^2$

$Area = A_1 + A_2 + A_{41} + A_{42} + A_5$
$= 75.7186 + 8.38 + 0.8103 + 1.2103 + 46.83$
$= \underline{132.9492}\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = $\underline{6}$ mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = $0.5*t_{min}$ = $\underline{7}$ mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27} = P*R_n / (S_n*E - 0.6*P) + Corrosion$
$= 3.6*393.4 / (1,380*1 - 0.6*3.6) + 0$
$= 1.03$ mm

$t_a = max[\ t_{a\ UG\text{-}27}\ ,\ t_{a\ UG\text{-}22}\ ]$
$= max[\ 1.03\ ,\ 0\ ]$
$= 1.03$ mm

$t_{b1} = P*R / (S*E - 0.6*P) + Corrosion$
$= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0$
$= 4.38$ mm

$t_{b1} = max[\ t_{b1}\ ,\ t_{b\ UG16}\ ]$
$= max[\ 4.38\ ,\ 1.5\ ]$
$= 4.38$ mm

$t_b = min[\ t_{b3}\ ,\ t_{b1}\ ]$
$= min[\ 8.33\ ,\ 4.38\ ]$
$= 4.38$ mm

$t_{UG\text{-}45} = max[\ t_a\ ,\ t_b\ ]$
$= max[\ 1.03\ ,\ 4.38\ ]$

= 4.38 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
$(\pi / 2)$*Nozzle OD*Leg*S_i = $(\pi / 2)$*812.8*9*689.532 = 79,232 kg_f

(2) Outer fillet weld in shear
$(\pi / 2)$*Pad OD*Leg*S_o = $(\pi / 2)$*1,125*11*689.532 = 134,035.43 kg_f

(3) Nozzle wall in shear
$(\pi / 2)$*Mean nozzle dia*t_n*S_n = $(\pi / 2)$*799.8*13*985.045 = 160,879.65 kg_f

(4) Groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*812.8*14*1,041.333 = 186,132.32 kg_f

(6) Upper groove weld in tension
$(\pi / 2)$*Nozzle OD*t_w*S_g = $(\pi / 2)$*812.8*15*1,041.333 = 199,427.48 kg_f

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

$W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v$
$= (3{,}443.3673 - 7{,}571.8558 + 2*13*1*(1*14 - 1*4.38))*1{,}407.207$
$=$ -54,575.42 kg_f

$W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v$
$= (837.9983 + 4{,}683 + 81.0321 + 121.032)*1{,}407.207$
$=$ 80,535.42 kg_f

$W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (837.9983 + 0 + 81.0321 + 0 + 2*13*14*1)*1{,}407.207$
$=$ 18,054.91 kg_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (837.9983 + 0 + 4{,}683 + 81.0321 + 121.032 + 0 + 2*13*14*1)*1{,}407.207$
$=$ 85,657.66 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -54,575.42 kg_f
Path 1-1 through (2) & (3) = 134,035.43 + 160,879.65 = 294,915.09 kg_f

Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -54,575.42 kg_f
Path 2-2 through (1), (4), (6) = 79,232 + 186,132.32 + 199,427.48 = 464,791.8 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -54,575.42 kg_f
Path 3-3 through (2), (4) = 134,035.43 + 186,132.32 = 320,167.75 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= (50*13 / 399.9)*(1 - 399.9 / infinity)
= 1.6254%

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
46.2067	73.857	17.7387	7.2677	--	46.83	2.0206	3.54	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(786.8, 393.4 + (13 - 0) + (14 - 0))$$
$$= 786.8 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(13 - 0) + 15)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 2.62 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

$$\begin{aligned} A &= 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})) \\ &= (0.5*(786.8*11.75*1 + 2*13*11.75*1*(1 - 1))) / 100 \\ &= 46.2067\ cm^2 \end{aligned}$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 17.7387 cm^2

$$\begin{aligned} &= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= (786.8*(1*14 - 1*11.75) - 2*13*(1*14 - 1*11.75)*(1 - 1)) / 100 \\ &= 17.7387\ cm^2 \end{aligned}$$

$$\begin{aligned} &= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\ &= (2*(14 + 13)*(1*14 - 1*11.75) - 2*13*(1*14 - 1*11.75)*(1 - 1)) / 100 \\ &= 1.2174\ cm^2 \end{aligned}$$

A_2 = smaller of the following= 7.2677 cm^2

$$\begin{aligned} &= 5*(t_n - t_{rn})*f_{r2}*t \\ &= (5*(13 - 2.62)*1*14) / 100 \\ &= 7.2677\ cm^2 \end{aligned}$$

$$\begin{aligned} &= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2} \\ &= (2*(13 - 2.62)*(2.5*13 + 15)*1) / 100 \\ &= 9.8632\ cm^2 \end{aligned}$$

$$\begin{aligned} A_{41} &= Leg^2*f_{r3} \\ &= (9^2*1) / 100 \\ &= 0.8103\ cm^2 \end{aligned}$$

$$\begin{aligned} A_{42} &= Leg^2*f_{r4} \\ &= (11^2*1) / 100 \\ &= 1.2103\ cm^2 \end{aligned}$$

$$\begin{aligned} A_5 &= (D_p - d - 2*t_n)*t_e*f_{r4} \\ &= ((1{,}125 - 786.8 - 2*13)*15*1) / 100 \\ &= 46.83\ cm^2 \end{aligned}$$

$$\begin{aligned} Area &= A_1 + A_2 + A_{41} + A_{42} + A_5 \\ &= 17.7387 + 7.2677 + 0.8103 + 1.2103 + 46.83 \\ &= 73.857\ cm^2 \end{aligned}$$

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 13 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 2.62 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[2.62 , 0]
= 2.62 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[8.33 , 3.54]
= 3.54 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[2.62 , 3.54]
= 3.54 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 300.62 / 812.8 = 0.3699
D_o / t = 812.8 / 2.62 = 310.5031

From table G: A = 0.000699
From table CS-2 Metric: B = 692.0637 kg/cm^2 (678.68 bar)

P_a = 4*B / (3*(D_o / t))
= 4*678.68 / (3*(812.8 / 2.62))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = 2.62 + = 2.62 mm

Nozzle (CL1)

1

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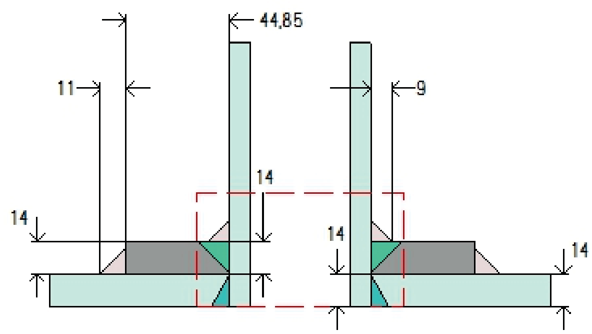

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	265°
Nozzle center line offset to datum line	6,128 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = $4*B / (3*(D_o / t))$
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CL2) 1

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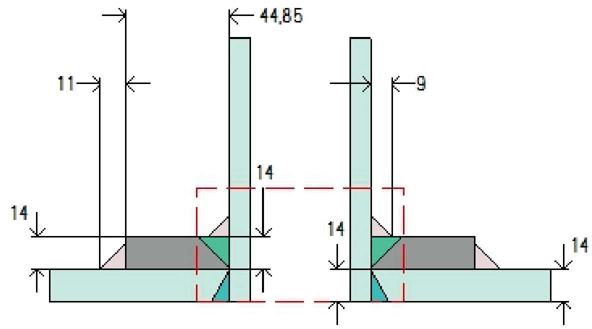

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	265°
Nozzle center line offset to datum line	178 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.26 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.25 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0754) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.86*21.42 / (1,180*1 - 0.6*3.86) =	0.0701 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0701*1 / (7.65 - 0) =	0.0092
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.86*1,675 / (1,380*1 - 0.6*3.86) =	4.69 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.69*1 / (14 - 0) =	0.3348
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.86 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.86 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.855*21.42 / (1{,}180*1 - 0.6*3.855)$$
$$= 0.0711 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.855*1{,}675 / (1{,}380*1 - 0.6*3.855)$$
$$= 4.69 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.855*1,675 / (1,380*0.85 - 0.6*3.855)
= 5.52 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.855*21.42 / (1,180*1 - 0.6*3.855) + 0
= 0.0711 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.0711 , 0]
= 0.0711 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.855*1,675 / (1,380*1 - 0.6*3.855) + 0
= 4.69 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.69 , 1.5]
= 4.69 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.69]
= 3.42 mm

t_{UG-45} = max[t_a , t_b]
= max[0.0711 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= \text{MAX}(d, R_n + (t_n - C_n) + (t - C)) \\
&= \text{MAX}(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\
&= 44.16 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= \text{MIN}(2.5^*(t - C), 2.5^*(t_n - C_n) + t_e) \\
&= \text{MIN}(2.5^*(14 - 0), 2.5^*(8.74 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7^*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CM1)

1

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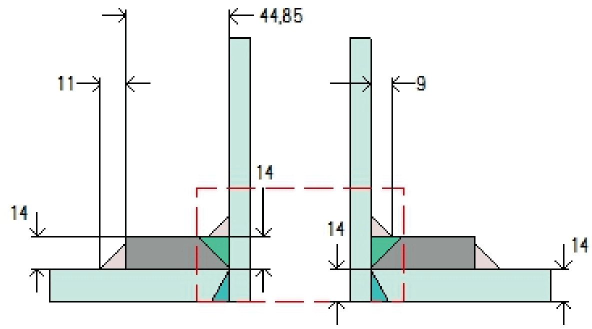


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	15°
Nozzle center line offset to datum line	6,128 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

t_{UG-45} = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\
&= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\
&= 44.16 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

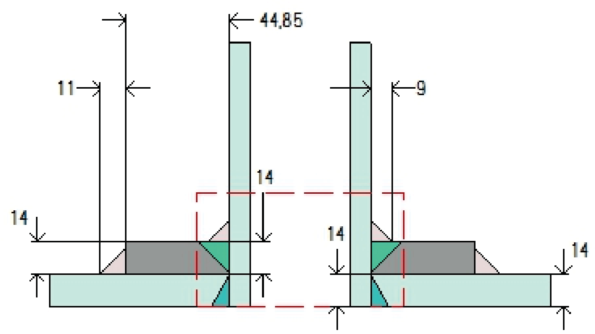
Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CM2)

1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	335°
Nozzle center line offset to datum line	6,128 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\
&= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\
&= 44.16 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

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

$$
\begin{aligned}
t_{rn} &= P*R_n / (S_n*E - 0.6*P) \\
&= 3.6*21.42 / (1{,}180*1 - 0.6*3.6) \\
&= 0.066 \text{ mm}
\end{aligned}
$$

Required thickness t_r from UG-37(a)

$$
\begin{aligned}
t_r &= P*R / (S*E - 0.6*P) \\
&= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6) \\
&= 4.38 \text{ mm}
\end{aligned}
$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

t_{UG-45} = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

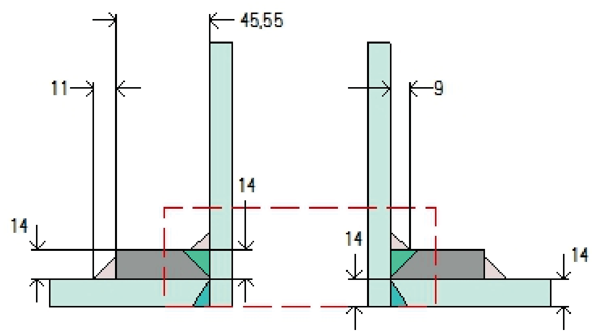
Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CN)

1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	310°
Nozzle center line offset to datum line	178 mm
End of nozzle to shell center	1,890 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 3 Sch 160 DN 80
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	66.65 mm
Pipe nominal wall thickness	11.13 mm
Pipe minimum wall thickness[1]	9.73 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	131.15 mm
Projection available outside vessel to flange face, Lf	201 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.26 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	180 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 3 Class 150 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.25 bar
MAWP rating	13.73 bar @ 202°C
MAP rating	19.6 bar @ 30°C
Hydrotest rating	30 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.1966) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.86*33.32 / (1,180*1 - 0.6*3.86) =	0.11 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.11*1 / (9.73 - 0) =	0.0112
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.86*1,675 / (1,380*1 - 0.6*3.86) =	4.69 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.69*1 / (14 - 0) =	0.3349
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.86 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							4.69	9.73

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.86 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\
&= MAX(66.65, 33.32 + (11.13 - 0) + (14 - 0)) \\
&= 66.65 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= MIN(2.5*(14 - 0), 2.5*(11.13 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

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

$$
\begin{aligned}
t_{rn} &= P*R_n / (S_n*E - 0.6*P) \\
&= 3.8562*33.32 / (1{,}180*1 - 0.6*3.8562) \\
&= 0.11 \text{ mm}
\end{aligned}
$$

Required thickness t_r from UG-37(a)

$$
\begin{aligned}
t_r &= P*R / (S*E - 0.6*P) \\
&= 3.8562*1{,}675 / (1{,}380*1 - 0.6*3.8562) \\
&= 4.69 \text{ mm}
\end{aligned}
$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.8562*1,675 / (1,380*0.85 - 0.6*3.8562)
= 5.52 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.13 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.8562*33.32 / (1,180*1 - 0.6*3.8562) + 0
= 0.11 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.11 , 0]
= 0.11 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.8562*1,675 / (1,380*1 - 0.6*3.8562) + 0
= 4.69 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.69 , 1.5]
= 4.69 mm

t_b = min[t_{b3} , t_{b1}]
= min[4.8 , 4.69]
= 4.69 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.11 , 4.69]
= 4.69 mm

Available nozzle wall thickness new, t_n = 0.875*11.13 = 9.73 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
4.8911	13.2004	--	6.2916	--	6.2159	0.6929	3.54	9.73

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(66.65, 33.32 + (11.13 - 0) + (14 - 0))$$
$$= 66.65 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(11.13 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.61 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

Allowable stresses: S_n = 1,203.264, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 0.8551

f_{r2} = lesser of 1 or S_n / S_v = 0.8551

f_{r3} = lesser of f_{r2} or S_p / S_v = 0.8551

f_{r4} = lesser of 1 or S_p / S_v = 1

A	=	$0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1}))$
	=	(0.5*(66.65*14*1 + 2*11.13*14*1*(1 - 0.8551))) / 100
	=	4.8911 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 0 cm^2

$= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (66.65*(1*14 - 1*14) - 2*11.13*(1*14 - 1*14)*(1 - 0.8551)) / 100
= 0 cm^2

$= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(14 + 11.13)*(1*14 - 1*14) - 2*11.13*(1*14 - 1*14)*(1 - 0.8551)) / 100
= 0 cm^2

A_2 = smaller of the following= 6.2916 cm^2

$= 5*(t_n - t_{rn})*f_{r2}*t$
= (5*(11.13 - 0.61)*0.8551*14) / 100
= 6.2916 cm^2

$= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(11.13 - 0.61)*(2.5*11.13 + 14)*0.8551) / 100
= 7.5168 cm^2

A_{41}	=	Leg^2*f_{r3}
	=	$(9^2*0.8551)$ / 100
	=	0.6929 cm^2

A_{42}	=	Leg^2*f_{r4}
	=	(0^2*1) / 100
	=	0 cm^2

(Part of the weld is outside of the limits)

A_5	=	$(D_p - d - 2*t_n)*t_e*f_{r4}$
	=	((133.3 - 66.65 - 2*11.13)*14*1) / 100
	=	6.2159 cm^2

Area	=	$A_1 + A_2 + A_{41} + A_{42} + A_5$
	=	0 + 6.2916 + 0.6929 + 0 + 6.2159
	=	13.2004 cm^2

As Area >= A the reinforcement is adequate.

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 11.13 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.61 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.61 , 0]
= 0.61 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[4.8 , 3.54]
= 3.54 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.61 , 3.54]
= 3.54 mm

Available nozzle wall thickness new, t_n = 0.875*11.13 = 9.73 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 201.59 / 88.9 = 2.2675
D_o / t = 88.9 / .61 = 144.8443

From table G: A = 0.000326
From table CS-2 Metric: B = 322.8268 kg/cm^2 (316.58 bar)

P_a = 4*B / (3*(D_o / t))
= 4*316.58 / (3*(88.9 / .61))
= 2.91 bar

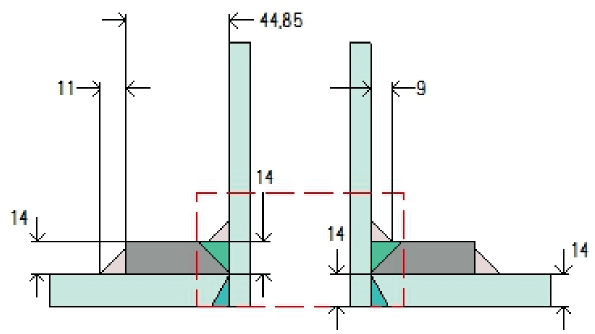
Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .61 + = .61 mm

Nozzle (CO1)

1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	345°
Nozzle center line offset to datum line	6,333 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$\begin{aligned} L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\ &= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\ &= 44.16 \text{ mm} \end{aligned}$$

Outer Normal Limit of reinforcement per UG-40

$$\begin{aligned} L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\ &= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14) \\ &= 35 \text{ mm} \end{aligned}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO2)

1

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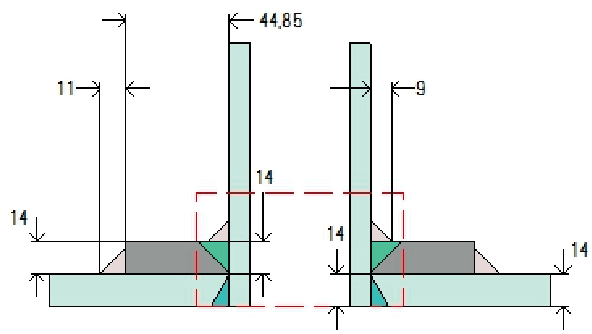


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	275°
Nozzle center line offset to datum line	4,838 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \text{MAX}(d, R_n + (t_n - C_n) + (t - C))$$
$$= \text{MAX}(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= \text{MIN}(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \text{MAX}(d, R_n + (t_n - C_n) + (t - C))$$
$$= \text{MAX}(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= \text{MIN}(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 12.05 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

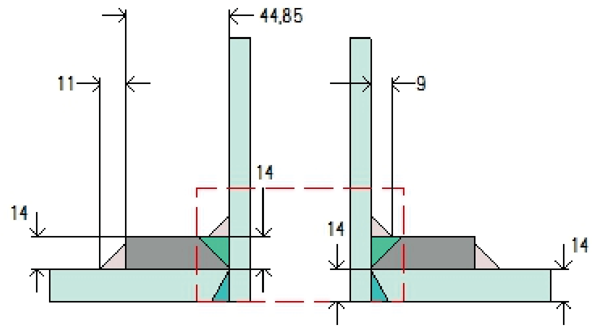
Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO3)

1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	345°
Nozzle center line offset to datum line	4,663 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))
= 44.16 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)
= 35 mm

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 12.05 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

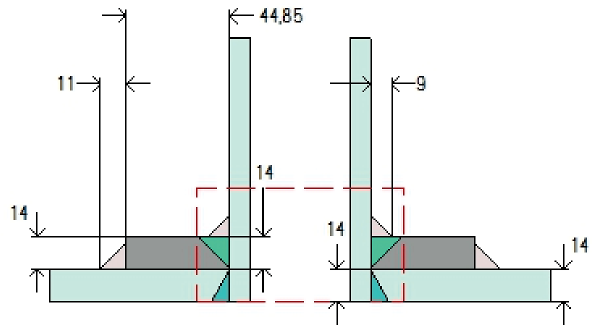
From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO4)



ASME Section VIII Division 1, 2017 Edition Metric	
Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Bottom existing shell
Orientation	305°
Nozzle center line offset to datum line	3,343 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No
Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.6 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.6*21.42 / (1{,}180*1 - 0.6*3.6)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.6*1{,}675 / (1{,}380*1 - 0.6*3.6)$$
$$= 4.38 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= MAX(d, R_n + (t_n - C_n) + (t - C)) \\
&= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\
&= 44.16 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO5) 1

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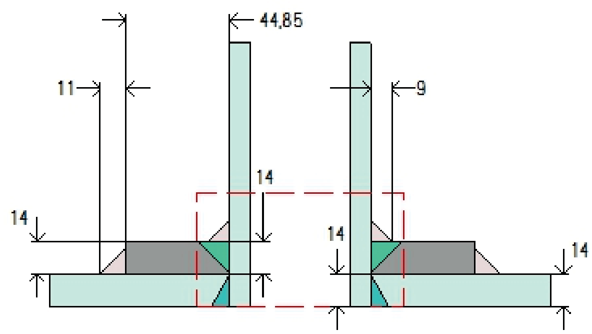

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	275°
Nozzle center line offset to datum line	3,168 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0705) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.6*21.42 / (1,180*1 - 0.6*3.6) =	0.0655 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0655*1 / (7.65 - 0) =	0.0086
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.6*1,675 / (1,380*1 - 0.6*3.6) =	4.38 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.38*1 / (14 - 0) =	0.3126
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (cm^2)</th><th colspan="2">UG-45 Summary (mm)</th></tr>
<tr><td colspan="7">For P = 3.6 bar @ 202 °C</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>3.42</td><td>7.65</td></tr>
</table>

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

UW-16 Weld Sizing Summary

Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.6 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = $MAX(d, R_n + (t_n - C_n) + (t - C))$
= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))
= 44.16 mm

Outer Normal Limit of reinforcement per UG-40

L_H = $MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$
= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)
= 35 mm

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

t_{rn} = $P*R_n / (S_n*E - 0.6*P)$
= 3.6*21.42 / (1,180*1 - 0.6*3.6)
= 0.066 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*1 - 0.6*3.6)
= 4.38 mm

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

t_r = P*R / (S*E - 0.6*P)
= 3.6*1,675 / (1,380*0.85 - 0.6*3.6)
= 5.15 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6*21.42 / (1,180*1 - 0.6*3.6) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6*1,675 / (1,380*1 - 0.6*3.6) + 0
= 4.38 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.38 , 1.5]
= 4.38 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.38]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, $R_n + (t_n - C_n) + (t - C)$)
= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))
= 44.16 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*($t_n - C_n$) + t_e)
= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)
= 35 mm

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 11.75 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm

$t_{w(min)}$ = $0.5*t_{min}$ = 7 mm

$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = $4*B / (3*(D_o / t))$
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO6)

1

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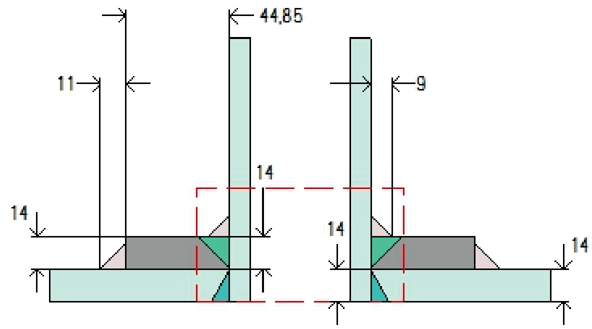

Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	275°
Nozzle center line offset to datum line	1,848 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.08 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.08 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.072) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.68*21.42 / (1,180*1 - 0.6*3.68) =	0.067 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.067*1 / (7.65 - 0) =	0.0088
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.68*1,675 / (1,380*1 - 0.6*3.68) =	4.47 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.47*1 / (14 - 0) =	0.3196
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (cm^2)</th><th colspan="2">UG-45 Summary (mm)</th></tr>
<tr><td colspan="7">For P = 3.68 bar @ 202 °C</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>3.42</td><td>7.65</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 size (mm)</td><td>Actual weld size (mm)</td><td>Status</td></tr>
<tr><td>Nozzle to pad fillet (Leg_{41})</td><td>6</td><td>6.3</td><td>weld size is adequate</td></tr>
<tr><td>Pad to shell fillet (Leg_{42})</td><td>7</td><td>7.7</td><td>weld size is adequate</td></tr>
</table>

Calculations for internal pressure 3.68 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))
= 44.16 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)
= 35 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 3.6807*21.42 / (1,180*1 - 0.6*3.6807)
= 0.066 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 3.6807*1,675 / (1,380*1 - 0.6*3.6807)
= 4.47 mm

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

t_r = P*R / (S*E - 0.6*P)
= 3.6807*1,675 / (1,380*0.85 - 0.6*3.6807)
= 5.27 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.6807*21.42 / (1,180*1 - 0.6*3.6807) + 0
= 0.066 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.6807*1,675 / (1,380*1 - 0.6*3.6807) + 0
= 4.48 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.48 , 1.5]
= 4.48 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.48]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$
\begin{aligned}
L_R &= \text{MAX}(d, R_n + (t_n - C_n) + (t - C)) \\
&= \text{MAX}(42.85, 21.42 + (8.74 - 0) + (14 - 0)) \\
&= 44.16 \text{ mm}
\end{aligned}
$$

Outer Normal Limit of reinforcement per UG-40

$$
\begin{aligned}
L_H &= \text{MIN}(2.5*(t - C), 2.5*(t_n - C_n) + t_e) \\
&= \text{MIN}(2.5*(14 - 0), 2.5*(8.74 - 0) + 14) \\
&= 35 \text{ mm}
\end{aligned}
$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO7)

1

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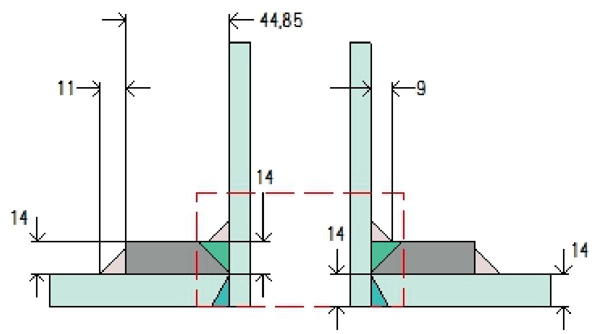


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom existing shell
Orientation	305°
Nozzle center line offset to datum line	1,673 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.1 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.1 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0723) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.7*21.42 / (1,180*1 - 0.6*3.7) =	0.0673 mm
Stress ratio = t_r*E* / (t_n - c) = 0.0673*1 / (7.65 - 0) =	0.0088
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.7*1,675 / (1,380*1 - 0.6*3.7) =	4.5 mm
Stress ratio = t_r*E* / (t_n - c) = 4.5*1 / (14 - 0) =	0.3212
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 3.7 bar @ 202 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for internal pressure 3.7 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 3.699*21.42 / (1,180*1 - 0.6*3.699)$$
$$= 0.066 \text{ mm}$$

Required thickness t_r from UG-37(a)

$$t_r = P*R / (S*E - 0.6*P)$$
$$= 3.699*1,675 / (1,380*1 - 0.6*3.699)$$
$$= 4.5 \text{ mm}$$

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

t_r = P*R / (S*E - 0.6*P)
= 3.699*1,675 / (1,380*0.85 - 0.6*3.699)
= 5.29 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG-27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.699*21.42 / (1,180*1 - 0.6*3.699) + 0
= 0.066 mm

t_a = max[$t_{a\ UG-27}$, $t_{a\ UG-22}$]
= max[0.066 , 0]
= 0.066 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.699*1,675 / (1,380*1 - 0.6*3.699) + 0
= 4.5 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.5 , 1.5]
= 4.5 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.5]
= 3.42 mm

t_{UG-45} = max[t_a , t_b]
= max[0.066 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = \text{MAX}(d, R_n + (t_n - C_n) + (t - C))$$
$$= \text{MAX}(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = \text{MIN}(2.5^*(t - C), 2.5^*(t_n - C_n) + t_e)$$
$$= \text{MIN}(2.5^*(14 - 0), 2.5^*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or 0.7^*t_{min} = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm

$t_{w(min)}$ = 0.5*t_{min} = 7 mm

$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

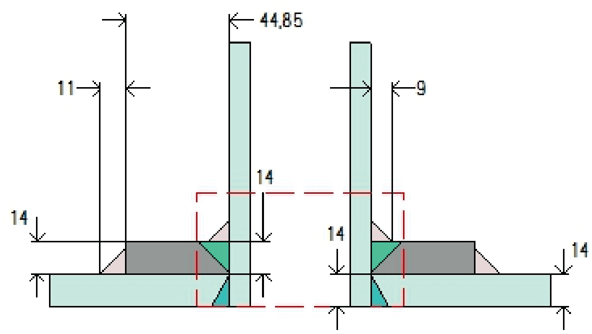
Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (CO8)

1

ASME Section VIII Division 1, 2017 Edition Metric	



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

Location and Orientation	
Located on	Bottom existing shell
Orientation	275°
Nozzle center line offset to datum line	178 mm
End of nozzle to shell center	1,840 mm
Passes through a Category A joint	No

Nozzle	
Description	NPS 2 Sch 160 DN 50
Access opening	No
Material specification	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Inside diameter, new	42.85 mm
Pipe nominal wall thickness	8.74 mm
Pipe minimum wall thickness[1]	7.65 mm
Corrosion allowance	0 mm
Projection available outside vessel, Lpr	81.15 mm
Projection available outside vessel to flange face, Lf	151 mm
Local vessel minimum thickness	14 mm
Liquid static head included	0.26 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	150.03 mm
Thickness, t_e	14 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm
Outer fillet, Leg_{42}	11 mm
Nozzle to vessel groove weld	14 mm
Pad groove weld	14 mm

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

ASME B16.5-2013 Flange	
Description	NPS 2 Class 300 WN A105
Bolt Material	SA-193 B7 Bolt <= 64 (II-D Metric p. 388, ln. 32)
Blind included	No
Rated MDMT	-48°C
Liquid static head	0.25 bar
MAWP rating	43.72 bar @ 202°C
MAP rating	51.1 bar @ 30°C
Hydrotest rating	77 bar @ 30°C
PWHT performed	Yes
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Notes	
Flange rated MDMT per UCS-66(b)(3) = -105°C (Coincident ratio = 0.0754) Bolts rated MDMT per Fig UCS-66 note (c) = -48°C	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 3.86*21.42 / (1,180*1 - 0.6*3.86) =	0.0701 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.0701*1 / (7.65 - 0) =	0.0092
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
t_r = 3.86*1,675 / (1,380*1 - 0.6*3.86) =	4.69 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.69*1 / (14 - 0) =	0.3348
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

<table>
<tr><th colspan="7">UG-37 Area Calculation Summary (cm^2)</th><th colspan="2">UG-45 Summary (mm)</th></tr>
<tr><td colspan="7">For P = 3.86 bar @ 202 °C</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>3.42</td><td>7.65</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 size (mm)</td><td>Actual weld size (mm)</td><td>Status</td></tr>
<tr><td>Nozzle to pad fillet (Leg_{41})</td><td>6</td><td>6.3</td><td>weld size is adequate</td></tr>
<tr><td>Pad to shell fillet (Leg_{42})</td><td>7</td><td>7.7</td><td>weld size is adequate</td></tr>
</table>

Calculations for internal pressure 3.86 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

L_R = MAX(d, R_n + (t_n - C_n) + (t - C))
= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))
= 44.16 mm

Outer Normal Limit of reinforcement per UG-40

L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)
= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)
= 35 mm

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

t_{rn} = P*R_n / (S_n*E - 0.6*P)
= 3.855*21.42 / (1,180*1 - 0.6*3.855)
= 0.0711 mm

Required thickness t_r from UG-37(a)

t_r = P*R / (S*E - 0.6*P)
= 3.855*1,675 / (1,380*1 - 0.6*3.855)
= 4.69 mm

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

t_r = P*R / (S*E - 0.6*P)
= 3.855*1,675 / (1,380*0.85 - 0.6*3.855)
= 5.52 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm
$t_{c(min)}$ = lesser of 6 mm or 0.7*t_{min} = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}27}$ = P*R_n / (S_n*E - 0.6*P) + Corrosion
= 3.855*21.42 / (1,180*1 - 0.6*3.855) + 0
= 0.0711 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[0.0711 , 0]
= 0.0711 mm

t_{b1} = P*R / (S*E - 0.6*P) + Corrosion
= 3.855*1,675 / (1,380*1 - 0.6*3.855) + 0
= 4.69 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[4.69 , 1.5]
= 4.69 mm

t_b = min[t_{b3} , t_{b1}]
= min[3.42 , 4.69]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.0711 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 2.91 bar @ 175 °C							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							3.42	7.65

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	7	7.7	weld size is adequate

Calculations for external pressure 2.91 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(42.85, 21.42 + (8.74 - 0) + (14 - 0))$$
$$= 44.16 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(14 - 0), 2.5*(8.74 - 0) + 14)$$
$$= 35 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 0.43 mm

From UG-37(d)(1) required thickness t_r = 14 mm

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

UW-16(c)(2) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 8.74 mm

$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm

$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 14 mm
$t_{w(min)}$ = 0.5*t_{min} = 7 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*11 = 7.7 mm

UG-45 Nozzle Neck Thickness Check

$t_{a\ UG\text{-}28}$ = 0.43 mm

t_a = max[$t_{a\ UG\text{-}28}$, $t_{a\ UG\text{-}22}$]
= max[0.43 , 0]
= 0.43 mm

t_{b2} = P*R / (S*E - 0.6*P) + Corrosion
= 2.9143*1,675 / (1,380*1 - 0.6*2.9143) + 0
= 3.54 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[3.54 , 1.5]
= 3.54 mm

t_b = min[t_{b3} , t_{b2}]
= min[3.42 , 3.54]
= 3.42 mm

$t_{UG\text{-}45}$ = max[t_a , t_b]
= max[0.43 , 3.42]
= 3.42 mm

Available nozzle wall thickness new, t_n = 0.875*8.74 = 7.65 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 151.27 / 60.33 = 2.5076
D_o / t = 60.33 / .43 = 139.0659

From table G: A = 0.000313
From table CS-2 Metric: B = 309.9467 kg/cm^2 (303.95 bar)

P_a = 4*B / (3*(D_o / t))
= 4*303.95 / (3*(60.33 / .43))
= 2.91 bar

Design thickness for external pressure P_a = 2.91 bar

t_a = t + Corrosion = .43 + = .43 mm

Nozzle (DC) 1

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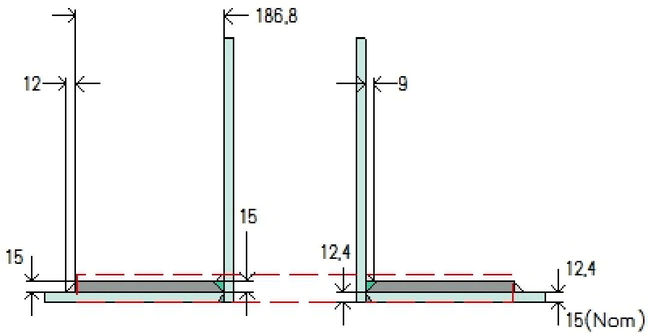


Note: round inside edges per UG-76(c)

Location and Orientation	
Located on	Bottom Head
Orientation	90°
End of nozzle to datum line	-1,614.4 mm
Calculated as hillside	No
Distance to head center, R	0 mm
Passes through a Category A joint	No

Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Inside diameter, new	380.4 mm
Nominal wall thickness	13 mm
Corrosion allowance	3 mm
Projection available outside vessel, Lpr	770.68 mm
Local vessel minimum thickness	12.4 mm
Liquid static head included	0.44 bar
Longitudinal joint efficiency	1

Reinforcing Pad	
Material specification	SA-516 70 (II-D Metric p. 18, ln. 33)
Diameter, D_p	780 mm
Thickness, t_e	15 mm
Is split	No

Welds	
Inner fillet, Leg_{41}	9 mm

Outer fillet, Leg_{42}	12 mm
Nozzle to vessel groove weld	12.4 mm
Pad groove weld	15 mm

UCS-66 Material Toughness Requirements Nozzle At Intersection	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 4.04*0.8984*3,356 / (2*1,380*1 - 0.2*4.04) =	4.41 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.41*1 / (12.4 - 3) =	0.4695
Reduction in MDMT, T_R from Fig UCS-66.1M =	35.5°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 35.5 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Nozzle	
t_r = 4.04*193.2 / (1,380*1 - 0.6*4.04) =	0.57 mm
Stress ratio = t_r*E^* / (t_n - c) = 0.57*1 / (13 - 3) =	0.0566
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-105°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

UCS-66 Material Toughness Requirements Pad	
Governing thickness, t_g =	13 mm
Exemption temperature from Fig UCS-66M Curve B =	-21.25°C
t_r = 4.04*0.8984*3,356 / (2*1,380*1 - 0.2*4.04) =	4.41 mm
Stress ratio = t_r*E^* / (t_n - c) = 4.41*1 / (12.4 - 3) =	0.4695
Reduction in MDMT, T_R from Fig UCS-66.1M =	35.5°C
Reduction in MDMT, T_{PWHT} from UCS-68(c) =	17°C
MDMT = max[MDMT - T_R - T_{PWHT}, -48] = max[-21.25 - 35.5 - 17 , -48] =	-48°C
Material is exempt from impact testing at the Design MDMT of 17°C.	

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For P = 4.04 bar @ 202 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
17.0518	79.4727	19.2709	4.4342	--	54.9598	0.8077	7.9	13

UG-41 Weld Failure Path Analysis Summary (kg_f)						
All failure paths are stronger than the applicable weld loads						
Weld load W	Weld load W_{1-1}	Path 1-1 strength	Weld load W_{2-2}	Path 2-2 strength	Weld load W_{3-3}	Path 3-3 strength
-1,719	84,716	162,716	10,022	201,819	87,362	163,869

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for internal pressure 4.04 bar @ 202 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(386.4, 193.2 + (13 - 3) + (12.4 - 3))$$
$$= 386.4 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)$$
$$= 23.5 \text{ mm}$$

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

$$t_{rn} = P*R_n / (S_n*E - 0.6*P)$$
$$= 4.0385*193.2 / (1{,}380*1 - 0.6*4.0385)$$
$$= 0.57 \text{ mm}$$

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

$$t_r = P*K_1*D / (2*S*E - 0.2*P)$$
$$= 4.0385*0.8984*3{,}356 / (2*1{,}380*1 - 0.2*4.0385)$$
$$= 4.41 \text{ mm}$$

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

t_r = P*D*K / (2*S*E - 0.2*P)
= 4.04*3,356*0.997623 / (2*1,380*1 - 0.2*4.04)
= 4.9 mm

Area required per UG-37(c)

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or S_p / S_v = 1

f_{r4} = lesser of 1 or S_p / S_v = 1

A = $d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})$
= (386.4*4.41*1 + 2*10*4.41*1*(1 - 1)) / 100
= 17.0518 cm^2

Area available from FIG. UG-37.1

A_1 = larger of the following= 19.2709 cm^2

= $d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (386.4*(1*9.4 - 1*4.41) - 2*10*(1*9.4 - 1*4.41)*(1 - 1)) / 100
= 19.2709 cm^2

= $2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1})$
= (2*(9.4 + 10)*(1*9.4 - 1*4.41) - 2*10*(1*9.4 - 1*4.41)*(1 - 1)) / 100
= 1.9348 cm^2

A_2 = smaller of the following= 4.4342 cm^2

= $5*(t_n - t_{rn})*f_{r2}*t$
= (5*(10 - 0.57)*1*9.4) / 100
= 4.4342 cm^2

= $2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2}$
= (2*(10 - 0.57)*(2.5*10 + 15)*1) / 100
= 7.5471 cm^2

A_{41} = Leg^2*f_{r3}
= (8.99^2*1) / 100
= 0.8077 cm^2

(Part of the weld is outside of the limits)

A_{42} = Leg^2*f_{r4}
= $(0^2*1) / 100$
= 0 cm^2

(Part of the weld is outside of the limits)

A_5 = $(D_p - d - 2*t_n)*t_e*f_{r4}$
= ((772.8 - 386.4 - 2*10)*15*1) / 100
= 54.9598 cm^2

Area = $A_1 + A_2 + A_{41} + A_{42} + A_5$
= 19.2709 + 4.4342 + 0.8077 + 0 + 54.9598
= 79.4727 cm^2

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = $0.7*t_{min}$ = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG\text{-}27}$ = $P*R_n / (S_n*E - 0.6*P)$ + Corrosion
= 4.0398*193.2 / (1,380*1 - 0.6*4.0398) + 3
= 3.57 mm

t_a = max[$t_{a\ UG\text{-}27}$, $t_{a\ UG\text{-}22}$]
= max[3.57 , 0]
= 3.57 mm

t_{b1} = 7.9 mm

t_{b1} = max[t_{b1} , $t_{b\ UG16}$]
= max[7.9 , 4.5]
= 7.9 mm

t_b = min[t_{b3} , t_{b1}]
= min[11.33 , 7.9]
= 7.9 mm

t_{UG-45} = max[t_a , t_b]
= max[3.57 , 7.9]
= 7.9 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

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

Groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2
Nozzle wall in shear:	0.7*1,407.207 =	985.045 kg_f/cm^2
Inner fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Outer fillet weld in shear:	0.49*1,407.207 =	689.532 kg_f/cm^2
Upper groove weld in tension:	0.74*1,407.207 =	1,041.333 kg_f/cm^2

Strength of welded joints:

(1) Inner fillet weld in shear
(π / 2)*Nozzle OD*Leg*S_i = (π / 2)*406.4*9*689.532 = 39,616 kg_f

(2) Outer fillet weld in shear
(π / 2)*Pad OD*Leg*S_o = (π / 2)*780*12*689.532 = 101,379.53 kg_f

(3) Nozzle wall in shear
(π / 2)*Mean nozzle dia*t_n*S_n = (π / 2)*396.4*10*985.045 = 61,336.79 kg_f

(4) Groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*406.4*9.4*1,041.333 = 62,489.01 kg_f

(6) Upper groove weld in tension
(π / 2)*Nozzle OD*t_w*S_g = (π / 2)*406.4*15*1,041.333 = 99,713.74 kg_f

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

W = (A - A_1 + 2*t_n*f_{r1}*(E_1*t - F*t_r))*S_v
= (1,705.1794 - 1,927.0929 + 2*10*1*(1*9.4 - 1*4.41))*1,407.207
= -1,719.13 kg_f

W_{1-1} = (A_2 + A_5 + A_{41} + A_{42})*S_v
= (443.4185 + 5,495.9844 + 80.774 + 0)*1,407.207
= 84,716.44 kg_f

W_{2-2} = (A_2 + A_3 + A_{41} + A_{43} + 2*t_n*t*f_{r1})*S_v
= (443.4185 + 0 + 80.774 + 0 + 2*10*9.4*1)*1,407.207
= 10,022.18 kg_f

$W_{3-3} = (A_2 + A_3 + A_5 + A_{41} + A_{42} + A_{43} + 2*t_n*t*f_{r1})*S_v$
$= (443.4185 + 0 + 5,495.9844 + 80.774 + 0 + 0 + 2*10*9.4*1)*1,407.207$
$=$ 87,362.14 kg_f

Load for path 1-1 lesser of W or W_{1-1} = -1,719.13 kg_f
Path 1-1 through (2) & (3) = 101,379.53 + 61,336.79 = 162,716.31 kg_f
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W_{2-2} = -1,719.13 kg_f
Path 2-2 through (1), (4), (6) = 39,616 + 62,489.01 + 99,713.74 = 201,818.75 kg_f
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W_{3-3} = -1,719.13 kg_f
Path 3-3 through (2), (4) = 101,379.53 + 62,489.01 = 163,868.53 kg_f
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
$= (50*13 / 196.7)*(1 - 196.7 / \text{infinity})$
$= 3.3045\%$

The extreme fiber elongation does not exceed 5%.

Reinforcement Calculations for MAEP

UG-37 Area Calculation Summary (cm^2)							UG-45 Summary (mm)	
For Pe = 1.18 bar @ 175 °C The opening is adequately reinforced							The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
18.1608	58.9179	0.0006	3.1497	--	54.9598	0.8077	6.3	13

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

UW-16 Weld Sizing Summary			
Weld description	Required weld size (mm)	Actual weld size (mm)	Status
Nozzle to pad fillet (Leg_{41})	6	6.3	weld size is adequate
Pad to shell fillet (Leg_{42})	6	8.4	weld size is adequate
Nozzle to shell groove (Lower)	7	9.4	weld size is adequate

Calculations for external pressure 1.18 bar @ 175 °C

Parallel Limit of reinforcement per UG-40

$$L_R = MAX(d, R_n + (t_n - C_n) + (t - C))$$
$$= MAX(386.4, 193.2 + (13 - 3) + (12.4 - 3))$$
$$= 386.4 \text{ mm}$$

Outer Normal Limit of reinforcement per UG-40

$$L_H = MIN(2.5*(t - C), 2.5*(t_n - C_n) + t_e)$$
$$= MIN(2.5*(12.4 - 3), 2.5*(13 - 3) + 15)$$
$$= 23.5 \text{ mm}$$

Nozzle required thickness per UG-28 t_{rn} = 3.3 mm

From UG-37(d)(1) required thickness t_r = 9.4 mm

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

Allowable stresses: S_n = 1,407.207, S_v = 1,407.207, S_p = 1,407.207 kg_f/cm^2

f_{r1} = lesser of 1 or S_n / S_v = 1

f_{r2} = lesser of 1 or S_n / S_v = 1

f_{r3} = lesser of f_{r2} or $S_p / S_v = 1$

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

$$
\begin{aligned}
A &= 0.5*(d*t_r*F + 2*t_n*t_r*F*(1 - f_{r1})) \\
&= (0.5*(386.4*9.4*1 + 2*10*9.4*1*(1 - 1))) / 100 \\
&= \underline{18.1608}\ \text{cm}^2
\end{aligned}
$$

Area available from FIG. UG-37.1

A_1 = larger of the following= 0.0006 cm^2

$$
\begin{aligned}
&= d*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= (386.4*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100 \\
&= 0.0006\ \text{cm}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2*(t + t_n)*(E_1*t - F*t_r) - 2*t_n*(E_1*t - F*t_r)*(1 - f_{r1}) \\
&= (2*(9.4 + 10)*(1*9.4 - 1*9.4) - 2*10*(1*9.4 - 1*9.4)*(1 - 1)) / 100 \\
&= 0\ \text{cm}^2
\end{aligned}
$$

A_2 = smaller of the following= 3.1497 cm^2

$$
\begin{aligned}
&= 5*(t_n - t_{rn})*f_{r2}*t \\
&= (5*(10 - 3.3)*1*9.4) / 100 \\
&= 3.1497\ \text{cm}^2
\end{aligned}
$$

$$
\begin{aligned}
&= 2*(t_n - t_{rn})*(2.5*t_n + t_e)*f_{r2} \\
&= (2*(10 - 3.3)*(2.5*10 + 15)*1) / 100 \\
&= 5.3606\ \text{cm}^2
\end{aligned}
$$

$$
\begin{aligned}
A_{41} &= Leg^2*f_{r3} \\
&= (8.99^2*1) / 100 \\
&= \underline{0.8077}\ \text{cm}^2
\end{aligned}
$$

(Part of the weld is outside of the limits)

$$
\begin{aligned}
A_{42} &= Leg^2*f_{r4} \\
&= (0^2*1) / 100 \\
&= \underline{0}\ \text{cm}^2
\end{aligned}
$$

(Part of the weld is outside of the limits)

$$
\begin{aligned}
A_5 &= (D_p - d - 2*t_n)*t_e*f_{r4} \\
&= ((772.8 - 386.4 - 2*10)*15*1) / 100 \\
&= \underline{54.9598}\ \text{cm}^2
\end{aligned}
$$

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

$= 0.0006 + 3.1497 + 0.8077 + 0 + 54.9598$
$= 58.9179\ cm^2$

As Area >= A the reinforcement is adequate.

UW-16(d) Weld Check

Inner fillet: t_{min} = lesser of 19 mm or t_n or t_e = 10 mm
$t_{c(min)}$ = lesser of 6 mm or $0.7*t_{min}$ = 6 mm
$t_{c(actual)}$ = 0.7*Leg = 0.7*9 = 6.3 mm

Outer fillet: t_{min} = lesser of 19 mm or t_e or t = 12 mm
$t_{w(min)}$ = $0.5*t_{min}$ = 6 mm
$t_{w(actual)}$ = 0.7*Leg = 0.7*12 = 8.4 mm

Lower groove: t_{min} = lesser of 19 mm or t_n or t = 10 mm
$t_{w(min)}$ = $0.7*t_{min}$ = 7 mm
$t_{w(actual)}$ = 9.4 mm

UG-45 Nozzle Neck Thickness Check

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

$t_{a\ UG-28}$ = 6.3 mm

t_a = max[$t_{a\ UG-28}$, $t_{a\ UG-22}$]
= max[6.3 , 0]
= 6.3 mm

t_{b2} = 4.43 mm

t_{b2} = max[t_{b2} , $t_{b\ UG16}$]
= max[4.43 , 4.5]
= 4.5 mm

t_b = min[t_{b3} , t_{b2}]
= min[11.33 , 4.5]
= 4.5 mm

t_{UG-45} = max[t_a , t_b]
= max[6.3 , 4.5]
= 6.3 mm

Available nozzle wall thickness new, t_n = 13 mm

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 175 °C) UG-28(c)

L / D_o = 3,058.64 / 406.4 = 7.5262
D_o / t = 406.4 / 3.3 = 123.1627

From table G: A = 0.000113
From table CS-2 Metric: B = 111.4156 kg/cm^2 (109.26 bar)

P_a = $4*B / (3*(D_o / t))$
= 4*109.26 / (3*(406.4 / 3.3))
= 1.18 bar

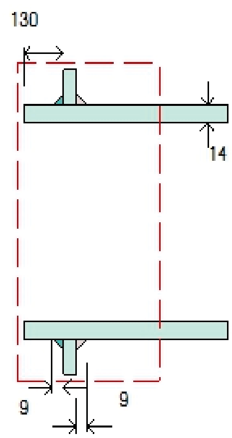
Design thickness for external pressure P_a = 1.18 bar

t_a = t + Corrosion = 3.3 + 3 = 6.3 mm

Access Opening (A1)

1

ASME Section VIII Division 1, 2017 Edition Metric	
Component	Skirt Opening
Description	Access Opening
Drawing Mark	A1
Sleeve Material	SA-516 70 (II-D Metric p. 18, ln. 33)
Location and Orientation	
Attached to	Support Skirt #2
Orientation	radial
Offset, L	900 mm
Angle, θ	330°
Distance, r	1,769 mm
Through a Category B Joint	No
Dimensions	
Inside Diameter	450 mm
Nominal Wall Thickness	14 mm
Skirt Thickness	10 mm
Leg_{41}	9 mm
Leg_{43}	9 mm
External Projection Available, L_{pr1}	80 mm
Internal Projection, L_{pr2}	130 mm
Corrosion – Inner	0 mm
Corrosion – Outer	0 mm



Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	A_T (cm^2)	A_r (cm^2)	Ratio	Status
Operating Hot & Corroded	Wind	Tensile	0.77	50.3385	3.4777	14.4748	OK
		Compressive	5.1	38.8315	22.9714	1.6904	OK
	Vortex shedding	Tensile	1.56	48.2457	7.0229	6.8697	OK
		Compressive	6.48	35.1733	29.1688	1.2059	OK
Operating Hot & New	Wind	Tensile	0.77	59.5541	3.4649	17.1876	OK
		Compressive	4.3	49.4255	19.3376	2.5559	OK
Empty Cold & Corroded	Wind	Tensile	1.01	49.7196	4.5261	10.985	OK
		Compressive	4.43	40.6346	19.9167	2.0402	OK
	Vortex shedding	Tensile	2.3	46.2733	10.3643	4.4647	OK
		Compressive	6.69	34.6104	30.1223	1.149	OK
Empty Cold & New	Wind	Tensile	1	58.8854	4.5129	13.0481	OK
		Compressive	3.73	51.0608	16.775	3.0439	OK
Shop Test New	Wind	Tensile	0	61.7652	0	N/A	OK
		Compressive	4.8	47.9915	21.5849	2.2234	OK
External Pressure Hot & Corroded	Wind	Tensile	0.77	50.3385	3.4777	14.4748	OK
		Compressive	5.1	38.8315	22.9714	1.6904	OK
	Vortex shedding	Tensile	1.56	48.2432	7.0271	6.8653	OK
		Compressive	6.48	35.1689	29.1761	1.2054	OK

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

Skirt Opening Reinforcement Calculations	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1,679*10)^{0.5}, 2*225] =$	129.58 mm
$L_{H1} = \min[1.5*10 , 0] + (225*14)^{0.5} =$	56.12 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[56.12, 80, 80] + 10 =$	66.12 mm
$L_{I1} = (225*14)^{0.5} =$	56.12 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[56.12, 130, 80] =$	56.12 mm
Corroded	
$L_R = \min[(1,680.6*8.4)^{0.5}, 2*225] =$	118.82 mm
$L_{H1} = \min[1.5*8.4 , 0] + (225*14)^{0.5} =$	56.12 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[56.12, 80, 67.2] + 8.4 =$	64.52 mm
$L_{I1} = (225*12.4)^{0.5} =$	52.82 mm

$L_{I2} = L_{pr2} =$	128.4 mm
$L_{I3} = 8*(8.4 + 0) =$	67.2 mm
$L_I = \min[\ 52.82, 128.4, 67.2] =$	52.82 mm
Operating Hot & Corroded Wind Tensile	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 0.77)\} / 100 =$	18.1245 cm^2
$A_2 = 2*(64.52 - 0.77)*14*1 / 100 =$	17.8506 cm^2
$A_3 = 2*52.82*12.4*1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 18.1245 + 17.8506 + 13.0995 + 0.81 + 0.4539 =$	50.3385 cm^2
$A_r = (450*0.77 + 2*14*0.77*(1 - 1)) / 100 =$	3.4777 cm^2
$A_T = 50.3385\ cm^2 \geq A_r = 3.4777\ cm^2$	
Operating Hot & Corroded Wind Compressive	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 5.1)\} / 100 =$	7.8305 cm^2
$A_2 = 2*(64.52 - 5.1)*14*1 / 100 =$	16.6376 cm^2
$A_3 = 2*52.82*12.4*1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 7.8305 + 16.6376 + 13.0995 + 0.81 + 0.4539 =$	38.8315 cm^2
$A_r = (450*5.1 + 2*14*5.1*(1 - 1)) / 100 =$	22.9714 cm^2
$A_T = 38.8315\ cm^2 \geq A_r = 22.9714\ cm^2$	
Operating Hot & New Wind Tensile	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*129.58*(1*10 - 0.77)\} / 100 =$	23.9198 cm^2
$A_2 = 2*(66.12 - 0.77)*14*1 / 100 =$	18.2994 cm^2
$A_3 = 2*56.12*14*1 / 100 =$	15.715 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 9^2*1 / 100 =$	0.81 cm^2
$A_T = 23.9198 + 18.2994 + 15.715 + 0.81 + 0.81 =$	59.5541 cm^2
$A_r = (450*0.77 + 2*14*0.77*(1 - 1)) / 100 =$	3.4649 cm^2
$A_T = 59.5541\ cm^2 \geq A_r = 3.4649\ cm^2$	

Operating Hot & New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 4.3)} / 100 =	14.7788 cm^2
A_2 = 2*(66.12 - 4.3)*14*1 / 100 =	17.3117 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 14.7788 + 17.3117 + 15.715 + 0.81 + 0.81 =	49.4255 cm^2
A_r = (450*4.3 + 2*14*4.3*(1 - 1)) / 100 =	19.3376 cm^2
A_T = 49.4255 cm^2 ≥ A_r = 19.3376 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.01)} / 100 =	17.5708 cm^2
A_2 = 2*(64.52 - 1.01)*14*1 / 100 =	17.7853 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 17.5708 + 17.7853 + 13.0995 + 0.81 + 0.4539 =	49.7196 cm^2
A_r = (450*1.01 + 2*14*1.01*(1 - 1)) / 100 =	4.5261 cm^2
A_T = 49.7196 cm^2 ≥ A_r = 4.5261 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 4.43)} / 100 =	9.4436 cm^2
A_2 = 2*(64.52 - 4.43)*14*1 / 100 =	16.8277 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 9.4436 + 16.8277 + 13.0995 + 0.81 + 0.4539 =	40.6346 cm^2
A_r = (450*4.43 + 2*14*4.43*(1 - 1)) / 100 =	19.9167 cm^2
A_T = 40.6346 cm^2 ≥ A_r = 19.9167 cm^2	
Empty Cold & New Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1

A_1 = {2*129.58*(1*10 - 1)} / 100 =	23.3163 cm^2
A_2 = 2*(66.12 - 1)*14*1 / 100 =	18.2342 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 23.3163 + 18.2342 + 15.715 + 0.81 + 0.81 =	58.8854 cm^2
A_r = (450*1 + 2*14*1*(1 - 1)) / 100 =	4.5129 cm^2
A_T = 58.8854 cm^2 ≥ A_r = 4.5129 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 3.73)} / 100 =	16.2546 cm^2
A_2 = 2*(66.12 - 3.73)*14*1 / 100 =	17.4712 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 16.2546 + 17.4712 + 15.715 + 0.81 + 0.81 =	51.0608 cm^2
A_r = (450*3.73 + 2*14*3.73*(1 - 1)) / 100 =	16.775 cm^2
A_T = 51.0608 cm^2 ≥ A_r = 16.775 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 4.8)} / 100 =	13.4846 cm^2
A_2 = 2*(66.12 - 4.8)*14*1 / 100 =	17.1719 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 13.4846 + 17.1719 + 15.715 + 0.81 + 0.81 =	47.9915 cm^2
A_r = (450*4.8 + 2*14*4.8*(1 - 1)) / 100 =	21.5849 cm^2
A_T = 47.9915 cm^2 ≥ A_r = 21.5849 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 0.77)} / 100 =	18.1245 cm^2
A_2 = 2*(64.52 - 0.77)*14*1 / 100 =	17.8506 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2

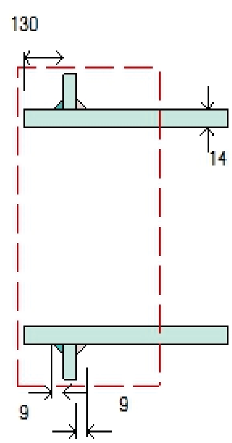
$A_{41} = 9^2*1 / 100 =$	$0.81\ cm^2$
$A_{43} = 6.74^2*1 / 100 =$	$0.4539\ cm^2$
$A_T = 18.1245 + 17.8506 + 13.0995 + 0.81 + 0.4539 =$	$50.3385\ cm^2$
$A_r = (450*0.77 + 2*14*0.77*(1 - 1)) / 100 =$	$3.4777\ cm^2$
$A_T = 50.3385\ cm^2 \geq A_r = 3.4777\ cm^2$	
External Pressure Hot & Corroded Wind Compressive	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 5.1)\} / 100 =$	$7.8305\ cm^2$
$A_2 = 2*(64.52 - 5.1)*14*1 / 100 =$	$16.6376\ cm^2$
$A_3 = 2*52.82*12.4*1 / 100 =$	$13.0995\ cm^2$
$A_{41} = 9^2*1 / 100 =$	$0.81\ cm^2$
$A_{43} = 6.74^2*1 / 100 =$	$0.4539\ cm^2$
$A_T = 7.8305 + 16.6376 + 13.0995 + 0.81 + 0.4539 =$	$38.8315\ cm^2$
$A_r = (450*5.1 + 2*14*5.1*(1 - 1)) / 100 =$	$22.9714\ cm^2$
$A_T = 38.8315\ cm^2 \geq A_r = 22.9714\ cm^2$	
Operating Hot & Corroded Vortex shedding Tensile	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 1.56)\} / 100 =$	$16.2524\ cm^2$
$A_2 = 2*(64.52 - 1.56)*14*1 / 100 =$	$17.63\ cm^2$
$A_3 = 2*52.82*12.4*1 / 100 =$	$13.0995\ cm^2$
$A_{41} = 9^2*1 / 100 =$	$0.81\ cm^2$
$A_{43} = 6.74^2*1 / 100 =$	$0.4539\ cm^2$
$A_T = 16.2524 + 17.63 + 13.0995 + 0.81 + 0.4539 =$	$48.2457\ cm^2$
$A_r = (450*1.56 + 2*14*1.56*(1 - 1)) / 100 =$	$7.0229\ cm^2$
$A_T = 48.2457\ cm^2 \geq A_r = 7.0229\ cm^2$	
Operating Hot & Corroded Vortex shedding Compressive	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 6.48)\} / 100 =$	$4.5579\ cm^2$
$A_2 = 2*(64.52 - 6.48)*14*1 / 100 =$	$16.252\ cm^2$
$A_3 = 2*52.82*12.4*1 / 100 =$	$13.0995\ cm^2$
$A_{41} = 9^2*1 / 100 =$	$0.81\ cm^2$
$A_{43} = 6.74^2*1 / 100 =$	$0.4539\ cm^2$

A_T = 4.5579 + 16.252 + 13.0995 + 0.81 + 0.4539 =	35.1733 cm^2
A_r = (450*6.48 + 2*14*6.48*(1 - 1)) / 100 =	29.1688 cm^2
A_T = 35.1733 cm^2 ≥ A_r = 29.1688 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 2.3)} / 100 =	14.4879 cm^2
A_2 = 2*(64.52 - 2.3)*14*1 / 100 =	17.4221 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 14.4879 + 17.4221 + 13.0995 + 0.81 + 0.4539 =	46.2733 cm^2
A_r = (450*2.3 + 2*14*2.3*(1 - 1)) / 100 =	10.3643 cm^2
A_T = 46.2733 cm^2 ≥ A_r = 10.3643 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 6.69)} / 100 =	4.0543 cm^2
A_2 = 2*(64.52 - 6.69)*14*1 / 100 =	16.1927 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 4.0543 + 16.1927 + 13.0995 + 0.81 + 0.4539 =	34.6104 cm^2
A_r = (450*6.69 + 2*14*6.69*(1 - 1)) / 100 =	30.1223 cm^2
A_T = 34.6104 cm^2 ≥ A_r = 30.1223 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.56)} / 100 =	16.2501 cm^2
A_2 = 2*(64.52 - 1.56)*14*1 / 100 =	17.6297 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 16.2501 + 17.6297 + 13.0995 + 0.81 + 0.4539 =	48.2432 cm^2

A_r = (450*1.56 + 2*14*1.56*(1 - 1)) / 100 =	7.0271 cm^2
A_T = 48.2432 cm^2 ≥ A_r = 7.0271 cm^2	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 6.48)} / 100 =	4.554 cm^2
A_2 = 2*(64.52 - 6.48)*14*1 / 100 =	16.2516 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 4.554 + 16.2516 + 13.0995 + 0.81 + 0.4539 =	35.1689 cm^2
A_r = (450*6.48 + 2*14*6.48*(1 - 1)) / 100 =	29.1761 cm^2
A_T = 35.1689 cm^2 ≥ A_r = 29.1761 cm^2	

Access Opening (A2)

1

<table>
<tr><th colspan="4">ASME Section VIII Division 1, 2017 Edition Metric</th></tr>
<tr><td colspan="2">**Component**</td><td colspan="2">Skirt Opening</td></tr>
<tr><td colspan="2">**Description**</td><td colspan="2">Access Opening</td></tr>
<tr><td colspan="2">**Drawing Mark**</td><td colspan="2">A2</td></tr>
<tr><td colspan="2">**Sleeve Material**</td><td colspan="2">SA-516 70 (II-D Metric p. 18, ln. 33)</td></tr>
<tr><th colspan="4">Location and Orientation</th></tr>
<tr><td colspan="2">**Attached to**</td><td colspan="2">Support Skirt #2</td></tr>
<tr><td colspan="2">**Orientation**</td><td colspan="2">radial</td></tr>
<tr><td colspan="2">**Offset, L**</td><td colspan="2">900 mm</td></tr>
<tr><td colspan="2">**Angle, θ**</td><td colspan="2">150°</td></tr>
<tr><td colspan="2">**Distance, r**</td><td colspan="2">1,769 mm</td></tr>
<tr><td colspan="2">**Through a Category B Joint**</td><td colspan="2">No</td></tr>
<tr><th colspan="4">Dimensions</th></tr>
<tr><td colspan="2">**Inside Diameter**</td><td>450 mm</td><td rowspan="10"></td></tr>
<tr><td colspan="2">**Nominal Wall Thickness**</td><td>14 mm</td></tr>
<tr><td colspan="2">**Skirt Thickness**</td><td>10 mm</td></tr>
<tr><td colspan="2">**Leg$_{41}$**</td><td>9 mm</td></tr>
<tr><td colspan="2">**Leg$_{43}$**</td><td>9 mm</td></tr>
<tr><td colspan="2">**External Projection Available, L$_{pr1}$**</td><td>80 mm</td></tr>
<tr><td colspan="2">**Internal Projection, L$_{pr2}$**</td><td>130 mm</td></tr>
<tr><td rowspan="2">**Corrosion**</td><td>**Inner**</td><td>0 mm</td></tr>
<tr><td>**Outer**</td><td>0 mm</td></tr>
</table>

<table>
<tr><th colspan="9">Skirt Opening Reinforcement Summary</th></tr>
<tr><th colspan="3"></th><th>Required Thickness t_r (mm)</th><th>A_T (cm^2)</th><th>A_r (cm^2)</th><th>Ratio</th><th>Status</th></tr>
<tr><td rowspan="4">Operating Hot & Corroded</td><td rowspan="2">Wind</td><td>Tensile</td><td>0.77</td><td>50.3385</td><td>3.4777</td><td>14.4748</td><td>OK</td></tr>
<tr><td>Compressive</td><td>5.1</td><td>38.8315</td><td>22.9714</td><td>1.6904</td><td>OK</td></tr>
<tr><td rowspan="2">Vortex shedding</td><td>Tensile</td><td>1.56</td><td>48.2457</td><td>7.0229</td><td>6.8697</td><td>OK</td></tr>
<tr><td>Compressive</td><td>6.48</td><td>35.1733</td><td>29.1688</td><td>1.2059</td><td>OK</td></tr>
<tr><td rowspan="2">Operating Hot & New</td><td rowspan="2">Wind</td><td>Tensile</td><td>0.77</td><td>59.5541</td><td>3.4649</td><td>17.1876</td><td>OK</td></tr>
<tr><td>Compressive</td><td>4.3</td><td>49.4255</td><td>19.3376</td><td>2.5559</td><td>OK</td></tr>
<tr><td rowspan="4">Empty Cold & Corroded</td><td rowspan="2">Wind</td><td>Tensile</td><td>1.01</td><td>49.7196</td><td>4.5261</td><td>10.985</td><td>OK</td></tr>
<tr><td>Compressive</td><td>4.43</td><td>40.6346</td><td>19.9167</td><td>2.0402</td><td>OK</td></tr>
<tr><td rowspan="2">Vortex shedding</td><td>Tensile</td><td>2.3</td><td>46.2733</td><td>10.3643</td><td>4.4647</td><td>OK</td></tr>
<tr><td>Compressive</td><td>6.69</td><td>34.6104</td><td>30.1223</td><td>1.149</td><td>OK</td></tr>
<tr><td rowspan="2">Empty Cold & New</td><td rowspan="2">Wind</td><td>Tensile</td><td>1</td><td>58.8854</td><td>4.5129</td><td>13.0481</td><td>OK</td></tr>
<tr><td>Compressive</td><td>3.73</td><td>51.0608</td><td>16.775</td><td>3.0439</td><td>OK</td></tr>
<tr><td rowspan="2">Shop Test New</td><td rowspan="2">Wind</td><td>Tensile</td><td>0</td><td>61.7652</td><td>0</td><td>N/A</td><td>OK</td></tr>
<tr><td>Compressive</td><td>4.8</td><td>47.9915</td><td>21.5849</td><td>2.2234</td><td>OK</td></tr>
<tr><td rowspan="4">External Pressure Hot & Corroded</td><td rowspan="2">Wind</td><td>Tensile</td><td>0.77</td><td>50.3385</td><td>3.4777</td><td>14.4748</td><td>OK</td></tr>
<tr><td>Compressive</td><td>5.1</td><td>38.8315</td><td>22.9714</td><td>1.6904</td><td>OK</td></tr>
<tr><td rowspan="2">Vortex shedding</td><td>Tensile</td><td>1.56</td><td>48.2432</td><td>7.0271</td><td>6.8653</td><td>OK</td></tr>
<tr><td>Compressive</td><td>6.48</td><td>35.1689</td><td>29.1761</td><td>1.2054</td><td>OK</td></tr>
</table>

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

Skirt Opening Reinforcement Calculations	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1,679*10)^{0.5}, 2*225] =$	129.58 mm
$L_{H1} = \min[1.5*10 , 0] + (225*14)^{0.5} =$	56.12 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[56.12, 80, 80] + 10 =$	66.12 mm
$L_{I1} = (225*14)^{0.5} =$	56.12 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[56.12, 130, 80] =$	56.12 mm
Corroded	
$L_R = \min[(1,680.6*8.4)^{0.5}, 2*225] =$	118.82 mm
$L_{H1} = \min[1.5*8.4 , 0] + (225*14)^{0.5} =$	56.12 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[56.12, 80, 67.2] + 8.4 =$	64.52 mm
$L_{I1} = (225*12.4)^{0.5} =$	52.82 mm

$L_{I2} = L_{pr2} =$	128.4 mm
$L_{I3} = 8*(8.4 + 0) =$	67.2 mm
$L_I = \min[52.82, 128.4, 67.2] =$	52.82 mm
Operating Hot & Corroded Wind Tensile	
$f_{r1} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$f_{r2} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$A_1 = \{2*118.82*(1*8.4 - 0.77)\} / 100 =$	18.1245 cm^2
$A_2 = 2*(64.52 - 0.77)*14*1 / 100 =$	17.8506 cm^2
$A_3 = 2*52.82*12.4*1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 18.1245 + 17.8506 + 13.0995 + 0.81 + 0.4539 =$	50.3385 cm^2
$A_r = (450*0.77 + 2*14*0.77*(1 - 1)) / 100 =$	3.4777 cm^2
$A_T = 50.3385\ cm^2 \geq A_r = 3.4777\ cm^2$	
Operating Hot & Corroded Wind Compressive	
$f_{r1} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$f_{r2} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$A_1 = \{2*118.82*(1*8.4 - 5.1)\} / 100 =$	7.8305 cm^2
$A_2 = 2*(64.52 - 5.1)*14*1 / 100 =$	16.6376 cm^2
$A_3 = 2*52.82*12.4*1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 7.8305 + 16.6376 + 13.0995 + 0.81 + 0.4539 =$	38.8315 cm^2
$A_r = (450*5.1 + 2*14*5.1*(1 - 1)) / 100 =$	22.9714 cm^2
$A_T = 38.8315\ cm^2 \geq A_r = 22.9714\ cm^2$	
Operating Hot & New Wind Tensile	
$f_{r1} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$f_{r2} = \min[1{,}407.21 / 1{,}101.29, 1] =$	1
$A_1 = \{2*129.58*(1*10 - 0.77)\} / 100 =$	23.9198 cm^2
$A_2 = 2*(66.12 - 0.77)*14*1 / 100 =$	18.2994 cm^2
$A_3 = 2*56.12*14*1 / 100 =$	15.715 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 9^2*1 / 100 =$	0.81 cm^2
$A_T = 23.9198 + 18.2994 + 15.715 + 0.81 + 0.81 =$	59.5541 cm^2
$A_r = (450*0.77 + 2*14*0.77*(1 - 1)) / 100 =$	3.4649 cm^2
$A_T = 59.5541\ cm^2 \geq A_r = 3.4649\ cm^2$	

Operating Hot & New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 4.3)} / 100 =	14.7788 cm^2
A_2 = 2*(66.12 - 4.3)*14*1 / 100 =	17.3117 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 14.7788 + 17.3117 + 15.715 + 0.81 + 0.81 =	49.4255 cm^2
A_r = (450*4.3 + 2*14*4.3*(1 - 1)) / 100 =	19.3376 cm^2
A_T = 49.4255 cm^2 ≥ A_r = 19.3376 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.01)} / 100 =	17.5708 cm^2
A_2 = 2*(64.52 - 1.01)*14*1 / 100 =	17.7853 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 17.5708 + 17.7853 + 13.0995 + 0.81 + 0.4539 =	49.7196 cm^2
A_r = (450*1.01 + 2*14*1.01*(1 - 1)) / 100 =	4.5261 cm^2
A_T = 49.7196 cm^2 ≥ A_r = 4.5261 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 4.43)} / 100 =	9.4436 cm^2
A_2 = 2*(64.52 - 4.43)*14*1 / 100 =	16.8277 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 9.4436 + 16.8277 + 13.0995 + 0.81 + 0.4539 =	40.6346 cm^2
A_r = (450*4.43 + 2*14*4.43*(1 - 1)) / 100 =	19.9167 cm^2
A_T = 40.6346 cm^2 ≥ A_r = 19.9167 cm^2	
Empty Cold & New Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1

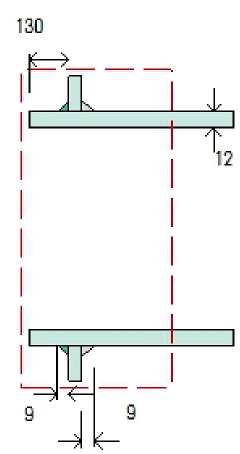
A_1 = {2*129.58*(1*10 - 1)} / 100 =	23.3163 cm^2
A_2 = 2*(66.12 - 1)*14*1 / 100 =	18.2342 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 23.3163 + 18.2342 + 15.715 + 0.81 + 0.81 =	58.8854 cm^2
A_r = (450*1 + 2*14*1*(1 - 1)) / 100 =	4.5129 cm^2
A_T = 58.8854 cm^2 ≥ A_r = 4.5129 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 3.73)} / 100 =	16.2546 cm^2
A_2 = 2*(66.12 - 3.73)*14*1 / 100 =	17.4712 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 16.2546 + 17.4712 + 15.715 + 0.81 + 0.81 =	51.0608 cm^2
A_r = (450*3.73 + 2*14*3.73*(1 - 1)) / 100 =	16.775 cm^2
A_T = 51.0608 cm^2 ≥ A_r = 16.775 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 4.8)} / 100 =	13.4846 cm^2
A_2 = 2*(66.12 - 4.8)*14*1 / 100 =	17.1719 cm^2
A_3 = 2*56.12*14*1 / 100 =	15.715 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 13.4846 + 17.1719 + 15.715 + 0.81 + 0.81 =	47.9915 cm^2
A_r = (450*4.8 + 2*14*4.8*(1 - 1)) / 100 =	21.5849 cm^2
A_T = 47.9915 cm^2 ≥ A_r = 21.5849 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 0.77)} / 100 =	18.1245 cm^2
A_2 = 2*(64.52 - 0.77)*14*1 / 100 =	17.8506 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2

$A_{41} = 9^2 * 1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2 * 1 / 100 =$	0.4539 cm^2
$A_T = 18.1245 + 17.8506 + 13.0995 + 0.81 + 0.4539 =$	50.3385 cm^2
$A_r = (450 * 0.77 + 2 * 14 * 0.77 * (1 - 1)) / 100 =$	3.4777 cm^2
$A_T = 50.3385\ cm^2 \geq A_r = 3.4777\ cm^2$	
External Pressure Hot & Corroded Wind Compressive	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2 * 118.82 * (1 * 8.4 - 5.1)\} / 100 =$	7.8305 cm^2
$A_2 = 2 * (64.52 - 5.1) * 14 * 1 / 100 =$	16.6376 cm^2
$A_3 = 2 * 52.82 * 12.4 * 1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2 * 1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2 * 1 / 100 =$	0.4539 cm^2
$A_T = 7.8305 + 16.6376 + 13.0995 + 0.81 + 0.4539 =$	38.8315 cm^2
$A_r = (450 * 5.1 + 2 * 14 * 5.1 * (1 - 1)) / 100 =$	22.9714 cm^2
$A_T = 38.8315\ cm^2 \geq A_r = 22.9714\ cm^2$	
Operating Hot & Corroded Vortex shedding Tensile	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2 * 118.82 * (1 * 8.4 - 1.56)\} / 100 =$	16.2524 cm^2
$A_2 = 2 * (64.52 - 1.56) * 14 * 1 / 100 =$	17.63 cm^2
$A_3 = 2 * 52.82 * 12.4 * 1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2 * 1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2 * 1 / 100 =$	0.4539 cm^2
$A_T = 16.2524 + 17.63 + 13.0995 + 0.81 + 0.4539 =$	48.2457 cm^2
$A_r = (450 * 1.56 + 2 * 14 * 1.56 * (1 - 1)) / 100 =$	7.0229 cm^2
$A_T = 48.2457\ cm^2 \geq A_r = 7.0229\ cm^2$	
Operating Hot & Corroded Vortex shedding Compressive	
$f_{r1} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$f_{r2} = \min[\ 1{,}407.21 / 1{,}101.29 , 1\ ] =$	1
$A_1 = \{2 * 118.82 * (1 * 8.4 - 6.48)\} / 100 =$	4.5579 cm^2
$A_2 = 2 * (64.52 - 6.48) * 14 * 1 / 100 =$	16.252 cm^2
$A_3 = 2 * 52.82 * 12.4 * 1 / 100 =$	13.0995 cm^2
$A_{41} = 9^2 * 1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2 * 1 / 100 =$	0.4539 cm^2

A_T = 4.5579 + 16.252 + 13.0995 + 0.81 + 0.4539 =	35.1733 cm^2
A_r = (450*6.48 + 2*14*6.48*(1 - 1)) / 100 =	29.1688 cm^2
A_T = 35.1733 cm^2 ≥ A_r = 29.1688 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 2.3)} / 100 =	14.4879 cm^2
A_2 = 2*(64.52 - 2.3)*14*1 / 100 =	17.4221 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 14.4879 + 17.4221 + 13.0995 + 0.81 + 0.4539 =	46.2733 cm^2
A_r = (450*2.3 + 2*14*2.3*(1 - 1)) / 100 =	10.3643 cm^2
A_T = 46.2733 cm^2 ≥ A_r = 10.3643 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 6.69)} / 100 =	4.0543 cm^2
A_2 = 2*(64.52 - 6.69)*14*1 / 100 =	16.1927 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 4.0543 + 16.1927 + 13.0995 + 0.81 + 0.4539 =	34.6104 cm^2
A_r = (450*6.69 + 2*14*6.69*(1 - 1)) / 100 =	30.1223 cm^2
A_T = 34.6104 cm^2 ≥ A_r = 30.1223 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.56)} / 100 =	16.2501 cm^2
A_2 = 2*(64.52 - 1.56)*14*1 / 100 =	17.6297 cm^2
A_3 = 2*52.82*12.4*1 / 100 =	13.0995 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 16.2501 + 17.6297 + 13.0995 + 0.81 + 0.4539 =	48.2432 cm^2

A_r = (450*1.56 + 2*14*1.56*(1 - 1)) / 100 =	$7.0271\ cm^2$
$A_T = 48.2432\ cm^2 \geq A_r = 7.0271\ cm^2$	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,407.21 / 1,101.29 , 1] =	1
f_{r2} = min[1,407.21 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 6.48)} / 100 =	$4.554\ cm^2$
A_2 = 2*(64.52 - 6.48)*14*1 / 100 =	$16.2516\ cm^2$
A_3 = 2*52.82*12.4*1 / 100 =	$13.0995\ cm^2$
$A_{41} = 9^2*1 / 100 =$	$0.81\ cm^2$
$A_{43} = 6.74^2*1 / 100 =$	$0.4539\ cm^2$
A_T = 4.554 + 16.2516 + 13.0995 + 0.81 + 0.4539 =	$35.1689\ cm^2$
A_r = (450*6.48 + 2*14*6.48*(1 - 1)) / 100 =	$29.1761\ cm^2$
$A_T = 35.1689\ cm^2 \geq A_r = 29.1761\ cm^2$	

Sleeve Opening (S) 1

ASME Section VIII Division 1, 2017 Edition Metric		
Component	Skirt Opening	
Description	Sleeve Opening	
Drawing Mark	S	
Opening for Nozzle	Nozzle (DC)	
Sleeve Material	SA-285 C (II-D Metric p. 10, ln. 3)	
Location and Orientation		
Attached to	Support Skirt #2	
Orientation	radial	
Offset, L	5,876 mm	
Angle, θ	90°	
Distance, r	1,769 mm	
Through a Category B Joint	No	
Dimensions		
Inside Diameter	585.6 mm	
Nominal Wall Thickness	12 mm	
Skirt Thickness	10 mm	
Leg_{41}	9 mm	
Leg_{43}	9 mm	
External Projection Available, L_{pr1}	80 mm	
Internal Projection, L_{pr2}	130 mm	
Corrosion Inner	0 mm	
Corrosion Outer	0 mm	

Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	A_T (cm^2)	A_r (cm^2)	Ratio	Status
Operating Hot & Corroded	Wind	Tensile	0.43	47.8248	2.5073	19.0745	OK
		Compressive	4.42	37.3868	25.8703	1.4452	OK
	Vortex shedding	Tensile	1.09	46.1006	6.3665	7.2412	OK
		Compressive	5.57	34.3728	32.6165	1.0538	OK
Operating Hot & New	Wind	Tensile	0.43	57.1745	2.5087	22.7907	OK
		Compressive	3.71	47.8775	21.7362	2.2027	OK
Empty Cold & Corroded	Wind	Tensile	0.66	47.2152	3.8717	12.1951	OK
		Compressive	3.74	39.1628	21.8952	1.7886	OK
	Vortex shedding	Tensile	1.75	44.3768	10.2249	4.3401	OK
		Compressive	5.64	34.201	33.0011	1.0364	OK
Empty Cold & New	Wind	Tensile	0.66	56.5151	3.8725	14.5941	OK
		Compressive	3.14	49.49	18.4014	2.6895	OK
Shop Test New	Wind	Tensile	0	58.3875	0	N/A	OK
		Compressive	4.74	44.9549	27.7807	1.6182	OK
External Pressure Hot & Corroded	Wind	Tensile	0.43	47.8248	2.5073	19.0745	OK
		Compressive	4.42	37.3868	25.8703	1.4452	OK
	Vortex shedding	Tensile	1.09	46.0986	6.371	7.2357	OK
		Compressive	5.57	34.3692	32.6245	1.0535	OK

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

Skirt Opening Reinforcement Calculations	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1,679*10)^{0.5}, 2*292.8] =$	129.58 mm
$L_{H1} = \min[1.5*10 , 0] + (292.8*12)^{0.5} =$	59.28 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[59.28, 80, 80] + 10 =$	69.28 mm
$L_{I1} = (292.8*12)^{0.5} =$	59.28 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[59.28, 130, 80] =$	59.28 mm
Corroded	
$L_R = \min[(1,680.6*8.4)^{0.5}, 2*292.8] =$	118.82 mm
$L_{H1} = \min[1.5*8.4 , 0] + (292.8*12)^{0.5} =$	59.28 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[59.28, 80, 67.2] + 8.4 =$	67.68 mm
$L_{I1} = (292.8*10.4)^{0.5} =$	55.18 mm

$L_{I2} = L_{pr2} =$	128.4 mm
$L_{I3} = 8*(8.4 + 0) =$	67.2 mm
$L_I = min[\ 55.18, 128.4, 67.2] =$	55.18 mm
Operating Hot & Corroded Wind Tensile	
$f_{r1} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$f_{r2} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 0.43)\} / 100 =$	18.9435 cm^2
$A_2 = 2*(67.68 - 0.43)*12*1 / 100 =$	16.1394 cm^2
$A_3 = 2*55.18*10.4*1 / 100 =$	11.478 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 18.9435 + 16.1394 + 11.478 + 0.81 + 0.4539 =$	47.8248 cm^2
$A_r = (585.6*0.43 + 2*12*0.43*(1 - 1)) / 100 =$	2.5073 cm^2
$A_T = 47.8248\ cm^2 \geq A_r = 2.5073\ cm^2$	
Operating Hot & Corroded Wind Compressive	
$f_{r1} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$f_{r2} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 4.42)\} / 100 =$	9.463 cm^2
$A_2 = 2*(67.68 - 4.42)*12*1 / 100 =$	15.1819 cm^2
$A_3 = 2*55.18*10.4*1 / 100 =$	11.478 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 9.463 + 15.1819 + 11.478 + 0.81 + 0.4539 =$	37.3868 cm^2
$A_r = (585.6*4.42 + 2*12*4.42*(1 - 1)) / 100 =$	25.8703 cm^2
$A_T = 37.3868\ cm^2 \geq A_r = 25.8703\ cm^2$	
Operating Hot & New Wind Tensile	
$f_{r1} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$f_{r2} = min[\ 1,101.29 / 1,101.29 , 1\ ] =$	1
$A_1 = \{2*129.58*(1*10 - 0.43)\} / 100 =$	24.805 cm^2
$A_2 = 2*(69.28 - 0.43)*12*1 / 100 =$	16.5233 cm^2
$A_3 = 2*59.28*12*1 / 100 =$	14.2262 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 9^2*1 / 100 =$	0.81 cm^2
$A_T = 24.805 + 16.5233 + 14.2262 + 0.81 + 0.81 =$	57.1745 cm^2
$A_r = (585.6*0.43 + 2*12*0.43*(1 - 1)) / 100 =$	2.5087 cm^2
$A_T = 57.1745\ cm^2 \geq A_r = 2.5087\ cm^2$	

Operating Hot & New Wind Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 3.71)} / 100 =	16.2961 cm^2
A_2 = 2*(69.28 - 3.71)*12*1 / 100 =	15.7353 cm^2
A_3 = 2*59.28*12*1 / 100 =	14.2262 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 16.2961 + 15.7353 + 14.2262 + 0.81 + 0.81 =	47.8775 cm^2
A_r = (585.6*3.71 + 2*12*3.71*(1 - 1)) / 100 =	21.7362 cm^2
A_T = 47.8775 cm^2 ≥ A_r = 21.7362 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 0.66)} / 100 =	18.3899 cm^2
A_2 = 2*(67.68 - 0.66)*12*1 / 100 =	16.0835 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 18.3899 + 16.0835 + 11.478 + 0.81 + 0.4539 =	47.2152 cm^2
A_r = (585.6*0.66 + 2*12*0.66*(1 - 1)) / 100 =	3.8717 cm^2
A_T = 47.2152 cm^2 ≥ A_r = 3.8717 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 3.74)} / 100 =	11.0761 cm^2
A_2 = 2*(67.68 - 3.74)*12*1 / 100 =	15.3448 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 11.0761 + 15.3448 + 11.478 + 0.81 + 0.4539 =	39.1628 cm^2
A_r = (585.6*3.74 + 2*12*3.74*(1 - 1)) / 100 =	21.8952 cm^2
A_T = 39.1628 cm^2 ≥ A_r = 21.8952 cm^2	
Empty Cold & New Wind Tensile	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1

A_1 = {2*129.58*(1*10 - 0.66)} / 100 =	24.2015 cm^2
A_2 = 2*(69.28 - 0.66)*12*1 / 100 =	16.4674 cm^2
A_3 = 2*59.28*12*1 / 100 =	14.2262 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 24.2015 + 16.4674 + 14.2262 + 0.81 + 0.81 =	56.5151 cm^2
A_r = (585.6*0.66 + 2*12*0.66*(1 - 1)) / 100 =	3.8725 cm^2
A_T = 56.5151 cm^2 ≥ A_r = 3.8725 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 3.14)} / 100 =	17.7719 cm^2
A_2 = 2*(69.28 - 3.14)*12*1 / 100 =	15.872 cm^2
A_3 = 2*59.28*12*1 / 100 =	14.2262 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 17.7719 + 15.872 + 14.2262 + 0.81 + 0.81 =	49.49 cm^2
A_r = (585.6*3.14 + 2*12*3.14*(1 - 1)) / 100 =	18.4014 cm^2
A_T = 49.49 cm^2 ≥ A_r = 18.4014 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*129.58*(1*10 - 4.74)} / 100 =	13.6211 cm^2
A_2 = 2*(69.28 - 4.74)*12*1 / 100 =	15.4876 cm^2
A_3 = 2*59.28*12*1 / 100 =	14.2262 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 9^2*1 / 100 =	0.81 cm^2
A_T = 13.6211 + 15.4876 + 14.2262 + 0.81 + 0.81 =	44.9549 cm^2
A_r = (585.6*4.74 + 2*12*4.74*(1 - 1)) / 100 =	27.7807 cm^2
A_T = 44.9549 cm^2 ≥ A_r = 27.7807 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 0.43)} / 100 =	18.9435 cm^2
A_2 = 2*(67.68 - 0.43)*12*1 / 100 =	16.1394 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2

$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 18.9435 + 16.1394 + 11.478 + 0.81 + 0.4539 =$	47.8248 cm^2
$A_r = (585.6*0.43 + 2*12*0.43*(1 - 1)) / 100 =$	2.5073 cm^2
$A_T = 47.8248\ cm^2 \geq A_r = 2.5073\ cm^2$	
External Pressure Hot & Corroded Wind Compressive	
$f_{r1} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$f_{r2} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 4.42)\} / 100 =$	9.463 cm^2
$A_2 = 2*(67.68 - 4.42)*12*1 / 100 =$	15.1819 cm^2
$A_3 = 2*55.18*10.4*1 / 100 =$	11.478 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 9.463 + 15.1819 + 11.478 + 0.81 + 0.4539 =$	37.3868 cm^2
$A_r = (585.6*4.42 + 2*12*4.42*(1 - 1)) / 100 =$	25.8703 cm^2
$A_T = 37.3868\ cm^2 \geq A_r = 25.8703\ cm^2$	
Operating Hot & Corroded Vortex shedding Tensile	
$f_{r1} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$f_{r2} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 1.09)\} / 100 =$	17.3775 cm^2
$A_2 = 2*(67.68 - 1.09)*12*1 / 100 =$	15.9812 cm^2
$A_3 = 2*55.18*10.4*1 / 100 =$	11.478 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2
$A_T = 17.3775 + 15.9812 + 11.478 + 0.81 + 0.4539 =$	46.1006 cm^2
$A_r = (585.6*1.09 + 2*12*1.09*(1 - 1)) / 100 =$	6.3665 cm^2
$A_T = 46.1006\ cm^2 \geq A_r = 6.3665\ cm^2$	
Operating Hot & Corroded Vortex shedding Compressive	
$f_{r1} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$f_{r2} = \min[\ 1{,}101.29 / 1{,}101.29\ ,\ 1\ ] =$	1
$A_1 = \{2*118.82*(1*8.4 - 5.57)\} / 100 =$	6.7255 cm^2
$A_2 = 2*(67.68 - 5.57)*12*1 / 100 =$	14.9054 cm^2
$A_3 = 2*55.18*10.4*1 / 100 =$	11.478 cm^2
$A_{41} = 9^2*1 / 100 =$	0.81 cm^2
$A_{43} = 6.74^2*1 / 100 =$	0.4539 cm^2

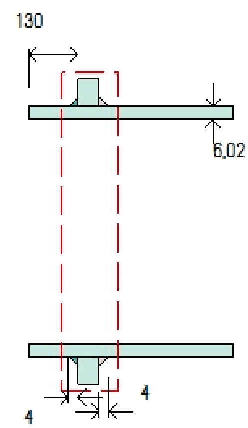
A_T = 6.7255 + 14.9054 + 11.478 + 0.81 + 0.4539 =	34.3728 cm^2
A_r = (585.6*5.57 + 2*12*5.57*(1 - 1)) / 100 =	32.6165 cm^2
A_T = 34.3728 cm^2 ≥ A_r = 32.6165 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.75)} / 100 =	15.8118 cm^2
A_2 = 2*(67.68 - 1.75)*12*1 / 100 =	15.8231 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 15.8118 + 15.8231 + 11.478 + 0.81 + 0.4539 =	44.3768 cm^2
A_r = (585.6*1.75 + 2*12*1.75*(1 - 1)) / 100 =	10.2249 cm^2
A_T = 44.3768 cm^2 ≥ A_r = 10.2249 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 5.64)} / 100 =	6.5694 cm^2
A_2 = 2*(67.68 - 5.64)*12*1 / 100 =	14.8896 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 6.5694 + 14.8896 + 11.478 + 0.81 + 0.4539 =	34.201 cm^2
A_r = (585.6*5.64 + 2*12*5.64*(1 - 1)) / 100 =	33.0011 cm^2
A_T = 34.201 cm^2 ≥ A_r = 33.0011 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 1.09)} / 100 =	17.3756 cm^2
A_2 = 2*(67.68 - 1.09)*12*1 / 100 =	15.981 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 17.3756 + 15.981 + 11.478 + 0.81 + 0.4539 =	46.0986 cm^2

A_r = (585.6*1.09 + 2*12*1.09*(1 - 1)) / 100 =	6.371 cm^2
A_T = 46.0986 cm^2 ≥ A_r = 6.371 cm^2	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,101.29 / 1,101.29 , 1] =	1
f_{r2} = min[1,101.29 / 1,101.29 , 1] =	1
A_1 = {2*118.82*(1*8.4 - 5.57)} / 100 =	6.7223 cm^2
A_2 = 2*(67.68 - 5.57)*12*1 / 100 =	14.9051 cm^2
A_3 = 2*55.18*10.4*1 / 100 =	11.478 cm^2
A_{41} = 9^2*1 / 100 =	0.81 cm^2
A_{43} = 6.74^2*1 / 100 =	0.4539 cm^2
A_T = 6.7223 + 14.9051 + 11.478 + 0.81 + 0.4539 =	34.3692 cm^2
A_r = (585.6*5.57 + 2*12*5.57*(1 - 1)) / 100 =	32.6245 cm^2
A_T = 34.3692 cm^2 ≥ A_r = 32.6245 cm^2	

Vent Hole (V1) 1

ASME Section VIII Division 1, 2017 Edition Metric	
Component	Skirt Opening
Description	Vent Hole
Drawing Mark	V1
Sleeve Material	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Location and Orientation	
Attached to	Support Skirt #1
Orientation	radial
Offset, L	620 mm
Angle, θ	0°
Distance, r	1,769 mm
Through a Category B Joint	No

Dimensions		
Pipe NPS and Schedule		NPS 4 Sch 40 (Std) DN 100
Inside Diameter		102.26 mm
Nominal Wall Thickness		6.02 mm
Skirt Thickness		10 mm
Leg_{41}		4 mm
Leg_{43}		4 mm
External Projection Available, L_{pr1}		80 mm
Internal Projection, L_{pr2}		130 mm
Corrosion	**Inner**	0 mm
	Outer	0 mm



Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	**A_T (cm^2)**	**A_r (cm^2)**	**Ratio**	**Status**
Operating Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5337	0.7823	24.9684	OK
		Compressive	5.27	7.1664	2.692	2.6621	OK
Operating Hot & New	Wind	Tensile	0.27	24.7928	0.2783	89.0984	OK
		Compressive	3.51	14.5808	1.7947	8.1246	OK
Empty Cold & Corroded	Wind	Tensile	0.45	20.1851	0.467	43.2256	OK
		Compressive	3.5	10.2784	1.7904	5.7409	OK
	Vortex shedding	Tensile	1.25	18.4682	1.2982	14.2254	OK
		Compressive	5.29	7.1278	2.7032	2.6368	OK
Empty Cold & New	Wind	Tensile	0.45	24.4013	0.4678	52.1594	OK
		Compressive	2.94	15.6778	1.5035	10.4276	OK
Shop Test New	Wind	Tensile	0	21.3418	0	N/A	OK
		Compressive	4.7	12.2934	2.4019	5.1183	OK
External Pressure Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5325	0.7829	24.9478	OK
		Compressive	5.27	7.1642	2.6927	2.6606	OK

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

Openings Subject to Axial Tension	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}^{2}*f_{r2}$	
$A_{43} = L_{43}^{2}*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1{,}679*10)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*10 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[17.54, 80, 80] + 10 =$	27.54 mm
$L_{I1} = (51.13*6.02)^{0.5} =$	17.54 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[17.54, 130, 80] =$	17.54 mm
Corroded	
$L_R = \min[(1{,}680.6*8.4)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*8.4 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[17.54, 80, 67.2] + 8.4 =$	25.94 mm
$L_{I1} = (51.13*4.42)^{0.5} =$	15.03 mm

$L_{I2} = L_{pr2} =$	128.4 mm
L_{I3} = 8*(8.4 + 0) =	67.2 mm
L_I = min[15.03, 128.4, 67.2] =	15.03 mm
Operating Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.27)} / 100 =	19.9048 cm^2
A_2 = 2*(27.54 - 0.27)*6.02*0.8551 / 100 =	2.8082 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.9048 + 2.8082 + 1.8062 + 0.1368 + 0.1368 =	24.7928 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2783 cm^2
A_T = 24.7928 cm^2 ≥ A_r = 0.2783 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.45)} / 100 =	16.2614 cm^2
A_2 = 2*(25.94 - 0.45)*6.02*0.8551 / 100 =	2.6248 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.2614 + 2.6248 + 1.1363 + 0.1368 + 0.0258 =	20.1851 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.467 cm^2
A_T = 20.1851 cm^2 ≥ A_r = 0.467 cm^2	

Empty Cold & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.45)} / 100 =	19.5321 cm^2
A_2 = 2*(27.54 - 0.45)*6.02*0.8551 / 100 =	2.7894 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.5321 + 2.7894 + 1.8062 + 0.1368 + 0.1368 =	24.4013 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.4678 cm^2
A_T = 24.4013 cm^2 ≥ A_r = 0.4678 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6413 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6413 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5337 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7823 cm^2
A_T = 19.5337 cm^2 ≥ A_r = 0.7823 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551

f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 1.25)} / 100 =	14.6267 cm^2
A_2 = 2*(25.94 - 1.25)*6.02*0.8551 / 100 =	2.5425 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 14.6267 + 2.5425 + 1.1363 + 0.1368 + 0.0258 =	18.4682 cm^2
A_r = (102.26*1.25 + 2*6.02*1.25*(1 - 0.8551)) / 100 =	1.2982 cm^2
A_T = 18.4682 cm^2 ≥ A_r = 1.2982 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6401 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6401 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5325 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7829 cm^2
A_T = 19.5325 cm^2 ≥ A_r = 0.7829 cm^2	

Division 2 4.5.17.3 Openings Subject to Axial Compression	
$\gamma_n = d / \{2*(R*t)^{0.5}\}$	(4.5.212)
$\gamma_n \leq \{(R / t) / 291 + 0.22\}^2$	
$t_{n,eff} = \min[t_n , t]$	
$t_{i,eff} = \min[t_i , t]$	
$L_R = 0.75*(R*t)^{0.5}$	
$L_H = \min[0.5*\{(d / 2)*t_n\}^{0.5} , 2.5*t_n , L_{pr1}]$	
$L_I = \min[0.5*\{(d / 2)*t_i\}^{0.5} , 2.5*t_i , L_{pr2}]$	
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(t - t_r) - 2*t_{n,eff}*(t - t_r)*(1 - f_{r1})$	
$A_2 = 2*L_H*t_{n,eff}*f_{r2}$	
$A_3 = 2*L_I*t_{i,eff}*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = 0.5*d*t_r$	(4.5.210)
New	
$\gamma_n = 102.26 / \{2*(1,679*10)^{0.5}\} =$	0.3946
$\gamma_n \leq \{(1,679 / 10) / 291 + 0.22\}^2 =$	0.6352
Area required factor for compressive side =	0.5
$L_R = 0.75*(1,679*10)^{0.5} =$	97.18 mm
$L_H = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 130] =$	8.77 mm
$t_{n,eff} = \min[6.02 , 10] =$	6.02 mm
$t_{i,eff} = \min[6.02 , 10] =$	6.02 mm
Corroded	
$\gamma_n = 102.26 / \{2*(1,680.6*8.4)^{0.5}\} =$	0.4303
$\gamma_n \leq \{(1,680.6 / 8.4) / 291 + 0.22\}^2 =$	0.8236
Area required factor for compressive side =	0.5
$L_R = 0.75*(1,680.6*8.4)^{0.5} =$	89.11 mm
$L_H = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = \min[0.5*\{(102.26 / 2)*4.42\}^{0.5} , 2.5*4.42 , 128.4] =$	7.52 mm
$t_{n,eff} = \min[6.02 , 8.4] =$	6.02 mm
$t_{i,eff} = \min[4.42 , 8.4] =$	4.42 mm
Operating Hot & Corroded Wind Compressive	

f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 3.51) - 2*6.02*(10 - 3.51)*(1 - 0.8551)} / 100 =	12.501 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 12.501 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	14.5808 cm^2
A_r = (0.5*102.26*3.51) / 100 =	1.7947 cm^2
A_T = 14.5808 cm^2 ≥ A_r = 1.7947 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 3.5) - 2*6.02*(8.4 - 3.5)*(1 - 0.8551)} / 100 =	8.6446 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 8.6446 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	10.2784 cm^2
A_r = (0.5*102.26*3.5) / 100 =	1.7904 cm^2
A_T = 10.2784 cm^2 ≥ A_r = 1.7904 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 2.94) - 2*6.02*(10 - 2.94)*(1 - 0.8551)} / 100 =	13.5979 cm^2

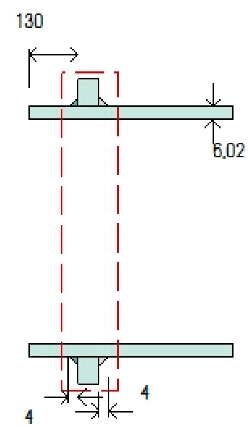
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 13.5979 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	15.6778 cm^2
A_r = (0.5*102.26*2.94) / 100 =	1.5035 cm^2
A_T = 15.6778 cm^2 ≥ A_r = 1.5035 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 4.7) - 2*6.02*(10 - 4.7)*(1 - 0.8551)} / 100 =	10.2136 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 10.2136 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	12.2934 cm^2
A_r = (0.5*102.26*4.7) / 100 =	2.4019 cm^2
A_T = 12.2934 cm^2 ≥ A_r = 2.4019 cm^2	
External Pressure Hot & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5326 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2

A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5326 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1664 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.692 cm^2
A_T = 7.1664 cm^2 ≥ A_r = 2.692 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.29) - 2*6.02*(8.4 - 5.29)*(1 - 0.8551)} / 100 =	5.4939 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.4939 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1278 cm^2
A_r = (0.5*102.26*5.29) / 100 =	2.7032 cm^2
A_T = 7.1278 cm^2 ≥ A_r = 2.7032 cm^2	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5303 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5303 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1642 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.6927 cm^2
A_T = 7.1642 cm^2 ≥ A_r = 2.6927 cm^2	

Vent Hole (V2)

1

ASME Section VIII Division 1, 2017 Edition Metric	
Component	Skirt Opening
Description	Vent Hole
Drawing Mark	V2
Sleeve Material	SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Location and Orientation	
Attached to	Support Skirt #1
Orientation	radial
Offset, L	620 mm
Angle, θ	90°
Distance, r	1,769 mm
Through a Category B Joint	No
Dimensions	
Pipe NPS and Schedule	NPS 4 Sch 40 (Std) DN 100
Inside Diameter	102.26 mm
Nominal Wall Thickness	6.02 mm
Skirt Thickness	10 mm
Leg_{41}	4 mm
Leg_{43}	4 mm
External Projection Available, L_{pr1}	80 mm
Internal Projection, L_{pr2}	130 mm
Corrosion Inner	0 mm
Corrosion Outer	0 mm



Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	A_T (cm^2)	A_r (cm^2)	Ratio	Status
Operating Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5337	0.7823	24.9684	OK
		Compressive	5.27	7.1664	2.692	2.6621	OK
Operating Hot & New	Wind	Tensile	0.27	24.7928	0.2783	89.0984	OK
		Compressive	3.51	14.5808	1.7947	8.1246	OK
Empty Cold & Corroded	Wind	Tensile	0.45	20.1851	0.467	43.2256	OK
		Compressive	3.5	10.2784	1.7904	5.7409	OK
	Vortex shedding	Tensile	1.25	18.4682	1.2982	14.2254	OK
		Compressive	5.29	7.1278	2.7032	2.6368	OK
Empty Cold & New	Wind	Tensile	0.45	24.4013	0.4678	52.1594	OK
		Compressive	2.94	15.6778	1.5035	10.4276	OK
Shop Test New	Wind	Tensile	0	21.3418	0	N/A	OK
		Compressive	4.7	12.2934	2.4019	5.1183	OK
External Pressure Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5325	0.7829	24.9478	OK
		Compressive	5.27	7.1642	2.6927	2.6606	OK

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

Openings Subject to Axial Tension	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1,679*10)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*10 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[17.54, 80, 80] + 10 =$	27.54 mm
$L_{I1} = (51.13*6.02)^{0.5} =$	17.54 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[17.54, 130, 80] =$	17.54 mm
Corroded	
$L_R = \min[(1,680.6*8.4)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*8.4 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[17.54, 80, 67.2] + 8.4 =$	25.94 mm
$L_{I1} = (51.13*4.42)^{0.5} =$	15.03 mm

$L_{I2} = L_{pr2}$ =	128.4 mm
L_{I3} = 8*(8.4 + 0) =	67.2 mm
L_I = min[15.03, 128.4, 67.2] =	15.03 mm
Operating Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.27)} / 100 =	19.9048 cm^2
A_2 = 2*(27.54 - 0.27)*6.02*0.8551 / 100 =	2.8082 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.9048 + 2.8082 + 1.8062 + 0.1368 + 0.1368 =	24.7928 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2783 cm^2
A_T = 24.7928 cm^2 ≥ A_r = 0.2783 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.45)} / 100 =	16.2614 cm^2
A_2 = 2*(25.94 - 0.45)*6.02*0.8551 / 100 =	2.6248 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.2614 + 2.6248 + 1.1363 + 0.1368 + 0.0258 =	20.1851 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.467 cm^2
A_T = 20.1851 cm^2 ≥ A_r = 0.467 cm^2	

Empty Cold & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.45)} / 100 =	19.5321 cm^2
A_2 = 2*(27.54 - 0.45)*6.02*0.8551 / 100 =	2.7894 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.5321 + 2.7894 + 1.8062 + 0.1368 + 0.1368 =	24.4013 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.4678 cm^2
A_T = 24.4013 cm^2 ≥ A_r = 0.4678 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6413 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6413 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5337 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7823 cm^2
A_T = 19.5337 cm^2 ≥ A_r = 0.7823 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551

f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 1.25)} / 100 =	14.6267 cm^2
A_2 = 2*(25.94 - 1.25)*6.02*0.8551 / 100 =	2.5425 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 14.6267 + 2.5425 + 1.1363 + 0.1368 + 0.0258 =	18.4682 cm^2
A_r = (102.26*1.25 + 2*6.02*1.25*(1 - 0.8551)) / 100 =	1.2982 cm^2
A_T = 18.4682 cm^2 ≥ A_r = 1.2982 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6401 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6401 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5325 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7829 cm^2
A_T = 19.5325 cm^2 ≥ A_r = 0.7829 cm^2	

Division 2 4.5.17.3 Openings Subject to Axial Compression	
$\gamma_n = d / \{2*(R*t)^{0.5}\}$	(4.5.212)
$\gamma_n \le \{(R / t) / 291 + 0.22\}^2$	
$t_{n,eff} = min[t_n , t]$	
$t_{i,eff} = min[t_i , t]$	
$L_R = 0.75*(R*t)^{0.5}$	
$L_H = min[0.5*\{(d / 2)*t_n\}^{0.5} , 2.5*t_n , L_{pr1}]$	
$L_I = min[0.5*\{(d / 2)*t_i\}^{0.5} , 2.5*t_i , L_{pr2}]$	
$f_{r1} = min[S_n / S , 1]$	
$f_{r2} = min[S_n / S , 1]$	
$A_1 = 2*L_R*(t - t_r) - 2*t_{n,eff}*(t - t_r)*(1 - f_{r1})$	
$A_2 = 2*L_H*t_{n,eff}*f_{r2}$	
$A_3 = 2*L_I*t_{i,eff}*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = 0.5*d*t_r$	(4.5.210)
New	
$\gamma_n = 102.26 / \{2*(1{,}679*10)^{0.5}\} =$	0.3946
$\gamma_n \le \{(1{,}679 / 10) / 291 + 0.22\}^2 =$	0.6352
Area required factor for compressive side =	0.5
$L_R = 0.75*(1{,}679*10)^{0.5} =$	97.18 mm
$L_H = min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 130] =$	8.77 mm
$t_{n,eff} = min[6.02 , 10] =$	6.02 mm
$t_{i,eff} = min[6.02 , 10] =$	6.02 mm
Corroded	
$\gamma_n = 102.26 / \{2*(1{,}680.6*8.4)^{0.5}\} =$	0.4303
$\gamma_n \le \{(1{,}680.6 / 8.4) / 291 + 0.22\}^2 =$	0.8236
Area required factor for compressive side =	0.5
$L_R = 0.75*(1{,}680.6*8.4)^{0.5} =$	89.11 mm
$L_H = min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = min[0.5*\{(102.26 / 2)*4.42\}^{0.5} , 2.5*4.42 , 128.4] =$	7.52 mm
$t_{n,eff} = min[6.02 , 8.4] =$	6.02 mm
$t_{i,eff} = min[4.42 , 8.4] =$	4.42 mm
Operating Hot & Corroded Wind Compressive	

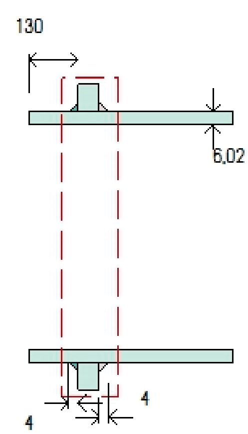
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 3.51) - 2*6.02*(10 - 3.51)*(1 - 0.8551)} / 100 =	12.501 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 12.501 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	14.5808 cm^2
A_r = (0.5*102.26*3.51) / 100 =	1.7947 cm^2
A_T = 14.5808 cm^2 ≥ A_r = 1.7947 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 3.5) - 2*6.02*(8.4 - 3.5)*(1 - 0.8551)} / 100 =	8.6446 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 8.6446 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	10.2784 cm^2
A_r = (0.5*102.26*3.5) / 100 =	1.7904 cm^2
A_T = 10.2784 cm^2 ≥ A_r = 1.7904 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 2.94) - 2*6.02*(10 - 2.94)*(1 - 0.8551)} / 100 =	13.5979 cm^2

A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 13.5979 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	15.6778 cm^2
A_r = (0.5*102.26*2.94) / 100 =	1.5035 cm^2
A_T = 15.6778 cm^2 ≥ A_r = 1.5035 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 4.7) - 2*6.02*(10 - 4.7)*(1 - 0.8551)} / 100 =	10.2136 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 10.2136 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	12.2934 cm^2
A_r = (0.5*102.26*4.7) / 100 =	2.4019 cm^2
A_T = 12.2934 cm^2 ≥ A_r = 2.4019 cm^2	
External Pressure Hot & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5326 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2

$A_{43} = 1.74^2*0.8551 / 100 =$	0.0258 cm^2
$A_T = 5.5326 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =$	7.1664 cm^2
$A_r = (0.5*102.26*5.27) / 100 =$	2.692 cm^2
$A_T = 7.1664\ cm^2 \geq A_r = 2.692\ cm^2$	
Empty Cold & Corroded Vortex shedding Compressive	
$f_{r1} = min[\ 1{,}203.26 / 1{,}407.21 , 1\ ] =$	0.8551
$f_{r2} = min[\ 1{,}203.26 / 1{,}407.21 , 1\ ] =$	0.8551
$A_1 = \{2*89.11*(8.4 - 5.29) - 2*6.02*(8.4 - 5.29)*(1 - 0.8551)\} / 100 =$	5.4939 cm^2
$A_2 = 2*8.77*6.02*0.8551 / 100 =$	0.9031 cm^2
$A_3 = 2*7.52*4.42*0.8551 / 100 =$	0.5682 cm^2
$A_{41} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_{43} = 1.74^2*0.8551 / 100 =$	0.0258 cm^2
$A_T = 5.4939 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =$	7.1278 cm^2
$A_r = (0.5*102.26*5.29) / 100 =$	2.7032 cm^2
$A_T = 7.1278\ cm^2 \geq A_r = 2.7032\ cm^2$	
External Pressure Hot & Corroded Vortex shedding Compressive	
$f_{r1} = min[\ 1{,}203.26 / 1{,}407.21 , 1\ ] =$	0.8551
$f_{r2} = min[\ 1{,}203.26 / 1{,}407.21 , 1\ ] =$	0.8551
$A_1 = \{2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)\} / 100 =$	5.5303 cm^2
$A_2 = 2*8.77*6.02*0.8551 / 100 =$	0.9031 cm^2
$A_3 = 2*7.52*4.42*0.8551 / 100 =$	0.5682 cm^2
$A_{41} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_{43} = 1.74^2*0.8551 / 100 =$	0.0258 cm^2
$A_T = 5.5303 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =$	7.1642 cm^2
$A_r = (0.5*102.26*5.27) / 100 =$	2.6927 cm^2
$A_T = 7.1642\ cm^2 \geq A_r = 2.6927\ cm^2$	

Vent Hole (V3) 1

ASME Section VIII Division 1, 2017 Edition Metric		
Component		Skirt Opening
Description		Vent Hole
Drawing Mark		V3
Sleeve Material		SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Location and Orientation		
Attached to		Support Skirt #1
Orientation		radial
Offset, L		620 mm
Angle, θ		180°
Distance, r		1,769 mm
Through a Category B Joint		No
Dimensions		
Pipe NPS and Schedule		NPS 4 Sch 40 (Std) DN 100
Inside Diameter		102.26 mm
Nominal Wall Thickness		6.02 mm
Skirt Thickness		10 mm
Leg_{41}		4 mm
Leg_{43}		4 mm
External Projection Available, L_{pr1}		80 mm
Internal Projection, L_{pr2}		130 mm
Corrosion	**Inner**	0 mm
	Outer	0 mm



Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	A_T (cm^2)	A_r (cm^2)	Ratio	Status
Operating Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5337	0.7823	24.9684	OK
		Compressive	5.27	7.1664	2.692	2.6621	OK
Operating Hot & New	Wind	Tensile	0.27	24.7928	0.2783	89.0984	OK
		Compressive	3.51	14.5808	1.7947	8.1246	OK
Empty Cold & Corroded	Wind	Tensile	0.45	20.1851	0.467	43.2256	OK
		Compressive	3.5	10.2784	1.7904	5.7409	OK
	Vortex shedding	Tensile	1.25	18.4682	1.2982	14.2254	OK
		Compressive	5.29	7.1278	2.7032	2.6368	OK
Empty Cold & New	Wind	Tensile	0.45	24.4013	0.4678	52.1594	OK
		Compressive	2.94	15.6778	1.5035	10.4276	OK
Shop Test New	Wind	Tensile	0	21.3418	0	N/A	OK
		Compressive	4.7	12.2934	2.4019	5.1183	OK
External Pressure Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5325	0.7829	24.9478	OK
		Compressive	5.27	7.1642	2.6927	2.6606	OK

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

Openings Subject to Axial Tension	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1,679*10)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*10 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[17.54, 80, 80] + 10 =$	27.54 mm
$L_{I1} = (51.13*6.02)^{0.5} =$	17.54 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[17.54, 130, 80] =$	17.54 mm
Corroded	
$L_R = \min[(1,680.6*8.4)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*8.4 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[17.54, 80, 67.2] + 8.4 =$	25.94 mm
$L_{I1} = (51.13*4.42)^{0.5} =$	15.03 mm

$L_{I2} = L_{pr2} =$	128.4 mm
$L_{I3} = 8*(8.4 + 0) =$	67.2 mm
$L_I = min[15.03, 128.4, 67.2] =$	15.03 mm
Operating Hot & Corroded Wind Tensile	
$f_{r1} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$f_{r2} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$A_1 = \{2*102.26*(1*8.4 - 0.27)\} / 100 =$	16.6343 cm^2
$A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =$	2.6435 cm^2
$A_3 = 2*15.03*4.42*0.8551 / 100 =$	1.1363 cm^2
$A_{41} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_{43} = 1.74^2*0.8551 / 100 =$	0.0258 cm^2
$A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =$	20.5768 cm^2
$A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =$	0.2773 cm^2
$A_T = 20.5768\ cm^2 \geq A_r = 0.2773\ cm^2$	
Operating Hot & New Wind Tensile	
$f_{r1} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$f_{r2} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$A_1 = \{2*102.26*(1*10 - 0.27)\} / 100 =$	19.9048 cm^2
$A_2 = 2*(27.54 - 0.27)*6.02*0.8551 / 100 =$	2.8082 cm^2
$A_3 = 2*17.54*6.02*0.8551 / 100 =$	1.8062 cm^2
$A_{41} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_{43} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_T = 19.9048 + 2.8082 + 1.8062 + 0.1368 + 0.1368 =$	24.7928 cm^2
$A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =$	0.2783 cm^2
$A_T = 24.7928\ cm^2 \geq A_r = 0.2783\ cm^2$	
Empty Cold & Corroded Wind Tensile	
$f_{r1} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$f_{r2} = min[1,203.26 / 1,407.21 , 1] =$	0.8551
$A_1 = \{2*102.26*(1*8.4 - 0.45)\} / 100 =$	16.2614 cm^2
$A_2 = 2*(25.94 - 0.45)*6.02*0.8551 / 100 =$	2.6248 cm^2
$A_3 = 2*15.03*4.42*0.8551 / 100 =$	1.1363 cm^2
$A_{41} = 4^2*0.8551 / 100 =$	0.1368 cm^2
$A_{43} = 1.74^2*0.8551 / 100 =$	0.0258 cm^2
$A_T = 16.2614 + 2.6248 + 1.1363 + 0.1368 + 0.0258 =$	20.1851 cm^2
$A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =$	0.467 cm^2
$A_T = 20.1851\ cm^2 \geq A_r = 0.467\ cm^2$	

Empty Cold & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.45)} / 100 =	19.5321 cm^2
A_2 = 2*(27.54 - 0.45)*6.02*0.8551 / 100 =	2.7894 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.5321 + 2.7894 + 1.8062 + 0.1368 + 0.1368 =	24.4013 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.4678 cm^2
A_T = 24.4013 cm^2 ≥ A_r = 0.4678 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6413 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6413 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5337 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7823 cm^2
A_T = 19.5337 cm^2 ≥ A_r = 0.7823 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551

f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 1.25)} / 100 =	14.6267 cm^2
A_2 = 2*(25.94 - 1.25)*6.02*0.8551 / 100 =	2.5425 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 14.6267 + 2.5425 + 1.1363 + 0.1368 + 0.0258 =	18.4682 cm^2
A_r = (102.26*1.25 + 2*6.02*1.25*(1 - 0.8551)) / 100 =	1.2982 cm^2
A_T = 18.4682 cm^2 ≥ A_r = 1.2982 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6401 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6401 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5325 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7829 cm^2
A_T = 19.5325 cm^2 ≥ A_r = 0.7829 cm^2	

Division 2 4.5.17.3 Openings Subject to Axial Compression	
$\gamma_n = d / \{2*(R*t)^{0.5}\}$	(4.5.212)
$\gamma_n \leq \{(R / t) / 291 + 0.22\}^2$	
$t_{n,eff} = \min[t_n , t]$	
$t_{i,eff} = \min[t_i , t]$	
$L_R = 0.75*(R*t)^{0.5}$	
$L_H = \min[0.5*\{(d / 2)*t_n\}^{0.5} , 2.5*t_n , L_{pr1}]$	
$L_I = \min[0.5*\{(d / 2)*t_i\}^{0.5} , 2.5*t_i , L_{pr2}]$	
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(t - t_r) - 2*t_{n,eff}*(t - t_r)*(1 - f_{r1})$	
$A_2 = 2*L_H*t_{n,eff}*f_{r2}$	
$A_3 = 2*L_I*t_{i,eff}*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = 0.5*d*t_r$	(4.5.210)
New	
$\gamma_n = 102.26 / \{2*(1,679*10)^{0.5}\} =$	0.3946
$\gamma_n \leq \{(1,679 / 10) / 291 + 0.22\}^2 =$	0.6352
Area required factor for compressive side =	0.5
$L_R = 0.75*(1,679*10)^{0.5} =$	97.18 mm
$L_H = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 130] =$	8.77 mm
$t_{n,eff} = \min[6.02 , 10] =$	6.02 mm
$t_{i,eff} = \min[6.02 , 10] =$	6.02 mm
Corroded	
$\gamma_n = 102.26 / \{2*(1,680.6*8.4)^{0.5}\} =$	0.4303
$\gamma_n \leq \{(1,680.6 / 8.4) / 291 + 0.22\}^2 =$	0.8236
Area required factor for compressive side =	0.5
$L_R = 0.75*(1,680.6*8.4)^{0.5} =$	89.11 mm
$L_H = \min[0.5*\{(102.26 / 2)*6.02\}^{0.5} , 2.5*6.02 , 80] =$	8.77 mm
$L_I = \min[0.5*\{(102.26 / 2)*4.42\}^{0.5} , 2.5*4.42 , 128.4] =$	7.52 mm
$t_{n,eff} = \min[6.02 , 8.4] =$	6.02 mm
$t_{i,eff} = \min[4.42 , 8.4] =$	4.42 mm
Operating Hot & Corroded Wind Compressive	

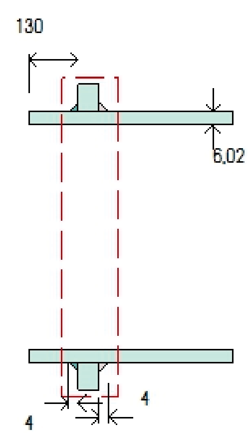
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 3.51) - 2*6.02*(10 - 3.51)*(1 - 0.8551)} / 100 =	12.501 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 12.501 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	14.5808 cm^2
A_r = (0.5*102.26*3.51) / 100 =	1.7947 cm^2
A_T = 14.5808 cm^2 ≥ A_r = 1.7947 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 3.5) - 2*6.02*(8.4 - 3.5)*(1 - 0.8551)} / 100 =	8.6446 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 8.6446 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	10.2784 cm^2
A_r = (0.5*102.26*3.5) / 100 =	1.7904 cm^2
A_T = 10.2784 cm^2 ≥ A_r = 1.7904 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 2.94) - 2*6.02*(10 - 2.94)*(1 - 0.8551)} / 100 =	13.5979 cm^2

A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 13.5979 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	15.6778 cm^2
A_r = (0.5*102.26*2.94) / 100 =	1.5035 cm^2
A_T = 15.6778 cm^2 ≥ A_r = 1.5035 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 4.7) - 2*6.02*(10 - 4.7)*(1 - 0.8551)} / 100 =	10.2136 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 10.2136 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	12.2934 cm^2
A_r = (0.5*102.26*4.7) / 100 =	2.4019 cm^2
A_T = 12.2934 cm^2 ≥ A_r = 2.4019 cm^2	
External Pressure Hot & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5326 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2

A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5326 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1664 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.692 cm^2
A_T = 7.1664 cm^2 ≥ A_r = 2.692 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.29) - 2*6.02*(8.4 - 5.29)*(1 - 0.8551)} / 100 =	5.4939 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.4939 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1278 cm^2
A_r = (0.5*102.26*5.29) / 100 =	2.7032 cm^2
A_T = 7.1278 cm^2 ≥ A_r = 2.7032 cm^2	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5303 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5303 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1642 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.6927 cm^2
A_T = 7.1642 cm^2 ≥ A_r = 2.6927 cm^2	

Vent Hole (V4) 1

ASME Section VIII Division 1, 2017 Edition Metric		
Component		Skirt Opening
Description		Vent Hole
Drawing Mark		V4
Sleeve Material		SA-106 B Smls Pipe (II-D Metric p. 14, ln. 10)
Location and Orientation		
Attached to		Support Skirt #1
Orientation		radial
Offset, L		620 mm
Angle, θ		270°
Distance, r		1,769 mm
Through a Category B Joint		No
Dimensions		
Pipe NPS and Schedule		NPS 4 Sch 40 (Std) DN 100
Inside Diameter		102.26 mm
Nominal Wall Thickness		6.02 mm
Skirt Thickness		10 mm
Leg_{41}		4 mm
Leg_{43}		4 mm
External Projection Available, L_{pr1}		80 mm
Internal Projection, L_{pr2}		130 mm
Corrosion	**Inner**	0 mm
	Outer	0 mm



Skirt Opening Reinforcement Summary							
			Required Thickness t_r (mm)	**A_T (cm^2)**	**A_r (cm^2)**	**Ratio**	**Status**
Operating Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5337	0.7823	24.9684	OK
		Compressive	5.27	7.1664	2.692	2.6621	OK
Operating Hot & New	Wind	Tensile	0.27	24.7928	0.2783	89.0984	OK
		Compressive	3.51	14.5808	1.7947	8.1246	OK
Empty Cold & Corroded	Wind	Tensile	0.45	20.1851	0.467	43.2256	OK
		Compressive	3.5	10.2784	1.7904	5.7409	OK
	Vortex shedding	Tensile	1.25	18.4682	1.2982	14.2254	OK
		Compressive	5.29	7.1278	2.7032	2.6368	OK
Empty Cold & New	Wind	Tensile	0.45	24.4013	0.4678	52.1594	OK
		Compressive	2.94	15.6778	1.5035	10.4276	OK
Shop Test New	Wind	Tensile	0	21.3418	0	N/A	OK
		Compressive	4.7	12.2934	2.4019	5.1183	OK
External Pressure Hot & Corroded	Wind	Tensile	0.27	20.5768	0.2773	74.1965	OK
		Compressive	4.18	9.0805	2.1375	4.2483	OK
	Vortex shedding	Tensile	0.75	19.5325	0.7829	24.9478	OK
		Compressive	5.27	7.1642	2.6927	2.6606	OK

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

Openings Subject to Axial Tension	
$L_R = \min[(R_{eff}*t)^{0.5}, 2*R_n]$	(4.5.4)
$L_{H1} = \min[1.5*t , t_e] + (R_n*t_n)^{0.5}$	(4.5.11)
$L_{H2} = L_{pr1}$	(4.5.12)
$L_{H3} = 8*(t + t_e)$	(4.5.13)
$L_H = \min[L_{H1}, L_{H2}, L_{H3}] + t$	(4.5.14)
$L_{I1} = (R_n*t_n)^{0.5}$	(4.5.16)
$L_{I2} = L_{pr2}$	(4.5.17)
$L_{I3} = 8*(t + t_e)$	(4.5.18)
$L_I = \min[L_{I1}, L_{I2}, L_{I3}]$	(4.5.19)
$f_{r1} = \min[S_n / S , 1]$	
$f_{r2} = \min[S_n / S , 1]$	
$A_1 = 2*L_R*(E_1*t - t_r)$	
$A_2 = 2*(L_H - t_r)*t_n*f_{r2}$	
$A_3 = 2*L_I*t_i*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = d*t_r + 2*t_n*t_r*(1 - f_{r1})$	
New	
$L_R = \min[(1{,}679*10)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*10 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(10 + 0) =$	80 mm
$L_H = \min[17.54, 80, 80] + 10 =$	27.54 mm
$L_{I1} = (51.13*6.02)^{0.5} =$	17.54 mm
$L_{I2} = L_{pr2} =$	130 mm
$L_{I3} = 8*(10 + 0) =$	80 mm
$L_I = \min[17.54, 130, 80] =$	17.54 mm
Corroded	
$L_R = \min[(1{,}680.6*8.4)^{0.5}, 2*51.13] =$	102.26 mm
$L_{H1} = \min[1.5*8.4 , 0] + (51.13*6.02)^{0.5} =$	17.54 mm
$L_{H2} = 80 =$	80 mm
$L_{H3} = 8*(8.4 + 0) =$	67.2 mm
$L_H = \min[17.54, 80, 67.2] + 8.4 =$	25.94 mm
$L_{I1} = (51.13*4.42)^{0.5} =$	15.03 mm

$L_{I2} = L_{pr2} =$	128.4 mm
L_{I3} = 8*(8.4 + 0) =	67.2 mm
L_I = min[15.03, 128.4, 67.2] =	15.03 mm
Operating Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.27)} / 100 =	19.9048 cm^2
A_2 = 2*(27.54 - 0.27)*6.02*0.8551 / 100 =	2.8082 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.9048 + 2.8082 + 1.8062 + 0.1368 + 0.1368 =	24.7928 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2783 cm^2
A_T = 24.7928 cm^2 ≥ A_r = 0.2783 cm^2	
Empty Cold & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.45)} / 100 =	16.2614 cm^2
A_2 = 2*(25.94 - 0.45)*6.02*0.8551 / 100 =	2.6248 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.2614 + 2.6248 + 1.1363 + 0.1368 + 0.0258 =	20.1851 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.467 cm^2
A_T = 20.1851 cm^2 ≥ A_r = 0.467 cm^2	

Empty Cold & New Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*10 - 0.45)} / 100 =	19.5321 cm^2
A_2 = 2*(27.54 - 0.45)*6.02*0.8551 / 100 =	2.7894 cm^2
A_3 = 2*17.54*6.02*0.8551 / 100 =	1.8062 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 19.5321 + 2.7894 + 1.8062 + 0.1368 + 0.1368 =	24.4013 cm^2
A_r = (102.26*0.45 + 2*6.02*0.45*(1 - 0.8551)) / 100 =	0.4678 cm^2
A_T = 24.4013 cm^2 ≥ A_r = 0.4678 cm^2	
External Pressure Hot & Corroded Wind Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.27)} / 100 =	16.6343 cm^2
A_2 = 2*(25.94 - 0.27)*6.02*0.8551 / 100 =	2.6435 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 16.6343 + 2.6435 + 1.1363 + 0.1368 + 0.0258 =	20.5768 cm^2
A_r = (102.26*0.27 + 2*6.02*0.27*(1 - 0.8551)) / 100 =	0.2773 cm^2
A_T = 20.5768 cm^2 ≥ A_r = 0.2773 cm^2	
Operating Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6413 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6413 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5337 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7823 cm^2
A_T = 19.5337 cm^2 ≥ A_r = 0.7823 cm^2	
Empty Cold & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551

f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 1.25)} / 100 =	14.6267 cm^2
A_2 = 2*(25.94 - 1.25)*6.02*0.8551 / 100 =	2.5425 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 14.6267 + 2.5425 + 1.1363 + 0.1368 + 0.0258 =	18.4682 cm^2
A_r = (102.26*1.25 + 2*6.02*1.25*(1 - 0.8551)) / 100 =	1.2982 cm^2
A_T = 18.4682 cm^2 ≥ A_r = 1.2982 cm^2	
External Pressure Hot & Corroded Vortex shedding Tensile	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*102.26*(1*8.4 - 0.75)} / 100 =	15.6401 cm^2
A_2 = 2*(25.94 - 0.75)*6.02*0.8551 / 100 =	2.5935 cm^2
A_3 = 2*15.03*4.42*0.8551 / 100 =	1.1363 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 15.6401 + 2.5935 + 1.1363 + 0.1368 + 0.0258 =	19.5325 cm^2
A_r = (102.26*0.75 + 2*6.02*0.75*(1 - 0.8551)) / 100 =	0.7829 cm^2
A_T = 19.5325 cm^2 ≥ A_r = 0.7829 cm^2	

Division 2 4.5.17.3 Openings Subject to Axial Compression	
$\gamma_n = d / \{2*(R*t)^{0.5}\}$	(4.5.212)
$\gamma_n \leq \{(R / t) / 291 + 0.22\}^2$	
$t_{n,eff} = min[\ t_n\ ,\ t]$	
$t_{i,eff} = min[\ t_i\ ,\ t]$	
$L_R = 0.75*(R*t)^{0.5}$	
$L_H = min[0.5*\{(d / 2)*t_n\}^{0.5}\ ,\ 2.5*t_n\ ,\ L_{pr1}\ ]$	
$L_I = min[0.5*\{(d / 2)*t_i\}^{0.5}\ ,\ 2.5*t_i\ ,\ L_{pr2}\ ]$	
$f_{r1} = min[\ S_n / S\ ,\ 1\ ]$	
$f_{r2} = min[\ S_n / S\ ,\ 1\ ]$	
$A_1 = 2*L_R*(t - t_r) - 2*t_{n,eff}*(t - t_r)*(1 - f_{r1})$	
$A_2 = 2*L_H*t_{n,eff}*f_{r2}$	
$A_3 = 2*L_I*t_{i,eff}*f_{r2}$	
$A_{41} = L_{41}{}^2*f_{r2}$	
$A_{43} = L_{43}{}^2*f_{r2}$	
$A_T = A_1 + A_2 + A_3 + A_{41} + A_{43}$	
$A_r = 0.5*d*t_r$	(4.5.210)
New	
$\gamma_n = 102.26 / \{2*(1{,}679*10)^{0.5}\} =$	0.3946
$\gamma_n \leq \{(1{,}679 / 10) / 291 + 0.22\}^2 =$	0.6352
Area required factor for compressive side =	0.5
$L_R = 0.75*(1{,}679*10)^{0.5} =$	97.18 mm
$L_H = min[0.5*\{(102.26 / 2)*6.02\}^{0.5}\ ,\ 2.5*6.02\ ,\ 80\ ] =$	8.77 mm
$L_I = min[0.5*\{(102.26 / 2)*6.02\}^{0.5}\ ,\ 2.5*6.02\ ,\ 130\ ] =$	8.77 mm
$t_{n,eff} = min[\ 6.02\ ,\ 10] =$	6.02 mm
$t_{i,eff} = min[\ 6.02\ ,\ 10] =$	6.02 mm
Corroded	
$\gamma_n = 102.26 / \{2*(1{,}680.6*8.4)^{0.5}\} =$	0.4303
$\gamma_n \leq \{(1{,}680.6 / 8.4) / 291 + 0.22\}^2 =$	0.8236
Area required factor for compressive side =	0.5
$L_R = 0.75*(1{,}680.6*8.4)^{0.5} =$	89.11 mm
$L_H = min[0.5*\{(102.26 / 2)*6.02\}^{0.5}\ ,\ 2.5*6.02\ ,\ 80\ ] =$	8.77 mm
$L_I = min[0.5*\{(102.26 / 2)*4.42\}^{0.5}\ ,\ 2.5*4.42\ ,\ 128.4\ ] =$	7.52 mm
$t_{n,eff} = min[\ 6.02\ ,\ 8.4] =$	6.02 mm
$t_{i,eff} = min[\ 4.42\ ,\ 8.4] =$	4.42 mm
Operating Hot & Corroded Wind Compressive	

f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 3.51) - 2*6.02*(10 - 3.51)*(1 - 0.8551)} / 100 =	12.501 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 12.501 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	14.5808 cm^2
A_r = (0.5*102.26*3.51) / 100 =	1.7947 cm^2
A_T = 14.5808 cm^2 ≥ A_r = 1.7947 cm^2	
Empty Cold & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 3.5) - 2*6.02*(8.4 - 3.5)*(1 - 0.8551)} / 100 =	8.6446 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 8.6446 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	10.2784 cm^2
A_r = (0.5*102.26*3.5) / 100 =	1.7904 cm^2
A_T = 10.2784 cm^2 ≥ A_r = 1.7904 cm^2	
Empty Cold & New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 2.94) - 2*6.02*(10 - 2.94)*(1 - 0.8551)} / 100 =	13.5979 cm^2

A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 13.5979 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	15.6778 cm^2
A_r = (0.5*102.26*2.94) / 100 =	1.5035 cm^2
A_T = 15.6778 cm^2 ≥ A_r = 1.5035 cm^2	
Shop Test New Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*97.18*(10 - 4.7) - 2*6.02*(10 - 4.7)*(1 - 0.8551)} / 100 =	10.2136 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_T = 10.2136 + 0.9031 + 0.9031 + 0.1368 + 0.1368 =	12.2934 cm^2
A_r = (0.5*102.26*4.7) / 100 =	2.4019 cm^2
A_T = 12.2934 cm^2 ≥ A_r = 2.4019 cm^2	
External Pressure Hot & Corroded Wind Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 4.18) - 2*6.02*(8.4 - 4.18)*(1 - 0.8551)} / 100 =	7.4466 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 7.4466 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	9.0805 cm^2
A_r = (0.5*102.26*4.18) / 100 =	2.1375 cm^2
A_T = 9.0805 cm^2 ≥ A_r = 2.1375 cm^2	
Operating Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5326 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2

A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5326 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1664 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.692 cm^2
A_T = 7.1664 cm^2 ≥ A_r = 2.692 cm^2	
Empty Cold & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.29) - 2*6.02*(8.4 - 5.29)*(1 - 0.8551)} / 100 =	5.4939 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.4939 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1278 cm^2
A_r = (0.5*102.26*5.29) / 100 =	2.7032 cm^2
A_T = 7.1278 cm^2 ≥ A_r = 2.7032 cm^2	
External Pressure Hot & Corroded Vortex shedding Compressive	
f_{r1} = min[1,203.26 / 1,407.21 , 1] =	0.8551
f_{r2} = min[1,203.26 / 1,407.21 , 1] =	0.8551
A_1 = {2*89.11*(8.4 - 5.27) - 2*6.02*(8.4 - 5.27)*(1 - 0.8551)} / 100 =	5.5303 cm^2
A_2 = 2*8.77*6.02*0.8551 / 100 =	0.9031 cm^2
A_3 = 2*7.52*4.42*0.8551 / 100 =	0.5682 cm^2
A_{41} = 4^2*0.8551 / 100 =	0.1368 cm^2
A_{43} = 1.74^2*0.8551 / 100 =	0.0258 cm^2
A_T = 5.5303 + 0.9031 + 0.5682 + 0.1368 + 0.0258 =	7.1642 cm^2
A_r = (0.5*102.26*5.27) / 100 =	2.6927 cm^2
A_T = 7.1642 cm^2 ≥ A_r = 2.6927 cm^2	

Rings #1 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Bottom existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.06 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	2,000 mm
Distance to previous support	1,500 mm
Distance to next support	2,280.17 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	0 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,280.17 / 3,378 = 0.675
D_o / t = 3,378 / 9.28 = 363.8675
From Table G: A = 2.9643E-04
From Table CS-2 Metric: B = 288.14 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*288.14 / (3*(3,378 / 9.28))
= 1.06 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.06*3,378 / (9.28 + 1,834 / 1,890.08)*1.02
= 265.802 kg_f/cm^2

From Table CS-2 Metric: A = 0.00026817 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,890.08*(9.28 + 1,834 / 1,890.08)*0.00026817] / 10.9 / 10000

$= 544.1\ cm^4$

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.06 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.06*1{,}890.08 / 10 = 203.34\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.06*1.02*1{,}890.08*3{,}378 / 100 = 686.87\ kg_f$
First moment of area, $Q = 33.49*2.69 = 90.0275\ cm^3$

Weld shear flow, $q = V*Q / I' = 75.8951\ kg_f/cm$
Combined weld load, $f_w = Sqr(203.3356^2 + 75.8951^2) = 217.04\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion \\
&= 10*217.04*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.4\ mm
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 2{,}280.17 / 3{,}378 = 0.675$
$D_o / t = 3{,}378 / 11.01 = 306.7133$
From Table G: A = 3.7395E-04
From Table CS-2 Metric: B = 363.99 kg_f/cm^2

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*363.99 / (3*(3{,}378 / 11.01)) \\
&= 1.58\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*1.58*3{,}378 / (11.01 + 1{,}834 / 1{,}890.08)*1.02 \\
&= 341.078\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00034361 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}378^2*1{,}890.08*(11.01 + 1{,}834 / 1{,}890.08)*0.00034361] / 10.9 / 10000 \\
&= 814.77\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.58 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.58*1,890.08 / 10 = 304.93 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.58*1.02*1,890.08*3,378 / 100 = 1,030.07 kg_f
First moment of area, Q = 33.49*2.69 = 90.0275 cm^3

Weld shear flow, $q = V*Q / I'$ = 113.817 kg_f/cm
Combined weld load, f_w = Sqr(304.9346^2 + 113.817^2) = 325.48 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*325.48*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 2.1\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #2 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Bottom existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.06 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	3,500 mm
Distance to previous support	1,600 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	0 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,600 / 3,378 = 0.4737
D_o / t = 3,378 / 8.08 = 418.1985
From Table G: A = 3.4021E-04
From Table CS-2 Metric: B = 330.96 kg_f/cm^2

P_a = $4*B / (3*(D_o / t))$
= 4*330.96 / (3*(3,378 / 8.08))
= 1.06 kg_f/cm^2

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.06*3,378 / (8.08 + 1,834 / 1,550)*1.02
= 294.322 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029677 (ring, 175°C)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3,378^2*1,550*(8.08 + 1,834 / 1,550)*0.00029677] / 10.9 / 10000$

$= 445.93\ cm^4$

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.06 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.06*1,550 / 10 = 166.75 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.06*1.02*1,550*3,378 / 100 = 563.28 kg_f
First moment of area, Q = 33.49*2.69 = 90.0275 cm^3

Weld shear flow, $q = V*Q / I'$ = 62.2393 kg_f/cm
Combined weld load, $f_w = Sqr(166.7493^2 + 62.2393^2)$ = 177.99 kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*1,407.207 = 773.964 kg_f/cm^2

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
= 10*177.99*(25.4 + 0) / (773.964*50.8) + 0
= 1.15 mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,600 / 3,378 = 0.4737
D_o / t = 3,378 / 10.18 = 331.9119
From Table G: A = 4.9357E-04
From Table CS-2 Metric: B = 481.22 kg_f/cm^2

$P_a = 4*B / (3*(D_o / t))$
= 4*481.22 / (3*(3,378 / 10.18))
= 1.93 kg_f/cm^2

$B = 0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.93*3,378 / (10.18 + 1,834 / 1,550)*1.02
= 439.366 kg_f/cm^2

From Table CS-2 Metric: A = 0.00044197 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3,378^2*1,550*(10.18 + 1,834 / 1,550)*0.00044197] / 10.9 / 10000$
= 814.77 cm^4

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.93 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.93*1,550 / 10 = 305.39 kg_f/cm
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*1.93*1.02*1,550*3,378 / 100 = 1,031.61 kg_f
First moment of area, Q = 33.49*2.69 = 90.0275 cm^3

Weld shear flow, q = V*Q / I' = 113.9867 kg_f/cm
Combined weld load, f_w = Sqr(305.3892^2 + 113.9867^2) = 325.97 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

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
= 10*325.97*(25.4 + 0) / (773.964*50.8) + 0
= 2.11 mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #3 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Bottom existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.06 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	5,100 mm
Distance to previous support	1,500 mm
Distance to next support	1,600 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	0 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,600 / 3,378 = 0.4737
D_o / t = 3,378 / 8.08 = 418.1985
From Table G: A = 3.4021E-04
From Table CS-2 Metric: B = 330.96 kg_f/cm^2

P_a = $4*B / (3*(D_o / t))$
= 4*330.96 / (3*(3,378 / 8.08))
= 1.06 kg_f/cm^2

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.06*3,378 / (8.08 + 1,834 / 1,550)*1.02
= 294.322 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029677 (ring, 175°C)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3{,}378^2*1{,}550*(8.08 + 1{,}834 / 1{,}550)*0.00029677] / 10.9 / 10000$

$= 445.93\ cm^4$

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.06 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.06*1{,}550 / 10 = 166.75\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.06*1.02*1{,}550*3{,}378 / 100 = 563.28\ kg_f$
First moment of area, $Q = 33.49*2.69 = 90.0275\ cm^3$

Weld shear flow, $q = V*Q / I' = 62.2393\ kg_f/cm$
Combined weld load, $f_w = Sqr(166.7493^2 + 62.2393^2) = 177.99\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*177.99*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.15\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}600 / 3{,}378 = 0.4737$
$D_o / t = 3{,}378 / 10.18 = 331.9119$
From Table G: A = 4.9357E-04
From Table CS-2 Metric: B = 481.22 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*481.22 / (3*(3{,}378 / 10.18))$$
$$= 1.93\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.93*3{,}378 / (10.18 + 1{,}834 / 1{,}550)*1.02$$
$$= 439.366\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00044197 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3{,}378^2*1{,}550*(10.18 + 1{,}834 / 1{,}550)*0.00044197] / 10.9 / 10000$$
$$= 814.77\ cm^4$$

I' for the composite corroded shell-ring cross section is 814.77 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.93 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.93*1,550 / 10 = 305.39 kg_f/cm
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*1.93*1.02*1,550*3,378 / 100 = 1,031.61 kg_f
First moment of area, Q = 33.49*2.69 = 90.0275 cm^3

Weld shear flow, q = V*Q / I' = 113.9867 kg_f/cm
Combined weld load, f_w = Sqr(305.3892^2 + 113.9867^2) = 325.97 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*325.97*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 2.11 \text{ mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #4 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	New shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	6,600 mm
Distance to previous support	1,160 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	25 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	12
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,400 = 0.4412
D_o / t = 3,400 / 7.8 = 436.1355
From Table G: A = 3.4655E-04
From Table CS-2 Metric: B = 337.16 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*337.16 / (3*(3,400 / 7.8))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,400 / (7.8 + 1,834 / 1,330)*1.02
= 291.937 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029437 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3,400^2$*1,330*(7.8 + 1,834 / 1,330)*0.00029437] / 10.9 / 10000

$= 380.94\ cm^4$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1,330 / 10 = 139.69\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1,330*3,400 / 100 = 474.95\ kg_f$
First moment of area, $Q = 66.19*1.74 = 114.843\ cm^3$

Weld shear flow, $q = V*Q / I' = 50.9546\ kg_f/cm$
Combined weld load, $f_w = Sqr(139.6911^2 + 50.9546^2) = 148.69\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1,407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*148.69*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 0.96\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1,500 / 3,400 = 0.4412$
$D_o / t = 3,400 / 11.78 = 288.6338$
From Table G: A = 6.4417E-04
From Table CS-2 Metric: B = 629.07 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*629.07 / (3*(3,400 / 11.78))$$
$$= 2.91\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*2.91*3,400 / (11.78 + 1,834 / 1,330)*1.02$$
$$= 574.203\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00057670 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3,400^2*1,330*(11.78 + 1,834 / 1,330)*0.00057670] / 10.9 / 10000$$
$$= 1,070.46\ cm^4$$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 2.91 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 2.91*1,330 / 10 = 394.11 kg_f/cm
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*2.91*1.02*1,330*3,400 / 100 = 1,339.97 kg_f
First moment of area, Q = 66.19*1.74 = 114.843 cm^3

Weld shear flow, q = V*Q / I' = 143.7572 kg_f/cm
Combined weld load, f_w = Sqr(394.1081^2 + 143.7572^2) = 419.51 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*419.51*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 2.71 \text{ mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #5

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	New shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	7,760 mm
Distance to previous support	1,500 mm
Distance to next support	1,160 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	25 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}500 / 3{,}400 = 0.4412$
$D_o / t = 3{,}400 / 7.8 = 436.1355$
From Table G: $A = 3.4655E-04$
From Table CS-2 Metric: $B = 337.16\ kg_f/cm^2$

$P_a = 4*B / (3*(D_o / t))$
$= 4*337.16 / (3*(3{,}400 / 7.8))$
$= 1.03\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*1.03*3{,}400 / (7.8 + 1{,}834 / 1{,}330)*1.02$
$= 291.937\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00029437 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3{,}400^2*1{,}330*(7.8 + 1{,}834 / 1{,}330)*0.00029437] / 10.9 / 10000$

$= 380.94\ cm^4$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,330 / 10 = 139.69 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,330*3,400 / 100 = 474.95 kg_f
First moment of area, Q = 66.19*1.74 = 114.843 cm^3

Weld shear flow, $q = V*Q / I'$ = 50.9546 kg_f/cm
Combined weld load, f_w = Sqr($139.6911^2 + 50.9546^2$) = 148.69 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*148.69*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 0.96\ \text{mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,400 = 0.4412
D_o / t = 3,400 / 11.78 = 288.6338
From Table G: A = 6.4417E-04
From Table CS-2 Metric: B = 629.07 kg_f/cm^2

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*629.07 / (3*(3{,}400 / 11.78)) \\
&= 2.91\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*2.91*3{,}400 / (11.78 + 1{,}834 / 1{,}330)*1.02 \\
&= 574.203\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00057670 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}400^2*1{,}330*(11.78 + 1{,}834 / 1{,}330)*0.00057670] / 10.9 / 10000 \\
&= 1{,}070.46\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 2.91 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 2.91*1,330 / 10 = 394.11 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*2.91*1.02*1,330*3,400 / 100 = 1,339.97 kg_f
First moment of area, Q = 66.19*1.74 = 114.843 cm^3

Weld shear flow, $q = V*Q / I'$ = 143.7572 kg_f/cm
Combined weld load, f_w = Sqr(394.1081^2 + 143.7572^2) = 419.51 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*419.51*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 2.71 \text{ mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #5 (Ring #2 in Group)

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	New shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	9,260 mm
Distance to previous support	1,500 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	25 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,400 = 0.4412
D_o / t = 3,400 / 7.8 = 436.1355
From Table G: A = 3.4655E-04
From Table CS-2 Metric: B = 337.16 kg_f/cm^2

$P_a = 4*B / (3*(D_o / t))$
$= 4*337.16 / (3*(3,400 / 7.8))$
$= 1.03\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*1.03*3,400 / (7.8 + 1,834 / 1,500)*1.02$
$= 296.996\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00029945 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3,400^2*1,500*(7.8 + 1,834 / 1,500)*0.00029945] / 10.9 / 10000$

$= 429.58\ cm^4$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}500 / 10 = 157.55\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}500*3{,}400 / 100 = 535.66\ kg_f$
First moment of area, $Q = 66.19*1.74 = 114.843\ cm^3$

Weld shear flow, $q = V*Q / I' = 57.4675\ kg_f/cm$
Combined weld load, $f_w = Sqr(157.5464^2 + 57.4675^2) = 167.7\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion \\
&= 10*167.7*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.08\ mm
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}500 / 3{,}400 = 0.4412$
$D_o / t = 3{,}400 / 11.28 = 301.5186$
From Table G: A = 5.9695E-04
From Table CS-2 Metric: B = 582.69 kg_f/cm^2

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*582.69 / (3*(3{,}400 / 11.28)) \\
&= 2.58\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*2.58*3{,}400 / (11.28 + 1{,}834 / 1{,}500)*1.02 \\
&= 535.866\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00053841 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}400^2*1{,}500*(11.28 + 1{,}834 / 1{,}500)*0.00053841] / 10.9 / 10000 \\
&= 1{,}070.46\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 1,070.46 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 2.58 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 2.58*1,500 / 10 = 393.95 kg_f/cm
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*2.58*1.02*1,500*3,400 / 100 = 1,339.42 kg_f
First moment of area, Q = 66.19*1.74 = 114.843 cm^3

Weld shear flow, $q = V*Q / I'$ = 143.6987 kg_f/cm
Combined weld load, f_w = Sqr(393.9477^2 + 143.6987^2) = 419.34 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

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
= 10*419.34*(25.4 + 0) / (773.964*50.8) + 0
= 2.71 mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #5 (Ring #3 in Group)

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	10,760 mm
Distance to previous support	1,500 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 7.77 = 434.8806
From Table G: A = 3.4558E-04
From Table CS-2 Metric: B = 336.22 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*336.22 / (3*(3,378 / 7.77))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (7.77 + 1,834 / 1,500)*1.02
= 295.991 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029844 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,500*(7.77 + 1,834 / 1,500)*0.00029844] / 10.9 / 10000

$= 421.31\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}500 / 10 = 157.55\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}500*3{,}378 / 100 = 532.19\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 58.3715\ kg_f/cm$
Combined weld load, $f_w = Sqr(157.5464^2 + 58.3715^2) = 168.01\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion \\
&= 10*168.01*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.09\ mm
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}500 / 3{,}378 = 0.4441$
$D_o / t = 3{,}378 / 9.42 = 358.7275$
From Table G: $A = 4.7172E-04$
From Table CS-2 Metric: $B = 459.8\ kg_f/cm^2$

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*459.8 / (3*(3{,}378 / 9.42)) \\
&= 1.71\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*1.71*3{,}378 / (9.42 + 1{,}834 / 1{,}500)*1.02 \\
&= 414.691\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00041729 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}378^2*1{,}500*(9.42 + 1{,}834 / 1{,}500)*0.00041729] / 10.9 / 10000 \\
&= 697.11\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.71 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.71*1,500 / 10 = 261.2 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.71*1.02*1,500*3,378 / 100 = 882.33 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7755 kg_f/cm
Combined weld load, f_w = Sqr($261.2001^2 + 96.7755^2$) = 278.55 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*278.55*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.8 \text{ mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #5 (Ring #4 in Group)

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	12,260 mm
Distance to previous support	1,500 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 7.77 = 434.8806
From Table G: A = 3.4558E-04
From Table CS-2 Metric: B = 336.22 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*336.22 / (3*(3,378 / 7.77))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (7.77 + 1,834 / 1,500)*1.02
= 295.991 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029844 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,500*(7.77 + 1,834 / 1,500)*0.00029844] / 10.9 / 10000

$= 421.31\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,500 / 10 = 157.55 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,500*3,378 / 100 = 532.19 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 58.3715 kg_f/cm
Combined weld load, f_w = Sqr(157.5464^2 + 58.3715^2) = 168.01 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion}$$
$$= 10*168.01*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.09\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 9.42 = 358.7275
From Table G: A = 4.7172E-04
From Table CS-2 Metric: B = 459.8 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*459.8 / (3*(3{,}378 / 9.42))$$
$$= 1.71\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.71*3{,}378 / (9.42 + 1{,}834 / 1{,}500)*1.02$$
$$= 414.691\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00041729 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3{,}378^2*1{,}500*(9.42 + 1{,}834 / 1{,}500)*0.00041729] / 10.9 / 10000$$
$$= 697.11\ cm^4$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.71 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.71*1,500 / 10 = 261.2 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.71*1.02*1,500*3,378 / 100 = 882.33 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7755 kg_f/cm
Combined weld load, $f_w = Sqr(261.2001^2 + 96.7755^2)$ = 278.55 kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*278.55*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #5 (Ring #5 in Group)

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	13,760 mm
Distance to previous support	1,500 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 7.77 = 434.8806
From Table G: A = 3.4558E-04
From Table CS-2 Metric: B = 336.22 kg_f/cm^2

P_a = $4*B / (3*(D_o / t))$
= 4*336.22 / (3*(3,378 / 7.77))
= 1.03 kg_f/cm^2

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.03*3,378 / (7.77 + 1,834 / 1,500)*1.02
= 295.991 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029844 (ring, 175°C)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3,378^2*1,500*(7.77 + 1,834 / 1,500)*0.00029844] / 10.9 / 10000$

$= 421.31\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}500 / 10 = 157.55\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}500*3{,}378 / 100 = 532.19\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 58.3715\ kg_f/cm$
Combined weld load, $f_w = Sqr(157.5464^2 + 58.3715^2) = 168.01\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*168.01*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.09\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}500 / 3{,}378 = 0.4441$
$D_o / t = 3{,}378 / 9.42 = 358.7275$
From Table G: A = 4.7172E-04
From Table CS-2 Metric: B = 459.8 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*459.8 / (3*(3{,}378 / 9.42))$$
$$= 1.71\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.71*3{,}378 / (9.42 + 1{,}834 / 1{,}500)*1.02$$
$$= 414.691\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00041729 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3{,}378^2*1{,}500*(9.42 + 1{,}834 / 1{,}500)*0.00041729] / 10.9 / 10000$$
$$= 697.11\ cm^4$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.71 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.71*1,500 / 10 = 261.2 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.71*1.02*1,500*3,378 / 100 = 882.33 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7755 kg_f/cm
Combined weld load, $f_w = Sqr(261.2001^2 + 96.7755^2)$ = 278.55 kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*278.55*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #6 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	15,260 mm
Distance to previous support	1,200 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 7.77 = 434.8806
From Table G: A = 3.4558E-04
From Table CS-2 Metric: B = 336.22 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*336.22 / (3*(3,378 / 7.77))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (7.77 + 1,834 / 1,350)*1.02
= 291.585 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029402 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,350*(7.77 + 1,834 / 1,350)*0.00029402] / 10.9 / 10000

$= 379.21\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,350 / 10 = 141.79 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,350*3,378 / 100 = 478.97 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 52.5343 kg_f/cm
Combined weld load, $f_w = Sqr(141.7917^2 + 52.5343^2)$ = 151.21 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion}$$
$$= 10*151.21*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 0.98\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 9.82 = 344.105
From Table G: A = 5.0268E-04
From Table CS-2 Metric: B = 490.17 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*490.17 / (3*(3,378 / 9.82))$$
$$= 1.9\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.9*3,378 / (9.82 + 1,834 / 1,350)*1.02$$
$$= 438.765\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00044137 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3,378^2*1,350*(9.82 + 1,834 / 1,350)*0.00044137] / 10.9 / 10000$$
$$= 697.11\ cm^4$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.9 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.9*1,350 / 10 = 261.29 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.9*1.02*1,350*3,378 / 100 = 882.63 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.8075 kg_f/cm
Combined weld load, f_w = Sqr($261.2866^2 + 96.8075^2$) = 278.64 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*278.64*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.8 \text{ mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #7

1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	16,460 mm
Distance to previous support	2,000 mm
Distance to next support	1,200 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 8.76 = 385.4397
From Table G: A = 3.0655E-04
From Table CS-2 Metric: B = 298.03 kg_f/cm^2

P_a = $4*B / (3*(D_o / t))$
= 4*298.03 / (3*(3,378 / 8.76))
= 1.03 kg_f/cm^2

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.03*3,378 / (8.76 + 1,834 / 1,600)*1.02
= 268.533 kg_f/cm^2

From Table CS-2 Metric: A = 0.00027091 (ring, 175°C)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3{,}378^2*1{,}600*(8.76 + 1{,}834 / 1{,}600)*0.00027091] / 10.9 / 10000$

$= 449.65\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}600 / 10 = 168.05\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}600*3{,}378 / 100 = 567.67\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 62.2629\ kg_f/cm$
Combined weld load, $f_w = Sqr(168.0495^2 + 62.2629^2) = 179.21\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion \\
&= 10*179.21*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.16\ mm
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 2{,}000 / 3{,}378 = 0.5921$
$D_o / t = 3{,}378 / 10.4 = 324.9059$
From Table G: A = 4.0051E-04
From Table CS-2 Metric: B = 390 kg_f/cm^2

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*390 / (3*(3{,}378 / 10.4)) \\
&= 1.6\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*1.6*3{,}378 / (10.4 + 1{,}834 / 1{,}600)*1.02 \\
&= 358.014\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00036057 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}378^2*1{,}600*(10.4 + 1{,}834 / 1{,}600)*0.00036057] / 10.9 / 10000 \\
&= 697.11\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.6 bar.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.6*1,600 / 10 = 260.97 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.6*1.02*1,600*3,378 / 100 = 881.57 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.6918 kg_f/cm
Combined weld load, f_w = Sqr($260.9743^2 + 96.6918^2$) = 278.31 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion}$$
$$= 10*278.31*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8 \text{ mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #8 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	18,460 mm
Distance to previous support	1,370 mm
Distance to next support	2,000 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 8.76 = 385.4397
From Table G: A = 3.0655E-04
From Table CS-2 Metric: B = 298.03 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*298.03 / (3*(3,378 / 8.76))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (8.76 + 1,834 / 1,685)*1.02
= 270.109 kg_f/cm^2

From Table CS-2 Metric: A = 0.00027249 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,685*(8.76 + 1,834 / 1,685)*0.00027249] / 10.9 / 10000

$= 473.52\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,685 / 10 = 176.98 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,685*3,378 / 100 = 597.83 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 65.5706 kg_f/cm
Combined weld load, $f_w = Sqr(176.9771^2 + 65.5706^2)$ = 188.73 kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*188.73*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.22\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 10.16 = 332.3316
From Table G: A = 3.8898E-04
From Table CS-2 Metric: B = 378.71 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*378.71 / (3*(3,378 / 10.16))$$
$$= 1.52\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.52*3,378 / (10.17 + 1,834 / 1,685)*1.02$$
$$= 348.628\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00035117 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3,378^2*1,685*(10.17 + 1,834 / 1,685)*0.00035117] / 10.9 / 10000$$
$$= 697.11\ cm^4$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.52 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.52*1,685 / 10 = 260.93 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.52*1.02*1,685*3,378 / 100 = 881.43 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.6768 kg_f/cm
Combined weld load, f_w = Sqr($260.9335^2 + 96.6768^2$) = 278.27 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion}$$
$$= 10*278.27*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8\ \text{mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #9

1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	19,830 mm
Distance to previous support	1,430 mm
Distance to next support	1,370 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,430 / 3,378 = 0.4233
D_o / t = 3,378 / 7.61 = 444.105
From Table G: A = 3.5263E-04
From Table CS-2 Metric: B = 343.12 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*343.12 / (3*(3,378 / 7.61))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (7.61 + 1,834 / 1,400)*1.02
= 298.404 kg_f/cm^2

From Table CS-2 Metric: A = 0.00030086 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,400*(7.61 + 1,834 / 1,400)*0.00030086] / 10.9 / 10000

$= 393.2\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,400 / 10 = 147.04 kg_f/cm
Radial shear load, V = $0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,400*3,378 / 100 = 496.71 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, q = V*Q / I' = 54.48 kg_f/cm
Combined weld load, f_w = Sqr($147.0433^2 + 54.48^2$) = 156.81 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*156.81*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.01\ mm$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,430 / 3,378 = 0.4233
D_o / t = 3,378 / 9.48 = 356.296
From Table G: A = 5.0159E-04
From Table CS-2 Metric: B = 489.09 kg_f/cm^2

$$P_a = 4*B / (3*(D_o / t))$$
$$= 4*489.09 / (3*(3,378 / 9.48))$$
$$= 1.83\ kg_f/cm^2$$

$$B = 0.75*P*D_o / (t + A_s / L_s)$$
$$= 0.75*1.83*3,378 / (9.48 + 1,834 / 1,400)*1.02$$
$$= 438.139\ kg_f/cm^2$$

From Table CS-2 Metric: A = 0.00044074 (ring, 175°C)

$$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$$
$$= [3,378^2*1,400*(9.48 + 1,834 / 1,400)*0.00044074] / 10.9 / 10000$$
$$= 697.11\ cm^4$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.83 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.83*1,400 / 10 = 261.28 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.83*1.02*1,400*3,378 / 100 = 882.62 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.8068 kg_f/cm
Combined weld load, f_w = Sqr($261.2846^2 + 96.8068^2$) = 278.64 kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S$ = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*278.64*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.8\ \text{mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #10

1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	21,260 mm
Distance to previous support	2,000 mm
Distance to next support	1,430 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 8.76 = 385.4397
From Table G: A = 3.0655E-04
From Table CS-2 Metric: B = 298.03 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*298.03 / (3*(3,378 / 8.76))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (8.76 + 1,834 / 1,715)*1.02
= 270.632 kg_f/cm^2

From Table CS-2 Metric: A = 0.00027301 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,715*(8.76 + 1,834 / 1,715)*0.00027301] / 10.9 / 10000

$= 481.95\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}715 / 10 = 180.13\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}715*3{,}378 / 100 = 608.47\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 66.738\ kg_f/cm$
Combined weld load, $f_w = Sqr(180.128^2 + 66.738^2) = 192.09\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion \\
&= 10*192.09*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.24\ mm
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 2{,}000 / 3{,}378 = 0.5921$
$D_o / t = 3{,}378 / 10.09 = 334.9033$
From Table G: $A = 3.8499E\text{-}04$
From Table CS-2 Metric: $B = 374.8\ kg_f/cm^2$

$$
\begin{aligned}
P_a &= 4*B / (3*(D_o / t)) \\
&= 4*374.8 / (3*(3{,}378 / 10.09)) \\
&= 1.49\ kg_f/cm^2
\end{aligned}
$$

$$
\begin{aligned}
B &= 0.75*P*D_o / (t + A_s / L_s) \\
&= 0.75*1.49*3{,}378 / (10.09 + 1{,}834 / 1{,}715)*1.02 \\
&= 345.514\ kg_f/cm^2
\end{aligned}
$$

From Table CS-2 Metric: A = 0.00034805 (ring, 175°C)

$$
\begin{aligned}
I_s' &= [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9 \\
&= [3{,}378^2*1{,}715*(10.09 + 1{,}834 / 1{,}715)*0.00034805] / 10.9 / 10000 \\
&= 697.11\ cm^4
\end{aligned}
$$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.49 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.49*1,715 / 10 = 260.92 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.49*1.02*1,715*3,378 / 100 = 881.39 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.6717 kg_f/cm
Combined weld load, f_w = Sqr($260.9199^2 + 96.6717^2$) = 278.25 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*278.25*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.8\ \text{mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #11 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	23,260 mm
Distance to previous support	1,000 mm
Distance to next support	2,000 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 8.76 = 385.4397
From Table G: A = 3.0655E-04
From Table CS-2 Metric: B = 298.03 kg_f/cm^2

$P_a = 4*B / (3*(D_o / t))$
$= 4*298.03 / (3*(3,378 / 8.76))$
$= 1.03\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*1.03*3,378 / (8.76 + 1,834 / 1,500)*1.02$
$= 266.478\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00026885 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3,378^2*1,500*(8.76 + 1,834 / 1,500)*0.00026885] / 10.9 / 10000$

$= 421.57\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,500 / 10 = 157.55 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.03*1.02*1,500*3,378 / 100 = 532.19 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 58.3715 kg_f/cm
Combined weld load, $f_w = Sqr(157.5464^2 + 58.3715^2)$ = 168.01 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

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
$= 10*168.01*(25.4 + 0) / (773.964*50.8) + 0$
$= 1.09$ mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 2,000 / 3,378 = 0.5921
D_o / t = 3,378 / 10.7 = 315.6117
From Table G: A = 4.1493E-04
From Table CS-2 Metric: B = 404.13 kg_f/cm^2

$P_a = 4*B / (3*(D_o / t))$
$= 4*404.13 / (3*(3,378 / 10.7))$
$= 1.71\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*1.71*3,378 / (10.7 + 1,834 / 1,500)*1.02$
$= 369.663\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00037223 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3,378^2*1,500*(10.7 + 1,834 / 1,500)*0.00037223] / 10.9 / 10000$
$= 697.11\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.71 bar.

Check the stiffener ring attachment welds per UG-30

Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.71*1,500 / 10 = 261.02 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.71*1.02*1,500*3,378 / 100 = 881.74 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7101 kg_f/cm
Combined weld load, f_w = Sqr($261.0234^2 + 96.7101^2$) = 278.36 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion}$$
$$= 10*278.36*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8 \text{ mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #12

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	24,260 mm
Distance to previous support	1,500 mm
Distance to next support	1,000 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,500 / 3,378 = 0.4441
D_o / t = 3,378 / 7.77 = 434.8806
From Table G: A = 3.4558E-04
From Table CS-2 Metric: B = 336.22 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*336.22 / (3*(3,378 / 7.77))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (7.77 + 1,834 / 1,250)*1.02
= 288.153 kg_f/cm^2

From Table CS-2 Metric: A = 0.00029058 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3,378^2$*1,250*(7.77 + 1,834 / 1,250)*0.00029058] / 10.9 / 10000

$= 351.14\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}250 / 10 = 131.29\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}250*3{,}378 / 100 = 443.49\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 48.6429\ kg_f/cm$
Combined weld load, $f_w = Sqr(131.2886^2 + 48.6429^2) = 140.01\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$
$= 10*140.01*(25.4 + 0) / (773.964*50.8) + 0$
$= 0.9\ mm$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}500 / 3{,}378 = 0.4441$
$D_o / t = 3{,}378 / 10.13 = 333.3061$
From Table G: $A = 5.2555E-04$
From Table CS-2 Metric: $B = 512.6\ kg_f/cm^2$

$P_a = 4*B / (3*(D_o / t))$
$= 4*512.6 / (3*(3{,}378 / 10.13))$
$= 2.05\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*2.05*3{,}378 / (10.13 + 1{,}834 / 1{,}250)*1.02$
$= 456.567\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00045917 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3{,}378^2*1{,}250*(10.13 + 1{,}834 / 1{,}250)*0.00045917] / 10.9 / 10000$
$= 697.11\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 2.05 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 2.05*1,250 / 10 = 261.35$ kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*2.05*1.02*1,250*3,378 / 100 = 882.83$ kg_f
First moment of area, $Q = 23.33*3.28 = 76.46$ cm^3

Weld shear flow, $q = V*Q / I' = 96.8302$ kg_f/cm
Combined weld load, $f_w = Sqr(261.3478^2 + 96.8302^2) = 278.71$ kg_f/cm

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1,407.207 = 773.964$ kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$$
$$= 10*278.71*(25.4 + 0) / (773.964*50.8) + 0$$
$$= 1.8 \text{ mm}$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #13 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	25,760 mm
Distance to previous support	1,700 mm
Distance to next support	1,500 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,700 / 3,378 = 0.5033
D_o / t = 3,378 / 8.22 = 410.7395
From Table G: A = 3.2645E-04
From Table CS-2 Metric: B = 317.49 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*317.49 / (3*(3,378 / 8.22))
= 1.03 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.03*3,378 / (8.22 + 1,834 / 1,600)*1.02
= 283.964 kg_f/cm^2

From Table CS-2 Metric: A = 0.00028638 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [$3{,}378^2$*1,600*(8.22 + 1,834 / 1,600)*0.00028638] / 10.9 / 10000

$= 449.5\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s = 1.03*1{,}600 / 10 = 168.05\ kg_f/cm$
Radial shear load, $V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1{,}600*3{,}378 / 100 = 567.67\ kg_f$
First moment of area, $Q = 23.33*3.28 = 76.46\ cm^3$

Weld shear flow, $q = V*Q / I' = 62.2629\ kg_f/cm$
Combined weld load, $f_w = Sqr(168.0495^2 + 62.2629^2) = 179.21\ kg_f/cm$

Allowable weld stress per UW-18(d) $S_w = 0.55*S = 0.55*1{,}407.207 = 773.964\ kg_f/cm^2$

Fillet weld size required to resist radial pressure and shear

$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$
$= 10*179.21*(25.4 + 0) / (773.964*50.8) + 0$
$= 1.16\ mm$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

$L / D_o = 1{,}700 / 3{,}378 = 0.5033$
$D_o / t = 3{,}378 / 9.67 = 349.4175$
From Table G: $A = 4.3048E-04$
From Table CS-2 Metric: $B = 419.36\ kg_f/cm^2$

$P_a = 4*B / (3*(D_o / t))$
$= 4*419.36 / (3*(3{,}378 / 9.67))$
$= 1.6\ kg_f/cm^2$

$B = 0.75*P*D_o / (t + A_s / L_s)$
$= 0.75*1.6*3{,}378 / (9.67 + 1{,}834 / 1{,}600)*1.02$
$= 382.296\ kg_f/cm^2$

From Table CS-2 Metric: A = 0.00038488 (ring, 175°C)

$I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
$= [3{,}378^2*1{,}600*(9.67 + 1{,}834 / 1{,}600)*0.00038488] / 10.9 / 10000$
$= 697.11\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.6 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.6*1,600 / 10 = 261.07 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.6*1.02*1,600*3,378 / 100 = 881.91 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7291 kg_f/cm
Combined weld load, f_w = Sqr($261.0747^2 + 96.7291^2$) = 278.42 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

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
= 10*278.42*(25.4 + 0) / (773.964*50.8) + 0
= 1.8 mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Rings #14 1

ASME Section VIII Division 1, 2017 Edition Metric	
Attached to	Top existing shell
Ring type	Structural tee
Description	T - 60 x 85 x t14
Material	SA-516 70 (II-D Metric p. 18, ln. 33)
External design pressure	1.03 bar
External design temperature	175°C
Corrosion allowance	0 mm
Distance from ring neutral axis to datum	27,460 mm
Distance to previous support	1,180.17 mm
Distance to next support	1,700 mm
Internal ring	No
Welds	
Weld configuration	Continuous both sides
Fillet weld leg size	9 mm
Vessel thickness at weld location, new	14 mm
Vessel corrosion allowance at weld location	3 mm
Stiffener thickness at weld location	14 mm
Ring Properties	
Max depth to thickness ratio	36
Ring distance to centroid	68.97 mm
Ring area	18.34 cm^2
Ring inertia	125.36 cm^4

External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,700 / 3,378 = 0.5033
D_o / t = 3,378 / 8.22 = 410.7395
From Table G: A = 3.2645E-04
From Table CS-2 Metric: B = 317.49 kg_f/cm^2

P_a = $4*B / (3*(D_o / t))$
= 4*317.49 / (3*(3,378 / 8.22))
= 1.03 kg_f/cm^2

B = $0.75*P*D_o / (t + A_s / L_s)$
= 0.75*1.03*3,378 / (8.22 + 1,834 / 1,440.08)*1.02
= 280.158 kg_f/cm^2

From Table CS-2 Metric: A = 0.00028257 (ring, 175°C)

I_s' = $[D_o^2*L_s*(t + A_s / L_s)*A] / 10.9$
= $[3,378^2*1,440.08*(8.22 + 1,834 / 1,440.08)*0.00028257] / 10.9 / 10000$

$= 404.61\ cm^4$

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.03 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.03*1,440.08 / 10 = 151.25 kg_f/cm
Radial shear load, V = 0.01*P*L_s*D_o = 0.01*1.03*1.02*1,440.08*3,378 / 100 = 510.93 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, q = V*Q / I' = 56.0398 kg_f/cm
Combined weld load, f_w = Sqr(151.2533^2 + 56.0398^2) = 161.3 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$t_w = f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + corrosion$
= 10*161.3*(25.4 + 0) / (773.964*50.8) + 0
= 1.04 mm

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Maximum Allowable External Pressure, (Corroded & at 175°C) UG-29(a)

L / D_o = 1,700 / 3,378 = 0.5033
D_o / t = 3,378 / 10.1 = 334.4965
From Table G: A = 4.5807E-04
From Table CS-2 Metric: B = 446.42 kg_f/cm^2

P_a = 4*B / (3*(D_o / t))
= 4*446.42 / (3*(3,378 / 10.1))
= 1.78 kg_f/cm^2

B = 0.75*P*D_o / (t + A_s / L_s)
= 0.75*1.78*3,378 / (10.1 + 1,834 / 1,440.08)*1.02
= 404 kg_f/cm^2

From Table CS-2 Metric: A = 0.00040660 (ring, 175°C)

I_s' = [D_o^2*L_s*(t + A_s / L_s)*A] / 10.9
= [3,378^2*1,440.08*(10.1 + 1,834 / 1,440.08)*0.00040660] / 10.9 / 10000
= 697.11 cm^4

I' for the composite corroded shell-ring cross section is 697.11 cm^4

As $I' >= I_s'$ a T - 60 x 85 x t14 stiffener is adequate for an external pressure of 1.78 bar.

Check the stiffener ring attachment welds per UG-30
Per UG-30(f)(1) the minimum attachment weld size is 6 mm

The fillet weld size of 9 mm is adequate per UG-30(f)(1).

Radial pressure load, $P*L_s$ = 1.78*1,440.08 / 10 = 261.16 kg_f/cm
Radial shear load, $V = 0.01*P*L_s*D_o$ = 0.01*1.78*1.02*1,440.08*3,378 / 100 = 882.2 kg_f
First moment of area, Q = 23.33*3.28 = 76.46 cm^3

Weld shear flow, $q = V*Q / I'$ = 96.7607 kg_f/cm
Combined weld load, f_w = Sqr(261.1602^2 + 96.7607^2) = 278.51 kg_f/cm

Allowable weld stress per UW-18(d) S_w = 0.55*S = 0.55*1,407.207 = 773.964 kg_f/cm^2

Fillet weld size required to resist radial pressure and shear

$$
\begin{aligned}
t_w &= f_w*(d_{weld\ segment} + d_{toe}) / (S_w*d_{weld\ total}) + \text{corrosion} \\
&= 10*278.51*(25.4 + 0) / (773.964*50.8) + 0 \\
&= 1.8\ \text{mm}
\end{aligned}
$$

The fillet weld size of 9 mm is adequate to resist radial pressure and shear.

Support Skirt #1 1

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Support Skirt		
Skirt is Attached To		Bottom Head		
Skirt Attachment Offset		152 mm down from the top seam		
Material		SA-516 70 (II-D Metric p. 18, ln. 33)		
		Impact Tested[1]	**Normalized**	**Fine Grain Practice**
		No	No	Yes
Design Temperature				
Internal		17°C		
External		17°C		
Dimensions				
Inner Diameter	**Top**	3,358 mm		
	Botttom	3,358 mm		
Length (includes base ring thickness)		976 mm		
Nominal Thickness		10 mm		
Corrosion	**Inner**	1.6 mm		
	Outer	0 mm		
Weight				
New		808.91 kg		
Corroded		808.91 kg		
Insulation\Lining				
		Thickness	**Density**	**Weight**
Lining		50 mm	2,400	1,217.16 kg
Insulation		50 mm	2,400	1,261.31 kg
		Spacing	**Individual Weight**	**Total Weight**
Insulation Supports		300 mm	5 kg	15 kg
Joint Efficiency				
Top		0.6		
Bottom		0.7		

[1]Impact testing requirements are not checked for supports

Skirt design thickness, largest of the following + corrosion = 6.99 mm

The governing condition is due to vortex shedding, compressive stress at the base, empty & corroded.

The skirt thickness of 10 mm is adequate.

Results Summary							
Loading	Condition	Tensile or Compressive Side	Governing Skirt Location	Temperature (°C)	Allowable Stress (kg_f/cm^2)	Calculated Stress/E (kg_f/cm^2)	Required thickness (mm)
Wind	operating, corroded	Tensile	bottom	17	1,407.21	65.47	0.39
		Compressive			630	319.61	4.26
	operating, new	Tensile	bottom	17	1,407.21	55.14	0.39
		Compressive			750.62	268.62	3.58
	empty, corroded	Tensile	top	30	1,407.21	116.04	0.69
		Compressive	bottom		630	268.7	3.58
	test, new	Tensile	bottom	30	750.62	-193.97	2.58
		Compressive				355.21	4.73
	vacuum, corroded	Tensile	bottom	17	1,407.21	65.47	0.39
		Compressive			630	319.61	4.26
Vortex shedding	operating, corroded	Tensile	top	17	1,407.21	197.2	1.18
		Compressive	bottom		630	402.16	5.36
	empty, corroded	Tensile	top	30	1,407.21	333.42	1.99
		Compressive	bottom		630	404.59	5.39
	vacuum, corroded	Tensile	top	17	1,407.21	197.36	1.18
		Compressive	bottom		630	402.26	5.36

Loading due to wind, operating & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*152{,}156.83 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
$=$ 0.39 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*148{,}133.06 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*104{,}146.2 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
$=$ 0.39 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 152{,}156.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*630.003/100*1)$
$=$ 4.26 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$

$= 148{,}133.06 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*104{,}146.2 / (\pi*3{,}369.6^2*630.003/100*1)$
$= 4.07$ mm

Loading due to wind, operating & new

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*152{,}115.01 / (\pi*3{,}368*1{,}407.207/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}368^2*1{,}407.207/100*0.7)$
$= 0.39$ mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*148{,}091.24 / (\pi*3{,}368*1{,}407.207/100*0.6) + 4*1e3*104{,}146.2 / (\pi*3{,}368^2*1{,}407.207/100*0.6)$
$= 0.39$ mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 152{,}115.01 / (\pi*3{,}368*750.619/100*1) + 4*1e3*111{,}233 / (\pi*3{,}368^2*750.619/100*1)$
$= 3.58$ mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 148{,}091.24 / (\pi*3{,}368*750.619/100*1) + 4*1e3*104{,}146.2 / (\pi*3{,}368^2*750.619/100*1)$
$= 3.42$ mm

Loading due to wind, empty & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*106{,}885.97 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
$= 0.65$ mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*102{,}862.2 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*104{,}146.2 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
$= 0.69$ mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi * D * S_c * E_c) + 4 * M / (\pi * D^2 * S_c * E_c)$
$= 106{,}885.97 / (\pi * 3{,}369.6 * 630.003/100 * 1) + 4 * 1e3 * 111{,}233 / (\pi * 3{,}369.6^2 * 630.003/100 * 1)$
$=$ 3.58 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi * D_t * S_c * E_c) + 4 * M_t / (\pi * D_t^2 * S_c * E_c)$
$= 102{,}862.2 / (\pi * 3{,}369.6 * 630.003/100 * 1) + 4 * 1e3 * 104{,}146.2 / (\pi * 3{,}369.6^2 * 630.003/100 * 1)$
$=$ 3.4 mm

Loading due to wind, test & new

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6 * W / (\pi * D * S_t * E) + 4 * M / (\pi * D^2 * S_t * E)$
$= -0.6 * 363{,}176.2 / (\pi * 3{,}368 * 750.619/100 * 1) + 4 * 1e3 * 10{,}664.9 / (\pi * 3{,}368^2 * 750.619/100 * 1)$
$=$ 2.58 mm

Required thickness, tensile stress at the top:

$t = -0.6 * W_t / (\pi * D_t * S_t * E) + 4 * M_t / (\pi * D_t^2 * S_t * E)$
$= -0.6 * 359{,}152.43 / (\pi * 3{,}368 * 750.619/100 * 1) + 4 * 1e3 * 9{,}802.1 / (\pi * 3{,}368^2 * 750.619/100 * 1)$
$=$ 2.57 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi * D * S_c * E_c) + 4 * M / (\pi * D^2 * S_c * E_c)$
$= 363{,}176.2 / (\pi * 3{,}368 * 750.619/100 * 1) + 4 * 1e3 * 10{,}664.9 / (\pi * 3{,}368^2 * 750.619/100 * 1)$
$=$ 4.73 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi * D_t * S_c * E_c) + 4 * M_t / (\pi * D_t^2 * S_c * E_c)$
$= 359{,}152.43 / (\pi * 3{,}368 * 750.619/100 * 1) + 4 * 1e3 * 9{,}802.1 / (\pi * 3{,}368^2 * 750.619/100 * 1)$
$=$ 4.67 mm

Loading due to wind, vacuum & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

t = $-0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
= $-0.6*152{,}156.83 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
= 0.39 mm

Required thickness, tensile stress at the top:

t = $-0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
= $-0.6*148{,}133.06 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*104{,}146.2 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
= 0.39 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

t = $W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
= $152{,}156.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*630.003/100*1)$
= 4.26 mm

Required thickness, compressive stress at the top:

t = $W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
= $148{,}133.06 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*104{,}146.2 / (\pi*3{,}369.6^2*630.003/100*1)$
= 4.07 mm

Loading due to vortex shedding, operating & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

t = $-0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
= $-0.6*152{,}156.83 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*173{,}070.9 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
= 1.09 mm

Required thickness, tensile stress at the top:

t = $-0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
= $-0.6*148{,}133.06 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*163{,}502.7 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
= 1.18 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

t = $W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
= $152{,}156.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*173{,}070.9 / (\pi*3{,}369.6^2*630.003/100*1)$

= 5.36 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 148{,}133.06 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*163{,}502.7 / (\pi*3{,}369.6^2*630.003/100*1)$
$= 5.13$ mm

Loading due to vortex shedding, empty & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*106{,}885.97 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*213{,}024.9 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
$= 1.81$ mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*102{,}862.2 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*201{,}845.5 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
$= 1.99$ mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 106{,}885.97 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*213{,}024.9 / (\pi*3{,}369.6^2*630.003/100*1)$
$= 5.39$ mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 102{,}862.2 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*201{,}845.5 / (\pi*3{,}369.6^2*630.003/100*1)$
$= 5.14$ mm

Loading due to vortex shedding, vacuum & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*152{,}156.83 / (\pi*3{,}369.6*1{,}407.207/100*0.7) + 4*1e3*173{,}144.1 / (\pi*3{,}369.6^2*1{,}407.207/100*0.7)$
$= 1.1$ mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*148{,}133.06 / (\pi*3{,}369.6*1{,}407.207/100*0.6) + 4*1e3*163{,}573 / (\pi*3{,}369.6^2*1{,}407.207/100*0.6)$
$=$ 1.18 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 152{,}156.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*173{,}144.1 / (\pi*3{,}369.6^2*630.003/100*1)$
$=$ 5.36 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 148{,}133.06 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*163{,}573 / (\pi*3{,}369.6^2*630.003/100*1)$
$=$ 5.13 mm

Support Skirt #2

ASME Section VIII Division 1, 2017 Edition Metric				
Component		Support Skirt		
Skirt is Attached To		Support Skirt #1		
Skirt Attachment Offset		0 mm up from the bottom seam		
Material		SA-285 C (II-D Metric p. 10, ln. 3)		
		Impact Tested[1]	Normalized	Fine Grain Practice
		No	No	No
Design Temperature				
Internal		17°C		
External		17°C		
Dimensions				
Inner Diameter	Top	3,358 mm		
	Botttom	3,358 mm		
Length (includes base ring thickness)		7,010 mm		
Nominal Thickness		10 mm		
Corrosion	Inner	1.6 mm		
	Outer	0 mm		
Weight				
New		5,782.54 kg		
Corroded		4,855.03 kg		
Insulation\Lining				
		Thickness	Density	Weight
Lining		50 mm	2,400	8,742.08 kg
Insulation		50 mm	2,400	9,059.2 kg
		Spacing	Individual Weight	Total Weight
Insulation Supports		300 mm	5 kg	115 kg
Joint Efficiency				
Top		0.7		
Bottom		0.7		

[1]Impact testing requirements are not checked for supports

Skirt design thickness, largest of the following + corrosion = 8.75 mm

The governing condition is due to vortex shedding, compressive stress at the base, empty & corroded.

The skirt thickness of 10 mm is adequate.

Results Summary							
Loading	Condition	Tensile or Compressive Side	Governing Skirt Location	Temperature (°C)	Allowable Stress (kg_f/cm^2)	Calculated Stress/E (kg_f/cm^2)	Required thickness (mm)
Wind	operating, corroded	Tensile	bottom	17	1,101.29	139.23	1.06
		Compressive			630	412.23	5.5
	operating, new	Tensile	bottom	17	1,101.29	116.42	1.06
		Compressive			750.62	347.36	4.63
	empty, corroded	Tensile	bottom	30	1,101.29	182.87	1.39
		Compressive			630	361.32	4.82
	empty, new	Tensile	bottom	30	1,101.29	153.06	1.39
		Compressive			750.62	304.61	4.06
	test, new	Tensile	bottom	30	750.62	-207.41	2.76
		Compressive				377.61	5.03
	vacuum, corroded	Tensile	bottom	17	1,101.29	139.23	1.06
		Compressive			630	412.23	5.5
Vortex shedding	operating, corroded	Tensile	bottom	17	1,101.29	291.16	2.22
		Compressive			630	518.57	6.91
	empty, corroded	Tensile	bottom	30	1,101.29	433.06	3.3
		Compressive			630	536.45	7.15
	vacuum, corroded	Tensile	bottom	17	1,101.29	291.34	2.22
		Compressive			630	518.7	6.92

Loading due to wind, operating & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*174,932.69 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*161,426.1 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 1.06 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*152,156.83 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*111,233 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 0.5 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 174,932.69 / (\pi*3,369.6*630.003/100*1) + 4*1e3*161,426.1 / (\pi*3,369.6^2*630.003/100*1)$
$=$ 5.5 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 152{,}156.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*630.003/100*1)$
$= 4.26$ mm

Loading due to wind, operating & new

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*175{,}818.39 / (\pi*3{,}368*1{,}101.293/100*0.7) + 4*1e3*161{,}426 / (\pi*3{,}368^2*1{,}101.293/100*0.7)$
$= 1.06$ mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*152{,}115.01 / (\pi*3{,}368*1{,}101.293/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}368^2*1{,}101.293/100*0.7)$
$= 0.5$ mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 175{,}818.39 / (\pi*3{,}368*750.619/100*1) + 4*1e3*161{,}426 / (\pi*3{,}368^2*750.619/100*1)$
$= 4.63$ mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 152{,}115.01 / (\pi*3{,}368*750.619/100*1) + 4*1e3*111{,}233 / (\pi*3{,}368^2*750.619/100*1)$
$= 3.58$ mm

Loading due to wind, empty & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*129{,}661.83 / (\pi*3{,}369.6*1{,}101.293/100*0.7) + 4*1e3*161{,}426.1 / (\pi*3{,}369.6^2*1{,}101.293/100*0.7)$
$= 1.39$ mm

Required thickness, tensile stress at the top:

$$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$$
$$= -0.6*106{,}885.97 / (\pi*3{,}369.6*1{,}101.293/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*1{,}101.293/100*0.7)$$
$$= 0.83 \text{ mm}$$

Leeward side (compressive)

Required thickness, compressive stress at base:

$$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$$
$$= 129{,}661.83 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*161{,}426.1 / (\pi*3{,}369.6^2*630.003/100*1)$$
$$= \underline{4.82} \text{ mm}$$

Required thickness, compressive stress at the top:

$$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$$
$$= 106{,}885.97 / (\pi*3{,}369.6*630.003/100*1) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*630.003/100*1)$$
$$= 3.58 \text{ mm}$$

Loading due to wind, empty & new

Windward side (tensile)

Required thickness, tensile stress at base:

$$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$$
$$= -0.6*130{,}589.34 / (\pi*3{,}368*1{,}101.293/100*0.7) + 4*1e3*161{,}426 / (\pi*3{,}368^2*1{,}101.293/100*0.7)$$
$$= \underline{1.39} \text{ mm}$$

Required thickness, tensile stress at the top:

$$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$$
$$= -0.6*106{,}885.97 / (\pi*3{,}368*1{,}101.293/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}368^2*1{,}101.293/100*0.7)$$
$$= 0.83 \text{ mm}$$

Leeward side (compressive)

Required thickness, compressive stress at base:

$$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$$
$$= 130{,}589.34 / (\pi*3{,}368*750.619/100*1) + 4*1e3*161{,}426 / (\pi*3{,}368^2*750.619/100*1)$$
$$= \underline{4.06} \text{ mm}$$

Required thickness, compressive stress at the top:

$$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$$
$$= 106{,}885.97 / (\pi*3{,}368*750.619/100*1) + 4*1e3*111{,}233 / (\pi*3{,}368^2*750.619/100*1)$$
$$= 3.01 \text{ mm}$$

Loading due to wind, test & new

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*386{,}879.58 / (\pi*3{,}368*750.619/100*1) + 4*1e3*10{,}664.9 / (\pi*3{,}368^2*750.619/100*1)$
$=$ 2.76 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*363{,}176.2 / (\pi*3{,}368*750.619/100*1) + 4*1e3*10{,}664.9 / (\pi*3{,}368^2*750.619/100*1)$
$=$ 2.58 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 386{,}879.58 / (\pi*3{,}368*750.619/100*1) + 4*1e3*10{,}664.9 / (\pi*3{,}368^2*750.619/100*1)$
$=$ 5.03 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 363{,}176.2 / (\pi*3{,}368*750.619/100*1) + 4*1e3*10{,}664.9 / (\pi*3{,}368^2*750.619/100*1)$
$=$ 4.73 mm

Loading due to wind, vacuum & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*174{,}932.69 / (\pi*3{,}369.6*1{,}101.293/100*0.7) + 4*1e3*161{,}426.1 / (\pi*3{,}369.6^2*1{,}101.293/100*0.7)$
$=$ 1.06 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*152{,}156.83 / (\pi*3{,}369.6*1{,}101.293/100*0.7) + 4*1e3*111{,}233 / (\pi*3{,}369.6^2*1{,}101.293/100*0.7)$
$=$ 0.5 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

t = $W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
= $174,932.69 / (\pi*3,369.6*630.003/100*1) + 4*1e3*161,426.1 / (\pi*3,369.6^2*630.003/100*1)$
= 5.5 mm

Required thickness, compressive stress at the top:

t = $W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
= $152,156.83 / (\pi*3,369.6*630.003/100*1) + 4*1e3*111,233 / (\pi*3,369.6^2*630.003/100*1)$
= 4.26 mm

Loading due to vortex shedding, operating & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

t = $-0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
= $-0.6*174,932.69 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*241,086.5 / (\pi*3,369.6^2*1,101.293/100*0.7)$
= 2.22 mm

Required thickness, tensile stress at the top:

t = $-0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
= $-0.6*152,156.83 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*173,070.9 / (\pi*3,369.6^2*1,101.293/100*0.7)$
= 1.4 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

t = $W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
= $174,932.69 / (\pi*3,369.6*630.003/100*1) + 4*1e3*241,086.5 / (\pi*3,369.6^2*630.003/100*1)$
= 6.91 mm

Required thickness, compressive stress at the top:

t = $W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
= $152,156.83 / (\pi*3,369.6*630.003/100*1) + 4*1e3*173,070.9 / (\pi*3,369.6^2*630.003/100*1)$
= 5.36 mm

Loading due to vortex shedding, empty & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*129,661.83 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*292,613.1 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 3.3 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*106,885.97 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*213,024.9 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 2.31 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 129,661.83 / (\pi*3,369.6*630.003/100*1) + 4*1e3*292,613.1 / (\pi*3,369.6^2*630.003/100*1)$
$=$ 7.15 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi*D_t*S_c*E_c) + 4*M_t / (\pi*D_t^2*S_c*E_c)$
$= 106,885.97 / (\pi*3,369.6*630.003/100*1) + 4*1e3*213,024.9 / (\pi*3,369.6^2*630.003/100*1)$
$=$ 5.39 mm

Loading due to vortex shedding, vacuum & corroded

Windward side (tensile)

Required thickness, tensile stress at base:

$t = -0.6*W / (\pi*D*S_t*E) + 4*M / (\pi*D^2*S_t*E)$
$= -0.6*174,932.69 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*241,180.8 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 2.22 mm

Required thickness, tensile stress at the top:

$t = -0.6*W_t / (\pi*D_t*S_t*E) + 4*M_t / (\pi*D_t^2*S_t*E)$
$= -0.6*152,156.83 / (\pi*3,369.6*1,101.293/100*0.7) + 4*1e3*173,144.1 / (\pi*3,369.6^2*1,101.293/100*0.7)$
$=$ 1.4 mm

Leeward side (compressive)

Required thickness, compressive stress at base:

$t = W / (\pi*D*S_c*E_c) + 4*M / (\pi*D^2*S_c*E_c)$
$= 174,932.69 / (\pi*3,369.6*630.003/100*1) + 4*1e3*241,180.8 / (\pi*3,369.6^2*630.003/100*1)$
$=$ 6.92 mm

Required thickness, compressive stress at the top:

$t = W_t / (\pi * D_t * S_c * E_c) + 4 * M_t / (\pi * D_t^2 * S_c * E_c)$
$= 152,156.83 / (\pi * 3,369.6 * 630.003/100 * 1) + 4 * 1e3 * 173,144.1 / (\pi * 3,369.6^2 * 630.003/100 * 1)$
$= 5.36$ mm

Skirt Base Ring

1

Inputs	
Base configuration	double base plate
Base plate material	A285-C
Base plate allowable stress, S_p	1,454.999 kg_f/cm^2
Foundation compressive strength	1,455.299 kg_f/cm^2
Concrete ultimate 28-day strength	1,455.299 kg_f/cm^2
Bolt circle, BC	3,530 mm
Base plate inner diameter, D_i	3,290 mm
Base plate outer diameter, D_o	3,580 mm
Base plate thickness, t_b	33 mm
Gusset separation, w	105 mm
Gusset height, h	240 mm
Gusset thickness, t_g	16 mm
Compression ring width	141 mm
Compression ring thickness, t_c	30 mm
Anchor Bolts	
Material	A307-B
Allowable stress, S_b	1,199.999 kg_f/cm^2
Bolt size and type	48 mm
Number of bolts, N	20
Corrosion allowance (applied to root radius)	1.5 mm
Anchor bolt clearance	14 mm
Bolt root area (corroded), A_b	11.55 cm^2
Diameter of anchor bolt holes, d_b	62 mm
Initial bolt preload	0% (0 kg_f/cm^2)
Bolt at 0°	No

Results Summary										
Load	Vessel condition	Base V (kg_f)	Base M (kg_f-m)	W (kg)	Required bolt area (cm^2)	t_r Base (mm)	Foundation bearing stress (kg_f/cm^2)	t_r comp ring (mm)	t_r gusset (mm)
Wind	operating, corroded	7,847.6	161,426.1	175,795.4	3.2267	25.27	33.9116	11.99	4.75
Wind	operating, new	7,847.6	161,426	176,681.1	3.2046	25.28	33.9214	11.91	4.75
Wind	empty, corroded	7,847.6	161,426.1	130,524.6	4.3585	24.97	33.1111	16.23	5.03
Wind	empty, new	7,847.6	161,426	131,452.1	4.3353	24.98	33.1367	16.14	5.02
Wind	test, new	1,566.3	10,664.9	387,742.3	0	22.38	26.6001	0	0
Wind	vacuum, corroded	7,847.6	161,426.1	175,795.4	3.2267	25.27	33.9116	11.99	4.75
Vortex shedding	operating, corroded	10,390.1	241,086.5	175,795.4	6.9879	30.33	48.8384	21.27	5.49
Vortex shedding	empty, corroded	12,040.9	292,613.1	130,524.6	10.5524	32.17	54.9368	28.76	6.51
Vortex shedding	vacuum, corroded	10,393.1	241,180.8	175,795.4	6.9923	30.33	48.8551	21.28	5.49

Anchor bolt load (operating, corroded + Wind)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*175,795.42 / 20 + 4 * 161,426.1 / (20*3.53)
= 3,872.09 kg_f

Required area per bolt = P / S_b = 3.2267 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, operating, corroded + Wind)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.539529:

K_1 = 1.9087, K_2 = 2.0895
L_1 = -5.3498, L_2 = 48.997, L_3 = 57.1956

Total tensile force on bolting

T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)
= (161,426.1 - 0.6*175,795.42 *(-0.1359 + 1.4528)) / (1.2445 + 1.4528)
= 8,351.02 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
= 100*8,351.02 / (2.49 * (3,435 / 2) * 1.9087)
= 102.349 kg_f/cm^2

Total compressive load on foundation

$C_c = T + W + \text{Bolt Preload}$
= 8,351.02 + 175,795.42 + 0
= 184,146.44 kg_f

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
= 100*184,146.44 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*2.0895)
= 33.912 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
= 1 / (1 + 102.349 / (3.5363*33.912))
= 0.539529

Base plate required thickness (operating, corroded + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*33.912*417.49^2 = 334.5\ kg_f$

$M_y = 0.01*-0.4477*33.912*101^2 = -1,548.9\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
= $(100*6*1,548.88 / 1,454.999)^{0.5}$
= 25.27 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
= $(100*3.91*1,374.51 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 11.99 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

S_a = 0.07031*(17000 - 0.485*(h / r)^2)
= 1,195.27 - 0.0341*(240 / 4.62)^2
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

S_g = F / (2 * A_g)
= 1,374.51 / (2 * 15.144)
= 45.381 kg_f/cm^2

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*(100*1,374.51*76 / (530.62*303*1,651.939))$^{2/3}$*(3,378 / 2)$^{1/3}$
= 2.42 mm

The skirt thickness is satisfactory.

Anchor bolt load (operating, new + Wind)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*176,681.12 / 20 + 4 * 161,426 / (20*3.53)
= 3,845.52 kg_f

Required area per bolt = P / S_b = 3.2046 cm^2

The area provided (13.4296 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, operating, new + Wind)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.542982:

K_1 = 1.9006, K_2 = 2.0973
L_1 = -5.8181, L_2 = 48.6363, L_3 = 57.5523

Total tensile force on bolting

T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)
= (161,426 - 0.6*176,681.12 *(-0.1478 + 1.4618)) / (1.2354 + 1.4618)
= 8,203.18 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
= 100*8,203.18 / (2.49 * (3,435 / 2) * 1.9006)
= 100.965 kg_f/cm^2

Total compressive load on foundation

C_c = T + W + Bolt Preload
= 8,203.18 + 176,681.12 + 0
= 184,884.3 kg_f

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
= 100*184,884.3 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*2.0973)
= 33.921 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
= 1 / (1 + 100.965 / (3.5363*33.921))
= 0.542982

Base plate required thickness (operating, new + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*33.921*417.49^2$ = 334.6 kg_f

$M_y = 0.01*-0.4477*33.921*101^2$ = -1,549.3 kg_f

$t_r = (6*M_{max} / S_p)^{0.5}$
= $(100*6*1,549.33 / 1,454.999)^{0.5}$
= 25.28 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
= $(100*3.91*1,355.92 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 11.91 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$

= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

S_a = 0.07031*(17000 - 0.485*(h / r)^2)
= 1,195.27 - 0.0341*(240 / 4.62)^2
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

S_g = F / (2 * A_g)
= 1,355.92 / (2 * 15.144)
= 44.768 kg_f/cm^2

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*(100*1,355.92*76 / (530.62*303*1,651.939))$^{2/3}$*(3,378 / 2)$^{1/3}$
= 2.4 mm

The skirt thickness is satisfactory.

Anchor bolt load (empty, corroded + Wind)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*130,524.56 / 20 + 4 * 161,426.1 / (20*3.53)
= 5,230.22 kg_f

Required area per bolt = P / S_b = 4.3585 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, empty, corroded + Wind)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.384574:

K_1 = 2.2576,	K_2 = 1.727	
L_1 = 15.6071,	L_2 = 64.9656,	L_3 = 41.0623

Total tensile force on bolting

$T = (M - 0.6*W*(L_1 + L_3)) / (L_2 + L_3)$
= (161,426.1 - 0.6*130,524.56 *(0.3964 + 1.043)) / (1.6501 + 1.043)
= 18,083.02 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
= 100*18,083.02 / (2.49 * (3,435 / 2) * 2.2576)
= 187.378 kg_f/cm^2

Total compressive load on foundation

C_c = T + W + Bolt Preload
= 18,083.02 + 130,524.56 + 0
= 148,607.58 kg_f

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
= 100*148,607.58 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*1.727)
= 33.111 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
= 1 / (1 + 187.378 / (3.5363*33.111))
= 0.384574

Base plate required thickness (empty, corroded + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*33.111*417.49^2 = 326.7\ kg_f$

$M_y = 0.01*-0.4477*33.111*101^2 = -1,512.3\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*1,512.31 / 1,454.999)^{0.5}$
= 24.97 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*2,516.41 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 16.23 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g$*(b - 0.25*25.41)
= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

S_a = 0.07031*(17000 - 0.485*(h / r)^2)
= 1,195.27 - 0.0341*(240 / 4.62)^2
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

S_g = F / (2 * A_g)
= 2,516.41 / (2 * 15.144)
= 83.083 kg_f/cm^2

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*(100*2,516.41*76 / (530.62*303*1,651.939))$^{2/3}$*(3,378 / 2)$^{1/3}$
= 3.63 mm

The skirt thickness is satisfactory.

Anchor bolt load (empty, new + Wind)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*131,452.08 / 20 + 4 * 161,426 / (20*3.53)
= 5,202.39 kg_f

Required area per bolt = P / S_b = 4.3353 cm^2

The area provided (13.4296 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, empty, new + Wind)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.387274:

K_1 = 2.2516, K_2 = 1.7337
L_1 = 15.241, L_2 = 64.69, L_3 = 41.3467

Total tensile force on bolting

$T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)$
$= (161,426 - 0.6*131,452.08 *(0.3871 + 1.0502)) / (1.6431 + 1.0502)$
$= 17,844.93\ kg_f$

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
$= 100*17,844.93 / (2.49 * (3,435 / 2) * 2.2516)$
$= 185.398\ kg_f/cm^2$

Total compressive load on foundation

$C_c = T + W + \text{Bolt Preload}$
$= 17,844.93 + 131,452.08 + 0$
$= 149,297\ kg_f$

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
$= 100*149,297 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*1.7337)$
= 33.137 kg_f/cm^2

As $f_c <= 1,455.299\ kg_f/cm^2$ the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
$= 1 / (1 + 185.398 / (3.5363*33.137))$
$= 0.387274$

Base plate required thickness (empty, new + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*33.137*417.49^2 = 326.9\ kg_f$

$M_y = 0.01*-0.4477*33.137*101^2 = -1,513.5\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*1,513.48 / 1,454.999)^{0.5}$
= 24.98 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*2,489.83 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 16.14 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
= $1,195.27 - 0.0341*(240 / 4.62)^2$
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 2,489.83 / (2 * 15.144)
= 82.205 kg_f/cm^2

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
= $1.76*(100*2,489.83*76 / (530.62*303*1,651.939))^{2/3}*(3,378 / 2)^{1/3}$
= 3.6 mm

The skirt thickness is satisfactory.

Anchor bolt load (test, new + Wind)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*387,742.31 / 20 + 4 * 10,664.9 / (20*3.53)
= -11,028.03 kg_f

The anchor bolts are satisfactory (no net uplift on anchor bolt)

Foundation bearing stress (test, new + Wind)

$A_c = \pi*(D_o^2 - D_i^2) / 4 - N*\pi*d_b^2 / 4$
= $\pi*(358^2 - 329^2) / 4 - 20*\pi*6.2^2 / 4$
= 15,043.67 cm^2

$I_c = \pi*(D_o^4 - D_i^4) / 64$
= $\pi*(358^4 - 329^4) / 64$
= 2.312E+08 cm^4

$f_c = N*A_b*Preload / A_c + W / A_c + M / 2*D_o / I_c$
= 20*13.4296*0 / 15,043.67 + 387,742.31 / 15,043.67 + 10*10,664.9 / 2*3,580 / 2.312E+08
= 26.6 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

Base plate required thickness (test, new + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*26.6*417.49^2 = 262.4\ kg_f$

$M_y = 0.01*-0.4477*26.6*101^2 = -1,214.9\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*1,214.93 / 1,454.999)^{0.5}$
= 22.38 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*0 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 0 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
$= 15.144\ cm^2$

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
$= 1,195.27 - 0.0341*(240 / 4.62)^2$
$= 1,103.357\ kg_f/cm^2$

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 0 / (2 * 15.144)
$= 0\ kg_f/cm^2$

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(100*0*76 / (530.62*303*1,651.939))^{2/3}*(3,378 / 2)^{1/3}$
= 0 mm

The skirt thickness is satisfactory.

Note: No local skirt reaction is present because the foundation resists the initial bolt preload.

Anchor bolt load (vacuum, corroded + Wind)

$P = -0.6*W / N + 4 * M / (N*BC)$
$= -0.6*175{,}795.42 / 20 + 4 * 161{,}426.1 / (20*3.53)$
$= 3{,}872.09\ kg_f$

Required area per bolt = P / S_b = 3.2267 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, vacuum, corroded + Wind)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

$E_c = 57{,}000*0.265154*Sqr(1{,}455.299) = 576{,}567.179\ kg_f/cm^2$

$n = E_s/E_c = 2{,}038{,}900.1 / 576{,}567.179 = 3.5363$

$t_s = (N*A_b) / (\pi*d)$
$= (20*1{,}342.9593) / (\pi*3{,}435)$
$= 2.49$ mm

From table 12.4 for k = 0.539529:

$K_1 = 1.9087,\ K_2 = 2.0895$
$L_1 = -5.3498,\ L_2 = 48.997,\ L_3 = 57.1956$

Total tensile force on bolting

$T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)$
$= (161{,}426.1 - 0.6*175{,}795.42 *(-0.1359 + 1.4528)) / (1.2445 + 1.4528)$
$= 8{,}351.02\ kg_f$

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
$= 100*8{,}351.02 / (2.49 * (3{,}435 / 2) * 1.9087)$
$= 102.349\ kg_f/cm^2$

Total compressive load on foundation

C_c = T + W + Bolt Preload
$= 8{,}351.02 + 175{,}795.42 + 0$
$= 184{,}146.44\ kg_f$

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$
$= 100*184{,}146.44 / (((145 - 2.49) + 3.5363*2.49)*(3{,}435 / 2)*2.0895)$
= 33.912 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
$= 1 / (1 + 102.349 / (3.5363*33.912))$
$= 0.539529$

Base plate required thickness (vacuum, corroded + Wind)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*33.912*417.49^2 = 334.5\ kg_f$

$M_y = 0.01*-0.4477*33.912*101^2 = -1,548.9\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*1,548.88 / 1,454.999)^{0.5}$
= 25.27 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*1,374.51 / (2,089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 11.99 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
$= 15.144\ cm^2$

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
$= 1,195.27 - 0.0341*(240 / 4.62)^2$
$= 1,103.357\ kg_f/cm^2$

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 1,374.51 / (2 * 15.144)
$= 45.381\ kg_f/cm^2$

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(100*1,374.51*76 / (530.62*303*1,651.939))^{2/3}*(3,378 / 2)^{1/3}$
= 2.42 mm

The skirt thickness is satisfactory.

Anchor bolt load (operating, corroded + Vortex shedding)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*175,795.42 / 20 + 4 * 241,086.5 / (20*3.53)
= 8,385.43 kg_f

Required area per bolt = P / S_b = 6.9879 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, operating, corroded + Vortex shedding)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.349197:

K_1 = 2.335,	K_2 = 1.6382	
L_1 = 20.3967,	L_2 = 68.5584,	L_3 = 37.3352

Total tensile force on bolting

T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)
= (241,086.5 - 0.6*175,795.42 *(0.5181 + 0.9483)) / (1.7414 + 0.9483)
= 32,128.5 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

f_s = T / (t_s * (d / 2) * K_1)
= 100*32,128.5 / (2.49 * (3,435 / 2) * 2.335)
= 321.877 kg_f/cm^2

Total compressive load on foundation

C_c = T + W + Bolt Preload
= 32,128.5 + 175,795.42 + 0
= 207,923.92 kg_f

Foundation bearing stress

f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)
= 100*207,923.92 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*1.6382)
= 48.838 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
$= 1 / (1 + 321.877 / (3.5363*48.838))$
$= 0.349197$

Base plate required thickness (operating, corroded + Vortex shedding)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*48.838*417.49^2 = 481.8\ kg_f$

$M_y = 0.01*-0.4477*48.838*101^2 = -2{,}230.6\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*2{,}230.65 / 1{,}454.999)^{0.5}$
= 30.33 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*4{,}322.68 / (2{,}089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 21.27 mm

The compression ring thickness is satisfactory.

Check gusset plate thickness (Bednar chapter 4.3)

Radius of gyration of gusset

$r = 0.289*t_g$
$= 0.289*16$
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
$= 0.01*16*(101 - 0.25*25.41)$
$= 15.144\ cm^2$

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
$= 1{,}195.27 - 0.0341*(240 / 4.62)^2$
$= 1{,}103.357\ kg_f/cm^2$

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
$= 4{,}322.68 / (2 * 15.144)$
$= 142.719\ kg_f/cm^2$

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(100*4{,}322.68*76 / (530.62*303*1{,}651.939))^{2/3}*(3{,}378 / 2)^{1/3}$

= 5.2 mm

The skirt thickness is satisfactory.

Anchor bolt load (empty, corroded + Vortex shedding)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*130,524.56 / 20 + 4 * 292,613.1 / (20*3.53)
= 12,662.92 kg_f

Required area per bolt = P / S_b = 10.5524 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, empty, corroded + Vortex shedding)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

t_s = (N*A_b) / (π*d)
= (20*1,342.9593) / (π*3,435)
= 2.49 mm

From table 12.4 for k = 0.248199:

K_1 = 2.555,	K_2 = 1.3644	
L_1 = 34.0562,	L_2 = 78.6518,	L_3 = 26.6373

Total tensile force on bolting

T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)
= (292,613.1 - 0.6*130,524.56 *(0.865 + 0.6766)) / (1.9978 + 0.6766)
= 64,270.75 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

f_s = T / (t_s * (d / 2) * K_1)
= 100*64,270.75 / (2.49 * (3,435 / 2) * 2.555)
= 588.46 kg_f/cm^2

Total compressive load on foundation

C_c = T + W + Bolt Preload
= 64,270.75 + 130,524.56 + 0
= 194,795.31 kg_f

Foundation bearing stress

f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)
= 100*194,795.31 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*1.3644)
= 54.937 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
= 1 / (1 + 588.46 / (3.5363*54.937))
= 0.248199

Base plate required thickness (empty, corroded + Vortex shedding)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*54.937*417.49^2 = 542\ kg_f$

$M_y = 0.01*-0.4477*54.937*101^2 = -2{,}509.2\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*2{,}509.19 / 1{,}454.999)^{0.5}$
= 32.17 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*7{,}902.78 / (2{,}089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 28.76 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
$= 1{,}195.27 - 0.0341*(240 / 4.62)^2$
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 7,902.78 / (2 * 15.144)
= 260.921 kg_f/cm^2

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(100*7{,}902.78*76 / (530.62*303*1{,}651.939))^{2/3}*(3{,}378 / 2)^{1/3}$
= 7.78 mm

The skirt thickness is satisfactory.

Anchor bolt load (vacuum, corroded + Vortex shedding)

P = -0.6*W / N + 4 * M / (N*BC)
= -0.6*175,795.42 / 20 + 4 * 241,180.8 / (20*3.53)
= 8,390.78 kg_f

Required area per bolt = P / S_b = 6.9923 cm^2

The area provided (11.5516 cm^2) by the specified anchor bolt is adequate.

Support calculations (Jawad & Farr chapter 12, vacuum, corroded + Vortex shedding)

Base plate width, t_c:	145	mm
Average base plate diameter, d:	3,435	mm
Base plate elastic modulus, E_s:	2,038,900.1	kg_f/cm^2
Base plate yield stress, S_y:	2,089.998	kg_f/cm^2

E_c = 57,000*0.265154*Sqr(1,455.299) = 576,567.179 kg_f/cm^2

n = E_s/E_c = 2,038,900.1 / 576,567.179 = 3.5363

$t_s = (N*A_b) / (\pi*d)$
$= (20*1{,}342.9593) / (\pi*3{,}435)$
= 2.49 mm

From table 12.4 for k = 0.349076:

K_1 = 2.3353, K_2 = 1.6379
L_1 = 20.413, L_2 = 68.5707, L_3 = 37.3224

Total tensile force on bolting

$T = (M - 0.6*W *(L_1 + L_3)) / (L_2 + L_3)$
= (241,180.8 - 0.6*175,795.42 *(0.5185 + 0.948)) / (1.7417 + 0.948)
= 32,160.15 kg_f

Tensile stress in bolts use the larger of f_s or bolt preload = 0 kg_f/cm^2

$f_s = T / (t_s * (d / 2) * K_1)$
= 100*32,160.15 / (2.49 * (3,435 / 2) * 2.3353)
= 322.158 kg_f/cm^2

Total compressive load on foundation

C_c = T + W + Bolt Preload
= 32,160.15 + 175,795.42 + 0
= 207,955.57 kg_f

Foundation bearing stress

$f_c = C_c / (((t_c - t_s) + n*t_s)*(d / 2)*K_2)$

= 100*207,955.57 / (((145 - 2.49) + 3.5363*2.49)*(3,435 / 2)*1.6379)
= 48.855 kg_f/cm^2

As f_c <= 1,455.299 kg_f/cm^2 the base plate width is satisfactory.

$k = 1 / (1 + f_s / (n*f_c))$
= 1 / (1 + 322.158 / (3.5363*48.855))
= 0.349076

Base plate required thickness (vacuum, corroded + Vortex shedding)

From Brownell & Young, Table 10.3:, l / b = 0.2419

$M_x = 0.01*0.0057*48.855*417.49^2 = 482\ kg_f$

$M_y = 0.01*-0.4477*48.855*101^2 = -2{,}231.4\ kg_f$

$t_r = (6*M_{max} / S_p)^{0.5}$
$= (100*6*2{,}231.41 / 1{,}454.999)^{0.5}$
= 30.33 mm

The base plate thickness is satisfactory.

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

$t_{cr} = (3.91*F / (S_y*(2*b / w+w / (2*l)-d_b*(2 / w+1 / (2*l)))))^{0.5}$
$= (100*3.91*4{,}326.45 / (2{,}089.998*(2*141 / 105+105 / (2*76)-62*(2 / 105+1 / (2*76)))))^{0.5}$
= 21.28 mm

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*16
= 4.62 mm

Cross sectional area of one gusset

$A_g = t_g*(b - 0.25*25.41)$
= 0.01*16*(101 - 0.25*25.41)
= 15.144 cm^2

Gusset allowable stress

$S_a = 0.07031*(17000 - 0.485*(h / r)^2)$
$= 1{,}195.27 - 0.0341*(240 / 4.62)^2$
= 1,103.357 kg_f/cm^2

Gusset axial stress due to bolt load

$S_g = F / (2 * A_g)$
= 4,326.45 / (2 * 15.144)
= 142.844 kg_f/cm^2

The gusset plate thickness is satisfactory.

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

$t = 1.76*(F*l / (M_b*h_c*S_s))^{2/3}*(OD_s / 2)^{1/3}$
$= 1.76*(100*4{,}326.45*76 / (530.62*303*1{,}651.939))^{2/3}*(3{,}378 / 2)^{1/3}$
$= 5.21$ mm

The skirt thickness is satisfactory.

Wind Code

Building Code: ASCE 7-05		
Elevation of base above grade		0.98 ft (0.30 m)
Increase effective outer diameter by		2.10 ft (0.64 m)
Wind Force Coefficient, Cf		0.7000
Occupancy Category (Table 1-1)		II
Basic Wind Speed, V		76.21 mph (122.6540 km/h)
Importance Factor, I		1.0000
Exposure Category		C
Wind Directionality Factor, Kd		0.9500
Top Deflection Limit		5.00 mm per m.
Topographic Factor, Kzt		1.0000
Enforce min. loading of 0.48 kPa		Yes
Hazardous, toxic, or explosive contents		No
Vessel Characteristics		
Height, h		122.4078 ft (37.3100 m)
Effective Width, b	Operating, Corroded	11.4627 ft (3.4939 m)
	Empty, Corroded	11.4627 ft (3.4939 m)
Fundamental Frequency, n_1	Operating, Corroded	1.1919 Hz
	Empty, Corroded	1.3185 Hz
	Vacuum, Corroded	1.1933 Hz
Damping coefficient, β	Operating, Corroded	0.0263
	Empty, Corroded	0.0217
	Vacuum, Corroded	0.0264

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
Operating, Corroded,Vortex Shedding
Empty, Corroded, Vortex Shedding
Vacuum, Corroded, Vortex Shedding
Wind Pressure Calculations
Wind Pressures at Critical Speed: Operating, Corroded
Wind Pressures at Critical Speed: Empty, Corroded
Wind Pressures at Critical Speed: Vacuum, Corroded

Wind Deflection Report: Operating, Corroded								
Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m⁴)	Platform Wind Shear at Bottom (kgf)	Total Wind Shear at Bottom (kgf)	Bending Moment at Bottom (kgf-m)	Deflection at Top (mm)
Top Head	36,422	4.17	1,956,632.7	*		177.1	3,419.5	17.33
Top existing shell	17,540	4.17	1,956,632.7	0.1649		4,334.4	51,607.6	16.77
New shell	14,510	4.19	1,956,632.7	0.333		4,954.1	65,679.7	5.65
Bottom existing shell	8,138	4.17	1,956,632.7	0.2093		6,250.5	103,236.4	4.16
Bottom Head (top)	7,986	4.17	1,956,632.7	*		6,281.4	104,188.8	1.51
Support Skirt #1	7,010	4.12	2,065,538.5	0.1262		6,472.8	111,233.1	1.46
Support Skirt #2		4.12	2,065,538.5	0.1262		7,847.6	161,426.1	1.14
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Empty, Corroded								
Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m⁴)	Platform Wind Shear at Bottom (kgf)	Total Wind Shear at Bottom (kgf)	Bending Moment at Bottom (kgf-m)	Deflection at Top (mm)
Top Head	36,422	4.17	2,068,393.7	*		177.1	3,419.5	17
Top existing shell	17,540	4.17	2,068,393.7	0.1649		4,334.4	51,607.6	16.45
New shell	14,510	4.19	2,068,393.7	0.333		4,954.1	65,679.7	5.59
Bottom existing shell	8,138	4.17	2,068,393.7	0.2093		6,250.5	103,236.4	4.13
Bottom Head (top)	7,986	4.17	2,068,393.7	*		6,281.4	104,188.8	1.51
Support Skirt #1	7,010	4.12	2,068,393.7	0.1262		6,472.8	111,233.1	1.45
Support Skirt #2		4.12	2,068,393.7	0.1262		7,847.6	161,426.1	1.14
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Vacuum, Corroded

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	36,422	4.17	1,973,152.1	*		177.1	3,419.5	17.28
Top existing shell	17,540	4.17	1,973,152.1	0.1649		4,334.4	51,607.6	16.73
New shell	14,510	4.19	1,973,152.1	0.333		4,954.1	65,679.7	5.64
Bottom existing shell	8,138	4.17	1,973,152.1	0.2093		6,250.5	103,236.4	4.16
Bottom Head (top)	7,986	4.17	1,973,152.1	*		6,281.4	104,188.8	1.51
Support Skirt #1	7,010	4.12	2,065,538.5	0.1262		6,472.8	111,233.1	1.46
Support Skirt #2		4.12	2,065,538.5	0.1262		7,847.6	161,426.1	1.14
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Operating, Corroded, Vortex Shedding

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	36,422	4.17	1,956,632.7	*		377.1	3,514.5	27.04
Top existing shell	17,540	4.17	1,956,632.7	0.1649		6,876.8	86,673.6	26.17
New shell	14,510	4.19	1,956,632.7	0.333		7,496.6	108,449.3	8.67
Bottom existing shell	8,138	4.17	1,956,632.7	0.2093		8,792.9	162,206.4	6.37
Bottom Head (top)	7,986	4.17	1,956,632.7	*		8,823.8	163,545.3	2.29
Support Skirt #1	7,010	4.12	2,065,538.5	0.1262		9,015.2	173,071	2.21
Support Skirt #2		4.12	2,065,538.5	0.1262		10,390.1	241,086.6	1.73
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Empty, Corroded, Vortex Shedding

Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm²)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	36,422	4.17	2,068,393.7	*		499.8	3,569.7	32.64
Top existing shell	17,540	4.17	2,068,393.7	0.1649		8,527.7	109,243.9	31.58
New shell	14,510	4.19	2,068,393.7	0.333		9,147.4	136,021.8	10.52
Bottom existing shell	8,138	4.17	2,068,393.7	0.2093		10,443.8	200,298.2	7.73
Bottom Head (top)	7,986	4.17	2,068,393.7	*		10,474.7	201,888.1	2.79
Support Skirt #1	7,010	4.12	2,068,393.7	0.1262		10,666.1	213,025	2.69
Support Skirt #2		4.12	2,068,393.7	0.1262		12,040.9	292,613.2	2.1
*Moment of Inertia I varies over the length of the component								

Wind Deflection Report: Vacuum, Corroded, Vortex Shedding								
Component	Elevation of Bottom above Base (mm)	Effective OD (m)	Elastic Modulus E (kg/cm^2)	Inertia I (m^4)	Platform Wind Shear at Bottom (kg_f)	Total Wind Shear at Bottom (kg_f)	Bending Moment at Bottom (kg_f-m)	Deflection at Top (mm)
Top Head	36,422	4.17	1,973,152.1	*		377.4	3,514.6	26.97
Top existing shell	17,540	4.17	1,973,152.1	0.1649		6,879.9	86,714.9	26.1
New shell	14,510	4.19	1,973,152.1	0.333		7,499.6	108,499.8	8.66
Bottom existing shell	8,138	4.17	1,973,152.1	0.2093		8,796	162,276.2	6.36
Bottom Head (top)	7,986	4.17	1,973,152.1	*		8,826.8	163,615.5	2.29
Support Skirt #1	7,010	4.12	2,065,538.5	0.1262		9,018.2	173,144.2	2.21
Support Skirt #2		4.12	2,065,538.5	0.1262		10,393.1	241,180.9	1.73
*Moment of Inertia I varies over the length of the component								

Wind Pressure (WP) Calculations

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

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

$= 2.01 * (Z/274.32)^{0.2105}$

qz $= 0.613 * Kz * Kzt * Kd * V^2 * I$

$= 0.613 * Kz * 1.0000 * 0.9500 * 34.0706^2 * 1.0000$

$= 675.9935 * Kz$

WP = max[qz * G * Cf, 0.0048 bar]

= max[qz * G * 0.7000, 0.0048 bar]

Design Wind Pressures							
Height Z (m)	Kz	qz (bar)	WP (bar)				
			Operating	Empty	Hydrotest New	Hydrotest Corroded	Vacuum
4.6	0.8489	0.0057	0.0048	0.0048	N.A.	N.A.	0.0048
6.1	0.9019	0.0061	0.0048	0.0048	N.A.	N.A.	0.0048
7.6	0.9453	0.0064	0.0048	0.0048	N.A.	N.A.	0.0048
9.1	0.9823	0.0066	0.0048	0.0048	N.A.	N.A.	0.0048
12.2	1.0436	0.0071	0.0048	0.0048	N.A.	N.A.	0.0048
15.2	1.0938	0.0074	0.0048	0.0048	N.A.	N.A.	0.0048
18.3	1.1366	0.0077	0.0048	0.0048	N.A.	N.A.	0.0048
21.3	1.1741	0.0079	0.0049	0.0049	N.A.	N.A.	0.0049
24.4	1.2075	0.0082	0.0050	0.0050	N.A.	N.A.	0.0050
27.4	1.2379	0.0084	0.0051	0.0051	N.A.	N.A.	0.0051
30.5	1.2656	0.0086	0.0053	0.0053	N.A.	N.A.	0.0053
36.6	1.3151	0.0089	0.0055	0.0055	N.A.	N.A.	0.0055
42.7	1.3585	0.0092	0.0056	0.0056	N.A.	N.A.	0.0056
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	10.8395 ft (3303.89 mm)		
Aspect ratio, Ar	11.2927		
	Operating, Corroded	Empty, Corroded	Vacuum, Corroded
Vortex shedding factor, C_1	2.5203	2.5203	2.5203
Vortex shedding factor, C_2	0.6000	0.6000	0.6000
Weight per foot of vessel, upper third, M	2,304.0857 lb/ft (34.2886 kg/cm)	1,871.0386 lb/ft (27.8441 kg/cm)	2,304.0857 lb/ft (34.2886 kg/cm)
Strouhal number, S	0.2000	0.2000	0.2000

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

Operating, Corroded: V_h = (1.1919*10.8395/0.2000)*(3600/5280) = 44.0436 mph (70.8812 km/h)
Empty, Corroded: V_h = (1.3185*10.8395/0.2000)*(3600/5280) = 48.7231 mph (78.4122 km/h)
Vacuum, Corroded: V_h = (1.1933*10.8395/0.2000)*(3600/5280) = 44.0965 mph (70.9665 km/h)

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

Operating, Corroded: V_{Ref} = 38.3669 mph (61.7455 km/h)
Empty, Corroded: V_{Ref} = 42.4433 mph (68.3058 km/h)
Vacuum, Corroded: V_{Ref} = 38.4130 mph (61.8198 km/h)

Corresponding reference wind speed, V_{Ref}

Operating, Corroded:	V_{Ref} = 76.2137 mph (122.6540 km/h)
Empty, Corroded:	V_{Ref} = 76.2137 mph (122.6540 km/h)
Vacuum, Corroded:	V_{Ref} = 76.2137 mph (122.6540 km/h)

Corresponding pressure at top of vessel, $q_h = .00256 * V_h^2$

Operating, Corroded:	$q_h = .00256 * (44.0436)^2 = 4.9660$ psf (bar)
Empty, Corroded:	$q_h = .00256 * (48.7231)^2 = 6.0773$ psf (bar)
Vacuum, Corroded:	$q_h = .00256 * (44.0965)^2 = 4.9779$ psf (bar)

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

Operating, Corroded:	FL = 4.9660*2.5203*10.8395 / (SQR(11.2927)*SQR(0.0263 - (0.6000*.0765*$(10.8395)^2$/2,304.0857)))
	= 260.7047 lb/ft (3.8797 kg/cm)
Empty, Corroded:	FL = 6.0773*2.5203*10.8395 / (SQR(11.2927)*SQR(0.0217 - (0.6000*.0765*$(10.8395)^2$/1,871.0386)))
	= 359.9287 lb/ft (5.3563 kg/cm)
Vacuum, Corroded:	FL = 4.9779*2.5203*10.8395 / (SQR(11.2927)*SQR(0.0264 - (0.6000*.0765*$(10.8395)^2$/2,304.0857)))
	= 260.8919 lb/ft (3.8825 kg/cm)

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

Wind Pressures at Critical Wind Speed: Operating, Corroded (V_h = 19.6892 m/sec)

Kz = $2.01 * (Z/Zg)^{2/\alpha}$
= $2.01 * (Z/274.32)^{0.2105}$
qz = $0.613 * Kz * Kd * Kzt * Vh^2 * I$
= $0.613 * Kz * 0.9500 * 1.0000 * (19.6892)^2 * 1.0000$
= 225.7572 * Kz
WP = qz * G⁻ * Cf
= qz * 0.8762 * 0.7000

Height Z(m)	Kz	qz(bar)	WP(bar)
4.6	0.8489	0.0019	0.0012
6.1	0.9019	0.0020	0.0012
7.6	0.9453	0.0021	0.0013
9.1	0.9823	0.0022	0.0014
12.2	1.0436	0.0024	0.0014
15.2	1.0938	0.0025	0.0015
18.3	1.1366	0.0026	0.0016
21.3	1.1741	0.0027	0.0016
24.4	1.2075	0.0027	0.0017
27.4	1.2379	0.0028	0.0017
30.5	1.2656	0.0029	0.0018
36.6	1.3151	0.0030	0.0018
42.7	1.3585	0.0031	0.0019

Wind Pressures at Critical Wind Speed: Empty, Corroded (V_h = 21.7812 m/sec)

Kz = $2.01 * (Z/Zg)^{2/\alpha}$
= $2.01 * (Z/274.32)^{0.2105}$
qz = $0.613 * Kz * Kd * Kzt * Vh^2 * I$
= $0.613 * Kz * 0.9500 * 1.0000 * (21.7812)^2 * 1.0000$
= $276.2781 * Kz$
WP = $qz * G^- * Cf$
= $qz * 0.8762 * 0.7000$

Height Z(m)	Kz	qz(bar)	WP(bar)
4.6	0.8489	0.0023	0.0014
6.1	0.9019	0.0025	0.0015
7.6	0.9453	0.0026	0.0016
9.1	0.9823	0.0027	0.0017
12.2	1.0436	0.0029	0.0018
15.2	1.0938	0.0030	0.0019
18.3	1.1366	0.0031	0.0019
21.3	1.1741	0.0032	0.0020
24.4	1.2075	0.0033	0.0020
27.4	1.2379	0.0034	0.0021
30.5	1.2656	0.0035	0.0021
36.6	1.3151	0.0036	0.0022
42.7	1.3585	0.0038	0.0023

Wind Pressures at Critical Wind Speed: Vacuum, Corroded (V_h = 19.7129 m/sec)

Kz $= 2.01 * (Z/Zg)^{2/\alpha}$
$= 2.01 * (Z/274.32)^{0.2105}$
qz $= 0.613 * Kz * Kd * Kzt * Vh^2 * I$
$= 0.613 * Kz * 0.9500 * 1.0000 * (19.7129)^2 * 1.0000$
$= 226.3007 * Kz$
WP $= qz * G^- * Cf$
$= qz * 0.8762 * 0.7000$

Height Z(m)	Kz	qz(bar)	WP(bar)
4.6	0.8489	0.0019	0.0012
6.1	0.9019	0.0020	0.0013
7.6	0.9453	0.0021	0.0013
9.1	0.9823	0.0022	0.0014
12.2	1.0436	0.0024	0.0014
15.2	1.0938	0.0025	0.0015
18.3	1.1366	0.0026	0.0016
21.3	1.1741	0.0027	0.0016
24.4	1.2075	0.0027	0.0017
27.4	1.2379	0.0028	0.0017
30.5	1.2656	0.0029	0.0018
36.6	1.3151	0.0030	0.0018
42.7	1.3585	0.0031	0.0019

Gust Factor Calculations

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

Gust Factor Calculations: Operating, Corroded

Vessel is considered a rigid structure as n_1 = 1.1919 Hz ≥ 1 Hz.

$\bar{z}$ = max[.60 * h , z_{min}]
= max[.60 * 122.4078 , 15.0000]
= 73.4447

$I_{\bar{z}}$ = c * $(33 / \bar{z})^{1/6}$
= 0.2000 * $(33 / 73.4447)^{1/6}$
= 0.1750

$L_{\bar{z}}$ = l * $(\bar{z} / 33)^{ep}$
= 500.0000 * $(73.4447 / 33)^{0.2000}$
= 586.7584

Q = Sqr(1 / (1 + .63 * $((b + h) / L_{\bar{z}})^{.63}$))
= Sqr(1 / (1 + .63 * $((11.4627 + 122.4078) / 586.7584)^{.63}$))
= 0.8950

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* 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)
= 0.8762

Gust Factor Calculations: Empty, Corroded

Vessel is considered a rigid structure as n_1 = 1.3185 Hz ≥ 1 Hz.

$\bar{z}$	= max[.60 * h , z_{min}]
	= max[.60 * 122.4078 , 15.0000]
	= 73.4447
$I_{\bar{z}}$	= c * $(33 / \bar{z})^{1/6}$
	= 0.2000 * $(33 / 73.4447)^{1/6}$
	= 0.1750
$L_{\bar{z}}$	= l * $(\bar{z} / 33)^{ep}$
	= 500.0000 * $(73.4447 / 33)^{0.2000}$
	= 586.7584
Q	= Sqr(1 / (1 + .63 * $((b + h) / L_{\bar{z}})^{.63}$))
	= Sqr(1 / (1 + .63 * $((11.4627 + 122.4078) / 586.7584)^{.63}$))
	= 0.8950
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* 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)
	= 0.8762

Gust Factor Calculations: Vacuum, Corroded

Vessel is considered a rigid structure as n_1 = 1.1933 Hz ≥ 1 Hz.

$\bar{z}$	= max[.60 * h , z_{min}]
	= max[.60 * 122.4078 , 15.0000]
	= 73.4447
$I_{\bar{z}}$	= c * $(33 / \bar{z})^{1/6}$
	= 0.2000 * $(33 / 73.4447)^{1/6}$
	= 0.1750
$L_{\bar{z}}$	= l * $(\bar{z} / 33)^{ep}$
	= 500.0000 * $(73.4447 / 33)^{0.2000}$
	= 586.7584
Q	= Sqr(1 / (1 + .63 * $((b + h) / L_{\bar{z}})^{.63}$))
	= Sqr(1 / (1 + .63 * $((11.4627 + 122.4078) / 586.7584)^{.63}$))
	= 0.8950
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* 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)
	= 0.8762

Gust Factor Calculations: Operating, Corroded, Vortex Shedding

Vessel is considered a rigid structure as n_1 = 1.1919 Hz ≥ 1 Hz.

$\bar{z}$	= max[.60 * h , z_{min}]
	= max[.60 * 122.4078 , 15.0000]
	= 73.4447

$I_{\bar{z}}$ = c * (33 / z̄)$^{1/6}$
= 0.2000 * (33 / 73.4447)$^{1/6}$
= 0.1750

$L_{\bar{z}}$ = l * (z̄ / 33)^{ep}
= 500.0000 * (73.4447 / 33)$^{0.2000}$
= 586.7584

Q = Sqr(1 / (1 + .63 * ((b + h) / $L_{\bar{z}}$)$^{.63}$))
= Sqr(1 / (1 + .63 * ((11.4627 + 122.4078) / 586.7584)$^{.63}$))
= 0.8950

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* 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)
= 0.8762

Gust Factor Calculations: Empty, Corroded, Vortex Shedding

Vessel is considered a rigid structure as n_1 = 1.3185 Hz ≥ 1 Hz.

z̄ = max[.60 * h , z_{min}]
= max[.60 * 122.4078 , 15.0000]
= 73.4447

$I_{\bar{z}}$ = c * (33 / z̄)$^{1/6}$
= 0.2000 * (33 / 73.4447)$^{1/6}$
= 0.1750

$L_{\bar{z}}$ = l * (z̄ / 33)^{ep}
= 500.0000 * (73.4447 / 33)$^{0.2000}$
= 586.7584

Q = Sqr(1 / (1 + .63 * ((b + h) / $L_{\bar{z}}$)$^{.63}$))
= Sqr(1 / (1 + .63 * ((11.4627 + 122.4078) / 586.7584)$^{.63}$))
= 0.8950

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* 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)
= 0.8762

Gust Factor Calculations: Vacuum, Corroded, Vortex Shedding

Vessel is considered a rigid structure as n_1 = 1.1933 Hz ≥ 1 Hz.

z̄ = max[.60 * h , z_{min}]
= max[.60 * 122.4078 , 15.0000]
= 73.4447

$I_{\bar{z}}$ = c * (33 / z̄)$^{1/6}$
= 0.2000 * (33 / 73.4447)$^{1/6}$
= 0.1750

$L_{\bar{z}}$ = l * (z̄ / 33)^{ep}
= 500.0000 * (73.4447 / 33)$^{0.2000}$
= 586.7584

Q = Sqr(1 / (1 + .63 * ((b + h) / $L_{\bar{z}}$)$^{.63}$))

$= Sqr(1 / (1 + .63 * ((11.4627 + 122.4078) / 586.7584)^{.63}))$

$= 0.8950$

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

$= 0.925 * (1 + 1.7 * 3.40 * 0.1750 * 0.8950) / (1 + 1.7 * 3.40 * 0.1750)$

$= 0.8762$

Table Lookup Values	
α = 9.5000, z_g = 274.32 m	[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]

Liquid Level bounded by Bottom Head 1

ASME Section VIII Division 1, 2017 Edition Metric	
Location from Datum (mm)	2,600
Operating Liquid Specific Gravity	1.065

Calculation of Platform #3 1

Circular Platform Design

Dead load		=	0.0012	N/mm^2
Live load		=	0.0025	N/mm^2
Designed load *(Dead load + Live load)*	f	=	0.0037	N/mm^2

Shape steel (Bracket)

Material of shape steel		:	SS400	
Yield stress of material	Fy	=	250	N/mm^2
Allowable bending stress, (0.66Sy)	F_B	=	165	N/mm^2

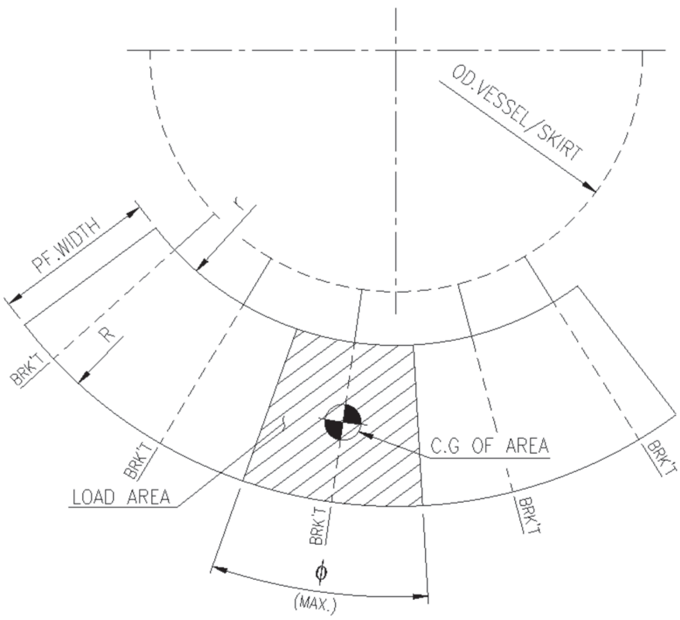
Vessel clip

Material of vessel clip		:	SA516 Gr.70	
Yield stress of material	F_y	=	260	N/mm^2
Yield stress of material at design temp.		=	225	N/mm^2
Allowable shear stress of weld clip to shell	S_S	=	90	N/mm^2

Bolt / Nut

Material of Bolt		:	A325	
Size of Bolt		:	M20	
Allowable shear load in bolts (from Table 9-9)	F_L	=	47,150	N

Area of platform

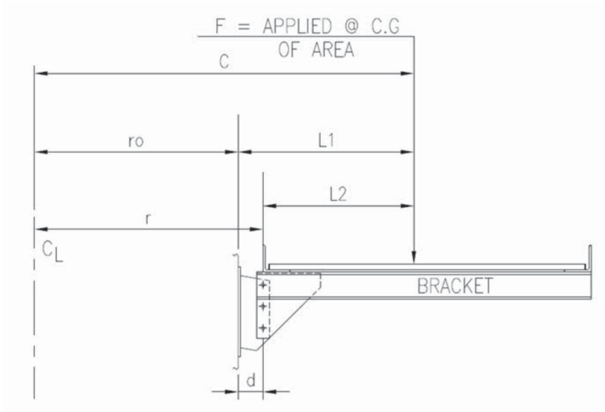


$$\text{Area} = \frac{(R^2 - r^2)\pi\phi}{360}$$

Area of platform					
Platform	Φ (Max)	R (mm)	r (mm)	Width (mm)	Area (mm^2)
#3	20	3125	1925	1200	1,057,670

<u>Bracket support with out kneebrace</u>

Computing moments in shell and bolt loads



Outside radius of vessel			=	r_o	
Distance from C.L of vessel to C.G. of area		C	=	$\dfrac{38.197(R^3 - r^3)\sin\frac{\phi}{2}}{(R^2 - r^2)\frac{\phi}{2}}$	
Size of bracket			=	C-150 x 75 x t6.5 x t10	
Section modulus of bracket		Z_b	=	115000	mm^3
Distance from r_o of vessel to CL. of bolts holes			=	d	
Number of bolts in a vertical row		n	=	2	
distance of bolt in vertical		b	=	70	mm
Number of bolts in a horizotal		m	=	2	
distance of bolt in horizontal		D	=	120	mm
Clip weld length	PF #3	i_1	=	250	mm
Thickness of clip		t	=	10	mm
Area of clip	PF #3	Ac	=	2500	mm^2
Filled weld size clip to shell		f_1	=	7	mm
Distance from r_o of vessel to C.G. of area			=	L_1	
Distance from CL. of bolts holes to C.G. of area			=	L_2	
Platform load per bracket		F	=	fA	
Loading per bolt		Ix	=	$2\left[\dfrac{nb^2(n^2-1)}{12}\right]$	
		Iy	=	$n\left[\dfrac{mD^2(m^2-1)}{12}\right]$	
		f_x	=	$\dfrac{(Fl_2)(n-1)b}{2Ip}$	
		f_y	=	$\dfrac{F}{mn} + \dfrac{Fl_2D}{2Ip}$	
		f_r	=	$\sqrt{(Fx^2 + Fy^2)}$	
Moment at shell		M_1	=	L_1F	
Shear stress of clip		s_1	=	F / Ac	
Shear stress of weld clip to shell		s_2	=	$F / (2i\, f_1 \sin 45^o)$	
Bending stress in bracket		f_b	=	M_1/Z_b	

Platform	Design data					
	d(mm)	r_o(mm)	F(N)	C(mm)	L_1(mm.)	L_2(mm.)
#3	316	1,789	3,889	2,559	770	454

Platform	Bending moment	Bending stress in bracket			Shear stress at clip		
	M_1(N-mm)	f_b(N/mm^2)	$f_b < F_B$	check	s_1 (N/mm^2)	$s_1 < S_S$	check
#3	2,996,566	26.06	YES	**Pass**	1.56	YES	**Pass**

Platform	Check bolt load							
	Ix	Iy	Ip	f_x(N)	f_y(N)	f_r(N)	$f_r < F_L$	check
#3	4,900	14,400	19,300	3,205	6,467	7,218	YES	**Pass**

Platform	Shear weld at clip		
	s_2 (N/mm^2)	$s_2 < S_S$	check
#3	1.57	YES	**Pass**

Summary load for checking local stress

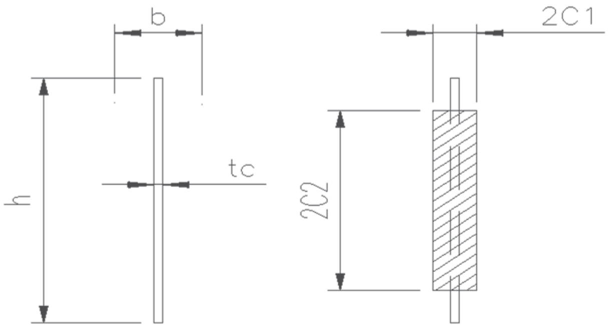
Radial load	P_r	=	0	N
Circumferential shear force	V_C	=	0	N
Circumferential moment	M_C	=	0	N-m
Maximum Longitudinal shear force	V_L	=	F	N
Maximum Longitudinal moment	M_L	=	M_1	N-m

Platform	P_r	V_C	M_C	V_L	M_L
#3	0	0	0	3,889	2,997

For worst case

Remark : Due to the programe can not calculate area cross section of attachments, so we have to convert to square section.

Refered from *" Pressure Vessel Design Manual "* by Dennis R. Moss



Platform	b	h	C1	C2	Width	Length
			0.5b	0.4h	$2C_1$	$2C_2$
	mm.	mm.	mm.	mm.	mm.	mm.
#3	74	250	37	100	74	200

* $b = t_{clip} + 2t_{weld} + 2t_{shell/skirt}$

t_{clip}	=	10	mm.
t_{weld}	=	7	mm.
t_{shell}	=	25	mm.

See calculation be designed by " COMPRESS " programe

PF clip #3

Geometry	
Height (radial)	416 mm
Width (circumferential)	74 mm
Length	200 mm
Fillet Weld Size:	7 mm
Located On	Bottom existing shell (810 mm from top end)
Location Angle	0.00°

Applied Loads	
Radial load, P_r	0 kg_f
Circumferential moment, M_c	0 kg_f-m
Circumferential shear, V_c	0 kg_f
Longitudinal moment, M_L	305.6 kg_f-m
Longitudinal shear, V_L	396.57 kg_f
Torsion moment, M_t	0 kg_f-m
Internal pressure, P	3.6 bar
Mean shell radius, R_m	1,682 mm
Design factor	3

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 1{,}682 / 14 = 120.1429$

$C_1 = 44$, $C_2 = 107$ mm

Local circumferential pressure stress = $P*R_i / T$ =439.207 kg_f/cm^2

Local longitudinal pressure stress = $P*R_i / (2*T)$ =219.639 kg_f/cm^2

Maximum combined stress (P_L+P_b+Q) = 1,301.66 kg_f/cm^2
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±4,221.62 kg_f/cm^2

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 565.97 kg_f/cm^2
Allowable local primary membrane stress (P_L) = ±1.5*S = ±2,110.81 kg_f/cm^2

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*	18.9803	0.0562	0	0	0	0	0	0	0	0
4C*	21.1589	0.0472	0	0	0	0	0	0	0	0
1C	0.1827	0.037	0	0	0	0	0	0	0	0
2C-1	0.1331	0.037	0	0	0	0	0	0	0	0
3A*	2.2638	0.0352	0	0	0	0	0	0	0	0
1A	0.0994	0.0378	0	0	0	0	0	0	0	0
3B*	10.4581	0.0473	-126.763	-126.763	126.763	126.763	0	0	0	0
1B-1	0.0539	0.0407	-735.691	735.691	735.691	-735.691	0	0	0	0
Pressure stress*			439.207	439.207	439.207	439.207	439.207	439.207	439.207	439.207
Total circumferential stress			-423.248	1,048.135	1,301.662	-169.721	439.207	439.207	439.207	439.207
Primary membrane circumferential stress*			312.444	312.444	565.971	565.971	439.207	439.207	439.207	439.207
3C*	20.5332	0.0472	0	0	0	0	0	0	0	0
4C*	20.5732	0.0562	0	0	0	0	0	0	0	0
1C-1	0.1489	0.0488	0	0	0	0	0	0	0	0
2C	0.1077	0.0488	0	0	0	0	0	0	0	0
4A*	2.86	0.0352	0	0	0	0	0	0	0	0
2A	0.0579	0.0461	0	0	0	0	0	0	0	0
4B*	3.0453	0.0473	-57.581	-57.581	57.581	57.581	0	0	0	0
2B-1	0.0802	0.0502	-887.836	887.836	887.836	-887.836	0	0	0	0
Pressure stress*			219.639	219.639	219.639	219.639	219.639	219.639	219.639	219.639
Total longitudinal stress			-725.778	1,049.893	1,165.056	-610.615	219.639	219.639	219.639	219.639
Primary membrane longitudinal stress*			162.057	162.057	277.22	277.22	219.639	219.639	219.639	219.639
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	-6.609	-6.609	6.609	6.609
Total Shear stress			0	0	0	0	-6.609	-6.609	6.609	6.609
Combined stress (P_L+P_b+Q)			-725.778	1,049.893	1,301.662	-610.615	439.418	439.418	439.418	439.418

* denotes primary stress.

Calculation of Platform #4 1

Circular Platform Design

Dead load		=	0.0012	N/mm^2
Live load		=	0.0025	N/mm^2
Designed load *(Dead load + Live load)*	f	=	0.0037	N/mm^2

Shape steel (Bracket)

Material of shape steel		:	SS400	
Yield stress of material	Fy	=	250	N/mm^2
Allowable bending stress, (0.66Sy)	F_B	=	165	N/mm^2

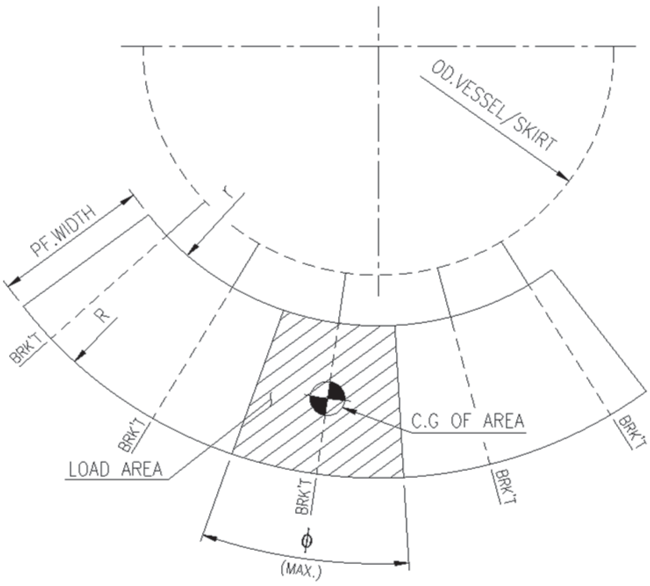
Vessel clip

Material of vessel clip		:	SA516 Gr.70	
Yield stress of material	F_y	=	260	N/mm^2
Yield stress of material at design temp.		=	225	N/mm^2
Allowable shear stress of weld clip to shell	S_S	=	90	N/mm^2

Bolt / Nut

Material of Bolt		:	A325	
Size of Bolt		:	M20	
Allowable shear load in bolts (from Table 9-9)	F_L	=	47,150	N

Area of platform

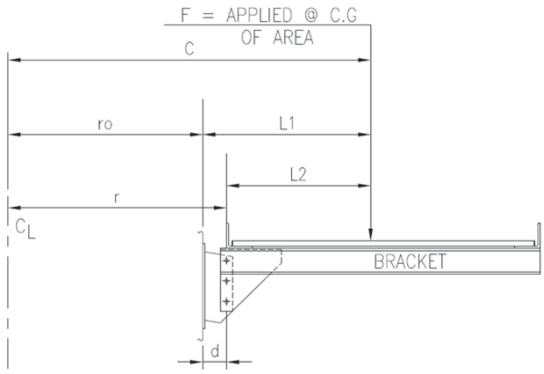


$$\text{Area} = \frac{(R^2 - r^2)\pi\phi}{360}$$

Area of platform					
Platform	Φ (Max)	R (mm)	r (mm)	Width (mm)	Area (mm^2)
#4	25	2925	1925	1000	1,058,106

<u>Bracket support with out kneebrace</u>

Computing moments in shell and bolt loads



Outside radius of vessel			=	r_o	
Distance from C.L of vessel to C.G. of area		C	=	$\frac{38.197(R^3 - r^3)\sin\frac{\Phi}{2}}{(R^2 - r^2)\frac{\Phi}{2}}$	
Size of bracket			=	C-150 x 75 x t6.5 x t10	
Section modulus of bracket		Z_b	=	115000	mm^3
Distance from r_o of vessel to CL. of bolts holes			=	d	
Number of bolts in a vertical row		n	=	2	
distance of bolt in vertical		b	=	70	mm
Number of bolts in a horizotal		m	=	2	
distance of bolt in horizontal		D	=	120	mm
Clip weld length	PF #4	i_1	=	250	mm
Thickness of clip		t	=	12	mm
Area of clip	PF #4	Ac	=	3000	mm^2
Filled weld size clip to shell		f_1	=	7	mm
Distance from r_o of vessel to C.G. of area			=	L_1	
Distance from CL. of bolts holes to C.G. of area			=	L_2	
Platform load per bracket		F	=	fA	
Loading per bolt		Ix	=	$2\left[\frac{nb^2(n^2-1)}{12}\right]$	
		Iy	=	$n\left[\frac{mD^2(m^2-1)}{12}\right]$	
		f_x	=	$\frac{(Fl_2)(n-1)b}{2Ip}$	
		f_y	=	$\frac{F}{mn} + \frac{Fl_2D}{2Ip}$	
		f_r	=	$\sqrt{(Fx^2 + Fy^2)}$	
Moment at shell		M_1	=	L_1F	
Shear stress of clip		s_1	=	F / Ac	
Shear stress of weld clip to shell		s_2	=	$F / (2i\ f_1 \sin45^o)$	
Bending stress in bracket		f_b	=	M_1/Z_b	

Platform	Design data					
	d(mm)	r_o(mm)	F(N)	C(mm)	L_1(mm.)	L_2(mm.)
#4	305	1,400	3,891	2,440	1,040	735

Platform	Bending moment	Bending stress in bracket			Shear stress at clip		
	M_1(N-mm)	f_b(N/mm^2)	$f_b < F_B$	check	s_1 (N/mm^2)	$s_1 < S_S$	check
#4	4,046,071	35.18	YES	**Pass**	1.30	YES	**Pass**

Platform	Check bolt load							
	Ix	Iy	Ip	f_x(N)	f_y(N)	f_r(N)	$f_r < F_L$	check
#4	4,900	14,400	19,300	5,185	9,862	11,142	YES	**Pass**

Platform	Shear weld at clip		
	s_2 (N/mm^2)	$s_2 < S_S$	check
#4	1.57	YES	**Pass**

Summary load for checking local stress

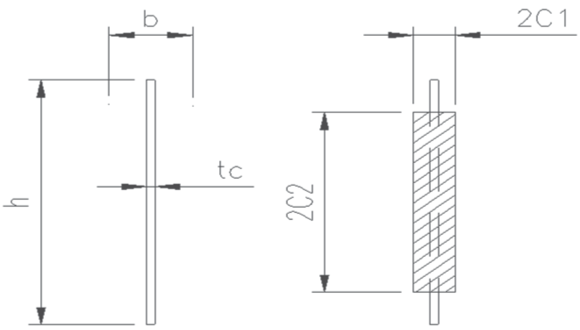
Radial load	P_r	=	0	N
Circumferential shear force	V_C	=	0	N
Circumferential moment	M_C	=	0	N-m
Maximum Longitudinal shear force	V_L	=	F	N
Maximum Longitudinal moment	M_L	=	M_1	N-m

Platform	P_r	V_C	M_C	V_L	M_L
#4	0	0	0	3,891	4,046

For worst case

Remark : Due to the programe can not calculate area cross section of attachments, so we have to convert to square section.

Refered from *" Pressure Vessel Design Manual "* by Dennis R. Moss



Platform	b	h	C1	C2	Width	Length
			0.5b	0.4h	$2C_1$	$2C_2$
	mm.	mm.	mm.	mm.	mm.	mm.
#4	54	250	27	100	54	200

* $b = t_{clip} + 2t_{weld} + 2t_{shell/skirt}$

t_{clip}	=	12	mm.
t_{weld}	=	7	mm.
t_{shell}	=	14	mm.

See calculation be designed by " COMPRESS " programe

PF clip#4

Geometry	
Height (radial)	405 mm
Width (circumferential)	54 mm
Length	200 mm
Fillet Weld Size:	7 mm
Located On	New shell (1,890 mm from bottom end)
Location Angle	0.00°

Applied Loads	
Radial load, P_r	0 kg_f
Circumferential moment, M_c	0 kg_f-m
Circumferential shear, V_c	0 kg_f
Longitudinal moment, M_L	412.6 kg_f-m
Longitudinal shear, V_L	396.77 kg_f
Torsion moment, M_t	0 kg_f-m
Internal pressure, P	3.6 bar
Mean shell radius, R_m	1,689 mm
Design factor	3

Maximum stresses due to the applied loads at the lug edge (includes pressure)

$\gamma = R_m / T = 1{,}689 / 22 = 76.7718$

$C_1 = 34$, $C_2 = 107$ mm

Local circumferential pressure stress = $P*R_i / T$ =279.962 kg_f/cm^2

Local longitudinal pressure stress = $P*R_i / (2*T)$ =139.981 kg_f/cm^2

Maximum combined stress (P_L+P_b+Q) = 804.8 kg_f/cm^2
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±4,221.62 kg_f/cm^2

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 331.85 kg_f/cm^2
Allowable local primary membrane stress (P_L) = ±1.5*S = ±2,110.81 kg_f/cm^2

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*	13.7914	0.0513	0	0	0	0	0	0	0	0
4C*	13.8559	0.0422	0	0	0	0	0	0	0	0
1C	0.2126	0.0318	0	0	0	0	0	0	0	0
2C-1	0.166	0.0318	0	0	0	0	0	0	0	0
3A*	0.9013	0.0295	0	0	0	0	0	0	0	0
1A	0.1025	0.0342	0	0	0	0	0	0	0	0
3B*	5.0859	0.0432	-51.886	-51.886	51.886	51.886	0	0	0	0
1B-1	0.0583	0.0373	-472.955	472.955	472.955	-472.955	0	0	0	0
Pressure stress*			279.962	279.962	279.962	279.962	279.962	279.962	279.962	279.962
Total circumferential stress			-244.879	701.03	804.803	-141.106	279.962	279.962	279.962	279.962
Primary membrane circumferential stress*			228.076	228.076	331.849	331.849	279.962	279.962	279.962	279.962
3C*	14.6463	0.0422	0	0	0	0	0	0	0	0
4C*	13.64	0.0513	0	0	0	0	0	0	0	0
1C-1	0.178	0.0438	0	0	0	0	0	0	0	0
2C	0.1379	0.0438	0	0	0	0	0	0	0	0
4A*	1.0665	0.0295	0	0	0	0	0	0	0	0
2A	0.0605	0.0431	0	0	0	0	0	0	0	0
4B*	1.4157	0.0432	-24.186	-24.186	24.186	24.186	0	0	0	0
2B-1	0.0923	0.0486	-575.532	575.532	575.532	-575.532	0	0	0	0
Pressure stress*			139.981	139.981	139.981	139.981	139.981	139.981	139.981	139.981
Total longitudinal stress			-459.737	691.328	739.699	-411.366	139.981	139.981	139.981	139.981
Primary membrane longitudinal stress*			115.795	115.795	164.167	164.167	139.981	139.981	139.981	139.981
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	-4.218	-4.218	4.218	4.218
Total Shear stress			0	0	0	0	-4.218	-4.218	4.218	4.218
Combined stress (P_L+P_b+Q)			-459.737	701.03	804.803	-411.366	280.103	280.103	280.103	280.103

* denotes primary stress.

Wind load design

Wind Pressure per ASCE 7-05

Wind Speed	V	=	40	m/s
Exposure Category		:	C	
Importance Factor	I	=	1.15	
Velocity pressure exposure coefficient		:	Kz	
Topographic factor , taken as 1.0	Kzt	=	1.0	
Wind directionality factor	Kd	=	0.95	
Force Coefficient	Cf	=	0.82	
Gust Effect Factor	G	=	0.85	
Vessle outside diameter	D	=	3378	mm.
Vessle height	H	=	37311.5	mm.
Velocity pressure on shell	P_{WS}	=	$0.613KzKztKdV^2I$	
Wind force	P	=	$P_{WS}GCfAe$	

1

Find effective outer diameter of vessel

effective OD. = 1.18(OD+2Insu) reference per "Pressure Vessel Design Handbook(Henry H. Bednar)"

part	ID.	thk.	Insu. Thk.	factor I	increase eff. OD.	Used OD.
	mm.	mm.	mm.		mm.	mm.
Existing Shell	3350	14	75	1.18	635.04	4163
New Shell		25			639	4189

1

Tower	Wind Height	Kz	Wind Pressure	OD	Effective area	Wind force	Shear force	Section length	Moment
*EL. Point	Above Ground								
(m)	z (m)		P_{WS} (N/m^2)	(m)	Ae (m^2)	P, (N)	F, (N)	(m)	M, (N-m)
36.30	38.8	1.36	1457	4.163	9.16	9303	9303	2.20	10233
30.2	36.6	1.31	1404	4.163	25.39	24845	34148	6.10	142758
27.1	30.5	1.26	1350	4.163	12.91	12144	46293	3.10	267441
24.1	27.4	1.24	1329	4.163	12.49	11566	57859	3.00	423667
21.0	24.4	1.21	1297	4.163	12.91	11663	69521	3.10	621106
17.7	21.3	1.17	1254	4.163	13.74	12005	81526	3.30	870333
17.5	18	1.13	1211	4.163	0.67	562	82088	0.16	883422
14.9	17.84	1.13	1211	4.189	11.06	9333	91421	2.64	1112454
14.5	15.2	1.09	1168	4.189	1.63	1330	92751	0.39	1148368
11.9	14.81	1.09	1168	4.189	10.93	8900	101651	2.61	1402063
8.8	12.2	1.04	1114	4.163	12.91	10024	111675	3.10	1732719
7.3	9.1	0.98	1050	4.163	6.24	4570	116246	1.50	1903660
5.8	7.6	0.94	1007	4.163	6.24	4384	120630	1.50	2081317
4.3	6.1	0.90	964	4.163	6.24	4197	124827	1.50	2265409
0	4.6	0.85	911	4.163	17.90	11364	136191	4.30	2826599

* Start elevation first ground EL.+300 mm.

Wind force at top column support at wind height above ground (z = 17.84m)	Pa	=	91421	N.
Moment at top column support	Ma	=	1112454	N-m.
Wind force at bottom column support	P	=	101651	N.
Overturning moment at bottom column support	Mb	=	1402063	N-m.

Column support design

--- Design Data ---

Referance "Pressure Vessel Design Handbook Second Edition, Henry H. Bednar, P.E."

Column material		:	SS400	
Column size		:	H-250 x 250 x t9 x t14	
Yield stress of material at design temp	Fy	=	240.0	N/mm^2
Modulus of elesticity	E	=	194880	N/mm^2
Weight top part (empty)	We	=	52000	kg.
Weight of top bracket	Wtb	=	1975	kg.
Weight of leg	Wl	=	3435	kg.
Weight of bottom bracket	Wbb	=	1975	kg.
Empty total load on top bracket	W_1	=	We+Wtb	
		=	53975	kg.
Empty total load on bottom bracket	W_2	=	We+Wtb+Wl+Wbb	
		=	59385	kg.
Inside redius of vessel	R	=	1675	mm.
Length of column	L	=	3030	mm.
Number of column	N	=	6	
Bolt circle diameter	Db	=	3688	mm.
Cross section area of column	A	=	15658	mm^2
Moment of inertia X-X	Ix	=	133140739	mm^4
Moment of inertia Y-Y	Iy	=	97337560	mm^4
Sumation of the moment of inertia of all culumn	ΣI	=	2Ix + 2Iy	
		=	460956598	mm^4
Minimum radius of gyration	r	=	78.8	mm.
Distance to Neutral Axis	c	=	125	mm.
Eccentric length of cl of column to shell	e	=	155	mm.
Wind force at top column support	Pa	=	91421	N.
Moment at top column support	Ma	=	1112454	N-m.
Maximum horizontal force at bottom column (wind)	P	=	101651	N.
Maximum bending moment at bottom column (wind)	Mb	=	1402063	N-m.

- Find allowable load

Coefficient for compact member	Cm	=	0.85	
Allowable compressive stress				
K- factor from AISC	K	=	1.2	
	KL / r	=	46.1	
From AISC table C-36	Fa	=	144.00	N/mm^2
Allowable bending stress	Fb	=	0.66Fy	
		=	158	N/mm^2
Euler stress divided by safty factor	Fe'	=	$\dfrac{12\pi^2 E}{23\left(\dfrac{KL}{r}\right)^2}$	
		=	472	N/mm^2

- Find maximum load on column (Top Bracket)

Empty condition	Fe	=	$(W_1 / N) + (4Ma / NDb)$	
		=	289343	N.
Lateral force per column	F	=	(P/N)Ix / ΣI	
		=	4893	N.

- Combind column stress in compression

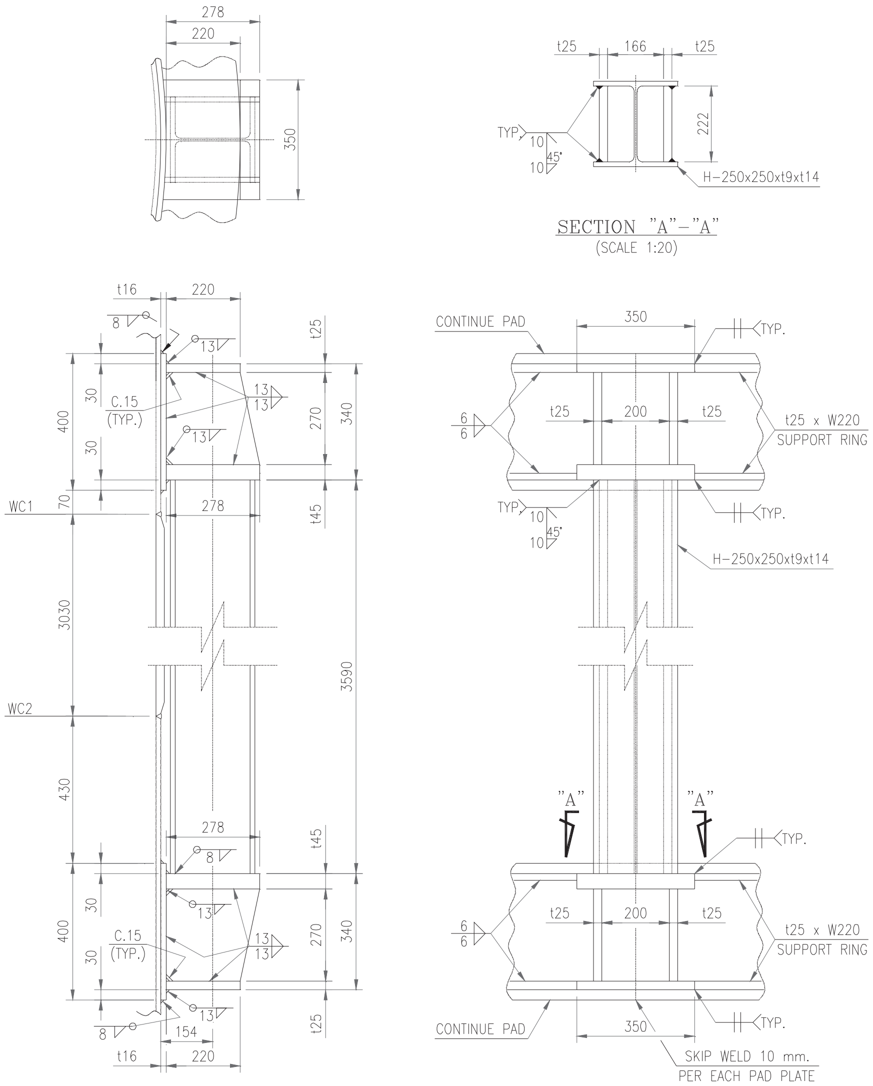
Empty condition

Bending stress	fb	=	eFe/(Ix/c)+F(3L/4)/(Ix/c)	
		=	52.5	N/mm^2
		<	Fb	**PASS**
Axial compression	fa	=	Fe / A	
		=	18.48	N/mm^2
		<	Fa	**PASS**
Combind stress	fa/Fa	=	0.128	
if fa/Fa <= 0.15, then	fa/Fa + fb/Fb	=	0.460	
if fa/Fa > 0.15, then	fa/Fa+Cmfb/[(1-fa/Fe')Fb]+fb/Fb	=	--fa/Fa <= 0.15--	
		<	1	**PASS**

Operating condition

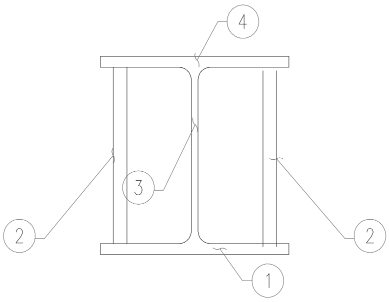
Bending stress	fb	=	eFo/(Ix/c)+F(3L/4)/(Ix/c)	
		=	39.7	N/mm^2
		<	Fb	**PASS**
Axial compression	fa	=	Fo / A	
		=	12.84	N/mm^2
		<	Fa	**PASS**
Combind stress	fa/Fa	=	0.0892	
if fa/Fa <= 0.15, then	fa/Fa + fb/Fb	=	0.340	
if fa/Fa > 0.15, then	fa/Fa+Cmfb/[(1-fa/Fe')Fb]+fb/Fb	=	--fa/Fa <= 0.15--	
		<	1	**PASS**

- Bracket load for design for operating



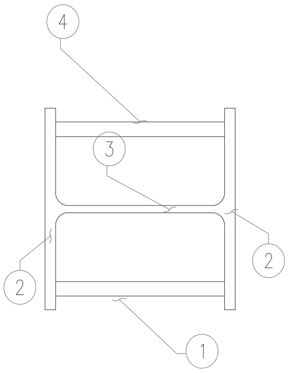
**Ring stress see report "Check Stress in Shell/Skirt and Ring Supports"

- Column property



Ix-x			
C_1	=	$\Sigma AY / \Sigma A$	
	=	125.00	mm
I_1	=	$\Sigma AY^2 + \Sigma I - C_1 \Sigma AY$	
	=	133140739.3	mm^4

Ix-x						
Item	A	Y	Y^2	AY	AY^2	I
1	3500	7	49	24500	171500	57167
2	6660	125	15625	832500	104062500	27352620
3	1998	125	15625	249750	31218750	8205786
4	3500	243	59049	850500	206671500	57167
Σ	15658			1957250	342124250	35672739



Iy-y			
C_1	=	$\Sigma AY / \Sigma A$	
	=	125.00	mm
I_1	=	$\Sigma AY^2 + \Sigma I - C_1 \Sigma AY$	
	=	97337559.83	mm^4

Iy-y						
Item	A	Y	Y^2	AY	AY^2	I
1	3330	30	870	98235	2897933	62438
2	7000	125	15625	875000	109375000	36458333
3	1998	125	15625	249750	31218750	13487
4	3330	221	48620	734265	161905433	62438
Σ	15658			1957250	305397115	36596695

- Base plate

Base plate material		:	SS400	
Allowable stress	Sb	=	114	N/mm^2
Base plate width	A	=	350	mm.
	B	=	220	mm.
Used base plate thickness	tb	=	25	mm.
Bearing pressure	f_c	=	F/AB	
		=	3.758	N/mm^2
Bending moment	M	=	$f_c A^2/10$	
		=	46031.9	N-mm
Base plate required thickness	tr	=	$\sqrt{\frac{6M}{bSb}}$	
		=	3.3	mm.
		<	tb	**PASS**

1

- Check weld

Empty condition load per support	F_1	=	Fe	=	289343	N
Empty total load on bottom bracket	F_2	=	W_2	=	582567	N
Wind force at bottom column support	F_3	=	P	=	101651	N

Shear stress of weld clip to pad

Yield stress of clip	F_Y	=	250	N/mm^2
Allowable shear stress ($0.4F_Y$)	S_S	=	100	N/mm^2
Weld size	f	=	13	mm.
Weld length	L	=	2030	mm.
Shear stress	s_{W3}	=	F_1 / (Lf Sin45^o)	
		=	15.51	N/mm^2
		<	S_S	**PASS**

Shear stress of weld pad to shell

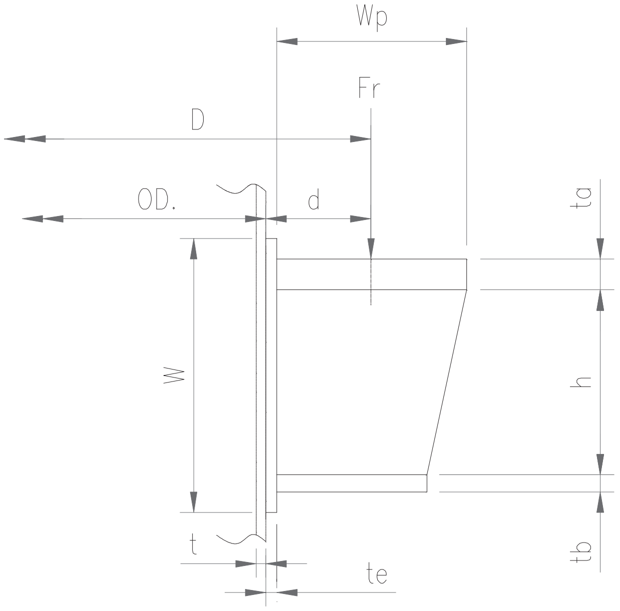
Yield stress of clip	F_Y	=	250	N/mm^2
Allowable shear stress ($0.4F_Y$)	S_S	=	100.00	N/mm^2
Weld size	f	=	8	mm.
Weld length	L	=	1700.00	mm.
Shear stress	s_{W3}	=	F_2 / (Lf Sin45^o)	
		=	60.58	N/mm^2
		<	S_S	**PASS**

Shear stress of weld leg to support

Yield stress of clip	F_Y	=	250	N/mm^2
Allowable shear stress ($0.4F_Y$)	S_S	=	100.00	N/mm^2
Weld size	f	=	8	mm.
Weld length	L	=	750.00	mm.
Shear stress	s_{W3}	=	F_3 / (Lf Sin45^o)	
		=	23.96	N/mm^2
		<	S_S	**PASS**

Check stress in shell/shell and ring supports

Refference from "PRESSURE VESSEL DESIGN HANBOOK, Second Edition, Henry H. Bednar, P.E."



Ring material		:	SS400	
Yeild stress of material	Y_S	=	240	N/mm^2
Allowable stress of material	S_b	=	114	N/mm^2
This support is attached to		:	Shell and shell	
Local shell outer diameter	OD	=	3,378	mm
Local shell thickness	t	=	14	mm
Local shell thickness	t	=	14	mm
Local shell inner corrosion	C_a	=	0	mm
Mean raduis of vessel after corroded	R_m	=	1682	mm
Shell thickness after corroded (at support lug)	t	=	11	mm
Shell thickness after corroded (at support lug)	ts	=	14	mm
Internal pressure	P	=	0	kg/cm^2
		=	0.00	N/mm^2
Vacuum pressure	P	=	0	kg/cm^2
		=	0.000	N/mm^2
Top ring width	W_p	=	278	mm
Top ring thickness	t_a	=	45	mm
Bottom ring width	b	=	220	mm
Bottom ring thickness	t_b	=	25	mm
Shell to center of load bearing area	d	=	155	mm
Gusset height	h	=	270	mm
Pad width, longitudinal direction	W	=	400	mm
Pad thickness (at shell)	t_e	=	16	mm
Pad thickness (at shell)	t_e	=	16	mm
Number of support lug	N	=	6	
Circle dimeter	D	=	3688	mm
Angular position	α	=	30	degree
Shell outside diameter + Pad	OD_P	=	3410	mm
Pad attachment fillet weld size	f_1	=	8	mm
Ring attachment fillet weld size	f_2	=	13	mm

Formular for ring design :

Stress at the support	σ	=	PR_m / t
Reaction at the support (Bednar 5.2)	F_r	=	$(4M / ND) + (W / N)$

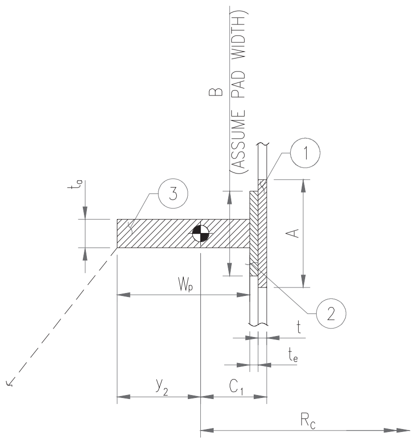
Reaction force on ring P_f acting perpendicular to the vessel longitudinal axis

	P_f	=	$F_r d / [\ h + 0.5(t_a + t_b)\ ]$
Internal moment in ring	$M_{1,2}$	=	$0.5P_f R_c\ [\ (1 / \alpha) - \text{Cot}\ \alpha\ ]$
Tension/Compression load in ring	T_1	=	$(P_f / \text{Tan}\ \alpha) / 2$
Stress in the shell top ring	S	=	$-(T_1 / A_{r1}) + (M_1 C_1 / I_1) + \sigma$
Stress in the top ring	S	=	$-(T_1 / A_{r1}) - (M_1 y_1 / I_1)$
Stress in the shell bottom ring	S	=	$(T_1 / A_{r2}) - (M_2 C_2 / I_2) + \sigma$
Stress in the bottom ring	S	=	$(T_1 / A_{r2}) + (M_2 y_2 / I_2)$
Bending moment at midpoints between loads	$M_{3,4}$	=	$0.5P_f R_c\ [\ (1/\text{Sin}\ \alpha) - (1/\alpha)]$
The axial trust loads	T_2	=	$(P_f / \text{Sin}\ \alpha\ ) / 2$
Stress between support in shell top ring	S	=	$-(T_2 / A_{r1}) - (M_3 C_1 / I_1) + \sigma$
Stress between support in top ring	S	=	$-(T_2 / A_{r1}) + (M_3 y_1 / I_1)$
Stress between support in shell bottom ring	S	=	$(T_2 / A_{r2}) + (M_4 C_2 / I_2) + \sigma$
Stress between support in bottom ring	S	=	$(T_2 / A_{r2}) - (M_4 y_2 / I_2)$
Stress at weld in pad to shell	S	=	$W / 2\pi OD f_1 \sin 45$
Stress at weld in ring to pad	S	=	$W / 4\pi OD_P f_2 \sin 45$

- Support ring at above shell

Properties of ring

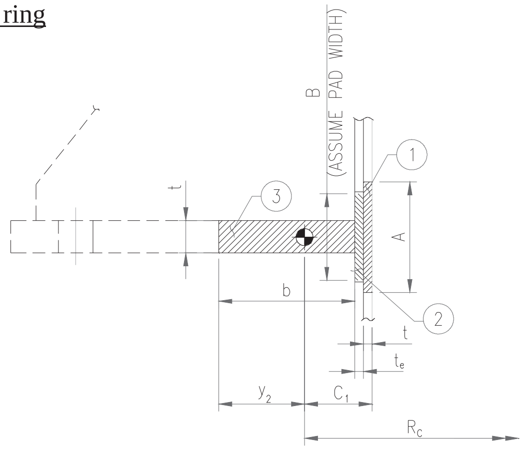
<u>Top ring</u>



A	=	$1.1(ODt)^{0.5}$	
	=	212.04	mm
B	=	400	mm
C_1	=	$\Sigma AY / \Sigma A$	
	=	104.09	mm
y_1	=	200.91	mm
R_c	=	1782.09	mm
I_1	=	$\Sigma AY^2 + \Sigma I - C_1 \Sigma AY$	
	=	197686868	mm^4

Item	A_{r1}	Y	Y^2	$A_{r1}Y$	$A_{r1}Y^2$	I
1	2332	6	30	12828	70556	23519
2	6400	19	361	121600	2310400	136533
3	12510	166	27556	2076660	344725560	80568570
Σ	21242			2211088	347106516	80728622

Bottom ring



A	=	$1.1(ODt)^{0.5}$	
	=	212.04	mm
B	=	400	mm
C_2	=	$\Sigma AY / \Sigma A$	
	=	62.39	mm
y_2	=	184.61	mm
R_c	=	1737.39	mm
I_2	=	$\Sigma AY^2 + \Sigma I - C_1 \Sigma AY$	
	=	72558096.7	mm^4

Item	A_{r2}	Y	Y^2	$A_{r2}Y$	$A_{r2}Y^2$	I
1	2332	6	30	12828	70556	23519
2	6400	19	361	121600	2310400	136533
3	5500	137	18769	753500	103229500	22183333
Σ	14232			887928	105610456	22343385

Stresses in Shell and Ring Girder Supports							
Condition	Weight Supported	Base Moment	Stress at Support	Reaction at support	Reaction force on ring	Int. moment in ring (top)	Int. moment in ring (bottom)
	W, (kg)	(N-m)	σ, (N/mm^2)	F_r, (N)	P_f, (N)	M_1, (N-mm)	M_2, (N-mm)
Empty	53975	1112454	0	289343	147043	23296857	22712495

Stresses in Shell and Ring Girder Supports							
Condition	Tension & Comp. load in ring	At Supports (S, N/mm^2)				Check, $S<1.5S_b$	The axial trust loads (top ring)
		Top Ring		Base Ring			
	T_1, (N)	In Shell	In Ring	In Shell	In Ring		M_3, (N-mm)
Empty	127343	6.3	-29.7	-10.58	66.74	Pass	11810427.9

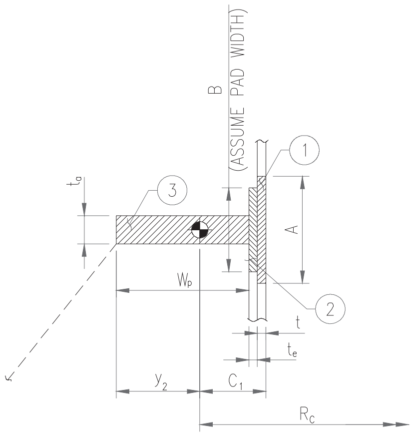
Stresses in Shell and Ring Girder Supports							
Condition	The axial trust loads (bottom ring)	Tension & Compression load in ring	Between Supports (N/mm^2)				Check, $S<1.5S_b$
			Top Ring		Base Ring		
	M_4, (N-mm)	T_2, (N)	In Shell	In Ring	In Shell	In Ring	
Empty	11514184	147043	-13.1	5.08	20.23	-18.96	Pass

Stresses in Shell and Ring Girder Supports			
Condition	Stress at weld in pad to shell	Stress at weld in ring to pad	Check, $S<0.55S_b$
	S, (N/mm^2)	S, (N/mm^2)	
Empty	4.41	1.34	Pass

- Support ring at below shell

Properties of ring

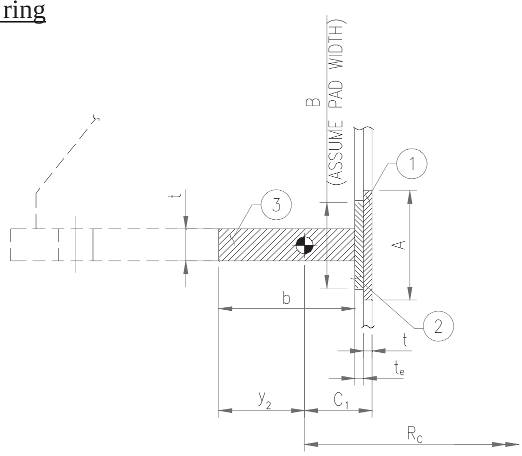
<u>Top ring</u>



A	=	$1.1(ODt)^{0.5}$	
	=	239.21	mm
B	=	400	mm
C_1	=	$\Sigma AY / \Sigma A$	
	=	102.36	mm
y_1	=	205.64	mm
R_c	=	1777.36	mm
I_1	=	$\Sigma AY^2 + \Sigma I - C_1\Sigma AY$	
	=	208098991	mm^4

Item	A_{r1}	Y	Y^2	$A_{r1}Y$	$A_{r1}Y^2$	I
1	3349	7	49.00	23443	164101	54700
2	6400	22	484	140800	3097600	136533
3	12510	169	28561	2114190	357298110	80568570
Σ	22259			2278433	360559811	80759804

<u>Bottom ring</u>



A	=	$1.1(ODt)^{0.5}$	
	=	239.21	mm
B	=	400	mm
C_2	=	$\Sigma AY / \Sigma A$	
	=	61.27	mm
y_2	=	188.73	mm
R_c	=	1736.27	mm
I_2	=	$\Sigma AY^2 + \Sigma I - C_1\Sigma AY$	
	=	76199059.8	mm^4

Item	A_{r2}	Y	Y^2	$A_{r2}Y$	$A_{r2}Y^2$	I
1	3349	7	49.00	23443	164101	54700
2	6400	22	484	140800	3097600	136533
3	5500	140	19600	770000	107800000	22183333
Σ	15249			934243	111061701	22374567

Stresses in Shell and Ring Girder Supports							
Condition	Weight Supported	Base Moment	Stress at Support	Reaction at support	Reaction force on ring	Int. moment in ring (top)	Int. moment in ring (bottom)
	W, (kg)	(N-m)	σ, (N/mm^2)	F_r, (N)	P_f, (N)	M_1, (N-mm)	M_2, (N-mm)
Empty	59385	1402063	0.00	350540	178143	28149316	27498477

Stresses in Shell and Ring Girder Supports							
Condition	Tension & Compression load in ring	At Supports (S, N/mm^2)				Check, $S<1.5S_b$	The axial trust loads (top ring)
		Top Ring		Base Ring			
	T_1, (N)	In Shell	In Ring	In Shell	In Ring		M_3, (N-mm)
Empty	154277	6.9	-34.75	-11.99	78.23	Pass	14270400

Stresses in Shell and Ring Girder Supports							
Condition	The axial trust loads (bottom ring)	Tension & Compression load in ring	Between Supports (N/mm^2)				Check, $S<1.5S_b$
			Top Ring		Base Ring		
	M_4, (N-mm)	T_2, (N)	In Shell	In Ring	In Shell	In Ring	
Empty	13940455	178143	-15.0	6.10	22.89	-22.85	Pass

Stresses in Shell and Ring Girder Supports			
Condition	Stress at weld in pad to shell	Stress at weld in ring to pad	Check, $S<0.55S_b$
	S, (N/mm^2)	S, (N/mm^2)	
Empty	4.85	1.48	Pass

Check local stress in shell at support (consider at wrost case by assume to lug support)

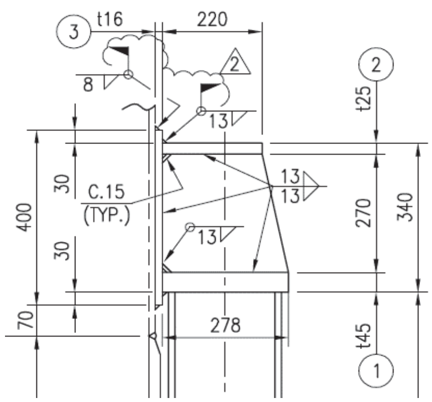
1

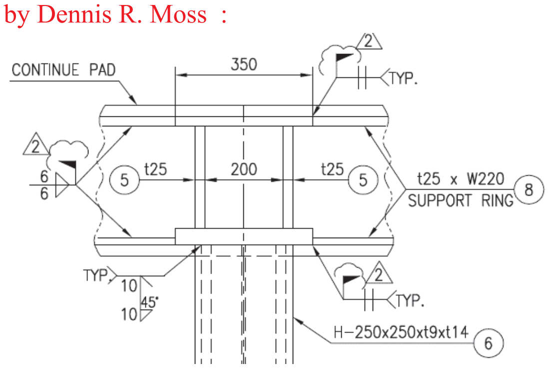
Load per column	P	=	289343	N.
Laterforce per column	F	=	4893	N.
Center of column to shell	C	=	154	mm.
Assume pad width	A	=	450	mm.
Pad length	B	=	400	mm.

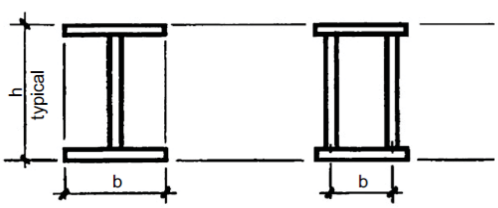
Radial load	P_r	=	F	
		=	4893	N
Circumferential shear force	V_C	=	F	
		=	4893	N
Circumferential moment	M_C	=	FC	
		=	754	N-m
Maximum Longitudinal shear force	V_L	=	P	
		=	289343	N
Maximum Longitudinal moment	M_L	=	PC	
		=	44559	N-m

Calculate area cross section of attachments, by Convert to square section.

Refered from " Pressure Vessel Design Manual " by Dennis R. Moss :







C_1	0.4b	0.5b
C_2	0.5h	0.5h

b	=	225	mm.
h	=	340	mm.
C_1	=	0.5b	
	=	113	mm
C_2	=	0.5h	
		170	mm.
Width	=	$2C_1$	
	=	225	mm.
Length	=	$2C_2$	
	=	340.0	mm.

Lug Support

Geometry	
Height (radial)	154 mm
Width (circumferential)	225 mm
Length	340 mm
Fillet Weld Size:	13 mm
Located On	Bottom existing shell (430 mm from top end)
Location Angle	0.00°
Reinforcement Pad	
Thickness	16 mm
Width	450 mm
Length	400 mm
Weld Size	8 mm

Applied Loads	
Radial load, P_r	4,893 N
Circumferential moment, M_c	754 N-m
Circumferential shear, V_c	4,893 N
Longitudinal moment, M_L	44,559 N-m
Longitudinal shear, V_L	289,342.99 N
Torsion moment, M_t	0 N-m
Internal pressure, P	0 kPa
Mean shell radius, R_m	1,683.5 mm
Design factor	3

Maximum stresses due to the applied loads at the lug edge

$\gamma = R_m / T = 1{,}683.5 / 27 = 62.3512$

$C_1 = 125.5$, $C_2 = 183$ mm

Local circumferential pressure stress = $P*R_i / T$ =0 MPa

Local longitudinal pressure stress = $P*R_i / (2*T)$ =0 MPa

Maximum combined stress (P_L+P_b+Q) = -146.34 MPa
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -37.49 MPa
Allowable local primary membrane stress (P_L) = ±1.5*S = ±207 MPa

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*	8.2251	0.1081	0	0	0	0	-0.883	-0.883	-0.883	-0.883
4C*	10.4222	0.0976	-1.124	-1.124	-1.124	-1.124	0	0	0	0
1C	0.1216	0.0855	0	0	0	0	-4.895	4.895	-4.895	4.895
2C-1	0.0867	0.0855	-3.489	3.489	-3.489	3.489	0	0	0	0
3A*	1.9603	0.0845	0	0	0	0	-0.172	-0.172	0.172	0.172
1A	0.0939	0.0916	0	0	0	0	-3.778	3.778	3.778	-3.778
3B*	6.9314	0.0959	-36.363	-36.363	36.363	36.363	0	0	0	0
1B-1	0.0431	0.0918	-102.311	102.311	102.311	-102.311	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-143.287	68.313	134.062	-63.583	-9.729	7.619	-1.827	0.407
Primary membrane circumferential stress*			-37.487	-37.487	35.239	35.239	-1.055	-1.055	-0.71	-0.71
3C*	8.734	0.0976	-0.938	-0.938	-0.938	-0.938	0	0	0	0
4C*	10.1679	0.1081	0	0	0	0	-1.096	-1.096	-1.096	-1.096
1C-1	0.1082	0.0994	-4.357	4.357	-4.357	4.357	0	0	0	0
2C	0.0723	0.0994	0	0	0	0	-2.91	2.91	-2.91	2.91
4A*	2.8731	0.0845	0	0	0	0	-0.283	-0.283	0.283	0.283
2A	0.0482	0.1044	0	0	0	0	-1.703	1.703	1.703	-1.703
4B*	2.1007	0.0959	-13.645	-13.645	13.645	13.645	0	0	0	0
2B-1	0.0604	0.1033	-127.36	127.36	127.36	-127.36	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-146.3	117.135	135.71	-110.295	-5.992	3.234	-2.02	0.393
Primary membrane longitudinal stress*			-14.582	-14.582	12.707	12.707	-1.379	-1.379	-0.814	-0.814
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0.359	0.359	-0.359	-0.359	0	0	0	0
Long shear from V_L			0	0	0	0	-14.638	-14.638	14.638	14.638
Total Shear stress			0.359	0.359	-0.359	-0.359	-14.638	-14.638	14.638	14.638
Combined stress (P_L+P_b+Q)			-146.341	117.135	135.785	-110.295	29.51	29.599	29.275	29.275
* denotes primary stress.										

Maximum stresses due to the applied loads at the pad edge

$\gamma = R_m / T = 1{,}683.5 / 11 = 153.0418$

$C_1 = 233$, $C_2 = 208$ mm

Local circumferential pressure stress = P^*R_i / T =0 MPa

Local longitudinal pressure stress = $P^*R_i / (2^*T)$ =0 MPa

Maximum combined stress (P_L+P_b+Q) = -366.75 MPa
Allowable combined stress (P_L+P_b+Q) = ±3*S = ±414 MPa

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = -143.47 MPa
Allowable local primary membrane stress (P_L) = ±1.5*S = ±207 MPa

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the pad 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*	10.8133	0.1303	0	0	0	0	-2.854	-2.854	-2.854	-2.854
4C*	18.9218	0.1343	-4.999	-4.999	-4.999	-4.999	0	0	0	0
1C	0.0647	0.1347	0	0	0	0	-15.699	15.699	-15.699	15.699
2C-1	0.0288	0.1347	-6.984	6.984	-6.984	6.984	0	0	0	0
3A*	5.7137	0.1333	0	0	0	0	-1.027	-1.027	1.027	1.027
1A	0.0657	0.1408	0	0	0	0	-10.363	10.363	10.363	-10.363
3B*	13.6696	0.1283	-138.467	-138.467	138.467	138.467	0	0	0	0
1B-1	0.0208	0.1262	-216.295	216.295	216.295	-216.295	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total circumferential stress			-366.746	79.814	342.78	-75.842	-29.944	22.18	-7.164	3.509
Primary membrane circumferential stress*			-143.466	-143.466	133.469	133.469	-3.882	-3.882	-1.827	-1.827
3C*	10.3551	0.1343	-2.737	-2.737	-2.737	-2.737	0	0	0	0
4C*	19.231	0.1303	0	0	0	0	-5.081	-5.081	-5.081	-5.081
1C-1	0.06	0.1318	-14.555	14.555	-14.555	14.555	0	0	0	0
2C	0.0389	0.1318	0	0	0	0	-9.439	9.439	-9.439	9.439
4A*	12.5208	0.1333	0	0	0	0	-2.144	-2.144	2.144	2.144
2A	0.0305	0.1415	0	0	0	0	-4.785	4.785	4.785	-4.785
4B*	5.534	0.1283	-55.048	-55.048	55.048	55.048	0	0	0	0
2B-1	0.0264	0.1318	-262.938	262.938	262.938	-262.938	0	0	0	0
Pressure stress*			0	0	0	0	0	0	0	0
Total longitudinal stress			-335.278	219.708	300.694	-196.073	-21.45	6.998	-7.591	1.717
Primary membrane longitudinal stress*			-57.785	-57.785	52.311	52.311	-7.226	-7.226	-2.937	-2.937
Shear from M_t			0	0	0	0	0	0	0	0
Circ shear from V_c			0.476	0.476	-0.476	-0.476	0	0	0	0
Long shear from V_L			0	0	0	0	-31.612	-31.612	31.612	31.612
Total Shear stress			0.476	0.476	-0.476	-0.476	-31.612	-31.612	31.612	31.612
Combined stress (P_L+P_b+Q)			-366.753	219.708	342.787	-196.073	63.79	65.024	63.225	63.253

* denotes primary stress.