FRP Composite Services Composite Engineering Design Finite Element Analysis

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ENGINEERING DESIGN REPORT

**UNDERGROUND HORIZONTAL TANK DEADMEN DESIGN**

Project Name: Underground FRP Storage Tank Anchoring Deadrnen 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

## Chapter 1 Design Inputs



#### Max. Design Burial Depth to the Top of the Tank

hbu  7ft

Water Density: ρ  0.0361 lb

w

3

in

FRP Density ρfrp  0.065 lb in

3

Content Specific Gravity sg  1.0

Buoyancy Design Safety Factor SFby  1.2

#### Saturated Backfill Material Density

ρfil  60 lb

ft3

 12 

 10 

 144 

 120 

   

Tank Inside Diameter D   8 ft   96 in

 6 

 5 

 72 

 60 

   

i  1  last(D)

 4 

 48 

Tank Radius R  D

2

 56ft  8in 

 65ft  2in 

 680 

 782 

   

Total Straight Shell Length H   52ft  5in    629  in

 46ft  9in 

 53ft  10in 

 561 

 646 

   

 53ft  10in   646 

 228 

 204 

 

#### Design Water Table Hwt

 D  hbu

  180  in

 156 

 144 

 

 132 

Dished Head Radius Rc  D

Dished Head Knuckle Radius rc  0.06D

 1.047  3 

#### Top Head Volume: V





 

 

10

605.915

310.228







gal

L\_H f\_voltsrc  R Rc 0

 

 130.878 

 75.739 

 

 38.779 

 5.004  4 

 10 

 3.95  104 

  4 

#### Tank Volume (Flooded): V

 2V

 πR2H   2.033  10



gal

L  L\_H   4 

 1.015  10 

 3 

 8.058  10 

 3 

 5.138  10 

 16000 

 11000 

 

#### Tank Estimated Empty Weight WFRP

  6600 lb

 4200 

 3900 

 

 3600 

## Chapter 2 Buoyancy Design

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

1. 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 Aprj  DH

 1.6  104 

 

 1.1  104 

 

 6.6  103 

#### Estimated Weight of Tank

Wbu\_FRP  WFRP  

 lb

#### Used to Counteract Buoyancy

 4.2  103 

 

 3.9  103 

 

 3.6  103 

 5.004  4 

 10 

 3.95  4 

 10 

 2.033  4 

#### Total Volume of Water Displaced V

 V  

10

 gal



h2o

L

 1.015  4

 3 

10

 8.058  10 

 3 

 5.138  10 

 4.173  105 

 

 3.294  105 

 

 1.695  105 

Total Weight of Water Displaced Wh2o  ρwVh2o  

lb

 8.464  104 

 4 

 6.72  10 

 

 4.285  104 

 1.001  6 

 10 

 7.905  5 

 10 

 4.069  5 

#### Design Buoyancy Force

F  2W

SF  

10

lb

#### (For Two Tanks)

by h2o

by

 2.031  10



5

 5 

 1.613  10 

 5 

 1.028  10 

 4 

 3 

 12 

 10 

   

#### Min. Backfill Height dbk

  3 ft

 2 

 2 

D   8 ft

 6 

 5 

   

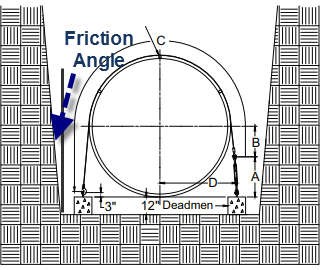
 2   4 

Soil Friction Angle (Estimated) ϕ  25deg

#### conservative friction angle selected.

ϕ  ϕ π  0.436 180deg

r



**FRP deadmen need to be placed outside the tank shadow.**

# Double Tank Design

### Soil Above Tank Centerline



Base Area ab  (DH)

 10 



 8 

 

Height h  d

 D   7

ft

 bk

2   5 

 4.5 

 

 4 

 55.957 

 44.766 

 

Δh  htanϕ    39.17  in

r  27.978 

 25.181 

 

 22.383 

 2.027  5 

 10 

 1.826  5 

 10 



 1.233  5  2

Top Area at  [(D  2Δh)(H  2Δh)]  

10

 7.894 



 in

4



10

4 

 7.685  10 

 4 

 6.408  10 

 3.357  103 



 

 3 

 2.149  10 

#### Cross Section of Friction Zone

Acr   1 Δhh   1.645  103  in2

#### On Each Side of Tank Directly Above Tank C.L.

 2 

 

 839.354 

 679.877 

 

 537.186 

### Soil Above Deadmen

 24 

 24 

 12 

 10 

   

#### FRP Deadmen Width bd

  18 in

 12 

 12 

D   8 ft

 6 

 5 

   

 12 

 4 

FRP Deadmen Length Ld  8ft  6in  102 in

 10 

 14 

 12 

 10 

   

#### FRP Deadmen Qty. (Per Tank)

N   6 

d  8 

 2 

D   8 ft

 6 

 5 

   

 0   4 

 

 

Soil Column Height Above Deadmen hd\_fr  D  dbk

 1.02  103 

 





 1.19  103 

#### Soil Directly Above Deadmen V

 N L b

 D  

306

 3

ft

d\_sl

 d d

d 2  









204 

42.5 



0 



 713.451 

 693.633 

 1  D2



 

190.254 3

Ld  ft

#### Soil in Friction Zone Above Deadmen

 2  2 

Vd\_fr  Nd tanϕr

  

  142.69 

 24.773 

 

 0 



3

4

2 

#### Volume of Backfill Above Tank

C.L. Used to Counteract Buoyancy

Vs\_t  h at  ab 

 7.014  103 

atab  1 π

1

D H

2

 

 3 

 4.985  10 

 3.058  103  3

Vs\_t  

ft

 1.374  103 

 

 1.244  103 

 

 954.928 

Spacing Between Adjacent Tanks ΔL  3ft

#### Overlapping Soil Zone



 75.914 

 53.531 

 

42.34

Overlapping Length Lov  (2Δh  ΔL)    in

 19.957 

 14.361 

 

 8.766 

#### Overlapping Area Height H



 Lov 1 

 

ov 



 2

tanϕr 



Overlapping Area Aov   1 Lov

 2

H 

ov

Overlapping Soil Volume

Total Volume of Backfill Used to Counteract Buoyancy

(For Two Tanks)



Vov  AovH

 



 

Vs  2 Vs\_t  Vd\_sl  Vd\_fr  Vov

 9.768  5 

 10 

 7.825  5 

 10 



 4.055  5 

#### Backfill Saturated Weight

W  V ρ

  

10

 lb



#### (For Two Tanks)

bk s

fil

 2.023  5

 5 

10

 1.549  10 

 5 

 1.137  10



 9.694  5 

 10 

 7.685  5 

 10 

10

#### Weight of Backfill Required



 3.937  5 

#### To Hold Down the Tank

Wc\_r  Fby  2Wbu\_FRP  

lb

5

#### When Totally Submerged (For Two Tanks)

 1.947  10 

 

1.535  5

 10 

 4 



 

Δ  Wbk  Wc\_r

 9.563  10 

 7.387  3 

 10 

 1.396  4 

 10 

 1.179 



Δ  

 7.573 



4

10

 lb



3

10

3 

 1.427  10 

 4 

 1.804  10 

checkbackfill  if Δ  0lb "Adequate"  "Additional Weight Req'd" 

i i

 "Adequate" 

 "Adequate" 

 

checkbackfill   "Adequate" 

 "Adequate" 

 "Adequate" 

 

 "Adequate" 

#### Downard Force on All Deadmen for Each Tank

 1.003  5 



 10 

 1.06  105 

   4 

Wc\_r  ρfil2Vs\_t  Vov

 2.388  10 

Pd  

2   

 lb

4

 1.702  10 

 3 

 3.323  10 

 3 

9.018  10 

Ndui  if Ndi **=** 0  1  Nd 

 i

#### Downard Force on Single Deadman for Each Tank

Pd\_ui  if Pdi  0lb

0lb

Pdi Ndui

otherwise

#### Qty of Turnbuckle Per Deadmen Ntb  2

Vertical Load Taken by Each Turnbuckle

Tv 

Pd\_u Ntb

 5.016  3 

 10 

 3.787  3 

 10 

Tv   1.99  103  lb

 



 1.063  3

10

 830.761 

 

 0 

#### Anchor Plate Dimensions

wa  12in La  12in

#### FRP Overlay Thk.

tov  0.5in

#### Shear Stress in FRP Overlay

 208.987 

 157.797 

 

τ 

Tv   82.923 psi

p 2wa  Latov

 44.31 

 34.615 

 

 0 

#### Allowable Shear Stress in FRP Overlay

τal 

2000psi  666.667psi 3

#### Compressive Stress in FRP Overlay

 34.831 

 26.3 

 

σp 

Tv waLa

  13.82 psi

 7.385 

 5.769 

 

 0 

#### Allowable Compressive Stress in FRP Overlay

σp\_al  20000 psi  6.667  103psi

3

checkcompsheari  if τpi  τal  σpi  σp\_al "OK"  "Inadequate" 

 

 "OK" 

 "OK" 

 

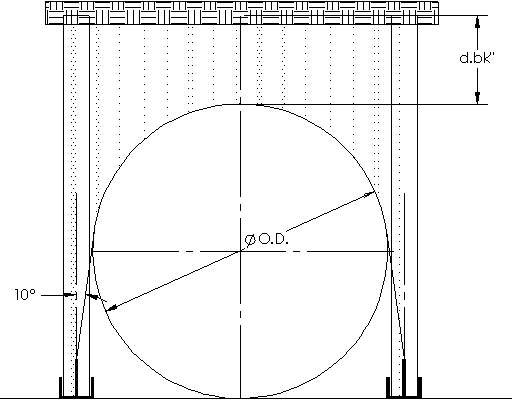
checkcompshear   "OK" 

 "OK" 

 "OK" 

 

 "OK" 



#### Considering strap angle at 10 deg.

Max. Tensile Force on Each Turnbuckle

 5.093  3 

 10 



 

 3.846 



3

10 

T 

Tv   2.021  103  lb

cos(10deg)

 

 1.08  3



10

 843.577 

 

 0 

#### 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

 4 

 4 

 

wstr

  3 in

 2 

 2 

 

 1 

Load in Strap Tstr  T

#### Pressure Under Each Strap p

str 



Tstr 0.9πDwstr

2

 5.093  3 

 10 

 6.255 

 3.846  3   5.667 

 10   

T   2.021  103  lb

p   4.963  psi OK

str  

str  5.304 

 1.08  3 

10

 4.973 

 843.577 

 

 0 

 

 0 

### LUG STRESS CHECK

Material A36 C.S. Galv. Tensile Strength Fulug  58ksi

Yield Strength Fylug  36ksi

#### Allowable Bending Stress

σalb  0.66Fylug  2.376  104psi

Hole Diameter dhole  1.25in

Diameter of Pin dpin  dhole  0.25in  1 in

Lug Height hlug  17in

#### Lug Width

wlug  6in

#### Lug Thk.

thk  0.25in

Lug Radius radius 

### Vertical Uplift

wlug  3 in 2

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

ϕgross  .90

ϕnet  .75

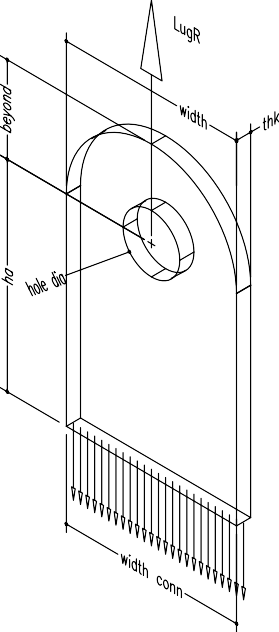
Ωgross  1.67

Ωnet  2

Shear lag factor U  1

An  thk2radius  dhole Fylug

Ftgross 

Ωgross

Vcap

1

 Ftgrossthk2radius

Vcap

1

 3.234  4

Ftnet 

10 lb

Fulug

Ω

10 lb

Vcap

2

net

 FtnetAnU

Vcap

2

 3.444  4

#### AISC(13th ed.), sect. J7

ϕbrg  .75

Ωbrg  2

Allow permanent deformation around hole due to bearing (mushrooming of hole)? Allowmushrooming  "yes"

#### Allowable Bearing Stress: Fbrg

 1.8 Fylug

Ωbrg

#### Allowable Load for Bearing:

Vcap 

3

Fbrgthkdpin

if Allowmushrooming **=** "no"

Vcap

1

if Allowmushrooming **=** "yes"

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

lb

10

Vcap

3

 3.234  4

#### shear yeilding

ϕsy  1

Ωsy  1.5

Rnsy **=** 0.6FylugAg

Vnsy  0.6Fylugthk2radius

10

Vcap 

4

Vnsy

Ωsy

Vcap

4

 2.16  4 lb

#### shear rupture

ϕsr  .75

Ωsr  2

Rnsr **=** 0.6FulugAnvsr

Anvsr  thk2radius  dhole

Vnsr  0.6FulugAnvsr

Vnsr

Vcap  Vcap

 2.066  4 lb

1. Ωsr 5

10

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

Block Shear ϕsb  .75

Ωsb  2

Ubs  1

#### tension is uniform

 dhole   dhole 





Agv  (radius)thk

Anv  radius 

thk

2 

Ant  radius 

thk

2 

Rnsb  min0.6FulugAnv  UbsFulugAnt 0.6FylugAgv  UbsFulugAnt

Rnsb

Vcap  Vcap

 2.532  4 lb

1. Ωsb 6

10

#### AISC(13th ed.), sect. D5 tensile rupture ϕtr  .75

Ωtr  2

Pntr **=** 2thkbeffFulug

b'eff 

2radius  dhole

if

(2thk  0.63in)

2radius  dhole 2

2

* 2thk  0.63in

otherwise

3 

dhole  4

dhole

beff 

 radius 

4

 if

2

3 b'eff  radius  2

 1.13in

  

b'eff otherwise

10

Vcap

7

 2thkbeff

Fulug

Ωtr

Vcap

7

 1.638  4 lb

shear rupture ϕsr  0.75 Ωsr  2

Pnsr **=** 0.6FulugAsf

a  radius 

dhole 2

 2.375in

amin  1.333beff  1.506in





Asf  2thka 

dpin 

 2 

Vcap

8

 0.6Fulug Asf

Ωsr

lb

10

Vcap

8

 2.501  4

#### AISC(13th ed.), sect. J2.4

Weld Strength

ϕfw  0.75

Ωfw  2.0

FEXX  70ksi

#### Allowable weld stress and load for bottom weld, 100% transverse to load

θ  90deg

weld 

1 in 4

dw 

weld

Swt 

2

0.6FEXX1  0.5sin(θ)1.5

Ωfw

Swt

 31.5ksi

Vcap8

 Swt

wlug

dw2

Vcap8  6.682  104 lb

 3.234  4 

 10 

 3.444  4 

 10 

 3.234  4 

 10 

 2.16  104 

Vcap  

 2.066 



 lb

4



10

4 

 2.532  10 

 4 

 1.638  10 

####  4 

 2.501  10 

#### Lug Lateral Bending Section Modulus

Zlug 

1 thkwlug2

#### Max. Lateral Load

6

Bending Moment

Flt  10000lbsin(10deg)  1.736  103 lb

Mlt  Flthlug  radius  2.431  104 inlb

Bending Stress σlt\_b 

Mlt Zlug

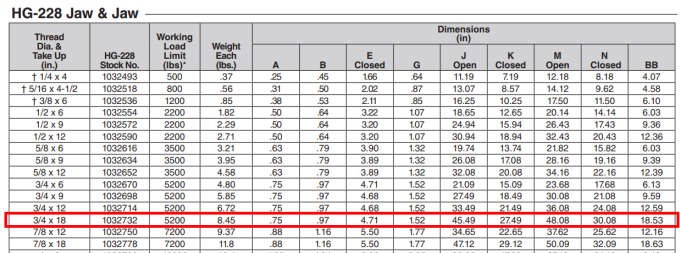
 1.621  104psi

σalb σlt\_b

 1.466

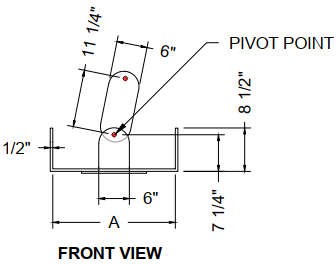
greater than 1, OK

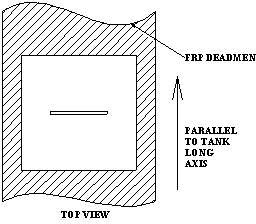
**Turnbuckle Selection**



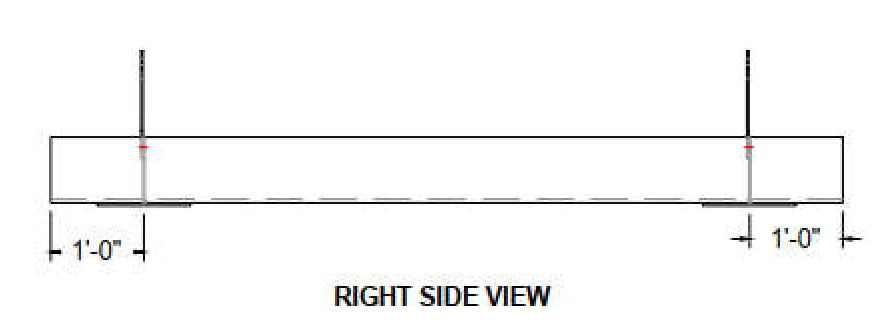
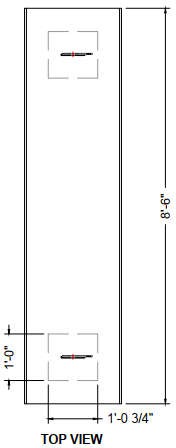
# Appendix A Design Sketches

## Anchor Plate Detail



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## FRP Deadmen Detail



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))

 12 

 10 

 4 

 3 

 24 

 24 

 20 

 28 

 40 

 56 

         

D   8 ft

d   3 ft

b   18  in

2N   12 

N 2N

  24 

 6 

 5 

bk  2 

 2 

d  12 

 12 

d  16 

 4 

tb d

 32 

 8 

         

 4 

 2 

 12 

 0 

 0 

**Two Tank Backfill Zone Detail**

