FRP Composite Services
Composite Engineering Design
Finite Element Analysis

D2020-02-08-02

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ENGINEERING DESIGN REPORT

UNDERGROUND HORIZONTAL TANK
DEADMEN DESIGN

Project Name: Underground FRP Storage Tank Anchoring Deadmen
Customer: Fiberglass Tank Solutions, LLC
Tank Dimension: 12'-0" Inside Diameter X 56'-8" Straight Shell Length
10'-0" Inside Diameter X 65'-2" Straight Shell Length
8'-0" Inside Diameter X 52'-5" Straight Shell Length
6'-0" Inside Diameter X 46'-9" Straight Shell Length
5'-0" Inside Diameter X 53'-10" Straight Shell Length
4'-0" Inside Diameter X 53'-10" Straight Shell Length
Design Water Table: Flooded to Grade
Tank Configuration: Dished Heads, Cylindrical Shell, Horizontal
Tank Construction: Filament Wound & Hand Layup
Deadmen Construction: Hand Layup & A36 C.S.

Design Engineer: Joann Du, P.E.
Revision: 1
Issue Date: 11/4/2020

STATE OF MISSOURI
JUAN
DU
NUMBER
PE-2010003331
PROFESSIONAL ENGINEER

exp 12/31/2020

Chapter 1 Design Inputs

Max. Design Burial Depth to the Top of the Tank $h_{bu} := 7 \cdot ft$

Water Density: $\rho_w := 0.0361 \cdot \frac{lb}{in^3}$

FRP Density $\rho_{frp} := 0.065 \cdot \frac{lb}{in^3}$

Content Specific Gravity $sg := 1.0$

Buoyancy Design Safety Factor $SF_{by} \equiv 1.2$

Saturated Backfill Material Density $\rho_{fil} := 60 \cdot \frac{lb}{ft^3}$

Tank Inside Diameter

$$D := \begin{pmatrix} 12 \\ 10 \\ 8 \\ 6 \\ 5 \\ 4 \end{pmatrix} \cdot ft = \begin{pmatrix} 144 \\ 120 \\ 96 \\ 72 \\ 60 \\ 48 \end{pmatrix} \cdot in$$

$i := 1 .. last(D)$

Tank Radius $R := \frac{D}{2}$

Total Straight Shell Length

$$H := \begin{pmatrix} 56 \cdot ft + 8 \cdot in \\ 65 \cdot ft + 2 \cdot in \\ 52 \cdot ft + 5 \cdot in \\ 46 \cdot ft + 9 \cdot in \\ 53 \cdot ft + 10 \cdot in \\ 53 \cdot ft + 10 \cdot in \end{pmatrix} = \begin{pmatrix} 680 \\ 782 \\ 629 \\ 561 \\ 646 \\ 646 \end{pmatrix} in$$

Design Water Table $H_{wt} := D + h_{bu} = \begin{pmatrix} 228 \\ 204 \\ 180 \\ 156 \\ 144 \\ 132 \end{pmatrix} \text{in}$

Dished Head Radius $R_c := D$

Dished Head Knuckle Radius $r_c := 0.06 \cdot D$

Top Head Volume: $V_{L\_H} := \overrightarrow{f\_volts(r_c, R, R_c, 0)} = \begin{pmatrix} 1.047 \times 10^3 \\ 605.915 \\ 310.228 \\ 130.878 \\ 75.739 \\ 38.779 \end{pmatrix} \cdot \text{gal}$

Tank Volume (Flooded): $V_L := \overrightarrow{\left(2V_{L\_H} + \pi \cdot R^2 \cdot H\right)} = \begin{pmatrix} 5.004 \times 10^4 \\ 3.95 \times 10^4 \\ 2.033 \times 10^4 \\ 1.015 \times 10^4 \\ 8.058 \times 10^3 \\ 5.138 \times 10^3 \end{pmatrix} \text{gal}$

Tank Estimated Empty Weight $W_{FRP} := \begin{pmatrix} 16000 \\ 11000 \\ 6600 \\ 4200 \\ 3900 \\ 3600 \end{pmatrix} \cdot \text{lb}$

Chapter 2 Buoyancy Design

1. Buoyant force acting on the underground tank is equal to the weight of fluid which the tank displaces.

2. Tank tank w/ stiffeners' weights, soil load above the tank within the friction angle specified, and the weight of the soil above the FRP deadmen are used to resist buoyancy.

Projected Area $A_{prj} := D \cdot H$

Estimated Weight of Tank Used to Counteract Buoyancy

$$W_{bu\_FRP} := W_{FRP} = \begin{pmatrix} 1.6 \times 10^4 \\ 1.1 \times 10^4 \\ 6.6 \times 10^3 \\ 4.2 \times 10^3 \\ 3.9 \times 10^3 \\ 3.6 \times 10^3 \end{pmatrix} lb$$

Total Volume of Water Displaced

$$V_{h2o} := V_L = \begin{pmatrix} 5.004 \times 10^4 \\ 3.95 \times 10^4 \\ 2.033 \times 10^4 \\ 1.015 \times 10^4 \\ 8.058 \times 10^3 \\ 5.138 \times 10^3 \end{pmatrix} gal$$

Total Weight of Water Displaced

$$W_{h2o} := \rho_w \cdot V_{h2o} = \begin{pmatrix} 4.173 \times 10^5 \\ 3.294 \times 10^5 \\ 1.695 \times 10^5 \\ 8.464 \times 10^4 \\ 6.72 \times 10^4 \\ 4.285 \times 10^4 \end{pmatrix} \cdot lb$$

Design Buoyancy Force
(For Two Tanks)

$$F_{by} := 2 \cdot W_{h2o} \cdot SF_{by} = \begin{pmatrix} 1.001 \times 10^6 \\ 7.905 \times 10^5 \\ 4.069 \times 10^5 \\ 2.031 \times 10^5 \\ 1.613 \times 10^5 \\ 1.028 \times 10^5 \end{pmatrix} \cdot lb$$

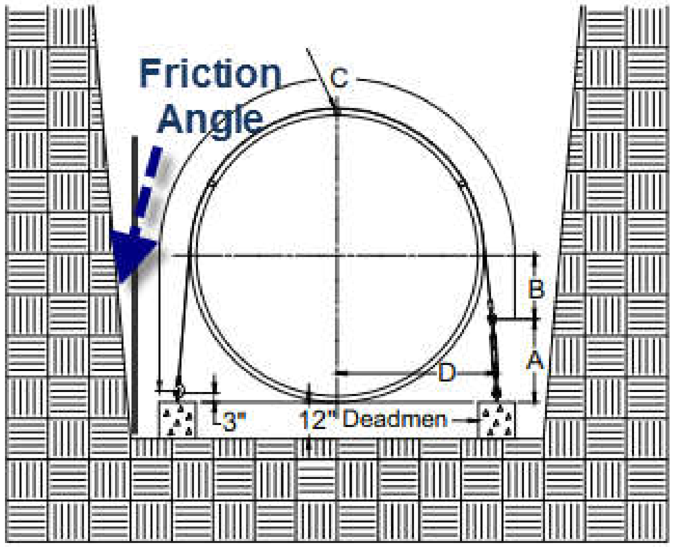
Min. Backfill Height

$$d_{bk} := \begin{pmatrix} 4 \\ 3 \\ 3 \\ 2 \\ 2 \\ 2 \end{pmatrix} \cdot ft \qquad D = \begin{pmatrix} 12 \\ 10 \\ 8 \\ 6 \\ 5 \\ 4 \end{pmatrix} \cdot ft$$

Soil Friction Angle (Estimated)

$\phi := 25 \cdot deg$ conservative friction angle selected.

$$\phi_r := \frac{\phi}{180 \cdot deg} \cdot \pi = 0.436$$



<u>FRP deadmen need to be placed outside the tank shadow.</u>

Double Tank Design

Soil Above Tank Centerline

Base Area $a_b := \overrightarrow{(D \cdot H)}$

Height $h := \overrightarrow{\left(d_{bk} + \frac{D}{2}\right)} = \begin{pmatrix} 10 \\ 8 \\ 7 \\ 5 \\ 4.5 \\ 4 \end{pmatrix} \cdot ft$

$$\Delta h := h \cdot \tan(\phi_r) = \begin{pmatrix} 55.957 \\ 44.766 \\ 39.17 \\ 27.978 \\ 25.181 \\ 22.383 \end{pmatrix} in$$

Top Area

$$a_t := \overrightarrow{[(D + 2\cdot\Delta h)(H + 2\cdot\Delta h)]} = \begin{pmatrix} 2.027\times10^5 \\ 1.826\times10^5 \\ 1.233\times10^5 \\ 7.894\times10^4 \\ 7.685\times10^4 \\ 6.408\times10^4 \end{pmatrix} in^2$$

Cross Section of Friction Zone
On Each Side of Tank
Directly Above Tank C.L.

$$A_{cr} := \overrightarrow{\left(\frac{1}{2}\cdot\Delta h\cdot h\right)} = \begin{pmatrix} 3.357\times10^3 \\ 2.149\times10^3 \\ 1.645\times10^3 \\ 839.354 \\ 679.877 \\ 537.186 \end{pmatrix} in^2$$

Soil Above Deadmen

FRP Deadmen Width

$$b_d := \begin{pmatrix} 24 \\ 24 \\ 18 \\ 12 \\ 12 \\ 12 \end{pmatrix}\cdot in \qquad D = \begin{pmatrix} 12 \\ 10 \\ 8 \\ 6 \\ 5 \\ 4 \end{pmatrix}\cdot ft$$

FRP Deadmen Length

$$L_d := 8\cdot ft + 6\cdot in = 102\,in$$

FRP Deadmen Qty.
(Per Tank)

$$N_d := \begin{pmatrix} 10 \\ 14 \\ 6 \\ 8 \\ 2 \\ 0 \end{pmatrix} \qquad D = \begin{pmatrix} 12 \\ 10 \\ 8 \\ 6 \\ 5 \\ 4 \end{pmatrix}\cdot ft$$

Soil Column Height Above Deadmen $h_{d\_fr} := \overrightarrow{(D + d_{bk})}$

Soil Directly Above Deadmen $V_{d\_sl} := \overrightarrow{\left(N_d \cdot L_d \cdot b_d \cdot \frac{D}{2}\right)} = \begin{pmatrix} 1.02 \times 10^3 \\ 1.19 \times 10^3 \\ 306 \\ 204 \\ 42.5 \\ 0 \end{pmatrix} \cdot ft^3$

Soil in Friction Zone Above Deadmen $V_{d\_fr} := \overrightarrow{\left[N_d \cdot \frac{1}{2} \cdot \tan(\phi_r) \cdot \left(\frac{D}{2}\right)^2 \cdot L_d\right]} = \begin{pmatrix} 713.451 \\ 693.633 \\ 190.254 \\ 142.69 \\ 24.773 \\ 0 \end{pmatrix} \cdot ft^3$

Volume of Backfill Above Tank C.L. Used to Counteract Buoyancy $V_{s\_t} := \overrightarrow{\left[\frac{h}{3} \cdot \left(a_t + a_b + \sqrt{a_t \cdot a_b}\right) - \frac{1}{4} \cdot \pi \cdot D^2 \cdot H \cdot \frac{1}{2}\right]}$

$$V_{s\_t} = \begin{pmatrix} 7.014 \times 10^3 \\ 4.985 \times 10^3 \\ 3.058 \times 10^3 \\ 1.374 \times 10^3 \\ 1.244 \times 10^3 \\ 954.928 \end{pmatrix} \cdot ft^3$$

Spacing Between Adjacent Tanks $\Delta L := 3 \cdot ft$

Overlapping Soil Zone

Overlapping Length $L_{ov} := \overrightarrow{(2 \cdot \Delta h - \Delta L)} = \begin{pmatrix} 75.914 \\ 53.531 \\ 42.34 \\ 19.957 \\ 14.361 \\ 8.766 \end{pmatrix} in$

Overlapping Area Height

$$H_{ov} := \overrightarrow{\left(\frac{L_{ov}}{2} \cdot \frac{1}{\tan(\phi_r)}\right)}$$

Overlapping Area

$$A_{ov} := \overrightarrow{\left(\frac{1}{2} \cdot L_{ov} \cdot H_{ov}\right)}$$

Overlapping Soil Volume

$$V_{ov} := \overrightarrow{\left(A_{ov} \cdot H\right)}$$

Total Volume of Backfill Used
to Counteract Buoyancy
(For Two Tanks)

$$V_s := \overrightarrow{\left[2 \cdot \left(V_{s\_t} + V_{d\_sl} + V_{d\_fr}\right) - V_{ov}\right]}$$

Backfill Saturated Weight
(For Two Tanks)

$$W_{bk} := \overrightarrow{\left(V_s \cdot \rho_{fil}\right)} = \begin{pmatrix} 9.768 \times 10^5 \\ 7.825 \times 10^5 \\ 4.055 \times 10^5 \\ 2.023 \times 10^5 \\ 1.549 \times 10^5 \\ 1.137 \times 10^5 \end{pmatrix} lb$$

Weight of Backfill Required
To Hold Down the Tank
When Totally Submerged
(For Two Tanks)

$$W_{c\_r} := \overrightarrow{\left(F_{by} - 2 \cdot W_{bu\_FRP}\right)} = \begin{pmatrix} 9.694 \times 10^5 \\ 7.685 \times 10^5 \\ 3.937 \times 10^5 \\ 1.947 \times 10^5 \\ 1.535 \times 10^5 \\ 9.563 \times 10^4 \end{pmatrix} \cdot lb$$

$$\Delta := \overrightarrow{\left(W_{bk} - W_{c\_r}\right)}$$

$$\Delta = \begin{pmatrix} 7.387 \times 10^3 \\ 1.396 \times 10^4 \\ 1.179 \times 10^4 \\ 7.573 \times 10^3 \\ 1.427 \times 10^3 \\ 1.804 \times 10^4 \end{pmatrix} lb$$

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$checkbackfill_i := \text{if}\left(\Delta_i \geq 0 \cdot lb, \text{"Adequate"}, \text{"Additional Weight Req'd"}\right)$

$$checkbackfill = \begin{pmatrix} \text{"Adequate"} \\ \text{"Adequate"} \\ \text{"Adequate"} \\ \text{"Adequate"} \\ \text{"Adequate"} \\ \text{"Adequate"} \end{pmatrix}$$

Downard Force on All Deadmen for Each Tank

$$P_d := \overrightarrow{\left[\frac{W_{c\_r} - \rho_{fil} \cdot \overrightarrow{\left(2 \cdot V_{s\_t} - V_{ov}\right)}}{2}\right]} = \begin{pmatrix} 1.003 \times 10^5 \\ 1.06 \times 10^5 \\ 2.388 \times 10^4 \\ 1.702 \times 10^4 \\ 3.323 \times 10^3 \\ -9.018 \times 10^3 \end{pmatrix} lb$$

$N_{du_i} := \text{if}\left(N_{d_i} = 0, 1, N_{d_i}\right)$

Downard Force on Single Deadman for Each Tank

$$P_{d\_u_i} := \begin{cases} 0 \cdot lb & \text{if } P_{d_i} \leq 0 \cdot lb \\ \dfrac{P_{d_i}}{N_{du_i}} & \text{otherwise} \end{cases}$$

Qty of Turnbuckle Per Deadmen $N_{tb} \equiv 2$

Vertical Load Taken by Each Turnbuckle

$$Tv := \frac{P_{d\_u}}{N_{tb}}$$

$$Tv = \begin{pmatrix} 5.016 \times 10^{3} \\ 3.787 \times 10^{3} \\ 1.99 \times 10^{3} \\ 1.063 \times 10^{3} \\ 830.761 \\ 0 \end{pmatrix} lb$$

Anchor Plate Dimensions

$$w_a := 12 \cdot in$$

$$L_a := 12 \cdot in$$

FRP Overlay Thk.

$$t_{ov} := 0.5 \cdot in$$

Shear Stress in FRP Overlay

$$\tau_p := \frac{Tv}{2 \cdot (w_a + L_a) \cdot t_{ov}} = \begin{pmatrix} 208.987 \\ 157.797 \\ 82.923 \\ 44.31 \\ 34.615 \\ 0 \end{pmatrix} \cdot psi$$

Allowable Shear Stress in FRP Overlay

$$\tau_{al} := \frac{2000 \cdot psi}{3} = 666.667 \cdot psi$$

Compressive Stress in FRP Overlay

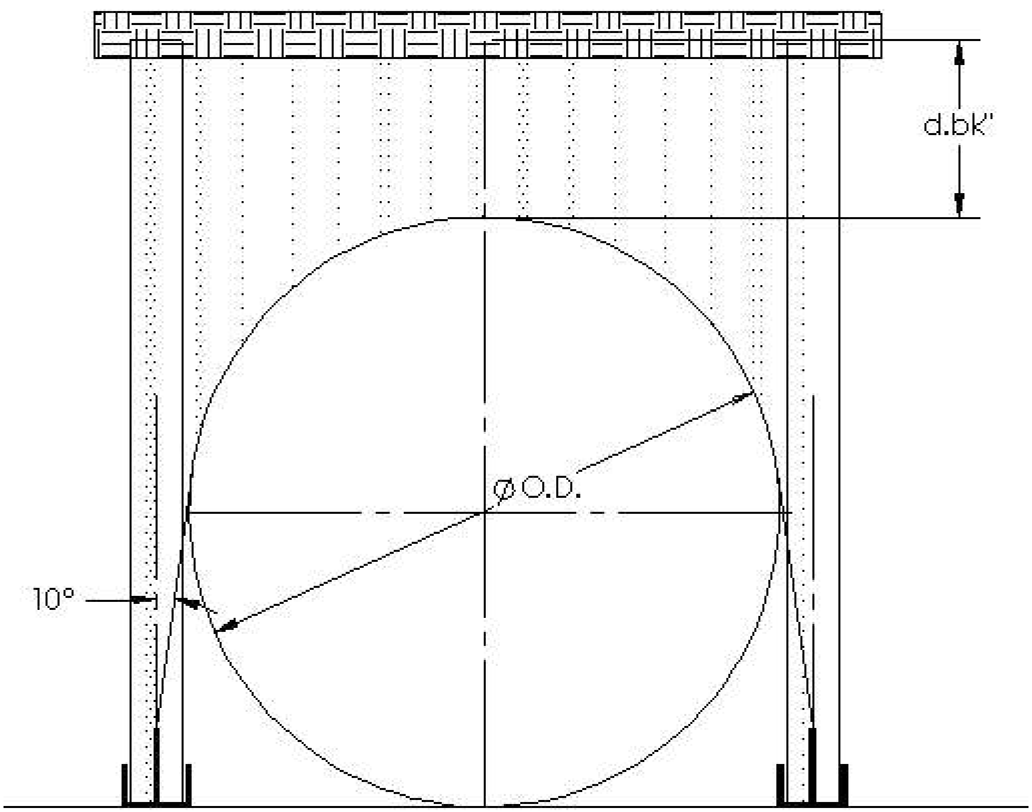
$$\sigma_p := \frac{Tv}{w_a \cdot L_a} = \begin{pmatrix} 34.831 \\ 26.3 \\ 13.82 \\ 7.385 \\ 5.769 \\ 0 \end{pmatrix} \cdot psi$$

Allowable Compressive Stress in FRP Overlay

$$\sigma_{p\_al} := 20000 \cdot \frac{psi}{3} = 6.667 \times 10^3 \cdot psi$$

$$checkcompshear_i := if\left(\tau_{p_i} \le \tau_{al} \wedge \sigma_{p_i} \le \sigma_{p\_al}, "OK", "Inadequate"\right)$$

$$checkcompshear = \begin{pmatrix} "OK" \\ "OK" \\ "OK" \\ "OK" \\ "OK" \\ "OK" \end{pmatrix}$$



Considering strap angle at 10 deg.

Max. Tensile Force on Each Turnbuckle

$$T := \overrightarrow{\frac{Tv}{\cos(10 \cdot deg)}} = \begin{pmatrix} 5.093 \times 10^3 \\ 3.846 \times 10^3 \\ 2.021 \times 10^3 \\ 1.08 \times 10^3 \\ 843.577 \\ 0 \end{pmatrix} lb$$

Turnbuckle must be rated for loads higher than "T" shown above.

Use 3/4"x18" turnbuckle with rated capacity of 5,200 lbs.

Hold Down Strap Width

$$w_{str} := \begin{pmatrix} 4 \\ 4 \\ 3 \\ 2 \\ 2 \\ 1 \end{pmatrix} \cdot in$$

Load in Strap $T_{str} := T$

Pressure Under Each Strap $p_{str} := \overrightarrow{\frac{T_{str}}{\frac{0.9\pi \cdot D}{2} \cdot w_{str}}}$

$$T_{str} = \begin{pmatrix} 5.093 \times 10^3 \\ 3.846 \times 10^3 \\ 2.021 \times 10^3 \\ 1.08 \times 10^3 \\ 843.577 \\ 0 \end{pmatrix} lb \qquad p_{str} = \begin{pmatrix} 6.255 \\ 5.667 \\ 4.963 \\ 5.304 \\ 4.973 \\ 0 \end{pmatrix} psi$$

OK

LUG STRESS CHECK

Material A36 C.S. Galv.

Tensile Strength $Fu_{lug} := 58 \cdot ksi$

Yield Strength $Fy_{lug} := 36 \cdot ksi$

Allowable Bending Stress $\sigma_{alb} := 0.66 \cdot Fy_{lug} = 2.376 \times 10^{4} \cdot psi$

Hole Diameter $d_{hole} := 1.25 \cdot in$

Diameter of Pin $d_{pin} := d_{hole} - 0.25 \cdot in = 1\ in$

Lug Height $h_{lug} := 17 \cdot in$

Lug Width $w_{lug} := 6 \cdot in$

Lug Thk. $thk := 0.25 \cdot in$

Lug Radius $radius := \frac{w_{lug}}{2} = 3\ in$

Vertical Uplift

AISC(13th ed.), sect. D2 and sect. J4-1
table D3.1

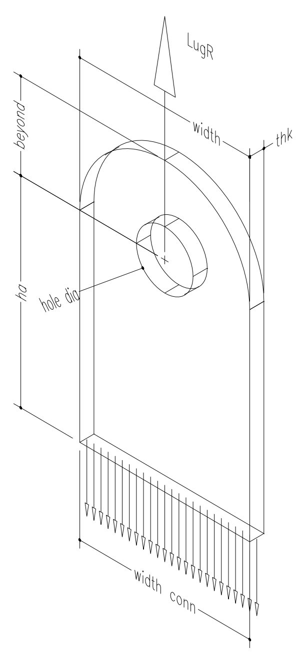
$\phi_{gross} := .90$ $\Omega_{gross} := 1.67$

$\phi_{net} := .75$ $\Omega_{net} := 2$

Shear lag factor $U := 1$

$An := thk \cdot (2 \cdot radius - d_{hole})$

$Ft_{gross} := \frac{Fy_{lug}}{\Omega_{gross}}$



$Vcap_1 := Ft_{gross} \cdot thk \cdot 2 \cdot radius$ $\quad Vcap_1 = 3.234 \times 10^4\ lb$

$$Ft_{net} := \frac{Fu_{lug}}{\Omega_{net}}$$

$Vcap_2 := Ft_{net} \cdot An \cdot U$ $\quad Vcap_2 = 3.444 \times 10^4\ lb$

AISC(13th ed.), sect. J7 $\quad \phi_{brg} := .75 \quad \Omega_{brg} := 2$

Allow permanent deformation around hole due to bearing (mushrooming of hole)? $Allow_{mushrooming} := \text{"yes"}$

Allowable Bearing Stress: $\quad F_{brg} := 1.8 \cdot \frac{Fy_{lug}}{\Omega_{brg}}$

Allowable Load for Bearing:

$$Vcap_3 := \begin{cases} F_{brg} \cdot thk \cdot d_{pin} & \text{if } Allow_{mushrooming} = \text{"no"} \\ Vcap_1 & \text{if } Allow_{mushrooming} = \text{"yes"} \end{cases}$$

$Vcap_3 = 3.234 \times 10^4\ lb$

AISC(13th ed.), sect. J4-2

shear yeilding $\quad \phi_{sy} := 1 \quad \Omega_{sy} := 1.5$

$Rn_{sy} = 0.6 \cdot Fy_{lug} \cdot Ag$

$Vn_{sy} := 0.6 \cdot Fy_{lug} \cdot thk \cdot 2 \cdot radius$

$Vcap_4 := \frac{Vn_{sy}}{\Omega_{sy}}$ $\quad Vcap_4 = 2.16 \times 10^4\ lb$

shear rupture $\quad \phi_{sr} := .75 \quad \Omega_{sr} := 2$

$Rn_{sr} = 0.6 \cdot Fu_{lug} \cdot Anv_{sr}$

$Anv_{sr} := thk \cdot (2 \cdot radius - d_{hole})$

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$$Vn_{sr} := 0.6 \cdot Fu_{lug} \cdot Anv_{sr}$$

$$Vcap_5 := \frac{Vn_{sr}}{\Omega_{sr}} \qquad Vcap_5 = 2.066 \times 10^4\ lb$$

AISC(13th ed.), sect. J4-3

Block Shear $\phi_{sb} := .75$ $\Omega_{sb} := 2$ $U_{bs} := 1$ tension is uniform

$$A_{gv} := (radius) \cdot thk \qquad A_{nv} := \left(radius - \frac{d_{hole}}{2}\right) \cdot thk \qquad A_{nt} := \left(radius - \frac{d_{hole}}{2}\right) \cdot thk$$

$$Rn_{sb} := \min\left(0.6 \cdot Fu_{lug} \cdot A_{nv} + U_{bs} \cdot Fu_{lug} \cdot A_{nt}, 0.6 \cdot Fy_{lug} \cdot A_{gv} + U_{bs} \cdot Fu_{lug} \cdot A_{nt}\right)$$

$$Vcap_6 := \frac{Rn_{sb}}{\Omega_{sb}} \qquad Vcap_6 = 2.532 \times 10^4\ lb$$

AISC(13th ed.), sect. D5

tensile rupture $\phi_{tr} := .75$ $\Omega_{tr} := 2$

$$Pn_{tr} = 2 \cdot thk \cdot b_{eff} \cdot Fu_{lug}$$

$$b'_{eff} := \begin{cases} (2 \cdot thk + 0.63 \cdot in) & \text{if } \dfrac{2 \cdot radius - d_{hole}}{2} > 2 \cdot thk + 0.63 \cdot in \\ \dfrac{2 \cdot radius - d_{hole}}{2} & \text{otherwise} \end{cases}$$

$$b_{eff} := \begin{cases} \left[\dfrac{3}{4} \cdot \left(radius - \dfrac{d_{hole}}{2}\right)\right] & \text{if } \dfrac{4}{3} \cdot b'_{eff} > radius - \dfrac{d_{hole}}{2} \\ b'_{eff} & \text{otherwise} \end{cases} = 1.13 \cdot in$$

$$Vcap_7 := 2 \cdot thk \cdot b_{eff} \cdot \frac{Fu_{lug}}{\Omega_{tr}} \qquad Vcap_7 = 1.638 \times 10^4\ lb$$

shear rupture $\phi_{sr} = 0.75$ $\Omega_{sr} = 2$

$$Pn_{sr} = 0.6 \cdot Fu_{lug} \cdot Asf$$

$$a := radius - \frac{d_{hole}}{2} = 2.375 \cdot in$$

$$a_{min} := 1.333 \cdot b_{eff} = 1.506 \cdot in$$

$$Asf := 2 \cdot thk \cdot \left(a + \frac{d_{pin}}{2}\right)$$

$$Vcap_8 := 0.6 \cdot Fu_{lug} \cdot \frac{Asf}{\Omega_{sr}}$$

$$Vcap_8 = 2.501 \times 10^4\,lb$$

AISC(13th ed.), sect. J2.4 Weld Strength $\phi_{fw} := 0.75$ $\Omega_{fw} := 2.0$ $F_{EXX} := 70 \cdot ksi$

Allowable weld stress and load for bottom weld, 100% transverse to load $\theta := 90 \cdot deg$

$weld := \frac{1}{4} \cdot in$ $dw := \frac{weld}{\sqrt{2}}$

$S_{wt} := \frac{0.6 \cdot F_{EXX}}{\Omega_{fw}} \cdot \left(1 + 0.5 \cdot \sin(\theta)^{1.5}\right)$ $S_{wt} = 31.5 \cdot ksi$ $Vcap_8 := S_{wt} \cdot w_{lug} \cdot dw \cdot 2$

$$Vcap_8 = 6.682 \times 10^4\,lb$$

$$Vcap = \begin{pmatrix} 3.234 \times 10^4 \\ 3.444 \times 10^4 \\ 3.234 \times 10^4 \\ 2.16 \times 10^4 \\ 2.066 \times 10^4 \\ 2.532 \times 10^4 \\ 1.638 \times 10^4 \\ 2.501 \times 10^4 \end{pmatrix} lb$$

Lug Lateral Bending Section Modulus $Z_{lug} := \frac{1}{6} \cdot thk \cdot w_{lug}{}^2$

Max. Lateral Load $F_{lt} := 10000 \cdot lb \cdot \sin(10 \cdot deg) = 1.736 \times 10^3\ lb$

Bending Moment $M_{lt} := F_{lt} \cdot \left(h_{lug} - radius\right) = 2.431 \times 10^4\ in \cdot lb$

Bending Stress $\sigma_{lt\_b} := \frac{M_{lt}}{Z_{lug}} = 1.621 \times 10^4 \cdot psi$

$\frac{\sigma_{alb}}{\sigma_{lt\_b}} = 1.466$ greater than 1, OK

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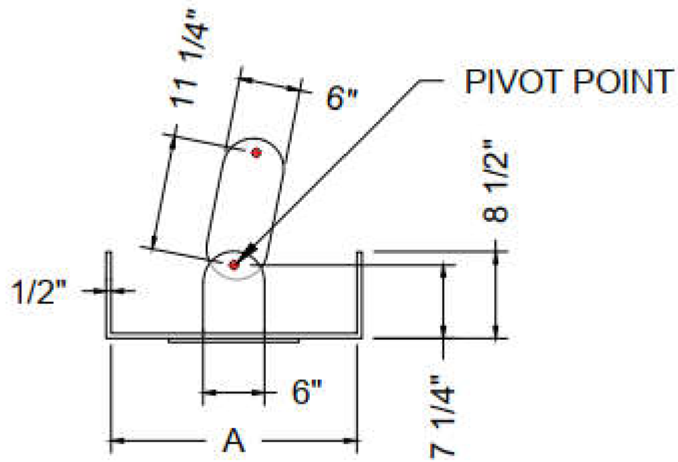
Turnbuckle Selection

HG-228 Jaw & Jaw

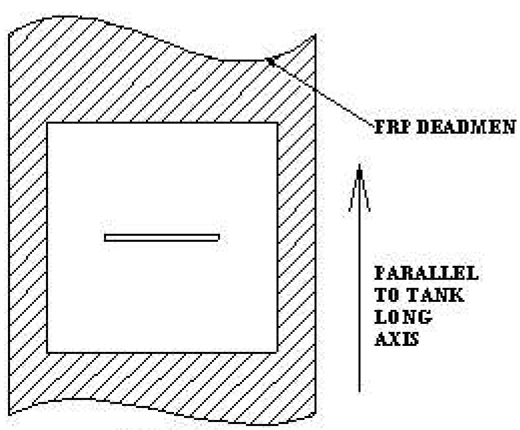
Thread Dia. & Take Up (in.)	HG-228 Stock No.	Working Load Limit (lbs)*	Weight Each (lbs.)	Dimensions (in)								
				A	B	E Closed	G	J Open	K Closed	M Open	N Closed	BB
† 1/4 x 4	1032493	500	.37	.25	.45	1.66	.64	11.19	7.19	12.18	8.18	4.07
† 5/16 x 4-1/2	1032518	800	.56	.31	.50	2.02	.87	13.07	8.57	14.12	9.62	4.58
† 3/8 x 6	1032536	1200	.85	.38	.53	2.11	.85	16.25	10.25	17.50	11.50	6.10
1/2 x 6	1032554	2200	1.82	.50	.64	3.22	1.07	18.65	12.65	20.14	14.14	6.03
1/2 x 9	1032572	2200	2.29	.50	.64	3.20	1.07	24.94	15.94	26.43	17.43	9.36
1/2 x 12	1032590	2200	2.71	.50	.64	3.20	1.07	30.94	18.94	32.43	20.43	12.36
5/8 x 6	1032616	3500	3.21	.63	.79	3.90	1.32	19.74	13.74	21.82	15.82	6.03
5/8 x 9	1032634	3500	3.95	.63	.79	3.89	1.32	26.08	17.08	28.16	19.16	9.39
5/8 x 12	1032652	3500	4.58	.63	.79	3.89	1.32	32.08	20.08	34.16	22.16	12.39
3/4 x 6	1032670	5200	4.80	.75	.97	4.71	1.52	21.09	15.09	23.68	17.68	6.13
3/4 x 9	1032698	5200	5.85	.75	.97	4.68	1.52	27.49	18.49	30.08	21.08	9.59
3/4 x 12	1032714	5200	6.72	.75	.97	4.68	1.52	33.49	21.49	36.08	24.08	12.59
3/4 x 18	1032732	5200	8.45	.75	.97	4.71	1.52	45.49	27.49	48.08	30.08	18.53
7/8 x 12	1032750	7200	9.37	.88	1.16	5.50	1.77	34.65	22.65	37.62	25.62	12.16
7/8 x 18	1032778	7200	11.8	.88	1.16	5.50	1.77	47.12	29.12	50.09	32.09	18.63
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix A Design Sketches

Anchor Plate Detail

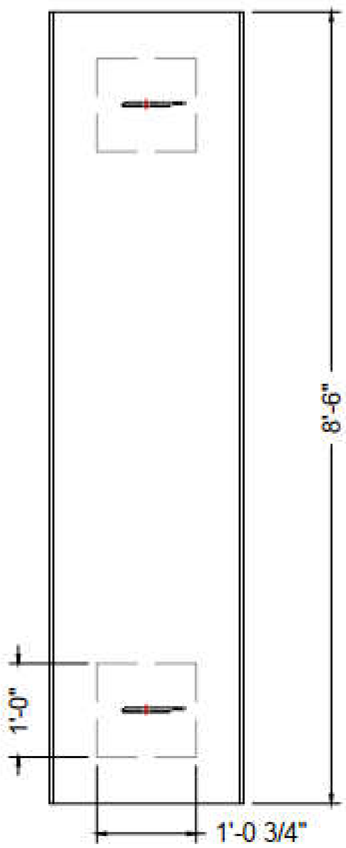


FRONT VIEW

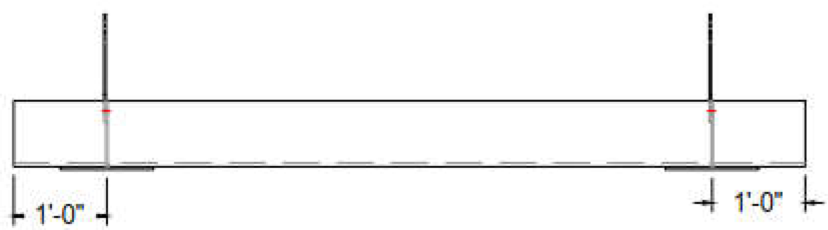


TOP VIEW

FRP Deadmen Detail



TOP VIEW



RIGHT SIDE VIEW

FRP Overlay : .51" - 3(M,R)M,2(M,R),2M

Tank ID	Min. Burial Depth	Deadmen Width	Deadmen Qty. (For Two Tanks)	Qty. of Turnbuckles (For Two Tanks))

$$D = \begin{pmatrix} 12 \\ 10 \\ 8 \\ 6 \\ 5 \\ 4 \end{pmatrix} \cdot ft \quad d_{bk} = \begin{pmatrix} 4 \\ 3 \\ 3 \\ 2 \\ 2 \\ 2 \end{pmatrix} \cdot ft \quad b_d = \begin{pmatrix} 24 \\ 24 \\ 18 \\ 12 \\ 12 \\ 12 \end{pmatrix} in \quad 2N_d = \begin{pmatrix} 20 \\ 28 \\ 12 \\ 16 \\ 4 \\ 0 \end{pmatrix} \quad N_{tb} \cdot 2 \cdot N_d = \begin{pmatrix} 40 \\ 56 \\ 24 \\ 32 \\ 8 \\ 0 \end{pmatrix}$$

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Two Tank Backfill Zone Detail