Design By:

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Design for the Packed Tower *Sample Design*

Fabricated By:

Project Reference #Sample
Revision 0

COLORADO LICENSED
STEVEN L WAGNER
PE.0051452
PROFESSIONAL ENGINEER

14 April 2025

Quantity:	(1) Required
Designation Number:	
End User:	
Installation Location:	
Project Specifications:	
Governing Standards:	
Vessel Contents:	(S.G. = $sg_{pr} = 1.25$ max.)
M.A.W.P.	$P_i = 0 \cdot psi$(g) (internal) at $T_{min} = 10 \cdot °F$ to $T_{max} = 180 \cdot °F$
M.A.E.W.P.	$P_e = 25 \cdot inWC$(g) (external) at $T_{min} = 10 \cdot °F$ to $T_{max} = 180 \cdot °F$

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Last Revision: 4/14/2025

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Design Notes

1. Material Selections and corrosion barrier requirements are by others.
2. Details in design may not be to scale.
3. FRP thicknesses are Type II and include non-structural FRP corrosion barriers, unless noted otherwise.
4. Anchorage requirements are by others.
5. Cast-in-place anchors are not recommended.
6. See installation requirements in support lug and lift lug designs.
7. Components are not designed for loads resulting from excessive process conditions, unless noted otherwise (e.g., impact loads, significant turbulence, vortexing). Vessels should be filled and emptied in a steady flow state that does not result in significant loads on components.
8. It is the end user's responsibility to ensure the vessel does not experience conditions more extreme than what is summarized in the Design Conditions section.
9. Lift lugs are not allowed to be used with internals installed (e.g., Demister, Packing, Brick).

Material Selections

Thermoplastic Liner:	None
FRP Corrosion Barrier	
- Resin:	Derakane 470
- Cure:	CoNap / MEKP or CHP
FRP Structural	
- Resin:	Derakane 470
- Cure:	CoNap / MEKP or CHP
Support System:	FRP
Lift Lugs:	FRP
Gaskets:	Full Face, EPDM

Nomenclature

Veils

$Ve \equiv 0.010 \cdot in$ - C-Veil ; $Cv \equiv 0.010 \cdot in$ - Carbon Veil ; $Ne \equiv 0.015 \cdot in$ - Synthetic Veil (Nexus)

Chopped Fibers

$Mat \equiv 0.040 \cdot in$ - 1.5 oz./sq.ft Mat ; $Z \equiv 0.020 \cdot in$ - 3/4 oz./sq.ft Mat ; $CS \equiv 0.001 \cdot in$ - 1mil Chopped Roving (Chopper Gun)

Woven/Stitched Fibers

$WR \equiv 0.032 \cdot in$ - 24 oz./sq.yrd Woven Roving

FRP corrosion barrier thickness....
$t_{cbf} \equiv 2 \cdot Ve + 3 \cdot Mat = 0.14\,in$

Portion of FRP corrosion barrier thickness NOT included in structural calculations:
$t_{cbn} \equiv t_{cbf} = 0.14\,in$

Exterior FRP corrosion barrier thickness NOT included in structural calculations:
$t_{cbe} \equiv Ve = 0.01\,in$

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Design Conditions

Density of water....

$\rho_w \equiv 62.4 \cdot pcf$

Unit definition for inches of water column....

$1\,inWC \equiv 0.0361 \cdot psi$

Design Factors

Operating loads....

$f_o \equiv 10$

Temporary loads....

$f_t \equiv 5$

Elastic stability....

$f_v \equiv 5$

Vessel Contents

Contents specific gravity....

$sg_{pr} \equiv 1.25$

Density of contents....

$\rho_{pr} \equiv \rho_w \cdot sg_{pr} = 78 \cdot pcf$

Packing maximum density....

$\rho_{pk} \equiv 25 \cdot pcf$

Design Pressure

Internal....

$P_i \equiv 0.0001 \cdot psi$

External....

$P_e \equiv 25 \cdot inWC = 0.903\,psi$

Design Temperature

Minimum design temperature....

$T_{min} \equiv °F(10) = 10 \cdot °F$

Maximum design temperature....

$T_{max} \equiv °F(180) = 180 \cdot °F$

Top Head Loads

Operating

Localized vertical Load....

$Fv_0 \equiv 0 \cdot lbf$

Radius of vertical load....

$rv_0 \equiv 6 \cdot in$

Uniform Live Load....

$P_l \equiv 10 \cdot psf$

Moment at top....

$M_a \equiv 0 \cdot ft \cdot lbf$

Torque....

$T_a \equiv 0 \cdot in \cdot lbf$

Temporary

Localized vertical Load....

$Fv_1 \equiv 500 \cdot lbf$

Radius of vertical load....

$rv_1 \equiv 6 \cdot in$

Moment at top....

$M_b \equiv 0 \cdot ft \cdot lbf$

Environmental Loads per ASCE 7-16, Chapter 15 - Nonbuilding Structures

Risk Category....
(Table 1.5-1)

$RC \equiv$ "IV"

Wind

Basic wind speed....
(Figure 26.5-1)

$v_w \equiv 120 \cdot mph$

Exposure category....
(Section 26.7.3)

$C_e \equiv$ "C"

Wind direction factor....
(Table 26.6-1)

$K_d \equiv 0.95$

Topographical factor....
(Section 26.8.2)

$K_{zt} \equiv 1.0$

Gust factor....
(Section 26.11.1)

$G_f \equiv 0.85$

Seismic

0.2 second spectral response acceleration....
(Figure 22-1)

$S_s \equiv 0.065$

1.0 second spectral response acceleration....
(Figure 22-2)

$S_1 \equiv 0.039$

Site Class....
(Section 11.4.2)

$SC \equiv$ "D"

Long-period transition period....
(Figure 22-14)

$T_L \equiv 12 \cdot sec$

Snow

Ground snow load....
(Fig. 7-1)

$P_g \equiv 0 \cdot psf$

Exposure factor....
(Table 7-2)

$C_E \equiv 0.9$

Thermal factor....
(Table 7-3)

$C_T \equiv 1.2$

External Flooding

Height above support line....

$h_b \equiv 0 \cdot in$

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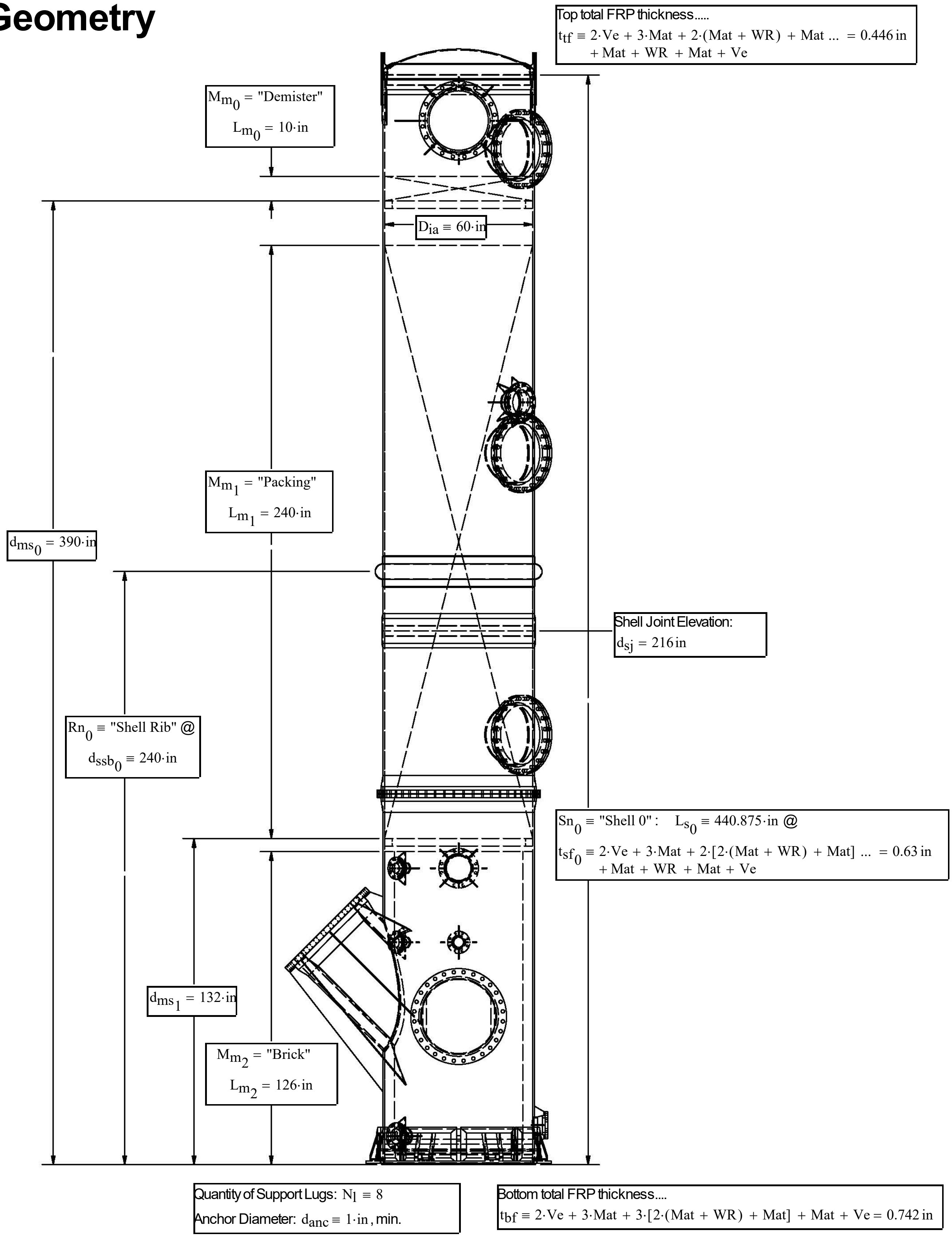
Geometry



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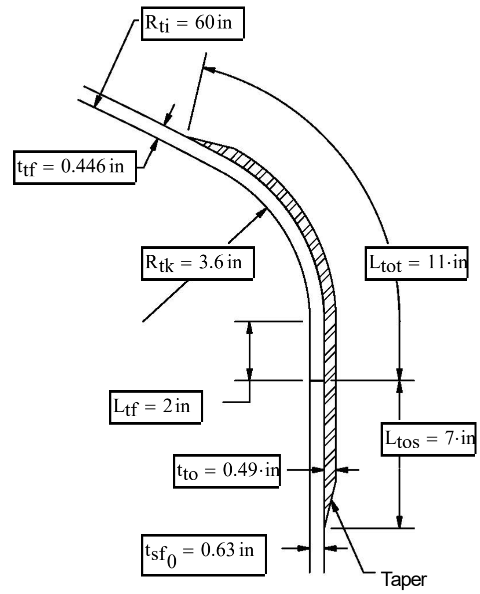
Fabrication Details

Internal Corrosion Barrier Overlay:
$t_{cbo} = 0.14\,in$ x $w_{cbf} \equiv 6\cdot in$ wide (centered at joint)

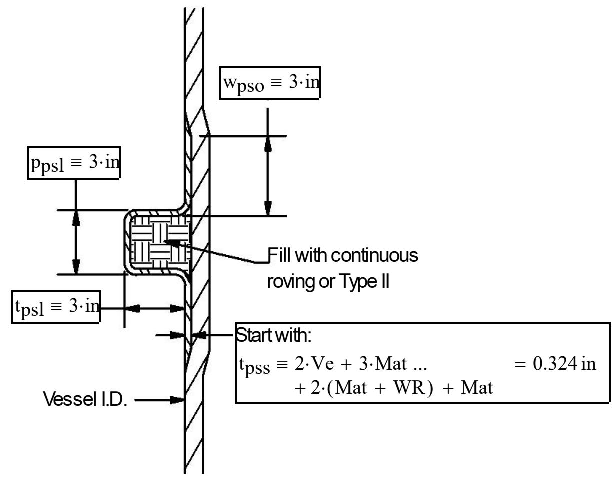
Taper ratio....
$TPR_r \equiv 4:1$
(Length : Thickness)
Taper angle with component....
$TPR_a = 14.036\cdot deg$

Head Shapes
Top: $T_t \equiv$ "ASME F&D"
Bottom: $T_b \equiv$ "Flat"

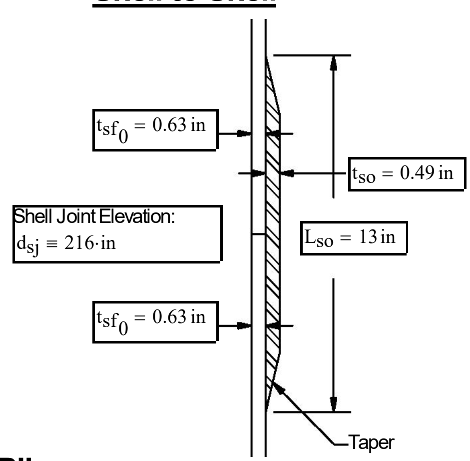
Top Head to Shell



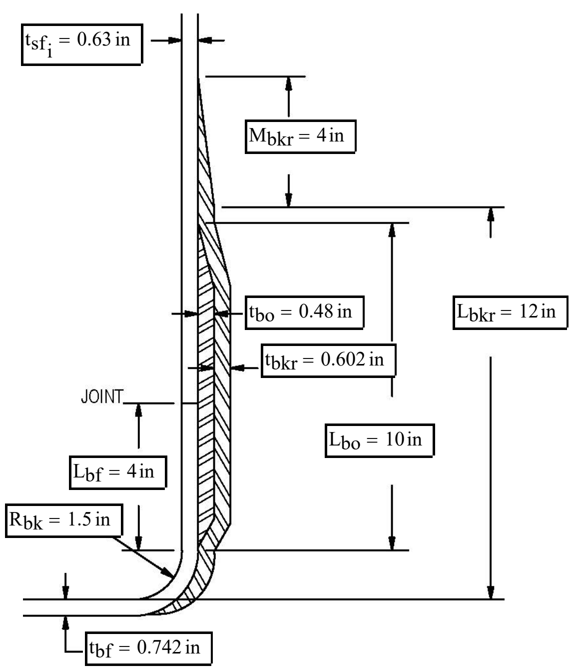
Internal Support Ledge



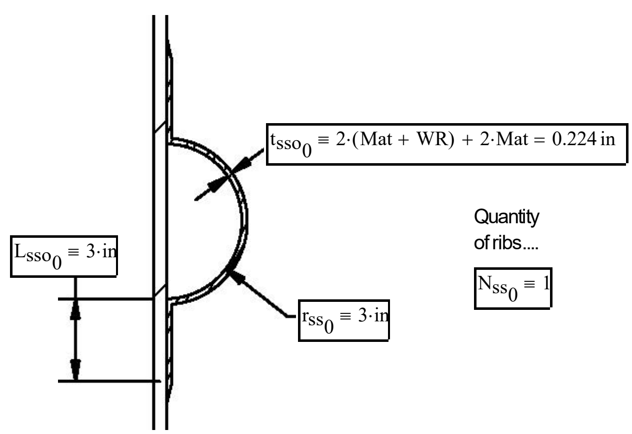
Shell to Shell



Flat Bottom to Shell



Shell Rib



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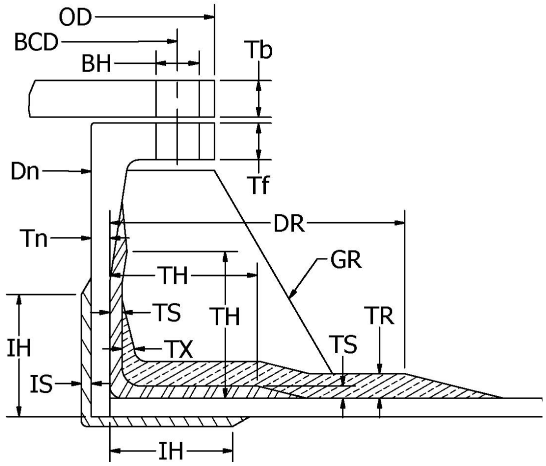
Nozzle Installations & Cutout Reinforcements



*Units: inches

Nomenclature

Mk:	Designation
Dn:	Chord length of cutout in the hoop direction and accounting for offset installations
EL:	Installation elevation from bottom tangent
Tn:	Neck thickness
TS:	Attachment overlay thickness
TH:	External Installation length
IS:	Internal installation thickness
IH:	Internal installation length
TR:	Reinforcement pad thickness
TX:	Reinforcement base thickness
DR:	Reinforcement pad length
GR:	Gusset requirement
N/R:	Not required

NS =

"Mk"	"Dn"	"EL"	"Tn"	"TS"	"TH"	"TR"	"TX"	"DR"	"IS"	"IH"	"GR"
"A"	36	96	0.69	0.7	6	0.94	0.47	18	0.69	3	"8 HD Plates"
"B1"	10	120	0.38	0.33	3	0.69	0.345	5	0.14	3	"8 HD Plates"
"D"	6	16	0.38	0.33	3	0.49	0.245	3	0.14	3	"Required"
"H1"	30	60	0.375	0.385	4	0.49	0.245	15	0.375	3	"None"
"K"	4	120	0.31	0.27	3	0.33	0.165	3	0.14	3	"Required"
"L"	4	120	0.31	0.27	3	0.33	0.165	3	0.14	3	"Required"
"P"	6	11.5	0.38	0.33	3	0.49	0.245	3	0.14	3	"Required"
"R"	4	90	0.31	0.27	3	0.33	0.165	3	0.14	3	"Required"
"T (new)"	4	90	0.31	0.27	3	0.33	0.165	3	0.14	3	"Required"
"B2"	10	308.5	0.38	0.33	3	0.51	0.255	5	0.14	3	"8 HD Plates"
"C"	24	422.5	0.69	0.37	3	0.51	0.255	12	0.14	3	"8 HD Plates"
"H2"	24	174	0.375	0.32	3	0.49	0.245	12	0.14	3	"None"
"H3"	24	288	0.375	0.32	3	0.49	0.245	12	0.14	3	"None"
"H5"	24	411	0.375	0.32	3	0.49	0.245	12	0.14	3	"None"

Heavy Duty Plate Gussets (HD):

Start with:

$t_{ps} \equiv 2\cdot[2\cdot(Mat + WR) + Mat] = 0.368\,in$

Attach with:

$t_{po} \equiv 2\cdot[2\cdot(Mat + WR) + Mat] = 0.368\,in$

x $w_{po} \equiv 3\cdot in$, each way.

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Weights & Capacities

Empty weight....

$\boxed{W_{ve} = 4456.468 \cdot lbf}$

*Empty weight does not include the demister, packing, and brick.
Lift lugs are not allowed to be used after items are installed.

Operating

Contents height above bottom tangent....

$H_{po} \equiv 96 \cdot in$

Capacity....

$\boxed{V_{vo} = 1165.955\,gal}$

Weight of vessel with product + miscellaneous items supported by vessel....

$\boxed{W_{vo} = 44431.457 \cdot lbf}$

Miscellaneous items....

$$MiscI = \begin{pmatrix} \text{"Demister"} & 1000 \\ \text{"Packing"} & 9817.477 \\ \text{"Brick"} & 17000 \end{pmatrix} \cdot lbf$$

Design

Contents height above bottom tangent....

$H_{pd} \equiv \sum L_s = 440.875\,in$

Capacity....

$\boxed{V_{vd} = 5387.215\,gal}$

Weight of vessel with product....

$\boxed{W_{vd} = 60629.411 \cdot lbf}$

Weight of vessel with water....

$W_{vw} = 49394.823 \cdot lbf$

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Loads Acting on Support System

1. Units are in pounds ($u_f \equiv \text{lbf}$), and foot-pounds ($u_m \equiv \text{ft}\cdot\text{lbf}$), unless noted otherwise.

Unfactored Loads

SSL =

"Load"	"Shear"	"Moment"	"Uplift"
"Dead (Min.)"	0	0	−4309
"Dead (Max.)"	0	0	−32126
"Dead (Operating)"	0	0	−15126
"Live"	0	0	1
"Wind"	4812	86935	878
"Seismic"	1467	15209	394
"Flooding"	0	0	0

Load Combinations (Factored)

1. Load combinations are provided as a courtesy and may not be properly factored to design items outside of the scope of this design. Load combinations used to design structures, foundations, anchorage and other items associated with this equipment should be determined by the engineer responsible for the respective design.
2. Loads have been factored and combined per ASCE 7.
3. Loads do not include seismic overstrength factor.

for Strength Design (LRFD)

Combined Loads on Support System

$AN_{2.3}$ =

"Load Case"	"Shear"	"Moment"	"Uplift"
"Live"	0	0	0
"Wind"	4812	86935	0
"Seismic"	1467	15209	0
"Flooding"	0	0	0

Governing Loads Resisted by One Lug

$Lug_{2.3}$ =

"Load Case"	"Shear"	"Uplift"
"Live"	0	0
"Wind"	602	8109
"Seismic"	184	0
"Flooding"	0	0

for Allowable Stress Design (ASD)

Combined Loads on Support System

$AN_{2.4}$ =

"Load Case"	"Shear"	"Moment"	"Uplift"
"Live"	0	0	0
"Wind"	2887	52161	0
"Seismic"	1027	10646	0
"Flooding"	0	0	0

Governing Loads Resisted by One Lug

$Lug_{2.4}$ =

"Load Case"	"Shear"	"Uplift"
"Live"	0	0
"Wind"	361	4833
"Seismic"	129	0
"Flooding"	0	0

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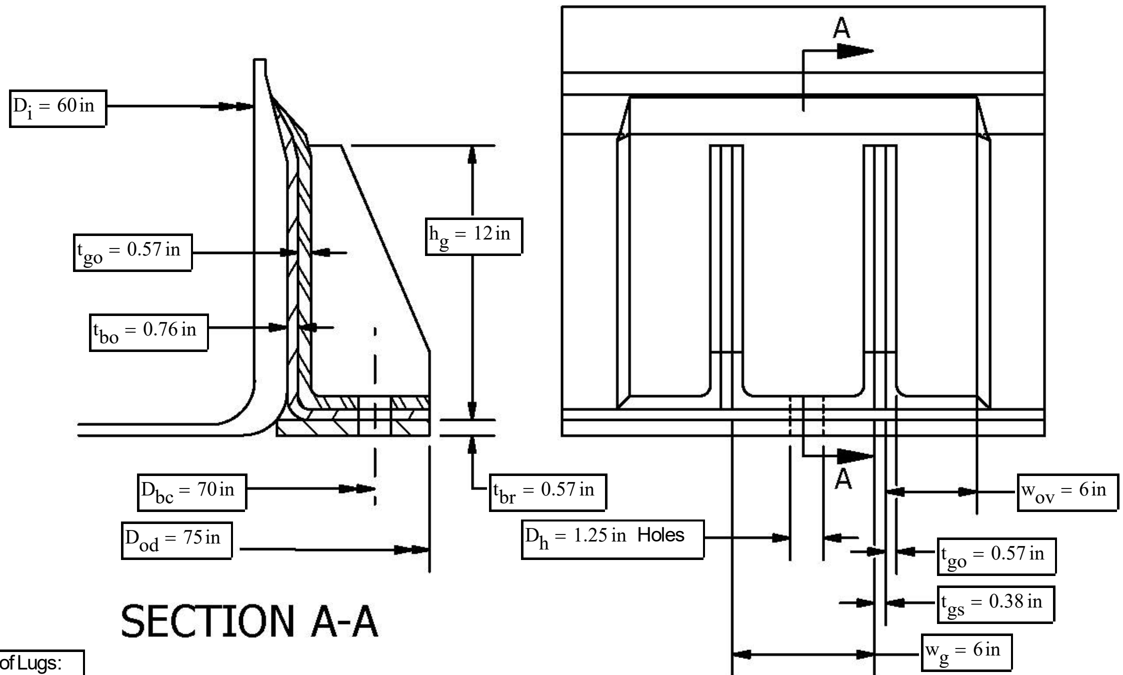
Base Hold Down - Single Ring

Notes:
1. Anchors & foundation designs by others.
2. Fill with grout under baseplate after vessel is filled.
3. Hand tighten nut + 1/4 turn after installation.
   - Nuts may need re-tightening after vessel is put into service.
4. Thicknesses are Type II unless noted otherwise

Nomenclature

$Mat \equiv 0.040 \cdot in$ - 1.5 oz./sq.ft Mat

$WR \equiv 0.035 \cdot in$ - 24 oz./sq.yrd Woven Roving



Number of Lugs:
$N_{lug} \equiv 8$

Base thickness....

$t_{br} \equiv 3 \cdot [2 \cdot (Mat + WR) + Mat] = 0.57 in$

Base outside overlay....

$t_{bo} \equiv 4 \cdot [2 \cdot (Mat + WR) + Mat] = 0.76 in$

Ring total thickness....

$t_r = 1.33 in$

Gusset starter plate thickness....

$t_{gs} \equiv 2 \cdot [2 \cdot (Mat + WR) + Mat] = 0.38 in$

Gusset overlay thickness....

$t_{go} \equiv 3 \cdot [2 \cdot (Mat + WR) + Mat] = 0.57 in$

Gusset total thickness....

$t_g = 1.52 in$

Gusset overlay width....

$w_{ov} \equiv 6 \cdot in$

Bolt circle diameter...

$D_{bc} \equiv 70 \cdot in$ (max)

Base OD....

$D_{od} \equiv D_{bc} + 5 \cdot in = 75 in$

Gusset height....

$h_g \equiv 12 \cdot in$

Gusset width....

$w_g \equiv 6 \cdot in$

Anchor hole diameter....

$D_h \equiv 1.25 \cdot in$

Washer diameter....

$D_w \equiv 2 \cdot in$

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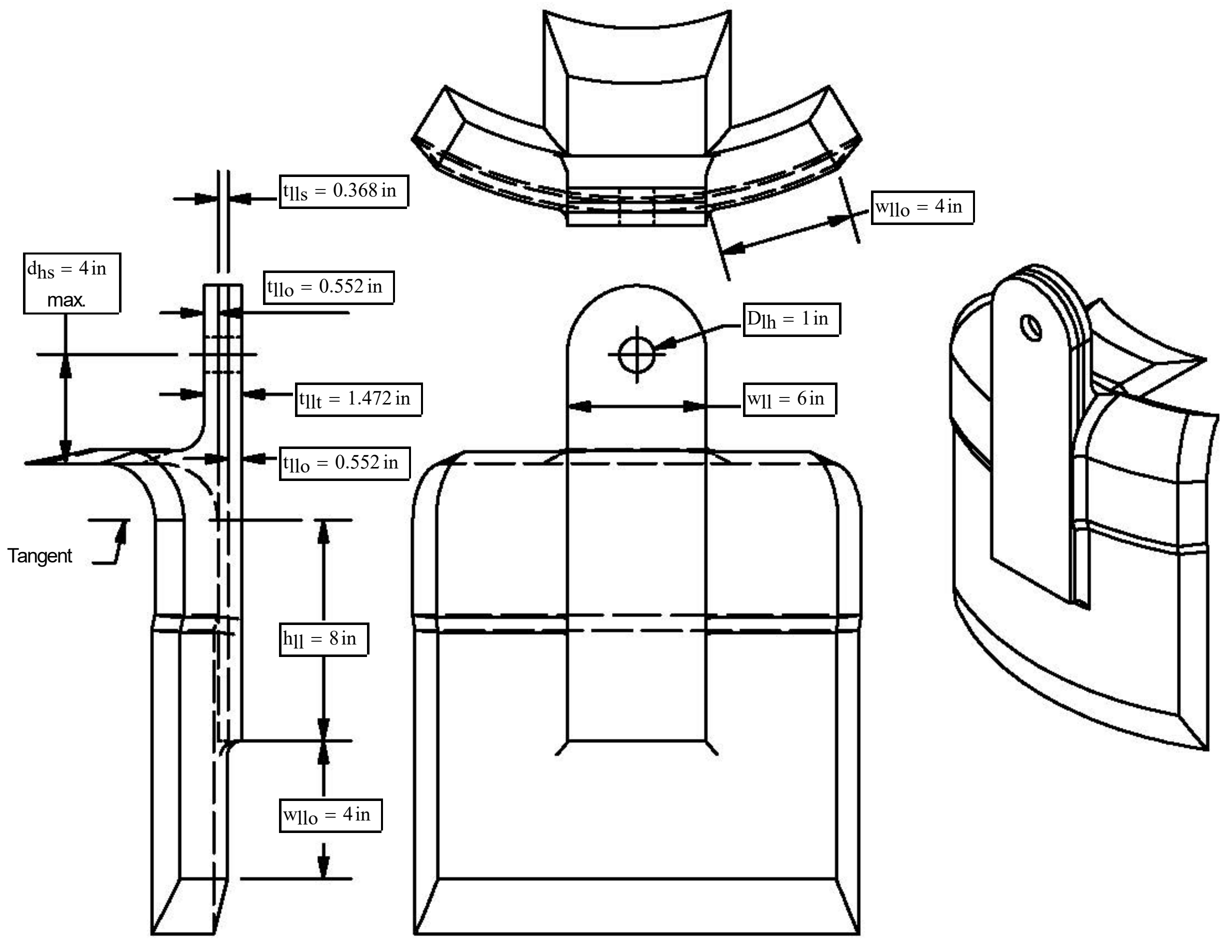
Design for FRP Lift Lugs

Notes:
1. Thicknesses are Type II, unless noted otherwise.



Nomenclature

$Mat \equiv 0.040 \cdot in$ - 1.5 oz./sq.ft Mat

$WR \equiv 0.032 \cdot in$ - 24 oz./sq.yrd Woven Roving

Quantity of lugs....

$\boxed{N_{ll} \equiv 2}$

Starter plate thickness....

$\boxed{t_{lls} \equiv 2 \cdot [2 \cdot (Mat + WR) + Mat] = 0.368\,in}$

Overlay thickness (each side)....

$\boxed{t_{llo} \equiv 3 \cdot [2 \cdot (Mat + WR) + Mat] = 0.552\,in}$

Width of lug....

$w_{ll} \equiv 6 \cdot in$

Length above vessel to center of hole....

$d_{hs} \equiv 4 \cdot in$ (max)

Length of lug attached to vessel wall....

$h_{ll} \equiv 8 \cdot in$

Diameter of shackle hole....

$D_{lh} \equiv 1 \cdot in$

Overlay width from lug....

$w_{llo} \equiv 4 \cdot in$

Design Conditions

Inside diameter....

$D_i \equiv 60 \cdot in$

Shell thickness at attachment....

$t_{st} \equiv 1 \cdot in$

Empty vessel weight....

$W_{ve} \equiv 4500 \cdot lbf$

Shock factor for dynamic loads....

$C_s \equiv 2$

Design factor....

$f_t \equiv 5$

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FRP Body Flange Design

Design & Fabrication Notes:

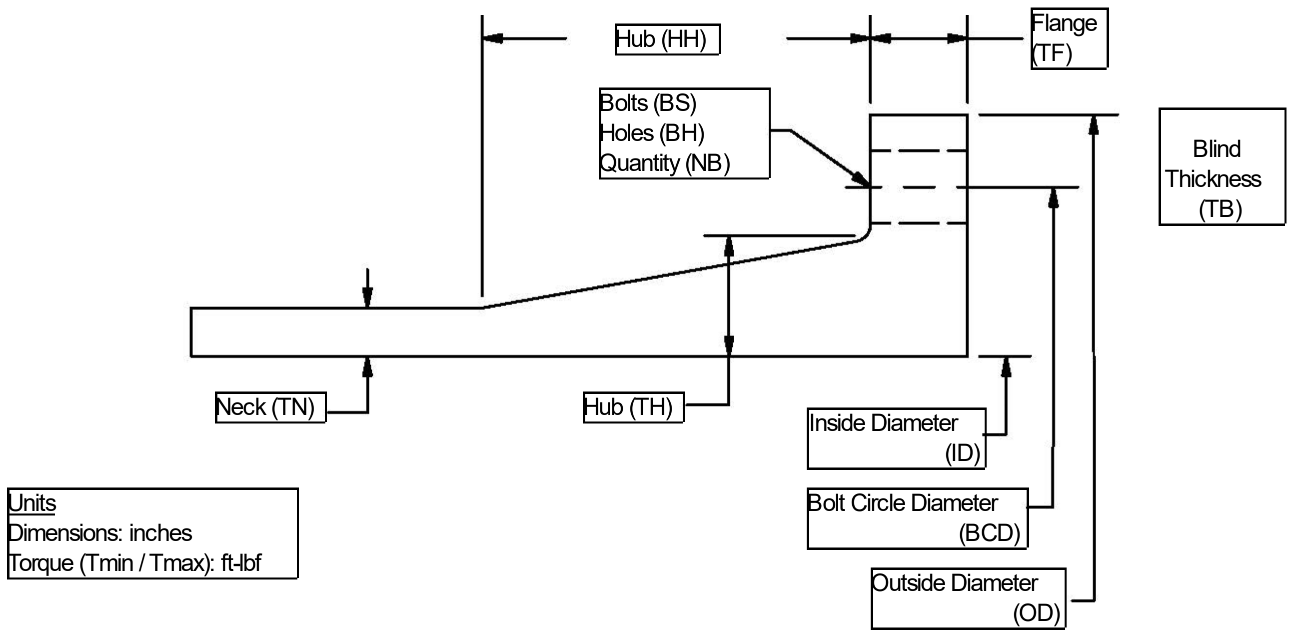
1. Thicknesses include non-structural FRP corrosion barriers.

Nomenclature

$Ve \equiv 0.01 \cdot in$ - C-Veil

$Ne \equiv 0.015 \cdot in$ - Synthetic Veil (Nexus)

$Mat \equiv 0.040 \cdot in$ - 1.5 oz./sq.ft Mat



FG =

"ID"	"Rating (psi)"	"OD"	"BCD"	"BH"	"BS"	"NB"	"TN"	"TF"	"TH"	"HH"	"Const."	"Tmin"	"Tmax"
60	0.5	66	64.5	0.625	0.5	52	0.63	1.5	1.31	4.08	"Type II"	9	15

Gasket

Gasket factor....

$m_g \equiv 1.0$

Gasket seating stress....

$y_g \equiv 100 \cdot psi$

Bolts

Allowable bolt tensile stress....

$\sigma_b \equiv 18.8 \cdot ksi$

Nut or friction factor for well lubricated studs....

$C_{ff} \equiv 0.15$

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Design for Nozzles Supporting External Loads

Nomenclature

$Ve \equiv 0.010 \cdot in$ - C-Veil

$Ne \equiv 0.015 \cdot in$ - Synthetic Veil (Nexus)

$Mat \equiv 0.04 \cdot in$ - 1.5 oz./sq.ft Mat

Geometry

1. Units are in inches ($u_d \equiv in$).
2. Thicknesses are total FRP.

$N_z \equiv$

"Mark"	"Size"	"Gusseting"	"Elevation"	"Neck Length"	"Neck th'k"	"Shell Curvature"	"Shell th'k"	"Reinf. Pad th'k"
"A"	36	"8 HD Plates"	96.	24.	0.69	30.	0.63	0.93
"B1"	10	"8 HD Plates"	120.	6.	0.38	30.	0.63	0.68
"D"	6	"Required"	16.	6.	0.38	30.	0.63	0.38
"K"	4	"Required"	120.	6.	0.31	30.	0.63	0.25
"L"	4	"Required"	120.	6.	0.31	30.	0.63	0.25
"P"	6	"Required"	11.5	6.	0.38	30.	0.63	0.38
"R"	4	"Required"	90.	6.	0.31	30.	0.63	0.25
"T (new)"	4	"Required"	90.	6.	0.31	30.	0.63	0.25
"B2"	10	"8 HD Plates"	308.5	6.	0.38	30.	0.63	0.5
"C"	24	"8 HD Plates"	422.5	6.	0.69	30.	0.63	0.5

External Loads

1. Loads are reported at the: $R_r \equiv$ "Nozzle Attachment".
2. Loads are assumed to be static, combined, and temporary (Design factor: $f_d \equiv 5$)
3. Units are in pounds ($u_f \equiv lbf$), and foot-pounds ($u_m \equiv in \cdot lbf$), unless noted otherwise.

$N_e \equiv$

"Mark"	"Size (in)"	"Radial Out"	"Radial In"	"Tan. Shear"	"Long. Shear"	"Torque"	"Tan. Moment"	"Long. Moment"
"A"	36	1124	1124	1376	1376	135239	95676	95676
"B1"	10	544	544	665	665	33810	23897	23897
"D"	6	339	339	416	416	14427	10178	10178
"K"	4	193	193	236	236	5399	3806	3806
"L"	4	193	193	236	236	5399	3806	3806
"P"	6	339	339	416	416	14427	10178	10178
"R"	4	193	193	236	236	5399	3806	3806
"T (new)"	4	193	193	236	236	5399	3806	3806
"B2"	10	544	544	665	665	33810	23897	23897
"C"	24	1124	1124	1376	1376	135239	95676	95676

Design Conditions

Portion of FRP corrosion barrier thickness NOT included in structural calculations:
$t_{cbn} \equiv 2 \cdot Ve + 3 \cdot Mat = 0.14\,in$

Internal design pressure....
$P_i \equiv 0 \cdot psi$

Specific gravity of product....
$sg_p \equiv 1.0$

Sidewall length....
$L_{tt} \equiv 300 \cdot in$

Operating liquid level....
$H_{po} \equiv 288 \cdot in$

Material Properties

Sidewall axial strength....
$\sigma_{atc} \equiv 15 \cdot ksi$

Sidewall hoop strength....
$\sigma_{htc} \equiv 25 \cdot ksi$

Sidewall shear strength....
$\sigma_{LTc} \equiv 10 \cdot ksi$

End ultimate strength....
$\sigma_{ate} \equiv 17 \cdot ksi$

End shear strength....
$\sigma_{LTe} \equiv 9 \cdot ksi$

Secondary bond peel strength....
$\sigma_p \equiv 500 \cdot \frac{lbf}{in}$

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Executive Profile

I am a Professional Engineer, licensed in 40 States and have over 17 years of experience focused in the design and manufacturing of composite industrial equipment (e.g. Storage Tanks, Scrubbers, Pressure Vessels, Pressure Pipe, & Duct). My expertise includes the design of fiberglass and thermoplastic lined fiberglass "dual laminate" containment systems.

Design Capabilities

I am proficient in the following industry preferred platforms for design and stress analysis:

- ➢ Finite Element Analysis (FEA) powered by Autodesk Inventor
- ➢ Laminate design analysis powered Trilam II
- ➢ Pipe Stress Analysis powered by Caesar II
- ➢ Customized calculation-based designs using Mathcad 15

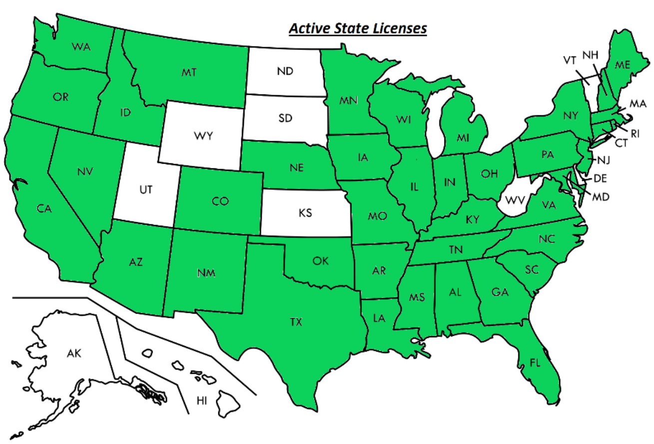
Active Memberships

- ➢ ASME BPV Section X Subcommittee
- ➢ ASME RTP-1 Subgroup on Fabrication
- ➢ ASME NPPS SC-FRP Subgroup on Design
- ➢ Dual Laminate Fabrication Association

Compliance with Leading Industry Standards

- ASME RTP-1 — Fiber Reinforced Plastic Corrosion-Resistant Equipment
- ASME Section X — Fiber Reinforced Plastic Pressure Vessels
- ASTM D3299 — Filament-Wound Corrosion Resistant Tanks
- ASTM D4097 — Contact-Molded Corrosion Resistant Tanks
- API 12P — Fiberglass Reinforced Plastic Tanks
- ASME B31.3 — Nonmetallic Pressure Piping Systems (NPPS)
- ASME NM.2 — Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems
- AWWA M45 — Fiberglass Pipe Design
- ASCE/SEI 7 — Minimum Design Loads for Buildings & Other Structures

*I am a recognized Qualified Designer where required by a given Standard.



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