FRP Composite Services Composite Engineering Design Finite Element Analysis

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**Rev.O**

ENGINEERING DESIGN REPORT

**FIBERGLASS REINFORCED PLASTIC UNDERGROUND HORIZONTAL STORAGE TANK**

End User: TBD Project Name: TBD

Customer: Fiberglass Tank Solutions, LLC Equipment Name:

Equipment Number:

Dimension: 10'-0" Inside Diameter X 65'-2" Straight Shell Length Design Water Table: Flooded to Grade

Configuration: Dished Heads, Cylindrical Shell, Horizontal Construction: Filament Wound & Hand Layup

Resin System: Stypol DCPD Resin w/ CoNAP/MEKP Corrosion Barrier: NA

Design Pressure: Atmospheric

Design Temperature: 100 deg. F max. Liquid Content: TBD.

Design Content Specific Gravity : 1.0 Seismic Load: NA

WmdLoad:NA

Design Ref. Standards: ASTM D3753-19 Equipment Service Location: TBD

Design Engineer: Joann Du, P.E. Revision: 0

Issue Date: 2/27/2020

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**Chapter 1 Design Inputs**

Shell Inside Diameter D  10ft  120in

Shell Inside Radius R 

D  60in 2

Total Straight Shell Height H  65ft  2in  782 in

Design Burial Depth to the Top of the Tank

hbu  7ft

Design Water Table Hwt  D  hbu  204 in

Applied Internal Pressure Pint  0psi

Applied External Pressure Pext  0psi

Corrosion Barrier Thk. tcb  0in

Max. Design Temperature Tmax  100F

Content Specific Gravity sg  1.0

Water Density: ρw  0.0361 lb in

3

FRP Density ρfrp  0.065 lb in

3

Submerged Soil Density ρws  70 lb ft

3

Concrete Desity

ρc  150 lb

ft

3

Design Safety Factor for Sustained Load Fs  10

Design Safety Factor for Transient Load Ft  5

Design Safety Factor for Vacuum Fvac  2.5

# Chapter 2 Design of Cylindrical Shell

* 1. **Shell Properties**

Shell Construction Filament Wound

Shell Structure Thk.: ts  tsuin  ( 0.31 ) in



 

Shell Total Thk: tstot  ts  tcb

## Shell & Head Thks, and Stiffener Design Work for Same Diameter Tank with Shorter Shell

**Length**



s

Shell Mean Radius: Rm

 t 

 R  

 2 

Rm  ( 60.155 )in

tstot  ( 0.31 )in



 

Shell Outer Diameter: Do  D  2tstot

Total Number of Shell Courses n  1

i  1  n

Shell Length: Ls  ( H )

Ls  782 in

H  782 in

Property Reduction Factor η  0.98

Conservative properties are used. See lamination analysis in App. B

Axial Tensile Modulus Hoop Tensile Modulus

Ea  ( 1953000 )ηpsi  1.914  106 psi Eh  ( 4199000 )ηpsi  4.115  6 psi

10

Axial Flexural Modulus Hoop Flexural Modulus

Eaf  ( 1588000 )ηpsi  1.556  106 psi Ehf  ( 4540000 )ηpsi  4.449  6 psi

10

Axial Hoop Poisson's Ratio Hoop Axial Poisson's Ratio

υah  ( 0.09 ) υha  ( 0.20 )



Shell moment of inertia: Is   π D  2tstot4  4

64 

D 

Burial Depth to The Bot. of Shell

 

LB  D  hbu

 

Height of Water Table Above the Bot. of Each Shell Section

hw  LB  204 in

# Loads Considered

The following loads will be considered for the structural analysis of the tank:

* Internal pressure
* Lateral earth loads
* Lateral water loads

# Internal Pressure

Shell internal pressure is a combination of applied pressure and hydrostatic pressure.



 

Internal Pressure on Shell Ps\_ip  Pint  ρwsgD

Ps\_ip  4.332psi

Shell Hoop Stress Due to Internal Pressure

σs\_ip 



Ps\_ipRm ts

σs\_ip  ( 840.618 )psi

Shell Hoop Tensile Strength σh\_al  0.01Eh

Shell Hoop Srain Due to Internal Pressure

εs\_ip 



σs\_ip Eh

εs\_ip  2.043  10 4 

Safety Factor of Shell Under



 σh\_al 

Internal Pressure SFs\_ip   σ 



s\_ip 

SFs\_ip  ( 48.952 )

checkshellforinternalpressure  if SFs\_ip  10 "OK"  "Inadequate" 

i  i 

checkshellforinternalpressure  ( "OK" )

# Earth Load

Ref : Das B.M.; Fundamentals of Geotechnical Engineering, 2000, p.291-295.



The ratio of the horizontal stress to the vertical stress is called the coefficient of earth pressure at rest,

κo , or

κo **=** σh

σv

Rearranging gives σh **=** κoγsh

|  |  |  |
| --- | --- | --- |
| h | = | depth of point of interest |
| γs | = | density of saturated or “moist” soil (Das, page 19) |

For granular soils, the coefficient of earth pressure at rest can be represented by the empirical relation.

κo **=** 1  sin(φ)

φ : soil friction angle

For select backfill material (conforming to the requirements of the Underground Horizontal Tank Installation Instructions Guidelines), we can assume φd  30 deg for calculation proposes.

Therefore κ

 φd 

 1  π  0.5

sin 

o

 180 

For the subject tank, we have the lateral earth pressure at rest as

Per\_L  κoρwsLB

# Lateral Water Load

Height of Water Table Above the Bot. of Shell

hw  204 in

Lateral Pressure at Rest Below Ground Water Table

Phy  ρwhw  7.364psi

# Combined Lateral Load

Combined Pressure Due to Earth Load and Water



Ps\_ep  Phy  Per\_L

 

Ps\_ep  11.496psi

# Stress Analysis

1. **Hoop/Circumferential Crushing**

If the tank is in a wet hole, the hydrostatic pressure on the outside of the cylinder produces compressive membrane stresses in the shell if the tank is empty.

The maximum compressive stress in the the cylindrical shell of the system occurs at the bottom of the tank. The expression for these stresses, for the cylinder are given by (Structural Plastics Design Manual, Vol. 2, 1984, ASCE, p. 928-930):

σs\_c 



Ps\_epRm ts

 tsu  ( 0.31 )

Shell Structure Thk.

σs\_c  2.231  103 psi

Compressive Strength of Shell σs\_a\_ep  20000psi

Safety Factor of Shell Under



 σs\_a\_ep 

Combined External Pressure SFs\_ep  





σs\_c 

SFs\_ep  ( 8.965 )

# Buckling Analysis

The design for underground global buckling is performed according to the methodology detailed in [Moser,A.P.; Buried Pipe Design,1990, pages 65-68 ]. For this analysis, the cylindrical part of the tank is analyzed for overall buckling against soil and underground water loading, neglecting the constraining end effects of the bottom.

The critical buckling pressure in global buckling mode is given by the modified Luscher formula by Meyerhof and Baike.

Modulus of Soil Reaction E'  2000psi SC3

Moment of Inertia of Tank per Unit Length

Is\_un  Isuin3

Buckling Safety Factor FSbu  2.5

Shell Hoop Flexural Modulus E  4.449  106 psi

hf

Poisson's Ratio υ  0.25



 E'  Ehf Is\_un 

Critical Buckling Pressure Pcr  2







1  υ2 





3 

R

m 

Pcr  ( 213.768 )psi



Actual Safety Factor Against

 Pcr 

Buckling FSbu\_a   P 

FSbu\_a  ( 18.594 )

 s\_ep 

checkshellbucklingi  if FSbu\_ai  FSbu "OK"  "Buckle" 

 

checkshellbuckling  ( "OK" )

# Trapezoidal Shell Stiffener Design

Stiffener Spacing on Shell Lst  24in

Max. Design Unsupported Length (This includes 1/3 of head depth)

 Lst\_max  Lst  4in2  16 in

Required Moment of Inertia of Stiffener

Psti\_q  Ps\_ep  11.496psi



Stiffener Construction: Filament Wound

Stiffener Top Hoop Tensile Modulus:

Esri  14000000psi

Stiffener Side Hoop Tensile Modulus:

Esrli  1400000psi

Stiffener Top FW Thk.: tsr  ( 0.34 )in

Stiffener Side Chop Thk.:

 ts\_sd  ( 0.34 )in

 

 

Shell Outside Diameter: Dsh\_o  D  2ts

Stiffener Effective Dimensions:

A  2in

i

Ci  2in

Bi  4in

Dsri  2in

Shell Thk: tsh  tstot  ( 0.31 ) in

Shell Hoop Tensile Modulus:

Esh

 Eh

 4.115 

10 psi

6 







ϕ  acos C  ϕ 180 



deg  ( 26.565 )deg





C 



2

 B  A2

2

 

π

 

Lsr 



C 

2

 B  A2



2 

 

Area of Sides: As  Lsrts\_sd



 

Effective Width of Cylinder: wes  B  2Dsr



 

Effective Area of Cylinder: Ac  westsh



 

Area of Top: At  Atsr



 

Area of Base: Ad  2 Dsr  ts\_sd ts\_sd

Total Effective Area of



Stiffener Excluding Shell: Atot  At  Ad  As

Effective Hoop Modulus of Stiffener and Cylinder:

Esrh 



EshAc  Esr At  Ad  EsrlAs  7.247  106 psi Ac  Atot

 

Required MOI of Ring:

Isr\_min 



Psti\_qLstDsh\_o3 24Esrh

 ( 2.784 ) 4

in



t

 tsh 

c

tsr

Esr

C Esrl

 tsr 

Esr

Effective CG From CG 

Outside of Shell:

A 



 

2  2



Esh

Ad  As

E



2 Esh

 A C 



E



2  Esh

Ac  As srl  At  Ad sr

CG  ( 0.624 ) in

Esh

Esh

 

 t

L 3

L t 3 

I of Each Side About the

Iside   s\_sd sr cos(ϕ)2  sr s\_sd sin(ϕ)2  4

Centroid of the Sides:

 12

12 

( 0.255 ) in

About the Centroid:



 Esrl 2 Esr 2 

 3

w t E

E Adts\_sd E

E Attsr 

 es sh sh



srh

srl

srh 

I1  

 12

 

Esrh



12 E

srh

2Iside 

12 







I  

 tsh 2

 Esh

 Esrl 

 ts\_sd 2

 Esrl  C

2 Esr 

2

 tsr 



2 tshwesCG  2   E

* Ad E

CG 

2   As E

  CG

2

* At E

C 

2  CG 

  

srh

srh 

 srh  

srh   

Effective MOI Considering Different Moduli of Shell and Stiffener: I



 

 4

 ( 4.185 )



e I1  I2

in

checkstiffenerMOIi  if Iei  Isr\_mini "Adequate"  "Stiffener Inadequate" 

 

checkstiffenerMOI  ( "Adequate" )



n

Moment of Inertial of Shell per Inch ΣIu

 Ie 

  

L

 st\_max 

ΣIu

 ( 0.262 )i 3

Stiffener Unit Weight Isu  ( 0.262 )



   

Wstif  π Do  2CG Atsr  Lsr  Dsr ts\_sdρfrp

Number of Stiffeners on Shell Nsr  ( 32 )



 

Wr  NsrWstif

Wstif

 ( 52.764 ) lb

W  1.688 

3



10 lb

ΣWr  Wr  1.688  103 lb

r

See FEA buckling analysis for shell w/ stiffeners.

## Shell W/ Stiffeners Under External Pressure Finite Element Analysis

See external pressure calculation in section 2.2 IV. Tank is simply supported at the bot. 180 deg. surface.

Buckling analysis is run to investigate the safety factor against buckling for the shell and stiffeners assembl



## Solid Model



**Meshed Model**

Buckling Safety Factors For Shell + Stiffeners Assembly

 "Mode No." "Buckling Factor of Safety" 

 1 3.2011



 2 3.2071

 3 3.3664

 3.3731

4



 5 3.4237



 Greater than min. buckling factor 2.5, OK.











# Chapter 3 Dished Heads W/ Stiffener Design

Head Construction Hand Layup

Head Configuration ASME F & D w/ Stiffeners

Head Straight Flange Length

sfth  1.5in

Head Structural Thk. tth  0.36in

Head Total Thk. tth\_tot  tth  tcb  0.36in

Tensile Modulus Eth  1500ksi

Tensile Strength Sth  15ksi

Flexural Modulus Eth\_f  1000ksi

Ultimate Flexural Strength Sth\_f  22ksi

Poisson's Ratio υ  0.25

Design Factor For Pressure Fs  10

Design Factor For Vacuum and Combined Load

Fvac  2.5

## 3.1 Head Design for Pressure

Head Construction: Hand Layup

Head Design Pressure: PH\_ip  Ps\_ip  4.332psi

Head Inside Dish Radius: Rc  120in

Head Inside Knuckle Radius: rc  8in

Minimum Required thk. For Pressure: t

h\_ip 

0.885PH\_ipRc

Sth Fs

 0.307 in

checkheadthkip  if tth\_tot  th\_ip "OK"  "Increase head thk."   "OK"

## Design of Head to Shell Joint

Joint Tensile Modulus: Ej  Eth

Secondary Bond Shear Strength: τj  2000psi

## Left & Right Head to Shell Joint

PH\_ip D  ts 

Min. Req'd Joint Thk.: tjH\_min 

 2

0.001Ej

1  0.174 in

Design Joint Thk.: tjH  tth  0.36 in

PH\_ip D  ts 

Min. Req'd Joint Length: LjH\_min   2 1

τ

j

2

Fs

 0.653 in

Design Joint length: See detail. in Appendix A

## Head Design for External Loads

Design Max External Pressure PH\_ep  Ps\_ep  11.496psi

## Finite Element Analysis of Dished Heads with Stiffeners

Applied Load : - Gravity

* External Water Pressure
* Soil Load

Boundary Condition: Fixed around the perimeter of the top head. (For simplicity of analysis.) Note : See Appendix A for stiffener size, location and FRP overlay thks.

Finite element analysis is performed based on the load and boundary conditions as stated above and material properties and thks specified in the previous sections of thie report. Solidworks 2012 Simulation is used for this analysis.

**FEA Solid Model**

**Meshed Model**



**1st Principal Stress**



**1st Principal Stress Detail**



Tank head is under external pressure. Max. allowable compressive stress in type II hand layup laminate is 20,000 psi / 3 = 6,667 psi. Higher stress (4,738 psi) is observed in the knuckle region of the dished head. Knuckle is under compression. Buckling analysis is run to evaluate the head's stability under external loads. The max stress in the rest of the area in the top head is less than 3,000 psi, and is thus considered acceptable.

**X - Stress**



**Y - Stress**



**Z - Stress**



**Resultant Displacement**



Less than 0.75", OK.

Note : Deflection is exaggerated by 20 times for clarity.

## Buckling Safety Factor

 "Mode No." "Buckling Factor of Safety" 

 1 2.5228 

 

 2 2.5326 

 3 2.5509 

 2.5731 

4





 5 2.7976 

Greater than 2.5. OK.



# Chapter 4 Component Weight

Weight of Each Head: WH  Wttoriheadρfrp rc R Rc 0  tth

WH  319.507lb

Head Depth: h

 

 

 R  R  r 

 D 

 2 

* rc

H c  c

c cosasin



   Rc  rc 

hH  20.803 in

Weight of Shell: WS  ρfrpπDH

tstot

 5.94  3

WS  5.94  103 lb

10 lb

Top Head Volume: VL\_H  f\_voltsrc  R Rc 0  628.374gal

Tank Volume (Flooded): VL  2VL\_H  πR2H

VL  3.954  104 gal

Content Weight: WL  ρcVL  7.929  5

10 lb

Extra FRP Dead Weight (Covers joints, nozzles, and repads etc.)

Wad1  1200lb

Total Weight Multiplication Factor: η  1.15

Total FRP Tank Weight: WFRP 

WS  2WH  Wad1  Wr η  1.089  4

Total FRP + Content Weight: WT  WFRP  WL  8.038  105 lb

10 lb

# Chapter 5 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, and the weight of the concrete deadman attached to the tank are used to resist buoyancy.

Buoyancy Design Safety Factor SFby  1.2

Saturated Backfill Material Density

Projected Area

Estimated Weight of Tank Used to Counteract Buoyancy

ρfil  70 lb

ft

3

Aprj  DH  9.384  104in2 Wby\_ww  WFRP  1.089  104 lb

Total Volume of Water Displaced Vh2o  VL  3.954  104 gal Total Weight of Water Displaced Wh2o  ρwVh2o  3.298  5lb Design Buoyancy Force Fby  Wh2oSFby  3.957  105lb

10

Min. Backfill Height dbk  3ft

Soil Friction Angle (Estimated) ϕ  20deg

 ϕ   0.349 180deg

ϕ πr



## Soil friction angle must be verified by end user. Ecavate area must be greater than 20 degree area. All excavated in situ soil must be replaced with primary backfill material. Back fill soil must be even and uniform in every direction.

Base Area ab  DH

Height h  dbk 

D  8ft 2

Δ  htanϕr  34.941 in

Top Area at  (D  2Δ)(H  2Δ)  1.618  5 2

10 in

Concrete Deadmen Qty Nd  8

Concrete Deadmen Length Ld  18ft

Unit Weight wd  2400lb

Concrete Deadmen Width bd  18in

Total Concrete Deadmen Weight

W  N w  ρc  ρw  1.122  4

When Submerged

d d d ρc

10 lb

Soil Above Deadmen Below Tank C.L. Vd\_sl  NdLdbd D  1.08  103ft3

2



Volume of Backfill and Soil Above Vs  h at  ab 

Tank Used to Counteract Buoyancy 3

atab 

1 2 1 3 3

D 10

π H  4.456  ft

4 2

Backfill Weight Wbk  Vs  Vd\_slρfil  3.875  105 lb

Weight of Concrete Required To Hold Down the Tank When Totally Submerged

Wc\_r  Fby  Wby\_ww  Wbk  2.684  103lb

checkbuoyancy  if Wd  Wc\_r "Adequate"  "Additional Weight Req'd"   "Adequate"

See concrete deadmen design sketch in Appendix A.

# Chapter 6 Lifting Lug Design

## Lifting Lug are Attached by Hoop Filament Wound Glass

A36 C.S. = Lifting Lug Material

WFRP  10888 lb

= Total Empty Tank Weight

NL  4

= Number of Lift Lugs

tlug  0.375in

= Thickness of Backing Plate

wL  8in

= Width of Backing Plate

hL  10in

= Height of Backing Plate

elift  1.5in

= Eccentricity

Sv  2000psi

= FRP Shear Strength

Sa  15000psi

= FRP Axial Tensile Strength

Sh  30000psi

= FRP Hoop Tensile Strength

to1  0.40in

λ  1.5

= Hoop Overwind Thk.

= Design Factor

A36 C.S. = Lug Material

Material properties from ASME Section II part D for ambient temperature.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Es** | **Sy** | **Su** |
| **A36** | 29000 ksi | 36 ksi | 58 ksi |
| **304 S.S.** | 29000 ksi | 30 ksi | 75 ksi |
| **316S.S.** | 29000 ksi | 30 ksi | 75 ksi |

Lug Eastic Modulus Ecs  29000ksi

Lug Yield Strength Fylug  36ksi

Lug Ultimate Tensile Strength Fulug  58ksi

## CALCULATIONS

Reinforcement pad thickness tp  0.043in5  0.215in

(All Mat Construction)

Reinforcement pad height Lp  hL  6in  16 in

Reinforcement pad width wp  wL  6in  14 in

Pad + shell thickness tps  tp  tsh  ( 0.525 ) in

Load per lug Flift 

λWFRP  4.083  3

NL

lb

10

Bending moment per lug ML  Fliftelift  6.125  103 inlb

Unit radial load on overwrap W

3Fliftelift lb

  287.086

max

wL2 in

Total radial load due to lug moment PL 

WmaxwL

 1.148 

2

103 lb

Overwind mean radius Ro  R  tps  ( 60.525 ) in

Hoop overwind load Ttl 

PLRo  6.95 

hL

3

10 lb



Hoop overwind tensile stress σo 

Ttl

h t

 1.738 

10 psi OK

3 

L o1

Shear across vessel wall τo 

PL

tpshL

 ( 218.732 )psi OK

Coefficient of bending in vessel wall: βL 

Poisson's ratio υ  0.25

 0.227 1

in

 1.28

Rotps

PL lb

Unit radial loading P   114.835

star hL in

Bending loads:

Max.L 

Pstar 4βL

 126.43 lb

Mhp.L  υMax.L  31.607 lb

Loads due to pressure: Zero during lift

NaxL  0

NhpL  0

Bending stress on shell, psi: σ

6Max.L

 

NaxL  2.752  103 psi

ax.L

2

tps

tps

σ 

6Mhp.L



NhpL  ( 688.054 )psi

hp.L

2

tps

tps

Safety factor for bending: Sa

σax.L Sh

σhp.L

 ( 5.45 )

 ( 43.601 )

* 3 OK
* 3 OK

## LIFTING RING STRESS CHECK

Diameter of Ring Rod dbolt  0.75in

Ring Outside Diameter odring  1.752in  3.5 in

Ring Inside Diameter idring  2in

Diameter of Pin dpin  1in

ϕgross  .90

ϕnet  .75

Ωgross  1.67

Ωnet  2

Shear lag factor U  1 table D3.1

Net area An  0.344 2

in

Tensile rupture in net area Ft

net 

Fulug

Ωnet

Vcap1  FtnetAnU

Vcap  9.976  3

1

10 lb

AISC(13th ed.), sect. J7 bearing strength

ϕbrg  .75

Ωbrg  2

LRFD

Allowmushrooming  "yes"

Allowable bearing stress: Fbrg

 1.8 Fylug

Ωbrg

Projected bearing area: Abrg  dpindbolt

Allowable load for bearing: Vcap2 

FbrgAbrg

if Allowmushrooming **=** "no"

Vcap  9.976  3

2

10 lb

Vcap1 if Allowmushrooming **=** "yes"

AISC(13th ed.), sect. J4-2 Strength of connecting elements in shear

shear yeilding

ϕsy  1

Ωsy  1.5

Net shear area: Anvsr  2 1 πd

4

2

bolt

shear rupture

ϕsr  .75

Ωsr  2

Net area subject to shear: Anvsr  Anvsr

Rnsr  0.6FulugAnvsr

Vcap3 

Rnsr

Ωsr

Vcap  1.537  4 lb

3

10

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

Block Shear

ϕsb  .75

Ωsb  2

Ubs  1

tension is uniform

Net area subject to tension Ant  An

Net area subject to shear Anv  Anvsr

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

Rnsb 4

AISC(13th ed.), J4-5

Vcap4 

Ωsb

Vcap4  2.535  10 lb

AISC(13th ed.), sect. D5

tensile rupture

ϕtr  .75

Ωtr  2

Pntr **=** 2thkbeffFulug

 9.976  103 

beff  dbolt beff  0.75 in

Vcap5  2An

Fulug

Ωtr

Vcap  1.995  4 lb

5

10

 3 

 9.976  10 

Vcap   1.537 

4  lb

 10 

 2.535  4 

 10 

 1.995  104 

# Chapter 7 Opening Reinforcement

Reference: RTP-1 3A-700 - 730

Pint  0.0

= Design Pressure

dn = Nozzle Diameter

hn = Nozzle Elevation

Pn = Pressure at Nozzle Centerline

tr = Required Reinforcement Thickness

Dr = Required Reinforcement Diameter

tn = Nozzle Neck Thickness

ti = Inside Bond Thickness

to = Outside Bond Thickness

H  782 in

Sr  Sth sg  1.00

= Max Liquid Level

= Strength of Reinforcement Laminate

= Specific Gravity of Tank Contents

# Shell Nozzle Opening Reinforcement

 4 

dn   24 in

 120 

hn   120 in



Δh  D  hn

 

 0 

Δh   0  in

     

 30 

k  1  lastdn

 120 

 0 

## Calculate Pressure at Each Nozzle:

Pnk  Pint  Δhksgρws

 0.00 

Pn   0.00 psi

 

 0.00 

## Calculate Reinforcement Diameter:



Drk  if dn   6in 2dn   dn  6in

 k  k  k 

 10 

Required Cutout Reinforcement Dia.: Dr   48 in

 

 60 

## Calculate Coefficient "K":

  dn  

 0.67 

Kn  if dn  6in  k   1.0

Kn   1.00 

k  k

 6in    

 1.00 

## Calculate Coefficient "M":

Laminate type: type  "X" (X for filament wound, I and II for HLU)

Hoop tensile strength for shell: σuk  0.01Eh1

Factor M M 

1 if type

σuk

15000psi

r

k

**=** "I"  type **=** "II"

otherwise

Calculated Structural Thk: T  t

c s

k 1

Theoretical Structural Wall Thk.: Tt  Tc

Factor V V  1

k 2

(pressure governs V=1, vacuum governs V=1/2)

## Calculate Reinforcement Thickness:

trk  V Mr Kn Ttk

k k k

 M T  T 

k  k k

r c t



trk  if trk  0.19in trk 0.19in

 

## Required Reinforcement Thickness: Use Reinforcment Thickness:

 0.283 

tr   0.425 in

 0.31 

trd   0.43 in

   

 0.425   0.43 

## Reinforcement should be made of type II laminate with mat and woven roving. Shell Nozzle Opening Reinforcement Summary

 4 

dn   24 in

 10 

Dr   48 in

 0.31 

trd   0.43 in

     

 30 

 60 

 0.43 

# Head Nozzle Reinforcement

dnc  ( 4 )in

m  1  lastdnc

hLc  ( 0 )in

lastdnc  1

ΔhLc  D  hLc

ΔhLc  ( 120 ) in

## Calculate Pressure At Each Nozzle:

Pncm  Pint  ρcΔhLcm

Pnc  ( 10.417 )psi

## Calculate Reinforcement Diameter:



Drcm  if dnc   6in 2dnc   dnc  6in

 m  m  m 

## Calculate Coefficient "K":

  dncm  

Knc

 if dnc  6in    1.0

Knc  ( 0.667 )

m  m  6in  

**Calculate Coefficient "M":** Laminate type: typec  "II" Factor M Mrc  1

m

Calculated structural thk: Tsc  tth

m

Theoretical structural thk: Ttc

m

 Tscm

1

Vrcm  2

(pressure governs V=1, vacuum/bending governs V=1/2)

## Calculate Reinforcement Thickness:

trcm  Vrc

m

Mrc

Knc

Ttc

 

m

m

m

trcm  if trcm  0.19in trcm 0.19in

trc  ( 0.19 )in

 

Design Repad Thk.: trc\_d  ( 0.19 )in

Drcm  dncm

Repad Width

wrcm 

8in if

* 8in

2

wrc  ( 3 ) in

Drcm  dncm 2

otherwise

Design Repad Width wrc\_d  wrc  ( 3 ) in

## Top Head Nozzle Reinforcement Summary

dnc  ( 4 )in

trc\_d  ( 0.19 )in

wrc\_d  ( 3 )in

# Appendix A Design Summaries and Sketches

**Tank Inside Diameter...................................** D  120in

**Straight Shell Length...................................** H  782in

**Shell Total Thk............................................** tstot  ( 0.31 )in

**Left/Right Head Combined Thk.....................** tth\_tot  0.36in

**Tank Empty Weight.....................................** WFRP  1.089  104 lb

## Lamination Sequence

Left & Right Heads 0.36" -3(M,R)M,2M

Shell 0.31" - 2FW,U,2(FW,U)FW

## Nomenclature For Lamination Sequence:

FW = 0.05" @ 89 deg. winding angle, 1 cycle of filament wound glass c = 0.02", 1 layer interspersed chopped strand glass, 0.7 oz/ft2

C\*\*\* = 1 layer of chopped strand glass - \*\*\* indicates thk. of layer in mils (C025 = 0.025") C = 0.043", 1 layer chopped strand glass, 1.5 oz/ft2

M = 0.043", 1 layer chopped strand glass mat, 1.5 oz/ft2 R = 0.033", 1 layer woven roving, 24 oz/sq. yd.

U = 0.02", 1 layer unidirectional roving

**Shell Stiffener Layout**

Total Stiffener Weight ΣWr  1.688  3

10 lb

Total # of Stiffeners Nsr  ( 32 )

Stiffener Spacing Lst  24 in



.

## Note : Bottom 180 deg. section of the tank is fully supported. See customer installation manual.

**Shell Stiffener Detail**



A  ( 2 ) in

B  ( 4 ) in

C  ( 2 ) in

Dsr  ( 2 ) in

Stiffener Thk.: tsr  ( 0.34 ) in

0.34" - 3C,U,3C,U,C

**Shell to Shell Joint Detail**



**Head Reinforcement & Head to Shell Joint Detail**



**Lifting Lugs**



**Nozzle Opening Reinforcement**

## Shell Nozzle Opening Reinforcement Summary

 4 

dn   24 in

 10 

Dr   48 in

 0.31 

trd   0.43 in

     

 30 

 60 

 0.43 

## Top Head Nozzle Reinforcement Summary

dnc  ( 4 )in

trc\_d  ( 0.19 )in

wrc\_d  ( 3 )in

**Concrete Deadmen Design**



18" wide x 8 3/4" tall x 18' long; 8 req'd

**Turnbuckle Selection**



# Appendix B Lamination Analysis Using Trilam

Stypol DCPD Resin used for construction of tank. Trilam analysis uses iso resin which has similar mechanical properties.

**Laminate Sequence Shell**



**Laminate Properties Shell**

