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31/8

ASME CODE CALCULATIONS

FOR

HIGH LEVEL WASTE EVAPORATOR

WESTINGHOUSE SAVANNAH RIVER CORPORATION

P.O.# AA-98-142-C

OAT: J-2519

by

Michael Holtz

TM-1360

ENGINEERING DOC. CONTROL-SRS

00311198

Sht 031

PROJECT: 4062
TITLE: ASME CODE CALCULATION
TM-1360
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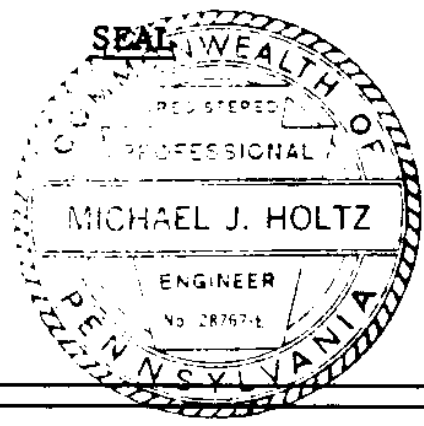
REVIEW AND CERTIFICATION [1]

DOCUMENT TITLE: [3] ASME CODE CALCULATIONS FOR HIGH LEVEL WASTE EVAPORATOR

REPORT NO. TM-1360 ; DOCUMENT CLASS: [2] A

THIS DOCUMENT CONFORMS TO THE REQUIREMENT OF THE DESIGN SPECIFICATION AND THE APPLICABLE SECTIONS OF THE GOVERNING CODES.

SEAL



ORIGINAL

PROFESSIONAL ENGINEER

APPROVALS (Signatures & Dates)

	ORIGINAL ISSUE	REV. 1	REV. 2	REV. 3	REV. 4	REV. 5
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NOTES:

[1] For all Class A documents customer has to respond in writing that all requirements of his design specification pertaining to the intent of this report has been satisfied.

[2] Class A: For review and written approval by customer. B: For submittal to customer, Information only, C: Internal document; not to be submitted to customer.

[3] This document is proprietary to Oat. Its confidentiality must be observed by the designated recipient.

[4] Code as follows:
1. Reviewed method of analysis only
2. Reviewed method of analysis and numerical computations
3. Verified by alternate calculation method.

DESIGN SUMMARY

Top Head 14'-0" OD torisherical 144" radius of dish (p. 3)
10.125"ikr tr=.1484" for internal pressure
G-3 material tr=.4955" for external pressure

Shell SB-582 G-3 material 9/16" thk (see p. 4)

Internal pressure:
tr=.1214" at top (no static head)
tr=.1351" at bottom (4.75 ft static head)

External pressure:
The shell is split into two parts by a stiffening ring

The top part is 85 inch long; tr=.4819"
The bottom part is 60 inch long; tr=.4236"

The shell is made 9/16" to make the inset nozzle self reinforced

Shell Stiffening Ring 316L material size 6"x .6875"thk
required moment of inertia=26.68 in^2
actual moment of inertia=36.44
(see p. 5-6)

Cone SB-582 G-3 material .4038"thk

Internal Pressure: tr=.1463 (p. 7)
Cone reinforcement (p. 11)
Arl=1.814 Ael=5.85 Therefore no additional reinforcement needed.

External Pressure:

The cone is split into 2 sections by a stiffening ring

The top section is 37.25" long; tr=.3848" (p. 7-8)
Cone reinforcement at large end (p. 8-9)
Area required: Arl=1.95 Ael=5.43
No reinforcement required.

Moment of Inertia requirement: 6" x .6875" ring
Is=7.91 I=12.375 (p. 8-10) 316L

The bottom section is 108.25" long; tr=.3995" (p.11)

Cone stiffening ring: 6" x .6875" 316L (p. 12-13)
Is=10.135 I=12.375

Bottom Cone Cover SB-582 G-3 material
11.25" radius spherically dished (p. 14)
Internal pressure: tr=.070
External pressure: tmin=.3125
Pext=319

Tubesheets G-3 material 2.375" thk (p. 15, Appendix A)

Warming Coil 1-1/2" sch. 40 G-3 material
tr=.06995 tnom=.145 tmin=.0644

Steam Chest G-3 material SB-582 G-3 material 3/8" thk
tr=.1848 (p. 16)

Tubes SB-622 G-3 material .1455" avg. wall (p. 16)
tr=.0685 internal pressure
tr=.0656 external pressure

Steam Chest Reservoir SA-312-316L welded pipe 6" sch. 40
tr=.1148 tnom=.28 tmin=.1825 (p.17)

Steam Chest Inset Nozzle SB-582 G-3 material 7/16"thk
tr=.298 (p.17)

Steam Chest Inset Nozzle Reinforcement (p.18-19)
No additional reinforcement required

Nozzles B1, B2 1-1/2" sch. 40 SB-622 G-3 (p.20)
tr=.1132 tnom=.145 tmin=.0644

Nozzle C1 4" sch. 40 SA-312-316L welded pipe
tr=.1184 tnom=.237 tmin=.145 (p. 31)
no additional reinforcement needed in steam chest reservoir

Nozzle C2, S2 2" sch. 80 SB-622 G-3 material
tr=.1132 tnom=.200 tmin=.1125 (p.41)

Nozzle E2 1" sch. 160 SA-312-316L smls
tr=.1223 tnom=.25 tmin=.1563 (p. 41)

Nozzle E1 48" SB-582 G-3 material 5/16" thk
tr=.1795 t=.3125 tmin=.25 (p.21)
Nozzle E1 has a 72" diameter 316L pad 9/16" thk (p. 22)

Flange and Cover (p. 23)
The flange is a flat face flange with a .25" O-ring
The flange and cover comprise a class 3, category 3 joint per ASME Section VIII, Div. 1, Appendix Y
flange thk is 1-3/8" stress=2851, Allowable=11700
cover thk is 1-3/8" stress=6995, tmin=.877
bolting - (8) 2" bolts SA-193-B8M
bolt stress=5001 allowable=14300

Nozzles F1, F2 2" sch 40 SB-622 G-3 material (p.42)
tr=.1132 tnom=.154 tmin=.135

Nozzles K1, K2 3" sch 40 SA-312-316L smls
tr=.1132 tnom=.216 tmin=.1295 (p. 36)
nozzles have a 6-1/2" diameter pad 3/8" thk 316L (p.37)

Nozzle S1 6" sch 40 SA-312-316L welded material (p.33)
tr=.1448 tnom=.280 tmin=.1825
no additional reinforcement required

Nozzle S3, S4 2" sch 40 SB-622 G-3 material
tr=.1132 tnom=.154 tmin=.0722 (p. 42)

Nozzles S5 3" sch 40 SB-622 G-3 material tr=.1132
tnom=.216 tmin=.189 (p. 28)
nozzle has reinforcement pad 6-1/2" dia. x 3/8" thk 316L (p.29)

Nozzle S6 6" x 5/16" thk SB-582-G3 material
tr=.1132 tnom=.3125 tmin=.25 (p.45)
reinforcement pad 72" x 9/16" thk (p. 46)

Nozzles U1, U2 3" sch 40 SB-622 G-3 material (p. 34)
tr=.1448 tnom=.28 tmin=.1825
no additional reinforcement required

Nozzle V 12" SA-240-316L material
tr=.1290 t=.4375 tmin=.375 (p.25)
elbow SA-312-316L sch. 40
no additional reinforcement required (p.26)

Nozzle V flange 1" thk 316L (p.27)
The flange is a class 1, category 3 flat face flange as defined in the ASME Code Section VIII, Div 1, Appendix Y
flange stress=543 allowable = 11700
bolt stress =5464 allowable = 14300

Nozzles Y1, Y2, Y3, Y4 3" sch 40 SA-312-316L smls
tr=.1132 tnom=.216 tmin=.1295 (p.36)
nozzles have a 6.5" diameter pad 3/8" thk 316L (p.37)

Nozzle X3 3" sch 40 SA-312-316L smls
tr=.1132 tnom=.216 tmin=.1295 (p. 36)
nozzle has a 7" diameter pad 3/8" thk 316L (p. 44)

Nozzle Z1, Z4 2" sch 160 SA-312-316L smls material ⚠
tr=.135 tnom=.343 tmin=.237 (p. 43)

Nozzle Z3 3" sch 40 SB-622 G-3
tr=.1132 tnom=.216 tmin=.1265 (p.28)
nozzles have a 7" diameter pad 3/8" thk 316L (p.30)

Steam Chest Downcomer Nozzle SA-312-316L smls
at steam chest SA-312-316L
3"sch 80 tr=.1848 tnom=.300 tmin=.200 (p.38)
no additional reinforcement required (p.39)
at reservoir tr=.1136 tnom=.216 tmin=.1265 (p.38)
no additional reinforcement required (p.40)

Hydrostatic Test Pressures (p. 47-48)

Vessel - 24 psig
Tube Bundle - 505 psig
Warming Coil - 246 psig

JOSEPH OAT CORPORATION
CHEMICAL ENGINEERS & FABRICATORS
NUCLEAR POWER COMPONENTS
ESTABLISHED 1788

p. 1

HEAT EXCHANGER ASME CODE REPORT

J- 2519

ASME SECTION VIII, Div. 1

Code Year 1989 Addenda 1991

Other (HEI, TEMA) _____

	SHELL	TUBE	WARMING COIL
Design Pressure psig	15/FV	325	155
Design Temperature °F	390°F	450	360
Hydrotest Pressure psig	24	505	246
Corrosion Allow	1/16"	1/16"	1/16"
Radiography	Full	Full	Full
Charpy Impact Test(YES/NO)	No	No	No

Shellside MDMT -20 °F @ 15 PSI
Tubeside MDMT -20 °F @ 325 PSI
Warming Coil MDMT -20 °F @ 155 PSI

Design Conditions

Top Head P = 15 psi + FV T = 390°F

Shell

P = 15 + static head = (15) + (4.75')(1.7)(.4332)

= 18.5 psi

P = 18.5 + FV T = 390°F

CONE

P = 18.5 psi + FV T = 390°F

Warming Coil

P = 155 + FV = 170 psi

T = 360°F

Steam Chest

P = 325 psi T = 450°F

CONE BOTTOM

P = 15 + (15')(1.7)(.4332) = 26 psi

T = 390°F

TOP HEAD — 14'-0" OD TORISPHERICAL HEAD
144" R of D 10.125" IKR
INT PRESSURE — .4955" MIN THK

APP 1-4 (d)

$$t = \frac{PLM}{2SE - .2P}$$

L = 144.0625
M = 1.694 @ L/r = [illegible] / 10.1875 = 14.141

$$t = \frac{(15)(144.0625)(1.694)}{(2)(21300)(1) - (.2)(15)} = .08594"$$

.0625 CA
.1484

External Pressure

UG-33(e) — t_{min} = .433" — R_o = 144.433

$$A = \frac{.125}{R_o/t} = .000375$$

B = 5030 (FIG UNF-28.45)

$$P_a = \frac{B}{R_o/t} = \frac{5030}{333.6} = 15.0$$

SHELL

Internal Pressure UG-27 (c)

Bottom $t = \frac{PR}{SE - .6P} = \frac{(18.5)(83.5625)}{(21300)(1) - (.6)(18.5)} = .0726$

$.0625$

$.1351$

Top $t = \frac{(15)(83.5625)}{(21300)(1) - (.6)(18.5)} = .0589$

$.0625$

$.1214$

External Pressure UG-28 (c)

L = straight length + 1/3 depth of head

$= 10'\text{-}11\tfrac{1}{2}'' + 2.5 + \frac{32}{3} = 145''$

use 1 stiffening ring @ 60" & 85"

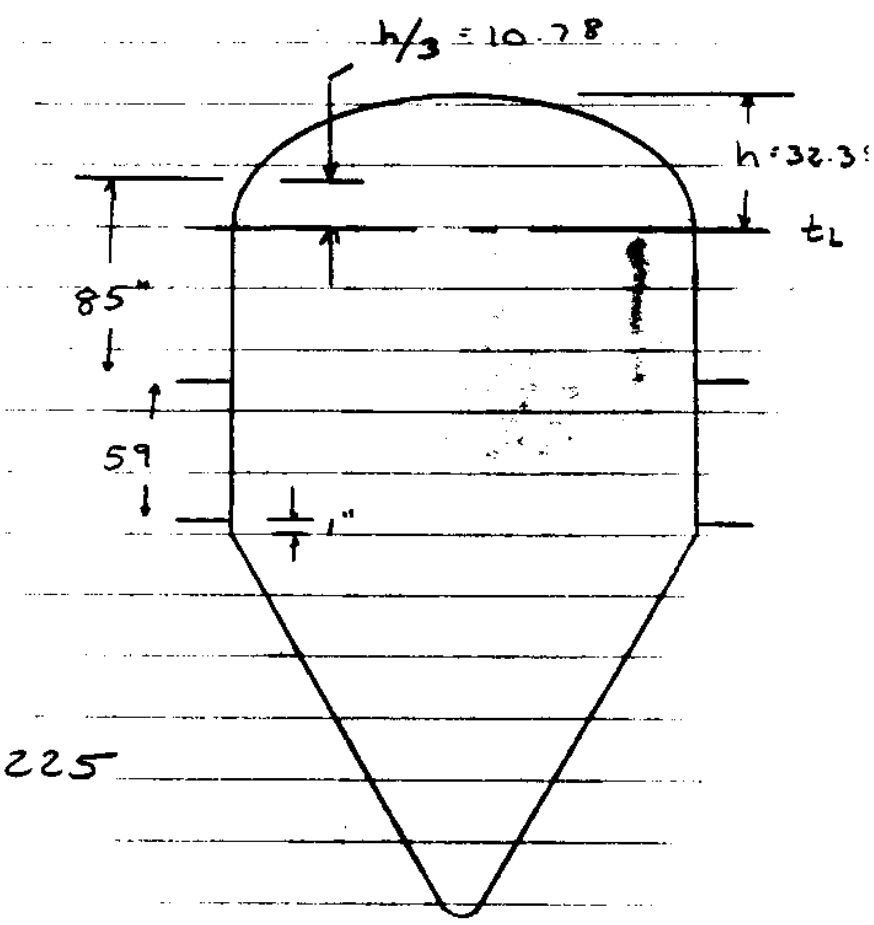
$L_1 = 60''$	$L_2 = 85$
$t_1 = .3611$	$t_2 = .4194$
$L_1/D_o = \frac{60}{168} = .357$	$L_2/D_o = \frac{85}{168} = .506$
$D_o/t_1 = \frac{168}{.3611} = 465$	$D_o/t_2 = \frac{168}{.4194} = 400$
$A = .00039$ $B = 5230$	$A = .00033$ $B = 4500$
$P_a = \frac{4}{3}\frac{B}{(D_o/t_1)}$	$P_a = \frac{4}{3}\frac{B}{(D_o/t_2)}$
$= \left(\frac{4}{3}\right)\left(\frac{5230}{465}\right) = 15$	$= \left(\frac{4}{3}\right)\left(\frac{4500}{400}\right) = 15$

Shell Stiffening Ring for external pressure
UG-28

Required moment of inertia

$$I_s' = \frac{D_o^2 L_s (t + A_s/L_s) A}{14}$$

Ring 6" × 1/16"
$A_s = 4.125 \text{ in}^2$



$$L_s = \frac{85 + 59}{2} = 72$$

$$B = \frac{3}{4}\left(\frac{P D_o}{t + A_s/L_s}\right)$$

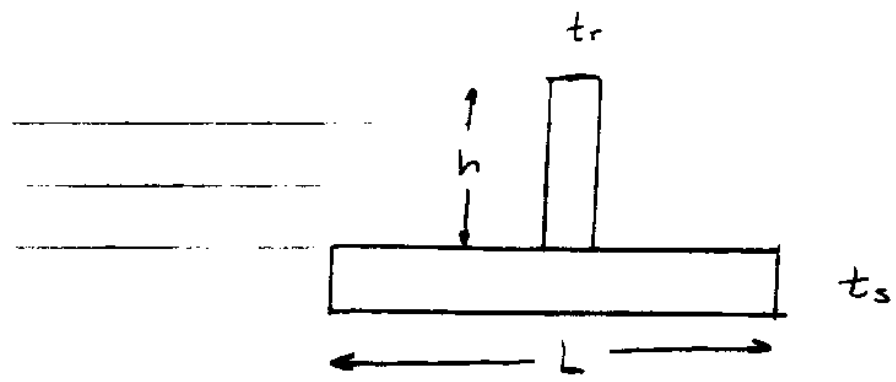
$$= \frac{3}{4}\left(\frac{(15)(168)}{(.39 + 4.125/72)}\right) = 4225$$

$A = .00032$ (Fig. HA-4)
$A = .00032$ (Fig NFN-18)

$t = .39$ @ $L = 72$

$$I_s' = \frac{(168)^2 (72)(.39 + 4.125/72)(.00032)}{10.9}$$

$= 26.68$



$$L = 1.1\sqrt{D_o\, t_s}$$

$$= 1.1\sqrt{(168)(.5)} = 10.08$$

$$\bar{y} = \frac{L t_s^2/2 + h\, t_r t_s + h^2 t_r/2}{L t_s + h\, t_r}$$

$$= \frac{(10.08)(.5)^2/2 + (6)(.6875)(.5) + (6)^2(.6875)/2}{(10.08)(.5) + (6)(.6875)}$$

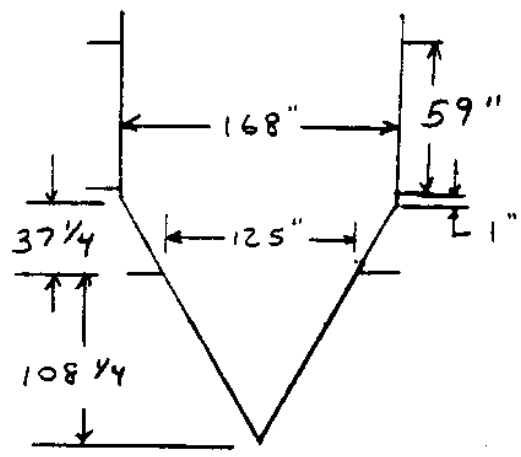
$$= 1.713''$$

$$I' = \frac{L t_s^3}{12} + \left(\bar{y} - \frac{t_s}{2}\right)^2 L t_s + \frac{t_r h^3}{12} + \left(\frac{h}{2} + t_s - \bar{y}\right)^2 h t_r$$

$$= \frac{(10.08)(.5)^3}{12} + \left(1.713 - \frac{.5}{2}\right)^2 (10.08)(.5)$$

$$+ \frac{(.6875)(6)^3}{12} + \left(\frac{6}{2} + .5 - 1.713\right)^2 (6)(.6875) = 36.44$$

CONE



INTERNAL PRESSURE UG-32 (g)

$$t = \frac{PD}{2\cos\alpha\,(SE - .6P)} = \frac{(18.5)(167.125)}{(2)(.866)(21300 - (.6)(18.5))}$$

$$= .0838$$

$$.0625 \quad CA$$

$$.1463$$

External Pressure - Cone Top Section UG-33 f

$\alpha = 30°$ $t = .3223$

$D_L = 168$ $te = (.3223)\cos 30 = .2791$

$\frac{D_L}{te} = 602$ $L = 37.25$

$$Le = \left(\frac{L}{2}\right)\left(1 + \frac{D_s}{D_L}\right) = \left(\frac{37.25}{2}\right)\left(1 + \frac{125}{168}\right) = 32.5$$

$$\frac{t_e}{D_L} = .193$$

$A = .0005 \qquad B = 6800$

$$P_a = \frac{4}{3}\frac{B}{(D_L/t_e)} = \left(\frac{4}{3}\right)\left(\frac{6800}{602}\right) = 15 \text{ psi}$$

Appendix 1-8

$$A_{rL} = \frac{K Q_L R_L \tan\alpha}{S_s E_1}\left[1 - .25\left(\frac{PR_L - Q_L}{Q_L}\right)\frac{\Delta}{\alpha}\right]$$

$$K = \frac{SE}{S_r E_r} = \frac{(21300)(26.4E6)}{(15600)(26.5E6)} = 1.36$$

$$Q_L = \frac{PR_L}{2} + \cancel{f_1}^{\,0} = \frac{(15)(84)}{2} = 630$$

$$A_{rL} = \frac{(1.36)(630)(84)(\tan 30)}{(21300)(1)}\left[1 - \frac{(1260-630)}{(4)(630)}\left(\frac{1.76}{30}\right)\right]$$

$= 1.95 \text{ in}^2$

$$A_{eL} = .55\sqrt{(D_L)(t_s)}\,(t_s + t_c/\cos\alpha)$$

$$= .55\sqrt{(168)(.5)}\,(.5 + .5/\cos 30)$$

$= 5.43$ ∴ No reinforcement needed

Check for moment of inertia at line of support

$$B = (.75)\left(\frac{F_L D_L}{A_{TL}}\right)$$

assume ring 6" × 1/16

$$A_{TL} = \frac{L_L t_s}{2} + \frac{L_c t_c}{2} + A_s$$

$L_L = 60"$ $t_s = .5$ $L_c = 44.17$

$t_c = .344$

$$A_{TL} = \frac{(60)(.5)}{2} + \frac{(44.17)(.344)}{2} + (6)(.6875)$$

$$= 26.722$$

$$F_L = PM + f_1 \tan\alpha$$

It is assumed that the evaporator is empty during the vacuum condition and the weight is negligible, ∴ $f_1 = 0$.

$$M = \frac{-R_L \tan\alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3 R_L \tan\alpha}$$

$$= \frac{(-84)(\tan 30)}{2} + \frac{60}{2} + \frac{[(84)^2 - (62.5)^2]}{(3)(84)(\tan 30)} = 27.4$$

$F_L = (15)(27.4) = 411$

$B = (.75)\left(\frac{(411)(168)}{26.722}\right) = 1938$

$A_c = \frac{2B}{E_c} = \frac{(2)(1938)}{27 \cdot 10^6} = .000144$ (NFN-18)

$A_R = \frac{2B}{E_r} = \frac{(2)(1938)}{26.4 \cdot 10^6} = .000147$ (HA-4)

$A = .000147$

$I_s = \frac{A\ D_L^2\ A_{TL}}{14} = \frac{(.000147)(168)^2(26.722)}{14}$

$= 7.91$

$I = \frac{bh^3}{12} = \frac{(.6875)(6)^3}{12} = 12.375 > I_s$

External Pressure - Cone Bottom Section

$\alpha = 30°$ $\quad t = .337$

$D_L = 125$ $\quad t_e = (.337)\cos 30 = .292$

$\frac{D_L}{t_e} = 428$ $\quad L = 108.25$

$L_e = \left(\frac{L}{2}\right)\left(1 + \cancel{\frac{D_s}{D_L}}^{\,0}\right) = 54.125$

$\frac{L_e}{D_L} = .433$ $\quad A = .00036$

$B = 4800$ $\quad P_a = \frac{4}{3}\frac{B}{(D_L/t_e)} = 15$

Cone reinforcement for internal pressure [App 1-5]

$\frac{P}{S_s E_1} = \frac{(15)}{(21300)(1)} = .0007042$ $\quad \Delta = 2.75$

$Q_L = \frac{PR_L}{2} + f_1 = \frac{(15)(83.5)}{2} + 0 = 624$

$A_{rL} = \frac{K Q_L R_L}{S_s E_1}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha = \frac{(1)(624)(83.5)}{(21300)(1)}\left(1 - \frac{2.75}{30}\right)$

$= 1.814 \text{ in}^2$

$A_{eL} = (t_s - t)\sqrt{R_L t_s} + (t_c - t_r)\sqrt{R_L t_c / \cos\alpha}$

$= (.5 - .089)\sqrt{(83.5)(.5)} + (.5 - .068)\sqrt{(83.5)(.5)/\cos(30)}$

$= 5.85 > A_{rL}$ No additional reinforcement needed.

Design of Cone Stiffening ring

The ASME Code does not have rules for calculating the requirements of intermediate stiffening rings on cones. Therefore, the stiffening ring will be designed treating the cone as an equivalent shell.

$$I_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{14}$$

$D_o = 125$ @ ring location

$L_s = \Sigma \frac{1}{2}$ length to next ring on each side along cone surface

$$L_s = \left(\frac{37.25 + 108.25}{2}\right)\left(\frac{1}{\cos 30}\right)$$

$= 84''$

t = cone required thickness: .337

A_s = stiffening ring cross section

$= (6'')(.6875) = 4.125$

$$B = \left(\frac{3}{4}\right)\left(\frac{P\,D_o}{t + A_s/L_s}\right) = (.75)\left(\frac{(15)(125)}{.337 + 4.125/84}\right)$$

$$= 3642$$

$$A = .00028$$

$$I_s = \frac{(125)^2(84)\left(.337 + (4.125/84)\right)(.00028)}{14}$$

$$= 10.135$$

$$I = \frac{bh^3}{12} = \frac{(6875)(6)^3}{12} = 12.375 > I_s$$

Bottom cone cover - Spherically dished head

11¼" radius of dish

<u>Internal Pressure</u>

UG-32 (f)

$$t = \frac{PL}{2SE - .2P} = \frac{(26)(11.25)}{(2)(21300) - (.2)(26)} = .007$$

.063

.070"

<u>External Pressure</u>

$$t = .375 - 1/16" = .3125$$

$$A = \frac{.125}{R_o/t} = \frac{.125}{11.25/.3125} = .00347$$

$$B = 11,500 \qquad P_a = \frac{B}{R_o/t} = \frac{11,500}{36} = 319$$

Tubesheets G-3 2 3/8"

There are no formulae in the ASME Code for rectangular tubesheets. The tubesheet is modeled using the beam strip method. The analysis is provided in Appendix A. The maximum stresses are determined as follows:

$\sigma =$ 23,480 psi (bending stress)

Allowable = (1.5) Sa = (1.5)(19350) = 29,025

Warming Coil G-3 1½" sch. 40

$$t = \frac{(1.9)(.5)(170)}{(21300) + (.4)(155)} = .00745$$

.0625

.06995

use sch. 40 $t = (.145)(.875) = .126 > .06995$

$t_{min} = .126 - 1/16" = .0644$

Steam Chest G-3

Semi-Cylinder SB-582 7 3/4" radius

$$t = \frac{PR}{SE - .6P} = \frac{(325)(7.75 + .0625)}{(20950) - (.6)(325)}$$

$$= .1223 + 1/16 = .1848$$

use 3/8" thk $t_{min} = 3/8 - 1/16 = .3125$

End Covers hemispherical head SB-582

$$t = \frac{PR}{(2)(SE - .1P)} = \frac{(325)(7.75 + .0625)}{(2)(20950 - (.1)(325)} = \begin{array}{r} .0607 \\ .0625 \\ \hline .1232 \end{array}$$

Use .62 nom thk

$t_{min} = .62 - 1/8$ (thinning) $- 1/16 = .4325$

Tubes SB-622 G-3

$$t = \frac{PR_o}{SE + .4P} = \frac{(340)(.375)}{(20950) + (.4)(325)} = \begin{array}{r} .00605 \\ .0625 \\ \hline .0685 \end{array}$$

USE .1455" AVG. WALL

External Pressure $L/D_o = 192$ $D_o/t = 240$ $t_{min} = .0031$

$A = .0000192$ $B = 2700$

$P = \frac{4}{3}\frac{B}{D_o/t} = 15$

Steam Chest Reservoir SA-312-316L welded Pipe

$$t = \frac{PR}{SE + .4P} = \frac{(325)(6.625)(.5)}{12950 + (.4)(325)}$$

$$= .0823 + 1/16 = .1448$$

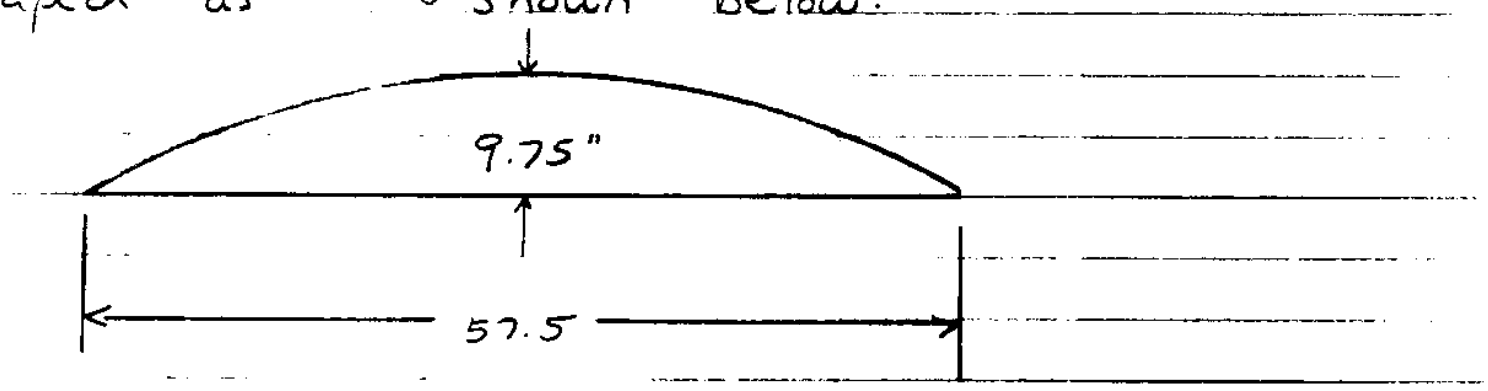
use std wall: .28"

$$t_{min} = (.28)(.875) - 1/16 = .1825$$

End caps 6" std wall

STEAM CHEST INSET NOZZLE

The inset nozzle is an obround nozzle. The short sides of the nozzle are effectively eliminated because of the curvature of the shell. The long sides of the nozzle are shaped as shown below:

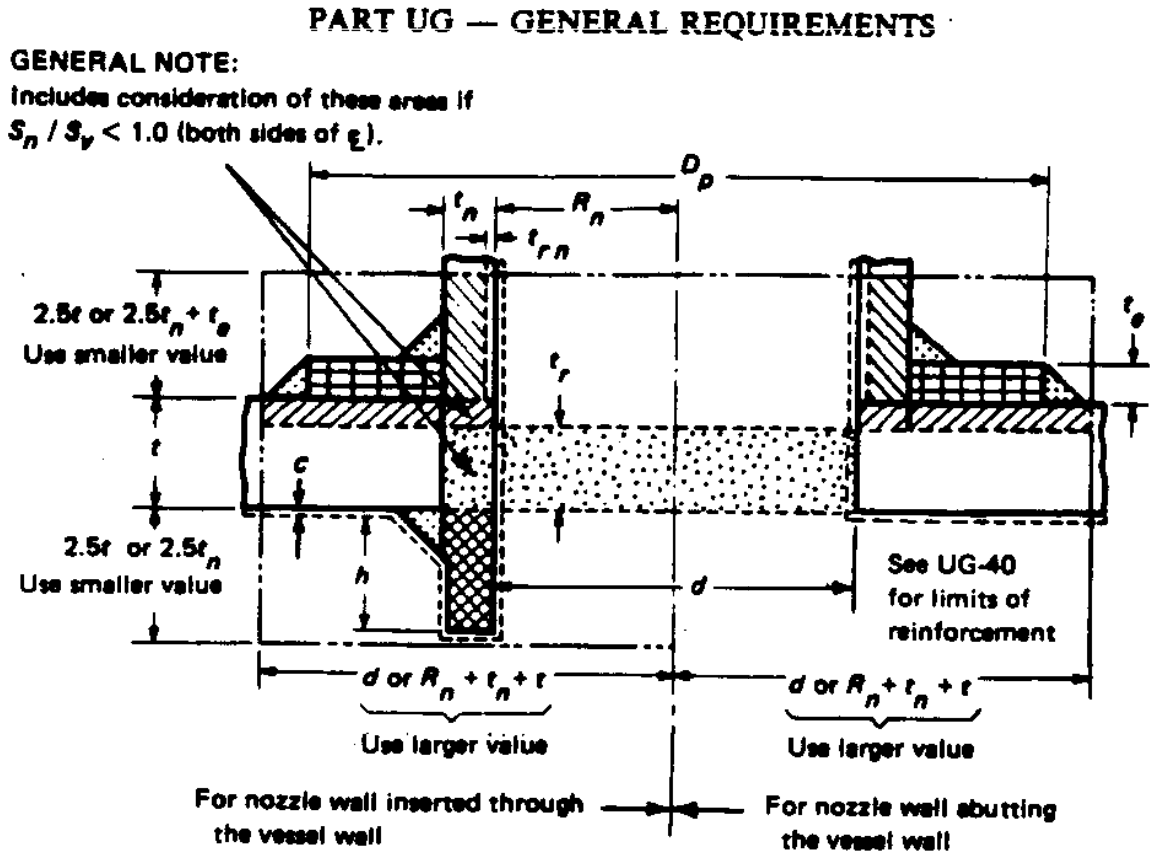


The side is treated as a non-circular flat plate

UG-34 (c)(3) $t = d\sqrt{ZCP/SE}$ C = .33

$$Z = 3.4 - 2.4\frac{d}{D} = 3.4 - (2.4)\left(\frac{9.75}{57.5}\right) = 3.0 \quad (2.5" \text{ MAX})$$

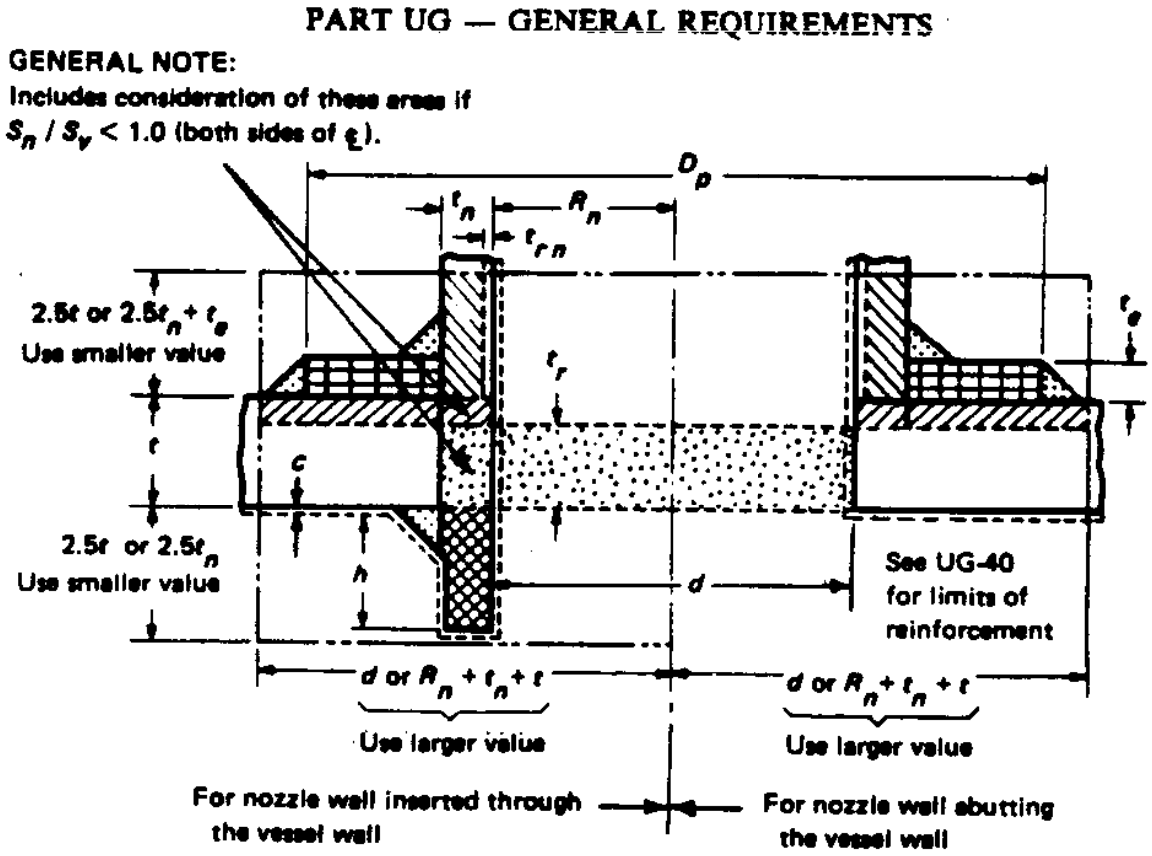
$$t = 9.75\sqrt{(2.5)(.33)(15)/21300} = .235 + .0625 = .298"$$



UG-37.1

tr = ——— = .0726 / .3611			t = .5	c = 1/16"
trn = ——— = .257			tn= .375	d = 26.25
F = 1.0	h = 1.0	E1 =	OBROUND NOZZLE > Long. Plane	
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0	

	INT	EXT (A/2
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)	1.906	4.739
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]	11.22	3.646
= A2 = (tn-trn)(5t) (fr2) smaller of = (tn-trn)(5tn)(fr2)		
= A3 = 2 (tn+c)(fr2)(h)	.875	.875
= A41 = outside nozzle/shell weld = (leg^2)(fr2)	.14	.14
= A43 = inside nozzle/shell weld = (leg^2)(fr2)	.14	.14
TOTAL = A1 + A2 + A3 + A41 + A43	12.4	4.80



UG-37.1

tr = ——— = .0726 / .3611			t = .5	c = 1/16
trn = ——— =			tn=	d = 78
F = .5	h =	E1 =	OBROUND NOZZLE > CIRC. PLANE	
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0	

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)	5.662	14.08
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]	33.33	24.92
= A2 = (tn-trn)(5t) (fr2) smaller of = (tn-trn)(5tn)(fr2)		
= A3 = 2 (tn-c)(fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr2)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
TOTAL = A1 + A2 + A3 + A41 + A43	33.33	24.92

Nozzles B1, B2 1½" sch. 40 G-3

Internal Pressure

a. $t_n = \frac{(15)(1.900)(.5)}{(21300) + (.4)(15)} = .0007$

b. $t_h = \frac{(15)(144)}{(2)(21300) - (.2)(15)} = .0507$

c. std. wall: $(.145)(.875) = .127$

USE sch. 40

$t_{min} = (.145)(.875) - 1/16 = .0644$

External Pressure

a. $D_o = 1.90$ $L = 6''$ $t_r = .045$

$\frac{D_o}{t} = 127$ $\frac{L}{D_o} = 3.16$ $A = .00028$

$B = 3750$ $P = \frac{4}{3}\frac{B}{D_o/t} = \left(\frac{4}{3}\right)\left(\frac{3750}{127}\right) = 39$

b. $t_2 = .0507$

Nozzle E, 48" ID in top head G-3

<u>Internal Pressure</u>

a. $t_n = \frac{(15)(24)}{(21300) - (.6)(15)} = .0169$

b. $t_h = \frac{(15)(144)}{(2)(21300) - (.2)(15)} = .0507$

c. std. wall pipe = .375

<u>External Pressure</u>

a. $D_o = 48.625$ $L = 22.5$ $t_r = .117$

$\frac{D_o}{t} = 416$ $L/D_o = \frac{22.5}{48.625} = .463$

$A = .00035$ $B = 4690$

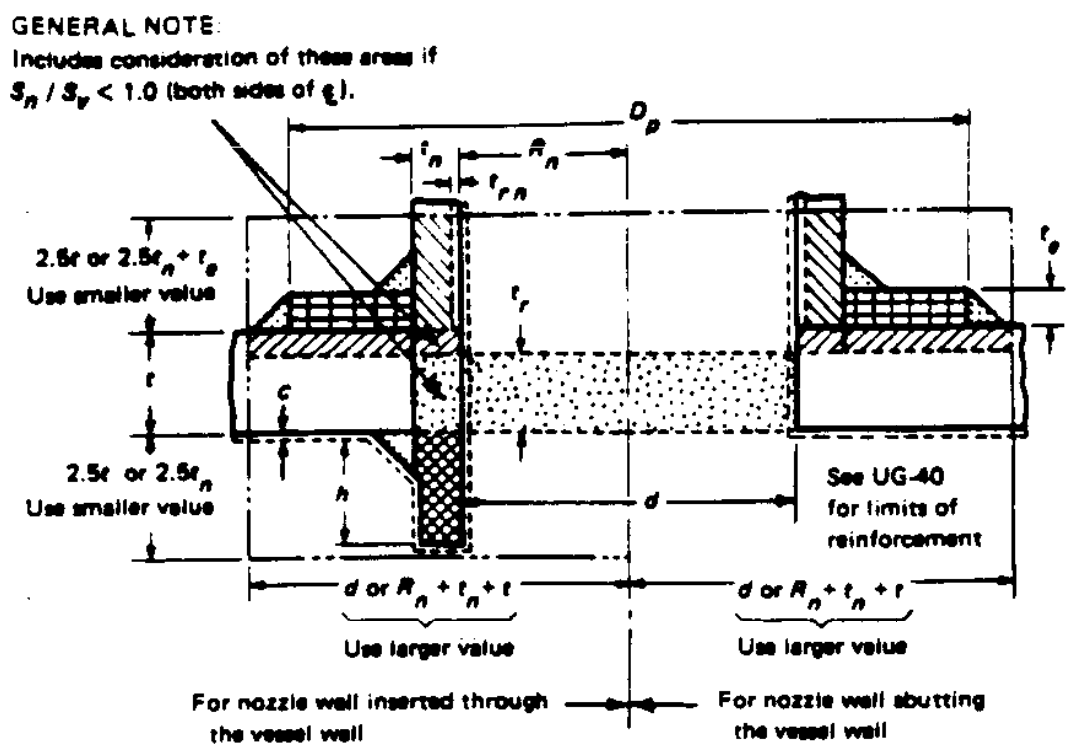
$P_a = \frac{4}{3} \frac{B}{D_o/t} = \left(\frac{4}{3}\right) \frac{(4690)}{(416)} = 15.$

b. $t_h = .0507$

use 1/4" + 1/16" CA = 5/16" thk

$t_{min} = .25$

Nozzle E_1



tr = INTERNAL / External = .086 / .433			t = .433	c = 1/16
trn = INTERNAL / External = .017 / .117			tn= .25	d = 48.
F = 1	h = 0	E1 = 1	Dp= 72	te= .5625
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732			$\frac{S_{316L}}{S_{G-3}} = \frac{15600}{21300} = .732$	

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		10.4
= [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] = A1 larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0.0
= (tn-trn)(5t) (fr2) = A2 smaller of = 2 (tn-trn)(2.5tn+te)(fr2)		
= A3 = 2 (tn-c) (fr2)(h)		0.0
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		10.5
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		10.5

ANALYSIS OF CLASS 3 CATEGORY 3 FLAT FACE FLANGES
PER ASME SECTION VIII,DIV 1 APPENDIX Y

*** INPUT DATA ***

PRESSURE = 15.
FLANGE ID = 48.750
FLANGE OD = 62.000
FLANGE BOLT CIRCLE = 58.000
GASKET DIAMETER = 50.000
FLANGE THICKNESS = 1.313
COVER THICKNESS = 1.313
BOLTING - 8 BOLTS OF 2.000DIAMETER
BOLTING CROSS SECTIONAL AREA = 21.22
RATIO OF COVER/FLANGE ELASTIC MODULUS = 1.000
RATIO OF FLG / BOLT ELASTIC MODULUS = 1.000

*** RESULTS ***

BOLT STRESS = 5001.
BOLT PRESTRESS = 3868.
FLANGE RADIAL STRESS AT BOLT CIRCLE = 2851.
FLANGE TANGENTIAL STRESS AT INSIDE DIAMETER = -1277.
COVER RADIAL STRESS AT BOLT CIRCLE = 6995.
COVER RADIAL STRESS AT INSIDE DIAMETER = 4470.
COVER TANGENTIAL STRESS AT INSIDE DIAMETER = -1754.
COVER RADIAL AND TANGENTIAL STRESS AT CENTER = 1932.

*** END OF ANALYSIS ***
Stop - Program terminated.

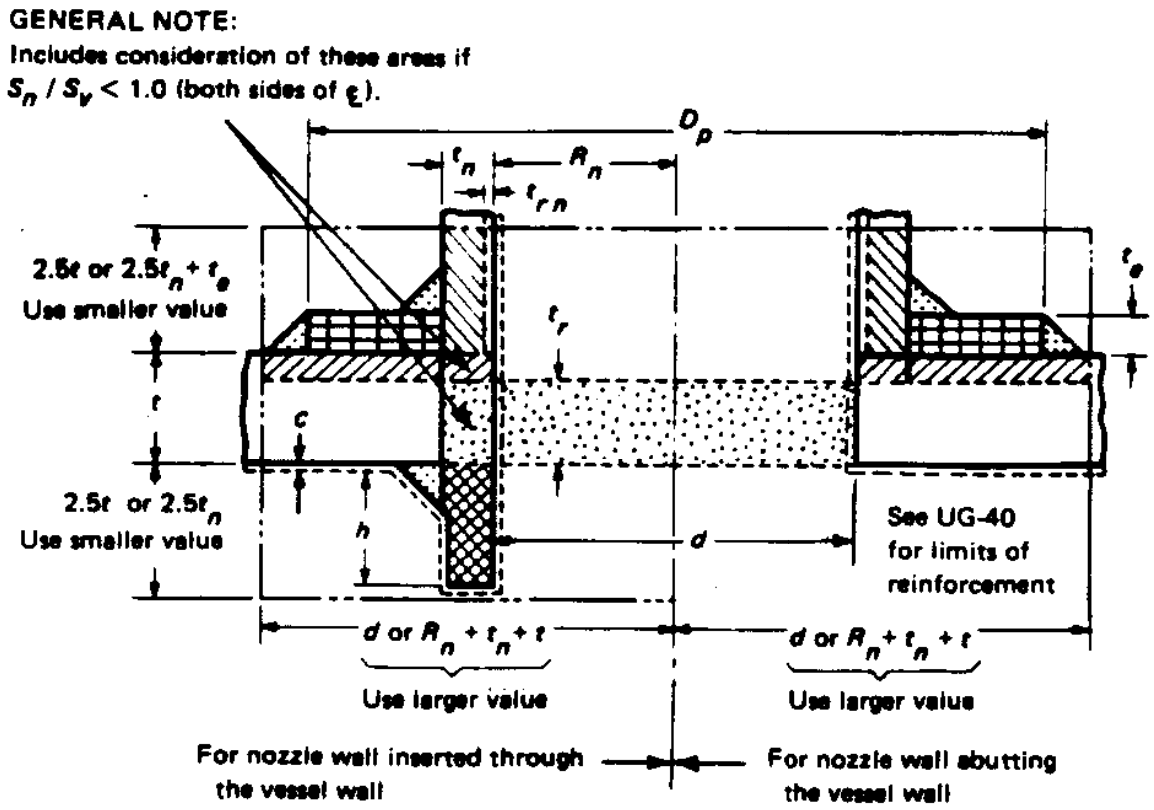
FLANGE AND COVER MATERIAL - 316L, ALLOWABLE STRESS = 11,700 PSI
BOLTING MATERIAL - SA-193-B8M (316) ALLOWABLE STRESS = 14,300

MINIMUM COVER THICKNESS FOR NOZZLE Z1 REINFORCEMENT CALCULATION

The governing stress in the cover is the maximum stress which occurs at the location of the nozzle. We will use the greater of the stresses that occur at the cover center and inside diameter and assume that stress to apply at the nozzle location. The governing stress is then the radial stress at the inside diameter = 4470 psi. Per equation 36 of Appendix Y, this stress is proportional to the inverse of the square of the cover thickness. Therefore, the minimum required cover thickness is determined as follows:

$$\frac{t_{II(min)}^2}{t_{II(act)}^2} = \frac{S_{RII}}{S_{RII(allowable)}}$$

$t_{II(min)}$ = sqrt(4470/11700)(1.3125) = .8113



UG-37.1

tr = ———— = .8113"			t = 1.3125	c = 1/16
trn = ———— = .0017			tn= .1265	d = 3.193
F = 1	h = 0	E1 = 1		
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0	

NOZZLE 21 in Deentrainment Column Cover

	INT	~~EXT~~ (~~fr2~~)
= A = (d) (tr) (F) + 2 (tn) (tr) (F) (1-fr1)	1.295	
= [(E1) (t) - (F) (tr)] [d - 2 (tn) (1-fr1)] = A1 larger of = [(E1) (t) - (F) (tr)] [2 (tn+t) - 2 (tn) (1-fr1)]	1.600	
= (tn-trn) (5t) (fr2) = A2 smaller of = (tn-trn) (5tn) (fr2)	.079	
= A3 = 2 (tn-c) (fr2) (h)		
= A41 = outside nozzle/shell weld = (leg^2) (fr2)		
= A43 = inside nozzle/shell weld = (leg^2) (fr2)		
TOTAL = A1 + A2 + A3 + A41 + A43	1.679	

Nozzle V 12" in Nozzle E, neck p.25

316 L

internal pressure

a. $t_1 = \frac{(15)(12.75)(.5)}{15600 + (.4)(15)} = .006$

b. $t_2 = .0507$

c. std. wall pipe = (.375)(.875) = .328

External Pressure

a. $D_o = 12.75$ $L = 38.25$ $t_{MIN} = .0665$

$\frac{D_o}{t} = 192$ $L/D_o = 3.0$

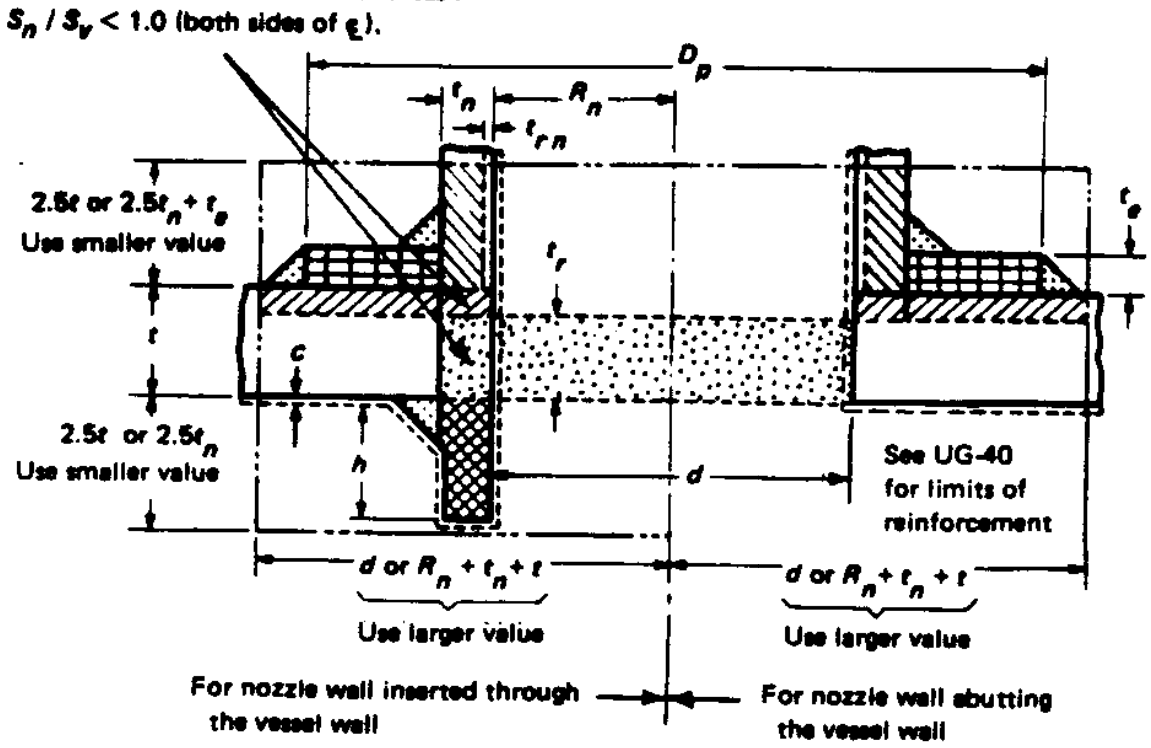
$A = .00016$ $B = 2160$

$P = \frac{4}{3} \frac{B}{D_o/t} = 15.$

b. $t_2 = .0507$

USE sch. 40 S .406

p.26



UG-37.1

tr = ———— = .112			t = .25	c = 1/16
trn = ———— = .0665			tn= .3435	d = 12.063
F = 1	h = 0	E1 = 1		
fr1 = Snoz/Svessel = .732 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= .732	

NOZZLE V 12"

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		.716
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		1.58
= A2 = (tn-trn)(5t) (fr2) smaller of = (tn-trn)(5tn)(fr2)		
= A3 = 2 (tn-c)(fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr2)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
TOTAL = A1 + A2 + A3 + A41 + A43		1.58

NOZZLE V FLANGE

```
ANALYSIS OF CLASS 1 CATEGORY 3 FLAT FACE FLANGES
PER ASME SECTION VIII,DIV 1  APPENDIX Y


*** INPUT DATA ***

  PRESSURE =     15.
  FLANGE ID =    12.875
  FLANGE OD =    19.000
  BOLT CIRCLE DIAMETER =    17.000
  GASKET DIAMETER =    14.000
  FLANGE THICKNESS =    1.000
  BOLTING -  3  BOLTS OF    .875 DIAMETER
  BOLTING CROSS SECTIONAL AREA =      1.26
  RATIO OF FLG / BOLT ELASTIC MODULUS =  1.000


*** RESULTS ***

  BOLT STRESS =     5464.
  BOLT PRESTRESS =     5361.
  FLANGE RADIAL STRESS AT BOLT CIRCLE =  542.756
  FLANGE TANGENTIAL STRESS AT INSIDE DIAMETER =     123.

*** END OF ANALYSIS ***
Stop - Program terminated.
```

Nozzles S_5, t_3 3" sch. 40

G-3

Internal Pressure

a. $t_n = \frac{(15)(3.5)(.5)}{(21300) + (.4)(15)} = .0012$

b. $t_n = .0507$

c. std wall pipe: $(.216)(.875) = .189$

External pressure

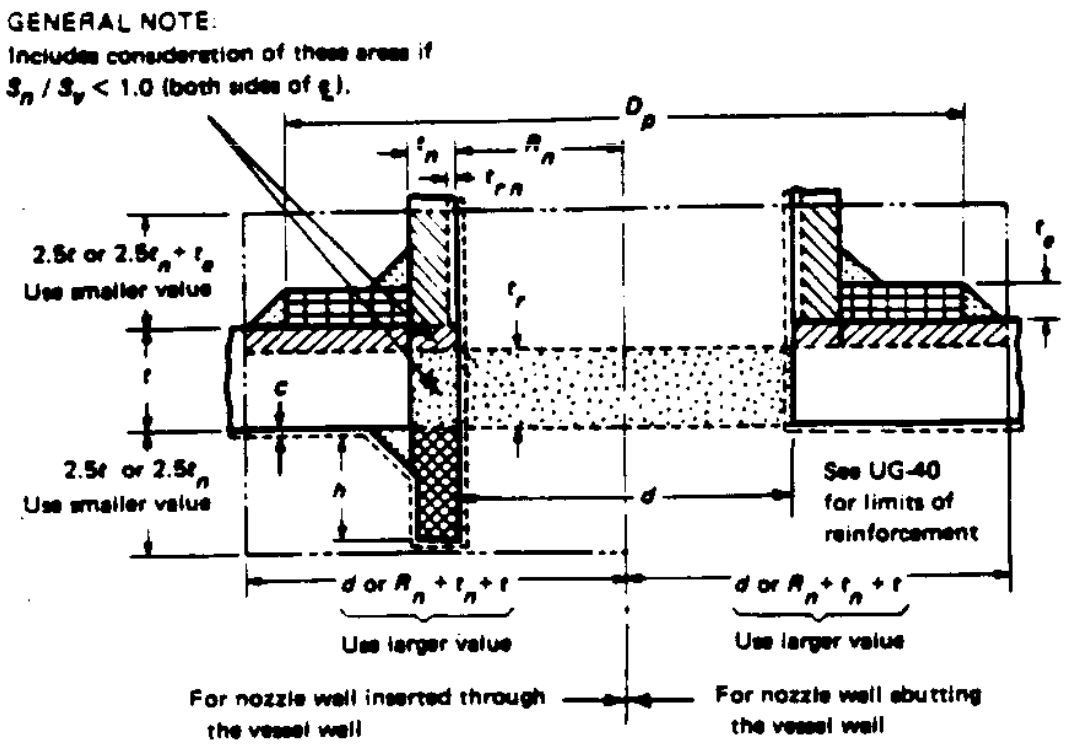
a. $t_n = .020$ $D_o/t = 175$ $L/D_o = 8/3.5 = 2.286$

$A = .00025$ $B = 3300$ $P = \frac{4}{3}\frac{B}{D_o/t} = 25$

b. $t_n = .0507$

Use sch. 40 : .216" thk

$t_{min} = (.216)(.875) - 1/16 = .1265$

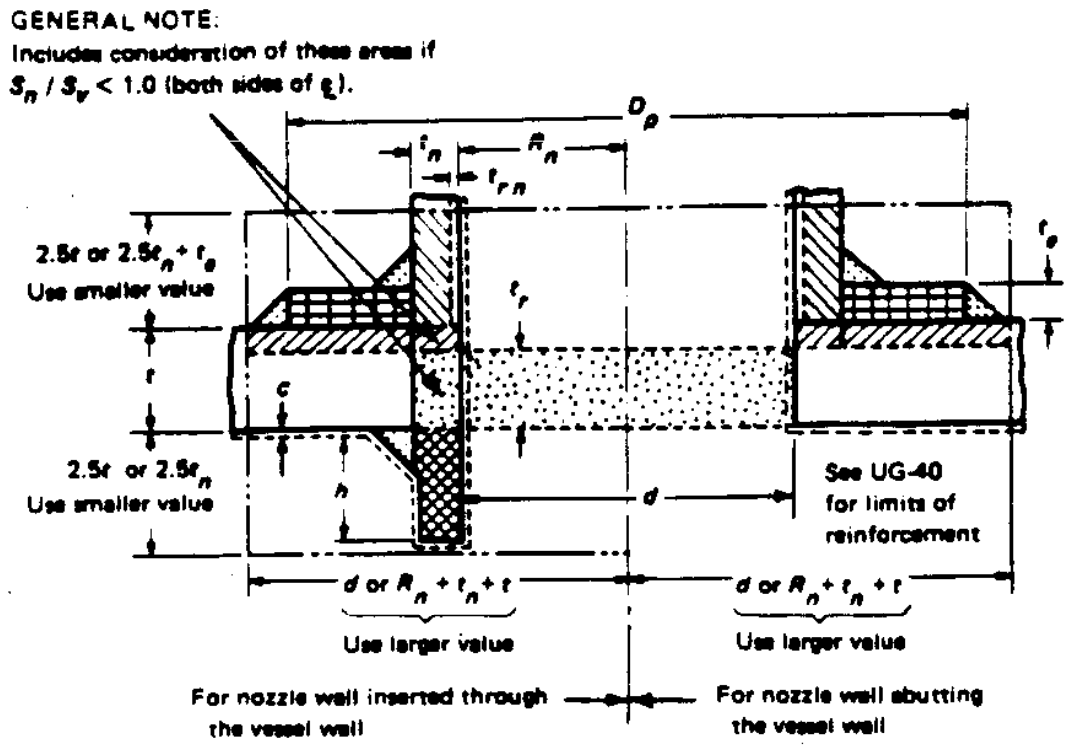


tr = ——— = .433			t = .433	c = 1/16
trn = ——— = .020			tn= .1265	d = 3.512
F = 1	h = 0	E1 =	Dp= 6.5	te= .375
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732				

d = chord dimension for hillside nozzle

NOZZLES S_5 sch. 40 3"

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		.760
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0
= A2 = (tn-trn)(5t) (fr2) .23 smaller of = 2 (tn-trn)(2.5tn+te)(fr2) .147		.147
= A3 = 2 (tn-c) (fr2)(h)		0
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		.7508
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		.898



tr = ——— = .433			t = .433	c = 1/16
trn = ——— = .020			tn= .1265	d = 3.749
F = 1	h = 0	E1 = 1	Dp= 7.0	te= .375
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732				

d = chord length hillside nozzle

Nozzle Z3 △1

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		.8116
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0
= A2 = (tn-trn)(5t) (fr2) smaller of = 2 (tn-trn)(2.5tn+te)(fr2)		
= A3 = 2 (tn-c) (fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		.823
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		.823

Nozzle C_1 SA-312-316L welded 4"
Located in 6" steam chest reservoir

a. $t_n = \frac{(325)(4.5)(.5)}{12950 + (.4)(325)} = .0559$

b. $t_s = .0511$

c. std wall $= (.237)(.875) = .207$

Use std wall $= .237$

$t_{min} = (.237)(.875) - 1/16 = .145"$

Nozzle Reinforcement

A = required area $= (d)(tr)(F) + (2)(tn)(tr)(F)(1-fr$

$fr_1 = 1.0$

$A = (4.21)(.0823)(1) + 0 = .3463$

$A_1 = ((E_1)(t) - (F)(tr))\ [d - (2)(tn)(1-fr_1)]$

$= (.1825 - .0823)(4.21)$

$= .422 > A$ No renforcement required

Check for App. 1-7

$$A_1 = [(E_1)(t) - (F)(t_r)][d/2 - (2)(t_n)(1 - f_{r_1})]$$

$$= (.1825 - .0823)(2.105) = .211$$

$$A_2 = (t_n - t_{rn})(5)(t_n) = (.145 - .0559)(5)(.145) = .0646$$

.275 in^2 is available within the limits of App. 1-7 and exceeds 2/3 the required area

Nozzle S_1 SA-312 - 316L welded
6" in 15½" head portion

a. $t_n = \frac{(325)(6.625)(.5)}{12950 + (.4)(325)} = .0823$

b. $t_s = .0607$

c. std wall $= (.280)(.875) = .245$

use sch. 40 s

$t_{min} = (.280)(.875) - 1/16 = .1825$

Nozzle Reinforcement

$f_{r1} = \frac{12950}{20950} = .618$

$A = (d)(t_r)(F) + (2)(t_n)(t_r)(F)(1 - f_{r1})$

$= (6.26)(.0607) + (2)(.1825)(.0607)(1 - .618) = .3884$

$A_1 = ((E_1)(t) - (F)(t_r))[d - (2)(t_n)(1 - f_{r1})]$

$= [(1)(.4325) - (.0607))][6.26 - (2)(.1825)(1 - .618)]$

$= 2.27$ ∴ No reinforcement required

Nozzle U_1, U_2 3" sch. 40S
located in shell G-3

Internal Pressure

a. $t_n = \frac{(15)(3.5)(.5)}{21300 + (.4)(15)} = .0012$

b. $t_s = .0589$

c. std. wall = (.216)(.875) = .189

External Pressure

a. $t_n = .020$ $D_o/t = 240$ $L/D_o = 8/3.5 = 2.286$

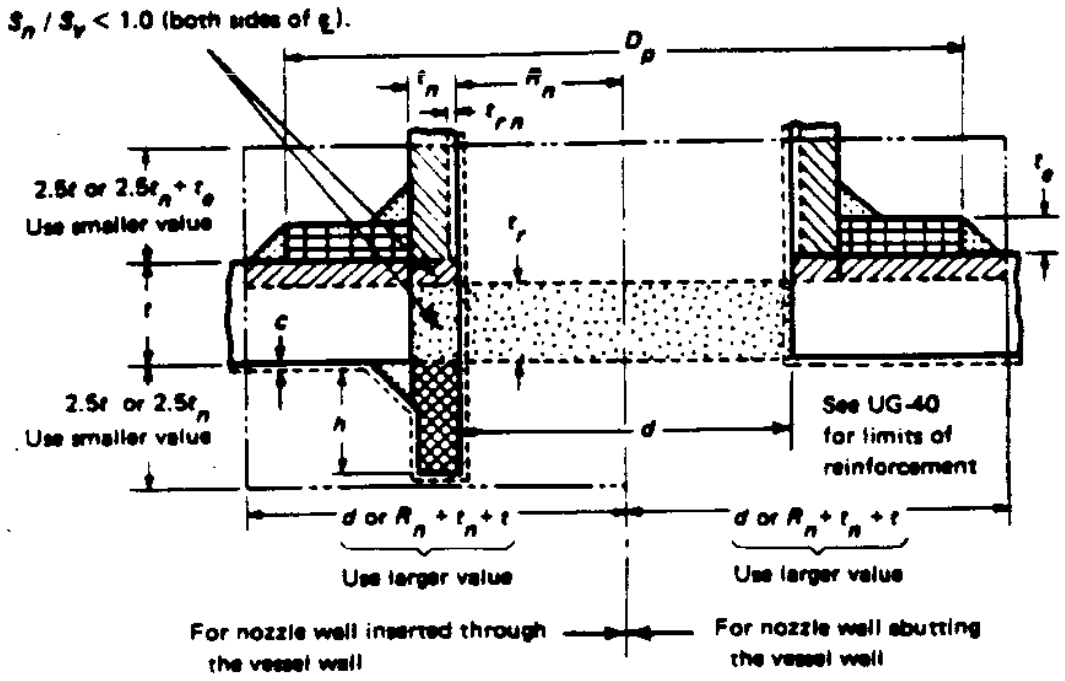
$A = .00025$ $B = 3300$ $P = \frac{4}{3}\frac{B}{D_o/t} = 25$

b. $t_s = .0589$

Use sch. 40 = .216" thk

$t_{min} = (.216)(.875) - 1/16 = .1265$

GENERAL NOTE:
Includes consideration of these areas if $S_n / S_v < 1.0$ (both sides of ℄).



tr = ———— = .4194			t = .5	c = 1/16
trn = ———— = .020			tn= .1265	d = 4.592
F = 1	h = .3162	E1 =1	Dp= 6.5	te= .5
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732				

$d = \sqrt{2}\,(d_o - 2t_n)$

Nozzles U_1, U_2

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		.963
= [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] = A1 larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		.370
= (tn-trn)(5t) (fr2) = .253 = A2 smaller of = 2 (tn-trn)(2.5tn+te)(fr2) = .173		.173
= A3 = 2 (tn-c) (fr2)(h)		.0405
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		.606
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		1.19

Nozzles $K_1, K_2, Y_1, Y_2, Y_3, Y_4, X_3$ 3" 316L sch.40
in top head SA-312 seamless

Internal Pressure

a. $t_n = \frac{(15)(3.5)(.5)}{15600 - (.4)(15)} = .00168$

b. $t_h = .0507$

c. std. wall pipe = (.216)(.875) = .189

$t_{min} = (.216)(.875) - 1/16 = .1265$

External Pressure

a. $t_n = .020$ $L = 8"$ $L/D_o = 8/3.5 = 2.286$

$D_o/t = 3.5/.020 = 175$

$A = .0002$ $B = 2600$

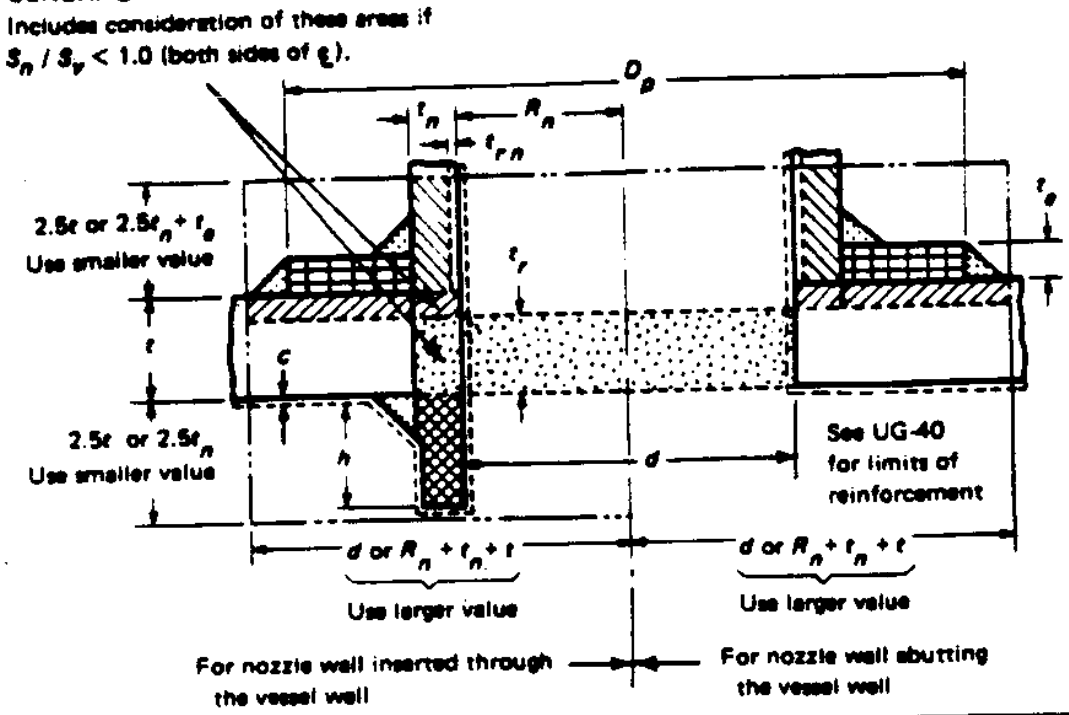
$P = \frac{4}{3} \frac{B}{D_o/t} = 19.8$

b. $t_n = .0507$

use sch. 40

$t_{min} = (.216)(.875) - 1/16" = .1295$

GENERAL NOTE:
Includes consideration of these areas if $S_n / S_v < 1.0$ (both sides of ℄).



tr = ——— = .433			t = .433	c = 1/16
trn = ——— = .020			tn= .1265	d = 3.512
F = 1	h = 0	E1 = 1	Dp= 6.5	te= .375
fr1 = Snoz/Svessel = .732 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= .732 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732				

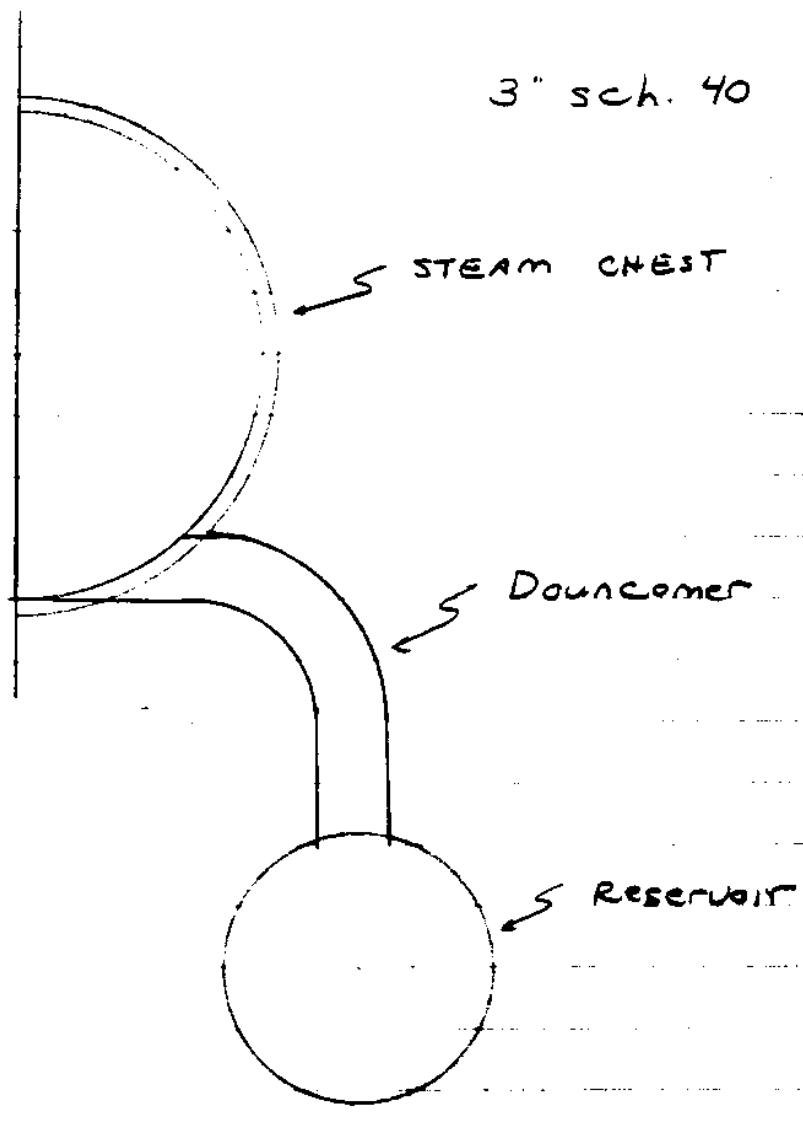
d: chord dimension, hillside nozzle

Nozzles $Y_1, Y_2, Y_3, Y_4, K_1, K_2$

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1) .268		.775
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0
= A2 = (tn-trn)(5t)(fr2) .169 smaller of = 2 (tn-trn)(2.5tn+te)(fr2) .108		.108
= A3 = 2 (tn-c) (fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		.7507
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		.859

Steam Chest Reservoir Downcomer

3" sch. 40 SA-312-316L



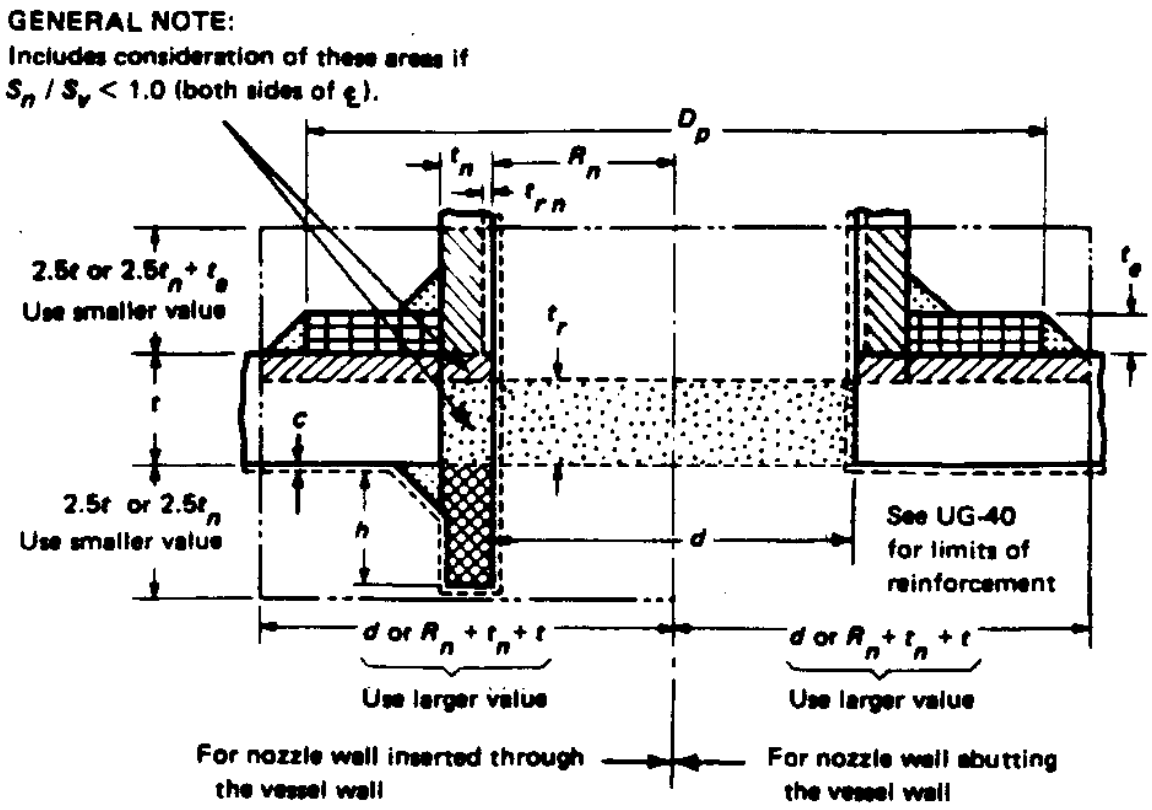
THICKNESS

a. $t_p = \frac{(325)(3.5)(.5)}{(15200) + (.4)(325)} = .0371$

b. $t_s = .1223$ @ steam chest $t_s = .0823$ @ reservoir

c. std wall = (.216)(.875) = .189

USE sch. 40 wall = .216 @ reservoir
MIN WALL = (.216)(.875) - 1/16 = .1265
use sch. 80 wall = .300 @ steam chest
min wall = (.300)(.875) - 1/16 = .200



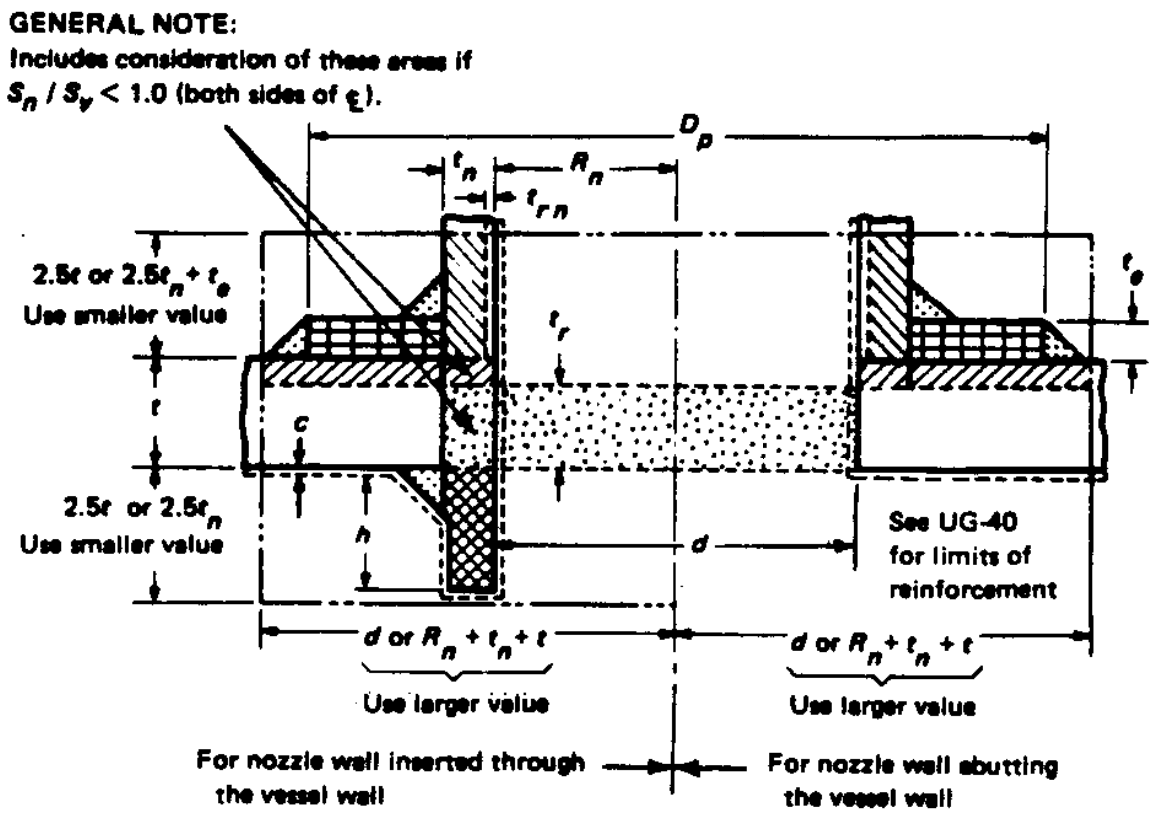
UG-37.1

tr = ———— = .1223			t = .3125	c = 1/16
trn = ———— = .0270			tn= .2375	d = 6.452
F = 1.0	h = 0.0	E1 = 1.0		
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0	

Downcomer - Steam Chest Reinforcement

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)	.789	
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]	1.227	
= A2 = (tn-trn)(5t) (fr2) smaller of = (tn-trn)(5tn)(fr2)		
= A3 = 2 (tn-c)(fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr2)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
TOTAL = A1 + A2 + A3 + A41 + A43	1.227	

p. 40



UG-37.1

tr = ———— = .0823			t = .1825	c = 1/16
trn = ———— = .0270			tn= .1265	d = 3.193
F = 1	h = 0	E1 = 1		
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0	

DOWNCOMER - STEAM CHEST RESERVOIR REINFORCEMENT

	INT	EXT (A/2
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)	.262	
= A1 = [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]	.320	
= A2 = (tn-trn)(5t) (fr2) smaller of = (tn-trn)(5tn)(fr2)		
= A3 = 2 (tn-c)(fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr2)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
TOTAL = A1 + A2 + A3 + A41 + A43	.320	

Nozzle C2, S2 2" sch. 80 Warming Coil
G-3

S_{all} = 21,600 psi @ T = 360°F

a. $t_n = \frac{(2.875)(155)(.5)}{21600 + (.4)(155)} = .0103$

b. $t_n = .0507$

c. std. wall = (.154)(.875) = .135

use sch 80 t_{min} = (.200)(.875) - 1/16 = .1125

Nozzle E2 1" sch. 160 Tube Bundle Vent
316L SA-312 - 316L Seamless

a. $t_n = \frac{(1.315)(.5)(325)}{(15,600) + (.4)(325)} = .0136$

b. t_s = .1223

c. std. wall = (.133)(.875) = .1164

use sch. 160 t_{min} = (.25)(.875) - 1/16" = .1563

Nozzles F_1, F_2, S_3, S_4 2" sch. 40 G-3
Top head

Internal Pressure

a. $t_n = \frac{(2.875)(15)(.5)}{(21300) + (.4)(15)} = .0010$

b. $t_n = .0507$

c. std wall = $(.154)(.875) = .135$

External Pressure

a. $t_n = .020$ $L = 8''$ $L/D_o = 8/2.875 = 2.783$

$D_o/t = 2.875/.020 = 144$

$A = .00027$ $B = 3600$

$P = \frac{4}{3} \frac{B}{D_o/t} = 33$

b. $t_n = .0507$

use sch. 40 $t_{min} = (.154)(.875) - 1/16 = .07225$

Nozzles Z_1, Z_4 2" sch. 160 SA-312-316L
Nozzle E, cover SMLS

Internal Pressure

a. $t_n = \frac{(2.375)(.5)(15)}{15600 + (.4)(15)} = .00114$

b. $t_c = .8113$

c. std. wall pipe = $(.154)(.875) = .135$

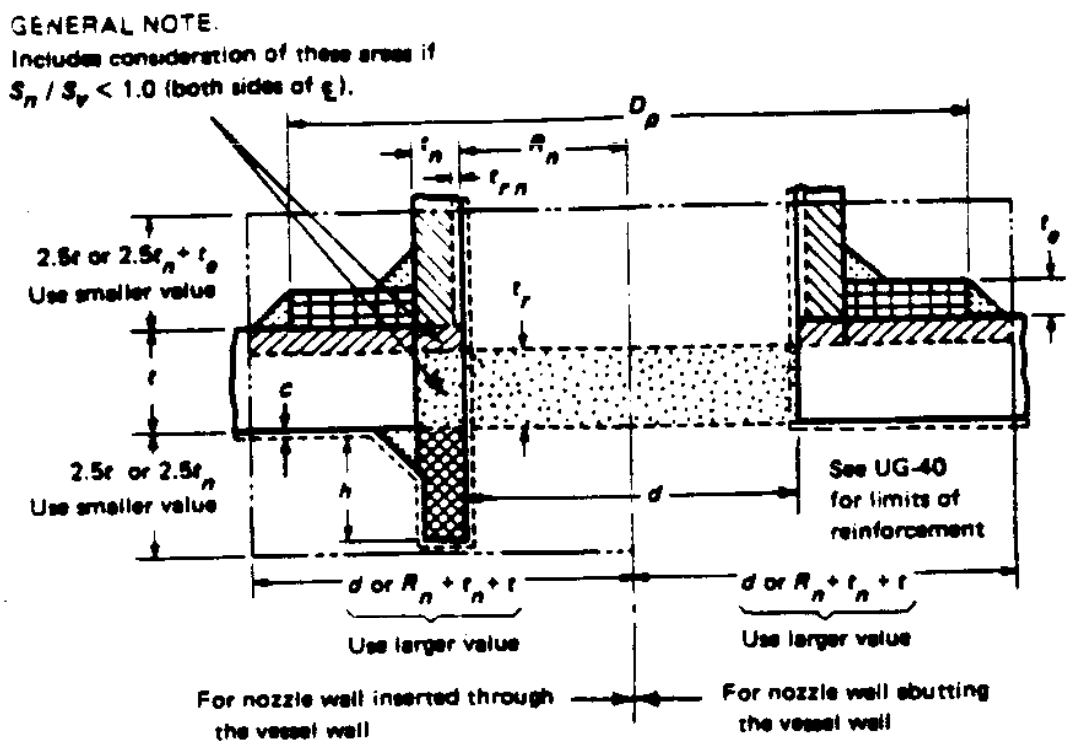
External Pressure

a. $t_n = .015$ $D_o/t = 158$ $L/D_o = 3.79$

$A = .00018$ $B = 2500$ $P = \left(\frac{4}{3}\right)\left(\frac{2500}{158}\right) = 21$

use sch. 160

$t_{min} = (.343)(.875) - 1/16" = .237$



tr = ——— = .433			t = 433	c = 1/16"
trn = ——— = .020			tn= .1265	d = 3.749
F = 1	h = 0	E1 = 1	Dp= 7'	te= .375
fr1 = Snoz/Svessel = .732 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= .732 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = 732			Nozzle X3	

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		.826
= [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] = A1 larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0
= (tn-trn)(5t) (fr2) .169 = A2 smaller of = 2 (tn-trn)(2.5tn+te)(fr2) .107		.107
= A3 = 2 (tn-c) (fr2)(h)		
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		
= A5 = (Dp-d-2tn)(te)(fr4) =		.823
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		.931

Nozzle S_6 △ 6"ø 5/16" thk G-3

Located in top head @ 60° radius

Internal Pressure

a. $t_n = \frac{(6.625)(.5)(15)}{(21300) + (.4)(15)} = .00233$

b. $t_n = .0507$

c. std. wall pipe = (.280)(.875) = .245

External Pressure

a. $t_n = .025$ $D_o/t = 6.625/.025 = 265$

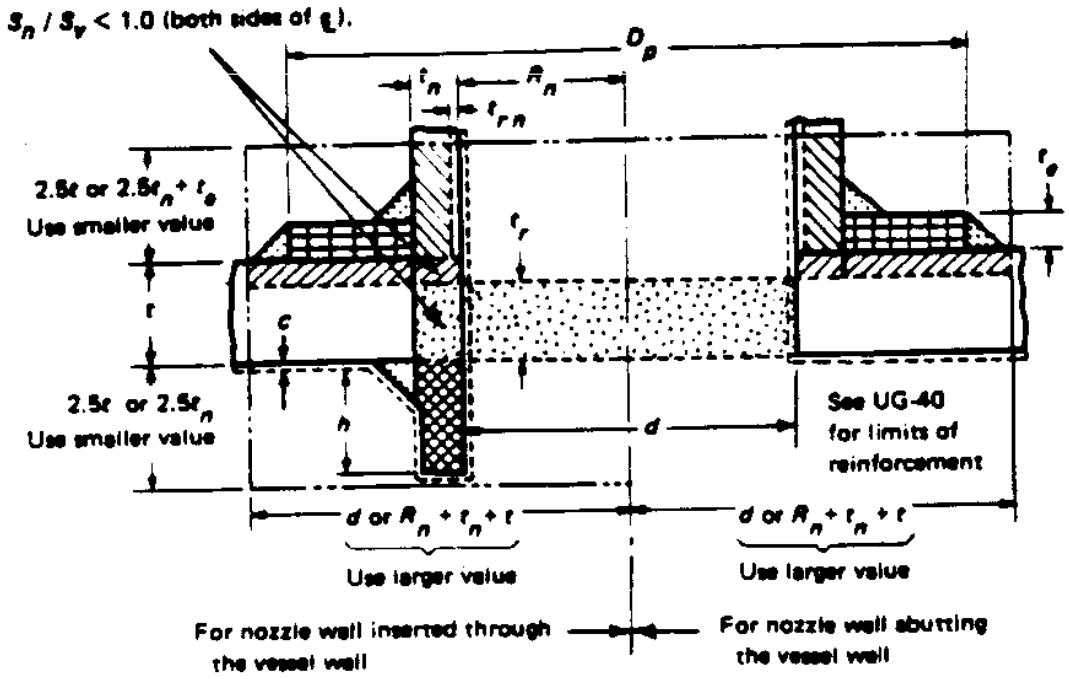
$L/D_o = 9/6.625 = 1.36$ $A = .00022$

$B = 3000$ $P = \frac{4}{3}\frac{B}{D_o/t} = \left(\frac{4}{3}\right)\left(\frac{3000}{265}\right) = 15$

use 5/16" thk

$t_{min} = .25"$

GENERAL NOTE:
Includes consideration of these areas if $S_n / S_v < 1.0$ (both sides of ℄).



tr = ——— = .086 .433			t = .433	c = 1/16
trn = ——— = .025			tn= .25	d =6.738 ⇐ hillside Chord
F = 1	h = 0	E1 = 1	Dp= 11.5	te= .5625
fr1 = Snoz/Svessel = 1.0 (fr1=1.0 when nozzle abuts shell)			fr2=Snoz/Svessel= 1.0 fr4=Spad/Svessel= .732	
fr3=lesser of fr2 or fr4 = .732			NOZZLE S6 △1	

	INT	EXT (A/2)
= A = (d)(tr)(F) + 2 (tn)(tr)(F)(1-fr1)		1.459
= [(E1)(t)-(F)(tr)] [d - 2(tn)(1-fr1)] = A1 larger of = [(E1)(t)-(F)(tr)] [2(tn+t)-2(tn)(1-fr1)]		0
= (tn-trn)(5t) (fr2) = A2 smaller of = 2 (tn-trn)(2.5tn+te)(fr2)		0
= A3 = 2 (tn-c) (fr2)(h)		0
= A41 = outside nozzle/shell weld = (leg^2)(fr3)		0
= A43 = inside nozzle/shell weld = (leg^2)(fr2)		0
= A5 = (Dp-d-2tn)(te)(fr4) =		1.755
TOTAL = A1 + A2 + A3 + A41 + A43 + A5		1.755

Hydrostatic Test Pressure

Vessel

Stress ratios

G-3 Shell $\frac{22,500}{21,300} = 1.056$

Static head correction

Normal operating level = 15' over bottom

$P_1 = (15')(.4332)(1.7) = 11$ psi

$P_2 = (26.53)(.4332) = 11.49$

Since $P_2 > P_1$, the static head during hydrotest is greater than normal operation and no correction required

$P_{hydro} = (15 \text{ psi})(1.5)(1.056) = 24$ psig

Tube Bundle

Stress ratios

G-3 plate $\frac{22,500}{20950} = 1.074$

Tubesheets $\frac{20,000}{19,350} = 1.036$

$P_{hydro} = (325)(1.5)(1.036) = 505$ psig

Warming Coil

Stress Ratio = $\frac{22500}{21300}$ = 1.056

P_{hydro} = (155)(1.5)(1.056) = 246 psi

APPENDICES

A. Tubesheet Analysis

B. Program listing for calculating stresses in flat face flanges to ASME Section VIII, App. Y (for checking and verification)

APPENDIX A

TUBESHEET ANALYSIS

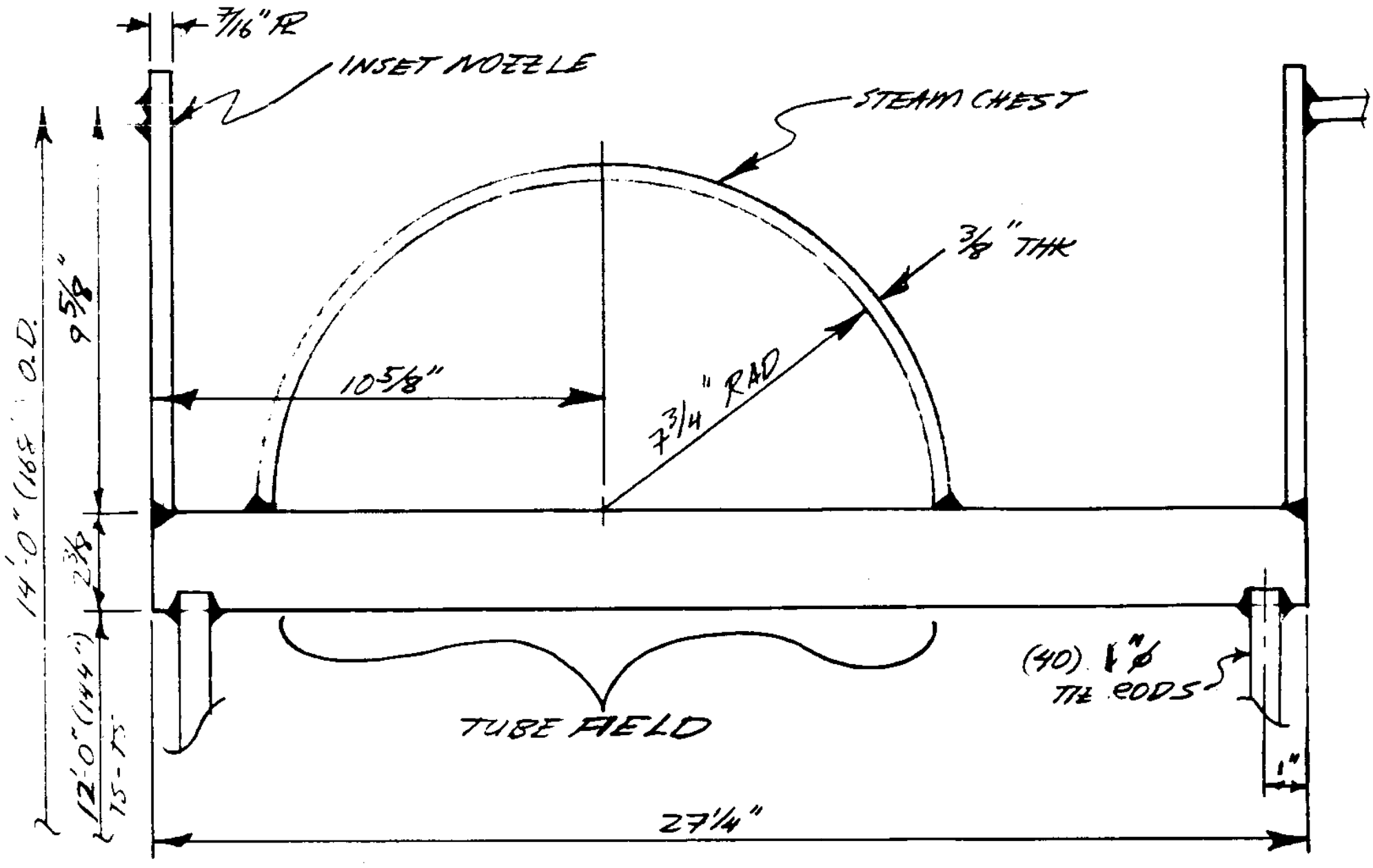
TUBESHEET THICKNESS CALCULATIONS (corroded)

The tubesheet is analyzed by a beam-strip type method. It is a rectangular tubesheet with an off-center tube field that is attached to a 14' O.D. shell with the tubes running across the diameter. The inside faces of the tubesheets are 12' apart. The long side of the tubesheet forms a chord segment in the vessel and is attached to the shell by an "inset nozzle" which has its maximum depth at the midpoint of the tubesheet long side. The short sides of the tubesheet meet the shell.

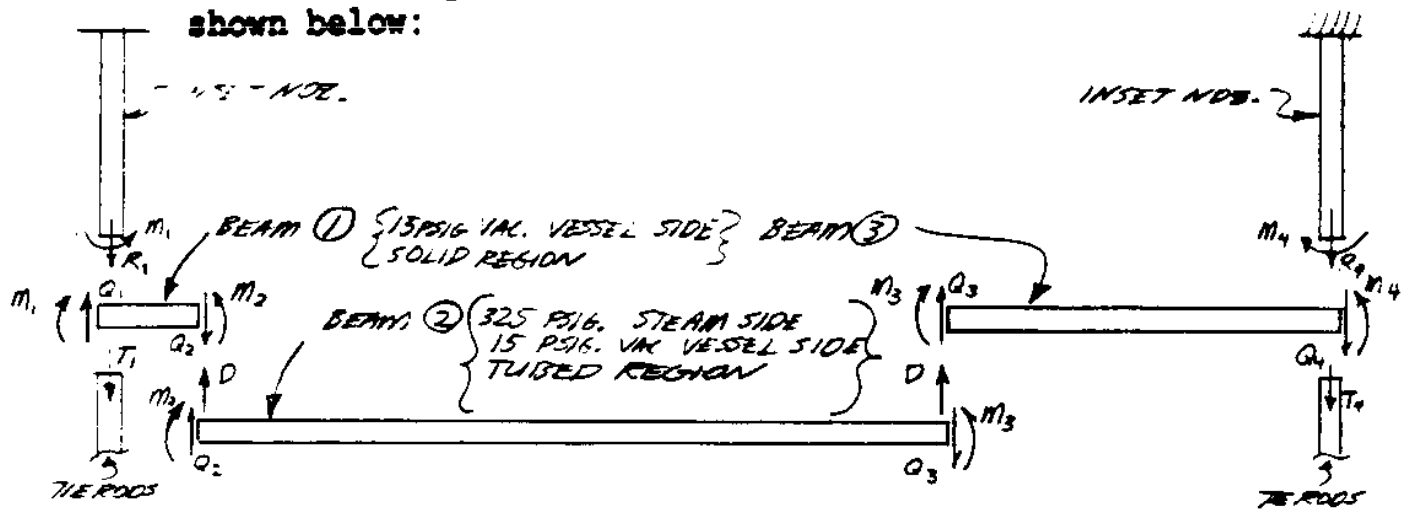
The 1" wide beam-strip is chosen to be at the midpoint of the tubesheet long side, running across the short dimension. The tubesheet is long compared to its width (L > 2*w) so bending in one direction only is considered. At the location of the beam-strip, the inset nozzle has its maximum depth and is most flexible at that point, providing the least amount of bending resistance at the edges of the tubesheet. The relationship between the end rotation and a moment applied at the end of a cantelever beam (the inset nozzle) is used as a boundary condition at each end of the tubesheet.

The tubesheet is not considered as being stayed by the tubes. Any axial thrust by the tubes is converted to an effective pressure. The steam pressure acts only on the ligament area (including the tube end). The difference in reaction of the steam pressure acting on the steam chest and on the ligaments is balanced by the stay rods, which are at the edges of the tubesheets, approximately coincident with the inset nozzle. The area on which the vessel pressure acts on is also reduced by the area of the tubes. The sum of all forces normal to the face of the tube resisted by the reactions a the inset nozzle.

A cross section of the tubesheet at the center is below:



The beam-strip is divided into three consecutive segments, which are shown below:



The Geometry Constants are as follows: (corroded) ca = 1/16"

Tube number	Tn := 648
Tube O.D.	Td := 0.75
Tube wall thickness	Tt := 0.0830
Tube pattern pitch (square)	Tp := 1.25
Tube pattern center	Tc := 10.5625
Tubesheet width	Tsw := 27.125
Tubesheet thickness	Tst := 2.3125
Steam chest I.D.	Scd := 15.625
Steam chest straight length	Scl := 57.5
Steam chest mean diameter	Scm := 15.9375
Inset nozzle length	Inl := 9.625
Inset nozzle thickness	Int := 0.375

The loads are as follows:

Steam Pressure	Ps := 325
Vessel Pressure	Pv := -15
Tube Thrust (lb/tube)	Tf := 0

The force "D" due to the steam pressure is as follows:

$$D := \frac{1 \cdot Scd \cdot Ps}{2} \qquad D = 2.539 \cdot 10^{3}$$

The Effective Pressure on the tube field, due to the steam pressure on the ligaments, normalized to the entire area within the steam chest is as follows:

$$Pse := Ps \cdot \frac{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl - \pi \cdot Tn \cdot \frac{(Td - 2 \cdot Tt)^2}{4}}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl}$$

$$Pse = 273.254$$

The Effective Pressure on the tube field, due to the vessel pressure on the ligaments, normalized to the entire area is as follows:

$$Pve := Pv \cdot \frac{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl - \pi \cdot Tn \cdot \frac{Td^2}{4}}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl}$$

$$Pve = -11.061$$

The Effective Pressure on the tube field, due to the axial thrust of the tubes, normalized to the entire area is as follows:

$$Pt := \frac{Tn \cdot Tf}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl} \qquad Pt = 0$$

The average ligament efficiency of the tube field is:

$$\eta a := \frac{Tp^2 - Td^2}{Tp^2} \qquad \eta a = 0.64$$

The minimum ligament efficiency of the tube field is:

$$\eta m := \frac{Tp - Td}{Tp} \qquad \eta m = 0.4$$

The section properties of the beams are as follows:

Inset Nozzle:

$$Ii := 1 \cdot \frac{Int^3}{12} \qquad Ii = 0.004$$

Tubesheet Solid Regions

$$Is := 1 \cdot \frac{Tst^3}{12} \qquad Is = 1.031$$

Tubesheet Tubed Region {double corrosion}

$$It := \eta a \cdot 1 \cdot \frac{(Tst - 0.0625)^3}{12}$$

$$It = 0.608$$

The relationship between the end rotation and the end moment on the inset nozzle is taken from Roark, "Formulas for Stress and Strain", 4th edition, table III, figures 1 & 9. Superimposed, the formulas for a cantelever beam with an end force and for one with an end couple yield the following relation:

θ = M*Inl/4*E*Ii

The three beam equations formed, which are to be solved for deflection, are shown below:

Beam 1: EIs(d^4v1/dx^4) = p(x) = -Pv

on the range: 0 < x < Ls1

Beam 2: EIt(d^4v2/dx^4) = p(x) = Pse - Pve - Pt

on the range: Ls1 < x < Ls2

substituting: y = x - Ls1 | 0 < y < Scm

Beam 3: EIs(d^4v3/dx^4) = p(x) = -Pv

on the range: Ls2 < x < Tsw

substituting: z = x - Ls2 | 0 < z < Lss

where:

$$Ls1 := Tc - \frac{Scm}{2} - \frac{Int}{2} \qquad Ls1 = 2.406$$

$$Ls2 := Tc + \frac{Scm}{2} - \frac{Int}{2} \qquad Ls2 = 18.344$$

$$Lss := Tsw - Ls2 - Int \qquad Lss = 8.406$$

The boundary conditions at the x = 0 end are as follows:

0a: M1*Inl/4*E*Ii = dv1(0)/dx

= (1/EIs){(-Pv/6)x^3 + (c0/2)x^2 + c1x + c2}

which, at x = 0, simplifies to:

M1 = 4*c2*Ii/L*Is

0b: M1 = EIs(d^2v1(0)/dx^2)

M1 = (-Pv/2)x^2 + c0x + c1

which, at x = 0, simplifies to:

M1 = c1

combining 0a & 0b yields:

c1 - c2(4Ii/Inl*Is) = 0

equation 0 coefficients are as follows:

$$b_0 := 0$$

$$a_{0,1} := 1$$

$$a_{0,2} := -4 \cdot \frac{Ii}{Is \cdot Inl} \qquad a_{0,2} = -0.002$$

1: 0 = v1(0) = (-Pv/24)x^4 + (c0/6)x^3 + (c1/2)x^2 + c2x + c3

which, at x = 0, simplifies to:

c3 = 0

equation 1 coefficients are as follows:

$$b_1 := 0$$

$$a_{1,3} := 1$$

The continuity equations at the junction between beams 1 and 2, where x = Ls1 and y = 0, are as follows:

2: v1(Ls1) = v2(0)

$$(1/EIs)\{(-Pv/24)x^4 + (c0/6)x^3 + (c1/2)x^2 + c2x + c3\}$$

$$= (1/EIt)\{((Pse-Pve-Pt)/24)y^4 + (c4/6)y^3 + (c5/2)y^2$$

$$+ c6y + c7\}$$

which, at x = Ls1 and y = 0, simplifies to:

$$c0(Ls1^3/6) + c1(Ls1^2/2) + c2(Ls1) + c3$$

$$- c7(Is/It) = Pv(Ls1^4/24)$$

equation 2 coefficients are as follows:

$$b_2 := Pv \cdot \frac{Ls1^4}{24} \qquad b_2 = -20.953$$

$$a_{2,0} := \frac{Ls1^3}{6} \qquad a_{2,0} = 2.322$$

$$a_{2,1} := \frac{Ls1^2}{2} \qquad a_{2,1} = 2.895$$

$$a_{2,2} := Ls1 \qquad a_{2,2} = 2.406$$

$$a_{2,3} := 1$$

$$a_{2,7} := -1 \cdot \frac{Is}{It} \qquad a_{2,7} = -1.696$$

3: dv1(Ls1)/dx = dv2(0)/dy

$$(1/EIs)\{(-Pv/6)x^3 + (c0/2)x^2 + c1x + c2\}$$

$$= (1/EIt)\{((Pse-Pve-Pt)/6)y^3 + (c4/2)y^2 + c5y + c6\}$$

which, at x = Ls1 and y = 0, simplifies to:

$$c0(Ls1^2/2) + c1(Ls1) + c2 - c6(Is/It)$$

$$= Pv(Ls1^3/6)$$

equation 3 coefficients are as follows:

$$b_3 := Pv \cdot \frac{Ls1^3}{6} \qquad b_3 = -34.831$$

$$a_{3,0} := \frac{Ls1^2}{2} \qquad a_{3,0} = 2.895$$

$$a_{3,1} := Ls1 \qquad a_{3,1} = 2.406$$

$$a_{3,2} := 1$$

$$a_{3,6} := -1 \cdot \frac{Is}{It} \qquad a_{3,6} = -1.696$$

4: EIs(d^2v1(Ls1)/dx^2) = EIt(d^2v2(0)/dy^2)

(-Pv/2)x^2 + c0x + c1 = ((Pse-Pve-Pt)/2)y^2 + c4y + c5

which, at x = Ls1 and y = 0, simplifies to:

c0(Ls1) + c1 - c5 = Pv(Ls1^2/2)

equation 4 coefficients are as follows:

$$b_4 := Pv \cdot \frac{Ls1^2}{2} \qquad b_4 = -43.425$$

$$a_{4,0} := Ls1 \qquad a_{4,0} = 2.406$$

$$a_{4,1} := 1$$

$$a_{4,5} := -1$$

5: EIs(d^3v1(Ls1)/dx^3) = EIt(d^3v2(0)/dy^3) + D

-Pvx + c0 = (Pse-Pve-Pt)y + c4 + D

which, at x = Ls1 and y = 0, simplifies to:

c0 - c4 = D + Pv(Ls1)

equation 5 coefficients are as follows:

$b_5 := D + Pv \cdot Ls1$ $\qquad b_5 = 2.503 \cdot 10^3$

$a_{5,0} := 1$

$a_{5,4} := -1$

The continuity equations at the junction between beams 2 and 3, where y = Scm and z = 0 are as follows:

6: v2(Scm) = v3(0)

(1/EIt){((Pse-Pve-Pt)/24)y^4 + (c4/6)y^3 + (c5/2)y^2 + c6y + c7} = (1/EIs){(-Pv/24)z^4 + (c8/6)z^3 + (c9/2)z^2 + c10z + c11}

which, at y = Scm and z = 0, simplifies to:

c4(Scm^3/6) + c5(Scm^2/2) + c6(Scm) + c7 - c11(It/Is) = (Pt+Pve-Pse)(Scm^4/24)

equation 6 coefficients are as follows:

$b_6 := (Pt + Pve - Pse) \cdot \frac{Scm^4}{24}$ $\qquad b_6 = -7.643 \cdot 10^5$

$a_{6,4} := \frac{Scm^3}{6}$ $\qquad a_{6,4} = 674.698$

$a_{6,5} := \frac{Scm^2}{2}$ $\qquad a_{6,5} = 127.002$

$a_{6,6} := Scm$ $\qquad a_{6,6} = 15.938$

$a_{6,7} := 1$

$a_{6,11} := -1 \cdot \frac{It}{Is}$ $\qquad a_{6,11} = -0.589$

7: dv2(Scm)/dy = dv3(0)/dz

(1/EIt){((Pse-Pve-Pt)/6)y^3 + (c4/2)y^2 + c5y + c6}

= (1/EIs){(-Pv/6)z^3 + (c8/2)z^2 + c9z + c10}

which, at y = Scm and z = 0, simplifies to:

c4(Scm^2/2) + c5(Scm) + c6 - c10(It/Is)

= (Pt+Pve-Pse)(Scm^3/6)

equation 7 coefficients are as follows:

$b_7 := (Pt + Pve - Pse)\cdot\frac{Scm^3}{6}$ $\quad b_7 = -1.918\cdot 10^5$

$a_{7,4} := \frac{Scm^2}{2}$ $\quad a_{7,4} = 127.002$

$a_{7,5} := Scm$ $\quad a_{7,5} = 15.938$

$a_{7,6} := 1$ $\quad a_{7,6} = 1$

$a_{7,10} := -1\cdot\frac{It}{Is}$ $\quad a_{7,10} = -0.589$

8: EIt(d^2v2(Scm)/dy^2) = EIs(d^2v3(0)/dz^2)

((Pse-Pve-Pt)/2)y^2 + c4y + c5 = (-Pv/2)z^2 + c8z + c9

which, at y = Scm and z = 0, simplifies to:

c4(Scm) + c5 - c9 = (Pt+Pve-Pse)(Scm^2/2)

equation 8 coefficients are as follows:

$b_8 := (Pt + Pve - Pse)\cdot\frac{Scm^2}{2}$ $\quad b_8 = -3.611\cdot 10^4$

$a_{8,4} := Scm$ $\quad a_{8,4} = 15.938$

$a_{8,5} := 1$

$a_{8,9} := -1$

9: EIt(d^3v2(Scm)/dy^3) = EIs(d^3v3(0)/dz^3) + D

(Pse-Pve-Pt)y + c4 = (-Pv)z + c8 + D

which, at y = Scm and z = 0, simplifies to:

c4 - c8 = (Pt+Pve-Pse)(Scm) + D

equation 9 coefficients are as follows:

$b_9 := (Pt + Pve - Pse) \cdot Scm + D$ $\qquad b_9 = -1.992 \cdot 10^3$

$a_{9,4} := 1$

$a_{9,8} := -1$

The boundary conditions at z = Lss are as follows:

10a: M4*Inl/4*E*Ii = dv3(Lss)/dz

= (1/EIs){(-Pv/6)z^3 + (c8/2)z^2 + c9z + c10}

which, at z = Lss, simplifies to:

M1 = 4*(Ii/Is*Inl){-Pv(Lss^3/6) + c8(Lss^2/2)

+ c9(Lss) + c10}

10b: M4 = EIs(d^2v3(Lss)/dz^2)

= (-Pv/2)z^2 + c8z + c9

which, at z = Lss, simplifies to:

M1 = -Pv(Lss^2/2) + c8(Lss) + c9

Combining 10a and 10b yields:

c8{(4Ii/Is*Inl)(Lss^2/2) - Lss} + c9{(4Ii/Is*Inl)(lss) -1}

+ c10(4Ii/Is*Inl) = (Pv){(4Ii/Is*Inl)(Lss^3/6)

- (Lss^2/2)}

equation 10 coefficients are as follows:

$$b_{10} := Pv \cdot \left[4 \cdot \frac{Ii}{Is \cdot Inl} \cdot \frac{Lss^3}{6} - \frac{Lss^2}{2} \right] \qquad b_{10} = 527.356$$

$$a_{10,8} := 4 \cdot \frac{Ii}{Is \cdot Inl} \cdot \frac{Lss^2}{2} - Lss \qquad a_{10,8} = -8.344$$

$$a_{10,9} := 4 \cdot \frac{Ii}{Is \cdot Inl} - 1 \qquad a_{10,9} = -0.998$$

$$a_{10,10} := 4 \cdot \frac{Ii}{Is \cdot Inl} \qquad a_{10,10} = 0.002$$

11: 0 = v3(Lss) = (-Pv/24)z^4 + (c8/6)z^3 + (c9/2)z^2 + c10z + c11

which, at z = Lss, simplifies to:

c8(Lss^3/6) + c9(Lss^2/2) + c10(Lss) + c11

= Pv(Lss^4/24)

equation 11 coefficients are as follows:

$$b_{11} := Pv \cdot \frac{Lss^4}{24} \qquad b_{11} = -3.121 \cdot 10^3$$

$$a_{11,8} := \frac{Lss^3}{6} \qquad a_{11,8} = 99.005$$

$$a_{11,9} := \frac{Lss^2}{2} \qquad a_{11,9} = 35.333$$

$$a_{11,10} := Lss \qquad a_{11,10} = 8.406$$

$$a_{11,11} := 1$$

Solve 12 x 12 Set of Tubesheet Beam Equations:

Stiffness Matrix

$$a = \begin{vmatrix} 0 & 1 & -0.002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \\ 2.322 & 2.895 & 2.406 & 1 & 0 & 0 & 0 & -1.696 & 0 & 0 & \\ 2.895 & 2.406 & 1 & 0 & 0 & 0 & -1.696 & 0 & 0 & 0 & \\ 2.406 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & \\ 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & \\ 0 & 0 & 0 & 0 & 674.698 & 127.002 & 15.938 & 1 & 0 & 0 & \\ 0 & 0 & 0 & 0 & 127.002 & 15.938 & 1 & 0 & 0 & 0 & -0.58 \\ 0 & 0 & 0 & 0 & 15.938 & 1 & 0 & 0 & 0 & -1 & \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8.344 & -0.998 & 0.00 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 99.005 & 35.333 & 8.40 \end{vmatrix}$$

Load Vector

$$b = \begin{vmatrix} 0 \\ 0 \\ -20.953 \\ -34.831 \\ -43.425 \\ 3 \\ 2.503 \cdot 10 \\ 5 \\ -7.643 \cdot 10 \\ 5 \\ -1.918 \cdot 10 \\ 4 \\ -3.611 \cdot 10 \\ 3 \\ -1.992 \cdot 10 \\ 527.356 \\ 3 \\ -3.121 \cdot 10 \end{vmatrix}$$

Solution

$$c := a^{-1} \cdot b$$

Coefficient Vector

$$c = \begin{pmatrix} 271.384 \\ 141.454 \\ 7.982 \cdot 10^{4} \\ 0 \\ -2.232 \cdot 10^{3} \\ 837.896 \\ 4.774 \cdot 10^{4} \\ 1.138 \cdot 10^{5} \\ -239.37 \\ 1.381 \cdot 10^{3} \\ -5.173 \cdot 10^{4} \\ 4.067 \cdot 10^{5} \end{pmatrix}$$

WRITEPRN(J2519TST) := c

TUBESHEET THICKNESS CALCULATIONS {corroded}

c := READPRN(J2519TST)

Input Load Data:

Tube Normal Thrust	Tfn := 0
Pressure (Steam Side)	Ps := 325
Pressure (Vessel Side)	Pv := -15

Input Geometry Data: (corroded) ca = 1/16"

Tube Number	Tn := 648
Tube O.D.	Td := 0.75
Tube wall thickness	Tt := 0.0830
Tube pattern pitch	Tp := 1.25
Tube pattern center	Tc := 10.5625
Tubesheet thickness	Tst := 2.3125
Tubesheet width	Tsw := 27.125
Steam chest inside diameter	Scd := 15.625
Steam chest mean diameter	Scm := 15.9375
Steam chest straight length	Scl := 57.5
Inset Nozzle Thickness	Int := 0.375

The Effective Pressure on the tube field, due to the axial thrust of the tubes, normalized to the entire area is as follows:

$$Pt := \frac{Tn \cdot Tfn}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl} \qquad Pt = 0$$

The Effective Pressure on the tube field, due to the steam pressure on the ligaments, normalized to the entire area is as follows:

$$Pse := \frac{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl - Tn \cdot \pi \cdot \frac{(Td - 2 \cdot Tt)^2}{4}}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl} \cdot Ps$$

$Pse = 273.254$

The Effective Pressure on the tube field, due to the vessel pressure on the ligaments, normalized to the entive area is as follows:

$$Pve := \frac{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl - Tn \cdot \pi \cdot \frac{Td^2}{4}}{\pi \cdot \frac{Scd^2}{4} + Scd \cdot Scl} \cdot Pv$$

$Pve = -11.061$

Pressure on the Tube field is:

$Pf := Pse - Pve - Pt$ $\qquad Pf = 284.315$

Shear and Bending In Each Beam Section

Beam # 1 at x = 0

$x := 0$

$Q1 := -Pv \cdot x + c_0$ $\qquad Q1 = 271.4$

$M1 := -Pv \cdot \frac{x^2}{2} + c_0 \cdot x + c_1$ $\qquad M1 = 141.5$

Beam # 2 at x = Ls1 (y = 0)

$Ls1 := Tc - \frac{Scm}{2} - \frac{Int}{2}$ $\qquad Ls1 = 2.406$

$y := 0$

$Q2 := Pf \cdot y + c_4$ $\qquad Q2 = -2.232 \cdot 10^3$

$$M2 := Pf \cdot \frac{y^2}{2} + c_4 \cdot y + c_5 \qquad M2 = 837.9$$

Beam # 2 at location of maximum bending

$$ym := \frac{-c_4}{Pf} \qquad ym = 7.85$$

$$Qm := Pf \cdot ym + c_4 \qquad Qm = 0$$

$$Mm := Pf \cdot \frac{ym^2}{2} + c_4 \cdot ym + c_5 \qquad Mm = -7.923 \cdot 10^3$$

Beam # 2 at x = Ls2 (y = Scm)

$$Ls2 := Tc + \frac{Scm}{2} - \frac{Int}{2} \qquad Ls2 = 18.344$$

$$y := Scm \qquad Scm = 15.938$$

$$Q3 := Pf \cdot y + c_4 \qquad Q3 = 2.299 \cdot 10^3$$

$$M3 := Pf \cdot \frac{y^2}{2} + c_4 \cdot y + c_5 \qquad M3 = 1.374 \cdot 10^3$$

Beam # 3 at x = Tsw - Int (z = Lss)

$$Lss := Tsw - Int - Ls2 \qquad Lss = 8.406$$

$$z := Lss$$

$$Q4 := -Pv \cdot z + c_8 \qquad Q4 = -113.306$$

$$M4 := -Pv \cdot \frac{z^2}{2} + c_8 \cdot z + c_9 \qquad M4 = -101.468$$

Cross Section Properties

Solid Region

$$As := 1 \cdot Tst \qquad As = 2.313$$

$$Is := 1 \cdot \frac{Tst^3}{12} \qquad Is = 1.031$$

$$cs := \frac{Tst}{2} \qquad cs = 1.156$$

Minimum Ligament Efficiency

$$\eta m := \frac{Tp - Td}{Tp} \qquad \eta m = 0.4$$

Tubed Region {double corrosion}

$$At := 1 \cdot (Tst - 0.0625) \cdot \eta m \qquad At = 0.9$$

$$It := 1 \cdot \frac{(Tst - 0.0625)^3}{12} \cdot \eta m \qquad It = 0.38$$

$$ct := \frac{Tst - 0.0625}{2} \qquad ct = 1.125$$

Stresses In Tubesheet

Beam 1 at x = 0

$$Ss := \frac{Q1}{As} \qquad Ss = 117.362$$

$$Sb := M1 \cdot \frac{cs}{Is} \qquad Sb = 158.761$$

$$S1 := \frac{Sb + \sqrt{Sb^2 + 4 \cdot Ss^2}}{2} \qquad S1 = 221.067$$

Beam 2 at x = Ls1 (y = 0)

$$Ss := \frac{Q2}{At} \qquad Ss = -2.48 \cdot 10^3$$

$$Sb := M2 \cdot \frac{ct}{It} \qquad Sb = 2.483 \cdot 10^3$$

$$S2 := \frac{Sb + \sqrt{Sb^2 + 4 \cdot Ss^2}}{2} \qquad S2 = 4.015 \cdot 10^3$$

Beam 2 at location on maximum bending $ym = 7.85$

$$Ss := \frac{Qm}{At} \qquad Ss = 0$$

$$Sb := Mm \cdot \frac{ct}{It} \qquad Sb = -2.348 \cdot 10^4$$

$$Sm := Sb \qquad Sm = -2.348 \cdot 10^4$$

Beam 2 at x = Ls2 (y = Scd)

$$Ss := \frac{Q3}{At} \qquad Ss = 2.555 \cdot 10^3$$

$$Sb := M3 \cdot \frac{ct}{It} \qquad Sb = 4.071 \cdot 10^3$$

$$S3 := \frac{Sb + \sqrt{Sb^2 + 4 \cdot Ss^2}}{2} \qquad S3 = 5.302 \cdot 10^3$$

Beam 3 at x = Tsw - Int (z = Lss)

$$Ss := \frac{Q4}{As} \qquad Ss = -48.997$$

$$Sb := M4 \cdot \frac{cs}{Is} \qquad Sb = -113.846$$

$$S4 := \frac{Sb - \sqrt{Sb^2 + 4 \cdot Ss^2}}{2} \qquad S4 = -132.03$$

Allowable Stress Comparison SB-582 N06985 @ 425F ASME Sect II-D

Membrane + Bending = 1.5*Sa $Sa := 1.5 \cdot 19350$ $\qquad Sa = 2.903 \cdot 10^4$

Maximum Stress Occurrs at middle of beam # 2 $\qquad Sm = -2.348 \cdot 10^4$

APPENDIX B

SOURCE LISTING FOR PROGRAMS FLATFACE

PROGRAMS FOR CALCULATING STRESSES AND THICKNESS OF FLAT FACE FLANGES TO ASME SECTION VIII, DIV 1, APPENDIX Y

1. Class 1, category 3 flanges
2. Class 3, category 3 flanges

```
      PROGRAM MAIN
      IMPLICIT REAL (M,J)
C     WRITE(*,*) 'ENTER P,B,A,C,G,hc,T
      READ(*,*) P,B,A,C,G,HSC,T
C *********PROGRAM TO CALCULATE STRESSES AND THICKNESS OF FLAT FACE FLG ****
C *********THIS PROGRAM WILL ANALYSE ONLY CLASS 1, CATEGORY 3 FLANGES ******
C*********************TO APPENDIX Y OF ASME SECTION VIII*********************
C     WRITE(*,*) 'ENTER NUMBER OF BOLTS, BOLT DIAMETER, BOLT ROOT AREA'
      READ(*,*) N,DB,BRA
      AB=N*BRA
      HCMAX = .5*(A-C)
      IF(HSC .LT. .001) HSC=HCMAX
C     WRITE(*,*) 'ENTER ELASTIC MODULUS RATIO - FLG/BOLT'
      READ(*,*)RE
      PI=3.14159
      H=.785*G*G*P
      HD=.785*B*B*P
      HT=H-HD
      HG=0.
      HSD=.5*(C-B)
      HST=.5*(C-G)
      HSG=.5*(C-G)
      B1=B
      MP=HD*HSD+HT*HST+HG*HSG
      D=DB+.125
      ALFA=(C+A)/(2*B1)
      BETA=(C+B1)/(2*B1)
      ARBAR=N*D/(PI*C)
      RB=4*ATAN(SQRT((1.+ARBAR)/(1-ARBAR)))/SQRT(1-ARBAR**2)-PI-2*ARBAR
      RB=RB/FLOAT(N)
      JS=(2*HSD/BETA + HSC/ALFA)/B1 +PI*RB
      ABL=ALOG10(A/B1)
      C1=-(.748-1.567*JS*ABL)/(1.+1.3*JS)
      JP=(HSD/BETA + HSC/ALFA)/B1 + PI*RB
      C2=(PI*P*(B1**3)/32 - 1.3*JP*MP)/(1.+1.3*JS)
      C3=0.
      C4=0.
      FP=0.
      BL= 2*T +DB
C
      T2=T*T
      T3=T*T2
      MS= JP*FP*MP/(T3+JS*FP)
      ETB=5.46*(JS*MS+JP*MP)/(PI*T3)
      HC=(MP+MS)/HSC
      WM1=H+HG+HC
      SIGMAB=WM1/AB
      SI=SIGMAB-1.159*HSC*HSC*(MP+MS)/(ALFA*T3*BL*RE*B1)
      SR=6*(MP+MS)/(T2*(PI*C-N*D))
      ST=T*ETB/B1
      write(*,700) P,B,A,C,G,T
700   FORMAT(5X,'ANALYSIS OF CLASS 1 CATEGORY 3 FLAT FACE FLANGES',
     1 /,5X,'PER ASME SECTION VIII,DIV 1  APPENDIX Y',///,5X,
     2'*** INPUT DATA ***',//,7X,'PRESSURE = 'F6.0,/,7X,'FLANGE ID = '
     3,F8.3,/,7X,'FLANGE OD = ',F8.3,/,7X,'BOLT CIRCLE DIAMETER = ',F8.3
     3,/,7X,'GASKET DIAMETER = 'F8.3,/,7X,'FLANGE THICKNESS = ',F7.3)
      WRITE(*,701) N,DB,AB
701   FORMAT(7X,'BOLTING - ',I2,2X,'BOLTS OF ',F6.3,' DIAMETER',/,
     1 7X,'BOLTING CROSS SECTIONAL AREA = ',F8.2)
      WRITE(*,703) RE
703   FORMAT(7X,'RATIO OF FLG / BOLT ELASTIC MODULUS = ',F6.3)
      WRITE(*,702) SIGMAB,SI,SR,ST
702   FORMAT(//,5X,'*** RESULTS ***',//,7X,'BOLT STRESS = ',F8.0,/,
     1 7X,'BOLT PRESTRESS = ',F8.0,/,7X,'FLANGE RADIAL STRESS AT BOLT CI
     1RCLE = ',F8.3,/,7X,'FLANGE TANGENTIAL STRESS AT INSIDE DIAMETER =
     2',F8.0,//,5X, '*** END OF ANALYSIS ***')
      STOP
      END
```

```
      PROGRAM MAIN
      IMPLICIT REAL (M,J)
C     WRITE(*,*) 'ENTER P,B,A,C,G,hc,T1,T2
      READ(*,*) P,B,A,C,G,HSC,T1,T2
C *********PROGRAM TO CALCULATE STRESSES AND THICKNESS OF FLAT FACE FLG ****
C *********THIS PROGRAM WILL ANALYSE ONLY CLASS 3, CATEGORY 3 FLANGES ******
C*********************TO APPENDIX Y OF ASME SECTION VIII*********************
C     WRITE(*,*) 'ENTER NUMBER OF BOLTS, BOLT DIAMETER, BOLT ROOT AREA'
      READ(*,*) N,DB,BRA
      AB=N*BRA
      HCMAX = .5*(A-C)
      IF(HSC .LT. .001) HSC=HCMAX
C     WRITE(*,*) 'ENTER ELASTIC MODULUS RATIOS - COVER/FLG,FLG/BOLT'
      READ(*,*)ER,RE
      PI=3.14159
      H=.785*G*G*P
      HD=.785*B*B*P
      HT=H-HD
      HG=0.
      HSD=.5*(C-B)
      HST=.5*(C-G)
      HSG=.5*(C-G)
      B1=B
      MP=HD*HSD+HT*HST+HG*HSG
      D=DB+.125
      ALFA=(C+A)/(2*B1)
      BETA=(C+B1)/(2*B1)
      ARBAR=N*D/(PI*C)
      RB=4*ATAN(SQRT((1.+ARBAR)/(1-ARBAR)))/SQRT(1-ARBAR**2)-PI-2*ARBAR
      RB=RB/FLOAT(N)
      JS=(2*HSD/BETA + HSC/ALFA)/B1 +PI*RB
      ABL=ALOG10(A/B1)
      C1=-(.748-1.567*JS*ABL)/(1.+1.3*JS)
      JP=(HSD/BETA + HSC/ALFA)/B1 + PI*RB
      C2=(PI*P*(B1**3)/32 - 1.3*JP*MP)/(1.+1.3*JS)
      C3=0.
      C4=0.
C
C     TA=2.45*SQRT(MP/((PI*C-N*D)*SF))
C     T1=1.1*TA
C     TB=.56*B1*SQRT(P/SF)
C     TC=AMAX1(TA,TB)
C     T2=1.1*TC
      T1S=T1**2
      T1C=T1**3
      T2S=T2**2
      T2C=T2**3
      X= 1.0/(1.+ER*T2C/T1C)
      P1= X*(C4-C2)/(1.206*ABL-X*C3-(1-X)*C1)
      P2=P1*ER*T2C/T1C
      MS1=C3*P1+C4
      MS2=C1*P2+C2
      MU1=1.206*P1*ABL
      MU2=1.206*P2*ABL
      MB1=MS1-MU1
      MB2=MS2-MU2
      BL=T1+T2+DB
      P3=5.46*(JS*MB1+JP*MP)/(PI*T1C) + P1/T1C
      P4= -1.337*(MS2-PI*P*(B1**3)/32.) /T2C
      HC=(MP+MB1)/HSC
      WM1=H+HG+HC
```

```
      SIGMAB=WM1/AB
      SI=SIGMAB-1.159*HSC*HSC*(MP+MB1)/(2*(1.-X)*ALFA*T1C*BL*RE*B1)
      SR1=6*(MP+MS1)/(T1S*(PI*C-N*D))
      ST1=T1*P3/B1
      SR2A=6*(MP+MS2)/(T2S*(PI*C-N*D))
      SR2B=6*MS2/(PI*B1*T2S)
      ST2A=T2*P4/B1 - 1.8*MS2/(PI*B1*T2S)
      ST2B=.3094*P*B1*B1/T2S  - 6*MS2/(PI*B1*T2S)
      write(*,700) P,B,A,C,G,T1,T2
  700 FORMAT(5X,'ANALYSIS OF CLASS 3 CATEGORY 3 FLAT FACE FLANGES',
     1 /,5X,'PER ASME SECTION VIII,DIV 1  APPENDIX Y',///,5X,
     2'*** INPUT DATA ***',//,7X,'PRESSURE = 'F6.0,/,7X,'FLANGE ID = '
     3,F8.3,/,7X,'FLANGE OD = ',F8.3,/,7X,'FLANGE BOLT CIRCLE = ',F8.3,
     3/,7X,'GASKET DIAMETER = 'F8.3,/,7X,'FLANGE THICKNESS = ',F7.3,/,7X
     5,'COVER THICKNESS = ',F7.3)
      WRITE(*,701) N,DB,AB
  701 FORMAT(7X,'BOLTING - ',I2,2X,'BOLTS OF ',F6.3,'DIAMETER',/,
     1 7X,'BOLTING CROSS SECTIONAL AREA = ',F8.2)
      WRITE(*,703) ER,RE
  703 FORMAT(7X,'RATIO OF COVER/FLANGE ELASTIC MODULUS = ',F6.3,/,
     1        7X,'RATIO OF FLG / BOLT   ELASTIC MODULUS = ',F6.3)
      WRITE(*,702) SIGMAB,SI,SR1,ST1,SR2A,SR2B,ST2A,ST2B
  702 FORMAT(//,5X,'*** RESULTS ***',//,7X,'BOLT STRESS = ',F8.0,/,
     1 7X,'BOLT PRESTRESS = ',F8.0,/,7X,'FLANGE RADIAL STRESS AT BOLT CI
     1RCLE = ',F8.0,/,7X,'FLANGE TANGENTIAL STRESS AT INSIDE DIAMETER =
     2',F8.0,/,7X,'COVER RADIAL STRESS AT BOLT CIRCLE = '
     3,F8.0,/,7X,'COVER RADIAL STRESS AT INSIDE DIAMETER = ',F8.0,/,7X,
     4 'COVER TANGENTIAL STRESS AT INSIDE DIAMETER = ',F8.0,/,7X,
     4 'COVER RADIAL AND TANGENTIAL STRESS AT CENTER = ',F8.0,//,5X,
     5 '*** END OF ANALYSIS ***')
      STOP
      END
```

END OF REPORT