Pressure Vessel Engineering

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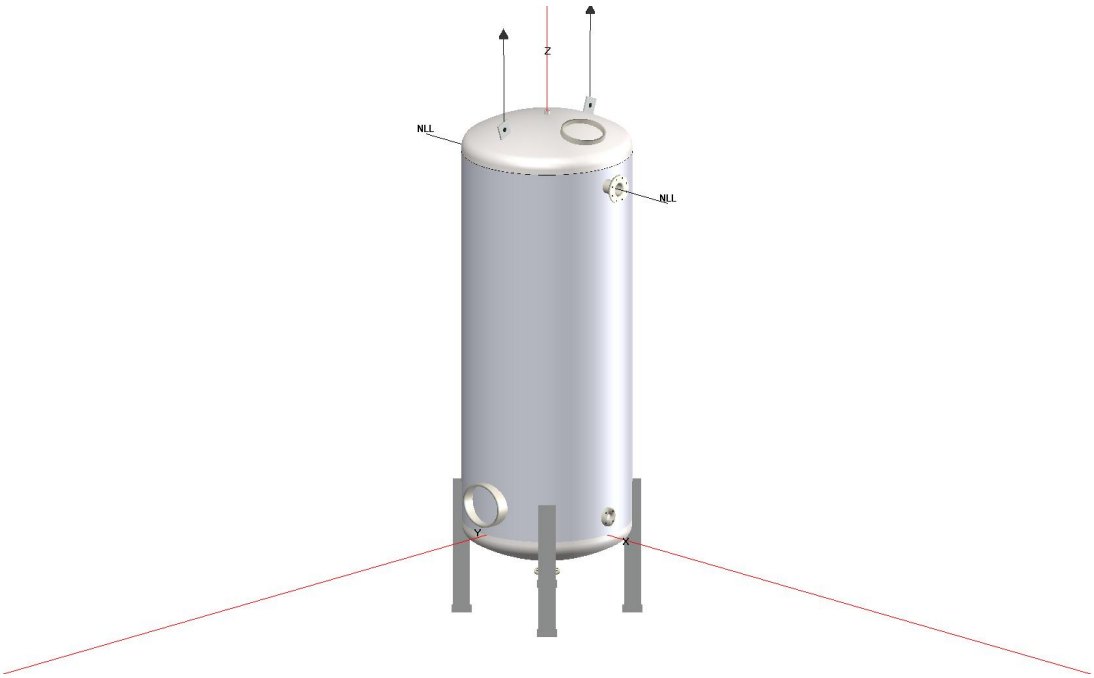

COMPRESS Pressure Vessel Design Calculations

Item: Compress Sample

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Settings Summary

COMPRESS 2012 Build 7200

Units: U.S. Customary

Datum Line Location: 0.00" from bottom seam

Design

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Design or Rating:	Get Thickness from Pressure
Minimum thickness:	0.0938" per UG-16(b)
Design for cold shut down only:	No
Design for lethal service (full radiography required):	No
Design nozzles for:	Design P only
Corrosion weight loss:	100% of theoretical loss
UG-23 Stress Increase:	1.20
Skirt/legs stress increase:	1.0
Minimum nozzle projection:	1"
Juncture calculations for $\alpha > 30$ only:	No
Preheat P-No 1 Materials > 1.25&#34 and <= 1.50" thick:	No
UG-37(a) shell tr calculation considers longitudinal stress:	No

Butt welds are tapered per Figure UCS-66.3(a).

Hydro/Pneumatic Test

Shop Hydrotest Pressure:	1.3 times vessel MAWP
Test liquid specific gravity:	1.00
Maximum stress during test:	90% of yield

Required Marking - UG-116

UG-116(e) Radiography:	RT4
UG-116(f) Postweld heat treatment:	None

Code Cases\Interpretations

Use Code Case 2547:	No
Apply interpretation VIII-1-83-66:	Yes
Apply interpretation VIII-1-86-175:	Yes
Apply interpretation VIII-1-83-115:	Yes
Apply interpretation VIII-1-01-37:	Yes
No UCS-66.1 MDMT reduction:	Yes
No UCS-68(c) MDMT reduction:	Yes
Disallow UG-20(f) exemptions:	No

UG-22 Loadings

UG-22(a) Internal or External Design Pressure :	Yes
UG-22(b) Weight of the vessel and normal contents under operating or test conditions:	Yes
UG-22(c) Superimposed static reactions from weight of attached equipment (external loads):	No
UG-22(d)(2) Vessel supports such as lugs, rings, skirts, saddles and legs:	Yes
UG-22(f) Wind reactions:	No
UG-22(f) Seismic reactions:	Yes
UG-22(j) Test pressure and coincident static head acting during the test:	Yes

Note: UG-22(b),(c) and (f) loads only considered when supports are present.

Nozzle Schedule

Nozzle mark	Service	Size	Materials								
			Nozzle	Impact	Norm	Fine Grain	Pad	Impact	Norm	Fine Grain	Flange
M1	Manway, Top	16" x 12" Elliptical Nozzle	SA-106 B Smls pipe	No	No	No	N/A	N/A	N/A	N/A	N/A
M2	Manway, Shell	16" x 12" Elliptical Nozzle	SA-106 B Smls pipe	No	No	No	N/A	N/A	N/A	N/A	N/A
N1	Inlet	NPS 4 Sch 160	SA-106 B Smls pipe	No	No	No	N/A	N/A	N/A	N/A	SO A105 Class 150
N2	Outlet/Drain	NPS 4 Sch 160	SA-106 B Smls pipe	No	No	No	N/A	N/A	N/A	N/A	SO A105 Class 150
N3	Vent	NPS 1 Class 6000 - threaded	SA-105	No	No	No	N/A	N/A	N/A	N/A	N/A
N4, N5	Process	2.44 IDx1.78	SA-240 316	No	No	No	N/A	N/A	N/A	N/A	N/A

Nozzle Summary

Nozzle mark	OD (in)	t_n (in)	Req t_n (in)	A_1?	A_2?	Shell			Reinforcement Pad		Corr (in)	A_a/A_r (%)
						Nom t (in)	Design t (in)	User t (in)	Width (in)	t_{pad} (in)		
M1	18	1	0.0806	Yes	Yes	0.68*	0.2269		N/A	N/A	0	197.0
M2	18	1	0.0829	Yes	Yes	0.5	0.2304		N/A	N/A	0	238.7
N1	4.5	0.531	0.237	Yes	Yes	0.5	N/A		N/A	N/A	0	Exempt
N2	4.5	0.531	0.237	Yes	Yes	0.68*	N/A		N/A	N/A	0	Exempt
N3	2.25	0.4675	0.0938	Yes	Yes	0.68*	N/A		N/A	N/A	0	Exempt
N4, N5	6	1.78	0.2302	Yes	Yes	0.5	N/A		N/A	N/A	0	Exempt

t_n: Nozzle thickness
Req t_n: Nozzle thickness required per UG-45/UG-16
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
* Head minimum thickness after forming

Pressure Summary

Pressure Summary for Chamber bounded by Head, Bottom and Head, Top

Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MDMT (°F)	MDMT Exemption		Impact Tested
Head, Top	150	120	217.35	-20	Note 1		No
Straight Flange on Head, Top	150	120	429.29	-20	Note 2		No
Shell	150	120	230.78	-20	Note 2		No
Straight Flange on Head, Bottom	150	120	425.12	-20	Note 2		No
Head, Bottom	150	120	212.82	-20	Note 3		No
Legs	150	120	150	N/A	N/A		N/A
Manway, Top (M1)	150	120	150	-20	Note 4		No
Manway, Shell (M2)	150	120	150	-20	Note 5		No
Inlet (N1)	150	120	150	-20	Note 6		No
Outlet/Drain (N2)	150	120	150	-20	Note 6		No
Vent (N3)	150	120	150	-20	Note 7		No
Process (N4, N5)	150	120	150	-320	Nozzle	N/A	No
					Pad	Note 8	No

Chamber design MDMT is -20 °F
Chamber rated MDMT is -20 °F @ 150 psi

Chamber MAWP hot & corroded is 150 psi @ 120 °F

This pressure chamber is not designed for external pressure.

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.

Notes for MDMT Rating:

Note #	Exemption	Details
1.	Straight Flange governs MDMT	
2.	Material is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.5 in
3.	Straight Flange governs MDMT	
4.	Nozzle is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.68 in.
5.	Nozzle is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.5 in.
6.	Nozzle is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.4646 in.
7.	Nozzle is impact test exempt per UG-20(f)	UCS-66 governing thickness = 0.4675 in.
8.	Rated MDMT per UHA-51(d)(1)(a) = -320 °F	

Design notes are available on the Settings Summary page.

Thickness Summary

Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Head, Top	SA-516 70	60 OD	10.486	0.68*	0.4708	0	0.85	Internal
Straight Flange on Head, Top	SA-516 70	60 OD	1.5	0.75	0.2638	0	0.85	Internal
Shell	SA-516 70	60 OD	120	0.5	0.3288	0	0.70	Internal
Straight Flange on Head, Bottom	SA-516 70	60 OD	1.5	0.75	0.2711	0	0.85	Internal
Head, Bottom	SA-516 70	60 OD	10.486	0.68*	0.4849	0	0.85	Internal

Nominal t: Vessel wall nominal thickness

Design t: Required vessel thickness due to governing loading + corrosion

Joint E: Longitudinal seam joint efficiency

* Head minimum thickness after forming

Load

internal: Circumferential stress due to internal pressure governs

external: External pressure governs

Wind: Combined longitudinal stress of pressure + weight + wind governs

Seismic: Combined longitudinal stress of pressure + weight + seismic governs

Weight Summary

Component	Weight (lb) Contributed by Vessel Elements										Surface Area ft²
	Metal New*	Metal Corroded*	Insulation	Insulation Supports	Lining	Piping + Liquid	Operating Liquid		Test Liquid		
							New	Corroded	New	Corroded	
Head, Top	656	656	0	0	0	0	0	0	737.1	737.1	25
Shell	3,139.7	3,139.7	0	0	0	0	11,265.9	11,265.9	11,858.9	11,858.9	155
Head, Bottom	691.8	691.8	0	0	0	0	734.4	734.4	734.4	734.4	26
Legs	252.2	252.2	0	0	0	0	0	0	0	0	43
TOTAL:	**4,739.8**	**4,739.8**	**0**	**0**	**0**	**0**	**12,000.2**	**12,000.2**	**13,330.4**	**13,330.4**	**249**

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

Component	Weight (lb) Contributed by Attachments										Surface Area ft²
	Body Flanges		Nozzles & Flanges		Packed Beds	Ladders & Platforms	Trays	Tray Supports	Rings & Clips	Vertical Loads	
	New	Corroded	New	Corroded							
Head, Top	0	0	43.2	43.2	0	0	0	0	6.8	0	1
Shell	0	0	77.1	77.1	0	0	0	0	0	0	2
Head, Bottom	0	0	24.5	24.5	0	0	0	0	0	0	1
Legs	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	**0**	**0**	**144.8**	**144.8**	**0**	**0**	**0**	**0**	**6.8**	**0**	**4**

Vessel operating weight, Corroded:	16,892 lb
Vessel operating weight, New:	16,892 lb
Vessel empty weight, Corroded:	4,891 lb
Vessel empty weight, New:	4,891 lb
Vessel test weight, New:	18,222 lb
Vessel test weight, Corroded:	18,222 lb
Vessel surface area:	253 ft²

Vessel center of gravity location - from datum - lift condition

Vessel Lift Weight, New:	4,891 lb
Center of Gravity:	56.2798"

Vessel Capacity

Vessel Capacity** (New):	1,596 US gal
Vessel Capacity** (Corroded):	1,596 US gal

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

Shop test pressure determination for Chamber bounded by Head, Bottom and Head, Top based on MAWP per UG-99(b)

Shop hydrostatic test gauge pressure is 195 psi at 70 °F (the chamber MAWP = 150 psi)

The shop test is performed with the vessel in the horizontal position.

Identifier	Local test pressure psi	Test liquid static head psi	UG-99(b) stress ratio	UG-99(b) pressure factor	Stress during test psi	Allowable test stress psi	Stress excessive?
Head, Top (1)	197.358	2.358	1	1.30	8,707	34,200	No
Straight Flange on Head, Top	197.355	2.355	1	1.30	7,795	34,200	No
Shell	197.364	2.364	1	1.30	11,743	34,200	No
Straight Flange on Head, Bottom	197.355	2.355	1	1.30	7,795	34,200	No
Head, Bottom	197.358	2.358	1	1.30	8,707	34,200	No
Inlet (N1)	195.217	0.217	1	1.30	14,130	51,300	No
Manway, Shell (M2)	196.588	1.588	1	1.30	11,599	51,300	No
Manway, Top (M1)	195.65	0.65	1	1.30	26,681	51,300	No
Outlet/Drain (N2)	196.362	1.362	1	1.30	10,266	51,300	No
Process (N4, N5)	195.217	0.217	1	1.30	5,060	51,300	No
Vent (N3)	196.323	1.323	1	1.30	8,926	51,300	No

Notes:
(1) Head, Top limits the UG-99(b) stress ratio.
(2) P_L stresses at nozzle openings have been estimated using the method described in PVP-Vol. 399, pages 77-82.
(3) $1.5*0.9*S_y$ used as the basis for the maximum local primary membrane stress at the nozzle intersection P_L.
(4) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The field test condition has not been investigated for the Chamber bounded by Head, Bottom and Head, Top.

The test temperature of 70 °F is warmer than the minimum recommended temperature of 10 °F so the brittle fracture provision of UG-99(h) has been met.

Commentary for Head, Bottom

Commentary for Head, Bottom:
Top and Bottom head are Post Formed Heat Treated per UCS-79(d)
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Head, Top

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Component:	F&D Head
Material Specification:	SA-516 70 (II-D p.18, ln. 19)

Straight Flange governs MDMT

Internal design pressure: P = 150 psi @ 120 °F

Static liquid head:

P_s= 0 psi (SG=1, H_s=0" Operating head)
P_{th}= 2.36 psi (SG=1, H_s=65.32" Horizontal test head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F
Rated MDMT = -20°F

No impact test performed
Material is not normalized
Material is not produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

Radiography:	Category A joints -	Seamless No RT
	Head to shell seam -	None UW-11(c) Type 1

Estimated weight*:	new = 656 lb	corr = 656 lb
Capacity*:	new = 87.9 US gal	corr = 87.9 US gal

* includes straight flange

Outer diameter	=	60"
Crown radius L	=	60"
Knuckle radius r	=	3.6"
Minimum head thickness	=	0.68"
Straight flange length L_{sf}	=	1.5"
Nominal straight flange thickness t_{sf}	=	0.75"

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	0.0938" + 0" = 0.0938"
Design thickness due to internal pressure (t)	=	0.4708"
Maximum allowable working pressure (MAWP)	=	217.35 psi

M (Corroded)

$M=1/4*[3 + (L / r)^{1/2}]=1/4*[3 + (60 / 3.6)^{1/2}]=1.770621$

M (New)

$M=1/4*[3 + (L / r)^{1/2}]=1/4*[3 + (60 / 3.6)^{1/2}]=1.770621$

Design thickness for internal pressure, (Corroded at 120 °F) Appendix 1-4(d)

$t = P*L_o*M / (2*S*E + P*(M - 0.2)) + Corrosion$

= 150*60.68*1.7706 / (2*20,000*0.85 + 150*(1.7706 - 0.2)) + 0
= 0.4707"

The head internal pressure design thickness is 0.4708".

Maximum allowable working pressure, (Corroded at 120 °F) Appendix 1-4(d)

$P = 2*S*E*t / (M*L_o - t*(M - 0.2)) - P_s$
= 2*20,000*0.85*0.68 / (1.7706*60.68 - 0.68*(1.7706 - 0.2)) - 0
= 217.35 psi

The maximum allowable working pressure (MAWP) is 217.35 psi.

% Extreme fiber elongation - UCS-79(d)

$EFE = (75*t / R_f)*(1 - R_f / R_o)$
= (75*0.75 / 3.975)*(1 - 3.975 / ∞)
= 14.1509%

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

Straight Flange on Head, Top

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Component: Straight Flange
Material specification: SA-516 70 (II-D p. 18, ln. 19)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 0.5 in

Internal design pressure: P = 150 psi @ 120 °F

Static liquid head:

P_s = 0 psi (SG = 1, H_s = 0",Operating head)
P_{th} = 2.36 psi (SG = 1, H_s = 65.25", Horizontal test head)

Corrosion allowance Inner C = 0" Outer C = 0"

Design MDMT = -20 °F No impact test performed
Rated MDMT = -20 °F Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
Circumferential joint - None UW-11(c) Type 1

Estimated weight	New = 59.3 lb	corr = 59.3 lb
Capacity	New = 17.45 US gal	corr = 17.45 US gal

OD = 60"
Length L_c = 1.5"
t = 0.75"

Design thickness, (at 120 °F) Appendix 1-1

t = $P*R_o / (S*E + 0.40*P)$ + Corrosion
= 150*30 / (20,000*0.85 + 0.40*150) + 0
= 0.2638"

Maximum allowable working pressure, (at 120 °F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t) - P_s$
= 20,000*0.85*0.75 / (30 - 0.40*0.75) - 0
= 429.29 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*0.75 / 29.625)*(1 - 29.625 / \infty)$
= 1.2658%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.2638"

The governing condition is due to internal pressure.

The cylinder thickness of 0.75" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	150	20,000	16,284	120	0	Seismic	0.1303	0.1301
Operating, Hot & New	150	20,000	16,284	120	0	Seismic	0.1303	0.1301
Hot Shut Down, Corroded	0	20,000	16,284	120	0	Seismic	0.0001	0.0003
Hot Shut Down, New	0	20,000	16,284	120	0	Seismic	0.0001	0.0003
Empty, Corroded	0	20,000	16,284	70	0	Seismic	0.0001	0.0002
Empty, New	0	20,000	16,284	70	0	Seismic	0.0001	0.0002
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	20,000	16,284	120	0	Weight	0.0002	0.0002

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Component: Cylinder
Material specification: SA-516 70 (II-D p. 18, ln. 19)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 0.5 in

Internal design pressure: P = 150 psi @ 120 °F

Static liquid head:

P_s = 4.12 psi (SG = 1, H_s = 114",Operating head)
P_{th} = 2.36 psi (SG = 1, H_s = 65.5", Horizontal test head)

Corrosion allowance Inner C = 0" Outer C = 0"

Design MDMT = -20 °F
Rated MDMT = -20 °F

No impact test performed
Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Longitudinal joint - None UW-11(c) Type 1
Top circumferential joint - None UW-11(c) Type 1
Bottom circumferential joint - None UW-11(c) Type 1

Estimated weight	New = 3,139.7 lb	corr = 3,139.7 lb
Capacity	New = 1,420.24 US gal	corr = 1,420.24 US gal

OD = 60"
Length L_c = 120"
t = 0.5"

Design thickness, (at 120 °F) Appendix 1-1

$t = P*R_o / (S*E + 0.40*P) + Corrosion$
$= 154.12*30 / (20,000*0.70 + 0.40*154.12) + 0$
$= 0.3288"$

Maximum allowable working pressure, (at 120 °F) Appendix 1-1

$P = S*E*t / (R_o - 0.40*t) - P_s$
$= 20,000*0.70*0.5 / (30 - 0.40*0.5) - 4.12$
$= 230.78$ psi

% Extreme fiber elongation - UCS-79(d)

$EFE = (50*t / R_f)*(1 - R_f / R_o)$
$= (50*0.5 / 29.75)*(1 - 29.75 / \infty)$
$= 0.8403\%$

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.3288"

The governing condition is due to internal pressure.

The cylinder thickness of 0.5" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Location	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c						
Operating, Hot & Corroded	150	20,000	15,117	120	0	Top	Seismic	0.0954	0.0873
						Bottom	Seismic	0.0952	0.0935
Operating, Hot & New	150	20,000	15,117	120	0	Top	Seismic	0.0954	0.0873
						Bottom	Seismic	0.0952	0.0935
Hot Shut Down, Corroded	0	20,000	15,117	120	0	Top	Seismic	0.0033	0.0063
						Bottom	Seismic	0.0031	0.0015
Hot Shut Down, New	0	20,000	15,117	120	0	Top	Seismic	0.0033	0.0063
						Bottom	Seismic	0.0031	0.0015
Empty, Corroded	0	20,000	15,117	70	0	Top	Seismic	0.0003	0.0023
						Bottom	Seismic	0.0002	0.0001
Empty, New	0	20,000	15,117	70	0	Top	Seismic	0.0003	0.0023
						Bottom	Seismic	0.0002	0.0001
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	20,000	15,117	120	0	Top	Weight	0.0013	0.0014
						Bottom	Weight	0.0034	0.0034

Inlet (N1)

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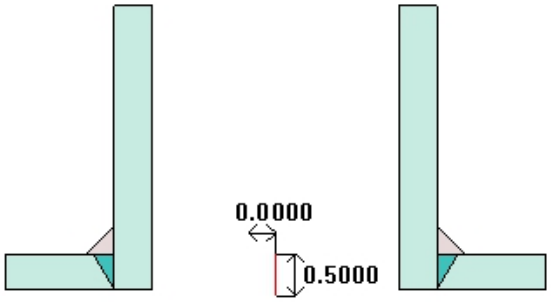
$t_{w(lower)}$ = 0.5 in
Leg_{41} = 0.375 in



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

Located on:	Shell
Liquid static head included:	0.0621 psi
Nozzle material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 4 Sch 160
Flange description:	NPS 4 Class 150 SO A105
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Flange rated MDMT: (UCS-66(b)(1)(b))	-20°F
Liquid static head on flange:	0 psi
ASME B16.5-2009 flange rating MAWP:	280 psi @ 120°F
ASME B16.5-2009 flange rating MAP:	285 psi @ 70°F
ASME B16.5-2009 flange hydro test:	450 psi @ 70°F
Flange external fillet weld leg (UW-21):	0.37 in (0.37 in min)
Flange internal fillet weld leg (UW-21):	0.25 in (0.25 in min)
PWHT performed:	No
Nozzle orientation:	0°
Local vessel minimum thickness:	0.5 in
User input radial limit of reinforcement:	6 in
Nozzle center line offset to datum line:	114 in
End of nozzle to shell center:	36 in
Nozzle inside diameter, new:	3.438 in
Nozzle nominal wall thickness:	0.531 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.469 in
Projection available outside vessel to flange face, Lf:	6 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 150.06 psi @ 120 °F							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2074	0.4646

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

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

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

Outlet/Drain (N2)

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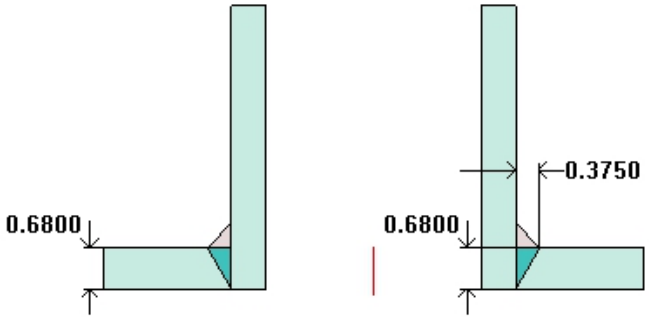
$t_{w(lower)}$ = 0.68 in
Leg_{41} = 0.375 in



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

Located on:	Head, Bottom
Liquid static head included:	4.7383 psi
Nozzle material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 4 Sch 160
Flange description:	NPS 4 Class 150 SO A105
Bolt Material:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Flange rated MDMT: (UCS-66(b)(1)(b))	-20°F
Liquid static head on flange:	4.7628 psi
ASME B16.5-2009 flange rating MAWP:	280 psi @ 120°F
ASME B16.5-2009 flange rating MAP:	285 psi @ 70°F
ASME B16.5-2009 flange hydro test:	450 psi @ 70°F
Flange external fillet weld leg (UW-21):	0.37 in (0.37 in min)
Flange internal fillet weld leg (UW-21):	0.25 in (0.25 in min)
PWHT performed:	No
Nozzle orientation:	0°
Calculated as hillside:	No
Local vessel minimum thickness:	0.68 in
End of nozzle to datum line:	-17.9442 in
Nozzle inside diameter, new:	3.438 in
Nozzle nominal wall thickness:	0.531 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	5.469 in
Projection available outside vessel to flange face, Lf:	6 in
Distance to head center, R:	0 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 154.74 psi @ 120 °F							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2074	0.4646

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

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

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

Vent (N3)

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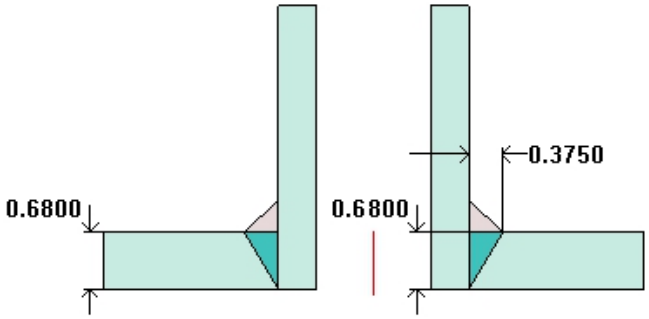
$t_{w(lower)}$ = 0.68 in
Leg_{41} = 0.375 in



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

Located on:	Head, Top
Liquid static head included:	0 psi
Nozzle material specification:	SA-105 (II-D p. 18, ln. 5)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	NPS 1 Class 6000 - threaded
Nozzle orientation:	0°
Calculated as hillside:	No
Local vessel minimum thickness:	0.68 in
End of nozzle to datum line:	132.9755 in
Nozzle inside diameter, new:	1.315 in
Nozzle nominal wall thickness:	0.4675 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	1 in
Distance to head center, R:	0 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 150 psi @ 120 °F							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.0938	0.4675

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

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

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

Process (N4, N5)

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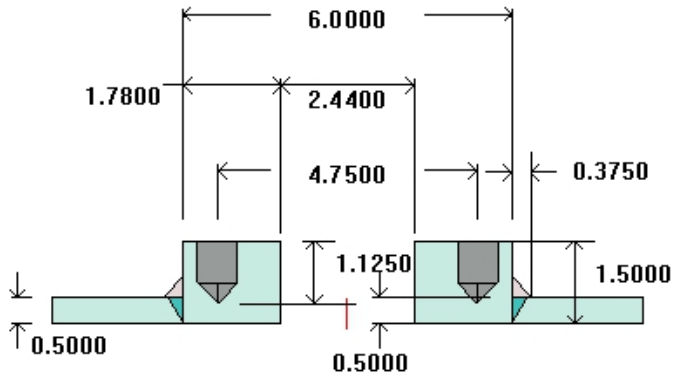

Pad inner diameter =	2.44 in
Pad thickness =	1.5 in
Tapped hole diameter =	0.75 in
Tapped hole depth =	1.125 in
Tapped hole bolt circle =	4.75 in
Raised face height =	0 in
Raised face outer diameter =	5.4725 in
Inner fillet =	0.375 in
$t_{w(lower)}$ =	0.5 in
D_p =	6 in
t_e =	1 in

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

Note: Thread engagement shall comply with the requirements of UG-43(g).

Located on:	Shell
Liquid static head included:	3.9425 psi
Nozzle material specification:	SA-240 316 (II-D p. 70, ln. 26)
Bolt material specification:	SA-193 B7 Bolt <= 2 1/2 (II-D p. 334, ln. 32)
Nozzle longitudinal joint efficiency:	1
Nozzle orientation:	0°
Local vessel minimum thickness:	0.5 in
Nozzle center line offset to datum line:	6 in
End of nozzle to shell center:	31 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	1 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 153.94 psi @ 120 °F							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
This nozzle is exempt from area calculations per UG-36(c)(3)(a)							0.2302	1.78

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

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

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

Manway, Top (M1)

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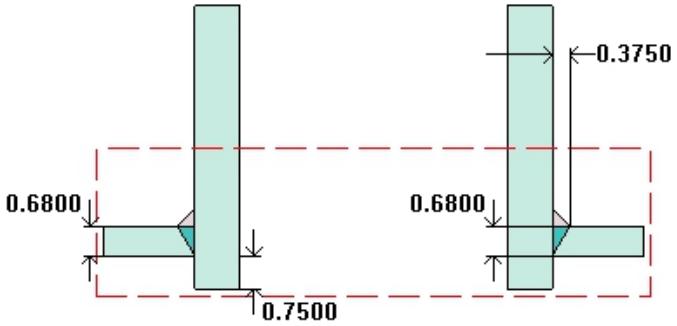

$t_{w(lower)}$ = 0.68 in
Leg_{41} = 0.375 in
Leg_{43} = 0 in
h_{new} = 0.75 in

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

Located on:	Head, Top
Liquid static head included:	0 psi
Nozzle material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	16" x 12" Elliptical Nozzle
Elliptical manway pressure rating:	300 psi @ 650 °F
Nozzle orientation:	0°
Calculated as hillside:	No
Local vessel minimum thickness:	0.68 in
User input radial limit of reinforcement:	12 in
End of nozzle to datum line:	130.0463 in
Nozzle inside diameter, new:	16 in
Nozzle nominal wall thickness:	1 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	1.5 in
Internal projection, h_{new}:	0.75 in
Distance to head center, R:	18 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 150 psi @ 120 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
3.6957	7.2805	3.4936	2.3842	1.2825	--	0.1202	0.0705	0.875

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

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

Manway, Shell (M2)

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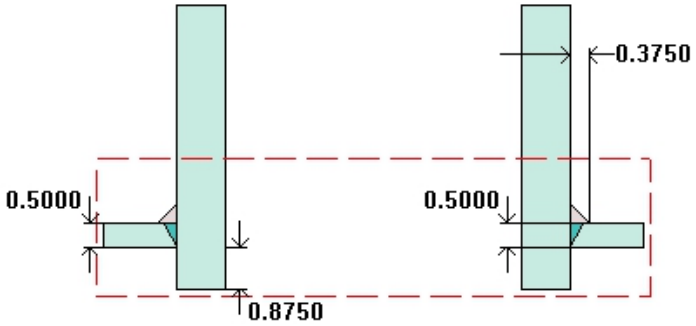

$t_{w(lower)}$ = 0.5 in
Leg_{41} = 0.375 in
Leg_{43} = 0 in
h_{new} = 0.875 in

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

Located on:	Shell
Liquid static head included:	4.0429 psi
Nozzle material specification:	SA-106 B Smls pipe (II-D p. 10, ln. 40)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	16" x 12" Elliptical Nozzle
Elliptical manway pressure rating:	300 psi @ 650 °F
Nozzle orientation:	90°
Local vessel minimum thickness:	0.5 in
Nozzle center line offset to datum line:	10 in
End of nozzle to shell center:	32.625 in
Nozzle inside diameter, new:	16 in
Nozzle nominal wall thickness:	1 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	2.625 in
Internal projection, h_{new}:	0.875 in

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 154.04 psi @ 120 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
1.8762	9.6446	6.0456	1.9825	1.4963	--	0.1202	0.0725	0.875

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

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

Reinforcement check in the plane parallel to the longitudinal axis

Reinforcement Calculations for Internal Pressure

UG-37 Area Calculation Summary (in^2) For P = 154.04 psi @ 120 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
A required	A available	A_1	A_2	A_3	A_5	A welds	t_{req}	t_{min}
2.831	6.7566	3.1576	1.9825	1.4963	--	0.1202	0.0725	0.875

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

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

Straight Flange on Head, Bottom

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Component: Straight Flange
Material specification: SA-516 70 (II-D p. 18, ln. 19)
Material is impact test exempt per UG-20(f)
UCS-66 governing thickness = 0.5 in

Internal design pressure: P = 150 psi @ 120 °F

Static liquid head:

P_s = 4.17 psi (SG = 1, H_s = 115.5",Operating head)
P_{th} = 2.36 psi (SG = 1, H_s = 65.25", Horizontal test head)

Corrosion allowance Inner C = 0" Outer C = 0"

Design MDMT = -20 °F
Rated MDMT = -20 °F

No impact test performed
Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Longitudinal joint - Seamless No RT
Circumferential joint - None UW-11(c) Type 1

Estimated weight	New = 59.3 lb	corr = 59.3 lb
Capacity	New = 17.45 US gal	corr = 17.45 US gal

OD = 60"
Length L_c = 1.5"
t = 0.75"

Design thickness, (at 120 °F) Appendix 1-1

t = $P*R_o$ / (S*E + 0.40*P) + Corrosion
= 154.17*30 / (20,000*0.85 + 0.40*154.17) + 0
= 0.2711"

Maximum allowable working pressure, (at 120 °F) Appendix 1-1

P = $S*E*t / (R_o - 0.40*t) - P_s$
= 20,000*0.85*0.75 / (30 - 0.40*0.75) - 4.17
= 425.12 psi

% Extreme fiber elongation - UCS-79(d)

EFE = $(50*t / R_f)*(1 - R_f / R_o)$
= $(50*0.75 / 29.625)*(1 - 29.625 / \infty)$
= 1.2658%

The extreme fiber elongation does not exceed 5%.

Design thickness = 0.2711"

The governing condition is due to internal pressure.

The cylinder thickness of 0.75" is adequate.

Thickness Required Due to Pressure + External Loads

Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	150	20,000	16,284	120	0	Seismic	0.1347	0.1324
Operating, Hot & New	150	20,000	16,284	120	0	Seismic	0.1347	0.1324
Hot Shut Down, Corroded	0	20,000	16,284	120	0	Seismic	0.0044	0.0021
Hot Shut Down, New	0	20,000	16,284	120	0	Seismic	0.0044	0.0021
Empty, Corroded	0	20,000	16,284	70	0	Seismic	0.0003	0.0001
Empty, New	0	20,000	16,284	70	0	Seismic	0.0003	0.0001
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	20,000	16,284	120	0	Weight	0.0048	0.0048

Head, Bottom

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Component: F&D Head
Material Specification: SA-516 70 (II-D p.18, ln. 19)
Straight Flange governs MDMT

Internal design pressure: P = 150 psi @ 120 °F

Static liquid head:

P_s= 4.52 psi (SG=1, H_s=125.306" Operating head)
P_{th}= 2.36 psi (SG=1, H_s=65.32" Horizontal test head)

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20°F
Rated MDMT = -20°F

No impact test performed
Material is not normalized
Material is not produced to fine grain practice
PWHT is not performed
Do not Optimize MDMT / Find MAWP

Radiography: Category A joints - Seamless No RT
Head to shell seam - None UW-11(c) Type 1

Estimated weight*: new = 691.8 lb corr = 691.8 lb
Capacity*: new = 87.9 US gal corr = 87.9 US gal
* includes straight flange

Outer diameter	=	60"
Crown radius L	=	60"
Knuckle radius r	=	3.6"
Minimum head thickness	=	0.68"
Straight flange length L_{sf}	=	1.5"
Nominal straight flange thickness t_{sf}	=	0.75"

See Component Commentary

Results Summary

The governing condition is internal pressure.

Minimum thickness per UG-16	=	0.0938" + 0" = 0.0938"
Design thickness due to internal pressure (t)	=	0.4849"
Maximum allowable working pressure (MAWP)	=	212.82 psi

M (Corroded)

$M=1/4*[3 + (L / r)^{1/2}]=1/4*[3 + (60 / 3.6)^{1/2}]=1.770621$

M (New)

$M=1/4*[3 + (L / r)^{1/2}]=1/4*[3 + (60 / 3.6)^{1/2}]=1.770621$

Design thickness for internal pressure, (Corroded at 120 °F) Appendix 1-4(d)

$t = P*L_o*M / (2*S*E + P*(M - 0.2)) + Corrosion$
$= 154.52*60.68*1.7706 / (2*20,000*0.85 + 154.52*(1.7706 - 0.2)) + 0$
$= 0.4848"$

The head internal pressure design thickness is 0.4849".

Maximum allowable working pressure, (Corroded at 120 °F) Appendix 1-4(d)

$P = 2*S*E*t / (M*L_o - t*(M - 0.2)) - P_s$
$= 2*20,000*0.85*0.68 / (1.7706*60.68 - 0.68*(1.7706 - 0.2)) - 4.52$
$= 212.82$ psi

The maximum allowable working pressure (MAWP) is 212.82 psi.

% Extreme fiber elongation - UCS-79(d)

$EFE = (75*t / R_f)*(1 - R_f / R_o)$
$= (75*0.75 / 3.975)*(1 - 3.975 / \infty)$
$= 14.1509\%$

The extreme fiber elongation exceeds 5 percent and the thickness exceeds 5/8 inch;. Heat treatment per UCS-56 is required if fabricated by cold forming.

Legs

Leg material:			SA G40.21 44W
Leg description:			W 6x15 (Flange in)
Number of legs:	N =	4	
Overall length:		42	in
Base to girth seam length:		30	in
Bolt circle:		64	in
Anchor bolt size:		0.75	inch series 8 threaded
Anchor bolt material:			SA-193 B7
Anchor bolts/leg:		2	
Anchor bolt allowable stress:	S_b =	20,000	psi
Anchor bolt corrosion allowance:		0	in
Anchor bolt hole clearance:		0.375	in
Base plate width:		7	in
Base plate length:		7	in
Base plate thickness:		0.75	in (0.1779 in required)
Base plate allowable stress:		24,000	psi
Foundation allowable bearing stress:		1,658	psi
User defined leg eccentricity:		0	in
Effective length coefficient:	K =	1.2	
Coefficient:	C_m =	0.85	
Leg yield stress:	F_y =	36,000	psi
Leg elastic modulus:	E =	29,000,000	psi
Leg to shell fillet weld:		0.25	in (0.0547 in required)
Legs braced:		No	

Note: The support attachment point is assumed to be 1 in up from the cylinder circumferential seam.

Conditions Investigated (Only Governing Condition Reported)

Weight operating corroded
Weight empty corroded
Seismic operating corroded
Seismic empty corroded

Loading	Force attack angle °	Leg position °	Axial end load lb_f	Shear resisted lb_f	Axial f_a psi	Bending f_{bx} psi	Bending f_{by} psi	Ratio H_{1-1}	Ratio H_{1-2}
Governing Condition **Seismic operating corroded** **Moment = 20,988.2 lb_f-ft**	**0**	0	-2,051.2	430.2	-463	3,940	0	0.1180	0.1444
		90	4,509.3	1,343.4	1,018	0	3,940	0.1911	0.2130
		180	8,706.9	430.2	1,965	3,940	0	0.2385	0.2568
		270	4,509.3	1,343.4	1,018	0	3,940	0.1911	0.2130
	45	0	-2,051.2	886.8	-463	5,743	1,839	0.2481	0.2977
		90	-2,051.2	886.8	-463	5,743	1,839	0.2481	0.2977
		180	8,706.9	886.8	1,965	5,743	1,839	0.3694	0.4101
		270	8,706.9	886.8	1,965	5,743	1,839	0.3694	0.4101
	56	0	-2,051.2	1,057.8	-463	5,418	2,572	0.2627	0.3148
		90	-2,051.2	715.8	-463	5,435	1,174	0.2133	0.2567
		180	8,706.9	1,057.8	1,965	5,418	2,572	0.3839	0.4273
		270	8,706.9	715.8	1,965	5,435	1,174	0.3344	0.3691

Leg Calculations (AISC manual ninth edition)

Axial end load, P_1 (Based on vessel total bending moment acting at leg attachment elevation)

$P_1 = (1 + 0.14*S_{DS})*W_t / N + 48*M_t / (N*D)$
$= (1 + 0.14*0.6)*16,639.39 / 4 + 48*20,988.2 / (4*60)$
$= 8,706.92$ lb_f

Allowable axial compressive stress, F_a (AISC chapter E)

$C_c = Sqr(2*\pi^2*E / F_y)$
$= Sqr(2*\pi^2*29,000,000 / 36,000)$
$= 126.0993$

$K*l / r = 1.2*28.5 / 1.4505 = 23.5787$

$F_a = 1 * (1 - (K*l / r)^2 / (2*C_c^2))*F_y / (5 / 3 + 3*(K*l / r) / (8*C_c)-(K*l / r)^3 / (8*C_c^3))$
$= 1 * (1 - (23.5787)^2 / (2*126.0993^2))*36,000 / (5 / 3 + 3*(23.5787) / (8*126.0993)-(23.5787)^3 / (8*126.0993^3))$
$= 20,375$ psi

Allowable axial compression and bending (AISC chapter H)

$F'_{ex} = 1*12*\pi^2*E / (23*(K*l / r)^2)$
$= 1*12*\pi^2*29,000,000 / (23*(23.5787)^2)$
$= 268,603$ psi

$F'_{ey} = 1*12*\pi^2*E / (23*(K*l / r)^2)$
$= 1*12*\pi^2*29,000,000 / (23*(13.3439)^2)$
$= 838,664$ psi

$F_b = 1*0.66*F_y$
$= 1*0.66*36,000$
$= 23,760$ psi

Compressive axial stress

$f_a = P_1 / A$
$= 8,706.92 / 4.43$
$= 1.965$ psi

Bending stresses

$f_{bx} = F*\cos(\alpha)*L / (I_x / C_x) + P_1*E_{cc} / (I_x / C_x)$
$= 1,057.84*\cos(56)*28.5 / (9.32 / 2.995) + 8,706.92*0 / (9.32 / 2.995)$
$= 5.418$ psi

$f_{by} = F*\sin(\alpha)*L / (I_y / C_y)$
$= 1,057.84*\sin(56)*28.5 / (29.1 / 3)$
$= 2.572$ psi

AISC equation $H_{1\text{-}1}$

$H_{1\text{-}1} = f_a / F_a + C_{mx}*f_{bx} / ((1 - f_a / F'_{ex})*F_{bx}) + C_{my}*f_{by} / ((1 - f_a / F'_{ey})*F_{by})$
$= 1,965 / 20,375 + 0.85*5,418 / ((1 - 1,965 / 268,603)*23,760) + 0.85*2,572 / ((1 - 1,965 / 838,664)*23,760)$
$= 0.3839$

AISC equation $H_{1\text{-}2}$

$H_{1\text{-}2} = f_a / (0.6*1*F_y) + f_{bx} / F_{bx} + f_{by} / F_{by}$
$= 1,965 / (0.6*1*36,000) + 5,418 / 23,760 + 2,572 / 23,760$
$= 0.4273$

4, W 6x15 legs are adequate.

Anchor bolts - Seismic operating corroded condition governs

Tensile loading per leg (2 bolts per leg)

$R = 48*M / (N*BC) - (0.6 - 0.14*S_{DS})*W / N$
$= 48*29,844.6 / (4*64) - (0.6 - 0.14*0.6)*16,891.61 / 4$
$= 3,416.84\ lb_f$

Required area per bolt

$A_b = R / (S_b*n)$
$= 3,416.84 / (20,000*2)$
$= 0.0854\ in^2$

Area of a 0.75 inch series 8 threaded bolt (corroded) = $0.302\ in^2$

0.75 inch series 8 threaded bolts are satisfactory.

Check the leg to vessel fillet weld, Bednar 10.3, Seismic operating corroded governs

Note: continuous welding is assumed for all support leg fillet welds.

The following leg attachment weld analysis assumes the fillet weld is present on three sides (leg top closure plate is used).

$Z_w = (2*b*d + d^2) / 3$
$= (2*5.99*13.5 + 13.5^2) / 3$
$= 114.66\ in^2$

$J_w = (b + 2*d)^3 / 12 - d^2*(b + d)^2 / (b + 2*d)$
$= (5.99 + 2*13.5)^3 / 12 - 13.5^2*(5.99 + 13.5)^2 / (5.99 + 2*13.5)$
$= 893.5287\ in^3$

$E = d^2 / (b + 2*d)$
$= 13.5^2 / (5.99 + 2*13.5)$
$= 5.524401\ in$

Governing weld load $f_x = Cos(56)*1,057.84 = 591.54\ lb_f$
Governing weld load $f_y = Sin(56)*1,057.84 = 876.99\ lb_f$

$f_1 = P_1 / L_{weld}$
$= 8,706.92 / 32.99$
$= 263.93\ lb_f/in$ (V_L direct shear)

$f_2 = f_y*L_{leg}*0.5*b / J_w$
$= 876.99*28.5*0.5*5.99 / 893.5287$
$= 83.78\ lb_f/in$ (V_L torsion shear)

$f_3 = f_y / L_{weld}$
$= 876.99 / 32.99$
$= 26.58\ lb_f/in$ (V_c direct shear)

$f_4 = f_y*L_{leg}*E / J_w$
$= 876.99*28.5*5.5244 / 893.5287$

= 154.53 lb_f/in (V_c torsion shear)

$f_5 = (f_x*L_{leg} + P_1*E_{cc}) / Z_w$
= (591.54*28.5 + 8,706.92*0) / 114.66
= 147.03 lb_f/in (M_L bending)

$f_6 = f_x / L_{weld}$
= 591.54 / 32.99
= 17.93 lb_f/in (Direct outward radial shear)

$f = Sqr((f_1 + f_2)^2 + (f_3 + f_4)^2 + (f_5 + f_6)^2)$
= $Sqr((263.93 + 83.78)^2 + (26.58 + 154.53)^2 + (147.03 + 17.93)^2)$
= 425.34 lb_f/in (Resultant shear load)

Required leg to vessel fillet weld leg size (welded both sides + top)

$t_w = f / (0.707*0.55*S_a)$
= 425.34 / (0.707*0.55*20,000)
= 0.0547 in

The 0.25 in leg to vessel attachment fillet weld size is adequate.

Base plate thickness check, AISC 3-106

$f_p = P / (B*N)$
= 10,173.49 / (7*7)
= 208 psi

m = (N - 0.95*d) / 2
= (7 - 0.95*5.99) / 2
= 0.6548 in

n = (B - 0.8*b) / 2
= (7 - 0.8*5.99) / 2
= 1.104 in

$L = 0.5*(d + b) / 2 - Sqr((0.5*(d + b))^2 / 4 - P / (4*F_p))$
= $0.5*(5.99 + 5.99) / 2 - Sqr((0.5*(5.99 + 5.99))^2 / 4 - 10,173.49 / (4*1,658))$
= 0.2681 in

$t_b = Largest(m, n, L)*Sqr(3*f_p / S_b)$
= 1.104*Sqr(3*208 / 24,000)
= 0.1779 in

The base plate thickness is adequate.

Check the leg to vessel attachment stresses, WRC-107 (Seismic operating corroded governs)

Applied Loads

Radial load:	P_r =	-627.07	lb_f
Circumferential moment:	M_c =	0	lb_f-in
Circumferential shear:	V_c =	0	lb_f
Longitudinal moment:	M_L =	17,871.47	lb_f-in
Longitudinal shear:	V_L =	-2,051.16	lb_f

Torsion moment:	M_t =	0	lb_f-in
Internal pressure:	P =	154.115	psi
Mean shell radius:	R_m =	29.75	in
Local shell thickness:	t =	0.5	in
Shell yield stress:	S_y =	37,100	psi

Maximum stresses due to the applied loads at the leg edge (includes pressure)

R_m / t = 29.75 / 0.5 = 59.5

C_1 = 2.995, C_2 = 10.715 in

Local circumferential pressure stress = $P*R_i$ / t =9,093 psi

Local longitudinal pressure stress = $P*R_i$ / (2*t) =4,546 psi

Maximum combined stress (P_L+P_b+Q) = 11,895 psi
Allowable combined stress (P_L+P_b+Q) = +-3*S = +-60,000 psi

The maximum combined stress (P_L+P_b+Q) is within allowable limits.

Maximum local primary membrane stress (P_L) = 9,923 psi
Allowable local primary membrane (P_L) = +-1.5*S = +-30,000 psi

The maximum local primary membrane stress (P_L) is within allowable limits.

Stresses at the leg 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*	2.7826	0.2782	0	0	0	0	117	117	117	117
4C*	7.1219	0.227	300	300	300	300	0	0	0	0
1C	0.0713	0.1685	0	0	0	0	1,073	-1,073	1,073	-1,073
2C-1	0.0369	0.1685	555	-555	555	-555	0	0	0	0
3A*	2.3949	0.154	0	0	0	0	0	0	0	0
1A	0.0714	0.1858	0	0	0	0	0	0	0	0
3B*	4.8127	0.2355	-530	-530	530	530	0	0	0	0
1B-1	0.02	0.2035	-1,417	1,417	1,417	-1,417	0	0	0	0
Pressure stress*			9,093	9,093	9,093	9,093	9,093	9,093	9,093	9,093
Total circumferential stress			8,001	9,725	11,895	7,951	10,283	8,137	10,283	8,137
Primary membrane circumferential stress*			8,863	8,863	9,923	9,923	9,210	9,210	9,210	9,210
3C*	3.7498	0.227	158	158	158	158	0	0	0	0
4C*	6.1817	0.2782	0	0	0	0	261	261	261	261
1C-1	0.0442	0.2361	665	-665	665	-665	0	0	0	0
2C	0.0326	0.2361	0	0	0	0	491	-491	491	-491
4A*	4.4851	0.154	0	0	0	0	0	0	0	0
2A	0.0274	0.2392	0	0	0	0	0	0	0	0
4B*	2.2573	0.2355	-439	-439	439	439	0	0	0	0
2B-1	0.023	0.273	-1,215	1,215	1,215	-1,215	0	0	0	0
Pressure stress*			4,546	4,546	4,546	4,546	4,546	4,546	4,546	4,546
Total longitudinal stress			3,715	4,815	7,023	3,263	5,298	4,316	5,298	4,316
Primary membrane longitudinal stress*			4,265	4,265	5,143	5,143	4,807	4,807	4,807	4,807
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	96	96	-96	-96
Total Shear stress			0	0	0	0	96	96	-96	-96

Combined stress (P_L+P_b+Q)	8,001	9,725	11,895	7,951	10,285	8,139	10,285	8,139

Note: * denotes primary stress.

Seismic Code

Method of seismic analysis:	**IBC 2009 ground supported**
	(Seismic analysis in accordance with ASCE 7-05. All paragraph, page, and table references are from ASCE 7-05.)
Site Class	E
Importance Factor:	I = 1.0000
Spectral Response Acceleration at short period (% g)	S_s = 75.00%
Spectral Response Acceleration at period of 1 sec (% g)	S_1 = 3.00%
Response Modification Coeficient from Table 15.4-2	R = 2.0000
Acceleration based site co-efficient:	F_a = 1.2000
Velocity based site co-efficient:	F_v = 3.5000
Long-period transition period:	T_L = 12.0000
Redundancy factor:	ρ = 1.0000
User Defined Vertical Accelerations Considered:	No

12.4.2.3 Basic Load Combinations for Allowable Stress Design
The following load combinations are considered in accordance with ASCE section 2.4.1:

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

Where

D = Dead load
P = Internal or external pressure load
P_s = Static head load
E = Seismic load $= E_h +/- E_v = \rho Q_E +/- 0.2S_{DS}D$

Vessel Characteristics

Vessel height: 13.4988 ft
Vessel Weight:
Operating, Corroded: 16,892 lb
Empty, Corroded: 4,891 lb

Period of Vibration Calculation

Fundamental Period, T:
Operating, Corroded: 0.084 sec (f = 12.0 Hz)
Empty, Corroded: 0.044 sec (f = 22.6 Hz)

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

$T = 2 * PI * Sqr(\{Sum(W_i * y_i^2)\} / \{g * Sum(W_i * y_i)\})$, where

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

Seismic Shear Reports:

Operating, Corroded
Empty, Corroded
Base Shear Calculations

Seismic Shear Report: Operating, Corroded

Component	Elevation of bottom above base (in)	Elastic modulus E (10^6 psi)	Inertia I (ft^4)	Seismic shear at Bottom (lbf)	Bending Moment at Bottom (lbf-ft)
Head, Top	150	29.2	*	271	201
Shell (top)	30	29.2	1.9947	3,374	21,058
Legs	0	29.0	0.0037	3,547	29,845
Shell (bottom)	30	29.2	1.9947	140	70
Head, Bottom	30	29.2	*	130	59
*Moment of Inertia I varies over the length of the component					

Seismic Shear Report: Empty, Corroded

Component	Elevation of bottom above base (in)	Elastic modulus E (10^6 psi)	Inertia I (ft^4)	Seismic shear at Bottom (lbf)	Bending Moment at Bottom (lbf-ft)
Head, Top	150	29.4	*	155	141
Shell (top)	30	29.4	1.9947	559	4,267
Legs	0	29.0	0.0037	616	5,778
Shell (bottom)	30	29.4	1.9947	39	24
Head, Bottom	30	29.4	*	38	20
*Moment of Inertia I varies over the length of the component					

11.4.3: Maximum considered earthquake spectral response acceleration

The maximum considered earthquake spectral response acceleration at short period, S_{MS}
$S_{MS} = F_a * S_s = 1.2000 * 75.00 / 100 = 0.9000$
The maximum considered earthquake spectral response acceleration at 1 s period, S_{M1}
$S_{M1} = F_v * S_1 = 3.5000 * 3.00 / 100 = 0.1050$

11.4.4: Design spectral response acceleration parameters

Design earthquake spectral response acceleration at short period, S_{DS}
$S_{DS} = 2 / 3 * S_{MS} = 2 / 3 * 0.9000 = 0.6000$
Design earthquake spectral response acceleration at 1 s period, S_{D1}
$S_{D1} = 2 / 3 * S_{M1} = 2 / 3 * 0.1050 = 0.0700$

12.4.2.3: Seismic Load Combinations: Vertical Term

Factor is applied to dead load.

Compressive Side: $= 1.0 + 0.14 * S_{DS}$
$= 1.0 + 0.14 * 0.6000$
$= 1.0840$
Tensile Side: $= 0.6 - 0.14 * S_{DS}$
$= 0.6 - 0.14 * 0.6000$
$= 0.5160$

Base Shear Calculations

Operating, Corroded
Empty, Corroded

Base Shear Calculations: Operating, Corroded

Paragraph 15.4.4: Period Determination

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

T = 0.0835 sec.

12.8.1: Calculation of Seismic Response Coefficient

C_s is the value computed below, bounded by C_sMin and C_sMax:
C_sMin is calculated with equation 15.4-1 and shall not be less than 0.03 (see ASCE 7-05 Supplement No. 2); in addition, if S_1 >= 0.6g, C_sMin shall not be less than eqn 15.4-2.
C_sMax calculated with 12.8-3 because (T = 0.0835) <= (T_L = 12.0000)

$C_s = S_{DS} / (R / I)$ = 0.6000 / (2.0000 / 1.0000) = 0.3000
C_sMin = max (0.044 * S_{DS} * I , 0.03) = max (0.044 * 0.6000 * 1.0000 , 0.03) = 0.0300
C_sMax = $S_{D1} / (T * (R / I))$ = 0.0700 / (0.0835 * (2.0000 / 1.0000)) = 0.4190
C_s = 0.3000

12.8.1: Calculation of Base Shear

$V = C_s * W$
= 0.3000 * 16,891.6133
= 5,067.48 lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h
Q_E = V
E_h = 0.7 * ρ * Q_E (Only 70% of seismic load considered as per Section 2.4.1)
= 0.70 * 1.0000 * 5,067.48
= 3,547.24 lb

Base Shear Calculations: Empty, Corroded

Paragraph 15.4.2: T < 0.06, so:
$V = 0.30 * S_{DS} * W * I$
= 0.30 * 0.6000 * 4,891.3789 * 1.0000
= 880.45 lb

12.4.2.1 Seismic Load Combinations: Horizontal Seismic Load Effect, E_h

Q_E = V

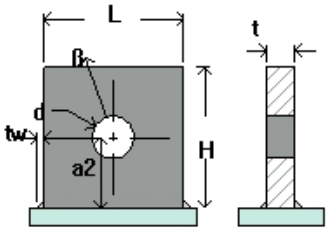
E_h = 0.7 * ρ * Q_E (Only 70% of seismic load considered as per Section 2.4.1)

= 0.70 * 1.0000 * 880.45

= 616.31 lb

Lifting Lug

Minimum report



Geometry Inputs

Attached To	Head, Top
Material	SA-516 70
Orientation	Longitudinal
Distance of Lift Point From Datum	130.8"
Angular Position	90.00°
Length of Lug, L	5"
Height of Lug, H	5"
Thickness of Lug, t	0.5"
Hole Diameter, d	1.5"
Pin Diameter, Dp	1.25"
Load Eccentricity, a_1	0"
Distance from Load to Shell or Pad, a_2	2.5"
Weld Size, t_w	0.25"
Load Angle Normal to Vessel, β	19.0000 °
Load Angle from Vertical, ϕ	-0.6391 °

Intermediate Values

Load Factor	1.5000
Vessel Weight (new, incl. Load Factor), W	7337 lb
Lug Weight (new), W_{lug}	3 lb
Allowable Stress, Tensile, σ_t	19980 psi
Allowable Stress, Shear, σ_s	13320 psi
Allowable Stress, Bearing, σ_p	29970 psi
Allowable Stress, Bending, σ_b	22201 psi

Allowable Stress, Weld Shear, $\tau_{allowable}$	13320 psi
Allowable Stress set to 1/3 Sy per ASME B30.20	No

Summary Values

Required Lift Pin Diameter, d_{reqd}	0.4215"
Required Lug Thickness, t_{reqd}	0.0992"
Lug Stress Ratio, σ_{ratio}	0.14
Weld Shear Stress Ratio, τ_{ratio}	0.26
Lug Design	Acceptable
Local Stresses	Acceptable