**FRP Composite Services Composite Engineering Design Finite Element Analysis**

**D2021·37·01** **jdu@frpcompositeservices.com** **(c) 310·913·5502**

**Rev.O**

ENGINEERING DESIGN REPORT

**FIBERGLASS REINFORCED PLASTIC UNDERGROUND HORIZONTAL STORAGE TANK**

End User: TBD Project Name: TBD

Customer: Fiberglass Tank Solutions, LLC

Eq uipment Name: Underground Storage Tank Equipment Number: TBD

Dimension: 4'-0" Inside Diameter X 42'-6" 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 Co ntent: TBD.

Design Content Specific Gravity : 1.0 Seismic Load: NA

*Wmd* Load:NA

Design Ref. Standards: ASTM 03753-19

Equipment Service Location: TBD

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

Issue Date: 5/26/2021

**Table of Contents**

**Chapter 1 Design Inputs**

**Chapter 2 Design of Cylindrical Shell Chapter 3 Dished Heads Design Chapter 4 Component Weight Chapter 5 Buoyancy Design**

**Chapter 6 Lifting Lug Design Chapter 7 Opening Reinforcement**

**Appendix A Design Summaries and Sketches Appendix B Lamination Analysis**

**Chapter 1 Design Inputs**

Shell Inside Diameter D  4ft  48in

Shell Inside Radius R 

D  24in 2

Total Straight Shell Height H  42ft  6in  510 in

Design Burial Depth to the Top of the Tank

hbu  7ft

Design Water Table Hwt  D  hbu  132 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: ρ  0.0361 lb

w

3

in

FRP Density ρfrp  0.065 lb in

3

Submerged Soil Density ρws  70 lb

ft3

Concrete Desity

ρc  150 lb

ft3

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  ( 0.24 ) in



 

Shell Total Thk: tstot  ts  tcb

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



Shell Mean Radius: Rm



 R 



ts 



2 

Rm  ( 24.12 )in

tstot  ( 0.24 )in



 

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



 

Mean Diameter Dm  D  tstot



Moment of Inertia I   π Do4  4

64 

D 

Total Number of Shell Courses n  1

i  1  n

Shell Length: Ls  ( H )

Ls  510 in

H  510 in

Property Reduction Factor η  0.98

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

Axial Tensile Modulus Hoop Tensile Modulus

E  ( 2058000 )ηpsi  2.017  6 psi E  ( 4248000 )ηpsi  4.163  6 psi

a 10

h 10

Axial Flexural Modulus Hoop Flexural Modulus

E  ( 1720000 )ηpsi  1.686  6 psi E  ( 4559000 )ηpsi  4.468  106 psi

af 10

hf

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

υah  ( 0.11 ) υha  ( 0.23 )

Burial Depth to The Bot. of Shell

 

LB  D  hbu

 

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

hw  LB  132 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  1.733psi

Shell Hoop Stress Due to σ 

s\_ip

Internal Pressure



Ps\_ipRm t

s

σs\_ip  ( 174.146 )psi

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



Shell Hoop Srain Due to Internal Pressure

εs\_ip 



σs\_ip Eh

εs\_ip

 4.183   5

Safety Factor of Shell Under



 σh\_al 

10

Internal Pressure SFs\_ip   σ 

SFs\_ip  ( 239.054 )

 s\_ip 

checkshellforinternalpressurei  if SFs\_ipi  10 "OK"  "Inadequate" 

 

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

σh

κo **=**

σ

v

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

 1 

 φd 

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  132 in

Lateral Pressure at Rest Below Ground Water Table

Phy  ρwhw  4.765psi

# Traffic Load

Deflection Lag Factor: DL  1.5

Section 5.7.3.3

Burial Depth to Top of Tank Hb  3ft

Modulus of Soil Reaction

of Pipe Zone Embedment

Soil Support Combining

Factor

E'b  1500psi

Sc  1.0

Table 5-4

Composite Modulus of Soil Reaction (Table 5-5) :

E'  ScE'b  1.5  103psi

Impact Factor: If 

1.1

1.0

if 2ft  Hb  3ft if Hb  3ft

HS-20 Live Load on Shell:

Fwh  16000lb

(HS - 20 Wheel Load)

The following calculation assumes a four-lane road with an AASHTO HS-20 truck centered in each 12 ft wide lane. The tank maybe perpendicular or parallel to the direction of truck travel or any intermediate position.

Load Width Parallel to Direction of Travel:

1.67ft  1.75Hb

43.67ft  1.75Hb

8



L1  0.83ft  1.75Hb

 

Section 5.7.3.6

Load Width Perpendicular to Direction of Travel:

L2 

if 2ft  Hb  2.48ft otherwise

Live Load on Pipe: WL 

 

FwhIf

L1L2

 2.989psi

Combined Pressure Due to Earth Load and Water



Ps\_ep  Phy  Per\_L

 

Ps\_ep  7.439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  ( 0.24 )

Shell Structure Thk.

σs\_c  ( 747.601 )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  ( 26.752 )

# 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





in

SC3

Moment of Inertia of Tank per Unit Length

Is\_un

 Isu 3

Buckling Safety Factor FSbu  2.5

Shell Hoop Flexural Modulus E  4.468  6 psi

hf 10

Poisson's Ratio υ  0.25

Max. Design Water Table to the Top of Duct

hwbu  7ft

Water Buoyancy Factor: Rw 

1 if hw **=** 0in

hwbu

1  0.33

hbu

otherwise

Empirical Coefficient of Elastic Support: B' 

1

 hbu

 0.065

1  4e



ft 

Allowable Buckling Pressure:

 

 1 Ehf Is\_un 

P  

cr

 FSbu



 32RwB'E'

3  Eq 5-21

Dm 



Valid for 2 ft =< h.bu <=80 ft without internal vacuum, or 4 ft =< h.bu <=80 ft with internal vacuum.

Pcr  ( 71.911 )psi

checkshellbucklingi  if Pcri  Ps\_ep "OK"  "Buckle" 

 

checkshellbuckling  ( "OK" )

# Trapezoidal Shell Stiffener Design

Stiffener Spacing on Shell Lst  36in

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

Lst\_max  Lst  2in2  32 in

Required Moment of Inertia of Stiffener

Psti\_q  Ps\_ep  7.439psi



Stiffener Construction: Filament Wound

Stiffener Top Hoop Tensile Modulus:

Esri  14000000psi

Stiffener Side Hoop Tensile Modulus:

Esrli  1400000psi

Stiffener Top Thk.: tsr  ( 0.24 )in

Stiffener Side Thk.:

ts\_sd  ( 0.24 )in

 

 

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

Stiffener E**f** ective Dimensions:

A  3in

i

Ci  1.5in

Bi  5in

Dsri  2in

Shell Thk: tsh  tstot  ( 0.24 ) in

Shell Hoop Tensile Modulus:

Esh

 Eh

 4.163  106 psi







ϕ  acos C 





C 



2

 B  A2

2

 

ϕ



180

π

deg  ( 33.69 )deg



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

E 



EshAc  Esr At  Ad  EsrlAs  7.578 

 

6 psi

Stiffener and Cylinder:

srh

10

Ac  Atot

Required MOI of Ring:

Isr\_min 



Psti\_qLstDsh\_o3 24Esrh

 ( 0.168 ) 4

in



 tsh 

c

t

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  ( 0.544 ) in

Esh

Esh

 

 t

L 3

L t 3 

I of Each Side About the Centroid of the Sides:

 12

Iside   s\_sd sr

4

cos(ϕ) sin(ϕ) ( 0.082 ) in

 2  sr s\_sd  2 

12 

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 Di**f** erent Moduli of Shell and Stiffener: I

 4

  ( 2.138 )

 

e I1  I2 in

checkstiffenerMOI  if Ie  Isr\_min  "Adequate"  "Stiffener Inadequate" 

i  i i 

checkstiffenerMOI  ( "Adequate" )



in

Moment of Inertial of Shell per Inch ΣIu

 Ie 

  

L

 st\_max 

ΣIu

 ( 0.067 ) 3

Stiffener Unit Weight Isu  ( 0.067 )



   

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

Number of Stiffeners on Shell Nsr  ( 14 )



 

Wr  NsrWstif

Wstif  ( 16.525 ) lb Wr  ( 231.357 ) lb

ΣWr  Wr  231.357 lb

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

Greater than min. buckling factor 2.5, OK.

# Chapter 3 Dished Heads

Head Construction Hand Layup

Head Configuration ASME F & D

Head Straight Flange Length

sfth  1.5in

Head Structural Thk. tth  0.24in

Head Total Thk. tth\_tot  tth  tcb  0.24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  1.733psi

Head Inside Dish Radius: Rc  48in

Head Inside Knuckle Radius: rc  3in

Minimum Required thk. For Pressure: t

h\_ip 

0.885PH\_ipRc

Sth Fs

 0.049 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  0.028 in

Design Joint Thk.: tjH  tth  0.24 in

PH\_ip D  ts 

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

τj

2

Fs

 0.105 in

Design Joint length: See detail. in Appendix A

## Head Design for External Loads

Design Max External Pressure PH\_ep  Ps\_ep  7.439psi

## Finite Element Analysis of Dished Heads

Applied Load : - Gravity

* External Water Pressure
* Soil Load

Boundary Condition: Fixed around the perimeter of the top head. (For simplicity of analysis.)

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**



Tank head is under external pressure. Max. allowable compressive stress in type II hand layup laminate is 20,000 psi / 3 = 6,667 psi. Max. 1st principal stress in the head is 704 psi. Buckling analysis is run to evaluate the head's stability under external loads.

**X - Stress**



**Y - Stress**



**Z - Stress**



**Resultant Displacement**



Less than 0.5", OK.

Note : Deflection is exaggerated by 36 times for clarity.

## Buckling Safety Factor

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

 1 9.8013



 2 9.9495

 3 10.296

 10.477

4



 5 10.686



 Greater than 2.5. OK.













# Chapter 4 Component Weight

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

WH  34.044 lb

Head Depth: h

 R

 

 

* R  r 

 D 

 2 

* rc

H c  c

c cosasin



   Rc  rc 

hH  8.201 in

Weight of Shell: WS  ρfrpπDH

tstot

 1.2  3

WS  1.2  103 lb

10 lb

Top Head Volume: VL\_H  f\_voltsrc  R Rc 0  39.318gal

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

VL  4.074  103 gal

Content Weight: WL  ρcVL  8.169  104 lb

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

Wad1  400lb

Total Weight Multiplication Factor: η  1.15

Total FRP Tank Weight: WFRP 

WS  2WH  Wad1  Wr η  2.184  103 lb

Total FRP + Content Weight: WT  WFRP  WL  8.387  104 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

ft3

Aprj  DH  2.448  104in2 Wby\_ww  WFRP  2.184  103 lb

Total Volume of Water Displaced Vh2o  VL  4.074  103 gal

Total Weight of Water Displaced Wh2o  ρwVh2o  3.397  104lb

Design Buoyancy Force Fby  Wh2oSFby  4.077  104lb

Min. Backfill Height dbk  3ft

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

ϕ  ϕ π  0.349 180deg

r



## 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  5ft 2

Δ  htanϕr  21.838 in

Top Area at  (D  2Δ)(H  2Δ)  5.076  104 in2

Concrete Deadmen Qty Nd  0

Concrete Deadmen Length Ld  16ft

Unit Weight wd  2400lb

Concrete Deadmen Width bd  12in

Total Concrete Deadmen Weight When Submerged

ρc  ρw

Wd  Ndwd  0

ρ

c

Soil Above Deadmen Below Tank C.L. Vd\_sl  NdLdbd D  0ft3

2



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

Tank Used to Counteract Buoyancy 3

1 2 1 3 3

D 10

atab  π H  1.012  ft

4 2

Backfill Weight Wbk  Vs  Vd\_slρfil  7.082  104 lb

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

Wc\_r  Fby  Wby\_ww  Wbk  3.224  104lb

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

# Chapter 6 Lifting Lug Design

## Lifting Lug are Attached by Hoop Filament Wound Glass

A36 C.S. = Lifting Lug Material

WFRP  2184 lb

= Total Empty Tank Weight

NL  2

= Number of Lift Lugs

tlug  0.25in

= Thickness of Backing Plate

wL  4in

= Width of Backing Plate

hL  10in

= Height of Backing Plate

elift  1.75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

= Hoop Overwind Thk.

λ  1.5 = 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  0.215 in

(All Mat Construction)

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

Reinforcement pad width wp  wL  6in  10 in

Pad + shell thickness tps  tp  tsh  ( 0.455 ) in

Load per lug Flift 

λWFRP

 1.638 

NL

103 lb

Bending moment per lug ML  Fliftelift  2.867  103 inlb

Unit radial load on overwrap W

3Fliftelift lb

  537.483

max

wL2 in

Total radial load due to lug moment PL 

WmaxwL 3

 1.075  10

lb

2

Overwind mean radius Ro  R  tps  ( 24.455 ) in

Hoop overwind load Ttl 

PLRo  2.629 

hL

3

10 lb



Hoop overwind tensile stress σo 

Shear across vessel wall τo 

Ttl hLto1

PL

tpshL

 ( 657.207 )psi OK

 ( 236.256 )psi OK

Coefficient of bending in vessel wall: βL 

Poisson's ratio υ  0.25

 0.384 1

in

 1.28

Rotps

PL lb

Unit radial loading P   107.497

star hL in

Bending loads:

Max.L 

Pstar 4βL

 70.035 lb

Mhp.L  υMax.L  17.509 lb

Loads due to pressure: Zero during lift

NaxL  0

NhpL  0

Bending stress on shell, psi: σax.L 

6Max.L



tps2

6Mhp.L

NaxL  2.03 

tps

NhpL

3 

10 psi

σhp.L 

2

tps



tps

 ( 507.438 )psi

Safety factor for bending: Sa

σax.L Sh

σhp.L

 ( 7.39 )

 ( 59.121 )

* 3 OK
* 3 OK

## LIFTING RING STRESS CHECK

Dimension of Square Rod drod  0.5in

Ring Outside Diameter odring  1.52in  3 in

Ring Inside Diameter idring  1.5in

Diameter of Pin dpin  0.75in

ϕgross  .90

ϕnet  .75

Ωgross  1.67

Ωnet  2

Shear lag factor U  1 table D3.1

Net area An 

2

0.5 

in 

2

0.25 in

2

Tensile rupture in net area Ft

net 

Fulug

Ωnet

10 lb

Vcap

1

 FtnetAnU

Vcap

1

 7.25  3

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drod

Allowable load for bearing: Vcap 

2

FbrgAbrg

if Allowmushrooming **=** "no"

Vcap

2

 7.25  3

Vcap

10 lb

1

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d

2

rod

shear rupture

ϕsr  .75

Ωsr  2

Net area subject to shear: Anvsr  Anvsr

Rnsr  0.6FulugAnvsr

Rnsr

Vcap  Vcap

 8.7  103 lb

3 Ωsr 3

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

Vcap  Vcap  1.595  10 lb

4 Ωsb 4

AISC(13th ed.), sect. D5

tensile rupture

ϕtr  .75

Ωtr  2

Pntr **=** 2thkbeffFulug

beff  drod beff  0.5 in

Fulug 4

 7.25  103 

Vcap

5

 2An

Ωtr

Vcap

5

 1.45  10 lb

 

3

 7.25  10 

Vcap  



8.7  103

 lb



min(Vcap)

Flift

 4.426

must be greater than 1

 1.595  4 

 10 

 1.45  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  510 in

Sr  Sth sg  1.00

= Max Liquid Level

= Strength of Reinforcement Laminate

= Specific Gravity of Tank Contents

# Shell Nozzle Opening Reinforcement

 4 

 48 

 8.742  10 15 

d   6 in

h   48 in



Δh 

Δh  

 15  in

n  

 

n  

D  hn

 8.742  10 

 24 

 48 

  15 

k  1  lastdn

 8.742  10 

Allowable Strain ε  0.001

## 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   12 in

 

 48 

## 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 Mrk 

1 if type

σuk

15000psi

**=** "I"  type **=** "II"

otherwise

Calculated Structural Thk: Tck  ts 

1

εs\_ip1 ε

Theoretical Structural Wall Thk.: Tt  Tc

Factor V V

k

 1

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

## Calculate Reinforcement Thickness:

trk  V Mr KnkTtk

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:

 0.19 

tr   0.19 in

 0.19 

trd   0.19 in

   

 0.19   0.19 

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

 4 

dn   6 in

 10 

Dr   12 in

 0.19 

trd   0.19 in

     

 24 

 48 

 0.19 

# Head Nozzle Reinforcement

dnc  ( 4 )in

hLc  ( 0 )in

ΔhLc  D  hLc

ΔhLc  ( 48 ) in

m  1  lastdnc lastdnc  1

## Calculate Pressure At Each Nozzle:

Pncm  Pint  ρcΔhLcm

Pnc  ( 4.167 )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 Mrcm  1

Calculated structural thk: Tscm  tth

Theoretical structural thk: Ttcm  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  48in

**Straight Shell Length...................................** H  510in

**Shell Total Thk............................................** tstot  ( 0.24 )in

**Left/Right Head Combined Thk.....................** tth\_tot  0.24in

**Tank Empty Weight.....................................** WFRP  2.184  103 lb

## Lamination Sequence

Left & Right Heads 0.24" - 2(M,R)2M Shell 0.24" - 2(FW,U)2FW

## 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  231.357 lb

Total # of Stiffeners Nsr  ( 14 )

Stiffener Spacing Lst  36 in



.

## Note : Bottom 150 deg. section of the tank is fully supported. See customer installation manual.

**Shell Stiffener Detail**



A  ( 3 ) in

B  ( 5 ) in

C  ( 1.5 ) in

Dsr  ( 2 ) in

Stiffener Thk.: tsr  ( 0.24 ) in

0.24" - 3C,U,2C

**Shell to Shell Joint Detail**



**Head to Shell Joint Detail**



**Lifting Lugs Detail**





**Lifting Lugs Attachment Bond Detail**



**Nozzle Opening Reinforcement**

## Shell Nozzle Opening Reinforcement Summary

 4 

dn   6 in

 10 

Dr   12 in

 0.19 

trd   0.19 in

     

 24 

 48 

 0.19 

## Top Head Nozzle Reinforcement Summary

dnc  ( 4 )in

trc\_d  ( 0.19 )in

wrc\_d  ( 3 )in

# 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**

