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Source Physics Experiment – DAG

Final Design Review Shot Canisters

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June 27, 2017

Outline

- **Pressure Vessel Design Scope**
- **Pressure Vessel Requirements**
 - Materials / Factors of Safety
- **Pressure Vessel Stats**
 - 211 Gallon Shot Size
 - 2111 Gallon Shot Size
 - 10550 Gallon Shot Size
- **Design / Analysis Overview**
 - BPVC Analysis (Sec 8, Div 1)
 - FEA (Structural Features)

Pressure Vessel Design Scope

- **Five pressure vessels (Canisters) are required for DAG experiments:**
 - DAG-1: 1000 kg TNT equivalent
 - DAG-2: 50000 kg TNT equivalent
 - DAG-3: 1000 kg TNT equivalent
 - DAG-4: 10000 kg TNT equivalent
 - DAG-5: 10000 kg TNT equivalent
- **Utilize common interfaces between mid-size and large-size vessels:**
 - 84" vessel diameter, common lifting interfaces / fixtures, designed for largest vessel loading / weights

Requirements

- **Contain Nitromethane, in the appropriate quantity**
 - Allow for Nitromethane expansion (temperature)
 - Keep Nitromethane level below the ground level
- **Interface with:**
 - Nitromethane handling system (fill / empty)
 - Inert gas may be used to force NM out of tank in the event it must be emptied
 - Top-of-the-hole support (ring)
 - Crane pendants (rigging)
 - Inert gas purge
 - Fireset / initiator system
 - Instrumentation (internal / external)

Pressure Vessel Requirements

- **Meet or exceed ASME BPVC section 8, division 1 requirements.**
 - Non-code stamped vessel.
- **DAG pressure vessels are designed with a commercial software package, Codeware Compress to the 2015 version of BPVC.**
 - Specific details to the analyses are listed later
- **Vessels will only be pressurized in the event the Nitromethane must be evacuated.**
 - Filled @ ambient, vented
 - Lowered while vented (filter stack on one or both fill / purge nozzles)

Factors of Safety

- **BPVC: 3.5 on ultimate incorporated into allowable stresses**
- **Lifting structure / attachments: 3.5 on yield / 5 on ultimate (exceeds ASME BTH 1)**
 - Lifting fixture, interfaces
 - Fasteners in lifting load path
 - Attachment points for swivel hoist rings
- **Non-lifting structure: 1.67 on yield / 2.0 on ultimate (AISC)**
 - Transportation @ breaking load requirements
 - Stemming operations while vessel is not attached to crane (landed)
 - Transportation / hydrostat fixtures (saddles, etc.)

Materials

- **A516 grade 70 (pressure vessel steel)**
 - All vessel components
 - Allowables:
 - BPVC: 20.0 KSI (BPVC Section 2)
 - Lifting: 10.85 KSI
 - Non-lifting (structural): 22.75 KSI
- **A36**
 - Saddles / transportation fixtures
 - Allowables
 - Lifting: 10.28 KSI
 - Non-lifting (structural): 21.55 KSI
- **Gaskets: Garlock Stress-Saver 6800**
 - Low torque requirements, EPDM for compatibility with NM

Small Sized Canister (211 Gal Shot Size)

- **Weights:**

- Vessel: 2143 lbs
- Vessel + Blinds: 2359 lbs
- Nitromethane: 2004 lbs

- **Vessel:**

- 42" outer diameter
- 0.375" wall thickness
- Cyl section length: 40.110"
- Flat, welded cover @ top
- Bottom Head: 2:1 ratio ASME type Ellipsoidal, 1.25" thick
- Openings: 1 X 20" NPS, 2 X 1.5" NPS
- Overall length: 57.422"

Mid Sized Canister (2111 Gal Shot Size)

- **Weights:**

- Vessel: 11586 lbs
- Vessel + Blinds: 11821 lbs
- Nitromethane: 20042 lbs

- **Vessel:**

- 42" outer diameter
- 0.375" wall thickness
- Cyl section length: 92.331"
- Flat, welded cover @ top
- Bottom Head: 2:1 ratio ASME type Ellipsoidal, 1.5" thick
- Openings: 1 X 20" NPS, 2 X 4" NPS
- Overall length: 116.394"

Large Sized Canister (10550 Gal Shot)

- **Weights:**

- Vessel: 21754 lbs
- Vessel + Blinds: 21989 lbs
- Nitromethane: 100210 lbs

- **Vessel:**

- 42" outer diameter
- 0.375" wall thickness
- Cyl section length: 458.416"
- Flat, welded cover @ top
- Bottom Head: 2:1 ratio ASME type Ellipsoidal, 1.5" thick
- Openings: 1 X 20" NPS, 2 X 4" NPS
- Overall length: 482.478"

Pressure Vessel Nozzles

- Short protrusion from top head to free up volume inside of lifting fixture.
- One primary nozzle, 20" NPS (17.938" ID, schedule 80)
 - ASME 16.5 class 150 flange (standard, welding neck), flat face for low durometer gaskets
- Two fill / purge nozzles
 - ASME 16.5 class 150 flange (standard, welding neck), flat face for low durometer gaskets
 - 4" NPS for mid-/large-size vessels (3.826" ID)
 - 1.5" NPS for small-size vessel (1.50" ID)
 - Two nozzles required to evacuate the vessel
 - One for fluid dip tube (fluid out, transfer to barrels)
 - One for pressurization system / pressure relief valve
- Detailed nozzle info / attachment: backup slides...

Nozzle Cover Torque (Garlock SS 6800)

- **Bolts: ASTM A193 Grade B7**
 - 4 X 0.50" for 1.5" NPS
 - 4 X 0.625" for 4.0" NPS
 - 20 X 1.125" for 20" NPS
- **250 PSI capable @ proper torque**

TYPICAL PHYSICAL PROPERTIES

	Style 3504 GYLON® STRESS SAVER®	Style XP STRESS SAVER®	Style 370 STRESS SAVER®	Style 6800 STRESS SAVER®
Composition	100% GYLON® PTFE with glass microspheres	Proprietary blend of fluoroelastomer (70 durometer)	100% Pure PTFE bonded to EPDM	EPDM only (65 durometer)
Color	Blue	Black	PTFE: Sky Blue EPDM: Off-white	Off-white
Temperature	+500°F (+260°C) -450°F (-268°C)	+400°F (+204°C) -15°F (-26°C)	+300°F (+150°C) -40°F (-40°C)	+300°F (+150°C) -40°F (-40°C)
Pressure ¹ psig (bar)	800 (55)	250 (17)	250 (17)	250 (17)
PxT (max) ^{1,2} , (psig x °F)(bar x °C)	250,000 (8,600)	50,000 (1,717)	50,000 (1,717)	50,000 (1,717)
Media ³	All solvents, most caustics and acids, hydrocarbons, refrigerants, cryogenics and potable water ⁴	Potable water, steam, most hydrocarbons, gases, solvents	Moderate acids, caustics, gases, water, hydrocarbons	Water, very mild acids and caustics
M&Y	3.2 / 475 psi	2.0 / 200 psi	2.0 / 400 psi	0.5 / 100 psi

Garlock Bolt Torque Values for Stress Saver® Gaskets B16.5 150# Flat Face Flanges					
Nominal Pipe Size	Number of Bolts	Size of Bolts	Minimum Suggested Torque	Preferred Torque Range	
(in)	Bolts	(in)	(ft. lbs)	Min. (ft. lbs)	Max (ft. lbs)
0.5	4	0.50	5	9	19
0.75	4	0.50	6	12	23
1	4	0.50	7	14	28
1.25	4	0.50	8	16	32
1.5	4	0.50	10	19	37
2	4	0.63	17	33	66
2.5	4	0.63	23	45	90
3	4	0.63	25	49	97
3.5	8	0.63	15	30	60
4	8	0.63	17	33	66
5	8	0.75	21	41	82
6	8	0.75	23	46	92
8	8	0.75	33	66	132
10	12	0.88	32	64	128
12	12	0.88	47	93	186
14	12	1.00	67	134	268
16	16	1.00	60	120	241
18	16	1.13	86	132	264
20	20	1.13	62	124	249
24	20	1.25	87	173	347

*NOTE 1: Table based on A193 B7 bolts or bolts of equal strength.
 *NOTE 2: Garlock does not recommend exceeding the flange manufacturers max. recommended torque.
 *NOTE 3: Min Torque value is equal to 300 PSI Compressive stress.
 *NOTE 4: Req'd Range creates 600 to 1200 PSI Compressive stress.

Information from: garlock.com

Analysis Overview

- **Load cases broken up for 3 vessel sizes**
 - Several mid-size vessel load cases are covered by identical design and conservative loading as large-size vessel
 - Pressure vessel construction is addressed by Compress, including nozzle attachment

Load Case	Type	Analysis Note	211 Gal	2110 Gal	10550 Gal	Note
1	Pressure Vessel	Vessel Construction	LC1	LC2	LC3	Compress
2	Structural	Support Ring Contact	LC4	N/A	LC5	
3	Structural	Soil Loading + Vessel Wt	LC6	N/A	LC7	
4.1	Transportation	Forward 0.8G + Downward Force	LC8	LC9	LC10	
4.2	Transportation	Rearward 0.5G + Downward Force	LC11	LC12	LC13	
4.3	Transportation	Lateral 0.5G + Downward Force	LC11*	LC14	LC15	211 gallon vessel to be transported in vertical orientation with ~symmetric strapping to flat bed
5	Transportation	Picking / Tripping, 1.0G	N/A	LC16*	LC16	10550 gallon vessel case is conservative for 2110 gallon case
6.1	Structural	Stuck in hole / 0.9 Yield	LC17	LC18	LC19	Iterative Process, will approximate 0.9X of yield stress
7	Pressure Vessel	Hydrostat (Water Wt + Pressure)	LC20	LC21	LC22	Small vessel: vertical; Mid/Large vessel: Horizontal, while on saddles
8.1	Structural	Lifting fixture structure	LC23	N/A	LC24	FEA of lifting structure / top of vessel
8.2	Structural	Lifting fixture bolted joint analysis	LC25	N/A	LC26	Bolted joint hand calcs: fastener sizing / torque

Analysis Condensed Summary

Load Case	Vessel	Max Stress (VM) KSI	Allowable Stress KSI	Margin KSI	FEA Type	Note
LC1	42"	N/A	N/A	N/A	Passed	Compress Analysis
LC2	84"M	N/A	N/A	N/A	Passed	Compress Analysis
LC3	84"L	N/A	N/A	N/A	Passed	Compress Analysis
LC4	42"	2.213	10.85	8.637	SPA / NL	Support Ring on Support Plates
LC5	84"L	6.4142	10.85	4.4358	MPA / NL	Support Ring on Support Plates
LC6	42"	9.139	22.75	13.611	SPA / NL	Soil loading on Vessel Head
LC7	84"L	12.1601	22.75	10.59	MPA	Soil loading on Vessel Head
LC16	84"M/L			0	**TBD**	Picking / Tripping (top)
LC16	84"M/L	8.592	10.85	2.258	MPA	Picking / Tripping (bottom)
LC27	42"	9.139	10.85	1.711	SPA / NL	Downhole Lifting
LC28	84"L	6.903	10.85	3.947	MPA	Downhole Lifting

*

***Note: full fidelity (updated since FDR (6/27))**

Small Sized Vessel

- **LC1: Vessel Construction / Nozzle Attachment (Compress)**
- **LC4: Support Ring Attachment to Vessel (Lifting while full)**
- **LC6: Soil Loading / Vessel Weight (Vessel landed, stemming, non-lifting)**
- **LC27: Vessel Lifting (full with NM, downhole). NOTE: met by LC6 load case.**

Small Sized Vessel: LC1, Compress

- COMPRESS 2017 Build 7700
- ASME Section VIII, Division 1, 2015 Edition
- Hydro: 1.3 X MAWP, 90% of yield
- Internal pressure (design): 30 PSI
- No external pressure

Pressure Summary

Component Summary							
Identifier	P Design (psi)	T Design (°F)	MAWP (psi)	MAP (psi)	MDMT (°F)	MDMT Exemption	Impact Tested
Welded Cover #2	30	120	32.6	33.06	-20	Note 1	No
Cylinder #1	30	120	303.95	305.76	-155	Note 2	No
Straight Flange on Ellipsoidal Head #3	30	120	1,004.03	1,005.92	-155	Note 4	No
Ellipsoidal Head #3	30	120	1,034.28	1,036.59	-155	Note 3	No
Nozzle #1 (A1)	30	120	32.6	33.05	-20	Nozzle Note 5	No
						Pad Note 6	No
Bolted Cover #2	30	120	175.46	175.46	-155	Note 7	No
Nozzle #2 (N2)	30	120	32.6	33.05	-20	Nozzle Note 8	No
						Pad Note 9	No
Bolted Cover #3	30	120	661.38	661.53	-155	Note 10	No
Nozzle #3 (N3)	30	120	32.6	33.05	-20	Nozzle Note 8	No
						Pad Note 9	No
Bolted Cover #4	30	120	661.38	661.53	-155	Note 10	No

Chamber Summary	
Design MDMT	-20 °F
Rated MDMT	-20 °F @ 32.6 psi
MAWP hot & corroded	32.6 psi @ 120 °F
MAP cold & new	33.05 psi @ 70 °F
(1) This pressure chamber is not designed for external pressure.	

Small Sized Vessel: Design Thicknesses

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Welded Cover #2	SA-516 70	41.25 OD	0.75	0.75	0.7199	0	1.00	Internal
Cylinder #1	SA-516 70	42 OD	39.48	0.375	0.0393	0	0.85	Internal
Straight Flange on Ellipsoidal Head #3	SA-516 70	40.75 ID	2	1.25	0.0383	0	0.85	Internal
Ellipsoidal Head #3	SA-516 70	40.75 ID	11.4375	1.25*	0.0388	0	0.85	Internal
Bolted Cover #2	SA-516 70	27.5 OD	1.375	1.375	1.2501	0	1.00	Internal
Bolted Cover #3	SA-516 70	5 OD	0.5625	0.5625	0.533	0	1.00	Internal
Bolted Cover #4	SA-516 70	5 OD	0.5625	0.5625	0.533	0	1.00	Internal
Support Skirt #1	SA-516 70	42 ID	4	1.5	0.002	0	0.55	Weight
*Head minimum thickness after forming								

Small Sized Vessel: Hydrostat / Nozzles

Hydrostatic Test

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

$$\begin{aligned}
 \text{Gauge pressure at } 70^{\circ}\text{F} &= \\
 &= 1.3 \cdot \text{MAWP} \cdot \text{LSR} \\
 &= 1.3 \cdot 32.6 \cdot 1 \\
 &= 42.37 \text{ psi}
 \end{aligned}$$

Vertical shop hydrostatic test				
Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor
Cylinder #1 (1)	43.968	1.594	1	1.30
Straight Flange on Ellipsoidal Head #3	44.041	1.666	1	1.30
Ellipsoidal Head #3	44.408	2.034	1	1.30
Welded Cover #2	42.787	0.412	1	1.30
Bolted Cover #2	42.374	0	1	1.30
Bolted Cover #3	42.519	0.144	1	1.30
Bolted Cover #4	42.519	0.144	1	1.30
Nozzle #1 (A1)	42.76	0.385	1	1.30
Nozzle #2 (N2)	42.76	0.385	1	1.30
Nozzle #3 (N3)	42.76	0.385	1	1.30
(1) Cylinder #1 limits the UG-99(b) stress ratio.				

Nozzle Schedule

Specifications								
Nozzle mark	Identifier	Size	Materials		Impact Tested	Normalized	Fine Grain	Flange
A1	Nozzle #1	20 OD x 1.031	Nozzle	SA-516 70	No	No	No	NPS 20 Class 150 WN A516 70
			Pad	SA-516 70	No	No	No	
N2	Nozzle #2	1.9 OD x 0.2	Nozzle	SA-516 70	No	No	No	NPS 1 1/2 Class 150 WN A516 70
			Pad	SA-516 70	No	No	No	
N3	Nozzle #3	1.9 OD x 0.2	Nozzle	SA-516 70	No	No	No	NPS 1 1/2 Class 150 WN A516 70
			Pad	SA-516 70	No	No	No	

LC4: 42" Vessel Support Ring

Load Case	LC4
Load Case Overview	Support ring contact for 42" dia vessel (211 gallon) Partial Vessel Cylinder, Removed 6" Below Support Ring; Welds modeled as Bonded areas; No vessel covers
Model Fidelity / Simplifications	Distributed Force (Vessel Wt + NM Wt + Bumper Head Wt): 2224+2004+1066=5294LB Vessel cylinder cross section (load in -Y) N/A N/A Contact (.65 static friction / compatible mesh) @ Bottom of Top Support Ring to LMC Support Plate (2" Thick, 43" Opening, 96" OD); Fixed translation (XYZ) @ Edge of Support Plate See above.
Load Type 1	
Load Placement 1	
Load Type 2	
Load Placement 2	
Boundary Condition Type	
Boundary Condition Location(s)	
Run Settings	Nonlinear (Large Deformations / Contacts); SPA
FEA Parameters	
Component Interaction (Bonded / Contact / Free)	Welds: Bonded, Face contact @ bottom of top support ring
Mesh Refinement Used	Max element size: 1.0" (global)
Element Total	148189 (Tet)
Material	A516 Grade 70
Poisson's ratio	.29 [-]
Density	.282 lb/in^3
Modulus of Elasticity	29000 KSI
Yield Strength	38 KSI
Ultimate Strength (Tensile)	70 KSI
FEA Results	
Allowable Stress	10.85 KSI (yield strength 38 KSI @ FoS of 3.5)
Peak Stress (VM) - Entire Model	2.213 KSI
Peak Displacement - Entire Model	.00493"
Areas removed from summary	None
Reason for removal (Riser: Geometry / Load Edge / BC Edge)	N/A
Peak Stress (VM) *	N/A
Other Notes	
Date	4/13/2017
Run time	229 min
Converged on maximum order	7
Stress Error (% of Max Prin Str)	0.2%

Margin: 8.64 KSI

LC4: 42" Vessel Support Ring

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LC4: 42" Vessel Support Ring

Stress von Mises (WCS)
(ksi)
LoadSet/LoadSet1: LC_4_ASSY Step 2, Time 1.0000E+00

2.213e+00
1.085e+01
8.137e+00
5.425e+00
2.713e+00
0.000e+00
3.239e-08

Stress von Mises (WCS)
(ksi)
Location: Components and Layers
LoadSet/LoadSet1: LC_4_ASSY Step 2, Time 1.0000E+00

2.21338
10.8500
8.13750
5.42500
2.71250
0.00000
0.00242

Displacement Magnitude (WCS)
(in)
Max Disp 4.9258E-03
LoadSet/LoadSet1: LC_4_ASSY Step 2, Time 1.0000E+00

0.00493
0.00450
0.00350
0.00250
0.00150
0.00050
0.00000

LC4 (OLD) DISPLACEMENT (IN)

LC6: 42" Vessel Soil Loading

Load Case	LC6
Load Case Overview	Soil Loading for 42" dia vessel (211 gallon) Partial Vessel Cylinder, Removed 6" Below Support Ring; Welds modeled as Bonded areas; No vessel covers
Model Fidelity / Simplifications	Distributed Force (Vessel Wt + NM Wt + Bumper Head Wt): 2224+2004+1066=5294LB / 4 Vessel cylinder cross section (load in -Y) Soil Pressure on all top horizontal surfaces: 6.5 PSI Blind cover tops / vessel welded cover top / support ring top Contact (infinite friction / compatible mesh) @ Nozzles / Flanges; Fixed XYZ @ Lift Fixture Bolt Holes See above.
Load Type 1	Nonlinear (Large Deformations / Contacts); SPA
Load Placement 1	
Load Type 2	
Load Placement 2	
Boundary Condition Type	
Boundary Condition Location(s)	
Run Settings	
FEA Parameters	
Component Interaction (Bonded / Contact / Free)	Welds: Bonded, Face contact nozzle flange faces Max element size: 1" (global), .1" at supporting ringweld roots / cutout roots
Mesh Refinement Used	217083 (Tet)
Element Total	A516 Grade 70
Material	.29 [-]
Poisson's ratio	.282 lb/in^3
Density	29000 KSI
Modulus of Elasticity	38 KSI
Yield Strength	70 KSI
Ultimate Strength (Tensile)	
FEA Results	
Allowable Stress	22.75 KSI (yield strength 38 KSI @ FoS of 1.67)
Peak Stress (VM) - Entire Model	9.139 KSI
Peak Displacement - Entire Model	.01308"
Areas removed from summary	None
Reason for removal (Riser: Geometry / Load Edge / BC Edge)	N/A
Peak Stress (VM) *	N/A
Other Notes	Geometric radiusing used to alleviate sharp corner singularities
Date	6/12/2017
Run time	333 min
Converged on maximum order	6
Stress Error (% of Max Prin Str)	1.3%

Margin: 1.711 KSI (lifting)
13.611 KSI (structural)

LC6: 42" Vessel Soil Loading

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LC6: 42" Vessel Soil Loading

NOTE: Shown at Lifting FoS (conservative for LC27)
Stemming allowable stress is 22.75 KSI

Small Vessel Lifting, Option 1

- Small vessel will be by hydrostat'd and transported in the vertical orientation
- 2 X Crosby® HR-1200 UNC Side Pull Hoist Rings
 - WLL 3000#: 5/8-11, .71" THD projection
- Attached to side of support ring (machined flats every 90 degrees).

RIGGING ACCESSORIES

HR-1200 Side Pull Hoist Rings

- Wide range of capacities available:
 - 650 lbs. to 29,000 lbs.
 - Metric sizes from 0.3 tonnes to 13 tonnes.
- Body components are Alloy Steel - Quenched and Tempered.
- Rated at 100% of Working Load Limit for angles up to 90 degrees.
- Each product is stamped with a Product Identification Code (PIC) for material traceability, along with a Working Load Limit, and the name Crosby or "CG".
- Hoist Ring body is furnished with Yellow Chromate finish for improved corrosion resistance.
- Utilize standard Crosby Red Pin® Shackles to connect to wire rope or synthetic slings. (sold separately)
- Multiple bolt lengths available to meet specific application requirements.
- Individually Proof Tested to 2-1/2 times Working Load Limit.
- All sizes are RFID EQUIPPED.

Load Rated

SEE APPLICATION AND WARNING INFORMATION
On pages 005 - 007
Data Equipped: www.crosbygroup.com

HR-1200 UNC Side Pull Hoist Rings

Weight Each (lbs.)	Working Load Limit (lbs.)	HR-1200 Stock No.	Hoist Ring Bolt Torque (FT.Lbs.)	Bolt Size A	EE Thread Proj. (in.) B	Dimensions (in)									Recommended Shackles			
						C	D	E	F	Dia. G	H	I	Red Pin® Shackles 200, 210, 215, 215, 2150, 2150		Red Pin Web Shackles S-201			
													Nominal Size (in.)	WLL (T)	Web Size (in.)	WLL (T)		
35	650	106/700	7	5/16-18x1.50	.59	1.00	.72	1.00	1.56	.80	.85	1.43	1/2, 5/8	2, 3-1/4	2	3-1/4		
36	800	106/704	12	3/8-16x1.50	.59	1.00	.72	1.00	1.56	.80	.85	1.43	1/2, 5/8	2, 3-1/4	2	3-1/4		
14	2000	106/708	28	1/2-13x2.00	.71	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2		
14	2000	106/712	28	1/2-13x2.50	1.21	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2		
15	3000	106/716	60	5/8-11x2.00	.71	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2		
15	3000	106/720	60	5/8-11x2.75	1.46	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2		
4.5	5000	106/724	100	3/4-10x2.75	.90	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
4.6	5000	106/728	100	3/4-10x3.50	1.65	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
4.6	6500	106/732	160	7/8-9x2.75	.90	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
4.8	6500	106/736	160	7/8-9x3.50	1.65	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
4.8	8000	106/740	230	1-8x3.00	1.15	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
5.0	8000	106/744	230	1-8x4.00	2.15	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4		
10.2	14000	106/748	470	1-1/4-7x4.5	2.22	5.59	1.57	3.75	3.91	1.47	1.92	3.42	1, 1-1/8, 1-1/4	8-1/2, 9-1/2, 12	3	8-1/2		
23.5	17000	106/756	800	1-1/2-6x5.5	2.98	7.31	2.06	4.75	5.10	2.11	2.41	4.29	1-3/8, 1-1/2, 1-3/4	13-1/2, 17, 25	-	-		
25.3	29000	106/764	1100	2-4-5x6.5	2.98	7.31	2.06	4.75	5.10	2.11	2.41	4.29	1-3/8, 1-1/2, 1-3/4	13-1/2, 17, 25	-	-		

*Ultimate Load is 5 times the Working Load Limit.

Small vessel + blinds: ~2400#

Small Vessel Lifting, Option 2

- Small vessel will be hydrostat'd and transported in the vertical orientation
- 2 X Crosby® HR-1000 UNC Heavy Lift Swivel Hoist Ring
 - WLL 4000#: 5/8-11, .69" THD projection
- Attached to top of support ring (threaded holes every 90 degrees).

Small vessel + blinds: ~2400#

Small Vessel Summary

- **Compress:** 32.6 PSI capable vessel (30 PSI design)
- **Soil loading** has substantial margin (13.6 KSI margin); also conservative for downhole lifting configuration (>1.7 KSI margin)
- **Support ring attachment** analyzed for prior geometry – needs to be updated for higher support ring, but design is expected to have substantial margin.
- **Transportation:** load cases have been run for using 4 swivel hoist rings (90 degrees apart on support ring) to chain vessel to truck bed (45 degree load angle) while sitting on hydrostat fixture (chamfered pipe). Addressing re-entrant corners for FEA; no issues expected (load case is at WLL for swivel hoist rings, DOT requires only 20% vessel weight)
- **Hydrostat:** FEA for vertical orientation while sitting on beveled pipe segment shows little-to-no stress on bottom head; design is adequate.
- **Small vessel design** will be complete once transportation configuration is finalized - FEA for preliminary configuration is done.

Large Sized Vessel

- LC3: Vessel Construction / Nozzle Attachment (Compress)
- LC5: Support Ring Attachment to Vessel (Lifting while full)
- LC7: Soil Loading / Vessel Weight (Vessel landed, stemming, non-lifting)
- LC16: Horizontal Pick / Trip (empty vessel, lifting)
- LC28: Vessel Lifting (full, downhole)

Large Sized Vessel: LC3, Compress

- COMPRESS 2017 Build 7700
- ASME Section VIII, Division 1, 2015 Edition
- Hydro: 1.3 X MAWP, 90% of yield
- Internal pressure (design): 30 PSI
- No external pressure

Pressure Summary

Component Summary							
Identifier	P Design (psi)	T Design (° F)	MAWP (psi)	MAP (psi)	MDMT (° F)	MDMT Exemption	Impact Tested
Welded Cover #2	30	120	108.99	108.99	-38.8	Note 1	No
Cylinder #1	30	120	134.06	152.33	-55	Note 2	No
Straight Flange on Ellipsoidal Head #1	30	120	584.81	603.19	-155	Note 4	No
Ellipsoidal Head #1	30	120	594.86	614.09	-155	Note 3	No
Nozzle #1 (A1)	30	120	59.75	59.75	-55	Note 5	No
Bolted Cover #2	30	120	175.46	175.46	-155	Note 6	No
Nozzle #2 (N2)	30	120	68.93	68.93	-55	Note 5	No
Bolted Cover #3	30	120	429.22	429.22	-155	Note 7	No
Nozzle #3 (N3)	30	120	68.93	68.93	-55	Note 5	No
Bolted Cover #4	30	120	429.22	429.22	-155	Note 7	No

Chamber Summary	
Design MDMT	-20 °F
Rated MDMT	-38.8 °F @ 59.75 psi
MAWP hot & corroded	59.75 psi @ 120 °F
MAP cold & new	59.75 psi @ 70 °F
(1) This pressure chamber is not designed for external pressure.	

Large Sized Vessel: Design Thicknesses

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Welded Cover #2	SA-516 70	83.25 OD	2.75	2.75	1.4419	0	1.00	Internal
Cylinder #1	SA-516 70	84 OD	457.166	0.375	0.1192	0	0.85	Internal
Straight Flange on Ellipsoidal Head #1	SA-516 70	82.75 ID	2.625	1.5	0.118	0	0.85	Internal
Ellipsoidal Head #1	SA-516 70	82.75 ID	22.1875	1.5*	0.1199	0	0.85	Internal
Bolted Cover #2	SA-516 70	27.5 OD	1.375	1.375	1.2501	0	1.00	Internal
Bolted Cover #3	SA-516 70	9 OD	0.75	0.75	0.7069	0	1.00	Internal
Bolted Cover #4	SA-516 70	9 OD	0.75	0.75	0.7069	0	1.00	Internal
Support Skirt #1	SA-516 70	84 ID	6	3	0.0265	0	0.55	Weight
*Head minimum thickness after forming								

Large Sized Vessel: Hydrostat / Nozzles

Hydrostatic Test

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

$$\begin{aligned} \text{Gauge pressure at } 70^{\circ}\text{F} &= \\ &= 1.3 \cdot \text{MAWP} \cdot \text{LSR} \\ &= 1.3 \cdot 59.75 \cdot 1 \\ &= 77.68 \text{ psi} \end{aligned}$$

Horizontal shop hydrostatic test				
Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor
Cylinder #1 (1)	80.681	3.005	1	1.30
Straight Flange on Ellipsoidal Head #1	80.672	2.996	1	1.30
Ellipsoidal Head #1	80.672	2.996	1	1.30
Welded Cover #2	80.681	3.005	1	1.30
Bolted Cover #2	79.503	1.826	1	1.30
Bolted Cover #3	80.118	2.442	1	1.30
Bolted Cover #4	78.385	0.709	1	1.30
Nozzle #1 (A1)	79.503	1.826	1	1.30
Nozzle #2 (N2)	80.114	2.438	1	1.30
Nozzle #3 (N3)	78.382	0.705	1	1.30

(1) Cylinder #1 limits the UG-99(b) stress ratio.
 (2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

Nozzle Schedule

Specifications								
Nozzle mark	Identifier	Size	Materials		Impact Tested	Normalized	Fine Grain	Blind
A1	Nozzle #1	20 OD x 1.031	Nozzle	SA-516 70	No	No	No	NPS 20 Class 150 WN A516 70
N2	Nozzle #2	4.5 OD x 0.337	Nozzle	SA-516 70	No	No	No	NPS 4 Class 150 WN A516 70
N3	Nozzle #3	4.5 OD x 0.337	Nozzle	SA-516 70	No	No	No	NPS 4 Class 150 WN A516 70

LC5: 84" Vessel Support Ring

Note: Full fidelity model (updated since FDR (6/27))

Load Case	LC5
Load Case Overview	Support ring contact for 84" dia vessel Partial Vessel Cylinder, Removed 12" Below Support Ring; Welds modeled as Bonded areas; No vessel covers
Model Fidelity / Simplifications	Distributed Force (Vessel Wt + NM Wt): 21986 + 100210 = 122196 LB / 4 = 30549 LB for quarter symmetry Vessel cylinder cross section (load in -Y)
Load Type 1	N/A
Load Placement 1	N/A
Load Type 2	
Load Placement 2	
Boundary Condition Type	Contact (frictionless) @ Bottom of Top Support Ring to LMC
Boundary Condition Location(s)	Support Plate (4" Thick, 85" Opening, 96" OD); Fixed translation (XYZ) @ Edge of Support Plate
Run Settings	See above. Nonlinear (Contacts); MPA
FEA Parameters	
Component Interaction (Bonded / Contact / Free)	Welds: Bonded, Face contact @ bottom of top support ring
Mesh Refinement Used	Max element size: 3.0" (global), .15" (local)
Element Total	178887 (Tet)
Material	A516 Grade 70
Poisson's ratio	.29 [-]
Density	.282 lb/in^3
Modulus of Elasticity	29000 KSI
Yield Strength	38 KSI
Ultimate Strength (Tensile)	70 KSI
FEA Results	
Allowable Stress	10.85 KSI (yield strength 38 KSI @ FoS of 3.5)
Peak Stress (VM) - Entire Model	6.4142 KSI
Peak Displacement - Entire Model	.00120"
Areas removed from summary	None
Reason for removal (Riser: Geometry / Load Edge / BC Edge)	N/A
Peak Stress (VM) *	N/A
Other Notes	
Date	7/3/2017
Run time	1357 min
Converged on maximum order	9
Stress Error (% of Max Prin Str)	3.4%

Margin: 4.435 KSI

LC5: 84" Vessel Support Ring

Note: Full fidelity model (updated since FDR (6/27))

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LC5: 84" Vessel Support Ring

Note: Full fidelity model (updated since FDR (6/27))

LC5 STRESS (VM, KSI)

LC5 DISPLACMENT (IN)

Bottom View

LC5 STRESS (VM, KSI)
MAX STRESS CLOSEUP

LC7: 84" Vessel Soil Loading

Load Case	LC7
Load Case Overview	Soil Loading for 84" dia vessel (10550 gallon) Partial Vessel Cylinder, Removed 12" Below Head; Welds modeled as Bonded areas; Nozzles removed, No holes in top of support ring Distributed Force (Vessel Wt + NM Wt): 21986 + 100210 = 122196 LB / 4 = 30549 LB for quarter symmetry Vessel cylinder cross section (load in -Y) Soil Pressure on all top horizontal surfaces: 6.5 PSI Support ring / top head horizontal surfaces Fixed XYZ @ Lift Fixture Bolt Holes See above.
Model Fidelity / Simplifications	QC
Load Type 1	
Load Placement 1	
Load Type 2	
Load Placement 2	
Boundary Condition Type	
Boundary Condition Location(s)	
Run Settings	
FEA Parameters	
Component Interaction (Bonded / Contact / Free)	Welds: Bonded Max element size: 2" (global), 0.15" weld root at bottom of support ring (to cylinder)
Mesh Refinement Used	205013 (Tet)
Element Total	A516 Grade 70
Material	.29 [-]
Poisson's ratio	.282 lb/in^3
Density	29000 KSI
Modulus of Elasticity	38 KSI
Yield Strength	70 KSI
Ultimate Strength (Tensile)	
FEA Results	
Allowable Stress	22.75 KSI (yield strength 38 KSI @ FoS of 1.67)
Peak Stress (VM) - Entire Model	9.163 KSI
Peak Displacement - Entire Model	.01595"
Areas removed from summary	None
Reason for removal (Riser: Geometry / Load Edge / BC Edge)	N/A
Peak Stress (VM) *	N/A
Other Notes	Geometric radiusing used to alleviate sharp corner singularities
Date	6/22/2017
Run time	38 min
Converged on maximum order	N/A
Stress Error (% of Max Prin Str)	2.9%

**Margin: 13.58 KSI (soil)
1.687 KSI (lifting)**

LC7: 84" Vessel Soil Loading

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LC7: 84" Vessel Soil Loading

NOTE: Shown at Lifting FoS (conservative for LC28)
Stemming allowable stress is 22.75 KSI

LC16: 84" Vessel Picking and Tripping: End

Load Case

Load Case Overview

Model Fidelity / Simplifications

Load Type 1
Load Placement 1
Boundary Condition Type 1
Boundary Condition 1 Location

Boundary Condition Type 2

Boundary Condition Location(s)
Run Settings

FEA Parameters

Component Interaction (Bonded / Contact / Free)
Mesh Refinement Used
Element Total
Material
Poisson's ratio
Density
Modulus of Elasticity
Yield Strength
Ultimate Strength (Tensile)

FEA Results

Allowable Stress
Peak Stress (VM) - Entire Model
Peak Displacement - Entire Model
Areas removed from summary
Reason for removal (Riser: Geometry / Load Edge / BC Edge)
Peak Stress (VM) *

Other Notes

Date
Run time
Converged on maximum order
Stress Error (% of Max Prin Str)

LC16

Picking and Tripping for the bottom half of the 84" dia vessel (10550 gallon)
Partial Vessel Cylinder, Broken at CG of vessel; Welds and threads modeled as Bonded areas;
Gravity load applied perpendicular to cylinder length
Gravity applied in x direction to entire model
Symmetry constraint
Surface of cylinder where vessel broken
Chain portion of swivel hoist ring dummy part constrained in all directions
See above.
Nonlinear (Contacts); Max Edge Order = 9; MPA

Welds: Bonded, Face contact SHR and SHR attachment
N/A
36892 (Tet)
A516 Grade 70
.29 [-]
.282 lb/in³
29000 KSI
38 KSI
70 KSI

10.85 KSI (yield strength 38 KSI @ FoS of 3.5)
8.59 KSI
.01478"
Swivel Hoist Ring dummy part
Did not care about stress in SHR
N/A

Geometric radiusing used to alleviate sharp corner singularities

6/1/2017
10.4 min
8
0.0%

Margin: 2.26 KSI

LC16: 84" Vessel Picking and Tripping: End

SIZE: 8"D, 4" tall

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LC16: 84" Vessel Picking and Tripping: End

Stress von Mises (WCS)

(ksi)

Displacement Magnitude (WCS)

(in)

Mid / Large Vessel Lifting, Option 1

- Mid / large vessels will be hydrostat'd and transported in the horizontal orientation
- **Top:**
 - 2 X Crosby® HR-1200 UNC Side Pull Hoist Rings
 - WLL 14000#: 1-1/4" - 7", 2.22" THD projection
 - Attached to side of support ring (machined flats every 90 degrees).
- **Bottom:**
 - Boss welded onto bottom head – central threaded hole.
 - 1 X Swivel Hoist Ring of choice for 2nd crane

RIGGING ACCESSORIES

HR-1200 Side Pull Hoist Rings

- Wide range of capacities available:
 - 650 lbs. to 29,000 lbs.
 - Metric sizes from 0.3 tonnes to 13 tonnes.
- Body components are Alloy Steel - Quenched and Tempered.
- Rated at 100% of Working Load Limit for angles up to 90 degrees.
- Each product is stamped with a Product Identification Code (PIC) for material traceability, along with a Working Load Limit, and the name Crosby or "CG".
- Hoist Ring body is furnished with Yellow Chromate finish for improved corrosion resistance.
- Utilize standard Crosby Red Pin® Shackles to connect to wire rope or synthetic slings. (sold separately)
- Multiple bolt lengths available to meet specific application requirements.
- Individually Proof Tested to 2-1/2 times Working Load Limit.
- All sizes are RFID EQUIPPED.

Load Rated

SEE APPLICATION AND WARNING INFORMATION
On Pages 005 - 007
Data Equated: www.crosbygroup.com

HR-1200 UNC Side Pull Hoist Rings

Weight Each (lbs.)	Working Load Limit (lbs.)	HR-1200 Stock No.	Hoist Ring Bolt Torque (FTLbs.)	Bolt Size A	EE Thread Proj. (in.) B	Dimensions (in.)							Recommended Shackles			
						C	D	E	F	Dia. G	H	I	Red Pin® Shackles 200, 210, 215, 215, 215, 215		Red Pin Web Shackles S-201	
													Nominal Size (in.)	WLL (T)	Web Size (in.)	WLL (T)
35	650	1067700	7	5/16-10x1.50	.59	1.00	.72	1.00	1.56	.80	.85	1.43	1/2, 5/8	2, 3-1/4	2	3-1/4
36	800	1067704	12	3/8-16x1.50	.59	1.00	.72	1.00	1.56	.80	.85	1.43	1/2, 5/8	2, 3-1/4	2	3-1/4
14	2000	1067708	28	1/2-13x2.00	.71	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2
14	2000	1067712	28	1/2-13x2.50	1.21	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2
15	3000	1067716	60	5/8-11x2.00	.71	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2
15	3000	1067720	60	5/8-11x2.75	1.46	2.97	.97	2.00	2.13	.93	1.07	1.79	5/8, 3/4	3-1/4, 4-3/4	2, 15	3-1/4, 4-1/2
4.5	5000	1067724	100	3/4-10x2.75	.90	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
4.6	5000	1067728	100	3/4-10x3.50	1.65	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
4.6	6500	1067732	160	7/8-9x2.75	.90	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
4.8	6500	1067736	160	7/8-9x3.50	1.65	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
4.8	8000	1067740	230	1-8x3.00	1.15	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
5.0	8000	1067744	230	1-8x4.00	2.15	4.32	1.34	3.00	3.00	1.07	1.35	2.42	7/8	6-1/2	2	6-1/4
10.2	14000	1067748	470	1-1/4-7x4.5	2.22	5.59	1.57	3.75	3.91	1.47	1.92	3.42	1-1/8, 1-1/4	8-1/2, 9-1/2, 12	3	8-1/2
23.5	17200	1067756	800	1-1/2-6x5.5	2.98	7.31	2.06	4.75	5.10	2.11	2.41	4.29	1-3/8, 1-1/2, 1-3/4	13-1/2, 17, 25	-	-
25.3	29000	1067764	1100	2-4.5x6.5	2.98	7.31	2.06	4.75	5.10	2.11	2.41	4.29	1-3/8, 1-1/2, 1-3/4	13-1/2, 17, 25	-	-

*Ultimate Load is 5 times the Working Load Limit.

Large vessel + blinds: ~22000#

Mid / Large Vessel Lifting, Option 2

- Mid / large vessels will be hydrostat'd and transported in the horizontal orientation

- **Top:**

- 2 X Crosby® HR-1000 UNC Heavy Lift Swivel Hoist Ring
 - WLL 15000#: 1-1/4 - 7, 2.09" THD projection
- Attached to top of support ring (threaded holes every 90 degrees).

- **Bottom:**

- Boss welded onto bottom head – central threaded hole.
- 1 X Swivel Hoist Ring of choice for 2nd crane

HR-1000 UNC Threads

Frame Size No.		HR-1000 Stock No.	Working Load Limit (lbs.)	Torque in Ft. Lbs.	Dimensions (in)									Weight Each (lbs.)
					Bolt Size A ±	Eff. Thread Projection Length B	C	D	Radius E	F	G	H		
	1	1068002	800	7	5/16 - 18 x 1.50	.52	3.69	.97	.62	.44	2.27	1.38	.60	
	1	1068006	1000	12	3/8 - 16 x 1.50	.52	3.69	.97	.62	.44	2.27	1.38	.62	
	2	1068010	2500	28	1/2 - 13 x 2.25	.69	6.26	1.96	1.25	.75	4.20	2.50	3.05	
	2 1/2	1068014	2500	28	1/2 - 13 x 2.75	1.19	6.26	1.96	1.25	.75	4.20	2.50	3.07	
	2	1068018	4000	60	5/8 - 11 x 2.25	.69	6.26	1.96	1.25	.75	4.20	2.50	3.11	
	2 1/2	1068022	4000	60	5/8 - 11 x 3.00	1.44	6.26	1.96	1.25	.75	4.20	2.50	3.18	
	2	1068026	5000	100	3/4 - 10 x 2.50	.94	6.26	1.96	1.25	.75	4.20	2.50	3.24	
	2 1/2	1068030	5000	100	3/4 - 10 x 3.00	1.44	6.26	1.96	1.25	.75	4.20	2.50	3.30	
	3	1068034	7000 **	100	3/4 - 10 x 3.00	.85	8.66	2.96	1.63	1.00	6.25	3.25	10.09	
	3 1/2	1068038	7000 **	100	3/4 - 10 x 3.50	1.35	8.66	2.96	1.63	1.00	6.25	3.25	10.21	
	3	1068042	8000	160	7/8 - 9 x 3.00	.85	8.66	2.96	1.63	1.00	6.24	3.25	10.21	
	3 1/2	1068046	8000	160	7/8 - 9 x 3.50	1.35	8.66	2.96	1.63	1.00	6.24	3.25	10.40	
	3	1068050	10000	230	1 - 8 x 3.50	1.35	8.66	2.96	1.63	1.00	6.24	3.25	10.50	
	3 1/2	1068054	10000	230	1 - 8 x 4.50	2.35	8.66	2.96	1.63	1.00	6.24	3.25	10.72	
	4	1068058	15000	470	1-1/4 - 7 x 5.00	2.09	11.21	3.71	2.00	1.25	7.82	4.00	21.90	
	4	1068062	24000	800	1-1/2 - 6 x 5.50	2.59	11.21	3.71	2.00	1.44	7.82	4.00	23.00	

Large vessel + blinds: ~22000#

LC28: 84" Vessel Lifting (Downhole)

Load Case	LC28
Load Case Overview	Lifting (downhole) for 84" dia vessel (10550 gallon) Partial Vessel Cylinder, Removed 12" Below Head; Welds modeled as Bonded areas; Nozzles removed
Model Fidelity / Simplifications	Distributed Force (Vessel Wt + NM Wt): $21986 + 100210 = 122196$ LB / 4 = 30549 LB for quarter symmetry
Load Type 1	Vessel cylinder cross section (load in -Y)
Load Placement 1	Soil Pressure on all top horizontal surfaces: 6.5 PSI
Load Type 2	Support ring / top head horizontal surfaces
Load Placement 2	Fixed XYZ @ Lift Fixture Bolt Holes
Boundary Condition Type	See above.
Boundary Condition Location(s)	MPA
Run Settings	
FEA Parameters	
Component Interaction (Bonded / Contact / Free)	Welds: Bonded Max element size: 2" (global), 0.15" weld root at bottom of support ring (to cylinder)
Mesh Refinement Used	288659 (Tet)
Element Total	A516 Grade 70
Material	.29 [-]
Poisson's ratio	.282 lb/in ³
Density	29000 KSI
Modulus of Elasticity	38 KSI
Yield Strength	70 KSI
Ultimate Strength (Tensile)	
FEA Results	
Allowable Stress	10.85 KSI (yield strength 38 KSI @ FoS of 3.5)
Peak Stress (VM) - Entire Model	6.903 KSI
Peak Displacement - Entire Model	.00112"
Areas removed from summary	None
Reason for removal (Riser: Geometry / Load Edge / BC Edge)	N/A
Peak Stress (VM) *	N/A
Other Notes	Geometric radiusing used to alleviate sharp corner singularities
Date	6/24/2017
Run time	604 min
Converged on maximum order	7
Stress Error (% of Max Prin Str)	2.2%

Margin: 3.948 KSI

LC28: 84" Vessel Lifting (Downhole)

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LC28: 84" Vessel Lifting (Downhole)

Large Vessel Summary

- **Compress: 59.75 PSI capable vessel (30 PSI design)**
- **Soil loading FEA is done – design is adequate.**
- **Support ring attachment FEA indicates adequate attachment for sitting at the top of the hole (post-FDR update).**
- **Transportation: preliminary saddle design has FEA models showing the saddles will not damage the vessel during hydrostat / transportation. Saddle design ongoing.**
- **Hydrostat: horizontal orientation being analyzed – will determine quantity and placement of saddles (and interactions with heads); should not affect vessel design.**
- **Downhole lifting FEA is done – design is adequate.**
- **Large vessel design will be complete once FEA is updated for support ring attachment and saddle design / implementation is complete.**

Mid Sized Vessel

- LC2: Vessel Construction / Nozzle Attachment (Compress)
- Several other cases are covered by large sized vessel design

Mid Sized Vessel: LC2, Compress

- COMPRESS 2017 Build 7700
- ASME Section VIII, Division 1, 2015 Edition
- Hydro: 1.3 X MAWP, 90% of yield
- Internal pressure (design): 30 PSI
- No external pressure

Pressure Summary

Component Summary							
Identifier	P Design (psi)	T Design (° F)	MAWP (psi)	MAP (psi)	MDMT (° F)	MDMT Exemption	Impact Tested
Welded Cover #2	30	120	108.79	108.99	-38.8	Note 1	No
Cylinder #1	30	120	148.83	152.33	-55	Note 2	No
Straight Flange on Ellipsoidal Head #1	30	120	599.58	603.19	-155	Note 4	No
Ellipsoidal Head #1	30	120	609.63	614.09	-155	Note 3	No
Nozzle #1 (A1)	30	120	59.55	59.75	-55	Note 5	No
Bolted Cover #2	30	120	175.46	175.46	-155	Note 6	No
Nozzle #2 (N2)	30	120	68.73	68.93	-55	Note 5	No
Bolted Cover #3	30	120	429.22	429.22	-155	Note 7	No
Nozzle #3 (N3)	30	120	68.73	68.93	-55	Note 5	No
Bolted Cover #4	30	120	429.22	429.22	-155	Note 7	No

Chamber Summary	
Design MDMT	-20 °F
Rated MDMT	-38.8 °F @ 59.55 psi
MAWP hot & corroded	59.55 psi @ 120 °F
MAP cold & new	59.75 psi @ 70 °F
(1) This pressure chamber is not designed for external pressure.	

Mid Sized Vessel: Design Thicknesses

Thickness Summary

Component Data								
Component Identifier	Material	Diameter (in)	Length (in)	Nominal t (in)	Design t (in)	Total Corrosion (in)	Joint E	Load
Welded Cover #2	SA-516 70	83.25 OD	2.75	2.75	1.4468	0	1.00	Internal
Cylinder #1	SA-516 70	84 OD	91.082	0.375	0.0828	0	0.85	Internal
Straight Flange on Ellipsoidal Head #1	SA-516 70	82.75 ID	2.625	1.5	0.0819	0	0.85	Internal
Ellipsoidal Head #1	SA-516 70	82.75 ID	22.1875	1.5*	0.0839	0	0.85	Internal
Bolted Cover #2	SA-516 70	27.5 OD	1.375	1.375	1.2501	0	1.00	Internal
Bolted Cover #3	SA-516 70	9 OD	0.75	0.75	0.7069	0	1.00	Internal
Bolted Cover #4	SA-516 70	9 OD	0.75	0.75	0.7069	0	1.00	Internal
Support Skirt #1	SA-516 70	84 ID	6	3	0.0072	0	0.55	Weight
*Head minimum thickness after forming								

Mid Sized Vessel: Hydrostat / Nozzles

Hydrostatic Test

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

$$\begin{aligned} \text{Gauge pressure at } 70^{\circ}\text{F} &= \\ &= 1.3 \cdot \text{MAWP} \cdot \text{LSR} \\ &= 1.3 \cdot 59.55 \cdot 1 \\ &= 77.42 \text{ psi} \end{aligned}$$

Horizontal shop hydrostatic test				
Identifier	Local test pressure (psi)	Test liquid static head (psi)	UG-99(b) stress ratio	UG-99(b) pressure factor
Cylinder #1 (1)	80.422	3.005	1	1.30
Straight Flange on Ellipsoidal Head #1	80.413	2.996	1	1.30
Ellipsoidal Head #1	80.413	2.996	1	1.30
Welded Cover #2	80.422	3.005	1	1.30
Bolted Cover #2	79.243	1.826	1	1.30
Bolted Cover #3	79.858	2.442	1	1.30
Bolted Cover #4	78.126	0.709	1	1.30
Nozzle #1 (A1)	79.243	1.826	1	1.30
Nozzle #2 (N2)	79.855	2.438	1	1.30
Nozzle #3 (N3)	78.122	0.705	1	1.30

(1) Cylinder #1 limits the UG-99(b) stress ratio.
 (2) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

Nozzle Schedule

Specifications								
Nozzle mark	Identifier	Size	Materials		Impact Tested	Normalized	Fine Grain	Blind
A1	Nozzle #1	20 OD x 1.031	Nozzle	SA-516 70	No	No	No	NPS 20 Class 150 WN A516 70
N2	Nozzle #2	4.5 OD x 0.337	Nozzle	SA-516 70	No	No	No	NPS 4 Class 150 WN A516 70
N3	Nozzle #3	4.5 OD x 0.337	Nozzle	SA-516 70	No	No	No	NPS 4 Class 150 WN A516 70

Midsize Vessel Summary

- **Compress: 59.55 PSI capable vessel (30 PSI design)**
- **Soil loading FEA is done – design is adequate.**
- **Support ring attachment FEA indicates adequate attachment for sitting at the top of the hole (post-FDR update).**
- **Transportation: preliminary saddle design has FEA models showing the saddles will not damage the vessel during hydrostat / transportation. Saddle design ongoing.**
- **Hydrostat: horizontal orientation being analyzed – will determine quantity and placement of saddles (and interactions with heads); should not affect vessel design.**
- **Downhole lifting FEA is done – design is adequate.**
- **Midsize vessel design will be complete once FEA is updated for support ring attachment and saddle design / implementation is complete.**

Backup Slides

Small Vessel: 20"NPS Nozzle Attachment

Nozzle #1 (A1)

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Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	0°
Distance to head center, R	0"
Passes through a Category A joint	No
Nozzle	
Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, In. 37)
Inside diameter, new	17.938"
Nominal wall thickness	1.031"
Corrosion allowance	0"
Projection available outside vessel, Lpr	4.81"
Projection available outside vessel to flange face, Lf	10.5"
Local vessel minimum thickness	0.75"
Liquid static head included	0.46 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D p. 18, In. 37)
Diameter, D _p	23"
Thickness, t _p	0.75"
Is split	No
Welds	
Inner fillet, Leg ₁	0.75"
Outer fillet, Leg ₂	0.625"
Nozzle to vessel groove weld	0.5625"
Pad groove weld	0.75"

ASME B16.5-2013 Flange	
Description	NPS 20 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt ≤ 2 1/2 (II-D p. 344, In. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	17.938"
Gasket	
Thickness, T	0.175"
Inner Diameter	17.938"
Outer Diameter	23"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.1144)	
Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Small Vessel: 1.5"NPS Nozzle Attachment

Nozzle #2 (N2)

ASME Section VIII Division 1, 2015 Edition

Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	180°
Distance to head center, R	17"
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D p. 18, ln. 37)
Inside diameter, new	1.5"
Nominal wall thickness	0.2"
Corrosion allowance	0"
Projection available outside vessel, Lpr	4.06"
Projection available outside vessel to flange face, Lf	6.5"
Local vessel minimum thickness	0.75"
Liquid static head included	0.46 psi
Longitudinal joint efficiency	1
Reinforcing Pad	
Material specification	SA-516 70 (II-D p. 18, ln. 37)
Diameter, D _p	2.9"
Thickness, t _p	0.25"
Is split	No
Welds	
Inner fillet, Leg ₄₁	0.25"
Outer fillet, Leg ₄₂	0.25"
Nozzle to vessel groove weld	0.25"
Pad groove weld	0.1875"

ASME B16.5-2013 Flange	
Description	NPS 1.5 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt <= 2 1/2 (II-D p. 344, ln. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0.16 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Full UW-11(a) Type 1
Gasket	
Thickness, T	0.175"
Inner Diameter	1.61"
Outer Diameter	2.88"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.1149)	
Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Mid Vessel: 20"NPS Nozzle Attachment

Nozzle #1 (A1)

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Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	0°
Distance to head center, R	0"
Passes through a Category A joint	No
Nozzle	
Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, ln. 37)
Inside diameter, new	17.938"
Nominal wall thickness	1.031"
Corrosion allowance	0"
Projection available outside vessel, L _{pr}	2.81"
Projection available outside vessel to flange face, L _f	8.5"
Local vessel minimum thickness	2.75"
Liquid static head included	0.2 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg ₄₁	0.5"
Nozzle to vessel groove weld	0.625"

ASME B16.5-2013 Flange	
Description	NPS 20 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt ≤ 2 1/2 (II-D p. 344, ln. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	17.938"
Gasket	
Thickness, T	0.175"
Inner Diameter	17.938"
Outer Diameter	23"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.209)	
Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Mid Vessel: 4"NPS Nozzle Attachment

Nozzle #2 (N2)

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Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	180°
Distance to head center, R	24"
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D p. 18, In. 37)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0"
Projection available outside vessel, L _{pr}	3"
Projection available outside vessel to flange face, L _f	6"
Local vessel minimum thickness	2.75"
Liquid static head included	0.2 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg ₄₁	0.375"
Nozzle to vessel groove weld	0.375"

ASME B16.5-2013 Flange	
Description	NPS 4 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt ≤ 2 1/2 (II-D p. 344, In. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Gasket	
Thickness, T	0.175"
Inner Diameter	4.03"
Outer Diameter	6.19"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.209)	
Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Large Vessel: 20"NPS Nozzle Attachment

Nozzle #1 (A1)

ASME Section VIII Division 1, 2015 Edition

Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	0°
Distance to head center, R	0"
Passes through a Category A joint	No
Nozzle	
Access opening	Yes
Material specification	SA-516 70 (II-D p. 18, ln. 37)
Inside diameter, new	17.938"
Nominal wall thickness	1.031"
Corrosion allowance	0"
Projection available outside vessel, Lpr	2.81"
Projection available outside vessel to flange face, Lf	8.5"
Local vessel minimum thickness	2.75"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg ₁	0.5"
Nozzle to vessel groove weld	0.625"

ASME B16.5-2013 Flange	
Description	NPS 20 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt ≤ 2 1/2 (II-D p. 344, ln. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Bore diameter, B (specified by purchaser)	17.938"
Gasket	
Thickness, T	0.175"
Inner Diameter	17.938"
Outer Diameter	23"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2097)	
Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Large Vessel: 4"NPS Nozzle Attachment

Nozzle #2 (N2)

ASME Section VIII Division 1, 2015 Edition

Note: round inside edges per UG-76(c)	
Location and Orientation	
Located on	Welded Cover #2
Orientation	180°
Distance to head center, R	24"
Passes through a Category A joint	No
Nozzle	
Access opening	No
Material specification	SA-516 70 (II-D p. 18, ln. 37)
Inside diameter, new	3.826"
Nominal wall thickness	0.337"
Corrosion allowance	0"
Projection available outside vessel, Lpr	3"
Projection available outside vessel to flange face, Lf	6"
Local vessel minimum thickness	2.75"
Liquid static head included	0 psi
Longitudinal joint efficiency	1
Welds	
Inner fillet, Leg ₄₁	0.375"
Nozzle to vessel groove weld	0.375"

ASME B16.5-2013 Flange	
Description	NPS 4 Class 150 WN A516 70
Bolt Material	SA-193 B7 Bolt ≤ 2 1/2 (II-D p. 344, ln. 31)
Blind included	Yes
Rated MDMT	-55°F
Liquid static head	0 psi
MAWP rating	280 psi @ 120°F
MAP rating	285 psi @ 70°F
Hydrotest rating	450 psi @ 70°F
PWHT performed	No
Impact Tested	No
Circumferential joint radiography	Spot UW-11(b) Type 1
Gasket	
Thickness, T	0.175"
Inner Diameter	4.03"
Outer Diameter	6.19"
Notes	
Flange rated MDMT per UCS-66(b)(3) = -155°F (Coincident ratio = 0.2097) Bolts rated MDMT per Fig UCS-66 note (c) = -55°F	

Saddle Design (Mid / Large Vessels)

- Welded A36 assemblies, used to do hydrostat and to transport (with top retention assembly).
- Preliminary FEA done to see impact of vessel sitting on saddle (done for 44 PSI hydrostat)
- Transport assembly will use soft gasket material to secure the top of the vessel (needs 20% of vessel weight to secure)

42" Vessel Hydrostat

Margin: 20.37 KSI

42" Vessel Transportation

Margin: 14.35 KSI