VOLUME II ATTACHMENTS

ATTACHMENT 3 Part I

LIGO-C960964-01-V

TITLE	DOCUMENT NO.	REVISION
I. Adapters And Spools		
Spool BE-3 & BE-3A(60 in)	V049-1-049	0
Spool BE-2 (60 in)	V049-1-050	0
Spool B-5 (30 in.)	V049-1-057	1
Spool B-6 (48 in)	V049-1-058	0
Spool B-7 (48 in)	V049-1-059	0
Spool B-8 (72 in)	V049-1-060	0
Spool B-9 (72 in)	V049-1-061	0
Spool BE-4 (44 in)	V049-1-076	0
Generic Spool Design	V049-1-077	0
Spool BE-5 (44 in)	V049-1-085	1
II. Supports		
Design of Flexible Support for Adapter A-7	V049-1-062	1
Design of Gate Valve Support	V049-1-086	0
Support Design for Mode Cleaner Tubes (B-2/B-3/B-5)	V049-1-087	1
Support Design for Beam Tube Manifold (BE-5)	V049-1-088	1
Support Design for Beam Tube Manifold (B-9)	V049-1-089	1
Support Design for Beam Tube Manifold (B-6/B-7)	V049-1-095	1
Turbo Cart Frame Extension	V049-1-098	0
III. Miscellanous		
Flange Bolting for Gate Valves	V049-1-063	0
Bellows Deflection Study	V049-1-068	0
Analysis of BSC Support Leg to Cross Beam Connection	V049-1-079	0
Analysis of Bolted Flange for Initial Out of Flatness	V049-1-080	0
Expansion Joint Tie Rod Lug Design	V049-1-084	2
Stiffener Rings At Axial Restraints	V049-1-108	0
BSC Portable Clean Room	V049-1-112	0
HAM Portable Clean Room	V049-1-113	0

TITLE	DOCUMENT NO.	REVISION
Miscellanous		
Flange Bolting for Gate Valves	V049-1-063	0
Bellows Deflection Study	V049-1-068	0
Analysis of BSC Support Leg to Cross Beam Connection	V049-1-079	0
Analysis of Bolted Flange for Initial Out of Flatness	V049-1-080	0
Expansion Joint Tie Rod Lug Design	V049-1-084	1
Stiffener Rings At Axial Restraints	V049-1-108	0
BSC Portable Clean Room	V049-1-112	0
HAM Portable Clean Room	V049-1-113	0

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-057
PAGE 1 OF 63

REV.	DEO #	DATE	BY:	CHECK
0	0131	4/19/96	WDB	RDC
1	0253	9/20/96	WDB	RDC

TITLE:

SPOOL B-5 (30 in)
Mode Cleaner Tube

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine spool/adapter shell thickness. Additionally when applicable, evaluate nozzle opening(s), calculate size and spacing of stiffener rings and support rings.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.53.

ASSUMPTIONS: None

INPUTS:

1. Design Temperature = 400° F.
2. Ion Pump 16 in. Ø Nozzle Loads
   P_R = 4354.0 lbf; M_C = M_L = 378.5ft-lbf; V_C = V_L = 126.5 lbf Ref: V049-1-045
3. Vacuum Pressure = 14.7 psi
4. Dwg V049-4-B5A

REFERENCES:

1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.53, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code are met for spool B-5 outer shell.

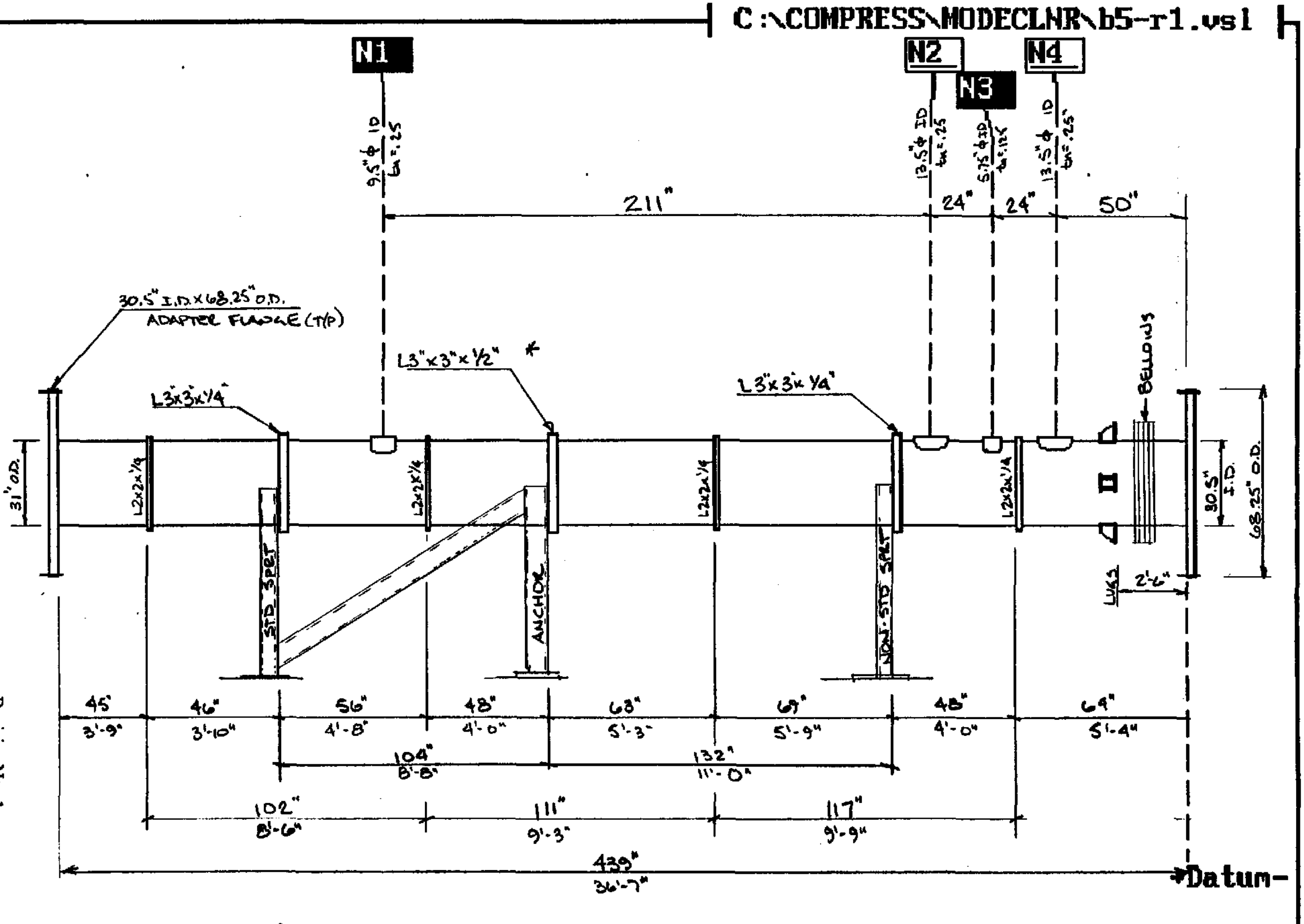
NOTES: Flanges are included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, 019.& 051
12″ CF Nozzle is a hillside nozzle offset 4″ above B-5's CL. Unbalanced vacuum load at 8″ nozzle (382. lbs) is omitted

TABLE OF CONTENTS

REVISION HISTORY

Rev. 0	Original Issue April 19, 1996
Rev. 1	Issue Date September 20, 1996

- Revised 8"CF & 12"CF nozzles to hillside nozzles
- Added unbalanced vacuum load at 12"CF nozzle
- Recalculated local and primary membrane stresses at the nozzles
- Revised the loading at the 16" CF nozzles, incorporating;
  valve weight + vacuum force
- Reversed locations of the 8"CF & 12"CF nozzles.
- Revised location of 12"CF nozzle and nearby 2" x 2" x 1/4" stiffner ring.
- Revised stiffner ring at anchor support to 3" x 3" x 1/2".



* L3x3x3/4 IS ADEQUATE AND WILL BE USED

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
Spool B-5	0.0	400.0	202.8	230.4	51.7	1.136		Not applicable	0.000
N4 N4 16" CF (14"od	0.0	400.0	130.5	148.2	14.7	1.136		Not applicable	0.000
N2 N2 16"CF (14"od)	0.0	400.0	130.5	148.2	14.7	1.136		Not applicable	0.000
N3 N3 8" CF (6"od)	0.0	400.0	119.9	136.2	14.7	1.136		Not applicable	0.000
N1 N1 12"CF (10"od)	0.0	400.0	135.9	154.4	14.7	1.136		Not applicable	0.000
Stiffner Rings (A)					14.7				
Support Rings (A)					14.7				
Support Ring (B)					14.7				
WHAM-5 END CONN.	0.0	0.0	10.2	10.2		1.000		Not applicable	0.000
WHAM-6 END CONN.	0.0	0.0	9.0	9.0		1.000		Not applicable	0.000
Stiffener Rings (B)					14.7				

Vessel MAWP hot & corroded is 9.03 psi @ 0 degrees F.

Vessel MAP new & cold is 9.03 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*1 = 22 psi

Vessel hydrotest pressure is 22 psi.

Weight Summary

```
Component -------------------------- Weight (lbs) Contributed by Vessel Elements ----------------------------
                  Metal   Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                    New    Corr   & sup    Beds                          & plat  & Misc  Liquid  Liquid   & flg
-------------------------------------------------------------------------------------------------------------
Spool b-5          3075    3075       0       0       0       0       0       0     278       0   11580      26
Wham-5 end conn    1539    1539       0       0       0       0       0       0       0       0       0       0
Wham-6 end conn    1539    1539       0       0       0       0       0       0       0       0       0       0

_______________  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______
                   6153    6153       0       0       0       0       0       0     278       0   11580      26


Vessel operating weight, corroded:   6,457 lbs
Vessel empty weight, corroded:       6,457 lbs
Vessel empty weight, new:            6,457 lbs
Vessel test weight, new:            18,037 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	6,456 lbs
Center of gravity to seam:	219.7 in

Nozzle Summary

```
-----------------------------------------------------------------------------------------
Nozzle        OD      tn    Req tn             Nom t    Req t   User t     Corr    Aa/Ar
mark        (in)    (in)     (in)   A1?  A2?    (in)     (in)     (in)     (in)      (%)
-----------------------------------------------------------------------------------------

N4         14.00  0.2500   0.1361    y    y   0.2500   0.1428   0.2500   0.0000    100.0
N2         14.00  0.2500   0.1361    y    y   0.2500   0.1428   0.2500   0.0000    100.0
N3          6.00  0.1250   0.1250    y    y   0.2500   0.1428            0.0000    117.6
N1         10.00  0.2500   0.1418    y    y   0.2500   0.1428            0.0000    100.1
-----------------------------------------------------------------------------------------
```

tn - nozzle thickness
Req tn - nozzle thickness required per UG-45/16
Nom t - vessel wall thickness
Req t - required vessel wall thickness due to pressure + corr per UG-37
User t - local vessel wall thickness (near opening)
Aa - area available per UG-37, governing condition
Ar - area required per UG-37, governing condition
Corr - corrosion allowance on nozzle id.

Nozzle Schedule

Nozzle mark	Service	Size	Materials						
			Nozzle	Impact?	Norm?	Pad	Impact?	Norm?	Flange
N4	16" cf (14"od)	13.50 IDx0.25	SA 240 304L HIGH	n	n				
N2	16"cf (14"od)	13.50 IDx0.25	SA 240 304L HIGH	n	n				
N3	8" cf (6"od)	5.75 IDx0.12	SA 240 304L HIGH	n	n				
N1	12"cf (10"od)	9.50 IDx0.25	SA 240 304L HIGH	n	n				

Thickness Summary

```
----------------------------------------------------------------------------------------------------
Component            ID      Length    Nom t    Req t   Joint           Governing            Deflect
Identifier          (in)      (in)     (in)     (in)      E     Load     Status     Stress     (in)
----------------------------------------------------------------------------------------------------
Spool b-5          30.50    439.00    0.2500   0.1428   0.85   external
----------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

COMPRESS 5.53 C:\COMPRESS\MODECLNR\B5-REV1.VSLD;q

Spool B-5

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component:	Cylinder
Material specification:	SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight:	new = 3074.7	corr = 3074.7	lb
capacity:	new = 1388.487	corr = 1388.487	US ga

ID = 30.5 length Lc= 439 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(15.25 + 0.6*0.25) - 0
= 230.4383 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.25/(15.25 + 0.6*0.25) - 0
= 202.8409 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 69/31 =2.2258 Do/t = 31/0.14281 = 217.0716
From table G: A = 0.000183
From table HA-3: B = 2408.6

Pa= 4*B/(3*Do/t)
= 4*2408.6/(3*31/0.14281)
= 14.7945 psi

Design thickness for external pressure Pa = 14.7945 psi:

= t + Corrosion
= 0.14281 + 0
= 0.14281 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 69/31 =2.2258 Do/t = 31/0.25 = 124
From table G: A = 0.000416
From table HA-3: B = 4816.4

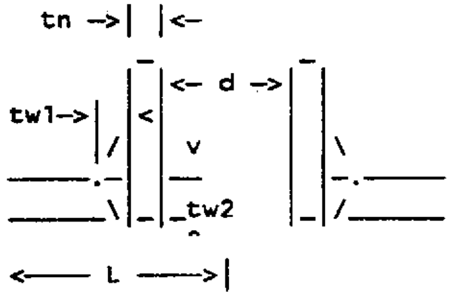
Pa= 4*B/(3*Do/t)

= 4*4816.4/(3*31/0.25)
= 51.7892 psi

N1 12"CF (10"od)

Opening N1 Reinforcement Calculations Per UG-37

Located on:	Spool B-5
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	75.5 degrees
End of nozzle to shell center:	18.125 in
Nozzle offset from center Lo:	4 in
Projection outside vessel Lpr:	3.15 in



```
corrosion allow = 0 in
noz thick new tn= .25 in
nozzle id. new d= 9.5 in
fillet weld tw1 = .25 in
groove weld tw2 = .1875 in

To datum L= 309 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.883 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 4.75)/15.3209)
= 55.17227

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 4.75)/15.3209)
= 92.80641

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3209*Sin((92.80641 - 55.17227)/2)
= 9.883 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 135.9225*4.75/(14700*1 - 0.6*135.9225)
= 0.0442 in

Required thickness tr from UG-37(a)

N1 12"CF (10"od)

tr = P*R/(S*E - 0.6*P)
= 135.9225*15.25/(14700*1 - 0.6*135.9225)
= 0.1418 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.883*0.1418*0.5 + 2*0.25*0.1418*0.5*(1 - 1)
= .7007 in^2

Area available

A1 = larger of the following = 1.77 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.883*(1*0.25-0.5*0.1418) - 2*0.25*(1*0.25-0.5*0.1418)*(1-1)
= 1.77 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-0.5*0.1418) - 2*0.25*(1*0.25-0.5*0.1418)*(1-1)
= .179 in^2

A2 = smaller of the following = 0.257 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0442)*1*0.25
= .257 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0442)*1*0.25
= .257 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.77 + 0.257 + 0.063
= 2.09 in^2

As Area > A the reinforcement is adequate for MAWP = 135.9225 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.5*0.1418*1 + 2*0.25*0.1418*1*(1 - 1)
= 1.3471 in^2

Area available

N1 12"CF (10"od)

A1 = larger of the following = 1.028 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.1418) - 2*0.25*(1*0.25-1*0.1418)*(1-1)
= 1.028 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1418) - 2*0.25*(1*0.25-1*0.1418)*(1-1)
= .108 in^2

Area = A1 + A2 + A41
= 1.028 + 0.257 + 0.063
= 1.348 in^2

As Area > A the reinforcement is adequate for MAWP = 135.9225 at 400 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0442 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1418 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.319375 in
The greater of tr2 or tr3:	tr5 = 0.1418 in
The lesser of tr4 or tr5:	tr6 = 0.1418 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1418 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*10*0.25*7203 = 28271.78 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*9.75*0.25*10290 = 39378.55 lbf

N1 12"CF (10"od)

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*10*0.1875*10878 = 32022.11 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.3471 - (9.5 - 2*0.25)*(1*0.25 - 1*0.1418))*14700
= 5487.51 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.257 + 0 + 0.063 + 0)*14700
= 4704 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.257 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*14700
= 6541.5 lbf

Load for path 1-1 lesser of W or W1-1 = 4704 lbf
Path 1-1 Thru (1) & (3) = 28271.78 + 39378.55 = 67650.33 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 5487.51 lbf
Path 2-2 Thru (1), (4) = 28271.78 + 32022.11 = 60293.89 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations For Nozzle MAP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.883 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 4.75)/15.3209)
= 55.17227

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 4.75)/15.3209)
= 92.80641

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3209*Sin((92.80641 - 55.17227)/2)
= 9.883 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 154.4704*4.75/(16700*1 - 0.6*154.4704)
= 0.0442 in

Required thickness tr from UG-37(a)

N1 12"CF (10"od)

tr= P*R/(S*E - 0.6*P)
= 154.4704*15.25/(16700*1 - 0.6*154.4704)
= 0.1418 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.883*0.1418*0.5 + 2*0.25*0.1418*0.5*(1 - 1)
= .7007 in^2

Area available

A1 = larger of the following = 1.77 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.883*(1*0.25-0.5*0.1418) - 2*0.25*(1*0.25-0.5*0.1418)*(1-1)
= 1.77 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-0.5*0.1418) - 2*0.25*(1*0.25-0.5*0.1418)*(1-1)
= .179 in^2

A2 = smaller of the following = 0.257 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0442)*1*0.25
= .257 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0442)*1*0.25
= .257 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.77 + 0.257 + 0.063
= 2.09 in^2

As Area > A the reinforcement is adequate for MAP = 154.4704 at 0 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.5*0.1418*1 + 2*0.25*0.1418*1*(1 - 1)
= 1.3471 in^2

Area available

N1 12"CF (10"od)

A1 = larger of the following = 1.028 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.1418) - 2*0.25*(1*0.25-1*0.1418)*(1-1)
= 1.028 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1418) - 2*0.25*(1*0.25-1*0.1418)*(1-1)
= .108 in^2

Area = A1 + A2 + A41
= 1.028 + 0.257 + 0.063
= 1.348 in^2

As Area > A the reinforcement is adequate for MAP = 154.4704 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0442 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1418 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.319375 in
The greater of tr2 or tr3:	tr5 = 0.1418 in
The lesser of tr4 or tr5:	tr6 = 0.1418 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1418 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*10*0.25*8183 = 32118.28 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*9.75*0.25*11690 = 44736.17 lbf

N1 12"CF (10"od)

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*10*0.1875*12358 = 36378.86 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.3471 - (9.5 - 2*0.25)*(1*0.25 - 1*0.1418))*16700
= 6234.11 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.257 + 0 + 0.063 + 0)*16700
= 5344 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.257 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7431.5 lbf

Load for path 1-1 lesser of W or W1-1 = 5344 lbf
Path 1-1 Thru (1) & (3) = 32118.28 + 44736.17 = 76854.45 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 6234.11 lbf
Path 2-2 Thru (1), (4) = 32118.28 + 36378.86 = 68497.14 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.883 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 4.75)/15.3214)
= 55.17357

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 4.75)/15.3214)
= 92.80632

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3214*Sin((92.80632 - 55.17357)/2)
= 9.883 in

Nozzle required thickness

L/Do = 3.15/10 = .315 Do/t = 10/0.02239 = 446.628
From table G: A = 0.000481
From table HA-3: B = 4941

Pa = 4*B/(3*Do/t)
= 4*4941/(3*10/0.02239)

= 14.7505 psi

Nozzle required thickness trn = .02239 in

Required thickness tr from UG-37(d)(1) = .1428 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(9.883*0.1428*0.5 + 2*0.25*0.1428*0.5*(1 - 1))
= .3528 in^2

Area available

A1 = larger of the following = 1.765 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.883*(1*0.25-0.5*0.1428) - 2*0.25*(1*0.25-0.5*0.1428)*(1-1)
= 1.765 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-0.5*0.1428) - 2*0.25*(1*0.25-0.5*0.1428)*(1-1)
= .179 in^2

A2 = smaller of the following = 0.285 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02239)*1*0.25
= .285 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02239)*1*0.25
= .285 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.765 + 0.285 + 0.063
= 2.113 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(9.5*0.1428*1 + 2*0.25*0.1428*1*(1 - 1))
= .6783 in^2

N1 12"CF (10"od)

Area available

A1 = larger of the following = 1.018 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= 1.018 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= .107 in^2

Area = A1 + A2 + A41
= 1.018 + 0.285 + 0.063
= 1.366 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.02239 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0153 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.319375 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.

COMPRESS 5.53 C:\COMPRESS\MODECLNR\B5-REV1.VSL

N1 12"CF (10"od)

Applied Loads

Radial load	Pr = 1042 lbf = VACUUM FORCE (END CAP LOAD)
Circumferential moment	Mc = 0 lbf-ft
Circumferential shear	Vc = 0 lbf
Longitudinal moment	ML = 0 lbf-ft
Longitudinal shear	VL = 0 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

$P_R = \pi r^2 (14.7)$

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 15.375 in
Rm/t = 61.5

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(4.75/5.25)^2 + 3*(4.75/5.25)^4)
= 2.117

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ 1914. PSI

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ 452. PSI

Maximum combined stress = ~~7215 psi~~ 9581. PSI
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = ~~1677 psi~~ 4043. PSI
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

$$\sigma_L = \frac{(14.7\text{ PSI})(15.375\text{ IN})}{2\,(.25\text{ IN})} = 452.\text{ PSI}$$

$$\sigma_C = \frac{(14.7\text{ PSI})(15.375\text{ IN})}{.25\text{ IN}} = 904\text{ PSI} \longrightarrow \sigma_C = (904\text{ PSI})(2.117) = 1914\text{ PSI}$$

MAX COMBINED STRESS = 7215 PSI + 452 PSI + 1914 PSI
= 9581. PSI

MAX PRIMARY STRESS = 1677 PSI + 452. PSI + 1914 PSI = 4043 PSI

N1 12"CF (10"od)

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	2.7030	0.285					-733	-733	-733	-733
4C*	6.1853	0.285	-1677	-1677	-1677	-1677				
1C	0.0648	0.285					-6482	6482	-6482	6482
2C-1	0.0135	0.285	-1350	1350	-1350	1350				
3A*	1.8945	0.285								
1A	0.0591	0.285								
3B*	3.9817	0.285								
1B-1	0.0125	0.285								
pressure stress*			-1914.	-1914.	-1914.	-1914.	-1914.	-1914.	-1914	-1914
Total circ stress			-4941.	-2241.	-4941	-2241.	-9129.	+3835	-9129	3835.
Primary membrane circ stress*			-3591	-3591	-3591	-3591.	-2647.	-2647.	-2647.	-2647.
3C*	2.7030	0.285	-733	-733	-733	-733				
4C*	6.1853	0.285					-1677	-1677	-1677	-1677
1C-1	0.0320	0.285	-3201	3201	-3201	3201				
2C	0.0306	0.285					-3061	3061	-3061	3061
4A*	5.8096	0.285								
2A	0.0245	0.285								
4B*	2.0592	0.285								
2B-1	0.0218	0.285								
pressure stress*			-452.	-452.	-452.	-452.	-452.	-452.	-452.	-452.
Total long stress			-4386.	2016.	-4386.	2016	-5190.	932.	-5190.	932.
Primary membrane long stress*			-1185.	-1185.	-1185.	-1185.	-2129	-2129	-2129.	-2129.
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-4941	-3591	-4941.	-3591	-9129.	3835	-9129	3835
MEMBRANE STRESS			-452.	-452.	-452.	-452.	-452.	-452.	-452.	-452.
MAX COMBINED STRESS			-5393	-4043	-5393.	-4043.	-9581	3383	-9581.	3383
MAX PRIMARY MEMBRANE			-3591	-3591	-3591	-3591.	-2647	-2647	-2647.	-2647
PRIMARY MEMBRANE STRESS			-452.	-452.	-452.	-452.	-452.	-452.	-452.	-452
MAX TOTAL PRIMARY MEMBRANE			-4043.	-4043.	-4043.	-4043.	-3099	-3099	-3099	-3099

N2 16"CF (14"od)

Opening N2 Reinforcement Calculations Per UG-37

Located on:	Spool B-5
User input vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	0 degrees
End of nozzle to shell center:	18.125 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	2.625 in

```
  tn ->|  |<-
       _          _
       | |<- d ->| |          corrosion allow = 0 in
tw1->| |<|       | |          noz thick new tn= .25 in
     |/| | v     | |\         nozzle id. new d= 13.5 in
______.-| |--    | |-.______  fillet weld tw1 = .25 in
______\|_|_tw2   |_|/______   groove weld tw2 = .1875 in
           ^
<---- L ---->|                To datum L= 98 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 130.5334*6.75/(14700*1 - 0.6*130.5334)
= 0.0603 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 130.5334*15.25/(14700*1 - 0.6*130.5334)
= 0.1361 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 13.5*0.1361*1 + 2*0.25*0.1361*1*(1 - 1)

= 1.8373 in^2

Area available

A1 = larger of the following = 1.538 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= 1.538 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= .114 in^2

A2 = smaller of the following = 0.237 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.538 + 0.237 + 0.063
= 1.838 in^2

As Area > A the reinforcement is adequate for MAWP = 130.5334 at 400 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0603 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1361 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.328125 in
The greater of tr2 or tr3:	tr5 = 0.1361 in
The lesser of tr4 or tr5:	tr6 = 0.1361 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1361 in

Available nozzle wall thickness new, tn = 0.25 in

N2 16"CF (14"od)

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*14*0.25*7203 = 39580.49 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.75*0.25*10290 = 55533.84 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*14*0.1875*10878 = 44830.96 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.8373 - (13.5 - 2*0.25)*(1*0.25 - 1*0.1361))*14700
= 5242.018 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.237 + 0 + 0.063 + 0)*14700
= 4410 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.237 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*14700
= 6247.5 lbf

Load for path 1-1 lesser of W or W1-1 = 4410 lbf
Path 1-1 Thru (1) & (3) = 39580.49 + 55533.84 = 95114.33 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 5242.018 lbf
Path 2-2 Thru (1), (4) = 39580.49 + 44830.96 = 84411.45 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations For Nozzle MAP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 148.2763*6.75/(16700*1 - 0.6*148.2763)
= 0.0603 in

N2 16"CF (14"od)

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 148.2763*15.25/(16700*1 - 0.6*148.2763)
= 0.1361 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 13.5*0.1361*1 + 2*0.25*0.1361*1*(1 - 1)
= 1.8373 in^2

Area available

A1 = larger of the following = 1.538 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= 1.538 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= .114 in^2

A2 = smaller of the following = 0.237 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.538 + 0.237 + 0.063
= 1.838 in^2

As Area > A the reinforcement is adequate for MAP = 148.2763 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

N2 16"CF (14"od)

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0.0603 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0.1361 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.328125 in
The greater of tr2 or tr3: tr5 = 0.1361 in
The lesser of tr4 or tr5: tr6 = 0.1361 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1361 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*14*0.25*8183 = 44965.59 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.75*0.25*11690 = 63089.47 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*14*0.1875*12358 = 50930.41 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.8373 - (13.5 - 2*0.25)*(1*0.25 - 1*0.1361))*16700
= 5955.218 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.237 + 0 + 0.063 + 0)*16700
= 5010 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.237 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7097.5 lbf

Load for path 1-1 lesser of W or W1-1 = 5010 lbf
Path 1-1 Thru (1) & (3) = 44965.59 + 63089.47 = 108055.1 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 5955.218 lbf
Path 2-2 Thru (1), (4) = 44965.59 + 50930.41 = 95896 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

N2 16"CF (14"od)

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

L/Do = 2.625/14 = .1875 Do/t = 14/0.02907 = 481.5962
From table G: A = 0.000747
From table HA-3: B = 5338.9

Pa = 4*B/(3*Do/t)
= 4*5338.9/(3*14/0.02907)
= 14.7811 psi

Nozzle required thickness trn = .02907 in

Required thickness tr from UG-37(d)(1) = .1428 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(13.5*0.1428*1 + 2*0.25*0.1428*1*(1 - 1))
= .9639 in^2

Area available

A1 = larger of the following = 1.447 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= 1.447 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= .107 in^2

A2 = smaller of the following = 0.276 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02907)*1*0.25
= .276 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02907)*1*0.25
= .276 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.447 + 0.276 + 0.063
= 1.786 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0.02907 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0153 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.328125 in
The greater of tr2 or tr3: tr5 = 0.0625 in
The lesser of tr4 or tr5: tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.

COMPRESS 5.53 C:\COMPRESS\MODECLNR\B5-REV1.VSL

N2 16"CF (14"od)

pplied Loads

Radial load Pr = 4354 lbf = PUMP WGHT + VACUUM FORCE
Circumferential moment Mc = 378.5 lbf-ft
Circumferential shear Vc = 126.5 lbf
Longitudinal moment ML = 378.5 lbf-ft
Longitudinal shear VL = 126.5 lbf
Torsion moment Mt = 0 lbf-ft
Internal pressure P = 0 psi

REF. Calc. V049-1-045

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 15.375 in
Rm/t = 61.5

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(6.75/7.25)^2 + 3*(6.75/7.25)^4)
= 2.214

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ 2002 PSI

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ 452. PSI

Maximum combined stress = ~~33193 psi~~ 35647 PSI
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = ~~6067 psi~~ 8521 PSI
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

$$\sigma_L = \frac{(14.7\text{ PSI})(15.375\text{ IN})}{2\,(.25\text{ IN})} = 452.0\text{ PSI}$$

$$\sigma_C = \frac{(14.7\text{ PSI})(15.375\text{ IN})}{.25\text{ IN}} = 904.05\text{ PSI} \rightarrow \sigma_C = 2.214(904.05\text{ PSI}) = 2002.\text{ PSI}$$

MAX COMBINED STRESS = 33193 PSI + 452. PSI + 2002 PSI
= 35647 PSI

MAX PRIMARY MEMBRANE STRESS = 6067 PSI + 452. PSI + 2002 PSI
= 8521 PSI.

N2 16"CF (14"od)

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	1.5557	0.398					-1762	-1762	-1762	-1762
4C*	4.3911	0.398	-4974	-4974	-4974	-4974				
1C	0.0648	0.398					-27085	27085	-27085	27085
2C-1	0.0065	0.398	-2717	2717	-2717	2717				
3A*	1.3830	0.398					-267	-267	267	267
1A	0.0573	0.398					-4079	4079	4079	-4079
3B*	2.5018	0.398	-483	-483	483	483				
1B-1	0.0079	0.398	-562	562	562	-562				
pressure stress*			-2002.	-2002.	-2002.	-2002.	-2002.	-2002.	-2002.	-2002
Total circ stress			-10738	-4180.	-8648.	-4338.	-35195.	27133.	-26503.	19509
Primary membrane circ stress*			-7459.	-7459	-6493	-6493	-4031.	-4031.	-3497.	-3497.
3C*	1.5557	0.398	-1762	-1762	-1762	-1762				
4C*	4.3911	0.398					-4974	-4974	-4974	-4974
1C-1	0.0160	0.398	-6688	6688	-6688	6688				
2C	0.0300	0.398					-12540	12540	-12540	12540
4A*	5.6652	0.398					-1093	-1093	1093	1093
2A	0.0227	0.398					-1616	1616	1616	-1616
4B*	1.4487	0.398	-279	-279	279	279				
2B-1	0.0158	0.398	-1125	1125	1125	-1125				
pressure stress*			-452	-452.	-452.	-452.	-452.	-452.	-452.	-452.
Total long stress			-10306	5320.	-7498	3628.	-20675	7637.	-15257.	6591.
Primary membrane long stress*			-2493.	-2493.	-1935.	-1935	-6519	-6519.	-4333.	-4333.
torsion moment Mt										
Circ shear from Vc			23	23	-23	-23				
Long shear from VL							-23	-23	23	23
Total Shear stress			23	23	-23	-23	-23	-23	23	23
Combined stress			-10738.	-7459	-8648	-6493	-35195.	27133.	-26503.	19509
Membrane Stress			-452.	-452.	-452.	-452.	-452.	-452.	-452.	-452
Max Combined Stress			-11190.	-7911.	-9100	-6945.	-35647.	26681.	-26955	19057.
Max Primary Membrane			-7459.	-7459.	-6493.	-6493.	-6519	-6519.	-4333.	-4333
σ Primary Membrane			-452.	-452.	-452.	-452.	-2002.	-2002.	-2002.	-2002.
Max Total Primary Membrane			-7911.	-7911.	-6945	-6945.	-8521.	-8521.	-6335	-6335.

N3 8" CF (6"od)

Opening N3 Reinforcement Calculations Per UG-37

Located on: Spool B-5
Local vessel thickness: .25 in
Liquid static head included: 0 psi
Flange description: Not installed

Nozzle material specification: SA 240 304L HIGH

Nozzle orientation: 75.5 degrees
End of nozzle to shell center: 18.125 in
Nozzle offset from center Lo: 4 in
Projection outside vessel Lpr: 3.15 in

```
  tn ->|  |<-
        _         _              corrosion allow = 0 in
       | |<- d ->| |             noz thick new tn= .125 in
tw1->| |<|       | |             nozzle id. new d= 5.75 in
     |/| |  v    | |\            fillet weld tw1 = .25 in
_____.-| |_      | |-.______     groove weld tw2 = .1875 in
______\|_|_tw2   |_|/_______
           ^
<---- L ---->|                   To datum L= 74 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.965 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3125 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 2.875)/15.3125)
= 63.32211

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 2.875)/15.3125)
= 85.78719

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3125*Sin((85.78719 - 63.32211)/2)
= 5.965 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 119.9299*2.875/(14700*1 - 0.6*119.9299)
= 0.0236 in

Required thickness tr from UG-37(a)

N3 8" CF (6"od)

tr= P*R/(S*E - 0.6*P)
= 119.9299*15.25/(14700*1 - 0.6*119.9299)
= 0.125 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.965*0.125*0.5 + 2*0.125*0.125*0.5*(1 - 1)
= .3728 in^2

Area available

A1 = larger of the following = 1.118 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.965*(1*0.25-0.5*0.125) - 2*0.125*(1*0.25-0.5*0.125)*(1-1)
= 1.118 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-0.5*0.125) - 2*0.125*(1*0.25-0.5*0.125)*(1-1)
= .141 in^2

A2 = smaller of the following = 0.063 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0.0236)*1*0.25
= .127 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0.0236)*1*0.125
= .063 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.118 + 0.063 + 0.063
= 1.244 in^2

As Area > A the reinforcement is adequate for MAWP = 119.9299 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.75*0.125*1 + 2*0.125*0.125*1*(1 - 1)
= .71875 in^2

Area available

N3 8" CF (6"od)

A1 = larger of the following = .719 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.125) - 2*0.125*(1*0.25-1*0.125)*(1-1)
= .719 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0.125) - 2*0.125*(1*0.25-1*0.125)*(1-1)
= .094 in^2

Area = A1 + A2 + A41
= 0.719 + 0.063 + 0.063
= .845 in^2

As Area > A the reinforcement is adequate for MAWP = 119.9299 at 400 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.125 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.0875 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0236 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.125 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.245 in
The greater of tr2 or tr3:	tr5 = 0.125 in
The lesser of tr4 or tr5:	tr6 = 0.125 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.125 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*6*0.25*7203 = 16963.06 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*5.875*0.125*10290 = 11864.05 lbf

N3 8" CF (6"od)

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*6*0.1875*10878 = 19213.27 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.71875 - (5.75 - 2*0.125)*(1*0.25 - 1*0.125))*14700
= 459.375 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.063 + 0 + 0.063 + 0)*14700
= 1852.2 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.063 + 0 + 0.063 + 0 + 2*0.125*0.25*1)*14700
= 2770.95 lbf

Load for path 1-1 lesser of W or W1-1 = 459.375 lbf
Path 1-1 Thru (1) & (3) = 16963.06 + 11864.05 = 28827.11 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 = 459.375 lbf
Path 2-2 Thru (1), (4) = 16963.06 + 19213.27 = 36176.33 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations For Nozzle MAP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.965 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3125 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 2.875)/15.3125)
= 63.32211

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 2.875)/15.3125)
= 85.78719

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3125*Sin((85.78719 - 63.32211)/2)
= 5.965 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 136.2431*2.875/(16700*1 - 0.6*136.2431)
= 0.0236 in

Required thickness tr from UG-37(a)

N3 8" CF (6"od)

tr= P*R/(S*E - 0.6*P)
= 136.2431*15.25/(16700*1 - 0.6*136.2431)
= 0.125 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.965*0.125*0.5 + 2*0.125*0.125*0.5*(1 - 1)
= .3728 in^2

Area available

A1 = larger of the following = 1.118 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.965*(1*0.25-0.5*0.125) - 2*0.125*(1*0.25-0.5*0.125)*(1-1)
= 1.118 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-0.5*0.125) - 2*0.125*(1*0.25-0.5*0.125)*(1-1)
= .141 in^2

A2 = smaller of the following = 0.063 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0.0236)*1*0.25
= .127 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0.0236)*1*0.125
= .063 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.118 + 0.063 + 0.063
= 1.244 in^2

As Area > A the reinforcement is adequate for MAP = 136.2431 at 0 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.75*0.125*1 + 2*0.125*0.125*1*(1 - 1)
= .71875 in^2

Area available

N3 8" CF (6"od)

A1 = larger of the following = .719 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.125) - 2*0.125*(1*0.25-1*0.125)*(1-1)
= .719 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0.125) - 2*0.125*(1*0.25-1*0.125)*(1-1)
= .094 in^2

Area = A1 + A2 + A41
= 0.719 + 0.063 + 0.063
= .845 in^2

As Area > A the reinforcement is adequate for MAP = 136.2431 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.125 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.0875 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0236 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.125 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.245 in
The greater of tr2 or tr3:	tr5 = 0.125 in
The lesser of tr4 or tr5:	tr6 = 0.125 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.125 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for MAP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*6*0.25*8183 = 19270.96 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*5.875*0.125*11690 = 13478.21 lbf

N3 8" CF (6"od)

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*6*0.1875*12358 = 21827.32 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.71875 - (5.75 - 2*0.125)*(1*0.25 - 1*0.125))*16700
= 521.875 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.063 + 0 + 0.063 + 0)*16700
= 2104.2 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.063 + 0 + 0.063 + 0 + 2*0.125*0.25*1)*16700
= 3147.95 lbf

Load for path 1-1 lesser of W or W1-1 = 521.875 lbf
Path 1-1 Thru (1) & (3) = 19270.96 + 13478.21 = 32749.17 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 = 521.875 lbf
Path 2-2 Thru (1), (4) = 19270.96 + 21827.32 = 41098.28 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.965 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3125 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((4 + 2.875)/15.3214)
= 63.33883

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((4 - 2.875)/15.3214)
= 85.78963

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*15.3214*Sin((85.78963 - 63.33883)/2)
= 5.965 in

Nozzle required thickness

L/Do = 3.15/6 = .525 Do/t = 6/0.01523 = 393.9593
From table G: A = 0.000333
From table HA-3: B = 4408.2

Pa = 4*B/(3*Do/t)
= 4*4408.2/(3*6/0.01523)

N3 8" CF (6"od)

= *14.9193 psi*

Nozzle required thickness trn = .01523 in

Required thickness tr from UG-37(d)(1) = .1428 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(5.965*0.1428*0.5 + 2*0.125*0.1428*0.5*(1 - 1))
= .213 in^2

Area available

A1 = larger of the following = 1.065 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.965*(1*0.25-0.5*0.1428) - 2*0.125*(1*0.25-0.5*0.1428)*(1-1)
= 1.065 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-0.5*0.1428) - 2*0.125*(1*0.25-0.5*0.1428)*(1-1)
= .134 in^2

A2 = smaller of the following = 0.069 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0.01523)*1*0.25
= .137 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0.01523)*1*0.125
= .069 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.065 + 0.069 + 0.063
= 1.197 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(5.75*0.1428*1 + 2*0.125*0.1428*1*(1 - 1))
= .41055 in^2

COMPRESS 5.53 C:\COMPRESS\MODECLNR\B5-REV1.VSLD;q

N3 8" CF (6"od)

Area available

A1 = larger of the following = .616 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.1428) - 2*0.125*(1*0.25-1*0.1428)*(1-1)
= .616 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0.1428) - 2*0.125*(1*0.25-1*0.1428)*(1-1)
= .08 in^2

Area = A1 + A2 + A41
= 0.616 + 0.069 + 0.063
= .748 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.01523 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0153 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.245 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for Pe.

NOTE:

N3 8"CF (6"OD) NOZZLE
IS QUALIFIED BY N1 FOR
WRC 107. NO FURTHER
NOZZLE EVALUATION IS REQ'D.

N4 16" CF (14"od)

Opening N4 Reinforcement Calculations Per UG-37

Located on:	Spool B-5
User input vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	0 degrees
End of nozzle to shell center:	18.125 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	2.625 in

```
  tn ->| |<-
        _          _            corrosion allow = 0 in
       | |<- d ->| |            noz thick new tn= .25 in
tw1->| |<|        | |           nozzle id. new d= 13.5 in
     |/| | v      | |\          fillet weld tw1 = .25 in
-----.-| |--      | |-.-----    groove weld tw2 = .1875 in
------\|_|_tw2    |_|/------
           ^

<---- L ---->|                  To datum L= 50 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 130.5334*6.75/(14700*1 - 0.6*130.5334)
= 0.0603 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 130.5334*15.25/(14700*1 - 0.6*130.5334)
= 0.1361 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 13.5*0.1361*1 + 2*0.25*0.1361*1*(1 - 1)

N4 16" CF (14"od)

= 1.8373 in^2

Area available

A1 = larger of the following = 1.538 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= 1.538 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
= .114 in^2

A2 = smaller of the following = 0.237 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0603)*1*0.25
= .237 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.538 + 0.237 + 0.063
= 1.838 in^2

As Area > A the reinforcement is adequate for MAWP = 130.5334 at 400 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0603 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1361 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.328125 in
The greater of tr2 or tr3:	tr5 = 0.1361 in
The lesser of tr4 or tr5:	tr6 = 0.1361 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1361 in

Available nozzle wall thickness new, tn = 0.25 in

N4 16" CF (14"od)

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*14*0.25*7203 = 39580.49 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.75*0.25*10290 = 55533.84 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*14*0.1875*10878 = 44830.96 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.8373 - (13.5 - 2*0.25)*(1*0.25 - 1*0.1361))*14700
= 5242.018 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.237 + 0 + 0.063 + 0)*14700
= 4410 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.237 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*14700
= 6247.5 lbf

Load for path 1-1 lesser of W or W1-1 = 4410 lbf
Path 1-1 Thru (1) & (3) = 39580.49 + 55533.84 = 95114.33 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 5242.018 lbf
Path 2-2 Thru (1), (4) = 39580.49 + 44830.96 = 84411.45 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations For Nozzle MAP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 148.2763*6.75/(16700*1 - 0.6*148.2763)
= 0.0603 in

N4 16" CF (14"od)

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
 = 148.2763*15.25/(16700*1 - 0.6*148.2763)
 = 0.1361 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
 = 13.5*0.1361*1 + 2*0.25*0.1361*1*(1 - 1)
 = 1.8373 in^2

Area available

A1 = larger of the following = 1.538 in^2

 = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
 = 13.5*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
 = 1.538 in^2

 = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
 = 2*(0.25+0.25)*(1*0.25-1*0.1361) - 2*0.25*(1*0.25-1*0.1361)*(1-1)
 = .114 in^2

A2 = smaller of the following = 0.237 in^2

 = 5*(tn - trn)*fr2*t
 = 5*(0.25 - 0.0603)*1*0.25
 = .237 in^2

 = 5*(tn - trn)*fr2*tn
 = 5*(0.25 - 0.0603)*1*0.25
 = .237 in^2

A41 = Leg^2*fr2
 = 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
 = 1.538 + 0.237 + 0.063
 = 1.838 in^2

As Area > A the reinforcement is adequate for MAP = 148.2763 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.1875 in
t1 + t2 = 0.3625 >= 1.25*tmin

N4 16" CF (14"od)

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0603 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1361 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.328125 in
The greater of tr2 or tr3:	tr5 = 0.1361 in
The lesser of tr4 or tr5:	tr6 = 0.1361 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1361 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*14*0.25*8183 = 44965.59 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.75*0.25*11690 = 63089.47 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*14*0.1875*12358 = 50930.41 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.8373 - (13.5 - 2*0.25)*(1*0.25 - 1*0.1361))*16700
= 5955.218 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.237 + 0 + 0.063 + 0)*16700
= 5010 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.237 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7097.5 lbf

Load for path 1-1 lesser of W or W1-1 = 5010 lbf
Path 1-1 Thru (1) & (3) = 44965.59 + 63089.47 = 108055.1 lbf
Path 1-1 is stronger than W1-1 so it is acceptable per UG-41(b)(1).

Load for path 2-2 lesser of W or W2-2 = 5955.218 lbf
Path 2-2 Thru (1), (4) = 44965.59 + 50930.41 = 95896 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

N4 16" CF (14"od)

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

L/Do = 2.625/14 = .1875   Do/t = 14/0.02907 = 481.5962
From table G: A = 0.000747
From table HA-3:   B = 5338.9

Pa= 4*B/(3*Do/t)
= 4*5338.9/(3*14/0.02907)
= 14.7811 psi

Nozzle required thickness trn = .02907 in

Required thickness tr from UG-37(d)(1) = .1428 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(13.5*0.1428*1 + 2*0.25*0.1428*1*(1 - 1))
= .9639 in^2

Area available

A1 = larger of the following   = 1.447 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= 1.447 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.1428) - 2*0.25*(1*0.25-1*0.1428)*(1-1)
= .107 in^2

A2 = smaller of the following   = 0.276 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02907)*1*0.25
= .276 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02907)*1*0.25
= .276 in^2

N4 16" CF (14"od)

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 1.447 + 0.276 + 0.063
= 1.786 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0.02907 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0153 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.328125 in
The greater of tr2 or tr3: tr5 = 0.0625 in
The lesser of tr4 or tr5: tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.

N4 16" CF (14"od)

Applied Loads

Radial load	Pr = 4354 lbf
Circumferential moment	Mc = 378.5 lbf-ft
Circumferential shear	Vc = 126.5 lbf
Longitudinal moment	ML = 378.5 lbf-ft
Longitudinal shear	VL = 126.5 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 15.375 in
Rm/t = 61.5

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(6.75/7.25)^2 + 3*(6.75/7.25)^4)
= 2.214

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ = 2002 psi $= \frac{(14.7)(15.375)}{(.25)} \times 2.214$

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ 452 psi $- \frac{(14.7)(15.375)}{2(.25}$

Maximum combined stress = -~~33193 psi~~
Allowable combined stress = +-3*S = +- 44100 psi   33193 + 2002 + 452 = 35647 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = ~~6067 psi~~
Allowable primary membrane stress = +-1.5*S = +- 22050 psi   6067 + 2002 + 452 = 8521 psi

The maximum primary membrane stress is within allowable limits.

N4 16" CF (14"od)

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	1.5557	0.398					-1762	-1762	-1762	-1762
✓4C*	4.3911	0.398	-4974	-4974	-4974	-4974				
1C	0.0648	0.398					-27085	27085	-27085	27085
2C-1	0.0065	0.398	-2717	2717	-2717	2717				
3A*	1.3830	0.398					-267	-267	267	267
1A	0.0573	0.398					-4079	4079	4079	-4079
✓3B*	2.5018	0.398	-483	-483	483	483				
1B-1	0.0079	0.398	-562	562	562	-562				
pressure stress* ✓			-2002.	-2002.	-2002.	-2002.	-2002.	-2002.	-2002.	-2002.
Total circ stress			-10738.	-4180.	-8648.	-4338.	-35195.	27133.	-26503.	19509.
Primary membrane circ stress*			-7459.	-7459.	-6493.	-6493.	-4031.	-4031.	-3497.	-3497.
3C*	1.5557	0.398	-1762	-1762	-1762	-1762				
4C*	4.3911	0.398					-4974	-4974	-4974	-4974
1C-1	0.0160	0.398	-6688	6688	-6688	6688				
2C	0.0300	0.398					-12540	12540	-12540	12540
4A*	5.6652	0.398					-1093	-1093	1093	1093
2A	0.0227	0.398					-1616	1616	1616	-1616
4B*	1.4487	0.398	-279	-279	279	279				
2B-1	0.0158	0.398	-1125	1125	1125	-1125				
pressure stress*			-452.	-452.	-452	-452.	-452.	-452.	-452.	-452.
Total long stress			-10306.	5320.	-7498.	3628.	-20675.	7637.	-15257.	6591.
Primary membrane long stress*			-2493.	-2493.	-1935.	-1935.	-6519.	-6519.	-4333.	-4333.
torsion moment Mt										
Circ shear from Vc			23	23	-23	-23				
Long shear from VL							-23	-23	23	23
Total Shear stress			23	23	-23	-23	-23	-23	23	23
Combined stress			-10738.	-7459.	-8648.	-6493.	-35195.	27133.	-26503.	19509.
MEMBRANE STRESS			-452.	-452.	-452.	-452	-452	-452.	-452.	-452
MAX COMBINED STRESS			-11190.	-7911.	-9100.	-6945.	-35647.	26681.	-26955.	19057.
MAX PRIMARY MEMBRANE			-7459	-7459.	-6493	-6493	-6519	-6519	-4333.	-4333.
PRIMARY MEMBRANE σ			-452.	-452.	-452.	-452.	-2002.	-2002.	-2002.	-2002.
MAX TOTAL PRIMARY MEMBRANE			-7911.	-7911.	-6945.	-6945.	-8521	-8521.	-6335.	-6335.

Stiffner Rings (A)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier: Stiffner Rings (A)
Ring material specification: SA 240 304L HIGH
Number of rings in this group: 2
Distance first ring to datum line: 64 in
Ring spacing: 117 in

Ring description: 2x2x1/4 Equal Angle
Ring is rolled: leg in (hard way)
Ring cross sectional area: As = 0.938 in^2
Ring moment of inertia: Ir = 0.348 in^4

Calculations for ring 64 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.14281 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 31 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 58.27083 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 0.938/58.27083))
= 2150.783

From table HA-3 (ring) A = 1.635851E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*58.27083*(0.14281 + 0.938/58.27083)*1.635851E-04)/10.9
= .1335474 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 58.27083 in

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.408 + 0.25/2

Stiffner Rings (A)

= 1.533 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 0.938*1.533/(0.7655676 + 0.938)
= .8440839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.06227*0.25^3/12 + 0.7655676*0.8440839^2
= .5494371 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.348 + 0.938*(0.8440839 - 1.533)^2
= .7931799 in^4

Total available I = I1 + I2 = 1.342617 in^4

The 2x2x1/4 Equal Angle vacuum stiffener is satisfactory.

Calculations for ring 181 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14281 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	31 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	66 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 0.938/66))
= 2176.604

From table HA-3 (ring) A = 1.655302E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*66*(0.14281 + 0.938/66)*1.655302E-04)/10.9
= .1512443 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 66 in

Stiffner Rings (A)

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
 = 1.408 + 0.25/2
 = 1.533 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 0.938*1.533/(0.7655676 + 0.938)
 = .8440839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 3.06227*0.25^3/12 + 0.7655676*0.8440839^2
 = .5494371 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 0.348 + 0.938*(0.8440839 - 1.533)^2
 = .7931799 in^4

Total available I = I1 + I2 = 1.342617 in^4

The 2x2x1/4 Equal Angle vacuum stiffener is satisfactory.

Stiffener Rings (B)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier: Stiffener Rings (B)
Ring material specification: SA 240 304L HIGH
Number of rings in this group: 2
Distance first ring to datum line: 292 in
Ring spacing: 108 in

Ring description: 2x2x1/4 Equal Angle
Ring is rolled: leg in (hard way)
Ring cross sectional area: As = 0.938 in^2
Ring moment of inertia: Ir = 0.348 in^4

Calculations for ring 292 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.14281 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 31 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 52 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 0.938/52))
= 2124.826

From table HA-3 (ring) A = 1.616295E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*52*(0.14281 + 0.938/52)*1.616295E-04)/10.9
= .1191894 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 52 in

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.408 + 0.25/2

= 1.533 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 0.938*1.533/(0.7655676 + 0.938)
 = .8440839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 3.06227*0.25^3/12 + 0.7655676*0.8440839^2
 = .5494371 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 0.348 + 0.938*(0.8440839 - 1.533)^2
 = .7931799 in^4

Total available I = I1 + I2 = 1.342617 in^4

The 2x2x1/4 Equal Angle vacuum stiffener is satisfactory.

Calculations for ring 400 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.14281 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 31 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 45.5 in

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*31/(0.14281 + 0.938/45.5))
 = 2091.321

From table HA-3 (ring) A = 1.591049E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
 = (31^2*45.5*(0.14281 + 0.938/45.5)*1.591049E-04)/10.9
 = .1043065 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
 = 1.1*Sqr(31*0.25)
 = 3.06227 in

W = Ls = 45.5 in

Stiffener Rings (B)

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.408 + 0.25/2
= 1.533 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 0.938*1.533/(0.7655676 + 0.938)
= .8440839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.06227*0.25^3/12 + 0.7655676*0.8440839^2
= .5494371 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.348 + 0.938*(0.8440839 - 1.533)^2
= .7931799 in^4

Total available I = I1 + I2 = 1.342617 in^4

The 2x2x1/4 Equal Angle vacuum stiffener is satisfactory.

Support Rings (A)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Support Rings (A)
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		112 in
Ring spacing:		236 in
Ring description:		3x3x1/4 Equal Angle
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.44 in^2
Ring moment of inertia:	Ir =	1.24 in^4

Calculations for ring 112 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14281 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	31 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	58.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 1.44/58.5))
= 2041.357

From table HA-3 (ring) A = 1.553394E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*58.5*(0.14281 + 1.44/58.5)*1.553394E-04)/10.9
= .1341392 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 58.5 in

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.158 + 0.25/2

Support Rings (A)

= 2.283 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.44*2.283/(0.7655676 + 1.44)
= 1.490555 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.06227*0.25^3/12 + 0.7655676*1.490555^2
= 1.70489 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 1.24 + 1.44*(1.490555 - 2.283)^2
= 2.144275 in^4

Total available I = I1 + I2 = 3.849166 in^4

The 3x3x1/4 Equal Angle vacuum stiffener is satisfactory.

Calculations for ring 348 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14281 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	31 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	54 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 1.44/54))
= 2016.649

From table HA-3 (ring) A = 1.534769E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*54*(0.14281 + 1.44/54)*1.534769E-04)/10.9
= .1238351 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 54 in

Support Rings (A)

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.158 + 0.25/2
= 2.283 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.44*2.283/(0.7655676 + 1.44)
= 1.490555 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.06227*0.25^3/12 + 0.7655676*1.490555^2
= 1.70489 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 1.24 + 1.44*(1.490555 - 2.283)^2
= 2.144275 in^4

Total available I = I1 + I2 = 3.849166 in^4

The 3x3x1/4 Equal Angle vacuum stiffener is satisfactory.

Support Ring (B)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier: Support Ring (B)
Ring material specification: SA 240 304L HIGH
Number of rings in this group: 1
Distance first ring to datum line: *244 in*

Ring description: 3x3x1/2 Equal Angle
Ring is rolled: leg in (hard way)
Ring cross sectional area: As = 2.75 in^2
Ring moment of inertia: Ir = 2.22 in^4

Calculations for ring 244 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.14281 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 31 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 55.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14281 + 2.75/55.5))
= 1776.751

From table HA-3 (ring) A = 1.353823E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*55.5*(0.14281 + 2.75/55.5)*1.353823E-04)/10.9
= .1274282 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.06227

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 55.5 in

Shell area A1 = W*ts = 0.7655676 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.068 + 0.25/2
= 2.193 in

Support Ring (B)

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 2.75*2.193/(0.7655676 + 2.75)
= 1.715441 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.06227*0.25^3/12 + 0.7655676*1.715441^2
= 2.256853 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 2.22 + 2.75*(1.715441 - 2.193)^2
= 2.847172 in^4

Total available I = I1 + I2 = 5.104024 in^4

The 3x3x1/2 Equal Angle vacuum stiffener is satisfactory.

BELLOWS LUGS

Lug material specification = SA 206 340L HIGH
Lug allowable stress = 24000 psi
Top plate width wp = 2 in
Base plate width wb = 6 in
Top plate thickness t = 0.375 in
Base plate thickness tb = 0.375 in
Lug length circ. direction L = 6 in
Gusset height h = 6 in
Gusset thickness tg = 0.375 in
Number of lugs = 3
Angular position, first lug = 120 degrees
Fillet weld size tw = 0.25 in
Force bearing width Fb = 3 in
Distance to load d = 4.5 in

Lug top plate required thickness, Bednar pg 153

ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
= 0.75*(1604*4.5*6)/(24000*2^2*6)
= 0.25 in

Lug gusset required thickness

Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2)
= 18000/(1 + (1/18000)*(6/(0.289*0.375))^2)
= 15380.89 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
= 1604*(3*4.5 - 6)/(15380.89*6^2*SIN(56.31)^2)
= 0.0314 in

Lug base plate required thickness

From Escoe table 4-8

fc = VL/(Fb*L) = 89.11111 psi

Mx = Cx*fc*Gs^2
= 0.1085*89.11111*5.25^2 = 266.4896

My = Cy*fc*wb^2
= -.124*89.11111*6^2 =-397.792

tb = Sqr(6*Mmax / Sa)
= Sqr(6*397.792 / 24000)
= 0.3154 in

Check lug attachment stresses

Radial load Pr = 0 lbf
Circumferential moment Mc = 0 lbf-ft
Circumferential shear Vc = 0 lbf
Longitudinal moment ML = 0 lbf-ft
Longitudinal shear VL = 1604 lbf

BELLOWS LUGS

Internal pressure P = 0 psi

Stresses at the lug edge per WRC bulletin 107 (psi)

Mean radius Rm = 15.375 in
Rm/t = 61.5

C1 = 3, C2 = 3.375 in

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Local circ. pressure stress = P*Rm/t = 0 psi

Local long. pressure stress = P*Rm/2t = 0 psi

Maximum combined stress = 950 psi
Allowable combined stress = +-1.5*S = +- 22050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = 0 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

BELLOWS LUGS

```
 ____________________________________________________________________________________
| From| Value  | beta|
| Fig.| read   |     |   Au      Al      Bu      Bl      Cu      Cl      Du      Dl
|_____|________|_____|_______________________________________________________________
| 3C* |3.9083  |0.222|
| 4C* |7.5544  |0.213|
| 1C  |0.0648  |0.203|
| 2C-1|0.0257  |0.203|
| 3A* |2.3818  |0.203|
| 1A  |0.0649  |0.223|
| 3B* |5.3623  |0.211|
| 1B-1|0.0191  |0.208|
| pressure stress*   |
|____________________|_______________________________________________________________
| Total circ stress  |
| Primary membrane   |
| circ stress*       |
|____________________|_______________________________________________________________
| 3C* |4.1149  |0.213|
| 4C* |7.3854  |0.222|
| 1C-1|0.0500  |0.215|
| 2C  |0.0334  |0.215|
| 4A* |5.3293  |0.203|
| 2A  |0.0274  |0.237|
| 4B* |2.3936  |0.211|
| 2B-1|0.0268  |0.226|
| pressure stress*   |
|____________________|_______________________________________________________________
| Total long stress  |
| Primary membrane   |
| long stress*       |
|____________________|_______________________________________________________________
| torsion moment Mt  |
| Circ shear from Vc |
| Long shear from VL |                                   -475    -475     475     475
|____________________|_______________________________________________________________
| Total Shear stress |                                   -475    -475     475     475
|____________________|_______________________________________________________________
| Combined stress    |                                    950     950     950     950
|____________________|_______________________________________________________________
```

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA	ENGINEERING CALCULATIONS	NO: V049-1-058 PAGE 1 OF 21

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/22/96	WDB	RDC

TITLE:

SPOOL B-6 (48 in)

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine spool/adapter shell thickness. Additionally when applicable, evaluate nozzle opening(s), calculate size and spacing of stiffener rings and support rings.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.31.

ASSUMPTIONS: None

INPUTS:

1. Vacuum Pressure = 14.7 psi
2. Design Temperature = 400 F.
3. Ion Pump Nozzle Loads

Pr = 2250.0 lbs

Mc = Ml = 4542.0 in-lbs

Vc = Vl = 126.5 lbs

REFERENCES:

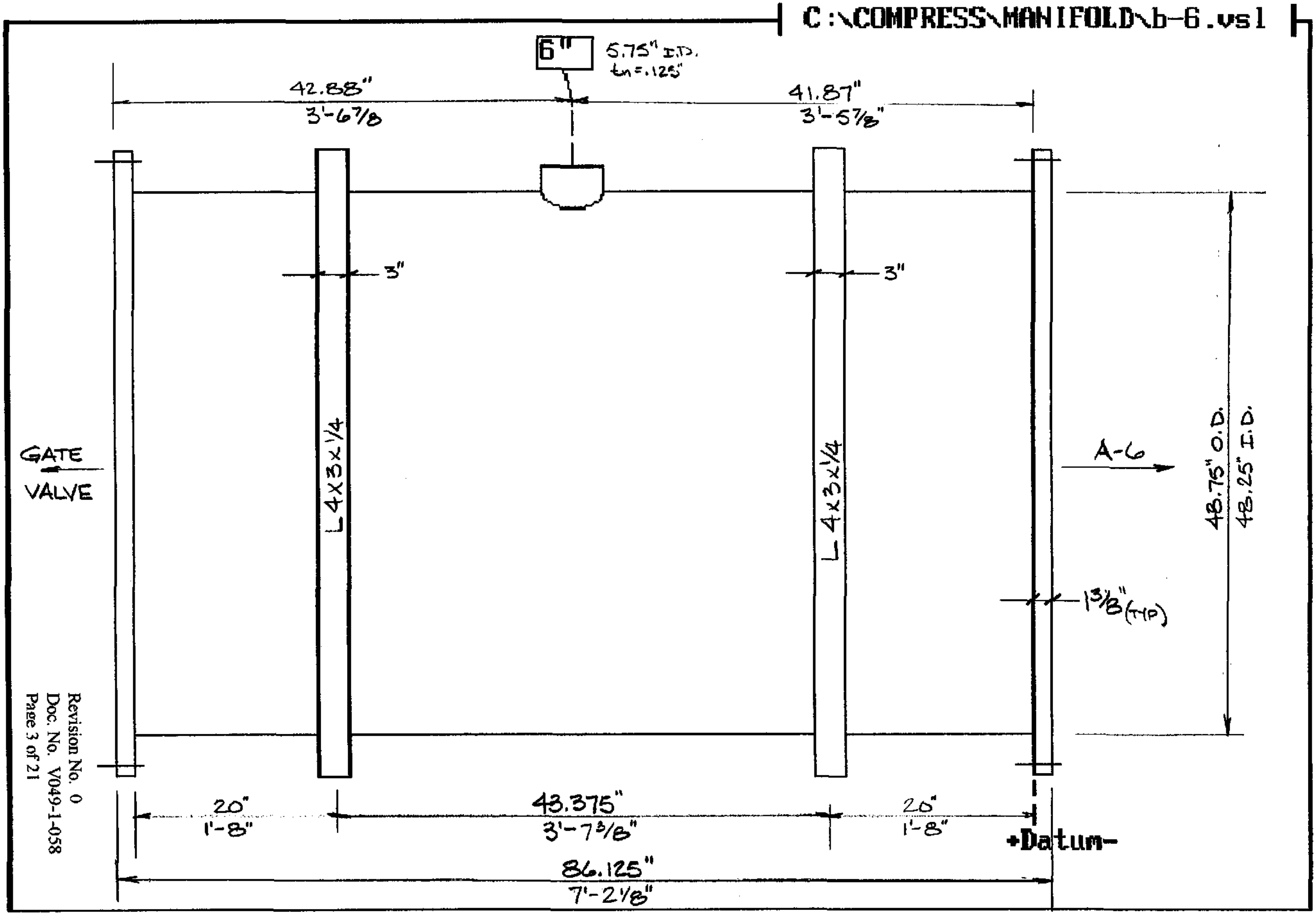
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code are met for spool B-6 outer shell.

NOTES: Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, 019.& 051

TABLE OF CONTENTS


C:\COMPRESS\MANIFOLD\b-6.vsl
6"
5.75" I.D.
tn=.125"
42.88"
3'-6 7/8
41.87"
3'-5 7/8"
3"
3"
L 4x3x1/4
L 4x3x1/4
GATE VALVE
A-6
48.75" O.D.
48.25" I.D.
1 3/8" (TYP)
20"
1'-8"
43.375"
3'-7 3/8"
20"
1'-8"
+Datum-
86.125"
7'-2 1/8"

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
Spool B-6	0.0	0.0	146.1	146.1	34.6	1.000		Not applicable	0.000
6" 6" od CF	0.0	0.0	0.0	0.0	14.7	1.000		Not applicable	0.000
48.25 id Flange	0.0	0.0	24.4	24.4		1.000		Not applicable	0.000
48.25" ID FLANGE	0.0	0.0	24.4	24.4		1.000		Not applicable	0.000
Support Rings					14.7				

Vessel MAWP hot & corroded is 0 psi @ 0 degrees F.

Vessel MAP new & cold is 0 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*1 = 22 psi

Vessel hydrotest pressure is 22 psi.

Weight Summary

```
Component ------------------------  Weight (lbs) Contributed by Vessel Elements  ------------------------------
                     Metal    Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                       New     Corr   & sup    Beds                          & plat  & Misc  Liquid  Liquid   & flg
----------------------------------------------------------------------------------------------------------------
Spool b-6              921      921       0       0       0       0       0       0     155       0    5504       2
48.25 id flange        483      483       0       0       0       0       0       0       0       0       0       0
48.25" id flang        483      483       0       0       0       0       0       0       0       0       0       0
---------------    -------  -------  ------  ------  ------  ------  ------  ------  ------  ------  ------  ------
                      1887     1887       0       0       0       0       0       0     155       0    5504       2


Vessel operating weight, corroded:   2,044 lbs
Vessel empty weight, corroded:       2,044 lbs
Vessel empty weight, new:            2,044 lbs
Vessel test weight, new:             7,548 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	2,044 lbs
Center of gravity to seam:	41.4 in

Nozzle Summary

```
-------------------------------------------------------------------------------------------
Nozzle       OD      tn     Req tn             Nom t    Req t   User t    Corr     Aa/Ar
mark        (in)    (in)     (in)   A1?  A2?   (in)     (in)     (in)     (in)      (%)
-------------------------------------------------------------------------------------------
6"          6.00   0.1250   0.0625   y    y   0.2500   0.1530            0.0000    146.2
-------------------------------------------------------------------------------------------
```

tn - nozzle thickness
Req tn - nozzle thickness required per UG-45/16
Nom t - vessel wall thickness
Req t - required vessel wall thickness due to pressure + corr per UG-37
User t - local vessel wall thickness (near opening)
Aa - area available per UG-37, governing condition
Ar - area required per UG-37, governing condition
Corr - corrosion allowance on nozzle id.

Nozzle Schedule

```
---------------------------------------------------------------------------------------------------------------
Nozzle      Service                Size                                 Materials
mark                                             Nozzle    Impact? Norm?   Pad       Impact? Norm?    Flange
---------------------------------------------------------------------------------------------------------------
6"      od cf                5.75 IDx0.12   SA 240 304L HIGH   n   n
---------------------------------------------------------------------------------------------------------------
```

Thickness Summary

```
------------------------------------------------------------------------------------------------------
Component                  ID      Length    Nom t    Req t   Joint         Governing            Deflect
Identifier                (in)      (in)     (in)     (in)     E     Load     Status    Stress     (in)
------------------------------------------------------------------------------------------------------
Spool b-6                 48.25     83.37    0.2500   0.1529  0.85   external
------------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

Spool B-6

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component:	Cylinder
Material specification:	SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight:	new = 921	corr = 921	lb
capacity:	new = 659.945	corr = 659.945	US ga

ID = 48.25 length Lc= 83.375 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(24.125 + 0.6*0.25) - 0
= 146.1895 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(24.125 + 0.6*0.25) - 0
= 146.1895 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 43.375/48.75 =0.8897 Do/t = 48.75/0.15297 = 318.6899
From table G: A = 0.000268
From table HA-3: B = 3540.3

Pa= 4*B/(3*Do/t)
= 4*3540.3/(3*48.75/0.15297)
= 14.8119 psi

Design thickness for external pressure Pa = 14.8119 psi:

= t + Corrosion
= 0.15297 + 0
= 0.15297 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 43.375/48.75 =0.8897 Do/t = 48.75/0.25 = 195
From table G: A = 0.000559
From table HA-3: B = 5073.4

Spool B-6

Pa= 4*B/(3*Do/t)
= 4*5073.4/(3*48.75/0.25)
= 34.6899 psi

6" od CF

Opening 6" Reinforcement Calculations Per UG-37

Located on:	Spool B-6
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	90 degrees
End of nozzle to shell center:	27.375 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	3 in

```
   tn ->| |<-
         _            _     corrosion allow = 0 in
        | |<- d ->| |       noz thick new tn= .125 in
 twl->| |<|         | |     nozzle id. new d= 5.75 in
      |/| v         | |\    fillet weld twl = .125 in
 ____.-| |_         | |-.____  groove weld tw2 = .1875 in
 _____\|_|_tw2      |_|/_____
            ^
 <--- L --->|               To datum L= 41.87 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3125 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 0*2.875/(16700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 0*24.125/(16700*1 - 0.6*0)
= 0 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 =1
fr2 = lesser of 1 or Sn/Sv so fr2 =1

6" od CF

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.75*0*1 + 2*0.125*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 1.438 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0) - 2*0.125*(1*0.25-1*0)*(1-1)
= 1.438 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0) - 2*0.125*(1*0.25-1*0)*(1-1)
= .188 in^2

A2 = smaller of the following = 0.078 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0)*1*0.25
= .156 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0)*1*0.125
= .078 in^2

A41 = Leg^2*fr2
= 0.125^2*1 = .016 in^2

Area = A1 + A2 + A41
= 1.438 + 0.078 + 0.016
= 1.532 in^2

As Area > A the reinforcement is adequate for MAWP = 0 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.125 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.0875 in
t1(actual) = 0.7*Leg = 0.7*0.125 = 0.0875 in
t2(actual) = 0.1875 in
t1 + t2 = 0.275 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.245 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*6*0.125*8183 = 9635.482 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*5.875*0.125*11690 = 13478.21 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*6*0.1875*12358 = 21827.32 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0 - (5.75 - 2*0.125)*(1*0.25 - 1*0))*16700
=-22962.5 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.078 + 0 + 0.016 + 0)*16700
= 1569.8 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.078 + 0 + 0.016 + 0 + 2*0.125*0.25*1)*16700
= 2613.55 lbf

Load for path 1-1 lesser of W or W1-1 =-22962.5 lbf
Path 1-1 Thru (1) & (3) = 9635.482 + 13478.21 = 23113.69 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 =-22962.5 lbf
Path 2-2 Thru (1), (4) = 9635.482 + 21827.32 = 31462.8 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3125 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

6" od CF

Nozzle required thickness

L/Do = 3/6 = .5 Do/t = 6/0.01491 = 402.4145
From table G: A = 0.000337
From table HA-3: B = 4461.6

Pa= 4*B/(3*Do/t)
= 4*4461.6/(3*6/0.01491)
= 14.7828 psi

Nozzle required thickness trn = .01491 in

Required thickness tr from UG-37(d)(1) = .153 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 =1
fr2 = lesser of 1 or Sn/Sv so fr2 =1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(5.75*0.153*1 + 2*0.125*0.153*1*(1 - 1))
= .4399 in^2

Area available

A1 = larger of the following = .558 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.153) - 2*0.125*(1*0.25-1*0.153)*(1-1)
= .558 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0.153) - 2*0.125*(1*0.25-1*0.153)*(1-1)
= .073 in^2

A2 = smaller of the following = 0.069 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0.01491)*1*0.25
= .138 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0.01491)*1*0.125
= .069 in^2

A41 = Leg^2*fr2
= 0.125^2*1 = .016 in^2

Area = A1 + A2 + A41
= 0.558 + 0.069 + 0.016
= .643 in^2

6" od CF

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0.01491 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0241 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.245 in
The greater of tr2 or tr3: tr5 = 0.0625 in
The lesser of tr4 or tr5: tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for Pe.

6" od CF

Applied Loads

Radial load	Pr = 416 lbf
Circumferential moment	Mc = 75 lbf-ft
Circumferential shear	Vc = 150 lbf
Longitudinal moment	ML = 5 lbf-ft
Longitudinal shear	VL = 10 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 24.25 in
Rm/t = 97

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(2.875/3.125)^2 + 3*(2.875/3.125)^4)
= 2.172

Local circ. pressure stress = I*P*Rm/t = 0 psi

Local long. pressure stress = P*Rm/2t = 0 psi

Maximum combined stress =-6976 psi
Allowable combined stress = +-1.5*S = +- 25050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-1375 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

6" od CF

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	11.046	0.108					-758	-758	-758	-758
4C*	14.634	0.108	-1004	-1004	-1004	-1004				
1C	0.0833	0.108					-3327	3327	-3327	3327
2C-1	0.0505	0.108	-2017	2017	-2017	2017				
3A*	3.8020	0.108					-215	-215	215	215
1A	0.0813	0.108					-2676	2676	2676	-2676
3B*	10.699	0.108	-40	-40	40	40				
1B-1	0.0315	0.108	-69	69	69	-69				
pressure stress*										
Total circ stress			-3130	1042	-2912	984	-6976	5030	-1194	108
Primary membrane circ stress*			-1044	-1044	-964	-964	-973	-973	-543	-543
3C*	11.046	0.108	-758	-758	-758	-758				
4C*	14.634	0.108					-1004	-1004	-1004	-1004
1C-1	0.0815	0.108	-3255	3255	-3255	3255				
2C	0.0516	0.108					-2061	2061	-2061	2061
4A*	6.5595	0.108					-371	-371	371	371
2A	0.0417	0.108					-1373	1373	1373	-1373
4B*	3.7815	0.108	-14	-14	14	14				
2B-1	0.0439	0.108	-96	96	96	-96				
pressure stress*										
Total long stress			-4123	2579	-3903	2415	-4809	2059	-1321	55
Primary membrane long stress*			-772	-772	-744	-744	-1375	-1375	-633	-633
torsion moment Mt										
Circ shear from Vc			64	64	-64	-64				
Long shear from VL							-4	-4	4	4
Total Shear stress			64	64	-64	-64	-4	-4	4	4
Combined stress			-4127	2582	-3907	2418	-6976	5030	-1321	108

Support Rings

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Support Rings
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		20 in
Ring spacing:		43.375 in
Ring description:		4x3x1/4 Un Equal Ang
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.69 in^2
Ring moment of inertia:	Ir =	2.77 in^4

Calculations for ring 20 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.15297 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	48.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	34.69792 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*48.75/(0.15297 + 1.69/34.69792))
= 2665.01

From table HA-3 (ring) A = 2.022839E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (48.75^2*34.69792*(0.15297 + 1.69/34.69792)*2.022839E-04)/10.9
= .3086327 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.840166

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(48.75*0.25)
= 3.840166 in

W = Ls = 34.69792 in

Shell area A1 = W*ts = 0.9600415 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.76 + 0.25/2
= 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.69*2.885/(0.9600415 + 1.69)
= 1.839839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.840166*0.25^3/12 + 0.9600415*1.839839^2
= 3.254748 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 2.77 + 1.69*(1.839839 - 2.885)^2
= 4.616091 in^4

Total available I = I1 + I2 = 7.870839 in^4

The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

Calculations for ring 63.375 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.15297 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	48.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	31.6875 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*48.75/(0.15297 + 1.69/31.6875))
= 2605.235

From table HA-3 (ring) A = 1.977894E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (48.75^2*31.6875*(0.15297 + 1.69/31.6875)*1.977894E-04)/10.9
= .2819162 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.840166

W = 1.1*Sqr(Do*ts)

Support Rings

= 1.1*Sqr(48.75*0.25)
= 3.840166 in

W = Ls = 31.6875 in

Shell area A1 = W*ts = 0.9600415 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.76 + 0.25/2
= 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.69*2.885/(0.9600415 + 1.69)
= 1.839839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 3.840166*0.25^3/12 + 0.9600415*1.839839^2
= 3.254748 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 2.77 + 1.69*(1.839839 - 2.885)^2
= 4.616091 in^4

Total available I = I1 + I2 = 7.870839 in^4

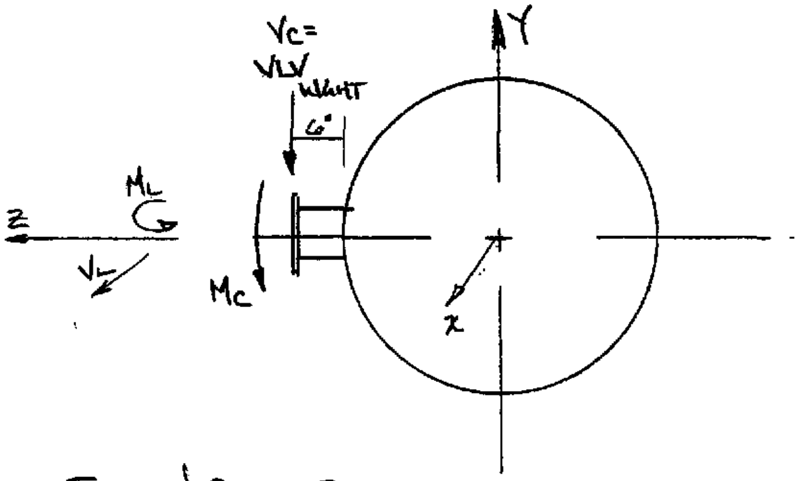
The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

LOADS @ 6"ϕ NOZZLE

- UNBALANCED VACUUM LOAD

$$F = PA$$
$$= (14.7 \text{\#}/\text{in}^2)(\pi(6)^2/4)$$
$$= 416 \text{ lbs.}$$

- Valve Weight < 150 lbs USE: 150 lbs FOR DESIGN
6" NOZZLE EXTENSION



FOR WRC-107

$P_R = 416 \text{ lbs}$

$V_C = 150 \text{ lbs.}$

$M_C = 150 \text{ lbs} (6 \text{ in}) = 900 \text{ in-lbs} = 75 \text{ FT-lbs}$

$V_L = 150 \text{ lbs} (0.05625 g) \cong 10 \text{ lbs}$

$M_L = 150 \text{ lbs} (6 \text{ in})(0.05625 g) \cong 5 \text{ FT-lbs.}$

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-059
PAGE 1 OF 21

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/22/96	WDB	RDC

TITLE:

SPOOL B-7 (48 in)

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine spool/adapter shell thickness. Additionally when applicable, evaluate nozzle opening(s), calculate size and spacing of stiffener rings and support rings.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.31.

ASSUMPTIONS: None

INPUTS:
1. Vacuum Pressure = 14.7 psi
2. Design Temperature = 400 F.
3. Ion Pump Nozzle Loads

Pr = 2250.0 lbs
Mc = Ml = 4542.0 in-lbs
Vc = Vl = 126.5 lbs

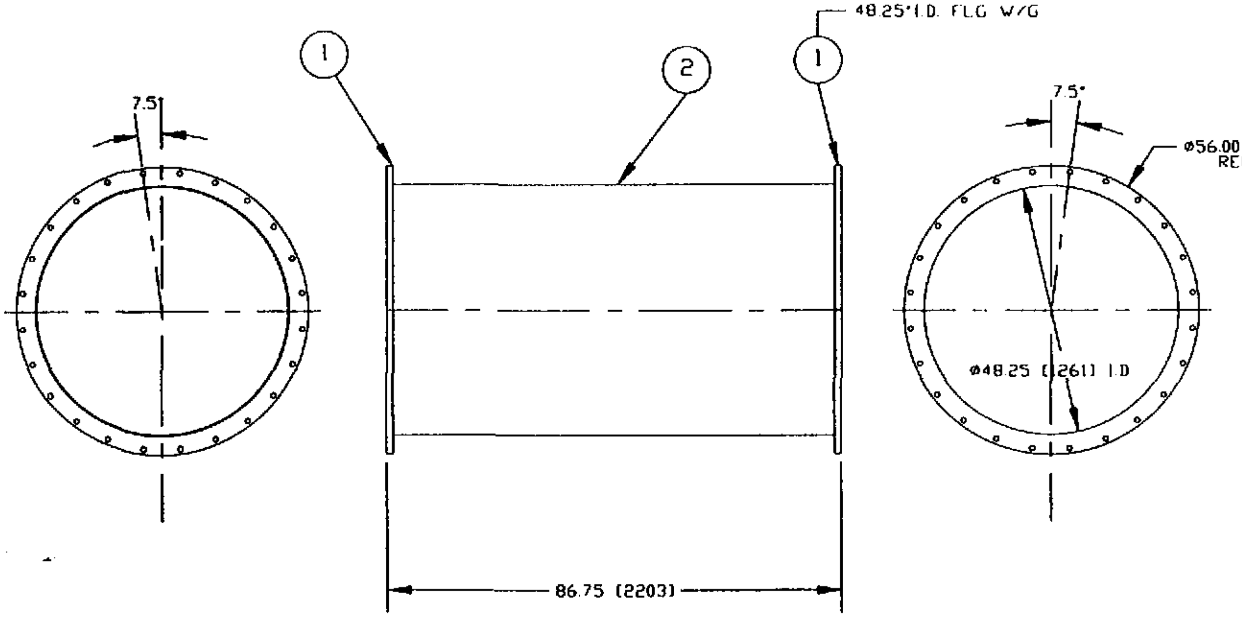
REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code are met for spool B-7 outer shell.

NOTES: Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, 019.& 051

TABLE OF CONTENTS



1 REQ'D

PROPRIETARY AND CONFIDENTIAL

THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION BELONGING TO PROCESS SYSTEMS INTERNATIONAL, INC OR ITS AFFILIATED COMPANIES AND SHALL BE USED ONLY FOR THE PURPOSE FOR WHICH IT WAS SUPPLIED. IT SHALL NOT BE COPIED, REPRODUCED OR OTHERWISE USED, NOR SHALL SUCH INFORMATION BE FURNISHED IN WHOLE OR IN PART TO OTHERS EXCEPT IN ACCORDANCE WITH THE TERMS OF ANY AGREEMENT UNDER WHICH IT WAS SUPPLIED OR WITH THE PRIOR WRITTEN CONSENT OF PROCESS SYSTEMS INTERNATIONAL, INC. AND SHALL BE RETURNED UPON REQUEST.

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR:MACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE RMS
BREAK CORNERS: 1/64 OUT.
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.

USED ON:

NEXT ASS'Y:

X	X					X	X	X	X
REV	DESCRIPTION					CHKD	DRWN	DATE	DCD#

ISSUE DESCRIPTION

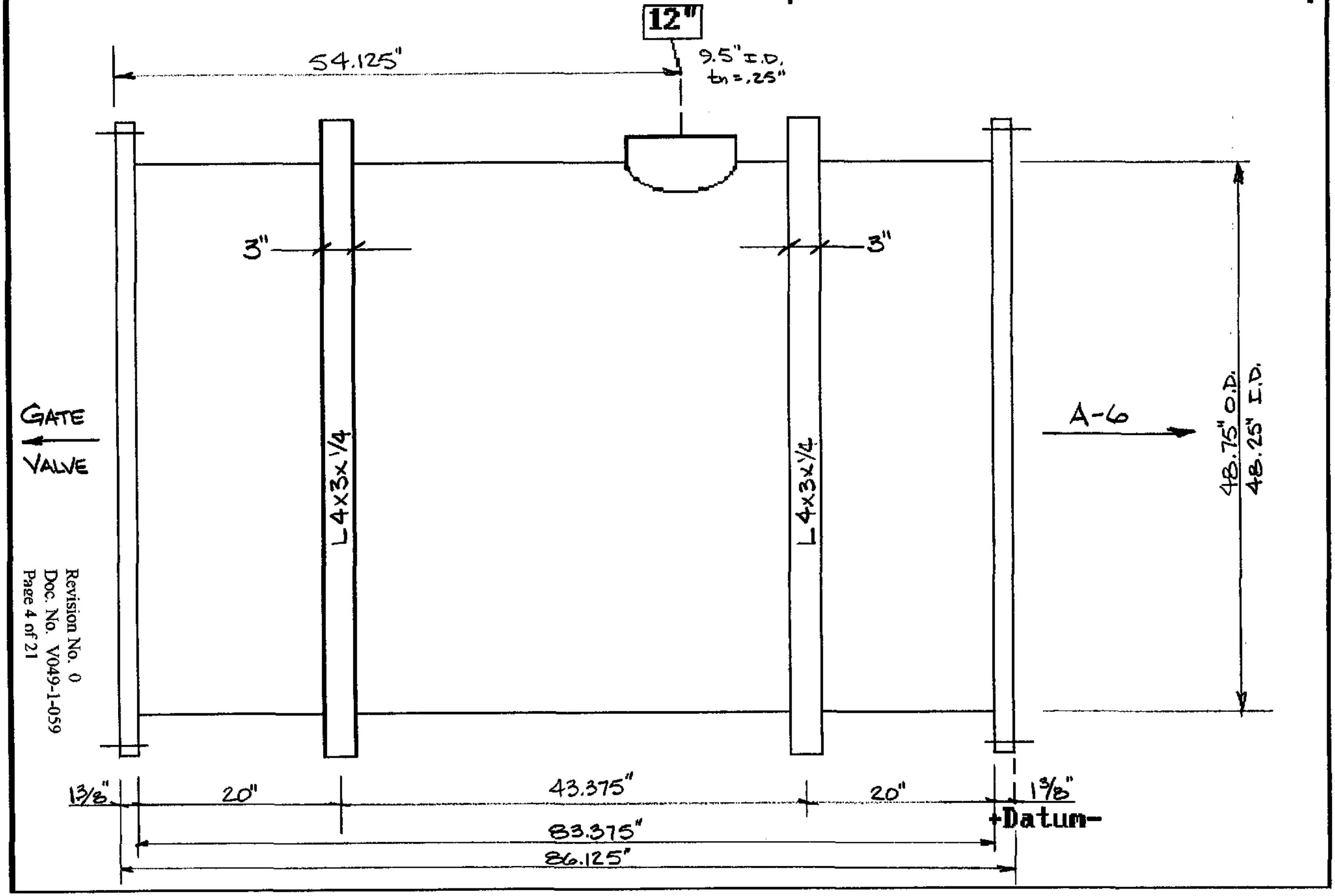
PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

SPOOL B-7
48"
LIGO VACUUM EQUIPMENT

CAD FILE: B7
SIZE: B
DWG NO: V049-4-B7
REV: 0
SCALE: 1/2"=1'-0"
SHEET: 1 OF 1

Jan 17, 1996 - 14:46:38

C:\COMPRESS\MANIFOLD\b-7.vsl



Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
Spool B-7	0.0	0.0	146.1	146.1	34.6	1.000		Not applicable	0.000
48.25" id Flange	0.0	0.0	24.5	24.5		1.000		Not applicable	0.000
48.25" id Flange	0.0	0.0	24.5	24.5		1.000		Not applicable	0.000
12" 12" CF	0.0	0.0	0.0	0.0	14.7	1.000		Not applicable	0.000
Stiffner Ring					14.7				

Vessel MAWP hot & corroded is 0 psi @ 0 degrees F.

Vessel MAP new & cold is 0 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

$= 1.5*Pe*1 = 22$ psi

Vessel hydrotest pressure is 22 psi.

Weight Summary

```
Component ------------------------ Weight (lbs) Contributed by Vessel Elements ----------------------------
                 Metal   Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                  New     Corr   & sup   Beds                           & plat  & Misc  Liquid  Liquid   & flg
-----------------------------------------------------------------------------------------------------------
Spool b-7          921     921      0       0       0       0       0       0     155       0    5504       7
48.25" id flang    472     472      0       0       0       0       0       0       0       0       0       0
48.25" id flang    472     472      0       0       0       0       0       0       0       0       0       0
_______________  _____   _____   _____   _____   _____   _____   _____   _____   _____   _____   _____   _____
                  1865    1865      0       0       0       0       0       0     155       0    5504       7


Vessel operating weight, corroded:   2,027 lbs
Vessel empty weight, corroded:       2,027 lbs
Vessel empty weight, new:            2,027 lbs
Vessel test weight, new:             7,531 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	2,027 lbs
Center of gravity to seam:	41.6 in

Nozzle Summary

```
------------------------------------------------------------------------------------------
Nozzle        OD       tn     Req tn              Nom t    Req t    User t    Corr    Aa/Ar
mark         (in)     (in)     (in)   A1?  A2?    (in)     (in)      (in)     (in)     (%)
------------------------------------------------------------------------------------------
12"         10.00   0.2500   0.0625    y    y    0.2500   0.1530             0.0000   174.7
------------------------------------------------------------------------------------------
```

tn - nozzle thickness
Req tn - nozzle thickness required per UG-45/16
Nom t - vessel wall thickness
Req t - required vessel wall thickness due to pressure + corr per UG-37
User t - local vessel wall thickness (near opening)
Aa - area available per UG-37, governing condition
Ar - area required per UG-37, governing condition
Corr - corrosion allowance on nozzle id.

Nozzle Schedule

```
---------------------------------------------------------------------------------------------------------------
Nozzle      Service                Size                                 Materials
mark                                             Nozzle   Impact? Norm?   Pad      Impact? Norm?    Flange
---------------------------------------------------------------------------------------------------------------

12"     cf                   9.50 IDx0.25    SA 240 304L HIGH  n   n
---------------------------------------------------------------------------------------------------------------
```

Thickness Summary

```
-----------------------------------------------------------------------------------------------------
Component              ID       Length    Nom t     Req t    Joint         Governing             Deflect
Identifier            (in)       (in)     (in)      (in)      E      Load   Status    Stress      (in)
-----------------------------------------------------------------------------------------------------
Spool b-7            48.25      83.37    0.2500    0.1529   0.85   external
-----------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

Spool B-7

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight:	new = 921	corr = 921	lb
capacity:	new = 659.945	corr = 659.945	US ga

ID = 48.25 length Lc= 83.375 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(24.125 + 0.6*0.25) - 0
= 146.1895 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(24.125 + 0.6*0.25) - 0
= 146.1895 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 43.375/48.75 =0.8897 Do/t = 48.75/0.15297 = 318.6899
From table G: A = 0.000268
From table HA-3: B = 3540.3

Pa= 4*B/(3*Do/t)
= 4*3540.3/(3*48.75/0.15297)
= 14.8119 psi

Design thickness for external pressure Pa = 14.8119 psi:

= t + Corrosion
= 0.15297 + 0
= 0.15297 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 43.375/48.75 =0.8897 Do/t = 48.75/0.25 = 195
From table G: A = 0.000559
From table HA-3: B = 5073.4

Spool B-7

Pa= 4*B/(3*Do/t)
= 4*5073.4/(3*48.75/0.25)
= 34.6899 psi

Opening 12" Reinforcement Calculations Per UG-37

Located on:	Spool B-7
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	90 degrees
End of nozzle to shell center:	27.375 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	3 in

```
   tn ->| |<-
          _        _
        | |<- d ->| |        corrosion allow = 0 in
twl->|  |<|       | |        noz thick new tn= .25 in
     |/ | |       | |        nozzle id. new d= 9.5 in
     |/ | |  v    | |\       fillet weld twl = .25 in
_____.-| | __     | |-._____ groove weld tw2 = .175 in
_____\|_|_tw2     |_|/______
           ^
<--- L --->|                 To datum L= 30.625 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 0*4.75/(16700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 0*24.125/(16700*1 - 0.6*0)
= 0 in

Area required

Allowable stresses: Sn = 16700, Sv = 16700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 =1
fr2 = lesser of 1 or Sn/Sv so fr2 =1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.5*0*1 + 2*0.25*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 2.375 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= 2.375 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= .25 in^2

A2 = smaller of the following = 0.313 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0)*1*0.25
= .313 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0)*1*0.25
= .313 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 2.375 + 0.313 + 0.063
= 2.751 in^2

As Area > A the reinforcement is adequate for MAWP = 0 at 0 Deg F

Check the welds - From UW-16(d):

tmin = lesser of 0.75 or tn or t, tmin = 0.25 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.175 in
t1(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in
t2(actual) = 0.175 in
t1 + t2 = 0.35 >= 1.25*tmin

The weld sizes for t1 and t2 are satisfactory.

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.319375 in
The greater of tr2 or tr3: tr5 = 0.0625 in
The lesser of tr4 or tr5: tr6 = 0.0625 in

12" CF

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*16700 = 12358 psi
Nozzle wall in shear = 0.7*16700 = 11690 psi
Inner fillet weld in shear = 0.49*16700 = 8183 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*10*0.25*8183 = 32118.28 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*9.75*0.25*11690 = 44736.17 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*10*0.175*12358 = 33953.61 lbf

Loading on welds per UG-41(b)(1)

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0 - (9.5 - 2*0.25)*(1*0.25 - 1*0))*16700
=-37575 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.313 + 0 + 0.063 + 0)*16700
= 6279.2 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.313 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 8366.7 lbf

Load for path 1-1 lesser of W or W1-1 =-37575 lbf
Path 1-1 Thru (1) & (3) = 32118.28 + 44736.17 = 76854.45 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 =-37575 lbf
Path 2-2 Thru (1), (4) = 32118.28 + 33953.61 = 66071.88 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

12" CF

Nozzle required thickness

L/Do = 3/10 = .3 Do/t = 10/0.02218 = 450.8566
From table G: A = 0.0005
From table HA-3: B = 4974.8

Pa= 4*B/(3*Do/t)
= 4*4974.8/(3*10/0.02218)
= 14.7121 psi

Nozzle required thickness trn = .02218 in

Required thickness tr from UG-37(d)(1) = .153 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, psi

fr1 = lesser of 1 or Sn/Sv so fr1 =1
fr2 = lesser of 1 or Sn/Sv so fr2 =1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(9.5*0.153*1 + 2*0.25*0.153*1*(1 - 1))
= .7268 in^2

Area available

A1 = larger of the following = .922 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.153) - 2*0.25*(1*0.25-1*0.153)*(1-1)
= .922 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.153) - 2*0.25*(1*0.25-1*0.153)*(1-1)
= .097 in^2

A2 = smaller of the following = 0.285 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02218)*1*0.25
= .285 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02218)*1*0.25
= .285 in^2

A41 = Leg^2*fr2
= 0.25^2*1 = .063 in^2

Area = A1 + A2 + A41
= 0.922 + 0.285 + 0.063
= 1.27 in^2

12" CF

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.02218 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0241 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.319375 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.

12" CF

Applied Loads

Radial load	Pr = 1155 lbf
Circumferential moment	Mc = 75 lbf-ft
Circumferential shear	Vc = 150 lbf
Longitudinal moment	ML =5 lbf-ft
Longitudinal shear	VL = 10 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 24.25 in
Rm/t = 97

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(4.75/5.25)^2 + 3*(4.75/5.25)^4)
= 2.117

Local circ. pressure stress = I*P*Rm/t = 0 psi

Local long. pressure stress = P*Rm/2t = 0 psi

Maximum combined stress =-9285 psi
Allowable combined stress = +-1.5*S = +- 25050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-2484 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

12" CF

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	6.0971	0.18					-1162	-1162	-1162	-1162
4C*	11.524	0.18	-2196	-2196	-2196	-2196				
1C	0.0610	0.18					-6764	6764	-6764	6764
2C-1	0.0227	0.18	-2517	2517	-2517	2517				
3A*	3.5774	0.18					-121	-121	121	121
1A	0.0627	0.18					-1238	1238	1238	-1238
3B*	8.1374	0.18	-18	-18	18	18				
1B-1	0.0166	0.18	-22	22	22	-22				
pressure stress*										
Total circ stress			-4753	325	-4673	317	-9285	6719	-6567	4485
Primary membrane circ stress*			-2214	-2214	-2178	-2178	-1283	-1283	-1041	-1041
3C*	6.0971	0.18	-1162	-1162	-1162	-1162				
4C*	11.524	0.18					-2196	-2196	-2196	-2196
1C-1	0.0487	0.18	-5400	5400	-5400	5400				
2C	0.0350	0.18					-3881	3881	-3881	3881
4A*	8.4746	0.18					-288	-288	288	288
2A	0.0283	0.18					-559	559	559	-559
4B*	3.6264	0.18	-8	-8	8	8				
2B-1	0.0221	0.18	-29	29	29	-29				
pressure stress*										
Total long stress			-6599	4259	-6525	4217	-6924	1956	-5230	1414
Primary membrane long stress*			-1170	-1170	-1154	-1154	-2484	-2484	-1908	-1908
torsion moment Mt										
Circ shear from Vc			38	38	-38	-38				
Long shear from VL							-3	-3	3	3
Total Shear stress			38	38	-38	-38	-3	-3	3	3
Combined stress			-6600	4259	-6526	4217	-9285	6719	-6567	4485

Stiffner Ring

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Stiffner Ring
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		20 in
Ring spacing:		43.375 in
Ring description:		4x3x1/4 Un Equal Ang
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.69 in^2
Ring moment of inertia:	Ir =	2.77 in^4

Calculations for ring 20 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.15297 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	48.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	31.6875 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*48.75/(0.15297 + 1.69/31.6875))
= 2605.235

From table HA-3 (ring) A = 1.977894E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (48.75^2*31.6875*(0.15297 + 1.69/31.6875)*1.977894E-04)/10.9
= .2819162 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 3.840166

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(48.75*0.25)
= 3.840166 in

W = Ls = 31.6875 in

Shell area A1 = W*ts = 0.9600415 in^2

Distance to the ring neutral axis

Stiffner Ring

Y2 = Ring NA + ts/2
 = 2.76 + 0.25/2
 = 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 1.69*2.885/(0.9600415 + 1.69)
 = 1.839839 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 3.840166*0.25^3/12 + 0.9600415*1.839839^2
 = 3.254748 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 2.77 + 1.69*(1.839839 - 2.885)^2
 = 4.616091 in^4

Total available I = I1 + I2 = 7.870839 in^4

The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

Calcs for ring 63.375 in from datum identical to ring 20 in from datum.

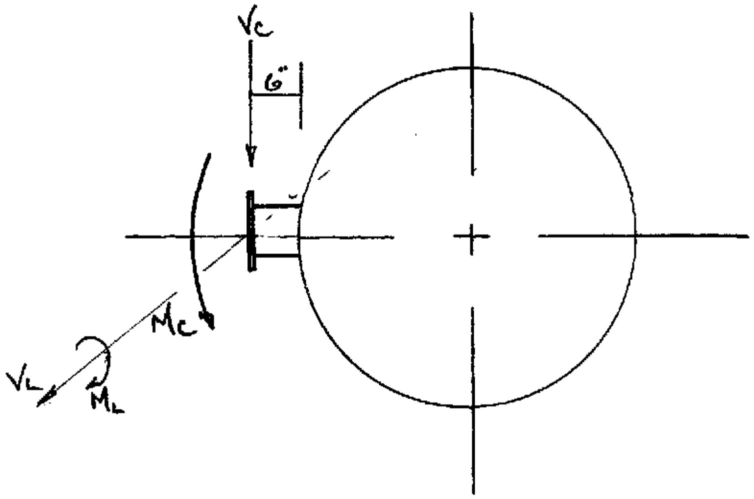
LOADS @ 12" CF (10" O.D. NOZZLE)

P_R = UNBALANCED VACUUM LOAD

= P A

$= (14.7\#/in^2)(\pi (10 in)^2/4)$

= 1155 #



P_R = 1155 lbs

V_C = VLV WEIGHT ≈ 150 lbs

M_C = 150 lbs (6 in) = 900 in-lbs = 75 ~~in~~FT-lbs

V_L = 150 lbs (0.05625) ≅ 10 lbs

M_L = 10 lbs (6 in) = 60 in-lbs = 5 FT-lbs.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-060
PAGE 1 OF 11

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/22/96	WDB	BDL

TITLE:

SPOOL B-8 (72 in)

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine spool/adapter shell thickness. Additionally when applicable, evaluate nozzle opening(s), calculate size and spacing of stiffener rings and support rings.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.31.

ASSUMPTIONS: None

INPUTS:
1. Vacuum Pressure = 14.7 psi
2. Design Temperature = 400 F.

REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

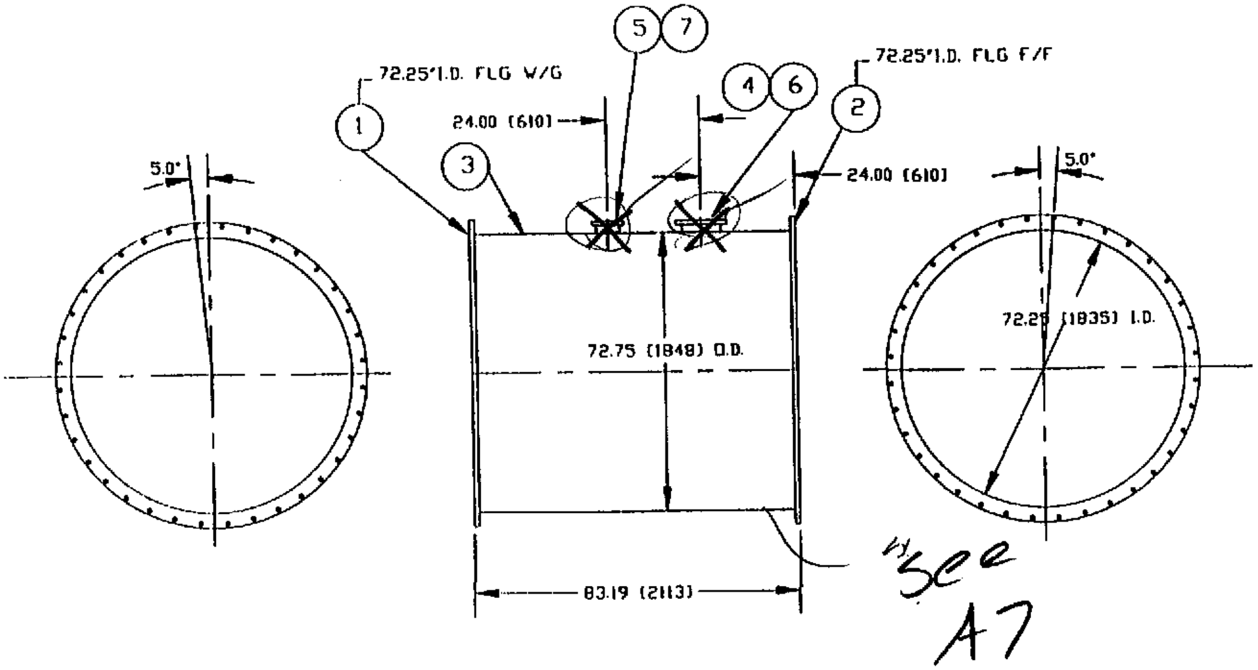
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code are met for spool B-8 outer shell.

NOTES:

Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, 019.& 051

TABLE OF CONTENTS



PROPRIETARY AND CONFIDENTIAL

THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION BELONGING TO PROCESS SYSTEMS INTERNATIONAL, INC. OR ITS AFFILIATED COMPANIES AND SHALL BE USED ONLY FOR THE PURPOSE FOR WHICH IT WAS SUPPLIED. IT SHALL NOT BE COPIED, REPRODUCED OR OTHERWISE USED, NOR SHALL SUCH INFORMATION BE FURNISHED IN WHOLE OR IN PART TO OTHERS EXCEPT IN ACCORDANCE WITH THE TERMS OF ANY AGREEMENT UNDER WHICH IT WAS SUPPLIED OR WITH THE PRIOR WRITTEN CONSENT OF PROCESS SYSTEMS INTERNATIONAL, INC. AND SHALL BE RETURNED UPON REQUEST.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR/MACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE RMS
BREAK CORNERS IN OUT
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.
USED ON
NEXT ASS'Y

REV	DESCRIPTION	CHKD	DRWN	DATE	DCD#
X	X	X	X	X	X

ISSUE DESCRIPTION

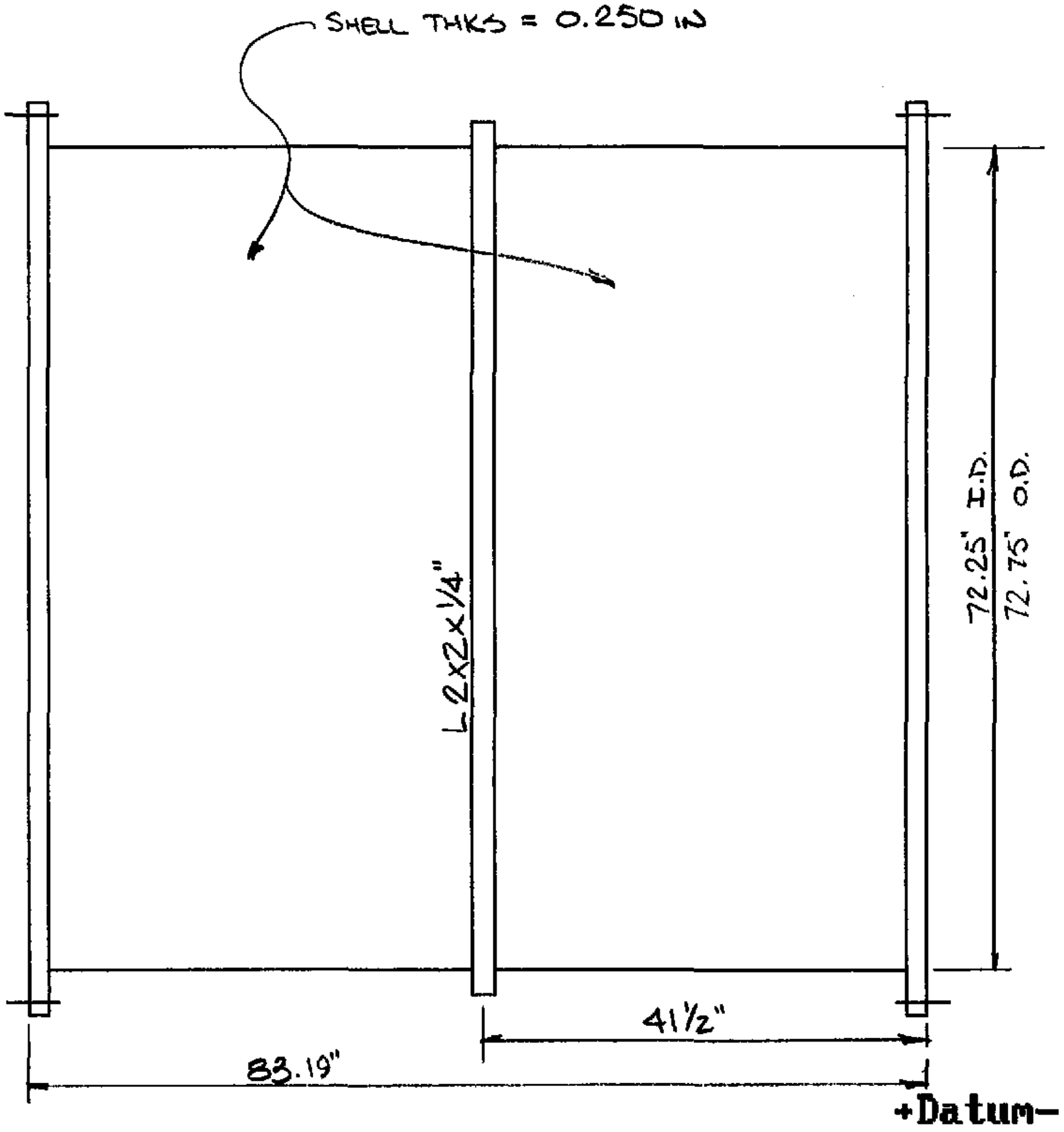
PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

SPOOL B-8
72"
LIGO VACUUM EQUIPMENT

CAD FILE: B8
SIZE: B
DWG. NO. V049-4-B8
REV. 0
SCALE 3/8"=1'-0"
SHEET 1 OF 1

4 3 2 1

C:\COMPRESS\MANIFOLD\b-8.vsl



Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
Spool B-8	0.0	0.0	97.8	97.8	21.9	1.000		Not applicable	0.000
72.25" id Flange	0.0	0.0	27.2	27.2		1.000		Not applicable	0.000
72.25" id Flange	0.0	0.0	28.4	28.4		1.000		Not applicable	0.000
Stiffner Ring					14.7				

Vessel MAWP hot & corroded is 27.27 psi @ 0 degrees F.

Vessel MAP new & cold is 27.27 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1 = 40.9 psi

Vessel hydrotest pressure is 40.9 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

```
Component ------------------------ Weight (lbs) Contributed by Vessel Elements ----------------------------
                 Metal    Metal   Trays  Packed    Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                  New     Corr    & sup   Beds                            & plat  & Misc  Liquid  Liquid   & flg
-------------------------------------------------------------------------------------------------------------
Spool b-8         1374     1374       0       0        0       0       0       0      63       0   12314       0
72.25" id flang    873      873       0       0        0       0       0       0       0       0       0       0
72.25" id flang    873      873       0       0        0       0       0       0       0       0       0       0
_______________  ______  ______  ______  ______   ______  ______  ______  ______  ______  ______  ______  ______
                  3120     3120       0       0        0       0       0       0      63       0   12314       0


Vessel operating weight, corroded:   3,183 lbs
Vessel empty weight, corroded:       3,183 lbs
Vessel empty weight, new:            3,183 lbs
Vessel test weight, new:             15,497 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new: 3,183 lbs
Center of gravity to seam: 41.1 in

Thickness Summary

```
-----------------------------------------------------------------------------------------------------
Component            ID       Length    Nom t     Req t    Joint           Governing              Deflect
Identifier          (in)       (in)      (in)      (in)      E      Load     Status     Stress    (in)
-----------------------------------------------------------------------------------------------------
Spool b-8           72.25     83.19     0.2500    0.2024   0.85    external
-----------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

Spool B-8

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 1373.7 corr = 1373.7 lb
capacity: new = 1476.469 corr = 1476.469 US ga

ID = 72.25 length Lc= 83.19 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(36.125 + 0.6*0.25) - 0
= 97.82909 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(36.125 + 0.6*0.25) - 0
= 97.82909 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 49.52083/72.75 =0.6807 Do/t = 72.75/0.20247 = 359.3125
From table G: A = 0.0003
From table HA-3: B = 3967.4

Pa= 4*B/(3*Do/t)
= 4*3967.4/(3*72.75/0.20247)
= 14.7222 psi

Design thickness for external pressure Pa = 14.7222 psi:

= t + Corrosion
= 0.20247 + 0
= 0.20247 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 49.52083/72.75 =0.6807 Do/t = 72.75/0.25 = 291
From table G: A = 0.000401
From table HA-3: B = 4785.4

Pa= 4*B/(3*Do/t)
= 4*4785.4/(3*72.75/0.25)
= 21.9262 psi

Stiffner Ring

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Stiffner Ring
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		1
Distance first ring to datum line:		41.5 in
Ring description:		2x2x1/4 Equal Angle
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	0.938 in^2
Ring moment of inertia:	Ir =	0.348 in^4

Calculations for ring 41.5 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.20247 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	45.60542 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.20247 + 0.938/45.60542))
= 3596.112

From table HA-3 (ring) A = 2.721819E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*45.60542*(0.20247 + 0.938/45.60542)*2.721819E-04)/10.9
= 1.344292 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 45.60542 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2

Stiffner Ring

= 1.408 + 0.25/2
= 1.533 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 0.938*1.533/(1.172787 + 0.938)
= .6812406 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.6812406^2
= .5503857 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.348 + 0.938*(0.6812406 - 1.533)^2
= 1.028513 in^4

Total available I = I1 + I2 = 1.578899 in^4

The 2x2x1/4 Equal Angle vacuum stiffener is satisfactory.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-061 PAGE 1 OF 25
REV.	DEO #	DATE	BY:	CHECK	TITLE:	
0	0136	4/22/96	WDB	RPC	**SPOOL B-9 (72 in)**	
					BY: W. Bilynsky	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine spool/adapter shell thickness. Additionally when applicable, evaluate nozzle opening(s), calculate size and spacing of stiffener rings and support rings.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.31.

ASSUMPTIONS: None

INPUTS:
1. Vacuum Pressure = 14.7 psi
2. Design Temperature = 400 F.

REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

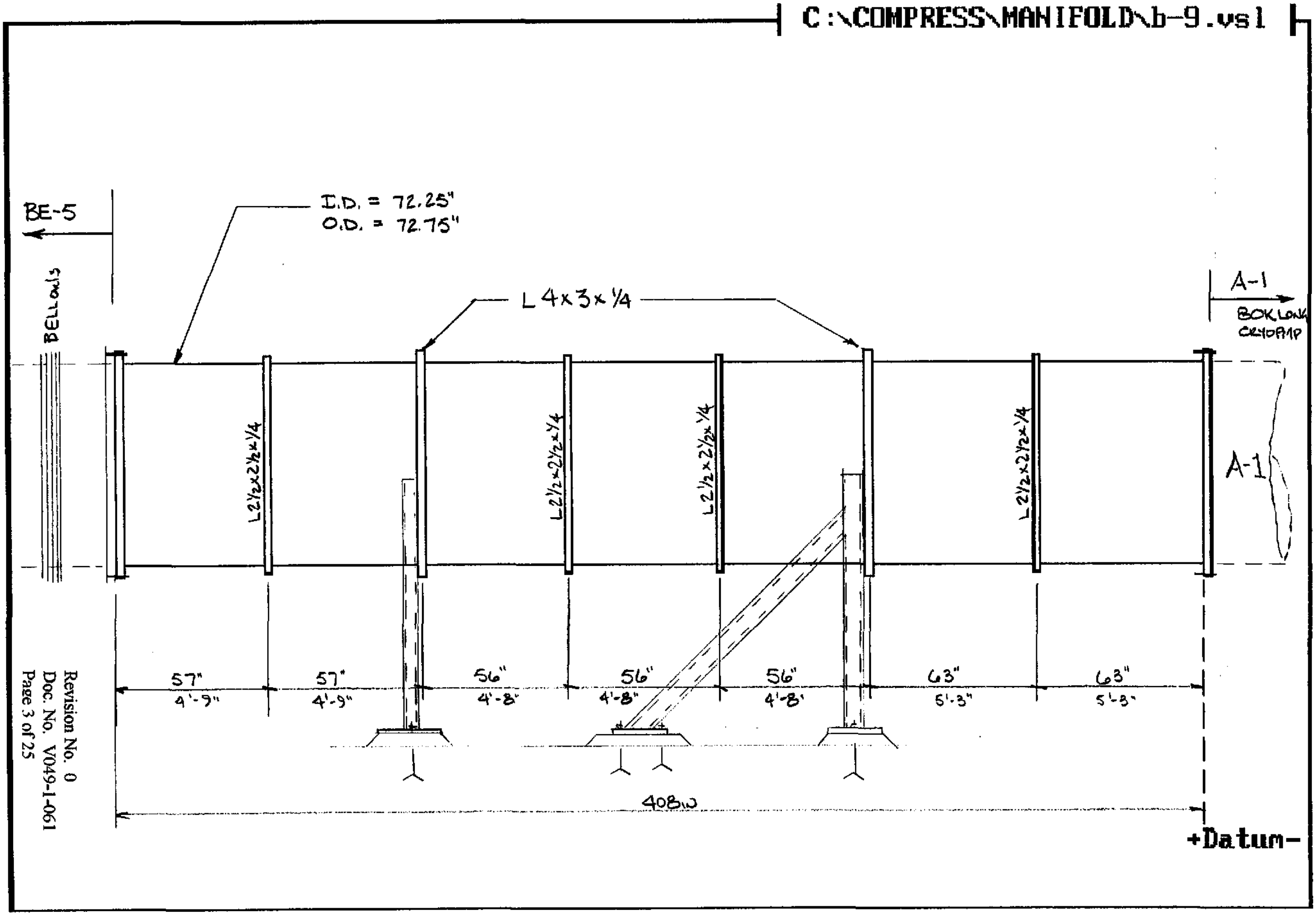
CONCLUSIONS: The requirements of the ASME Code are met for spool B-9 outer shell.

NOTES:

Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, 019.& 051

TABLE OF CONTENTS

Spool B-9 (72 in dia)


C:\COMPRESS\MANIFOLD\b-9.vsl
BE-5
BELLOWS
I.D. = 72.25"
O.D. = 72.75"
L 4x3x1/4
A-1
BOK LONK
CRYOAMP
L2½x2½x¼
L2½x2½x¼
L2½x2½x¼
L2½x2½x¼
A-1
57"
4'-9"
57"
4'-9"
56"
4'-8"
56"
4'-8"
56"
4'-8"
63"
5'-3"
63"
5'-3"
408in
+Datum-

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
Spool B-9	0.0	0.0	97.8	97.8	16.6	1.000		Not applicable	0.000
Stiffner Rings					14.7				
Support Rings					14.7				
REDUCING FLG	0.0	0.0	1.9	1.9		0.880		Not applicable	0.000
ADAPTER FLG	0.0	0.0	1.9	1.9		0.880		Not applicable	0.000
Stiffener Rings (B)					14.7				

Vessel MAWP hot & corroded is 1.95 psi @ 0 degrees F.

Vessel MAP new & cold is 1.95 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*0.88 = 19.4 psi

Vessel hydrotest pressure is 19.4 psi.

Weight Summary

```
Component ------------------------ Weight (lbs) Contributed by Vessel Elements ----------------------------
                Metal    Metal    Trays   Packed    Insul   Lining   Piping   Ladder    Rings     Oper     Test   Nozzle
                  New     Corr    & sup     Beds                             & plat   & Misc   Liquid   Liquid    & flg
-------------------------------------------------------------------------------------------------------------------------

Spool b-9        6737     6737        0        0        0        0        0        0      550        0    60394        0
Reducing flg      840      840        0        0        0        0        0        0        0        0        0        0
Adapter flg       840      840        0        0        0        0        0        0        0        0        0        0
______________  ______  _______  _______  _______  _______  _______  _______  _______  _______  _______  _______  _______

                 8417     8417        0        0        0        0        0        0      550        0    60394        0


Vessel operating weight, corroded:    8,967 lbs
Vessel empty weight, corroded:        8,967 lbs
Vessel empty weight, new:             8,967 lbs
Vessel test weight, new:             69,361 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	8,968 lbs
Center of gravity to seam:	204.2 in

Thickness Summary

```
------------------------------------------------------------------------------------------------
Component           ID      Length    Nom t    Req t   Joint         Governing             Deflect
Identifier         (in)      (in)     (in)     (in)      E     Load    Status     Stress     (in)
------------------------------------------------------------------------------------------------
Spool b-9         72.25    408.00   0.2500   0.2386   0.85   external
------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

Spool B-9

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component:	Cylinder
Material specification:	SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight:	new = 6737.3	corr = 6737.3	lb
capacity:	new = 7241.248	corr = 7241.248	US ga

ID = 72.25 length Lc= 408 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(36.125 + 0.6*0.25) - 0
= 97.82909 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(36.125 + 0.6*0.25) - 0
= 97.82909 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 71.02084/72.75 =0.9762 Do/t = 72.75/0.23867 = 304.8142
From table G: A = 0.000256
From table HA-3: B = 3380.3

Pa= 4*B/(3*Do/t)
= 4*3380.3/(3*72.75/0.23867)
= 14.7863 psi

Design thickness for external pressure Pa = 14.7863 psi:

= t + Corrosion
= 0.23867 + 0
= 0.23867 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 71.02084/72.75 =0.9762 Do/t = 72.75/0.25 = 291
From table G: A = 0.000275
From table HA-3: B = 3633.7

Pa= 4*B/(3*Do/t)
 = 4*3633.7/(3*72.75/0.25)
 = 16.6493 psi

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Stiffner Rings
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		63 in
Ring spacing:		119 in
Ring description:		2.5x2.5x1/4 Equal A
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.19 in^2
Ring moment of inertia:	Ir =	0.703 in^4

Calculations for ring 63 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.23867 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	67.01041 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.23867 + 1.19/67.01041))
= 3127.846

From table HA-3 (ring) A = 2.370539E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*67.01041*(0.23867 + 1.19/67.01041)*2.370539E-04)/10.9
= 1.977858 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 67.01041 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Stiffner Rings

Y2 = Ring NA + ts/2
 = 1.783 + 0.25/2
 = 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 1.19*1.908/(1.172787 + 1.19)
 = .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 4.691149*0.25^3/12 + 1.172787*0.9609499^2
 = 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 0.703 + 1.19*(0.9609499 - 1.908)^2
 = 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 182 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.23867 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 72.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 56 in

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*72.75/(0.23867 + 1.19/56))
 = 3085.829

From table HA-3 (ring) A = 2.338996E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
 = (72.75^2*56*(0.23867 + 1.19/56)*2.338996E-04)/10.9
 = 1.653091 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)

Stiffner Rings

= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 56 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Support Rings

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Support Rings
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		126 in
Ring spacing:		168 in
Ring description:		4x3x1/4 Un Equal Ang
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.69 in^2
Ring moment of inertia:	Ir =	2.77 in^4

Calculations for ring 126 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.23867 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	59.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.23867 + 1.69/59.5))
= 3003.177

From table HA-3 (ring) A = 2.276935E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*59.5*(0.23867 + 1.69/59.5)*2.276935E-04)/10.9
= 1.756862 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 59.5 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Support Rings

Y2 = Ring NA + ts/2
= 2.76 + 0.25/2
= 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.69*2.885/(1.172787 + 1.69)
= 1.703113 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*1.703113^2
= 3.407887 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 2.77 + 1.69*(1.703113 - 2.885)^2
= 5.130688 in^4

Total available I = I1 + I2 = 8.538576 in^4

The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

Calculations for ring 294 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.23867 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	56.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.23867 + 1.69/56.5))
= 2986.314

From table HA-3 (ring) A = 2.26427E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*56.5*(0.23867 + 1.69/56.5)*2.26427E-04)/10.9
= 1.66837 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)

Support Rings

= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 56.5 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.76 + 0.25/2
= 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.69*2.885/(1.172787 + 1.69)
= 1.703113 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*1.703113^2
= 3.407887 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 2.77 + 1.69*(1.703113 - 2.885)^2
= 5.130688 in^4

Total available I = I1 + I2 = 8.538576 in^4

The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

Stiffener Rings (B)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Stiffener Rings (B)
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		2
Distance first ring to datum line:		238 in
Ring spacing:		113 in
Ring description:		2.5x2.5x1/4 Equal A
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.19 in^2
Ring moment of inertia:	Ir =	0.703 in^4

Calculations for ring 238 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.23867 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	56 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.23867 + 1.19/56))
= 3085.829

From table HA-3 (ring) A = 2.338996E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*56*(0.23867 + 1.19/56)*2.338996E-04)/10.9
= 1.653091 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 56 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Stiffener Rings (B)

Y2 = Ring NA + ts/2
 = 1.783 + 0.25/2
 = 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 1.19*1.908/(1.172787 + 1.19)
 = .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 4.691149*0.25^3/12 + 1.172787*0.9609499^2
 = 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 0.703 + 1.19*(0.9609499 - 1.908)^2
 = 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 351 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.23867 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 72.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 57 in

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*72.75/(0.23867 + 1.19/57))
 = 3090.261

From table HA-3 (ring) A = 2.342323E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
 = (72.75^2*57*(0.23867 + 1.19/57)*2.342323E-04)/10.9
 = 1.682587 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)

Stiffener Rings (B)

= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 57 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

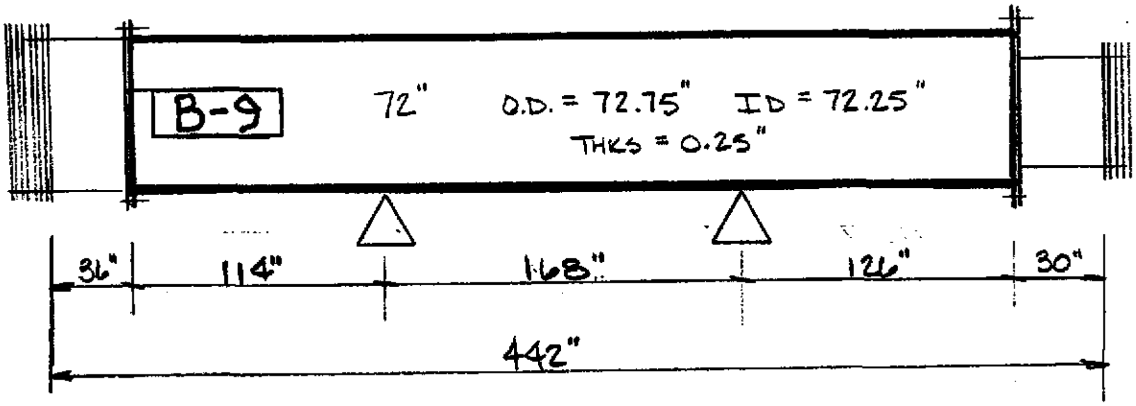
I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

CHECK LONGITUDINAL STRESSES IN VACUUM SHELL

BEAM MANIFOLD B-9 WILL BE USED AS THE BASELINE
FOR 72" BEAM TUBE MANIFOLDS. SUPPORT SPACING
IS 168"



MATERIAL - TYPE 304L

$E = 28.3 \times 10^6$ PSI @ 70°F
$E = 26.5 \times 10^6$ PSI @ 400°F

PROPERTIES OF BEAM TUBE MANIFOLD.

$$A = \frac{\pi}{4}\left(D_o^2 - d_i^2\right) = 0.7854\left[(72.75\,\text{in})^2 - (72.25\,\text{in})^2\right]$$

$$A = 56.94\ \text{in}^2$$

$$I = \frac{\pi}{64}\left(D_o^4 - d_i^4\right) = 0.049\left[(72.75\,\text{in})^4 - (72.25\,\text{in})^4\right]$$

$$I = 37412.7\ \text{in}^4$$

$$S = \frac{\pi}{32}\left(D_o^4 - d_i^4\right) / D_o$$

$$= 0.098\left[(72.75\,\text{in})^4 - (72.25\,\text{in})^4 / 72.75\right]$$

$$= 1028.5\ \text{in}^3$$

REFERENCE: ASME CODE UG-23
SECTION VIII, DIVISION 1

$$A = \frac{0.125}{\left(R_o/_t\right)} = \left(\frac{0.125}{36.375''/.25''}\right)$$

$$A = 0.000859$$

GO TO FIG HA-3
CHART FOR AUSTENTIC STEEL, TYPE 304L

FOR $A = .000859$ @ 400°F
$\sigma_{all} \cong 5400$ PSI

AXIAL BENDING & VACUUM STRESS

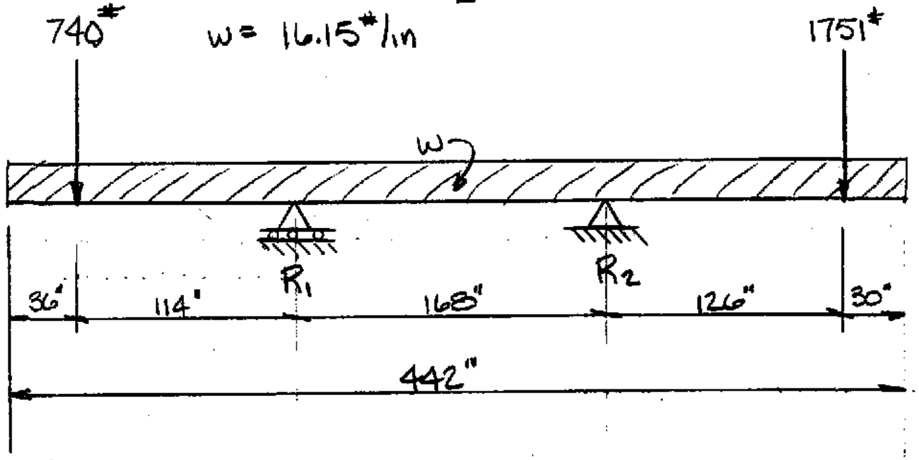
$$f_a = \frac{PR_o}{2t} + \frac{Mc}{I}$$

$$= \frac{(14.7\ \#/_{IN^2})(36.375_{IN})}{2\,(.250_{IN})} + \frac{Mc}{I}$$

$$\frac{Mc}{I} = \frac{M}{S}$$

DETERMINE M_{MAX}

$$w = \left(490\,\#/\mathrm{FT}^3\right)\left[\frac{(\pi)\left((72.75\,\mathrm{IN})^2 - (72.25\,\mathrm{IN})^2\right)}{4}\right]\left(1\,\mathrm{FT}^3/1728\,\mathrm{in}^3\right)$$



CONSERVATIVELY ASSUME TWO PINNED SUPPORTS

from overhang @ $M_{R2} = (1751\#)(126\,\mathrm{IN}) + \frac{(16.15\,\#/\mathrm{in})(156\,\mathrm{IN})^2}{2} = 417139.2$ IN-lbs

from overhang @ $M_{R1} = (740\#)(114\,\mathrm{IN}) + \frac{(16.15\,\#/\mathrm{IN})(150\,\mathrm{IN})^2}{2} = 266047.5$ IN-lbs

Between Supports $M = \frac{wL^2}{8} = \frac{(16.15\,\#/\mathrm{IN})(168\,\mathrm{IN})^2}{8} = 56977.2$ IN-lbs

$M_{MAX} = 417139.2$ IN-lbs.

$$f_a = \frac{(14.7\ \#/in^2)(36.375\ in)}{2\ (.250\ in)} + \frac{417139.2\ in\text{-}lb}{1028.5\ in^3}$$

$$= 1069.4\ \#/in^2 + 405.6\ \#/in^2$$

$$f_a = 1475\ \#/IN^2$$

$$F_{allow} = 5400\ lb/in^2$$

$\therefore$ O.K

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division (see UCS-66). The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below].

(c) Design temperatures listed in excess of the maximum temperatures listed in the tables referenced in UG-23 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials which satisfy all of the following.

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a), shall not exceed that given in (a) or (b) below:

(a) $^1/_2$ in. for materials listed in Curve A of Fig. UCS-66;

(b) 1 in. for materials listed in Curve B, C, or D of Fig. UCS-66.

(2) The completed vessel shall be hydrostatically tested per UG-99(b), (c), or (k).

(3) Design temperature is no warmer than 650°F nor colder than −20°F. Occasional operating temperatures colder than −20°F are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[8]

Vessels covered by this Division of Section VIII shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition and for test conditions, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered [see UG-98, UG-99(e), and 3-2].

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions (this includes additional pressure due to static head of liquids);

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion.

UG-23 MAXIMUM ALLOWABLE STRESS VALUES[9]

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Subpart 1 of Section II, Part D. A listing of these materials are given in the following tables, which are included in Subsection C.

---

[8] It is recommended that a suitable margin be provided above the pressure at which the vessel will be normally operated to allow for probable pressure surges in the vessel up to the setting of the pressure relieving devices (see UG-134).

[9] For the basis on which the tabulated stress values have been established, see Appendix 1 of Section II, Part D.

Table UCS-23 Carbon and Low Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other carbon steels)

Table UNF-23 Nonferrous Metals (stress values in Section II, part D, Table 3 for bolting, and Table 1B for other nonferrous metals)

Table UHA-23 High Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other high alloy steels)

Table UCI-23 Maximum Allowable Stress Values in Tension for Cast Iron

Table UCD-23 Maximum Allowable Stress Values in Tension for Cast Ductile Iron

Table UHT-23 Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Table 1A)

Table ULT-23 Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor *B* determined by the following procedure where

t = the minimum required thickness of the cylindrical shell or tube, in.

R_o = outside radius of cylindrical shell or tube, in.

E = modulus of elasticity of material at design temperature, psi. The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3.[10] (Interpolation may be made between lines for intermediate temperatures.)

The joint efficiency for butt-welded joints shall be taken as unity.

The value of *B* shall be determined as follows.

Step 1. Using the selected values of t and R, calculate the value of factor *A* using the following formula:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of *A* calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value at *A* falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of *A* falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor *B*. This is the maximum allowable compressive stress for the values of t and R_o used in Step 1.

Step 4. For values of *A* falling to the left of the applicable material/temperature line, the value of *B*, psi, shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

Step 5. Compare the value of *B* determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. If the value of *B* is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of *B* is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

The joint efficiency for butt welded joints may be taken as unity.

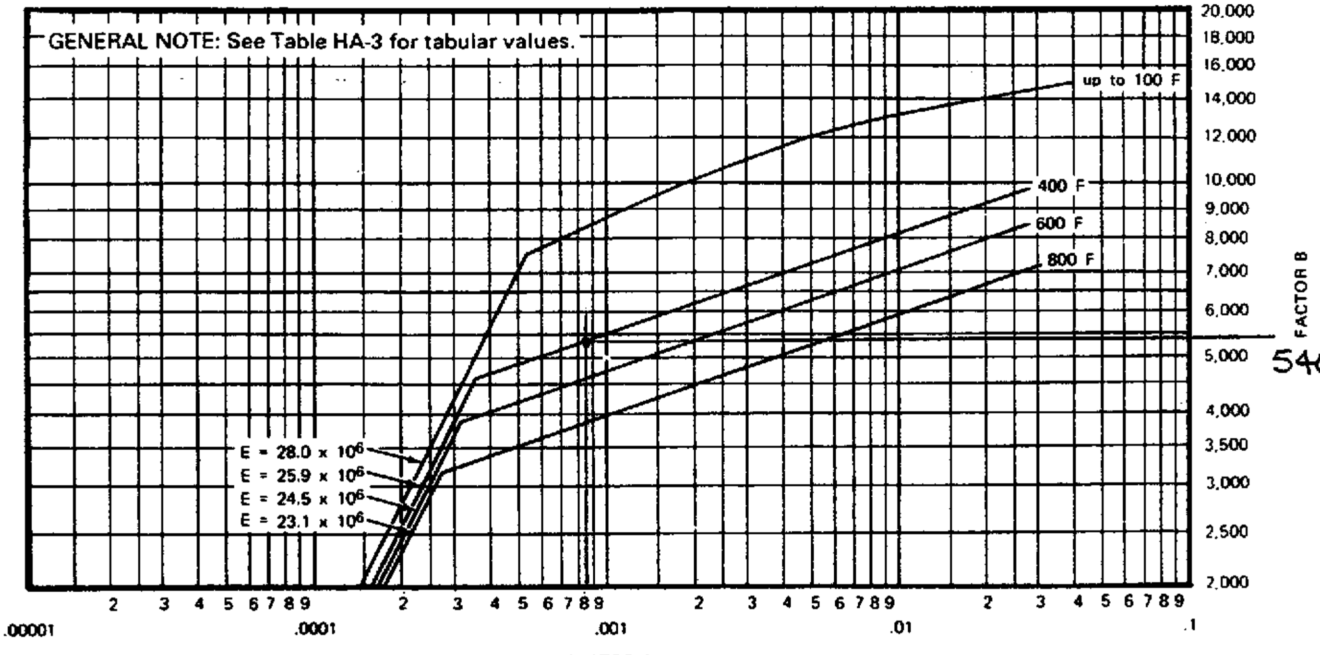
(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combi-

TABLE UG-23.1
MAXIMUM METAL TEMPERATURE FOR WHICH FACTOR OF 1.2 IS APPLICABLE

Table in Which Material Is Listed	Temp., °F
UCS-23	700
UNF-23.1	300
UNF-23.2	150
UNF-23.3	900
UNF-23.4	600
UNF-23.5	600
UHA-23	800
UHT-23	700

---

[10] Note that the modulus of elasticity values listed in UF-27 of this Division shall not be used for axial compression design.



5400psi

A= 0.00086

FIG. HA-3 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–0.035 MAXIMUM CARBON, TYPE 304L) [NOTE (1)]

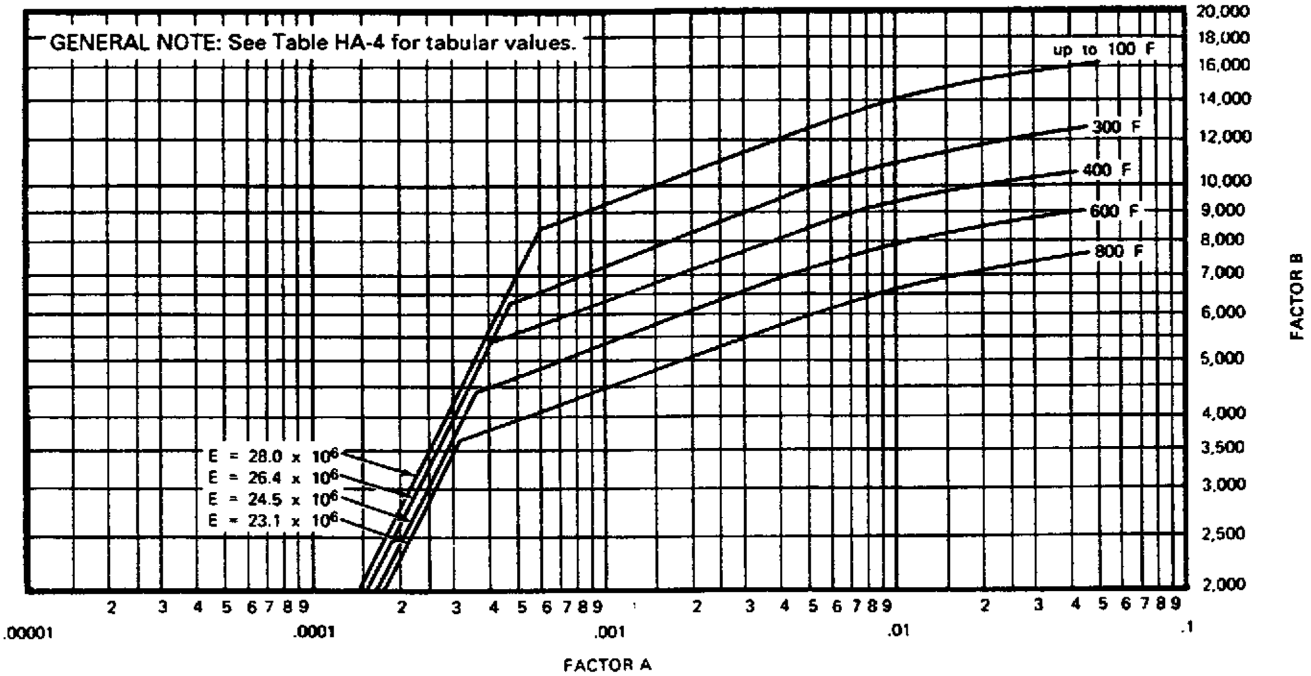


FIG. HA-4 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–Mo–0.035 MAXIMUM CARBON, TYPES 316L AND 317L) [NOTE (1)]

TABLE HA-3
TABULAR VALUES FOR FIG. HA-3

Temp., °F	A	B, psi	Temp., °F	A	B, psi
100	0.100 −04	0.139 +03	600	0.100 −04	0.121 +03
	0.524 −03	0.767 +04		0.313 −03	0.393 +04
	0.200 −02	0.103 +05		0.100 −02	0.484
	0.600	0.125		0.100 −01	0.722
	0.100 −01	0.144		0.100 +00	0.855
	0.100 +00	0.153			
400	0.100 −04	0.128 +03	800	0.100 −04	0.114 +03
	0.352 −03	0.468 +04		0.270 −03	0.322 +04
	0.100 −02	0.562		0.150 −02	0.435
	0.100 −01	0.834		0.100 −01	0.606
	0.100 +00	0.987		0.100 +00	0.736

0.859 -03 →

TABLE HA-4
TABULAR VALUES FOR FIG. HA-4

Temp., °F	A	B, psi	Temp., °F	A	B, psi
100	0.100 −04	0.140 +03	400	0.100 −04	0.133 +03
	0.587 −03	0.857 +04		0.402 −03	0.547 +04
	0.700 −02	0.135 +05		0.700 −02	0.916
	0.100 −01	0.143		0.100 −01	0.958
	0.200	0.155		0.400	0.108 +05
	0.500	0.166		0.100 +00	0.108
	0.100 +00	0.166			
			600	0.100 −04	0.122 +03
300	0.100 −04	0.133 +03		0.355 −03	0.448 +04
	0.466 −03	0.638 +04		0.500 −02	0.738
	0.500 −02	0.102 +05		0.100 −01	0.812
	0.600	0.104		0.500	0.936
	0.100 −01	0.112		0.100 +00	0.936
	0.500	0.129			
	0.100 +00	0.129	800	0.100 −04	0.116 +03
				0.316 −03	0.373 +04
				0.500 −02	0.610
				0.100 −01	0.675
				0.500	0.788
				0.100 +00	0.788

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-050
PAGE 1 OF 9

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/23/96	WDB	RDC

TITLE:

SPOOL BE-2 (60 in)

BY: W. Bilynsky
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Evaluate outer shell of spool piece BE-2 for required thickness per ASME Code, Section VIII, Division I.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.31. Treat bellows sectioned cylinder as continuous.

ASSUMPTIONS:

INPUTS:
1. Vacuum pressure = 14.7 psi
2. Design Temperature = 400 F.

REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:

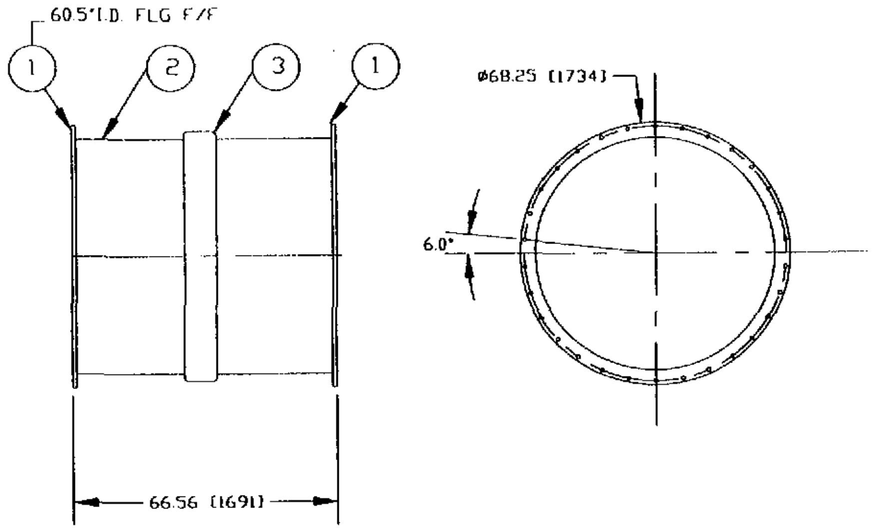
(See Attached)

CONCLUSIONS:

The requirements of the ASME Code are met for spool BE-2 outer shell.

NOTES: Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, & 019.

TABLE OF CONTENTS



4 REQ'D

ID CONFIDENTIAL

THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION BELONGING TO PROCESS SYSTEMS INTERNATIONAL, INC. OR ITS AFFILIATED COMPANIES AND SHALL BE USED ONLY FOR THE PURPOSE FOR WHICH IT WAS SUPPLIED. IT SHALL NOT BE COPIED, REPRODUCED OR OTHERWISE USED, NOR SHALL SUCH INFORMATION BE FURNISHED IN WHOLE OR IN PART TO OTHERS EXCEPT IN ACCORDANCE WITH THE TERMS OF ANY AGREEMENT UNDER WHICH IT WAS SUPPLIED OR WITH THE PRIOR WRITTEN CONSENT OF PROCESS SYSTEMS INTERNATIONAL, INC. AND SHALL BE RETURNED UPON REQUEST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR:MACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE RMS
BREAK CORNERS: IN: OUT:
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.
USED ON
NEXT ASS'Y:

REV	DESCRIPTION	CHKD	DRVN	DATE	DECN
X	X	X	X	X	X

ISSUE DESCRIPTION

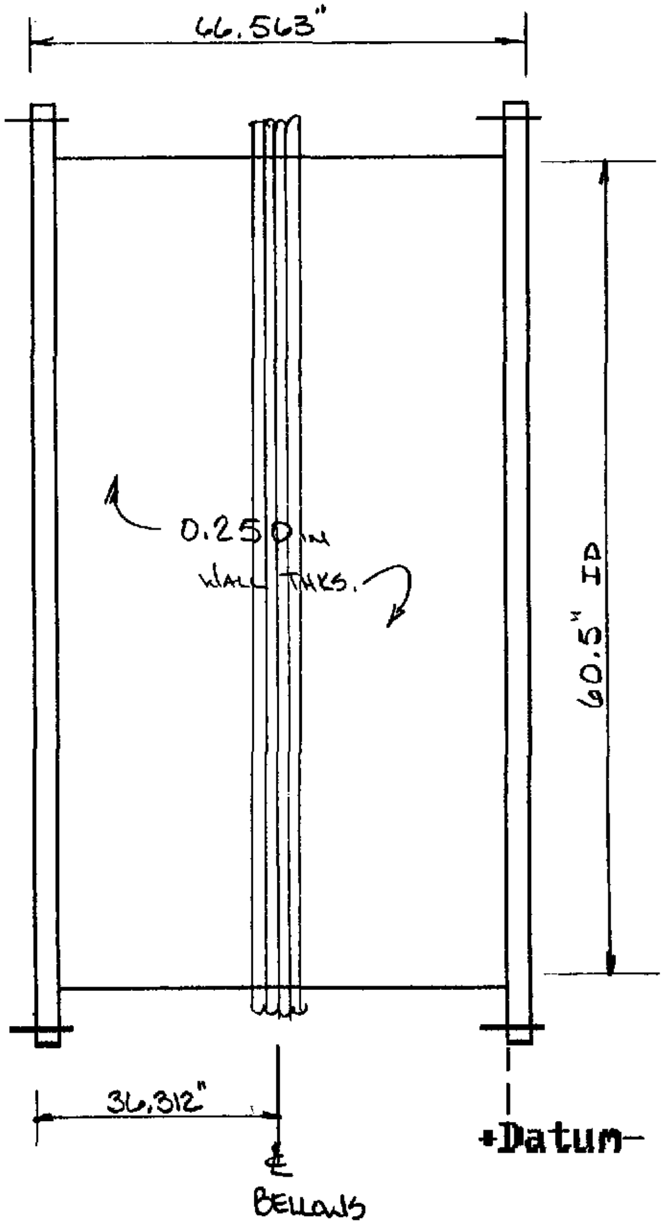
PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

SPOOL BE-2
60"
LIGO VACUUM EQUIPMENT

CAD FILE BE2
SIZE B
DWG. NO. V049-4-BE2
REV. 0
SCALE 3/8"=1'-0"
SHEET 1 OF 1

Jan 17, 1996 - 14:05:11

C:\COMPRESS\ADAPTER\be-2.vsl



Pressure Summary

Pressure summary for pressure chamber 1

```
___________________________________________________________________________________________________________________
|                        |   P     |   T     |  MAWP   |  MAP    |   Pe    | UG-99  |        UCS-66               |Corrosion|
|      Identifier        | design  | design  |         |         |external| Ratio  |  MDMT       Exemption or     |Allowance|
|                        | (psi)   |(deg F)  | (psi)   | (psi)   | (psi)   |        | (deg F)   Stress Reduction  |  (in)   |
|------------------------|---------|---------|---------|---------|---------|--------|-----------------------------|---------|
| BE-2                   |    0.0  |    0.0  |  116.7  |  116.7  |   27.1  | 1.000  |        | Not applicable     |  0.000  |
| 60-1/2" id Flange(R|    0.0  |    0.0  |    6.0  |    6.0  |         | 1.000  |        | Not applicable     |  0.000  |
| 60-1/2" id Flange      |    0.0  |    0.0  |    6.1  |    6.1  |         | 1.000  |        | Not applicable     |  0.000  |
|________________________|_________|_________|_________|_________|_________|________|________|____________________|_________|
```

Vessel MAWP hot & corroded is 6.09 psi @ 0 degrees F.

Vessel MAP new & cold is 6.09 psi @ 0 degrees F.

Vessel allowable external pressure is 27.19 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*1 = 40.8 psi

Vessel hydrotest pressure is 40.8 psi.

Weight Summary

```
Component ------------------------- Weight (lbs) Contributed by Vessel Elements ----------------------------
                  Metal   Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                    New    Corr   & sup    Beds                           & plat  & Misc  Liquid  Liquid   & flg
-------------------------------------------------------------------------------------------------------------
Be-2                502     502       0       0       0       0       0       0       0       0    3769       0
60-1/2" id flan     639     639       0       0       0       0       0       0       0       0       0       0
60-1/2" id flan     639     639       0       0       0       0       0       0       0       0       0       0
_______________  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______

                   1780    1780       0       0       0       0       0       0       0       0    3769       0


Vessel operating weight, corroded:   1,780 lbs
Vessel empty weight, corroded:       1,780 lbs
Vessel empty weight, new:            1,780 lbs
Vessel test weight, new:             5,549 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new: 1,780 lbs
Center of gravity to seam: 17.7 in

Thickness Summary

```
------------------------------------------------------------------------------------------
Component            ID      Length    Nom t    Req t   Joint       Governing          Deflect
Identifier          (in)      (in)     (in)     (in)      E     Load    Status   Stress ,  (in)
------------------------------------------------------------------------------------------
Be-2               60.50     36.31    0.2500   0.1730  0.85   external
------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

BE-2

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 502.4 corr = 502.4 lb
capacity: new = 451.896 corr = 451.896 US ga

ID = 60.5 length Lc= 36.312 t = 0.25 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(30.25 + 0.6*0.25) - 0
= 116.7352 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(30.25 + 0.6*0.25) - 0
= 116.7352 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 43.35367/61 =0.7107 Do/t = 61/0.17305 = 352.4993
From table G: A = 0.000296
From table HA-3: B = 3914

Pa= 4*B/(3*Do/t)
= 4*3914/(3*61/0.17305)
= 14.8048 psi

Design thickness for external pressure Pa = 14.8048 psi:

= t + Corrosion
= 0.17305 + 0
= 0.17305 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 43.35367/61 =0.7107 Do/t = 61/0.25 = 244
From table G: A = 0.000501
From table HA-3: B = 4976.5

BE-2

```
Pa= 4*B/(3*Do/t)
  = 4*4976.5/(3*61/0.25)
  = 27.194 psi
```

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-049
PAGE 1 OF 15

REV.	DEO #	DATE	BY:	CHECK
0	139	4.24.96	WDB	AGR

TITLE:

SPOOL BE-3 & BE-3A (60 in)

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Evaluate outer shell of spool piece BE-3/BE-3A for required thickness per ASME Code, Section VIII, Division I. Additionally evaluate offset flanges. BE-3 uses a single plate for eccentric matchup. BE-3A uses a flange connection for eccentric matchup.

METHOD: Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.53. Treat bellows sectioned cylinder as continuous. Localized stresses due to eccentric flange matchup/alignment are reviewed per Roark Stress calculations.

ASSUMPTIONS:

See Calculation

INPUTS:
1. Vacuum pressure = 14.7 psi
2. Design Temperature = 400 F.

REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.53, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Roark & Young's Formulas for Stress and Strain 6th Edition
4. Doc. No. V049-1-066 - LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:

V049-1-084 - Expansion Joint Tie-Rod Lug Design

CONCLUSIONS:

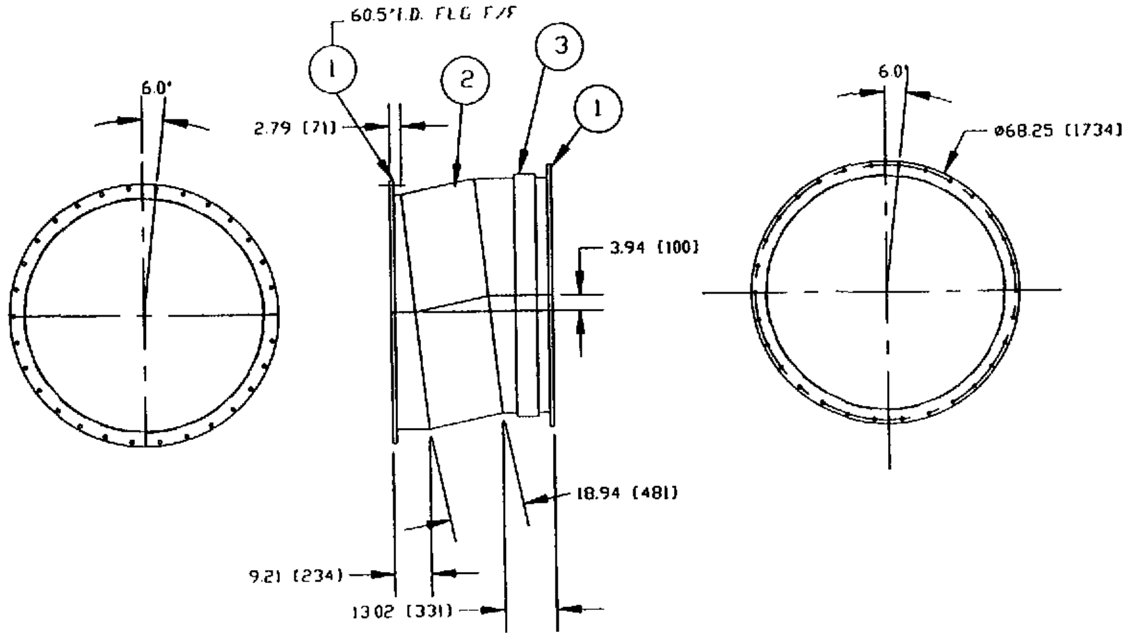
REQUIRED SHELL THICKNESS FOR BE-3 & BE-3A = 0.375"

The requirements of the ASME Code are met for spool BE-3/BE-3A outer shell.

NOTES: Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinders open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, & 019.

TABLE OF CONTENTS

Revision No. 0
Doc. No. V049-1-049
Page 3 of 15



ELEVATION

6 ~~4~~ REQ'D

PROPRIETARY AND CONFIDENTIAL

THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION BELONGING TO PROCESS SYSTEMS INTERNATIONAL, INC. OR ITS AFFILIATED COMPANIES AND SHALL BE USED ONLY FOR THE PURPOSE FOR WHICH IT WAS SUPPLIED. IT SHALL NOT BE COPIED, REPRODUCED OR OTHERWISE USED, NOR SHALL SUCH INFORMATION BE FURNISHED IN WHOLE OR IN PART TO OTHERS EXCEPT IN ACCORDANCE WITH THE TERMS OF ANY AGREEMENT UNDER WHICH IT WAS SUPPLIED OR WITH THE PRIOR WRITTEN CONSENT OF PROCESS SYSTEMS INTERNATIONAL, INC. AND SHALL BE RETURNED UPON REQUEST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR MACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE RMS
BREAK CORNERS: IN OUT
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.

USED ON:

NEXT ASS'Y:

REV	DESCRIPTION	CHKD	DRWN	DATE	DEOP
x	x	x	x	x	x

ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

SPOOL BE-3
60"
LIGO VACUUM EQUIPMENT

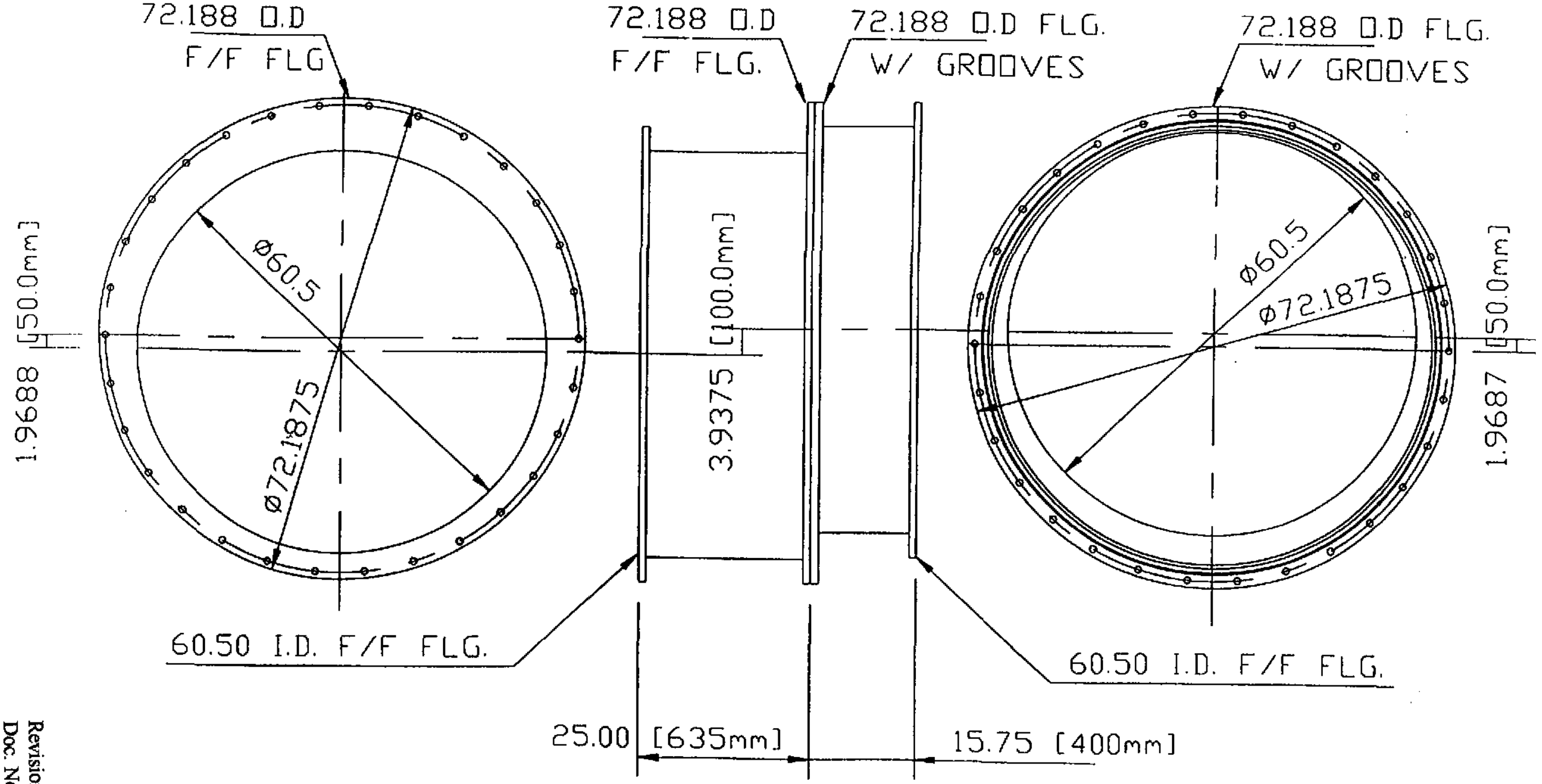
CAD FILE	SIZE	DWG NO	REV
BE3	B	V049-4-BE3	0

SCALE 3/8"=1'-0"

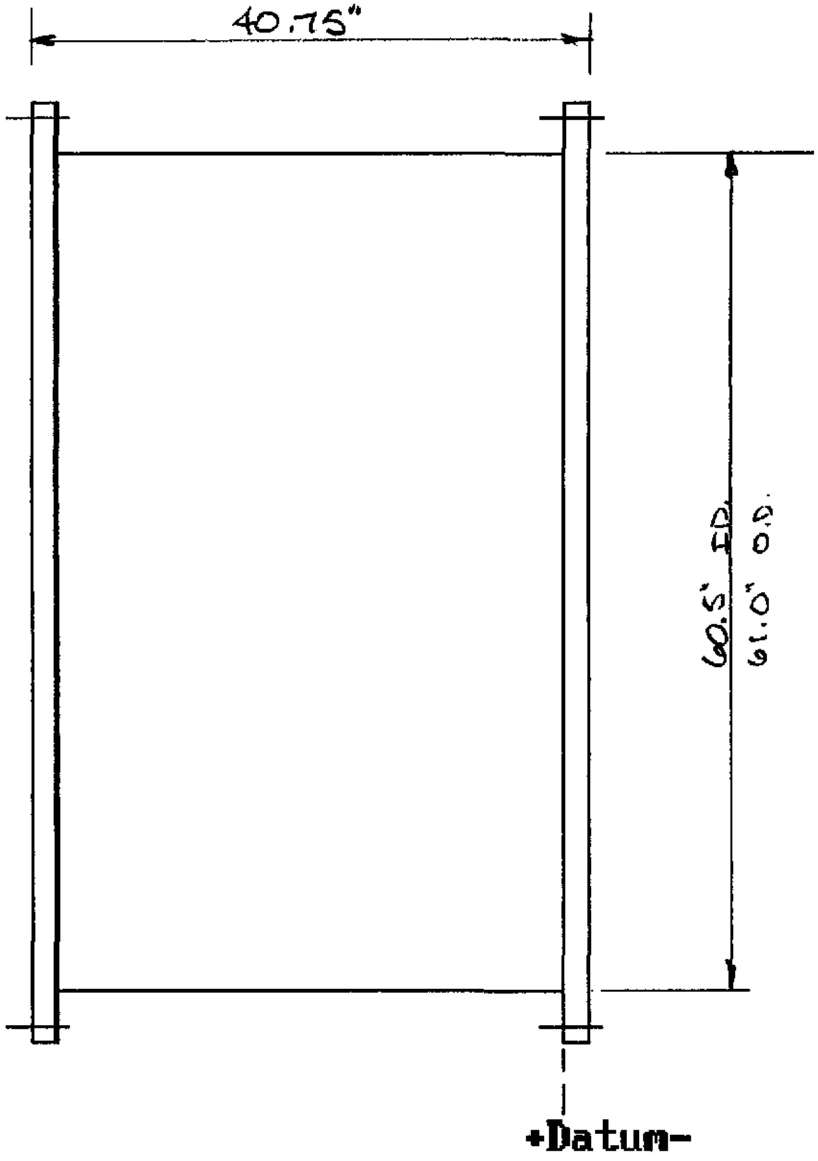
SHEET 1 OF 1

Jan 17, 1996 - 14:07:21

BE-3A


72.188 O.D
F/F FLG
72.188 O.D
F/F FLG.
72.188 O.D FLG.
W/ GROOVES
72.188 O.D FLG.
W/ GROOVES
Ø60.5
Ø72.1875
Ø60.5
Ø72.1875
1.9688 [50.0mm]
3.9375 [100.0mm]
1.9687 [50.0mm]
60.50 I.D. F/F FLG.
60.50 I.D. F/F FLG.
25.00 [635mm]
15.75 [400mm]

C:\COMPRESS\ADAPTER\be-3.vsl



NOTE: THE MODEL USED FOR THE DESIGN OF THE SHELL WALL THICKNESS IS CONSERVATIVELY MODELLED AS A STRAIGHT RUN. IN REALITY THE PLATE FOR FIT UP OF ECCENTRIC SPOOLS (WHICH IS AT MIDPOINT) ACTS AS A STIFFENER. NO STIFFENER WAS USED FOR SHELL WALL DESIGN. THE BELLOWS SECTION IS MODELLED AS CONTINUOUS SHELL.

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
BE-3	0.0	0.0	116.7	116.7	26.7	1.000		Not applicable	0.000
60-1/2" id Flange	0.0	0.0	20.4	20.4		1.000		Not applicable	0.000
60-1/2" id Flange	0.0	0.0	20.4	20.4		1.000		Not applicable	0.000

Vessel MAWP hot & corroded is 20.43 psi @ 0 degrees F.

Vessel MAP new & cold is 20.43 psi @ 0 degrees F.

Vessel allowable external pressure is 26.71 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*1 = 40.1 psi

Vessel hydrotest pressure is 40.1 psi.

Weight Summary

```
Component ------------------------ Weight (lbs) Contributed by Vessel Elements ----------------------------
                 Metal   Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                   New    Corr   & sup    Beds                          & plat  & Misc  Liquid  Liquid   & flg
-----------------------------------------------------------------------------------------------------------
Be-3               564     564       0       0       0       0       0       0       0       0    4230       0
60-1/2" id flan    668     668       0       0       0       0       0       0       0       0       0       0
60-1/2" id flan    668     668       0       0       0       0       0       0       0       0       0       0
_______________  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______

                  1900    1900       0       0       0       0       0       0       0       0    4230       0


Vessel operating weight, corroded:   1,900 lbs
Vessel empty weight, corroded:       1,900 lbs
Vessel empty weight, new:            1,900 lbs
Vessel test weight, new:             6,130 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new: 1,900 lbs
Center of gravity to seam: 19.9 in

Thickness Summary

```
----------------------------------------------------------------------------------------------------
Component               ID       Length    Nom t    Req t   Joint          Governing            Deflect
Identifier             (in)       (in)     (in)     (in)      E     Load      Status   Stress     (in)
----------------------------------------------------------------------------------------------------
Be-3                  60.50      40.75    0.2500   0.1804  0.85   external
----------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

BE-3

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 563.8 corr = 563.8 lb
capacity: new = 507.126 corr = 507.126 US ga

ID = 60.5 length Lc= 40.75 t = 0.25 in (new)

NOTE: REQUIRED SHELL THKS = 0.375". THKS. IS GOVERNED BY CALC No. V049-1-084

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(30.25 + 0.6*0.25) - 0
= 116.7352 psi

MAWP: (Corroded & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(30.25 + 0.6*0.25) - 0
= 116.7352 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 47.79167/61 =0.7835 Do/t = 61/0.18048 = 337.9876
From table G: A = 0.000284
From table HA-3: B = 3753.8

Pa= 4*B/(3*Do/t)
= 4*3753.8/(3*61/0.18048)
= 14.8084 psi

Design thickness for external pressure Pa = 14.8084 psi:

= t + Corrosion
= 0.18048 + 0
= 0.18048 in

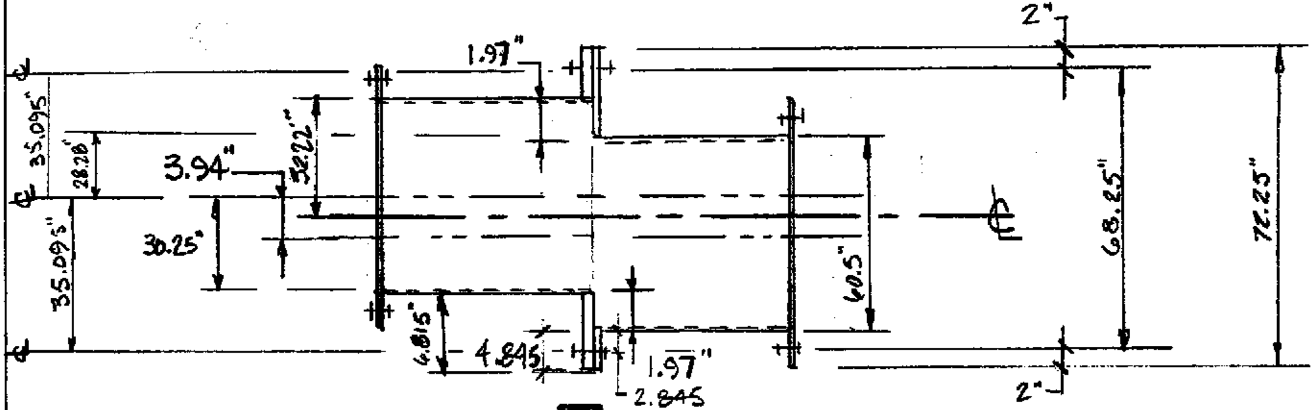
Maximum Allowable External Pressure: (Corroded @ 400 deg F)

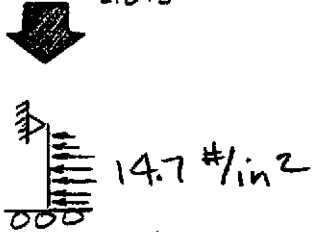
L/Do = 47.79167/61 =0.7835 Do/t = 61/0.25 = 244
From table G: A = 0.000452
From table HA-3: B = 4887.2

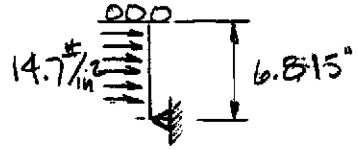
Pa= 4*B/(3*Do/t)
  = 4*4887.2/(3*61/0.25)
  = 26.706 psi

EVALUATE ECCENTRICITY OF SPOOL BE-3A

ECCENTRIC MATCH UP OF SPOOL PIECES PRODUCES AN OVERHANG OF APPROX 2 in (1.97") THIS AREA NEEDS TO BE EVALUATED FOR LOCALIZED STRESSES.







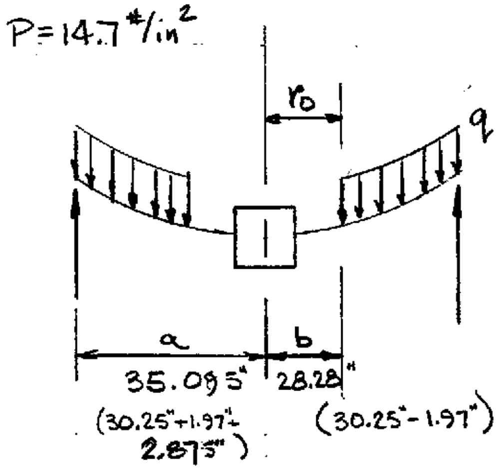
<u>FOR QUICK REVIEW</u> :

ASSUME ANNULAR PLATE WITH 2 in BEARING SURFACE. CONSIDER OUTER EDGE SIMPLY SUPPORTED, INNER EDGE GUIDED. CONSIDER DISTRIBUTED LOAD ACTING ON ONE SIDE ONLY.

<u>REF.</u> FORMULAS FOR STRESS AND STRAIN
ROARK'S SIXTH EDITION

CHAPTER 10 TABLE 24 CASE 2 B

$$\text{MAX } M = M_{rb}$$



$$M_{rb} = \frac{q a^2}{C_8} L_{17}$$

$$Q_a = \frac{-q}{2a}\left(a^2 - r_o^2\right)$$

SHEAR FORCE

$$Q_a = -\frac{14.7\,\#/in^2/in}{2\,(35.095\,in)}\left[\left(35.095\,in\right)^2 - \left(28.28\,in\right)^2\right]$$

$$= 90.45 \text{ lbs.}$$

MAX BENDING MOMENT

$$M_{rb} = \frac{(14.7\,\#/in^2/in)(35.095\,in)^2}{C_8}\left(L_{17}\right)$$

where

$$C_8 = \tfrac{1}{2}\left[1 + \nu + (1-\nu)\left(\frac{b}{a}\right)^2\right]$$

$$= \tfrac{1}{2}\left[1 + .3 + (1-.3)\left(\frac{28.28}{35.095}\right)^2\right]$$

$\nu = 0.3$ poison's ratio
$b = 28.28$ in
$a = 35.095$ in

$$C_8 = 0.8773$$

$$L_{17} = \tfrac{1}{4}\left[1 - \frac{1-\nu}{4}\left\{1 - \left(\frac{r_o}{a}\right)^4\right\} - \left(\frac{r_o}{a}\right)^2\left\{1 + (1+\nu)\ln\frac{a}{r_o}\right\}\right]$$

$$= \tfrac{1}{4}\left[1 - \frac{1-.3}{4}\left\{1 - \left(\frac{28.28}{35.095}\right)^4\right\} - \left(\frac{28.28}{35.095}\right)^2\left\{1 + (1+.3)\ln\frac{35.095}{28.28}\right\}\right]$$

$$L_{17} = 0.0168$$

$$M_{rb} = \frac{(14.7\ \#/in^2/in)(35.095 in)^2}{0.8773} (0.0168)$$

$$M_{MAX} = M_{rb} = 346.7 \text{ lb-in}$$

ASSUME 1" THK PLATE

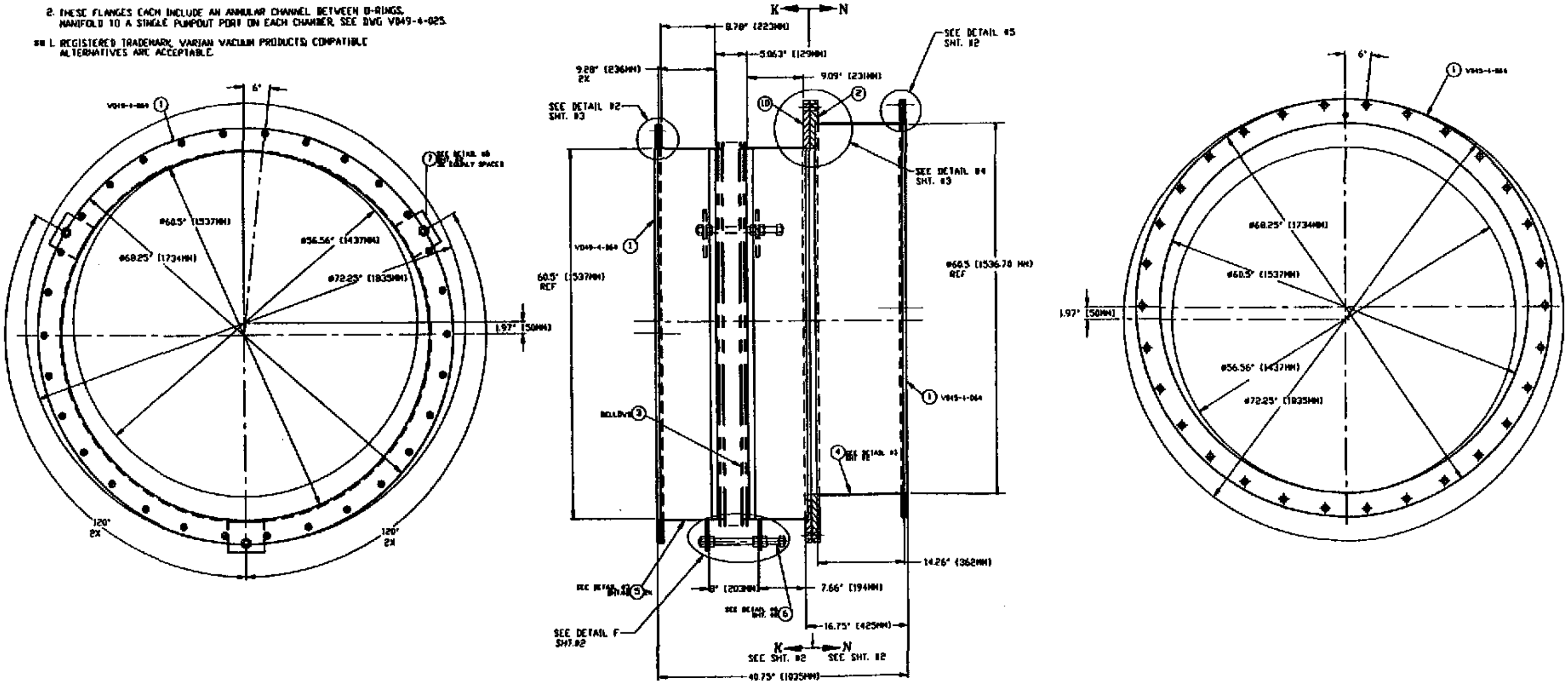
$$\sigma_{max} = \frac{6 M_{rb}}{t^2} = \frac{6(346.7 \text{ lb-in})}{(1.00 in)^2} = 2080 \#/in^2$$

SHEAR STRESS & Bending Stress are relatively small and therefore eccentricity is acceptable.
Additinally BE-3 WILL USE (1) BLANK PLATE WHICH WILL ALLOW WELDING OF THE TWO OFFSET SPOOLS. BE-3A WILL USE A FLANGE CONNECTION.
THE MIN PLATE THKS WILL BE 1" (as used above) FOR BE-3. BE-3A WILL USE STANDARD FLANGE THICKNESS FOR THE SPECIALLY MILLED FLANGES.

NOTES:

10. LEAK TEST & METHOD PER PSI SPEC: V049-2-014
9. CERTIFIED MANUFACTURER'S MATERIAL TEST REPORTS REQUIRED.
8. BOLT HOLES TO STRADDLE CENTERLINES OF VESSEL AS SHOWN.
7. CLEAN PER SPEC: V049-2-015
6. DO NOT USE CARBON STEEL BRUSHES OR BRUSHES CONTAMINATED WITH CARBON STEEL ON STAINLESS OR ALUMINUM MATERIAL.
5. DIMENSIONS SHOWN IN PARENTHESES ARE IN MILLIMETERS.
4. CHAMBER FABRICATION TO BE IN ACCORDANCE WITH SPEC. V049-2-044.
3. FOR FLANGE DETAILS SEE DWGS.
2. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS. MANIFOLD TO A SINGLE PUMPOUT PORT ON EACH CHAMBER. SEE DWG V049-4-025.
** 1. REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATIVES ARE ACCEPTABLE.

ITEM	PART NUMBER	SUFFIX	QTY	UM	DESCRIPTION
1	V049-4-064	3	2		60.5" ID FLANGE DETAIL (FLAT)
2	V049-4-067	3	1	-	60.5 ID 1.96 OFFSET FLANGE DETAIL (GROOVE)
3	-	3	1		BELLOWS
4	DETAIL #3	3	1		60.5 I.D. SHELL, 304L SST.
5	DETAIL #3	3	2		60.5 I.D.SHELL, 304L SST.
6	DETAIL #6	3	3		TIE ROD, 1-8UNC THREADED ROD 304L SST.
7	DETAIL #7	3	6		TIE LUG, 1" THK. 304L SST.
8	DETAIL #8	3	1		UNION, 2" THK. 304L SST.
9	-	3	15		NUT, HEX 1-8UNC 304 SST.
2	V049-4-066	3	1	-	60.5 ID 1.96 OFFSET FLANGE DETAIL (FLAT)



Revision No. 0
Doc. No. V049-1-049
Page 15 of 15

PROPRIETARY AND CONFIDENTIAL

DWG. NO. | DESCRIPTION | DWG. NO. | DESCRIPTION

REFERENCE DRAWINGS

UNLESS OTHERWISE SPECIFIED

DO NOT SCALE THIS DRAWING

USED ON

NEXT ASSY

REV | DESCRIPTION | CHKD | DRWN | DATE | DSGN

ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL, INC.

ADAPTER BE-3A
60.5 ID 3.94 OFFSET
LIGO VACUUM EQUIPMENT

CAD FILE 493C3AS1 | SIZE D | DWG NO V049-4-BE3A | REV. P1

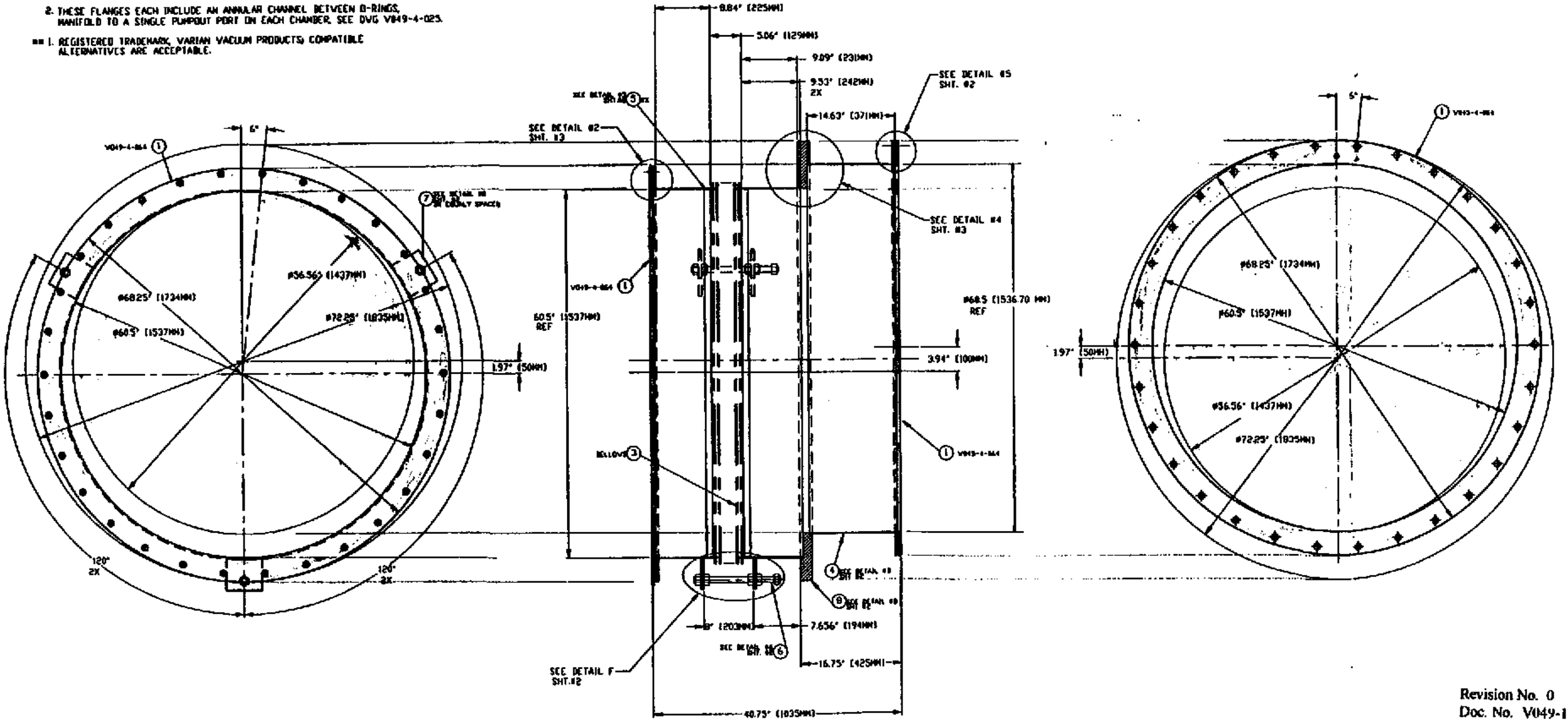
SCALE NONE | SHEET 1 OF 1

ITEM	PART NUMBER	SUFFIX	QTY	UM	DESCRIPTION
1	V049-4-064	3	2		60.5' ID FLANGE DETAIL (FLAT)
2	-	-	-	-	/
3	-	3	1		BELLOWS
4	DETAIL #3	3	1		60.5 I.D. SHELL, 304L SST.
5	DETAIL #3	3	2		60.5 I.D.SHELL, 304L SST.
6	DETAIL #6	3	3		TIE ROD, 1-8UNC THREADED ROD 304L SST.
7	DETAIL #7	3	6		TIE LUG 1" THK. 304L SST.
8	DETAIL #8	3	1		UNION, 2" THK. 304L SST.
9	-	3	15		NUT, HEX 1-8UNC 304 SST.

NOTES:

10. LEAK TEST & METHOD PER PSI SPEC: V049-2-014
9. CERTIFIED MANUFACTURER'S MATERIAL TEST REPORTS REQUIRED.
8. BOLT HOLES TO STRADDLE CENTERLINES OF VESSEL AS SHOWN.
7. CLEAN PER SPEC: V049-2-015
6. DO NOT USE CARBON STEEL BRUSHES OR BRUSHES CONTAMINATED WITH CARBON STEEL ON STAINLESS OR ALUMINUM MATERIAL.
5. DIMENSIONS SHOWN IN PARENTHESES ARE IN MILLIMETERS.
4. CHAMBER FABRICATION TO BE IN ACCORDANCE WITH SPEC. V049-2-044.
3. FOR FLANGE DETAILS SEE DWGS.
2. THESE FLANGES EACH INCLUDE AN ANNULAR CHANNEL BETWEEN O-RINGS, MANIFOLD TO A SINGLE PUMPOUT PORT ON EACH CHAMBER. SEE DWG V049-4-025.

** 1. REGISTERED TRADEMARK, VARIAN VACUUM PRODUCTS; COMPATIBLE ALTERNATIVES ARE ACCEPTABLE.



Revision No. 0
Doc. No. V049-1-049
Page 14 of 15

PROPRIETARY AND CONFIDENTIAL

[illegible]

DWG. NO. | DESCRIPTION | DWG. NO. | DESCRIPTION
REFERENCE DRAWINGS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
[illegible]

DO NOT SCALE THIS DRAWING
USED ON
NEXT ASSY

REV | DESCRIPTION | CHKD | DRWN | DATE | ECO#
TOV
ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL, INC.
[illegible]

ADAPTER BE-3
60.5 ID 3.94 OFFSET
LIGO VACUUM EQUIPMENT

CAD FILE V049BE3
SIZE D
DWG NO. V049-4-BE3
REV P1
SCALE NONE
SHEET 1 OF 1

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-076

PAGE 1 OF 8

REV.	DEO #	DATE	BY:	CHECK
[illegible]	0128	4-1-96	AGR	WDB

TITLE: SPOOL BE-4 DESIGN

By: ART ROUSSOPOULOS

DEPT.: 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: QUALIFY THE DESIGN OF SPOOL PIECE BE-4 TO ASME VIII REQUIREMENTS

METHOD: COMPRESS 5.53 COMPUTER PRESSURE VESSEL SOFTWARE

A UMPTIONS: SEE CALCS

INPUTS: "STRUCTURAL DESIGN CRITERIA" DOC. NO. V049-1-066

REFERENCES: LIGO DWG. V049-4-BE4
DOC. NO. V049-1-066, LIGO VAC. EQUIP. STRUCT. DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

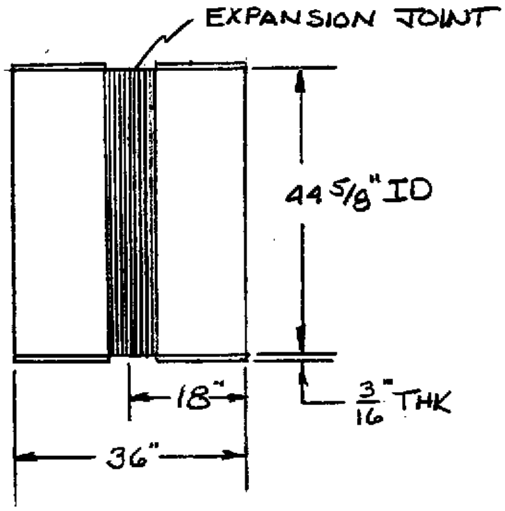
CONCLUSIONS: SPOOL PIECE BE-4, AS SHOWN IN SKETCH, IS IN CONFORMANCE WITH ASME VIII REQUIREMENTS

N TES: COMPRESS FILE NAME: SP_B4 FILED IN DIRECTORY :\41896

DESIGN SKETCH

SK-V049-1-076 RO

SPOOL BE-4



REV O
Doc. No. V049-1-076
P. 2 OF 8

TABLE OF CONTENTS

3.12.1996

REV O
Doc. No. V049-1-076
P. 3 OF 8

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL BE-4	0.0	400.0	104.4	118.6	25.1	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 104.47 psi @ 400 degrees F.

Vessel MAP new & cold is 118.69 psi @ 0 degrees F.

Vessel allowable external pressure is 25.16 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 178 psi

Vessel hydrotest pressure is 178 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Weight (lbs) Contributed by Vessel Elements											
	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool be-4	276	276	0	0	0	0	0	0	0	0	2033	0
	276	276	0	0	0	0	0	0	0	0	2033	0

Vessel operating weight, corroded: 276 lbs

Vessel empty weight, corroded: 276 lbs

Vessel empty weight, new: 276 lbs

Vessel test weight, new: 2,309 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	276 lbs
Center of gravity to seam:	18 in

Thickness Summary

Component	ID	Length	Nom t	Req t	Joint		Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E	Load	Status	Stress	(in)
Spool be-4	44.62	36.00	0.1875	0.1521	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL BE-4

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight:	new = 275.6	corr = 275.6	lb
capacity:	new = 243.745	corr = 243.745	US ga

ID = 44.625 length Lc= 36 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 118.6873 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 104.4732 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 47.4375/45 =1.0542 Do/t = 45/0.15219 = 295.683
From table G: A = 0.000247
From table HA-3: B = 3260.4

Pa= 4*B/(3*Do/t)
= 4*3260.4/(3*45/0.15219)
= 14.7022 psi

Design thickness for external pressure Pa = 14.7022 psi:

= t + Corrosion
= 0.15219 + 0
= 0.15219 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 47.4375/45 =1.0542 Do/t = 45/0.1875 = 240
From table G: A = 0.000342
From table HA-3: B = 4528.5

REV 0
Doc. No. V049-1-076

SPOOL BE-4

```
Pa= 4*B/(3*Do/t)
  = 4*4528.5/(3*45/0.1875)
  = 25.1583 psi
```

REV 0

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-085
PAGE 1 OF 47

REV.	DEO #	DATE	BY:	CHECK
0	0141	4/24/96	WDB	AGR
1	0293	9/19/96	WDB	RDL

TITLE:

SPOOL BE-5 (72 in)

BY: W. Bilynsky

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:

Determine spool minimum shell thickness. Additionally, evaluate nozzle openings, calculate size and spacing of stiffener rings and support rings.

METHOD:

Thickness requirements per the ASME code, Section VIII, Division I, are derived using the COMPRESS computer program, version 5.53.

ASSUMPTIONS: See Calculation

INPUTS:

1. Vacuum pressure = 14.7 psi
2. Design Temperature = 400 F.
3. Unbalanced Loads at Roughing Pump Nozzles
   6" dia = 382. lbs 10" dia = 1042. lbs

REF CALC V049-1-087
P. 10

REFERENCES:

1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels.
2. COMPRESS 5.53, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066 - LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:

CONCLUSIONS: The requirements of the ASME Code are met for spool BE-5's outer shell.

NOTES: Flanges were included in the COMPRESS model simulating radial stiffeners at the cylinder's open end(s). For flange design and analysis see calculation numbers V049-1-016, 017, 018, & 019.

TABLE OF CONTENTS

REVISION HISTORY

Rev. 0 Original Issue
April 24, 1996

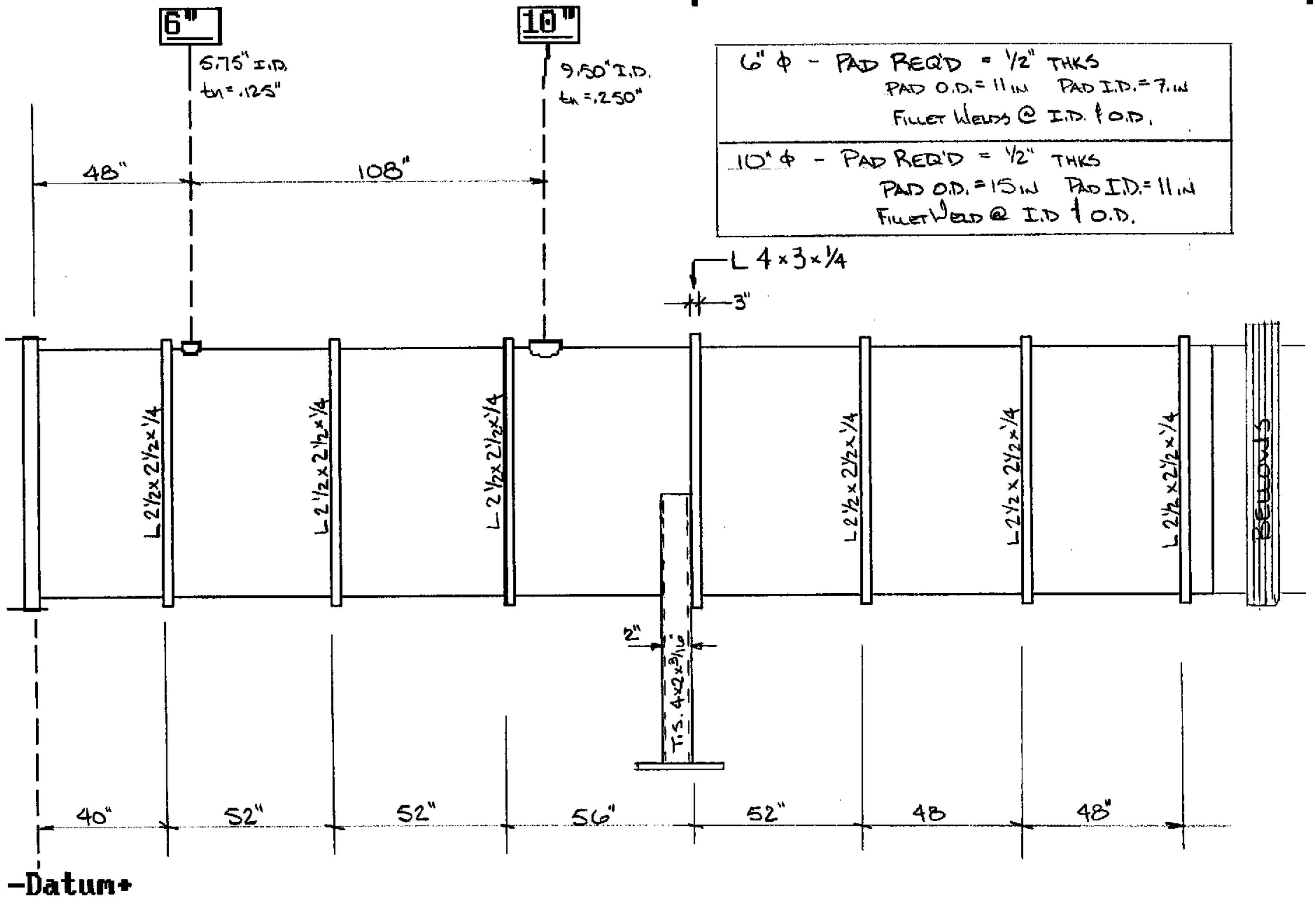
Rev. 1 Issue Date
September 19, 1996

- Revised location of 6″ dia. & 10″ dia. nozzles
- Recalculated local and primary membrane stresses at the nozzles
- Revised 2″ x 2″ x 1/4″ stiffner rings to 2-1/2″ x 2-1/2″ x 1/4″ stiffner rings
- Relocated stiffner rings to accomodate revised nozzle locations.

C:\COMPRESS\MANIFOLD\be-5r1.vsl

6" ϕ - PAD REQ'D = 1/2" THKS
PAD O.D. = 11 IN PAD I.D. = 7. IN
FILLET WELDS @ I.D. & O.D.

10" ϕ - PAD REQ'D = 1/2" THKS
PAD O.D. = 15 IN PAD I.D. = 11 IN
FILLET WELD @ I.D & O.D.



Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
BE-5	0.0	400.0	86.1	97.8	21.4	1.136		Not applicable	0.000
Flange @ B-1	0.0	0.0	17.5	17.5		1.000		Not applicable	0.000
6" 6" Roughing Pmp	0.0	400.0	0.0	0.0	14.7	1.136		Not applicable	0.000
10" 10" Roughing Pm	0.0	400.0	0.0	0.0	14.7	1.136		Not applicable	0.000
Support Ring					14.7				
Stiffner Rings (Fla					14.7				
Stiffner Rings (Bel					14.7				

Vessel MAWP hot & corroded is 0 psi @ 0 degrees F.

Vessel MAP new & cold is 0 psi @ 0 degrees F.

Vessel allowable external pressure is 14.7 psi @ 400 degrees F.

Hydrotest pressure calculation based on Pe

= 1.5*Pe*1 = 22 psi

Vessel hydrotest pressure is 22 psi.

Weight Summary

```
Component ------------------------ Weight (lbs) Contributed by Vessel Elements ---------------------------
                 Metal   Metal   Trays  Packed   Insul  Lining  Piping  Ladder   Rings    Oper    Test  Nozzle
                   New    Corr   & sup    Beds                          & plat  & Misc  Liquid  Liquid   & flg
-----------------------------------------------------------------------------------------------------------
Be-5              5945    5945       0       0       0       0       0       0     597       0   53289      14
Flange @ b-1       840     840       0       0       0       0       0       0       0       0       0       0
_______________ ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______  ______
                  6785    6785       0       0       0       0       0       0     597       0   53289      14
```

```
Vessel operating weight, corroded:   7,396 lbs
Vessel empty weight, corroded:       7,396 lbs
Vessel empty weight, new:            7,396 lbs
Vessel test weight, new:            60,685 lbs
```

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	7,395 lbs
Center of gravity to seam:	198.8 in

Nozzle Summary

```
-------------------------------------------------------------------------------------
Nozzle        OD      tn     Req tn            Nom t    Req t   User t    Corr   Aa/Ar
mark         (in)    (in)    (in)   A1?  A2?   (in)     (in)     (in)     (in)    (%)
-------------------------------------------------------------------------------------
6"           6.00   0.1250  0.0625   y    y   0.2500   0.2135            0.0000  197.1
10"         10.00   0.2500  0.0625   y    y   0.2500   0.2135            0.0000  121.3
-------------------------------------------------------------------------------------
```

tn - nozzle thickness
Req tn - nozzle thickness required per UG-45/16
Nom t - vessel wall thickness
Req t - required vessel wall thickness due to pressure + corr per UG-37
User t - local vessel wall thickness (near opening)
Aa - area available per UG-37, governing condition
Ar - area required per UG-37, governing condition
Corr - corrosion allowance on nozzle id.

Nozzle Schedule

```
--------------------------------------------------------------------------------------------
Nozzle      Service              Size                          Materials
mark                                        Nozzle     Impact? Norm?  Pad        Impact? Norm?  Flange
--------------------------------------------------------------------------------------------
6"     roughing pmp       5.75 IDx0.12   SA 240 304L HIGH  n    n    SA 240 304L HIG  n    n
10"    roughing pmp       9.50 IDx0.25   SA 240 304L HIGH  n    n    SA 240 304L HIG  n    n
--------------------------------------------------------------------------------------------
```

Thickness Summary

```
------------------------------------------------------------------------------------------------
Component             ID     Length    Nom t    Req t   Joint         Governing               Deflect
Identifier           (in)     (in)      (in)     (in)     E     Load     Status     Stress     (in)
------------------------------------------------------------------------------------------------
Be-5                 72.25   360.00    0.2500   0.2135  0.85   external
------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

BE-5

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 5944.7 corr = 5944.7 lb
capacity: new = 6389.336 corr = 6389.336 US ga

OD = 72.75 length Lc= 360 t = 0.25 in (new)

MAP: (New & at 0 deg F) Appendix 1-1(a)

P = S*E*t/(Ro - 0.4*t) - Ps
= 16700*0.85*0.25/(36.375 - 0.4*0.25) - 0
= 97.82909 psi

MAWP: (Corroded & at 400 deg F) Appendix 1-1(a)

P = S*E*t/(Ro - 0.4*t) - Ps
= 14700*0.85*0.25/(36.375 - 0.4*0.25) - 0
= 86.11303 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 56/72.75 =0.7698 Do/t = 72.75/0.21354 = 340.6856
From table G: A = 0.000286
From table HA-3: B = 3780.5

Pa= 4*B/(3*Do/t)
= 4*3780.5/(3*72.75/0.21354)
= 14.7957 psi

Design thickness for external pressure Pa = 14.7957 psi:

= t + Corrosion
= 0.21354 + 0
= 0.21354 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 56/72.75 =0.7698 Do/t = 72.75/0.25 = 291
From table G: A = 0.000353
From table HA-3: B = 4675.5

BE-5

Pa= 4*B/(3*Do/t)
 = 4*4675.5/(3*72.75/0.25)
 = 21.4227 psi

6" Roughing Pmp

Opening 6" Reinforcement Calculations Per UG-37

Located on:	BE-5
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	Not installed
Nozzle material specification:	SA 240 304L HIGH
Pad material specification:	SA 240 304L HIGH
Nozzle orientation:	90 degrees
End of nozzle to shell center:	39.375 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	3 in

```
      tn ->| |<-                         corrosion allow = 0 in
dp->|        _         _    |<-          noz thick new tn= .125 in
    |      | |<- d ->| |tw1              nozzle id. new d= 5.75 in
->| |<tw2  | |       |> |<-|             pad diameter dp = 9 in
__| ___/   | |       |\___               pad thickness te= .25 in
te|/|      | |       |      |\           fillet weld tw1 = .25 in
___________|_|_v     |__________         fillet weld tw2 = .25 in
__________/|_|_tw3   |_|\_______         groove weld tw3 = .25 in
               ^
<----- L ----->|                         To datum L= 48 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .5625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 0*2.875/(14700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 0*36.125/(14700*1 - 0.6*0)
= 0 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, Sp = 14700 psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1

6" Roughing Pmp

fr2 = lesser of 1 or Sn/Sv so fr2 = 1
fr3 = lesser of fr2 or Sp/Sv so fr3 = 1
fr4 = lesser of 1 or Sp/Sv so fr4 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.75*0*1 + 2*0.125*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 1.438 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0) - 2*0.125*(1*0.25-1*0)*(1-1)
= 1.438 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.125)*(1*0.25-1*0) - 2*0.125*(1*0.25-1*0)*(1-1)
= .188 in^2

A2 = smaller of the following = 0.141 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0)*1*0.25
= .156 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.125 - 0)*(2.5*0.125 + 0.25)*1
= .141 in^2

A41 = Leg^2*fr3
= 0.25^2*1 = .063 in^2

A42 = Leg^2*fr4
= 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (9 - 5.75 - 2*0.125)*0.25*1
= .75 in^2

Area = A1 + A2 + A41 + A42 + A5
= 1.438 + 0.141 + 0.063 + 0.063 + 0.75
= 2.455 in^2

As Area > A the reinforcement is adequate for MAWP = 0 at 400 Deg F

Check the welds - From UW-16(c)(2)

Inner Fillet: tmin = lesser of 0.75 or tn or te, tmin = 0.125 in
tw(min) = 0.7*tmin = 0.0875 in
tw(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer Fillet: tmin = lesser of 0.75 or te or t, tmin = 0.25 in
tw(min) = 0.5*tmin = 0.125 in

6" Roughing Pmp

tw(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.245 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi
Outer fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*6*0.25*7203 = 16963.06 lbf

(2) Outer fillet weld in shear
(Pi/2)*Pad O.D.*Leg*So = 1.57*9*0.25*7203 = 25444.6 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*5.875*0.125*10290 = 11864.05 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*6*0.25*10878 = 25617.69 lbf

Loading on welds per UG-41(b)(1)

W = (A - A1 + 2*tn*fr1*(E1*t - F*tr))*Sv
= (0 - 1.438 + 2*0.125*1*(1*0.25 - 1*0))*14700
=-20219.85 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.141 + 0.75 + 0.063 + 0.063)*14700
= 14949.9 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.141 + 0 + 0.063 + 0 + 2*0.125*0.25*1)*14700
= 3917.55 lbf

W3-3 = (A2 + A3 + A5 + A41 + A42 + A43 + 2*tn*t*fr1)*Sv
= (0.141 + 0 + 0.75 + 0.063 + 0.063 + 0 + 2*0.125*0.25*1)*14700

= 15868.65 lbf

Load for path 1-1 lesser of W or W1-1 =-20219.85 lbf
Path 1-1 Thru (2) & (3) = 25444.6 + 11864.05 = 37308.65 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 =-20219.85 lbf
Path 2-2 Thru (1), (4) = 16963.06 + 25617.69 = 42580.75 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W3-3 =-20219.85 lbf
Path 3-3 Thru (2), (4) = 25444.6 + 25617.69 = 51062.29 lbf
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Pad strength = A5*Sp = 11025 lbf
Outer fillet weld strength is adequate.

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 5.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .5625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3125 in

Nozzle required thickness

L/Do = 3/6 = .5	Do/t = 6/0.01491 = 402.4145
From table G:	A = 0.000337
From table HA-3:	B = 4461.6

Pa= 4*B/(3*Do/t)
= 4*4461.6/(3*6/0.01491)
= 14.7828 psi

Nozzle required thickness trn = .01491 in

Required thickness tr from UG-37(d)(1) = .2135 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, Sp = 14700 psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1
fr3 = lesser of fr2 or Sp/Sv so fr3 = 1
fr4 = lesser of 1 or Sp/Sv so fr4 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(5.75*0.2135*1 + 2*0.125*0.2135*1*(1 - 1))
= .6138 in^2

Area available

6" Roughing Pmp

```
A1 = larger of the following          = .21 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 5.75*(1*0.25-1*0.2135) - 2*0.125*(1*0.25-1*0.2135)*(1-1)
  = .21 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.25+0.125)*(1*0.25-1*0.2135) - 2*0.125*(1*0.25-1*0.2135)*(1-1)
  = .027 in^2

A2 = smaller of the following          = 0.124 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.125 - 0.01491)*1*0.25
  = .138 in^2

  = 2*(tn - trn)*(2.5*tn + te)*fr2
  = 2*(0.125 - 0.01491)*(2.5*0.125 + 0.25)*1
  = .124 in^2

A41 = Leg^2*fr3
   = 0.25^2*1 = .063 in^2

A42 = Leg^2*fr4
   = 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
  = (9 - 5.75 - 2*0.125)*0.25*1
  = .75 in^2

Area = A1 + A2 + A41 + A42 + A5
  = 0.21 + 0.124 + 0.063 + 0.063 + 0.75
  = 1.21 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F
```

UG-45 Nozzle Neck Thickness Check

```
Wall thickness per UG-45(a):        tr1 = 0.01491 in (E = 1)
Wall thickness per UG-45(b)(2):     tr2 = 0.0361 in
Wall thickness per UG-16(b):        tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):      tr4 = 0.245 in
The greater of tr2 or tr3:          tr5 = 0.0625 in
The lesser of tr4 or tr5:           tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.125 in

The nozzle neck thickness is adequate for Pe.
```

6" Roughing Pmp

Applied Loads

Radial load	Pr = 382 lbf
Circumferential moment	Mc = 0 lbf-ft
Circumferential shear	Vc = 0 lbf
Longitudinal moment	ML = 0 lbf-ft
Longitudinal shear	VL = 0 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 36.25 in
Rm/t = 72.5

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(2.875/3.25)^2 + 3*(2.875/3.25)^4)
= 2.046

Local circ. pressure stress = I*P*Rm/t = ~~[illegible]~~ $= \frac{(14.7\ \#/in^2)(36.25\ in)}{.50\ in} = 1065.75\ \#/in^2$ -2180.5

Local long. pressure stress = P*Rm/2t = ~~[illegible]~~ $= \frac{(14.7\ \#/in^2)(36.25\ in)}{2(.50\ in)} = 532.875\ \#/in^2$

Maximum combined stress = -~~[illegible]~~ *
Allowable combined stress = +-1.5*S = +- 22050 psi
**

= 1424 psi + 533 psi + 2.046(1066 psi)
= 4138 psi < 22050 psi ∴ OK

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = ~~[illegible]~~
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

264 psi + 533 psi + 2.046(1066 psi)
= 3775 psi < 22050 psi ∴ OK.

The maximum primary membrane stress is within allowable limits.

* SEE NEXT PAGE

** 3.0 S IS ACCEPTABLE FOR DISCONTINUITY STRESS.

6" Roughing Pmp

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	11.329	0.072					-239	-239	-239	-239
4C*	12.546	0.072	-264	-264	-264	-264				
1C	0.1292	0.072					-1185	1185	-1185	1185
2C-1	0.0941	0.072	-863	863	-863	863				
3A*	2.1475	0.072								
1A	0.0964	0.072								
3B*	7.2821	0.072								
1B-1	0.0472	0.072								
pressure stress*			-2181	-2181	-2181	-2181	-2181	-2181	-2181	-2181
Total circ stress			-3308	-1582	-3308	-1582	-3605	-1236	-3605	-1236
Primary membrane circ stress*			-2445	-2445	-2445	-2445	-2420	-2420	-2420	-2420
3C*	11.329	0.072	-239	-239	-239	-239				
4C*	12.546	0.072					-264	-264	-264	-264
1C-1	0.1318	0.072	-1208	1208	-1208	1208				
2C	0.0921	0.072					-844	844	-844	844
4A*	3.0956	0.072								
2A	0.0551	0.072								
4B*	2.1329	0.072								
2B-1	0.0753	0.072								
pressure stress*			-533	-533	-533	-533	-533	-533	-533	-533
Total long stress			-1980	436	-1980	436	-1641	47	-1641	47
Primary membrane long stress*			-772	-772	-772	-772	-797	-797	-797	-797
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-3308	-2445	-3308	-2445	-3605	-2420	-3605	-2420
MEMBRANE Stress			-533	-533	-533	-533	-533	-533	-533	-533
Max Combined Stress			-3841	-2978	-3841	-2978	-4138	-2953	-4138	-2953

6" Roughing Pmp

Stresses at the pad edge per WRC bulletin 107 (psi)

Mean radius Rm = 36.25 in
Rm/t = 145

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(2.875/4.75)^2 + 3*(2.875/4.75)^4)
= 1.375

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ $\frac{(14.7\#/in^2)(36.25in)}{.25}$ = 2131.5 (1.375) = 2931 psi

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ $\frac{(14.7\#/in^2)\ (36.25)}{2(.25)}$ = -1065.75 ≈ 1066 psi

Maximum combined stress = -~~3264 psi~~
Allowable combined stress = +-1.5*S = +- 22050 psi

3264psi + 2931psi + 1066psi = 7261psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = -~~843 psi~~
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

843 psi + 2931psi + 1066psi = 4840 psi

The maximum primary membrane stress is within allowable limits.

6" Roughing Pmp

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	12.969	0.109					-547	-547	-547	-547
4C*	19.996	0.109	-843	-843	-843	-843				
1C	0.0741	0.109					-2717	2717	-2717	2717
2C-1	0.0405	0.109	-1485	1485	-1485	1485				
3A*	5.6709	0.109								
1A	0.0761	0.109								
3B*	14.481	0.109								
1B-1	0.0255	0.109								
pressure stress*			-2931	-2931	-2931	-2931	-2931	-2931	-2931	-2931
Total circ stress			-5259	-2289	-5259	-2289	-6195	-761	-6195	-761
Primary membrane circ stress*			-3774	-3774	-3774	-3774	-3478	-3478	-3478	-3478
3C*	12.969	0.109	-547	-547	-547	-547				
4C*	19.996	0.109					-843	-843	-843	-843
1C-1	0.0726	0.109	-2662	2662	-2662	2662				
2C	0.0437	0.109					-1603	1603	-1603	1603
4A*	11.040	0.109								
2A	0.0378	0.109								
4B*	5.5923	0.109								
2B-1	0.0351	0.109								
pressure stress*			-1066	-1066	-1066	-1066	-1066	-1066	-1066	-1066
Total long stress			-4275	1049	-4275	1049	-3512	-306	-3512	-306
Primary membrane long stress*			-1613.	-1613.	-1673.	-1673.	-1909	-1909.	-1909	-1909
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-5259	-3774	-5259	-3774	-6195	-3478	-6195	-3478
Membrane Stress			-1066	-1066	-1066	-1066	-1066	-1066	-1066	-1066
MaxCombined stress			-6325	-4840	-6325	-4840	-7261	-4544.	-7261.	-4544.

10" Roughing Pmp

Opening 10" Reinforcement Calculations Per UG-37

Located on: BE-5
Local vessel thickness: .25 in
Liquid static head included: 0 psi
Flange description: Not installed

Nozzle material specification: SA 240 304L HIGH

Pad material specification: SA 240 304L HIGH

Nozzle orientation: 90 degrees
End of nozzle to shell center: 39.375 in
Nozzle offset from center Lo: 0 in
Projection outside vessel Lpr: 3 in

```
     tn ->| |<-                 corrosion allow = 0 in
dp->|      _        _      |<-  noz thick new tn= .25 in
    |     | |<- d ->| |tw1 |    nozzle id. new d= 9.5 in
->| |<tw2 | |       > | |<-|    pad diameter dp = 12 in
__|  ___/ | |       | \___      pad thickness te= .25 in
te|/|     | |       | |    |\   fillet weld tw1 = .25 in
__________|_|_v     | |________ fillet weld tw2 = .1875 in
_________/|_|_tw3   |_|\_______ groove weld tw3 = .25 in
             ^
<----- L ------>|               To datum L= 156 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.5 in
Normal to the vessel wall outside 2.5*(t-C) = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 0*4.75/(14700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 0*36.125/(14700*1 - 0.6*0)
= 0 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, Sp = 14700 psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1

10" Roughing Pmp

fr2 = lesser of 1 or Sn/Sv so fr2 = 1
fr3 = lesser of fr2 or Sp/Sv so fr3 = 1
fr4 = lesser of 1 or Sp/Sv so fr4 = 1

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 9.5*0*1 + 2*0.25*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 2.375 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= 2.375 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= .25 in^2

A2 = smaller of the following = 0.313 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0)*1*0.25
= .313 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.25 - 0)*(2.5*0.25 + 0.25)*1
= .438 in^2

A41 = Leg^2*fr3
= 0.25^2*1 = .063 in^2

A42 = Leg^2*fr4
= 0.1875^2*1 = .035 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (12 - 9.5 - 2*0.25)*0.25*1
= .5 in^2

Area = A1 + A2 + A41 + A42 + A5
= 2.375 + 0.313 + 0.063 + 0.035 + 0.5
= 3.286 in^2

As Area > A the reinforcement is adequate for MAWP = 0 at 400 Deg F

Check the welds - From UW-16(c)(2)

Inner Fillet: tmin = lesser of 0.75 or tn or te, tmin = 0.25 in
tw(min) = 0.7*tmin = 0.175 in
tw(actual) = 0.7*Leg = 0.7*0.25 = 0.175 in

Outer Fillet: tmin = lesser of 0.75 or te or t, tmin = 0.25 in
tw(min) = 0.5*tmin = 0.125 in

10" Roughing Pmp

tw(actual) = 0.7*Leg = 0.7*0.1875 = 0.13125 in

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a): tr1 = 0 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.319375 in
The greater of tr2 or tr3: tr5 = 0.0625 in
The lesser of tr4 or tr5: tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for MAWP.

Allowable stresses in joints UG-45(c) and UW-15(c)

Groove weld in tension = 0.74*14700 = 10878 psi
Nozzle wall in shear = 0.7*14700 = 10290 psi
Inner fillet weld in shear = 0.49*14700 = 7203 psi
Outer fillet weld in shear = 0.49*14700 = 7203 psi

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*10*0.25*7203 = 28271.78 lbf

(2) Outer fillet weld in shear
(Pi/2)*Pad O.D.*Leg*So = 1.57*12*0.1875*7203 = 25444.6 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*9.75*0.25*10290 = 39378.55 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*10*0.25*10878 = 42696.15 lbf

Loading on welds per UG-41(b)(1)

W = (A - A1 + 2*tn*fr1*(E1*t - F*tr))*Sv
= (0 - 2.375 + 2*0.25*1*(1*0.25 - 1*0))*14700
=-33075 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.313 + 0.5 + 0.063 + 0.035)*14700
= 13391.7 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.313 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*14700
= 7364.7 lbf

W3-3 = (A2 + A3 + A5 + A41 + A42 + A43 + 2*tn*t*fr1)*Sv
= (0.313 + 0 + 0.5 + 0.063 + 0.035 + 0 + 2*0.25*0.25*1)*14700

= 15229.2 lbf

Load for path 1-1 lesser of W or W1-1 =-33075 lbf
Path 1-1 Thru (2) & (3) = 25444.6 + 39378.55 = 64823.14 lbf
Path 1-1 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 2-2 lesser of W or W2-2 =-33075 lbf
Path 2-2 Thru (1), (4) = 28271.78 + 42696.15 = 70967.93 lbf
Path 2-2 is stronger than W so it is acceptable per UG-41(b)(2).

Load for path 3-3 lesser of W or W3-3 =-33075 lbf
Path 3-3 Thru (2), (4) = 25444.6 + 42696.15 = 68140.75 lbf
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Pad strength = A5*Sp = 7350 lbf
Outer fillet weld strength is adequate.

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 9.5 in
Normal to the vessel wall outside 2.5*(t-C) = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Nozzle required thickness

L/Do = 3/10 = .3 Do/t = 10/0.0222 = 450.4505
From table G: A = 0.000501
From table HA-3: B = 4976.5

Pa= 4*B/(3*Do/t)
= 4*4976.5/(3*10/0.0222)
= 14.7304 psi

Nozzle required thickness trn = .0222 in

Required thickness tr from UG-37(d)(1) = .2135 in

Area required

Allowable stresses: Sn = 14700, Sv = 14700, Sp = 14700 psi

fr1 = lesser of 1 or Sn/Sv so fr1 = 1
fr2 = lesser of 1 or Sn/Sv so fr2 = 1
fr3 = lesser of fr2 or Sp/Sv so fr3 = 1
fr4 = lesser of 1 or Sp/Sv so fr4 = 1

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(9.5*0.2135*1 + 2*0.25*0.2135*1*(1 - 1))
= 1.0141 in^2

Area available

10" Roughing Pmp

A1 = larger of the following = .347 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.2135) - 2*0.25*(1*0.25-1*0.2135)*(1-1)
= .347 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.25)*(1*0.25-1*0.2135) - 2*0.25*(1*0.25-1*0.2135)*(1-1)
= .037 in^2

A2 = smaller of the following = 0.285 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0222)*1*0.25
= .285 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.25 - 0.0222)*(2.5*0.25 + 0.25)*1
= .399 in^2

A41 = Leg^2*fr3
= 0.25^2*1 = .063 in^2

A42 = Leg^2*fr4
= 0.1875^2*1 = .035 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (12 - 9.5 - 2*0.25)*0.25*1
= .5 in^2

Area = A1 + A2 + A41 + A42 + A5
= 0.347 + 0.285 + 0.063 + 0.035 + 0.5
= 1.23 in^2

As Area > A the reinforcement is adequate for Pe = 14.7 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.0222 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0361 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.319375 in
The greater of tr2 or tr3:	tr5 = 0.0625 in
The lesser of tr4 or tr5:	tr6 = 0.0625 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.0625 in

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.

10" Roughing Pmp

Applied Loads

Radial load Pr = 1042 lbf
Circumferential moment Mc = 0 lbf-ft
Circumferential shear Vc = 0 lbf
Longitudinal moment ML = 0 lbf-ft
Longitudinal shear VL = 0 lbf
Torsion moment Mt = 0 lbf-ft
Internal pressure P = 0 psi

Stresses at the nozzle OD per WRC bulletin 107 (psi)

Mean radius Rm = 36.25 in
Rm/t = 72.5

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(4.75/5.25)^2 + 3*(4.75/5.25)^4)
= 2.117

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ $\frac{(14.7)(36.25)}{.50\text{ in}} \times 2.117 = 2256$ psi

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ $\frac{14.7\ (36.25)}{2(.50)} = 533$ psi

Maximum combined stress = ~~-2680 psi~~
Allowable combined stress = +-1.5*S = +- 22050 psi 2680psi + 2256psi + 533psi = 5469 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = ~~644 psi~~
Allowable primary membrane stress = +-1.5*S = +- 22050 psi 644psi + 2256psi + 533psi = 3433 psi

The maximum primary membrane stress is within allowable limits.

10" Roughing Pmp

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	8.3260	0.121					-479	-479	-479	-479
4C*	11.196	0.121	-644	-644	-644	-644				
1C	0.0880	0.121					-2201	2201	-2201	2201
2C-1	0.0550	0.121	-1375	1375	-1375	1375				
3A*	2.7955	0.121								
1A	0.0836	0.121								
3B*	7.8807	0.121								
1B-1	0.0333	0.121								
pressure stress*			-2256	-2256	-2256	-2256	-2256	-2256	-2256	-2256
Total circ stress			-4275	-1525	-4275	-1525	-4936	-534	-4936	-534
Primary membrane circ stress*			-2900	-2900	-2400	-2900	-2735	-2735	-2735	-2735
3C*	8.3260	0.121	-479	-479	-479	-479				
4C*	11.196	0.121					-644	-644	-644	-644
1C-1	0.0885	0.121	-2213	2213	-2213	2213				
2C	0.0565	0.121					-1413	1413	-1413	1413
4A*	4.8491	0.121								
2A	0.0433	0.121								
4B*	2.7447	0.121								
2B-1	0.0488	0.121								
pressure stress*			-533	-533	-533	-533	-533	-533	-533	-533
Total long stress			-3225	1201	-3225	1201	-2590	236	-2590	236
Primary membrane long stress*			-1012	-1012	-1012	-1012	-1177	-1177	-1177	-1177
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-4275	-2900	-4275	-2900	-4936	-2735	-4936	-2735
Membrane Stress			-533	-533	-533	-533	-533	-533	-533	-533
Max Combined stress			-4808	-3433	-4808	-3433	-5469	-3268	-5469	-3268

10" Roughing Pmp

Stresses at the pad edge per WRC bulletin 107 (psi)

Mean radius Rm = 36.25 in
Rm/t = 145

Stress concentration factor Kn (tension) = 1
Stress concentration factor Kb (bending) = 1

Pressure stress intensity factor, Farr equation 11.5

I = .25*(4 + 3*(r/x)^2 + 3*(r/x)^4)
= .25*(4 + 3*(4.75/6.1875)^2 + 3*(4.75/6.1875)^4)
= 1.702

Local circ. pressure stress = I*P*Rm/t = ~~0 psi~~ $\frac{(14.7)(36.25)}{.25} \times 1.702 = 3628$ psi

Local long. pressure stress = P*Rm/2t = ~~0 psi~~ $\frac{(14.7)(36.25)}{2(.25)} = 1066$ psi

Maximum combined stress = -~~7218 psi~~
Allowable combined stress = +-1.5*S = +- 22050 psi

7218 psi + 3628 psi + 1066 psi = 11912 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = -~~1998 psi~~
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

1998 + 3628 + 1066 = 6692 psi

The maximum primary membrane stress is within allowable limits.

10" Roughing Pmp

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	9.0084	0.145					-1036	-1036	-1036	-1036
4C*	17.379	0.145	-1998	-1998	-1998	-1998				
1C	0.0618	0.145					-6182	6182	-6182	6182
2C-1	0.0259	0.145	-2591	2591	-2591	2591				
3A*	5.3595	0.145								
1A	0.0653	0.145								
3B*	12.060	0.145								
1B-1	0.0175	0.145								
pressure stress*			-3628	-3628	-3628	-3628	-3628	-3628	-3628	-3628
Total circ stress			-8217	-3035	-8217	-3035	-10846	1518	-10846	1518
Primary membrane circ stress*			-5626	-5626	-5626	-5626	-4664	-4664	-4664	-4664
3C*	9.0084	0.145	-1036	-1036	-1036	-1036				
4C*	17.379	0.145					-1998	-1998	-1998	-1998
1C-1	0.0547	0.145	-5472	5472	-5472	5472				
2C	0.0370	0.145					-3701	3701	-3701	3701
4A*	12.155	0.145								
2A	0.0304	0.145								
4B*	5.0456	0.145								
2B-1	0.0232	0.145								
pressure stress*			-1066	-1066	-1066	-1066	-1066	-1066	-1066	-1066
Total long stress			-7574	3370	-7574	3370	-6765	637	-6765	637
Primary membrane long stress*			-2162	-2102	-2102	-2102	-3064	-3064	-3064	-3064
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-8217	-5626	-8217	-5626	-10846	-4664	-10846	-4664
Membrane Stress			-1066	-1066	-1066	-1066	-1066	-1066	-1066	-1066
Max Combined Stress			-9283	-6692	-9283	-6692	-11912	-5730	-11912	-5730

Support Ring

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Identifier:		Support Ring
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		1
Distance first ring to datum line:		200 in
Ring description:		4x3x1/4 Un Equal Ang
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.69 in^2
Ring moment of inertia:	Ir =	2.77 in^4

Calculations for ring 200 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21354 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	54 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.69/54))
= 3275.939

From table HA-3 (ring) A = 2.481685E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*54*(0.21354 + 1.69/54)*2.481685E-04)/10.9
= 1.593146 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 54 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 2.76 + 0.25/2

Support Ring

= 2.885 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 1.69*2.885/(1.172787 + 1.69)
 = 1.703113 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 4.691149*0.25^3/12 + 1.172787*1.703113^2
 = 3.407887 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 2.77 + 1.69*(1.703113 - 2.885)^2
 = 5.130688 in^4

Total available I = I1 + I2 = 8.538576 in^4

The 4x3x1/4 Un Equal Ang vacuum stiffener is satisfactory.

Stiffner Rings (Flange End)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Identifier:		Stiffner Rings (Flange End)
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		3
Distance first ring to datum line:		40 in
Ring spacing:		52 in
Ring description:		2.5x2.5x1/4 Equal A
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.19 in^2
Ring moment of inertia:	Ir =	0.703 in^4

Calculations for ring 144 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21354 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	54 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/54))
= 3404.698

From table HA-3 (ring) A = 2.578282E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*54*(0.21354 + 1.19/54)*2.578282E-04)/10.9
= 1.592563 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 54 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2

= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 92 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.21354 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 72.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 52 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/52))
= 3392.492

From table HA-3 (ring) A = 2.569126E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*52*(0.21354 + 1.19/52)*2.569126E-04)/10.9
= 1.533632 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

Stiffner Rings (Flange End)

W = Ls = 52 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 40 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.21354 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 72.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 47.56274 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/47.56274))
= 3362.132

From table HA-3 (ring) A = 2.546351E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*47.56274*(0.21354 + 1.19/47.56274)*2.546351E-04)/10.9
= 1.402884 in^4

Stiffner Rings (Flange End)

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 47.56274 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Stiffner Rings (Bellows End)

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Identifier:		Stiffner Rings (Bellows End)
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		3
Distance first ring to datum line:		252 in
Ring spacing:		48 in
Ring description:		2.5x2.5x1/4 Equal A
Ring is rolled:		leg in (hard way)
Ring cross sectional area:	As =	1.19 in^2
Ring moment of inertia:	Ir =	0.703 in^4

Calculations for ring 348 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21354 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	32.44767 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/32.44767))
= 3205.525

From table HA-3 (ring) A = 2.428844E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*32.44767*(0.21354 + 1.19/32.44767)*2.428844E-04)/10.9
= .9574919 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 32.44767 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2

Stiffner Rings (Bellows End)

= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 300 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.21354 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 72.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 48 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/48))
= 3365.347

From table HA-3 (ring) A = 2.548763E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*48*(0.21354 + 1.19/48)*2.548763E-04)/10.9
= 1.415768 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

Stiffner Rings (Bellows End)

W = Ls = 48 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

Calculations for ring 252 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21354 in
Corroded shell thickness:	ts =	0.25 in
Shell outer diameter:	Do =	72.75 in
Design temperature:	=	400 deg F
External design pressure:	P =	14.7 psi
Stiffener supported length:	Ls =	50 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21354 + 1.19/50))
= 3379.408

From table HA-3 (ring) A = 2.559311E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*50*(0.21354 + 1.19/50)*2.559311E-04)/10.9
= 1.4747 in^4

Stiffner Rings (Bellows End)

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 4.691149

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(72.75*0.25)
= 4.691149 in

W = Ls = 50 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2
= 1.783 + 0.25/2
= 1.908 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
= 1.19*1.908/(1.172787 + 1.19)
= .9609499 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
= 4.691149*0.25^3/12 + 1.172787*0.9609499^2
= 1.089089 in^4

Inertia of the ring about the combined section NA

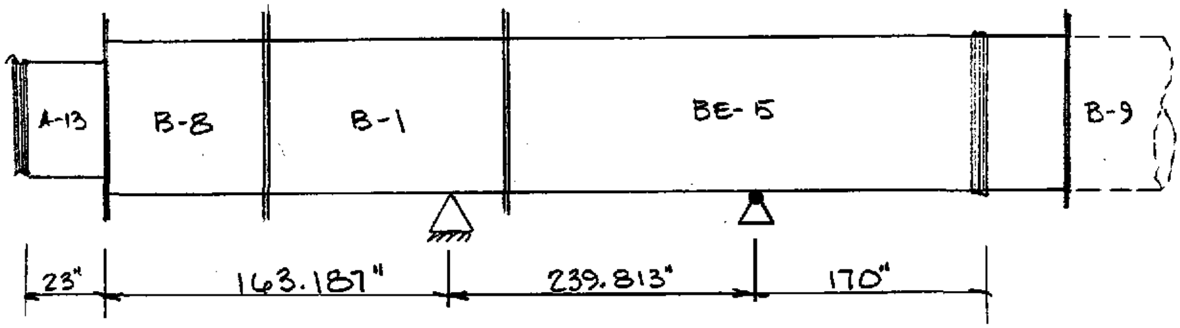
I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

Total available I = I1 + I2 = 2.859405 in^4

The 2.5x2.5x1/4 Equal A vacuum stiffener is satisfactory.

CHECK LONGITUDINAL STRESSES IN VACUUM SHELL

BE-5, B-1, B-8 OD = 72.75" I.D. = 72.25"



MATERIAL-TYPE 304L

$E = 28.3 \times 10^6$ PSI @ 70°F
$E = 26.5 \times 10^6$ PSI @ 400°F

PROPERTIES OF BEAM TUBE MANIFOLD

$$A = \frac{\pi (D_o^2 - D_i^2)}{4} = \frac{\pi}{4}\left[(72.75\text{in})^2 - (72.25\text{in})^2\right]$$

$$A = 56.94 \text{ IN}^2$$

$$I = \frac{\pi}{64}(D_o^4 - D_i^4) = \frac{\pi}{4}\left[(72.75\text{in})^4 - (72.25\text{in})^4\right]$$

$$I = 37412.7 \text{ IN}^4$$

$$S = \frac{\pi}{32}(D_o^4 - D_i^4)/D_o = \frac{\pi}{32}\left[\frac{(72.75\text{in})^4 - (72.25\text{in})^4}{72.75\text{in}}\right]$$

$$S = 1028.5 \text{ IN}^3$$

REFERENCE

ASME CODE UG-23
SECTION VIII, DIVISION 1

$$A = \left(\frac{0.125}{R_o / t}\right) = \left(\frac{0.125}{36.375'' / 0.25''}\right)$$

$$A = 0.000859$$

GO TO FIG HA-3

CHART FOR AUSTENTIC STEEL, TYPE 304L

FOR $A = 0.000859$ @ 400°F

$\sigma_{all} \cong 5400$ psi

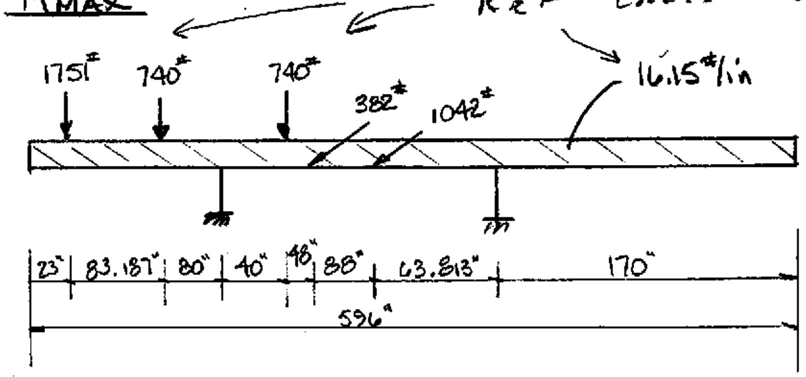
AXIAL BENDING & VACUUM STRESS

$$f_a = \frac{PR_o}{2t} + \frac{Mc}{I}$$

$$= \frac{(14.7\,\#/in^2)(36.375\,in)}{(2)(0.250\,in)} + \frac{M}{S}$$

MMAX

REF CALCS 085 & 088



$$w = \left(\frac{490\,lbs}{FT^3}\right)\left(\frac{FT^3}{1728\,in^3}\right)\left[\frac{\pi\,(72.75\,in)^2 - (72.25\,in)^2}{4}\right] = 16.15\,\#/in$$

CONSERVATIVELY ASSUME TWO PINNED SUPPORTS

BENDING MOMENT @ LEFT END

$$M_L = \frac{(16.15\,\#/\text{in})(186.187\,\text{in})^2}{2} + (1751\,\#)(163.187\,\text{in}) + (740\,\#)(80\,\text{in})$$

$$= 624865\ \text{in-lbs}$$

BENDING MOMENT BETWEEN SUPPORTS

$$M = \frac{(16.15\,\#/\text{in})(239.813\,\text{in})^2}{8} + \frac{740\,\text{lbs}\,(40)(199.813)}{239.813\,\text{in}} +$$

$$\frac{382\,\text{lbs}\,(88\,\text{in})(151.813)}{239.813\,\text{in}} + \frac{1042\,\text{lbs}\,(176\,\text{in})(63.813\,\text{in})}{239.813\,\text{in}}$$

$$M = 210843.\ \text{in-lbs}$$

BENDING MOMENT @ RIGHT END

$$M_R = \frac{(16.15\,\#/\text{in})(170\,\text{in})^2}{2}$$

$$M_R = 233368.\ \text{in-lbs}$$

$$\therefore M_{MAX} = 624865\ \text{in-lbs.}$$

UG-20 DESIGN TEMPERATURE

(a) Maximum. Except as required in UW-2(d)(3), the maximum temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered (see 3-2). If necessary, the metal temperature shall be determined by computation or by measurement from equipment in service under equivalent operating conditions.

(b) Minimum. The minimum metal temperature used in design shall be the lowest expected in service except when lower temperatures are permitted by the rules of this Division (see UCS-66). The minimum mean metal temperature shall be determined by the principles described in (a) above. Consideration shall include the lowest operating temperature, operational upsets, autorefrigeration, atmospheric temperature, and any other sources of cooling [except as permitted in (f)(3) below].

(c) Design temperatures listed in excess of the maximum temperatures listed in the tables referenced in UG-23 are not permitted. In addition, design temperatures for vessels under external pressure shall not exceed the maximum temperatures given on the external pressure charts.

(d) The design of zones with different metal temperatures may be based on their determined temperatures.

(e) Suggested methods for obtaining the operating temperature of vessel walls in service are given in Appendix C.

(f) Impact testing per UG-84 is not mandatory for pressure vessel materials which satisfy all of the following.

(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a), shall not exceed that given in (a) or (b) below:

(a) $^1/_2$ in. for materials listed in Curve A of Fig. UCS-66;

(b) 1 in. for materials listed in Curve B, C, or D of Fig. UCS-66.

(2) The completed vessel shall be hydrostatically tested per UG-99(b), (c), or (k).

(3) Design temperature is no warmer than 650°F nor colder than −20°F. Occasional operating temperatures colder than −20°F are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

UG-21 DESIGN PRESSURE[8]

Vessels covered by this Division of Section VIII shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition and for test conditions, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered [see UG-98, UG-99(e), and 3-2].

UG-22 LOADINGS

The loadings to be considered in designing a vessel shall include those from:

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions (this includes additional pressure due to static head of liquids);

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of:

(1) internals (see Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion.

UG-23 MAXIMUM ALLOWABLE STRESS VALUES[9]

(a) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in Subpart 1 of Section II, Part D. A listing of these materials are given in the following tables, which are included in Subsection C.

---

[8] It is recommended that a suitable margin be provided above the pressure at which the vessel will be normally operated to allow for probable pressure surges in the vessel up to the setting of the pressure relieving devices (see UG-134).

[9] For the basis on which the tabulated stress values have been established, see Appendix 1 of Section II, Part D.

TABLE UG-23.1
MAXIMUM METAL TEMPERATURE FOR WHICH FACTOR OF 1.2 IS APPLICABLE

Table in Which Material Is Listed	Temp., °F
UCS-23	700
UNF-23.1	300
UNF-23.2	150
UNF-23.3	900
UNF-23.4	600
UNF-23.5	600
UHA-23	800
UHT-23	700

Table UCS-23 Carbon and Low Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other carbon steels)

Table UNF-23 Nonferrous Metals (stress values in Section II, part D, Table 3 for bolting, and Table 1B for other nonferrous metals)

Table UHA-23 High Alloy Steel (stress values in Section II, Part D, Table 3 for bolting, and Table 1A for other high alloy steels)

Table UCI-23 Maximum Allowable Stress Values in Tension for Cast Iron

Table UCD-23 Maximum Allowable Stress Values in Tension for Cast Ductile Iron

Table UHT-23 Ferritic Steels with Properties Enhanced by Heat Treatment (stress values in Section II, Part D, Table 1A)

Table ULT-23 Maximum Allowable Stress Values in Tension for 5%, 8%, and 9% Nickel Steels and 5083-0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction

(b) The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined by the following procedure where

t = the minimum required thickness of the cylindrical shell or tube, in.
R_o = outside radius of cylindrical shell or tube, in.
E = modulus of elasticity of material at design temperature, psi. The modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3.[10] (Interpolation may be made between lines for intermediate temperatures.)

The joint efficiency for butt-welded joints shall be taken as unity.

The value of B shall be determined as follows.

Step 1. Using the selected values of t and R, calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R_o/t)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature (see UG-20). Interpolation may be made between lines for intermediate temperatures.

In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of t and R_o used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B, psi, shall be calculated using the following formula:

$$B = \frac{AE}{2}$$

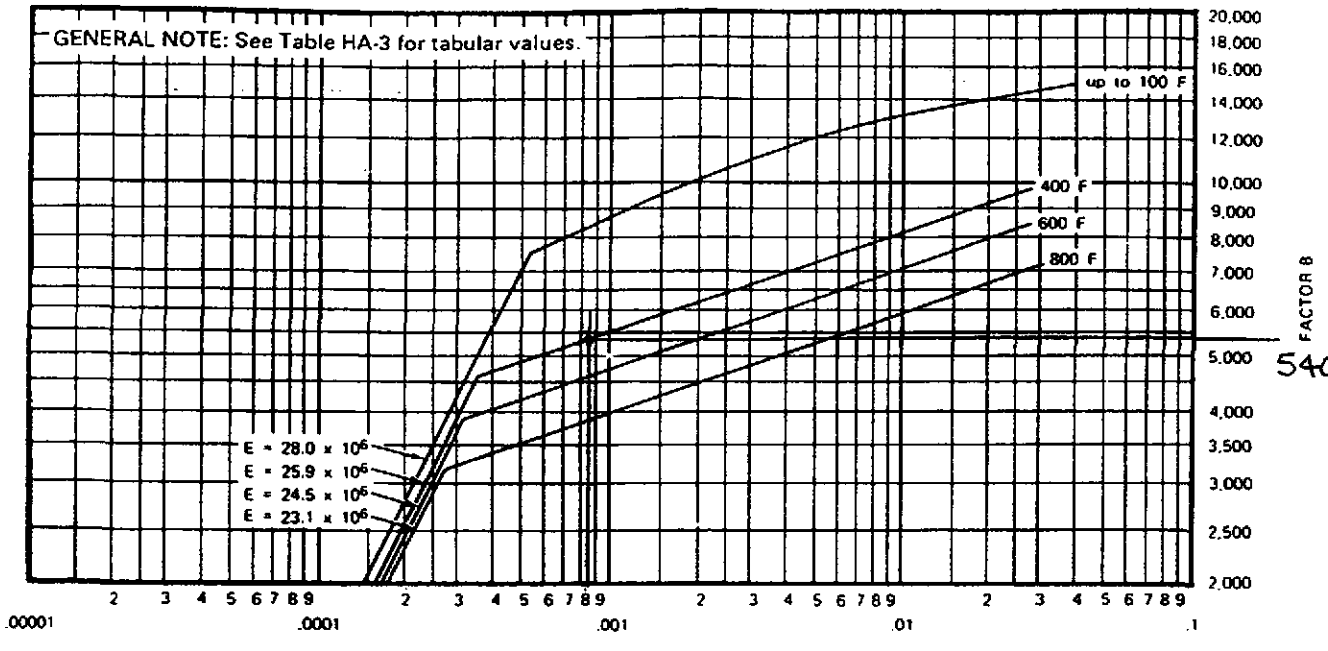
Step 5. Compare the value of B determined in Steps 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of t and R_o. If the value of B is smaller than the computed compressive stress, a greater value of t must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

The joint efficiency for butt welded joints may be taken as unity.

(c) The wall thickness of a vessel computed by these rules shall be determined such that, for any combi-

---

[10] Note that the modulus of elasticity values listed in UF-27 of this Division shall not be used for axial compression design.



5400psi

A= 0.00086

FIG. HA-3 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–0.035 MAXIMUM CARBON, TYPE 304L) [NOTE (1)]

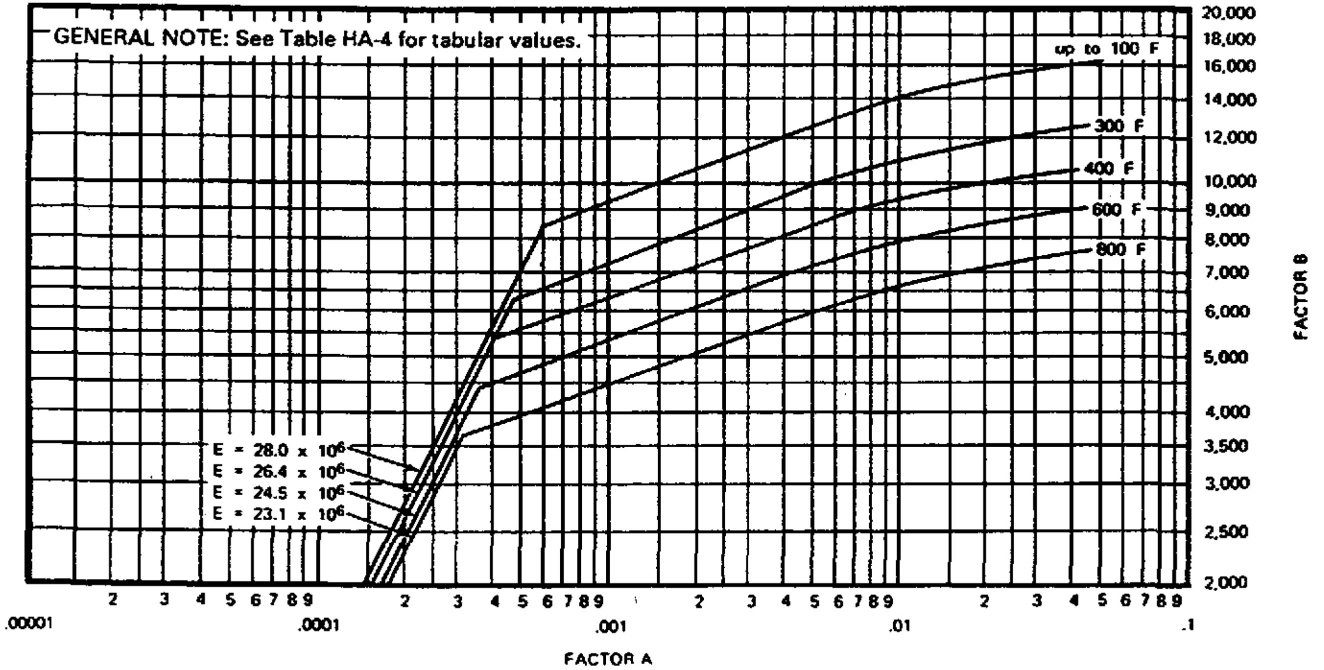


FIG. HA-4 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–Mo–0.035 MAXIMUM CARBON, TYPES 316L AND 317L) [NOTE (1)]

TABLE HA-3
TABULAR VALUES FOR FIG. HA-3

Temp., °F	A	B, psi	Temp., °F	A	B, psi
100	0.100 -04	0.139 +03	600	0.100 -04	0.121 +03
	0.524 -03	0.767 +04		0.313 -03	0.393 +04
	0.200 -02	0.103 +05		0.100 -02	0.484
	0.600	0.125		0.100 -01	0.722
	0.100 -01	0.144		0.100 +00	0.855
	0.100 +00	0.153			
400	0.100 -04	0.128 +03	800	0.100 -04	0.114 +03
	0.352 -03	0.468 +04		0.270 -03	0.322 +04
	0.100 -02	0.562		0.150 -02	0.435
	0.100 -01	0.834		0.100 -01	0.606
	0.100 +00	0.987		0.100 +00	0.736

0.859 -03 →

TABLE HA-4
TABULAR VALUES FOR FIG. HA-4

Temp., °F	A	B, psi	Temp., °F	A	B, psi
100	0.100 -04	0.140 +03	400	0.100 -04	0.133 +03
	0.587 -03	0.857 +04		0.402 -03	0.547 +04
	0.700 -02	0.135 +05		0.700 -02	0.916
	0.100 -01	0.143		0.100 -01	0.958
	0.200	0.155		0.400	0.108 +05
	0.500	0.166		0.100 +00	0.108
	0.100 +00	0.166			
			600	0.100 -04	0.122 +03
300	0.100 -04	0.133 +03		0.355 -03	0.448 +04
	0.466 -03	0.638 +04		0.500 -02	0.738
	0.500 -02	0.102 +05		0.100 -01	0.812
	0.600	0.104		0.500	0.936
	0.100 -01	0.112		0.100 +00	0.936
	0.500	0.129			
	0.100 +00	0.129	800	0.100 -04	0.116 +03
				0.316 -03	0.373 +04
				0.500 -02	0.610
				0.100 -01	0.675
				0.500	0.788
				0.100 +00	0.788

$$f_a = \frac{(14.7\ \#/in^2)(36.375\ in)^{*}}{2(.250\ in)} + \frac{624865\ in\text{-}lbs}{1028.5\ in^3}$$

$$= 1069.4\ \#/in^2 + 607.5\ lb/in^2$$

$$f_a = 1676.925\ lb/in^2$$

$$F_a = 5400\ lb/in^2$$

$$f_a < F_a \therefore \underline{O.K}$$

* $\frac{pr}{2t}$ IS CONSERVATIVE SINCE BELLOWS LIMITS AXIAL LOAD TO A LOWER VALUE THAN FULL END CAP FORCE

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-077

PAGE 1 OF 56

REV.	DEO #	DATE	BY:	CHECK
0	0128	4-2-96	AGR	WDB

TITLE: ADAPTER SPOOL PIECE DESIGNS

By: ART ROUSSOPOULOS **DEPT.:** 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: QUALIFY SPOOL PIECES BY DESIGN SIMILARITY

METHOD: · CLASSICAL DESIGN SIMILARITY

ASSUMPTIONS: SEE CALCS

INPUTS: "STRUCTURAL DESIGN CRITERIA" DOC. NO. V049-1-66

REFERENCES: DOC. NO. V049-1-075
DOC. NO. V049-1-076
DOC. NO. V049-1-066, LIGO VAC. EQUIP. STRUCT. DESIGN CRITERIA.

CALCULATIONS: **(SEE ATTACHED)**

CONCLUSIONS: ALL SPOOL PIECES AS SHOWN IN DESIGN SKETCHES ARE IN CONFORMANCE WITH ASME VIII REQUIREMENTS VIA SIMILARITY QUALIFICATION TO REFERENCED DOCUMENTS.

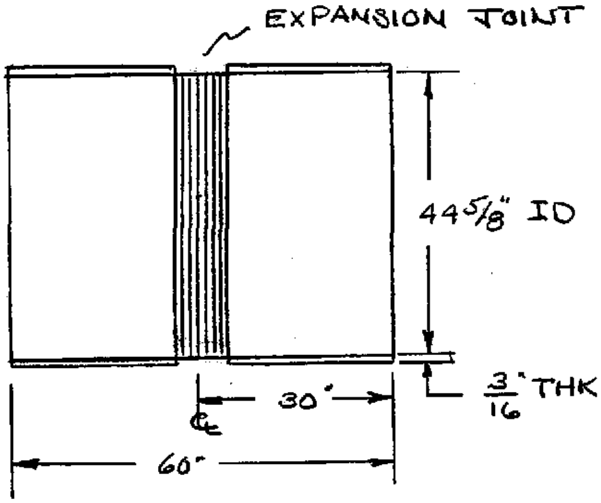
NOTES: SEE P. 2 FOR COMPRESS FILE NAMES FILED IN DIRECTORY :\41896\SP_ ....

TABLE OF CONTENTS

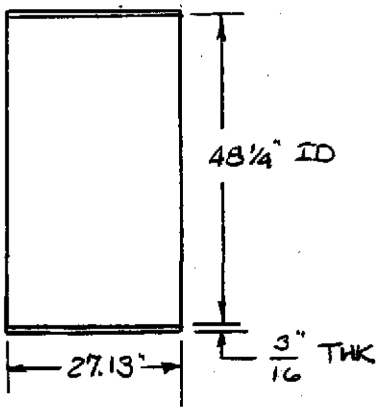
1.0 DESIGN SKETCH

SK-V049-1-077 REVO SHT 1 OF 4

1.1- ADAPTER / SPOOL A-1 REF: DWG. V049-4-A1

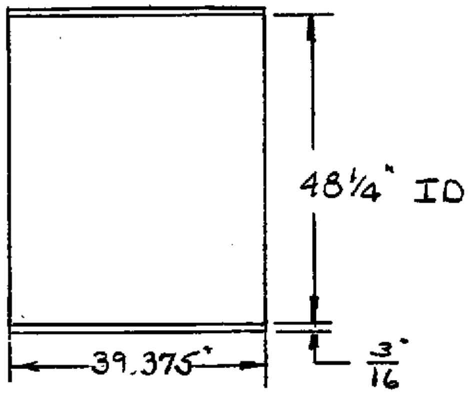


1.2. - ADAPTER / SPOOL A-2 REF: DWG. V049-4-A2

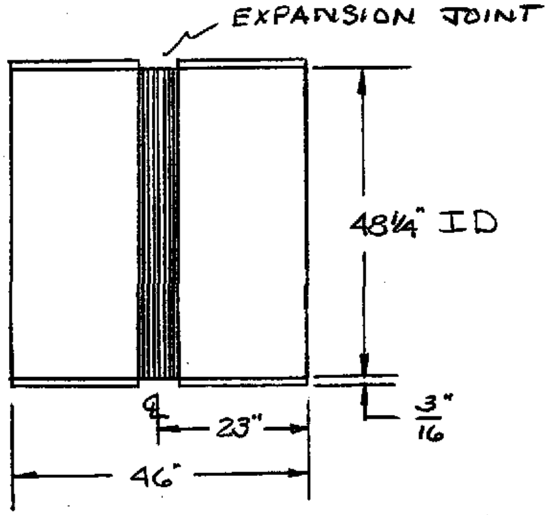


SK-V049-1-077 REV0 SHT 2 OF 4

1.3. - ADAPTER/SPOOL A-3 REF: DWG. V049-4-A3

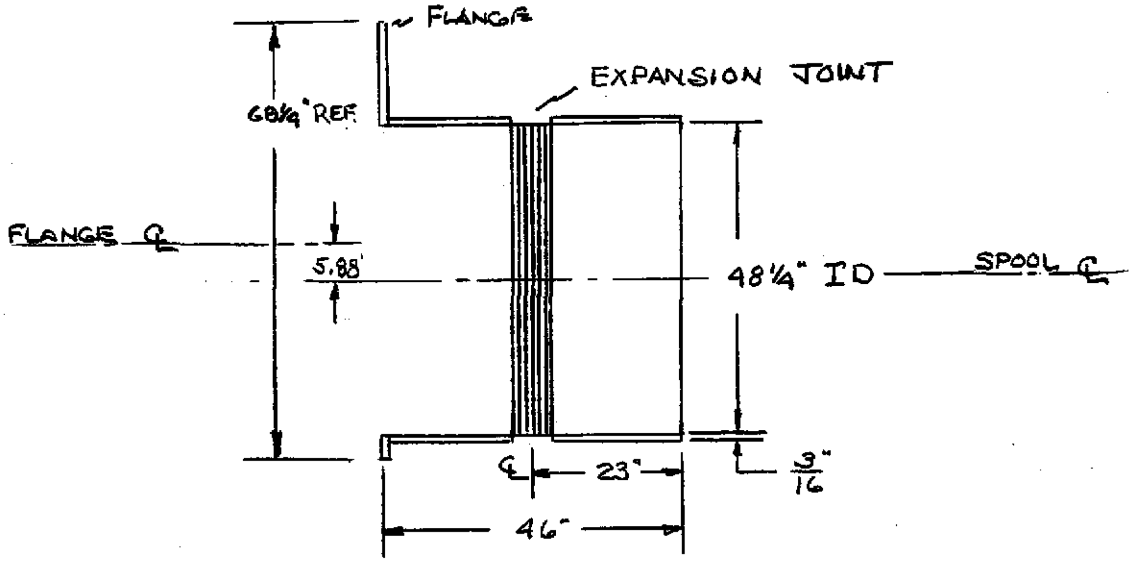


1.4. - ADAPTER/SPOOL A-6 REF: DWG. V049-4-A6

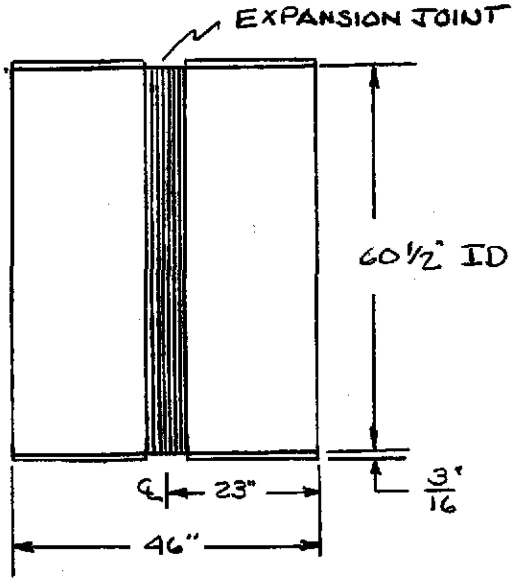


SK-V049-1-077 REVO SHT 3 OF 4

1.5. - ADAPTER/SPOOL A-12 REF: DWG. V049-4-A12

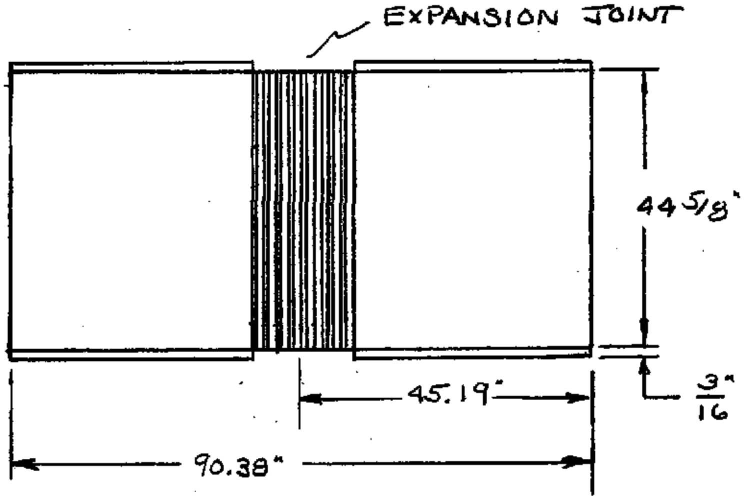


1.6. - ADAPTER/SPOOL A-13 REF: DWG. V049-4-A13

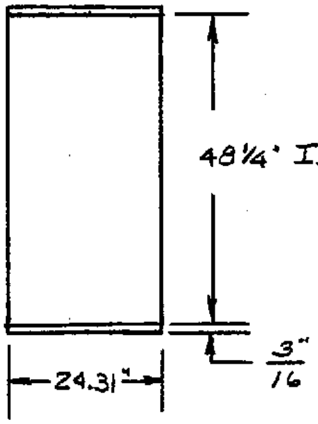


SK-V049-1-077 REVO SHT 4 OF 4

1.7- ADAPTER/SPOOL A-14 REF: DWG V049-4-A14



1.8.- ADAPTER/SPOOL A-15 REF: DWG. V049-4-A15



2.- QUALIFICATION

QUALIFICATION WILL BE BASED ON ANALYZING THE WORSE CASE LENGTH FOR EACH SIMILAR ADAPTER / SPOOL DIAMETER

2.1 • 44 5/8" ID FOR SPOOLS: A-1 + A-14

- WORSE CASE LENGTH = 45.19" FOR A-14
- CHECK PROTECTED EXPANSION JOINT AXIAL COMPRESSIVE CYLINDER/SPOOL PIECE STRESS VERSUS MAXIMUM ALLOWABLE LONGITUDINAL COMPRESSIVE STRESS PER ASME VIII, SECTION UG-23.
- PROTECTED EXPANSION JOINT CIRCUMFERENTIAL COMPRESSIVE STRESS: 63.3#/IN (DATA TAKEN FROM 60 1/2" ID EXPANSION JOINT FOR A WORSE CASE 2 IN COMPRESSION SPRING RATE) ∴ 100#/IN LONGITUDINAL COMPRESSIVE STRESS FOR A 2" TRAVEL WILL BE USED FOR DESIGN

$$\therefore F_{APPLIED} = \pi D_o (100) = \pi(44.625 + .375)(100) = 14{,}137^{\#}$$

$$\sigma_{APPLIED} = \frac{F}{A_{METAL}} = \frac{14{,}137}{\pi/4\,(45^2 - 44.625^2)} = 536^{\#}/in^2$$

- UG-23 ALLOWABLE LONGITUDINAL STRESS: SHALL BE THE SMALLER OR THE FOLLOWING:

1.- MAXIMUM ALLOWABLE TENSILE STRESS PER ASME II, PART D, SUBPART 1 $\sigma_{ALLOW} = 14{,}700$ PSI AT 400°F

2 - B - DETERMINED BY:

$$A = \frac{.125}{(R_o/t)} = = \frac{.125}{[(45/2)/.154]} = .0009$$

WHERE: t = .154" REQUIRED t FROM COMPRESS OUTPUT FOR A-14

$\sigma_{ALLOW} = 5{,}800$ PSI AT 400°F - FROM FIG. HA-3, ASME II, PART D, SUBPART 3

$\therefore \sigma_{APPLIED} = 536$ PSI $< \sigma_{ALLOW} = 5{,}800$ PSI ∴ OK

2.2 • <u>48¼" ID FOR SPOOLS: A-2, A-3, A-6, A-12 + A-15</u>

- WORSE CASE LENGTH = 46" FOR SPOOLS A-6 + A-12

- APPLIED LONGITUDINAL STRESS σ_{APP}:

$$\sigma_{APP} = \frac{\pi D_o(.1}{A_{METAL}} = \frac{\pi(48.25+.375)(.100)}{\pi/4(48.625^2-48.25^2)} = 535 \text{ PSI}$$

- ALLOWABLE LONGITUDINAL STRESS: σ_{ALLOW}

$\sigma_{ALLOW} = 5800 \text{PSI} > \sigma_{APA} = 535 \text{ PSI} \therefore \text{OK}$

WHERE: $A = \frac{.125}{R_o/t} = \frac{.125}{(24.3125/.1731)} = .0009$

$R_o = 48.625/2 = 24.3125$

$t = .1731"$ (COMPRESS $t_{REQ.}$)

$\sigma_{ALLOW} = 5800$ PSI AT 400°F FROM FIG. HA-3

2.3 • <u>60½" ID FOR SPOOL A-13</u>

$$-\sigma_{APP} = \frac{\pi D_o \times 100}{A_{METAL}} = \frac{\pi(60.5+.375)(.100)}{\pi/4(60.875^2-60.5^2)} = 535 \text{ PSI}$$

$-\sigma_{ALLOW} = 6{,}700 \text{PSI} > \sigma_{APA} = 535 \text{PSI} \therefore \text{OK}$

WHERE: $A = \frac{.125}{R_o/t} = \frac{.125}{30.4375/.1627} = .0007$

$R_o = 60.875/2 = 30.4375"$

$t = .1627"$ (COMPRESS t_{REQ})

$\sigma_{ALLOW} = 6{,}700$ PSI AT 400°F FROM FIG. HA-3

TABLE OF CONTENTS

3.1

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-1	0.0	400.0	104.4	118.6	16.4	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 104.47 psi @ 400 degrees F.

Vessel MAP new & cold is 118.69 psi @ 0 degrees F.

Vessel allowable external pressure is 16.41 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 178 psi

Vessel hydrotest pressure is 178 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

11

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-1	459	459	0	0	0	0	0	0	0	0	3388	0
	459	459	0	0	0	0	0	0	0	0	3388	0

Weight (lbs) Contributed by Vessel Elements

Vessel operating weight, corroded:	459 lbs
Vessel empty weight, corroded:	459 lbs
Vessel empty weight, new:	459 lbs
Vessel test weight, new:	3,847 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	459 lbs
Center of gravity to seam:	30 in

Thickness Summary

```
-----------------------------------------------------------------------------------------
Component              ID       Length     Nom t     Req t    Joint        Governing            Deflect
Identifier            (in)       (in)      (in)      (in)       E    Load     Status   Stress    (in)
-----------------------------------------------------------------------------------------
Spool a-1            44.62      60.00     0.1875    0.1812    0.85  external
-----------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E   - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind   - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-1

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 459.3 corr = 459.3 lb
capacity: new = 406.242 corr = 406.242 US ga

ID = 44.625 length Lc= 60 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 118.6873 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 104.4732 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 71.4375/45 =1.5875 Do/t = 45/0.18126 = 248.2622
From table G: A = 0.00021
From table HA-3: B = 2767.7

Pa= 4*B/(3*Do/t)
= 4*2767.7/(3*45/0.18126)
= 14.8644 psi

Design thickness for external pressure Pa = 14.8644 psi:

= t + Corrosion
= 0.18126 + 0
= 0.18126 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 71.4375/45 =1.5875 Do/t = 45/0.1875 = 240
From table G: A = 0.000224
From table HA-3: B = 2954

3.12.1996

SPOOL A-1

```
Pa= 4*B/(3*Do/t)
  = 4*2954/(3*45/0.1875)
  = 16.4111 psi
```

TABLE OF CONTENTS

3.2

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
SPOOL A-2	0.0	400.0	96.6	109.8	24.5	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 96.66 psi @ 400 degrees F.

Vessel MAP new & cold is 109.81 psi @ 0 degrees F.

Vessel allowable external pressure is 24.59 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 164.7 psi

Vessel hydrotest pressure is 164.7 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Weight (lbs) Contributed by Vessel Elements										
	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-2	224	224	0	0	0	0	0	0	0	0	1791	0
	224	224	0	0	0	0	0	0	0	0	1791	0

Vessel operating weight, corroded: 224 lbs
Vessel empty weight, corroded: 224 lbs
Vessel empty weight, new: 224 lbs
Vessel test weight, new: 2,015 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new: 224 lbs
Center of gravity to seam: 13.6 in

Thickness Summary

Component	ID	Length	Nom t	Req t	Joint		Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E	Load	Status	Stress	(in)
Spool a-2	48.25	27.13	0.1875	0.1454	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-2

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 224.5 corr = 224.5 lb
capacity: new = 214.744 corr = 214.744 US ga

ID = 48.25 length Lc= 27.13 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 109.8118 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 96.66065 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 39.17167/48.625 =0.8056 Do/t = 48.625/0.14547 = 334.2614
From table G: A = 0.00028
From table HA-3: B = 3700.4

Pa= 4*B/(3*Do/t)
= 4*3700.4/(3*48.625/0.14547)
= 14.7605 psi

Design thickness for external pressure Pa = 14.7605 psi:

= t + Corrosion
= 0.14547 + 0
= 0.14547 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 39.17167/48.625 =0.8056 Do/t = 48.625/0.1875 = 259.3333
From table G: A = 0.0004
From table HA-3: B = 4783.3

SPOOL A-2

```
Pa= 4*B/(3*Do/t)
  = 4*4783.3/(3*48.625/0.1875)
  = 24.5928 psi
```

3.12.1996

TABLE OF CONTENTS

3.3

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-3	0.0	400.0	96.6	109.8	20.5	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 96.66 psi @ 400 degrees F.

Vessel MAP new & cold is 109.81 psi @ 0 degrees F.

Vessel allowable external pressure is 20.54 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 164.7 psi

Vessel hydrotest pressure is 164.7 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-3	326	326	0	0	0	0	0	0	0	0	2599	0
	326	326	0	0	0	0	0	0	0	0	2599	0

Vessel operating weight, corroded:	326 lbs
Vessel empty weight, corroded:	326 lbs
Vessel empty weight, new:	326 lbs
Vessel test weight, new:	2,925 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	326 lbs
Center of gravity to seam:	19.7 in

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (in)
Spool a-3	48.25	39.37	0.1875	0.1651	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-3

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 325.8 corr = 325.8 lb
capacity: new = 311.668 corr = 311.668 US ga

ID = 48.25 length Lc= 39.375 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 109.8118 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 96.66065 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 51.41666/48.625 =1.0574 Do/t = 48.625/0.16519 = 294.358
From table G: A = 0.000248
From table HA-3: B = 3273.7

Pa= 4*B/(3*Do/t)
= 4*3273.7/(3*48.625/0.16519)
= 14.8287 psi

Design thickness for external pressure Pa = 14.8287 psi:

= t + Corrosion
= 0.16519 + 0
= 0.16519 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 51.41666/48.625 =1.0574 Do/t = 48.625/0.1875 = 259.3333
From table G: A = 0.000302
From table HA-3: B = 3994.1

SPOOL A-3

```
Pa= 4*B/(3*Do/t)
  = 4*3994.1/(3*48.625/0.1875)
  = 20.5352 psi
```

TABLE OF CONTENTS

3.4

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-6	0.0	400.0	96.6	109.8	18.0	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 96.66 psi @ 400 degrees F.

Vessel MAP new & cold is 109.81 psi @ 0 degrees F.

Vessel allowable external pressure is 18.07 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 164.7 psi

Vessel hydrotest pressure is 164.7 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Weight (lbs) Contributed by Vessel Elements										
	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-6	381	381	0	0	0	0	0	0	0	0	3037	0
	381	381	0	0	0	0	0	0	0	0	3037	0

Vessel operating weight, corroded:	381 lbs
Vessel empty weight, corroded:	381 lbs
Vessel empty weight, new:	381 lbs
Vessel test weight, new:	3,418 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	381 lbs
Center of gravity to seam:	23 in

Thickness Summary

```
------------------------------------------------------------------------------------------------
Component              ID      Length    Nom t     Req t    Joint          Governing              Deflect
Identifier            (in)      (in)      (in)      (in)      E     Load     Status      Stress     (in)
------------------------------------------------------------------------------------------------
Spool a-6             48.25     46.00    0.1875    0.1731   0.85   external
------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-6

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 380.6 corr = 380.6 lb
capacity: new = 364.108 corr = 364.108 US ga

ID = 48.25 length Lc= 46 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 109.8118 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 96.66065 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 58.04166/48.625 =1.1937 Do/t = 48.625/0.17311 = 280.8908
From table G: A = 0.000237
From table HA-3: B = 3127.1

Pa= 4*B/(3*Do/t)
= 4*3127.1/(3*48.625/0.17311)
= 14.8437 psi

Design thickness for external pressure Pa = 14.8437 psi:

= t + Corrosion
= 0.17311 + 0
= 0.17311 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 58.04166/48.625 =1.1937 Do/t = 48.625/0.1875 = 259.3333
From table G: A = 0.000266
From table HA-3: B = 3513.7

SPOOL A-6

```
Pa= 4*B/(3*Do/t)
  = 4*3513.7/(3*48.625/0.1875)
  = 18.0653 psi
```

TABLE OF CONTENTS

3.5

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
SPOOL A-12	0.0	400.0	96.6	109.8	18.0	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 96.66 psi @ 400 degrees F.

Vessel MAP new & cold is 109.81 psi @ 0 degrees F.

Vessel allowable external pressure is 18.07 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 164.7 psi

Vessel hydrotest pressure is 164.7 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-12	381	381	0	0	0	0	0	0	0	0	3037	0
	381	381	0	0	0	0	0	0	0	0	3037	0

Weight (lbs) Contributed by Vessel Elements

Vessel operating weight, corroded:	381 lbs
Vessel empty weight, corroded:	381 lbs
Vessel empty weight, new:	381 lbs
Vessel test weight, new:	3,418 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	381 lbs
Center of gravity to seam:	23 in

3.12.1996

Thickness Summary

Component	ID	Length	Nom t	Req t	Joint		Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E	Load	Status	Stress	(in)
Spool a-12	48.25	46.00	0.1875	0.1724	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-12

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 380.6 corr = 380.6 lb
capacity: new = 364.108 corr = 364.108 US ga

ID = 48.25 length Lc= 46 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 109.8118 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 96.66065 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 58.04166/48.625 =1.1937 Do/t = 48.625/0.17249 = 281.9004
From table G: A = 0.000236
From table HA-3: B = 3113.8

Pa= 4*B/(3*Do/t)
= 4*3113.8/(3*48.625/0.17249)
= 14.7277 psi

Design thickness for external pressure Pa = 14.7277 psi:

= t + Corrosion
= 0.17249 + 0
= 0.17249 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 58.04166/48.625 =1.1937 Do/t = 48.625/0.1875 = 259.3333
From table G: A = 0.000266
From table HA-3: B = 3513.7

SPOOL A-12

```
Pa= 4*B/(3*Do/t)
  = 4*3513.7/(3*48.625/0.1875)
  = 18.0653 psi
```

TABLE OF CONTENTS

3.6

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-13	0.0	400.0	77.1	87.6	19.5	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 77.16 psi @ 400 degrees F.

Vessel MAP new & cold is 87.66 psi @ 0 degrees F.

Vessel allowable external pressure is 19.55 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 131.5 psi

Vessel hydrotest pressure is 131.5 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-13	238	238	0	0	0	0	0	0	0	0	2387	0
	238	238	0	0	0	0	0	0	0	0	2387	0

Vessel operating weight, corroded:	238 lbs
Vessel empty weight, corroded:	238 lbs
Vessel empty weight, new:	238 lbs
Vessel test weight, new:	2,625 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	238 lbs
Center of gravity to seam:	11.5 in

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Governing Load	Governing Status	Governing Stress	Deflect (in)
Spool a-13	60.50	23.00	0.1875	0.1627	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-13

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 238.4 corr = 238.4 lb
capacity: new = 286.231 corr = 286.231 US ga

ID = 60.5 length Lc= 23 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(30.25 + 0.6*0.1875) - 0
= 87.65953 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(30.25 + 0.6*0.1875) - 0
= 77.16138 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 37.08333/60.875 =0.6092 Do/t = 60.875/0.1627 = 374.1549
From table G: A = 0.000315
From table HA-3: B = 4167.7

Pa= 4*B/(3*Do/t)
= 4*4167.7/(3*60.875/0.1627)
= 14.852 psi

Design thickness for external pressure Pa = 14.852 psi:

= t + Corrosion
= 0.1627 + 0
= 0.1627 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 37.08333/60.875 =0.6092 Do/t = 60.875/0.1875 = 324.6667
From table G: A = 0.000389
From table HA-3: B = 4759.9

SPOOL A-13

```
Pa= 4*B/(3*Do/t)
  = 4*4759.9/(3*60.875/0.1875)
  = 19.5478 psi
```

TABLE OF CONTENTS

3.7

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-14	0.0	400.0	104.4	118.6	20.9	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 104.47 psi @ 400 degrees F.

Vessel MAP new & cold is 118.69 psi @ 0 degrees F.

Vessel allowable external pressure is 20.93 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 178 psi

Vessel hydrotest pressure is 178 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-14	346	346	0	0	0	0	0	0	0	0	2552	0
	346	346	0	0	0	0	0	0	0	0	2552	0

Weight (lbs) Contributed by Vessel Elements

Vessel operating weight, corroded:	346 lbs
Vessel empty weight, corroded:	346 lbs
Vessel empty weight, new:	346 lbs
Vessel test weight, new:	2,898 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	346 lbs
Center of gravity to seam:	22.6 in

Thickness Summary

```
------------------------------------------------------------------------------------------------
Component              ID      Length   Nom t    Req t   Joint         Governing            Deflect
Identifier            (in)      (in)    (in)     (in)      E     Load    Status    Stress    (in)
------------------------------------------------------------------------------------------------
Spool a-14            44.62    45.19    0.1875   0.1633  0.85    external
------------------------------------------------------------------------------------------------
```

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-14

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 345.9 corr = 345.9 lb
capacity: new = 305.968 corr = 305.968 US ga

ID = 44.625 length Lc= 45.19 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 118.6873 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(22.3125 + 0.6*0.1875) - 0
= 104.4732 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 56.6275/45 =1.2584 Do/t = 45/0.16331 = 275.5496
From table G: A = 0.000231
From table HA-3: B = 3047.2

Pa= 4*B/(3*Do/t)
= 4*3047.2/(3*45/0.16331)
= 14.7448 psi

Design thickness for external pressure Pa = 14.7448 psi:

= t + Corrosion
= 0.16331 + 0
= 0.16331 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 56.6275/45 =1.2584 Do/t = 45/0.1875 = 240
From table G: A = 0.000285
From table HA-3: B = 3767.1

SPOOL A-14

```
Pa= 4*B/(3*Do/t)
  = 4*3767.1/(3*45/0.1875)
  = 20.9283 psi
```

TABLE OF CONTENTS

3.8

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	P design (psi)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
SPOOL A-15	0.0	400.0	96.6	109.8	24.9	1.136		Not applicable	0.000

Vessel MAWP hot & corroded is 96.66 psi @ 400 degrees F.

Vessel MAP new & cold is 109.81 psi @ 0 degrees F.

Vessel allowable external pressure is 24.94 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1.136 = 164.7 psi

Vessel hydrotest pressure is 164.7 psi.

Note: vessel MAP rating not valid unless hydrotest pressure based on MAP.

Weight Summary

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool a-15	201	201	0	0	0	0	0	0	0	0	1605	0
	201	201	0	0	0	0	0	0	0	0	1605	0

Vessel operating weight, corroded:	201 lbs
Vessel empty weight, corroded:	201 lbs
Vessel empty weight, new:	201 lbs
Vessel test weight, new:	1,806 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	201 lbs
Center of gravity to seam:	12.2 in

Thickness Summary

Component	ID	Length	Nom t	Req t	Joint		Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E	Load	Status	Stress	(in)
Spool a-15	48.25	24.31	0.1875	0.1412	0.85	external			

Nom t - vessel wall thickness
Req t - required vessel wall thickness due to governing loading
E - longitudinal seam joint efficiency

Load:
internal - circ stress due to internal pressure governs
external - external pressure governs
wind - combined long stress due to STATUS + wind governs
seismic - combined long stress due to STATUS + seismic governs

SPOOL A-15

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

External design pressure: Pe= 14.7 psi @ 400 deg F

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Spot UW-11(b) type 1
Category B joints - Spot UW-11(b) type 1

Estimated weight: new = 201.1 corr = 201.1 lb
capacity: new = 192.423 corr = 192.423 US ga

ID = 48.25 length Lc= 24.31 t = 0.1875 in (new)

MAP: (New & at 0 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 109.8118 psi

MAWP: (Corroded & at 400 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.1875/(24.125 + 0.6*0.1875) - 0
= 96.66065 psi

External Pressure: (Corroded & at 400 deg F) UG-28

L/Do = 36.35167/48.625 =0.7476 Do/t = 48.625/0.14122 = 344.3209
From table G: A = 0.00029
From table HA-3: B = 3833.9

Pa= 4*B/(3*Do/t)
= 4*3833.9/(3*48.625/0.14122)
= 14.8462 psi

Design thickness for external pressure Pa = 14.8462 psi:

= t + Corrosion
= 0.14122 + 0
= 0.14122 in

Maximum Allowable External Pressure: (Corroded @ 400 deg F)

L/Do = 36.35167/48.625 =0.7476 Do/t = 48.625/0.1875 = 259.3333
From table G: A = 0.000433
From table HA-3: B = 4850.4

SPOOL A-15

Pa= 4*B/(3*Do/t)
= 4*4850.4/(3*48.625/0.1875)
= 24.9378 psi

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-062
PAGE 1 OF 20

REV.	DEO #	DATE	BY:	CHECK
0	0025	4/12/96	RDC	WDB
1	0233	9/18/96	RDC	WDB

TITLE:

Design of Flexible Support (A-7)

BY: R. D. Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipmemt

PROJECT NO: V59049

PURPOSE:

Analyze and evaluate supports for thermal expansion, weight, and seismic forces. Ensure that requirements of AISC Specification are met.

METHOD:

Classical hand calculation methods are used to determine moments and forces in members. The evaluation is performed in accordance with the AISC Code, Ninth Edition.

ASSUMPTIONS:

Standard assumptions of linear structural analysis are included in this calculation.

INPUTS:

1. The weight of spool A-7 is taken from another calculation (V049-1-052).
2. The seismic acceleration is 0.05625 g.
3. The temperature rise during bakeout is from 70°F to 400°F.

REFERENCES:

1. AISC Steel Manual, Ninth Edition.
2. Doc. No. V049-1-066, LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:

(SEE ATTACHED)

CONCLUSIONS:

The requirements of the AISC Code are met. Axial growth of the shell is allowed by bending of the support leg columns without imposing stresses that are beyond the limits of the Code.

NOTES:

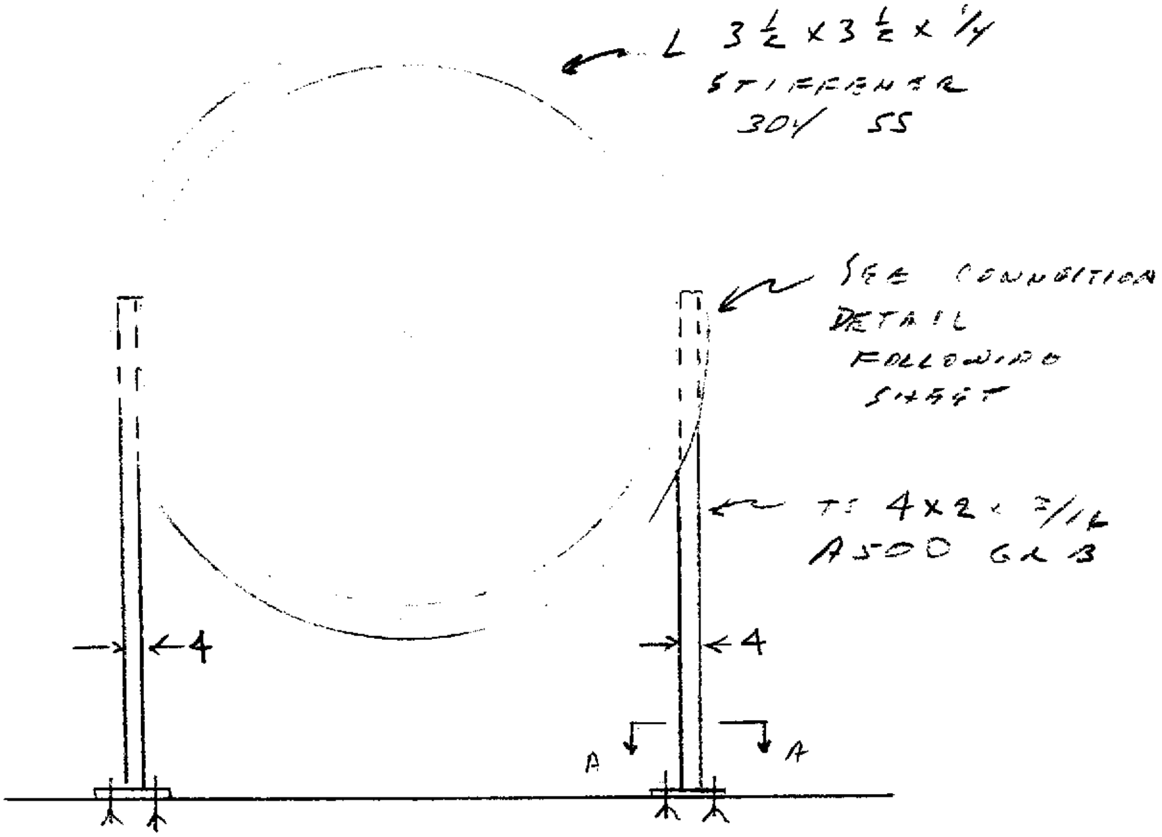
TABLE OF CONTENTS

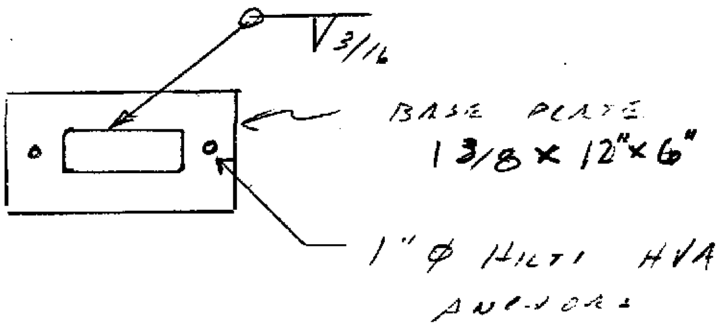
REVISION HISTORY

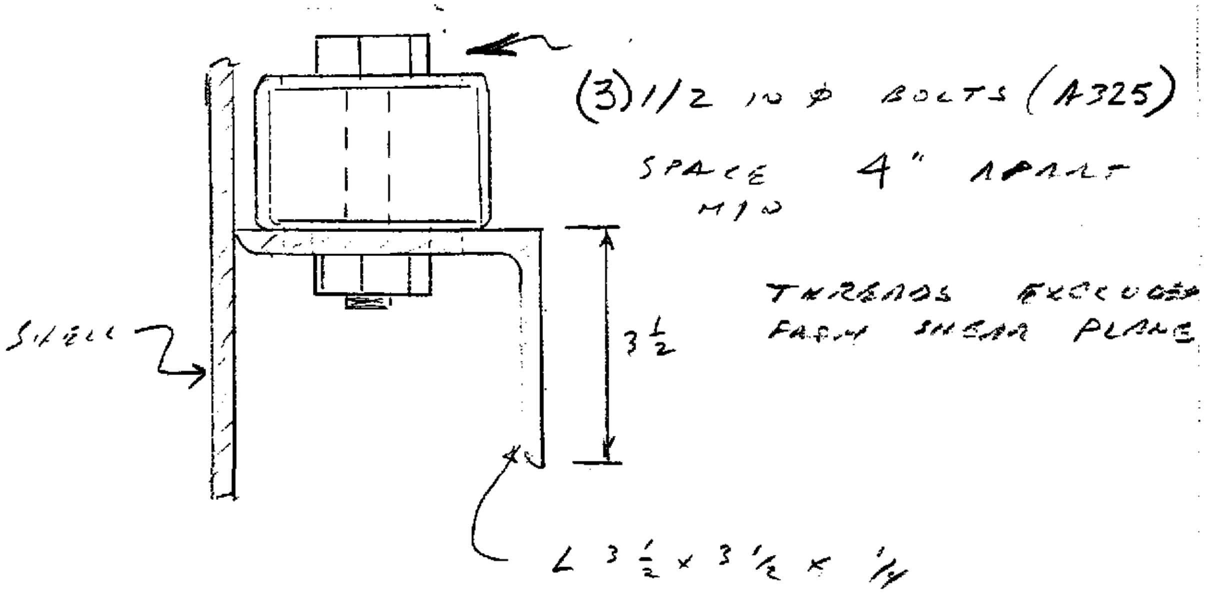
Rev. 0	Original Issue April 12, 1996
Rev. 1	Issue Date September 18, 1996

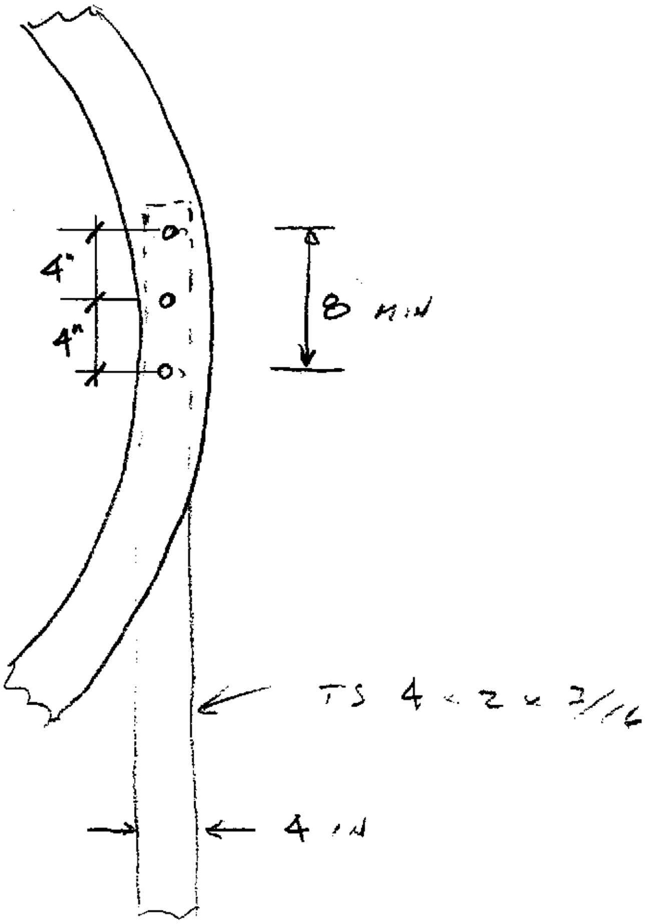
- Revised the nozzle loads to incorporate the vacuum force + valve weight
- Changed the tube steel from 3″ x 2″ x 3/16″ to 4″ x 2″ x 3/16″
- Revised the support leg calculation

SUPPORT LEGS AT CENTER OF
ADAPTER A-7






(3) 1/2 IN ϕ BOLTS (A325)
SPACE 4" APART MIN
THREADS EXCLUDED FROM SHEAR PLANE
3 1/2
SHELL
L 3 1/2 x 3 1/2 x 1/4


4"
4"
8 MIN
TS 4 x 2 x 3/16
4 IN

ESTIMATED WT OF ADAPTER A-1

1 IN PLATE FOR 72.25 IN FLANGE

OD = 8.0 IN

ID = 44.63 IN

$t = 1.0$ IN

WEIGHT $W_1 = \frac{\pi}{4}(80^2 - 44.63^2)(1)(.29)$

$= 1000$ LB

CYLINDER

ASSUME LENGTH IS FROM ABOVE PLATE TO END OF ADAPTER EVEN THOUGH GATE VALVE SHIELD SUPPORT PARTS ON VALVE SIDE OF BELLOWS. THIS WT WILL CONSERVATIVELY ESTIMATE BELLOWS WT.

$L = 60$ IN

ID = 44.63

$t = 3/16$

$W_2 = \pi(44.63)(3/16)(60)(.29)$

$= 457$ LB

$W_1 + W_2 = 1000 + 457 = 1457$

ADD 20% FOR BOLTS, TIE RODS, ETC.

$W_3 = .20(1457) = 291$ LB

TOTAL $W = 1457 + 291$

$= 1748$ LB

WT OF A7

W = 7543   SEE CALC
"ADAPTER A-7"

TOTAL WEIGHT FOR A1 & A7

W_T = 1748 + 7543

= 9291 LB

THE OVERALL LENGTH OF THE 2 SPOOLS IS

L_{A1} = 60

L_{A7} = 167

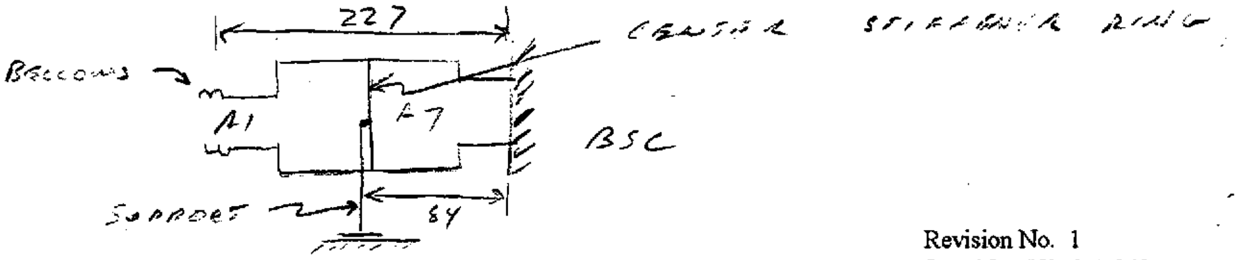
L_T = 167+60 = 227 IN

APPROX. UNIFORMLY DISTRIBUTED WT

$w = \frac{9291}{227}$

= 41 LB/IN

THE COMBINED SPOOLS, A1 & A7, WILL BE SUPPORTED AT THE BSC AND AT THE SUPPORT THAT WILL BE LOCATED AT THE APPROXIMATE CENTER STIFFENER OF A7. THE BELLOWS IN A1 WILL NOT PROVIDE SUPPORT



BENDING MOMENT IN A7 SHELL AT CENTER SUPPORT

$$M = w\frac{(227-84)^2}{2} \quad \text{FOR CANTILEVER}$$

$$= 41\frac{(227-84)^2}{2}$$

$$= 419200 \text{ IN LB}$$

MOMENT OF INERTIA OF THE 72.25 IN SHELL FOR A7

$$I = \pi r_{AV}^3 t$$

$$t = 3/8$$

$$r_{AV} = \frac{72.25 + .375}{2}$$

$$= 36.31$$

$$I = \pi (36.31)^3 (.375)$$

$$= 56400 \text{ IN}^4$$

MAX SHELL BENDING STRESS

$$S_b = \frac{M r_o}{I}$$

$$= \frac{419200\left(36.31 + \frac{.375}{2}\right)}{56400}$$

$$= 270 \text{ psi}$$

LOW

THERMAL GROWTH AT SUPPORT FROM CENTER OF BSC.

MAX TEMP

$$T = 400\,°F$$

FROM ROOM TEMP

$$\Delta T = 400 - 70 = 330\,°F$$

FROM BACK OF 60 IN PORT TO BSC ℄ THE DISTANCE IS

$$S = \frac{113.75}{2}$$ REF DWG V049-4-001

$$= 57 \text{ IN}$$

TOTAL LENGTH FROM BSC ℄ TO SUPPORT AT CENTER OF A7

$$L = 57 + 84 = 141 \text{ IN}$$

THERMAL DEFLECTION DURING BAKEOUT

$$\delta = \alpha L \Delta T$$ ↙ FOR 304/304L *

$$\alpha = 9.19(10)^{-6} \frac{\text{IN}}{\text{IN }°\text{F}}$$

$$\delta = 9.15(10)^{-6}(141)(330)$$

$$= .43 \text{ IN}$$

* ASME B&PVC SECT II
TABLE TE-1 FOR
18 Cr - 8 Ni

ASSUME THAT THE SUPPORT AT THE CENTER OF A7 RESISTS THE FULL WEIGHT LOAD, 9291 LB. ADD THE ION PUMP WGHT + VACUUM PRESSURE = 4354 lbs. $W_T = 9291 + 4354 = 13645.$ LB

$$P = \frac{13645}{2} = 6822.5 \text{ LB}$$

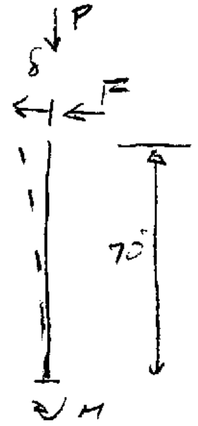
IN EA. LEG

$$= 6.82\,K$$

TRY A TUBE STEEL COLUMN, TS 4 x 2 x 3/16

$$A = 2.02 \text{ IN}^2$$

BEND IT ABOUT WEAK AXIS



$$I_y = 1.29 \text{ IN}^4$$

P_{cr} = 26 K FOR KL = 6 FT
REF AISC CODE

$$\delta = \frac{F\ell^3}{3EI}$$

$$F = \frac{3(29)(10)^6(1.29)(.43)}{70^3}$$

$$= 141. \text{ LB}$$

$$M = F\ell = 141(70) = 9870 \text{ IN-LB}$$

ALTERNATIVELY, IF THE STIFFENER RING RESTRAINS THE COLUMN FROM ROTATION, THE BENDING MOMENT WILL BE GREATER

$$M = \frac{6EI\delta}{\ell^2}$$

REF: GERE & WEAVER
TABLE B-4

$$= \frac{6(29)(10)^6(1.29)(.43)}{70^2}$$

$$= 19698. \text{ IN-LB}$$

BENDING STRESS IN COL

$$f_{by} = \frac{M}{S_y}$$

$$S_y = 1.29 \text{ in}^3$$

$$f_{by} = \frac{19698 \text{ in-lbs}}{1.29 \text{ in}^3} = 15.3 \text{ KSI}$$

FOR WEAK AXIS BENDING, ALLOWABLE STRESS IS

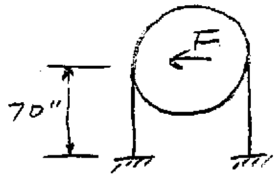
$$F_{by} = .66 F_y$$

$F_y = 46$ KSI FOR A500 GR B

$$F_{by} = .66(46)$$
$$= 30.4 \text{ KSI}$$

$$\frac{f_{by}}{F_{by}} = \frac{15.3}{30.4} = .50$$

ACCOUNT FOR LATERAL SEISMIC FORCE. TRY WITHOUT CROSS BRACING. SUPPORT LEGS AND STIFFENER RING BEHAVE AS A RIGID FRAME



$F = a W_T$

$a = .05625$ REF CALC NO. V049-1-031

$W_T = 13645$

$F = .05625(13645.)$
$= 768.$ LB.

FOR EACH SUPPORT LEG THE LATERAL FORCE IS

$$F = \frac{768}{2} = 384.\ \text{LB}$$

THE MAXIMUM BENDING MOMENT IS

$$M = 384(70)$$

$$= 26880.\ \text{IN} - \text{LB}$$

FOR STRONG AXIS BENDING

$$S_x = 1.93 \quad \text{FOR} \quad TS\ 4 \times 2 \times 3/16$$

$$f_{bx} = \frac{M}{S_x}$$

$$= \frac{26880.\ \text{in-lbs}}{1.93\ \text{in}^3}$$

$$= 13927.\ \text{psi}$$

MAX LATERAL DEFLECTION

$$\Delta = \frac{F l^3}{3 E I_x}$$

$$I_y = 3.87\ \text{in}^4$$

$$\Delta = \frac{384(70)^3}{3(29)(10)^6(3.87)}$$

$$= .39\ \text{in} \qquad \text{OK}$$

EVALUATE TUBE STEEL SUPPORT LEGS FOR NORMAL OPERATING LOADS (WEIGHT + THERMAL EXPANSION). FOR THIS CASE THERE IS NO STRONG AXIS BENDING

ADD P-Δ EFFECT TO WEAK AXIS BENDING

$$M = 19698 + 6822.5\,(.43)$$

$$= 19698 + 2934.$$

$$= 22632.$$

$$f_{b_y} = \frac{M}{S_y}$$

$$= \frac{22632.}{1.29} =$$

$$= 17{,}544 \text{ psi} = 17.5 \text{ ksi}$$

$$\frac{f_a}{F_a} = \frac{P}{P_{cr}} = \frac{6.82}{26} = .26 > .15$$

∴ USE EQ H1-1 & H1-2 OF AISC CODE

$$\frac{f_a}{.60F_y} + \frac{f_b}{F_{bx}} + \frac{f_{b_y}}{F_{b_y}} < 1.0 \qquad (H1\text{-}2)$$

$$f_a = \frac{P}{A}$$

$$A = 2.02$$

$$f_a = \frac{6.82}{2.02} = 3.376 \text{ ksi}$$

$$\frac{3.376}{.60(46)} + 0 + \frac{17.5}{30.4}$$

$$= .12 + 0 + .58 = .70 < 1.0 \qquad (H1\text{-}2)$$

OK

AMPLIFICATION FACTOR FOR EQ H1-1

$$\frac{K l_b}{r_b} = \frac{1.0\,(70)}{.798}$$ K=1.0 CONSERVATIVE

← r_y FOR PLANE OF BENDING.

$$\frac{K l_b}{r_b} = 88$$

$F'_e = 19.28$ KSI TABLE 8, AISC

$$\frac{f_a}{F'_{ey}} = \frac{3.376}{19.28} = .175$$

$$1 - \frac{f_a}{F_{ey}} = 1 - .175 = .825$$

$$C_{my} = 1.0$$

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_{by}} \le 1.0$$ EQ H1-1

$$.26 + 0 + \frac{1.0\,(17.5)}{(.825)\,30.4}$$

$$= .26 + 0 + .70 = .96 < 1.0$$ OK

∴ TS 4×2×3/16 IS ACCEPTABLE FOR NORMAL LOAD CONDITION

EVALUATE TUBE STEEL SUPPORT LEGS FOR NORMAL PLUS SEISMIC LOAD

ADD P-Δ EFFECT FOR SEISMIC FORCE

$$M = 26880 \overset{\swarrow P.12}{} + 13645(.68)$$

$$= 26880 + 9279$$

$$= 36159.$$

CONSERVATIVE
ACT Δ = .39
P. 12

$$f_{by} = \frac{36159}{1.93}$$

$$= 18735.\ psi$$

$$\frac{KL_b}{r_b} = \frac{1.0(70)}{1.38} = 50.7$$

$$F'_e = 58$$

$$\frac{f_a}{F'_{ey}} = \frac{3.376}{58} = .06$$

$$1 - \frac{f_a}{F'_{ey}} = .94$$

GET F_{by}

$$\frac{b}{t} = \frac{2}{3/16} = 10.67 < \frac{190}{\sqrt{F_y}} = \frac{190}{\sqrt{46}} = 28$$

FROM AISC, TABLE B5.1, TS 4×2×3/16 IS COMPACT

FROM AISC, EQ F3-2

$$L_{c\,MIN} = 1950\frac{b}{F_y} = \frac{1950(2)}{46} = 85$$

$$> L_b = 70$$

$$\therefore \quad F_{by} = .66\ F_y$$

$F_{by} = .66(46)$ FOR A500 GR B

$= 30.4$ KSI

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1-\frac{f_a}{F'_{ex}}\right)F_{bx}} + \frac{C_{my} f_{by}}{\left(1-\frac{f_a}{F'_{ey}}\right)F_{by}} < 1.33$$

$C_{mx} = 1.0$

$$.26 + \frac{1.0(18.7)}{.94(30.4)} + .7$$

$$.26 + .65 + .70 = 1.61 > 1.33$$

IT MAY BE SHOWN THAT C_{my} IS LESS THAN 1.0 SINCE THE FRAME IS BRACED AGAINST JOINT TRANSLATION IN THE LONG DIRECTION BY THE ADAPTER AND ITS CONNECTION TO THE BEAM SPLITTER,

$C_{my} = .6 - .4\ M_1/M_2$

SINCE $M_1 = M_2$ & LEG IS BENT IN REVERSE CURVATURE

$C_{my} = .6 - .4(1.0) = .2$

$.26 + .65 + .2(.70) = 1.05 < 1.33$ OK

ALSO NOTE - THE PROBABILITY OF AN EARTHQUAKE DURING BAKEOUT IS EXTREMELY LOW

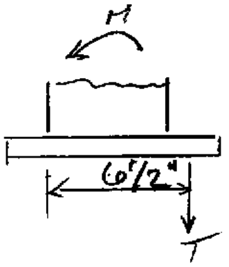
ANCHOR BOLT

THE ANCHOR RESISTS THE STRONG AXIS SEISMIC MOMENT

$M = 36159$ in-lbs. P.15

$6\frac{1}{2}T = M$

$T = 5563$ lbs.



ADD 20% TO ACCOUNT FOR PRYING

$T = 1.2\,(5.563K)$

$= 6.676K$

USE 1 IN HILTI HVA ADHESIVE ANCHORS @ 8¼" EMBT

$T_{ALL} = 10.96^K > T = 6.676^K$

SEE CALC V049-1-024, p. 27

MAX SHEAR

$V = \frac{384}{2} = .192\ K$

$V << V_{ALL} = 7.63^K$ ok

$$\frac{6.676}{10.96} + \frac{.192}{7.63} = .63 < 1.0 \therefore \underline{O.K}$$

BOLTS FOR UPPER CONNECTION OF LEG TO STIFFENER

TRY 3 - 1/2" ∅ BOLTS IN BEARING WITH THREADS EXCLUDED FROM SHEAR PLANE

$$A_B = \pi (.25)^2$$
$$= .196 \text{ SHEAR AREA}$$

FOR WEIGHT

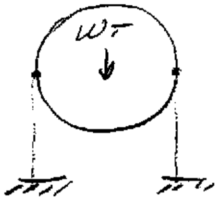
$$f_v = \frac{P}{3A_B}$$
$$= \frac{6.82}{3(.196)}$$
$$11.6 \text{ KSI} < 17 \text{ KSI}$$

OK FOR A325

BEARING

$$A_p = 1/4\,(1/2) = .125$$

$$f_p = \frac{6.82}{3(.125)} = 18.2 \text{ ksi} < .9\,F_y \text{ OK}$$



SEISMIC STRESSES ARE LOW

BOLTS CONT

FOR BENDING DUE TO THERMAL EXP

$M = 19698$ (NO P-Δ AT TOP OF LEG)

FOR 8 in SPACING BOLT TENSION IS

$$T = \frac{M}{8(1)} = \frac{19698}{8(1)}$$

$= 2.462$ K PER BOLT

TENSILE STRESS AREA

$A_T = .142$ in^2 AISC P 4-147

$$f_t = \frac{2.462}{.142}$$

$= 17.34$ KSI ok

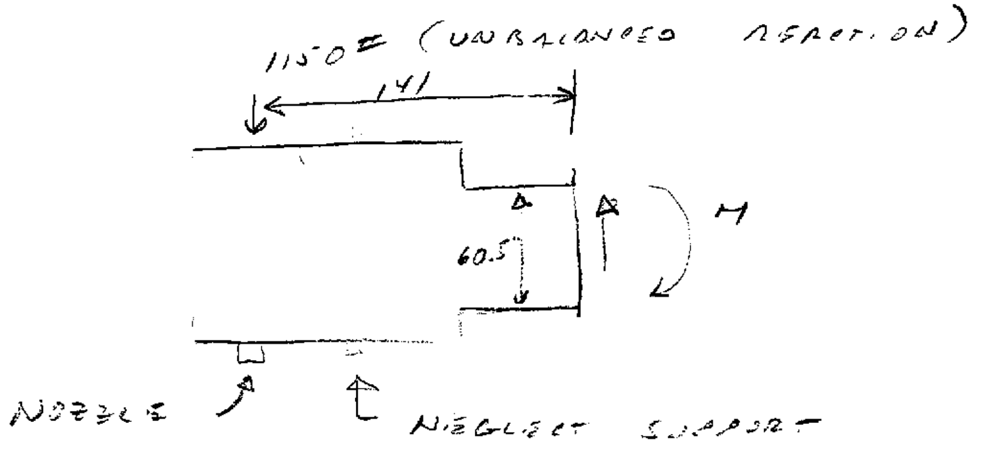
$17.34 < \underline{44.0}$ KSI

USE 5/8" ϕ A325 BOLTS

A7

REACTION OF NOZZLE UNBALANCED FORCE

PLAN
VIEW



$$M = 1150(141) = 19880 \text{ IN-LB}$$

FORCE PER IN OF CIRCUMFERENCE

$$I = \pi r^3 t$$
$$= \pi (30.25)^3 t = 86961 \text{ IN}^3 t$$

$$f = \frac{M r}{I} = \frac{19880 (30.25)}{86961 t}$$

$$= 6.9 \frac{\text{LB}}{\text{IN}}$$

FOR THE 1/4 PAR RED WELD

$$f_t = \frac{6.9}{1/8} = 55 \text{ psi}$$ NEGLIGIBLE

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-086

PAGE 1 OF 9

REV.	DEO #	DATE	BY:	CHECK
0	0029	4-11-96	AGR	RDC

TITLE: 44" GATE VALVE SUPPORT

By: ART ROUSSOPOULOS **DEPT.:** 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: DESIGN A GROUND SUPPORT FOR THE 44" GATE VALVE

METHOD: · CLASSICAL STRESS ANALYSIS

ASSUMPTIONS: SEE CALCS

INPUTS: GATE VALVE VENDOR DWG'S D103279 + D103225-01 FOR ASSEMBLED DW = 7000 # + SUPPORT LOCATIONS / GEOMETRY

REFERENCES: AISC - MSC - 9TH ED
BLODGETT - "DESIGN OF WELDED STRUCTURES"
Doc. No. V049-1-066, LIGO VACUUM EQUIP STRUCTURAL DESIGN CRITERIA

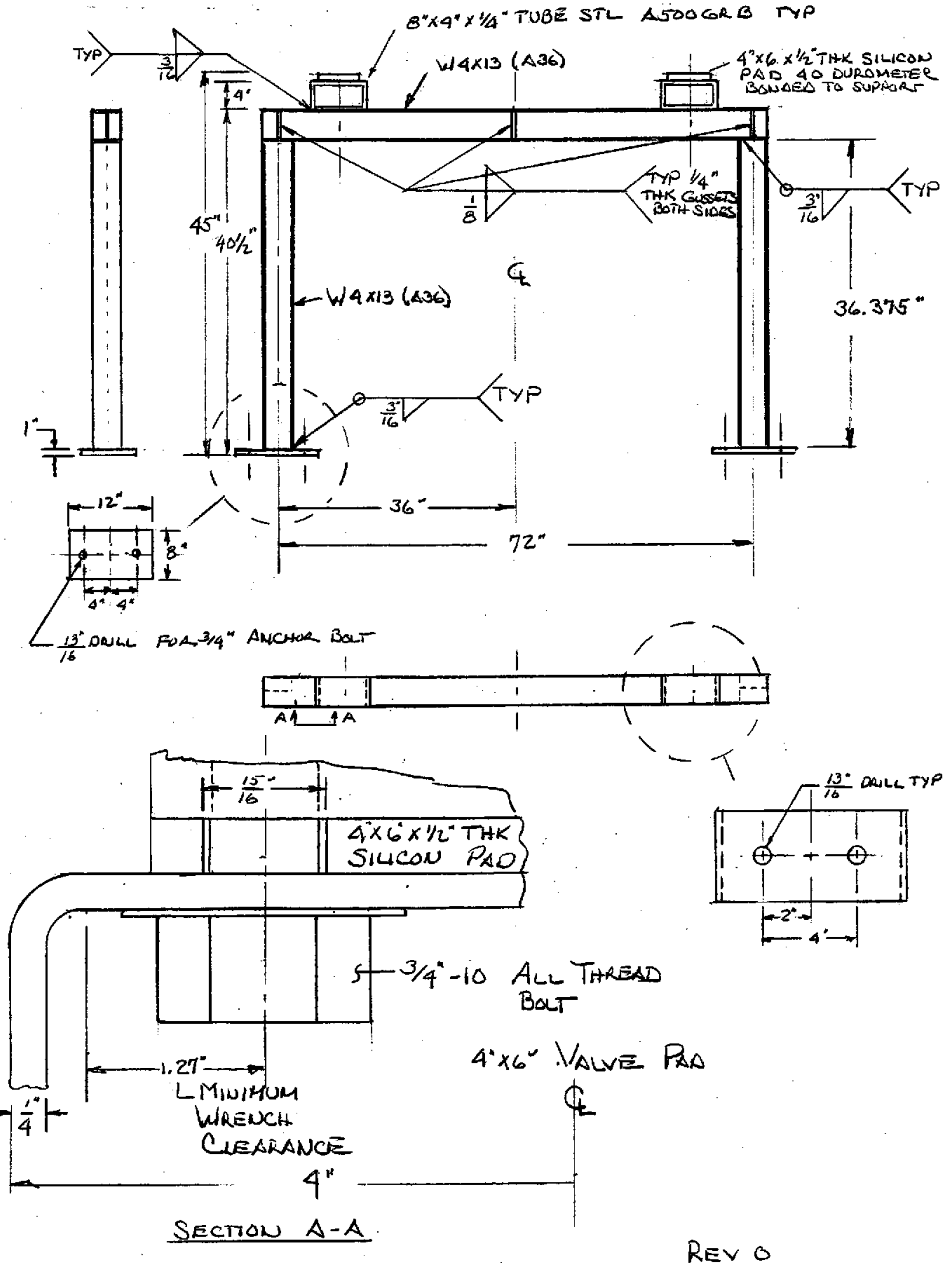
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS:

NOTES:

TABLE OF CONTENTS

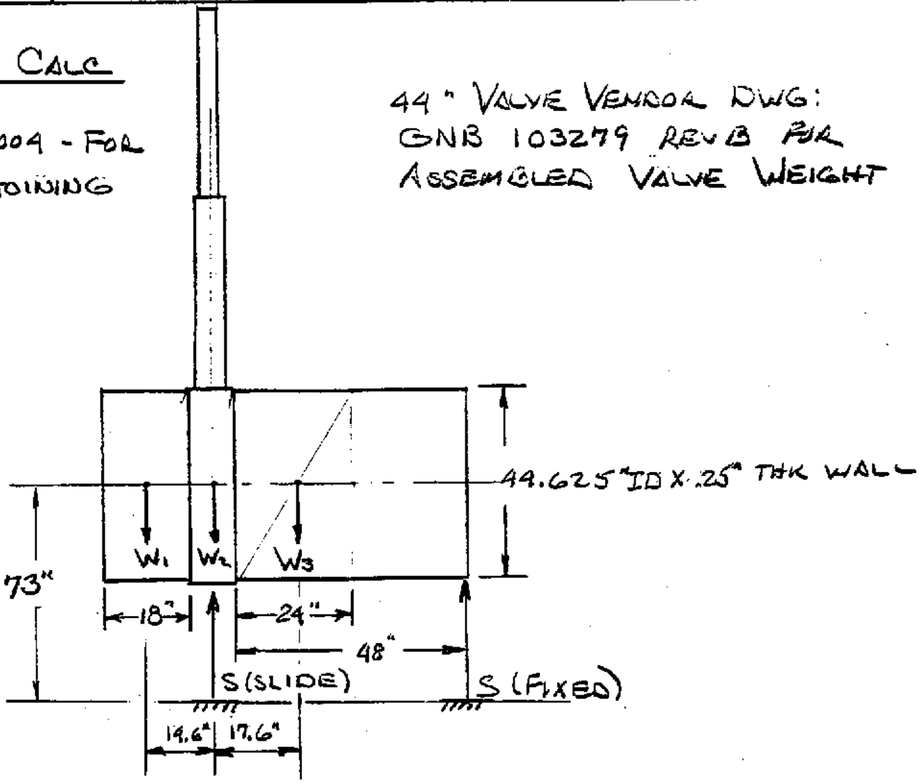
1.0 - DESIGN SKETCH
SK-V049-1-086, REV 0



2.- DEADWEIGHT CALC

REF: DWG. V049-5-004 - FOR WORSE CASE ADJOINING TUBE LOADS

44" VALVE VENDOR DWG: GNB 103279 REV B FOR ASSEMBLED VALVE WEIGHT



$W_1 = \pi/4\,(45.125^2 - 44.625^2)(18)(.283) = 180\#$

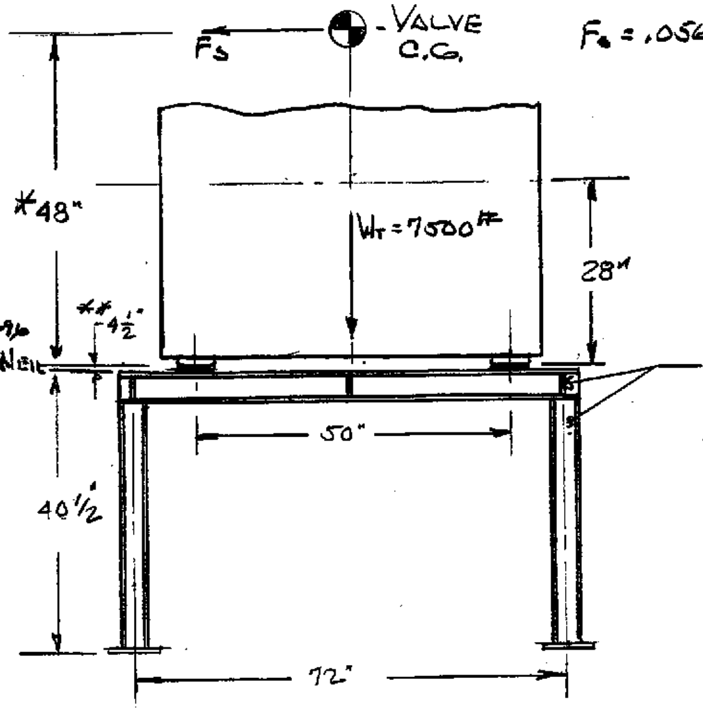
$W_2 = 7000\#$ (ASSEMBLED VALVE WEIGHT)

$W_3 = \pi/4\,(45.125^2 - 44.625^2)(24)(.283) = 239\#$

$\Sigma W = 180 + 7000 + 239 = 7{,}419\#$

- USE 7500# FOR SUPPORT DESIGN

$F_s = .05625(7500) = 422\#$



W4X13
$A = 3.83\ IN^2$
$I_x = 11.3\ IN^4$
$S_x = 5.46\ IN^3$
$I_y = 3.86\ IN^4$
$S_y = 1.9\ IN^3$
$r_y = 1.0\ IN$

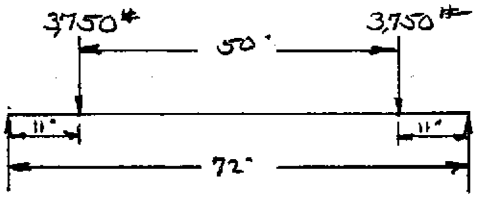
* NOTE:
48" G.G. LOCATION FOR 44" VALVE IS PER TELECON ON 4-11-96 WITH GNP SHAWN MCNEIL

** SEE DESIGN SKETCH FOR ACTUAL SUPPORT DETAIL

3. - HORIZONTAL W4X13 BEAM SUPPORT

MODEL:

- DEADWEIGHT



REF: BLODGETT, CASE 3AC, P. 8.1-6

$M_{MAX} = 11(3750) = 41,250$ IN-#

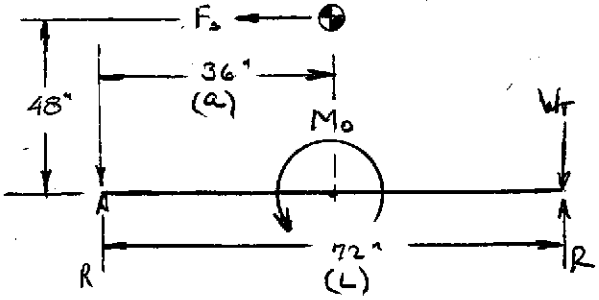
$\sigma_{MAX} = .6S_y = .6(36,000) = 21,600$ PSI

$\therefore S_{REQ} = \dfrac{M_{MAX}}{\sigma_{MAX}} = \dfrac{41,250}{21,600} = 1.91$ IN^3

$S_{ACTUAL} = 5.46$ IN^3 > 1.91 IN^3 $\therefore$ OK

$\sigma_{ACTUAL} = \dfrac{41,250}{5.46} = 7,555$ PSI $= \sigma_{DW}$

- LATERAL SEISMIC



$M_o = 48(422) = 20,256$ IN-#

WHERE: $F_S = 422$#

$R = M_o/L = 20,256/72 = 281$#

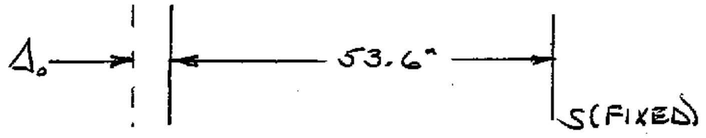
$W_T = 7419/2 - 281 = 3428$# (COMPRESSION)

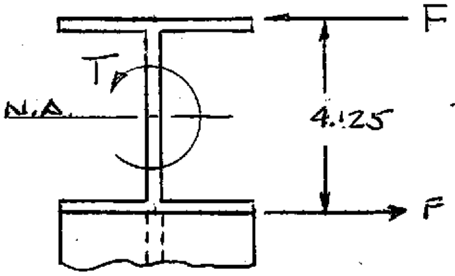
REF: BLODGETT, CASE 3Eb, P. 8.1-10

$M_{MAX} = \dfrac{M_o a}{L} = \dfrac{(20,256)(36)}{(72)} = 10,128$ IN-#

$\sigma_{SEIS} = \dfrac{10128}{5.46} = 1,855$ PSI

• TORSION DUE TO THERMAL EXPANSION LOADS



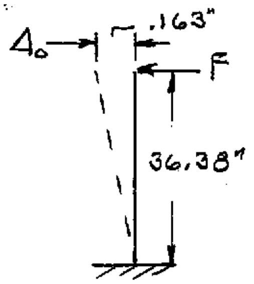


$T = 4.125 F_{TH} = 4.125 (2274) = 9380$ IN-#

$$\Delta_o = \alpha L \Delta T = 9.19 \times 10^{-6} (53.6)(330) = .163''$$

WHERE: $\alpha = 9.19 \times 10^{-6}$ IN/IN/°F AT 400°F

MODEL: - DEFLECTION DUE TO THERMAL MOVEMENT: .163"

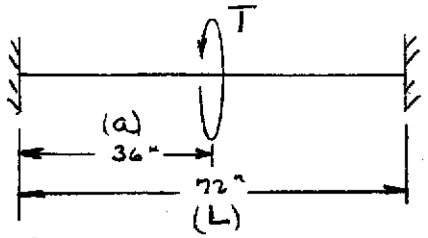


REF: BLODGETT, CASE 1Aa, P. 8.1-3

$$\Delta_o = \frac{FL^3}{3EI}$$

$$F_{TH} = \frac{3EI\Delta_o}{L^3} = \frac{3(29\times10^6)(2\times3.86)(.163)}{(36.38)^3} = 2274^{\#}$$

MODEL: - TORSIONAL STRESS



REF: BLODGETT, CASE 3, P. 8.2-1

$$\tau_T = \frac{Ta}{L} = \frac{9380 (36)}{72} = 4690 \text{ PSI.}$$

- <u>COMBINING STRESSES</u> - FOR HORIZONTAL BEAM SUPPORT

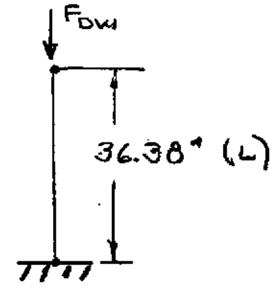
- BY SUPERPOSITION:

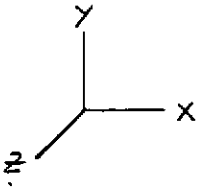
$\sigma = \sigma_{DW} + \sigma_{SEISMIC} = 7555 + 1855 = 9410 \angle .6S_Y \therefore OK$

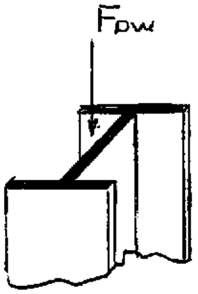
$\tau = 4{,}690$ PSI $\angle .4S_Y = 14{,}400$ PSI $\therefore OK$

4. - VERTICAL W4x13 COLUMN SUPPORT

MODEL:







$$\frac{KL}{r} = \frac{(1.0)(36.38)}{1.0} = 36.38$$

A. - CON'T

- AXIAL COMPRESSIVE STRESS

$$\sigma_A = \frac{F_{DW}}{A} = \frac{7500}{2(3.83)} = 979 \text{ PSI} = f_a$$

- ALLOWABLE COMPRESSIVE STRESS REF: AISC, E2, P.5-42

$$\frac{KL}{r} = 36.38$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2(\pi^2)(29\times10^6)}{(36{,}000)}} = 126$$

$$KL/r < C_c$$

$$\therefore F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right]F_y}{\frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}}$$

$$F_a = \frac{\left[1 - \frac{(36.38)^2}{2(126)^2}\right](36{,}000)}{\frac{5}{3} + \frac{3(36.38)}{8(126)} - \frac{(36.38)^3}{8(126)^3}} = 19{,}470 \text{ PSI} > \sigma_A = 979 \text{ PSI}$$

$\therefore$ OK

5.- ANCHOR BOLTS.

- VERTICAL LOAD COMPRESSION ONLY ∴ SHEAR LOAD USED FOR 3/4" DIA ANCHOR BOLT DESIGN

- SHEAR LOAD:

– SEISMIC SHEAR = F_S = 422# (SEE P.5)

– THERMAL SHEAR = 1201#

TOTAL SHEAR = 422 + 1201 = 1623#

– SHEAR LOAD PER TWO(2) ANCHOR BOLTS:

$\frac{1623}{2} = 812\# < 4800\#$ FOR 3/4 HILTI HVA ∴ OK

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-087
PAGE 1 OF 57

REV.	DEO #	DATE	BY:	CHECK
0	0025	4/5/96	WDB	AGR ✓
1	0293	9/19,96	WDB	RJC

TITLE:
Design of Generic Support Scheme for;
Mode Cleaner Tubes B-5, B-2 & B-3

BY: W. Bilynsky
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. The purpose of this calculation is to design a generic support scheme for the Mode Cleaner Tubes (MCT's) B-5, B-2 & B-3. The support scheme for the MCT's is designed allowing thermal axial growth due to 'bakeout'. Thermal growth occurs in opposite directions from an anchor at midpoint of the MCT, therefore to facilitate this concept, the support scheme is made up of an anchor and two flexible supports. MCT B-5 was used for the generic design. The anchor location for B-5 was chosen based on the free area around the pipe bridge. The flexible supports were located using 0.50 in. as the maximum allowed thermal displacement.

METHOD: A STAAD model of MCT B-5 was developed and used for design. Baseplates, anchor bolts and thru-bolted connections at the support to MCT interface were designed based on STAAD design output. From previous design, the MCT's weight was determined including weight of flanges, and nozzle loads. A uniform load representing the MCT's deadweight was applied to the model, additionally this load was factored for seismic accelerations and applied as a uniform horizontal load. A thermal load of 330 F was applied along the length of the Mode Cleaner Tube.

ASSUMPTIONS: See Calculation

INPUTS:
Vessel wght = 6437.0 lbs, Flange wght = 1539.0 lbs
External Nozzle Loads:
$P_R = 4354.0$ lbf, $M_C = M_L = 4542.0$ in-lbf, $V_C = V_L = 126.5$ lbf, (ref V049-1-045)
Seismic Acceleration = 0.05625 g.
Unbalanced Vacuum Forces: @ Jt 200 = 382 lbf. @ Jt 500 = 1042. lbf
@ Jt 7 = 33780. lbf (conservative force;
actual force = 32600. lb ref V049-1-108)

REFERENCES:
1. STAAD-III release 21, Research Engineers
2. COMPRESS - Computer Aided Vessel Design program - version 5.53
3. ASD - AISC 9th edition
4. V049-1-066, LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:
V049-1-057 rev 1 - Mode Cleaner Tube B-5

CONCLUSIONS:
The requirements of the AISC Code and the LIGO Vacuum Equipment Structural Design Criteria are met.

NOTES: STAAD-III Computer file: B5MCTR1.*

PROCESS SYSTEMS INTERNATIONAL, INC. **WESTBOROUGH, MA**	**ENGINEERING** **CALCULATIONS**	**NO: V049-1-087** **Rev. No. 1** **PAGE 2 OF 57**
PROJECT: LIGO VACUUM EQUIPMENT	**PROJECT NO: V59049**	
CALCULATION TITLE: Design of Generic Support Scheme for Mode Cleaner Tubes B-5, B-3, & B-2		

TABLE OF CONTENTS

REVISION HISTORY

Rev. 0 Original Issue
April 5, 1996

Rev. 1 Issue Date
September 19, 1996

- Reversed Location of 10" and 6" Ø nozzles
- Added unbalanced vacuum load to ion pump nozzle loads.
- Added unbalanced vacuum load (33.78 k) due to the bellows at the HAM.
- Revised baseplates to Plate 12" x 12" x 1-3/8" and 6" x 12" x 1-3/8".
- Revised Structural Tube Steel members to 4" x 4" x 1/2" thk.
- Revised body of calc to reflect changes due to new vacuum load.
- Added additional weld calculations
- Revised design details to reflect change in members.
- Revised stiffener/support ringsto 3" x 3" x 1/4" & 3 x 3 x 1/2
  (REF CALC V049-1-057, P. 4)

PROCESS SYSTEMS INTERNATIONAL, INC. **WESTBOROUGH, MA**	**ENGINEERING CALCULATIONS**	**NO: V049-1-087** **Rev. No. 1** **PAGE 4 OF 57**
PROJECT: LIGO VACUUM EQUIPMENT	**PROJECT NO: V59049**	

CALCULATION TITLE: Design of Generic Support Scheme for Mode Cleaner Tubes B-5, B-3, & B-2

DISCUSSION

Mode Cleaner Tubes

Support Scheme

Step 1 - Based on the external loading of the ion pumps and portable roughing pumps, B-5 was used for designing the generic support scheme for all the mode cleaner tubes i.e. B-5, B-2 & B-3. Anchorage was preferred at midspan but due to limiting space (i.e. “stay clear zone”) the anchor was relocated as near to the pipe bridge(midspan) as was permissible.

Step 2 - Flexible supports were located based on a maximum allowable thermal displacement of 1/2 inch. This in turn determined the maximum spacing between anchor and flexible support.

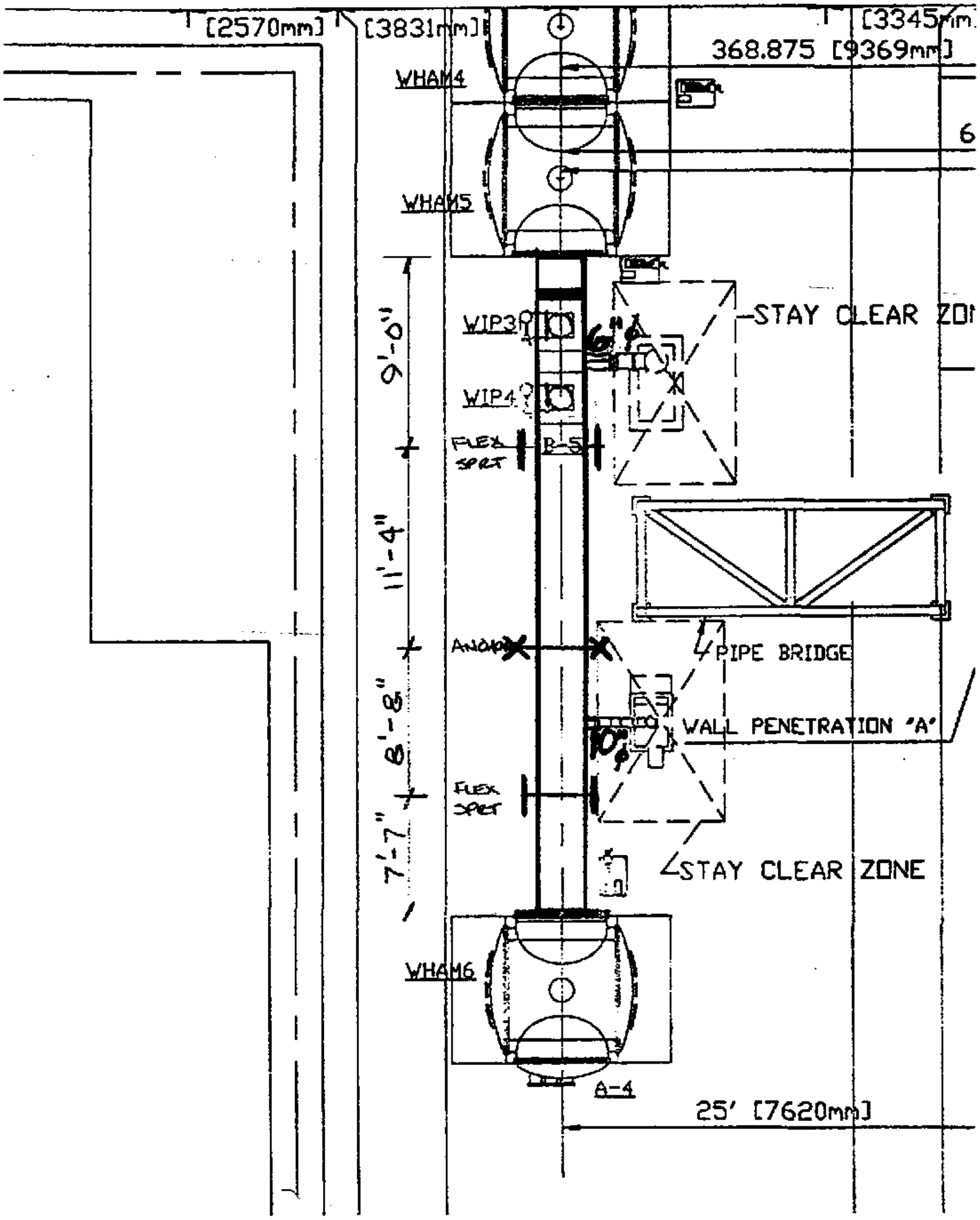
Step 3 - A finite element model which includes the properties of the mode cleaner tube shell and the support frame was generated using the STAAD structural design computer program.

Step 4 - Applicable loading conditions were determined. These included; deadweight for vessel and flanges, unbalanced vacuum pressure loads at pump nozzles and at the HAM bellows, uniform thermal load for the Mode Cleaner Tube, and seismic factors.

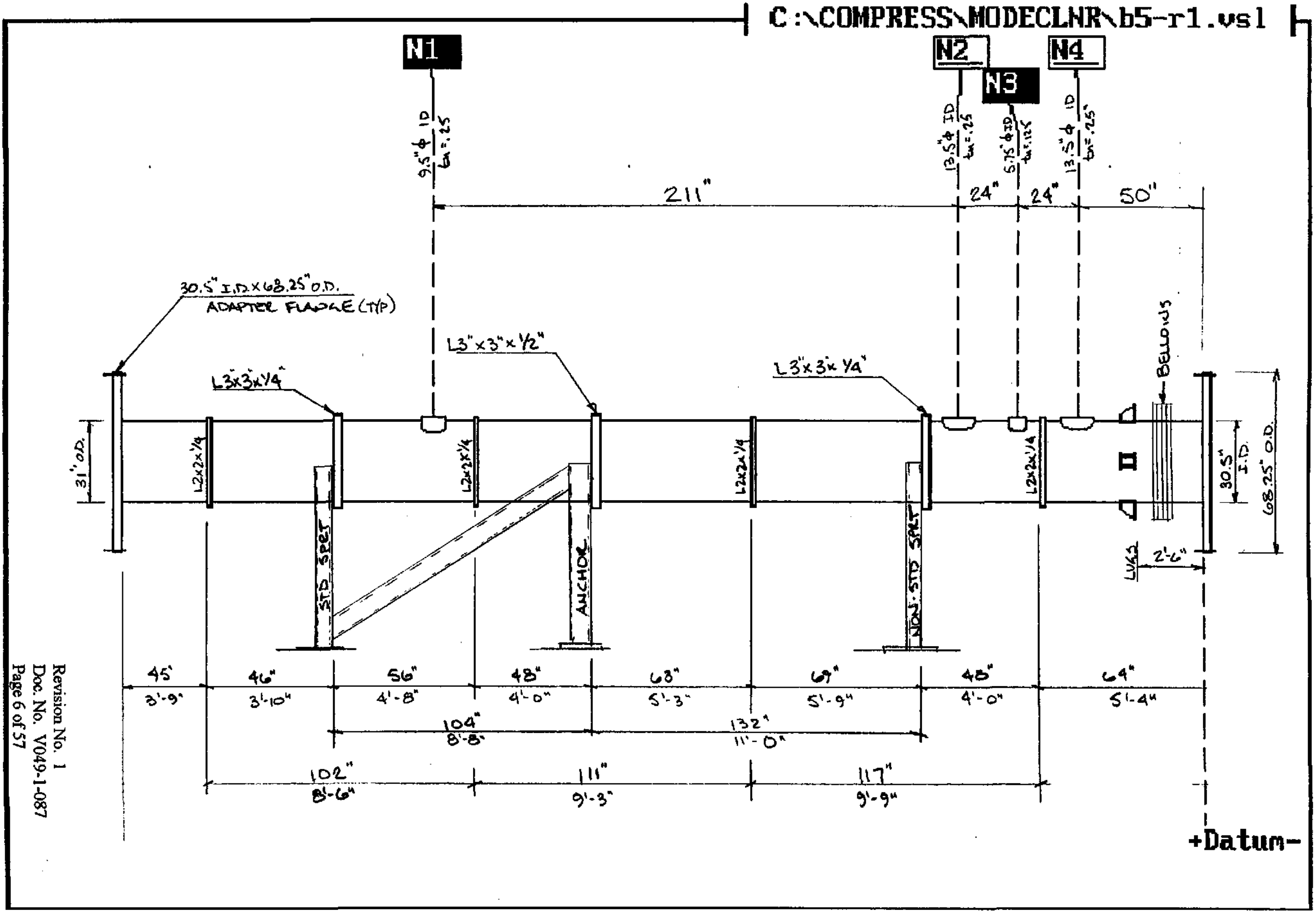
Step 5 - Computer output results were evaluated.

Step 6 - Using computer generated forces and reactions, anchors, baseplates, welds and bolted connections (support legs to vessel stiffener rings) were designed.

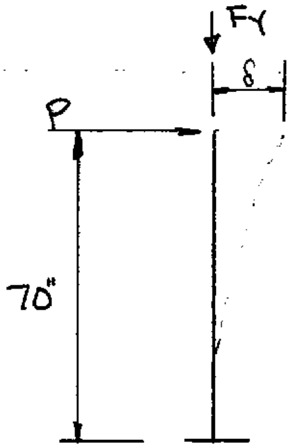
MODE CLEANER TUBE B-5



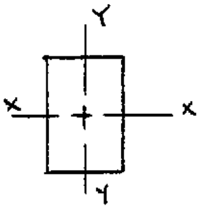
GENERAL ARRANGEMENT


C:\COMPRESS\MODECLNR\b5-r1.vsl
N1
9.5"ϕ ID
tn=.25
N2
13.5"ϕ ID
tn=.25
N3
5.75"ϕ ID
tn=.125
N4
13.5"ϕ ID
tn=.25"
211"
24"
24"
50"
30.5" I.D.x 68.25" O.D.
ADAPTER FLANGE (TYP)
L3"x3"x1/2"
L3x3x1/4
L3"x3"x 1/4"
BELLOWS
31" O.D.
L2x2x1/4
L2x2x1/4
L2x2x1/4
L2x2x1/4
STD SPRT
ANCHOR
NON-STD SPRT
30.5" I.D.
68.25" O.D.
LUGS
2'-6"
45'
3'-9"
46"
3'-10"
56"
4'-8"
48"
4'-0"
63"
5'-3"
69"
5'-9"
48"
4'-0"
64"
5'-4"
104"
8'-8"
132"
11'-0"
102"
8'-6"
111"
9'-3"
117"
9'-9"
+Datum-

Max Allowable Thermal Displacement



For T.S. 3×2×3/16"



$A = 1.64$

$I_x = 1.86$ $\quad I_y = .977$

$S_x = 1.24$ $\quad S_y = .977$

$r_x = 1.06$ $\quad r_y = .771$

$$\frac{KL}{r_y} = \frac{1.0\,(70\,\text{in})}{.771} = 90.79$$

$F_a = 15986\ \text{lb/in}^2$

$$f_a = \frac{F_Y}{A}$$

$F_Y = 2000$ lbs max (ref. calc. V049-1-057)

$$f_b = \frac{M_y}{S_y} \Rightarrow M_y = PL \Rightarrow P = \frac{3EI_y(\delta)}{L^3} \therefore$$

$$\delta = \frac{PL^3}{3EI_y}$$

Max Allowable Assuming One Direction Bending

$$\delta_{allow} = \frac{f_{b_{allow}}(S_y)(L)^3}{L(3)(E)(I_y)}$$

$$= \frac{.6\,(36000\ \text{lb/in}^2)\,(.977\ \text{in}^3)\,(70\ \text{in})^3}{(70\ \text{in})(3)(29E06\ \text{lb/in}^2)\,(.977\ \text{in}^4)}$$

$$= 1.22\ \text{in}$$

- ONLY BENDING CONSIDERED
- AXIAL STRESSES NEGLECTED
- UNDER CONSERVATIVE

$\therefore\ \delta_{max} < 1.22$

MAX ALLOWABLE DISPLACEMENT (δ_{max})

ASSUMING STIFFENER RING RESTRAINS AGAINST ROTATION:

$$f_b = \frac{M_y}{S_y} \Longrightarrow M_y = \frac{6 E I_y \delta}{L^2}$$

ref. Gere & Weaver
Table 8-4

$$M_y = f_b (S_y)$$

$$\frac{6 E I_y \delta}{L^2} = f_b (S_y)$$

T.S. 3×2×3/16"

$I_y = .977 in^4$
$S_y = .977 in^3$

$$\delta_{max} = \frac{f_b (S_y)(L)^2}{6 E I_y}$$

$$= \frac{(.6)(36000\ lb/in^2)(.977 in^3)(70 in)^2}{6(29E6\ lb/in^2)(.977 in^4)}$$

$$\delta_{max} = 0.608 in \approx 0.61 in$$

- only one directional bending considered
- axial neglected.

FOR SUPPORT DESIGN

CONSERVATIVELY MINIMIZE THERMAL

DISPLACEMENTS TO < 1/2 in.

THERMAL DISPLACEMENTS AT SUPPORTS #TS. 4, 6,

$$\delta_{THERM} = \alpha \, \Delta T \, L$$

WHERE :

$\alpha = 9.19 \times 10^{-6}$ IN/IN°F (FOR SA 204-340L HIGH)

$\Delta T = 400°F - 70°F$

$= 330°F$

$L =$ DISTANCE (ANCHOR TO FLEX SUPPORT)

δ_{THERM} WHERE $L = 104"$

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(104")$$

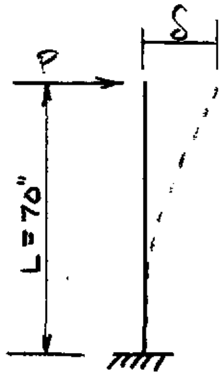
$$= .315 \text{ IN.}$$ (0.30858 STAAD MODEL)

δ_{THERM} WHERE $L = 136$ IN

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(136 \text{ IN})$$

$$= .412 \text{ IN}$$ (0.41925 STAAD MODEL)

EQUIVALENT FORCE DUE TO DISPLACEMENT ASSUMING A CANTILEVER



USING T.S. 3x2x3/16

$I_{yy} = .977 \text{ IN}^4$

$$\delta = \frac{PL^3}{3 E I_y} \Rightarrow P = \frac{(\delta) 3 E I_y}{L^3}$$

$$P = \frac{\delta \, (3)(29000000. \#/in^2)(.977 \text{ IN}^4)}{(70 \text{ IN})^3}$$

$\delta_{.315 in} \Rightarrow P = 78$ lbs.

$\delta_{.412 in} \Rightarrow P = 102$ lbs.

LOAD COMBINATIONS

1. D.W.
2. D.W. + VACUUM PRESSURE + THERMAL
3. D.W. + VACUUM PRESSURE + THERMAL + SEISMIC AXIAL
4. D.W. + VACUUM PRESSURE + THERMAL + SEISMIC LATERAL
5. THERMAL DISPLACEMENT "BAKEOUT"

1. D.W. -

DEAD WEIGHT = VESSEL WGHT = 6437 lbs ⇒ $\frac{6437 \text{ lbs}}{439 \text{ in}} = 14.66\text{\#}/\text{in}$

= FLANGE WEIGHT = 1539. lbs

2. D.W + VACUUM + THERMAL

VACUUM PRESSURE = UNBALANCED LOADS @ PORTABLE MAIN ROUGHING PUMPS

@ 10" ϕ NOZZLE

$$F = PA = (14.7\text{\#}/\text{in}^2)(\pi D^2/4)$$
$$= (14.7\text{\#}/\text{in}^2)(\pi\,(9.5\text{in})^2/4)$$
$$= 1042 \text{ lbs}$$

@ 6" ϕ NOZZLE

$$F = (14.7\text{\#}/\text{in}^2)(\pi\,(5.75\text{in})^2/4)$$
$$= 382. \text{ lbs.}$$

@ Bellows End (going away from BSC END)

$F_V = 33780$ lb

THERMAL = 330°F FOR BEAM TUBE MANIFOLD.

3. D.W. + VACUUM PRESSURE + THERMAL DISP. + SEISMIC AXIAL

D.W + VACUUM PRESSURE + THERMAL = LOAD CASE # 2

SEISMIC AXIAL = (14.66#/in)(.05625 g) = 0.825
(UNIFORM LOAD for Shell)

SEISMIC AXIAL = 126.5 #. @ NOZZLES 16" ϕ = Fx
= 4542 in-lbs @ NOZZLES 16" ϕ = Mz } Calc 045

4. D.W. + VACUUM PRESSURE + THERMAL + SEISMIC LATERAL

D.W. + VACUUM PRESSURE + THERMAL DISTR = LOAD CASE #2

SEISMIC LATERAL = 0.825#/in Uniform LOAD LATERAL @ SHELL

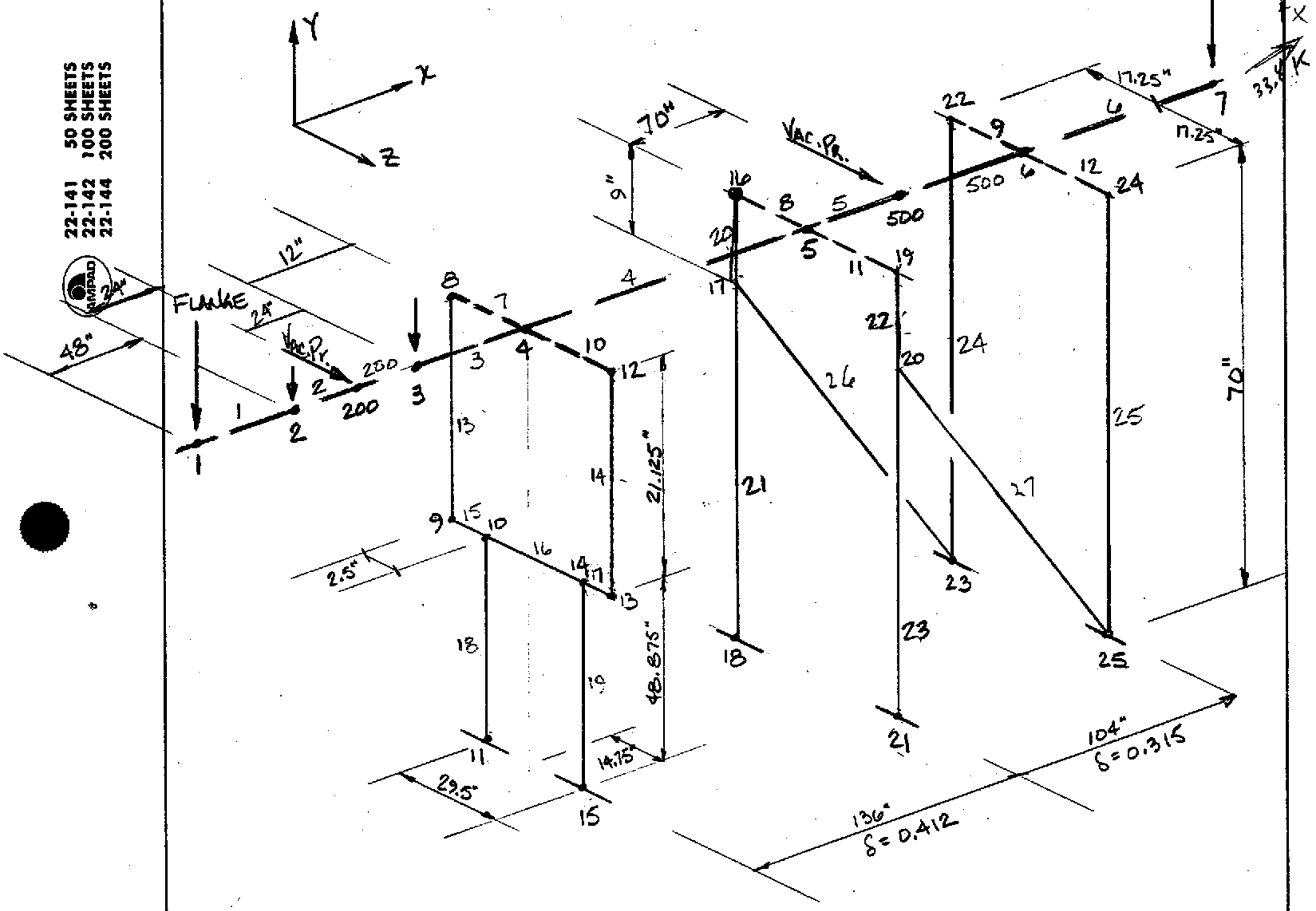
SEISMIC LATERAL = 126.5# @ 16" NOZZLES (2) = FZ

= 4542 IN-lbs @ 16" NOZZLES (2) = Mx

STAAD MODEL

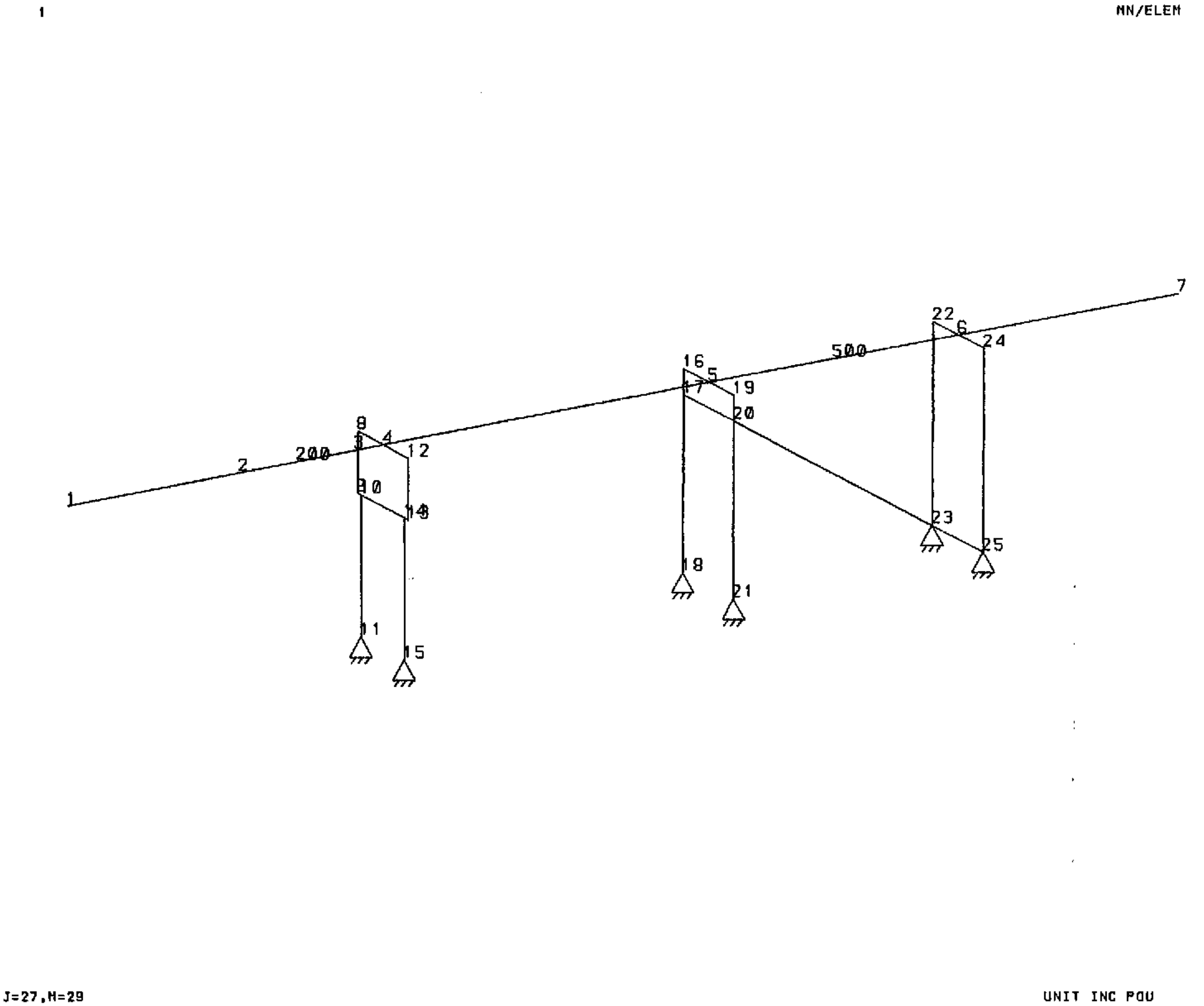
━━━ = VESSEL

─── = STRUCTURAL MEMBERS (FRAME SUPPORT)



STRUCTURE DATA

TYPE = SPACE
NJ = 27
NM = 29
NE = 0
NS = 6
NL = 4
XMAX= 463.0
YMAX= 70.0
ZMAX= 34.5



USER ID:Process Systems International

STAAD POST-PLOT (REV: 21.0)

TITLE: 85 MODE CLEANER TUBE SUPPORTS

DATE: MAR 28, 1996

```
          **************************************************
          *                                                *
          *            S T A A D - III                     *
          *            Revision 21.0                       *
          *            Proprietary Program of              *
          *            Research Engineers, Inc.            *
          *            Date=    SEP 20, 1996               *
          *            Time=    14: 7:27                   *
          *                                                *
          *       USER ID: PROCESS SYSTEMS INTERNATIONAL IN *
          **************************************************

  1. STAAD SPACE B5 MODE CLEANER TUBE SUPPORT
  2. INPUT WIDTH 72
  3. *** REV. 1  INPUT FILE B5MCTR1
  4. UNIT INCHES POUND
  5. JOINT COORDINATES
  6. 1 -24. 0. 0.; 2 48. 0. 0.; 3 96. 0. 0.; 4 108. 0. 0.; 5 244. 0. 0.
  7. 6 348. 0. 0.; 7 439. 0. 0.; 8 108. 0. -17.25; 9 108. -21.125 -17.25
  8. 10 108. -21.125 -14.75; 11 108. -70. -14.75; 12 108. 0. 17.25
  9. 13 108. -21.125 17.25; 14 108. -21.125 14.75; 15 108. -70. 14.75
 10. 16 244. 0. -17.25; 17 244. -9. -17.25; 18 244. -70. -17.25
 11. 19 244. 0. 17.25; 20 244. -9. 17.25; 21 244. -70. 17.25
 12. 22 348. 0. -17.25; 23 348. -70. -17.25; 24 348. 0. 17.25
 13. 25 348. -70. 17.25; 200 72. 0. 0.; 500 314. 0. 0.
 14. MEMBER INCIDENCES
 15. 1 1 2; 3 3 4; 4 4 5; 6 6 7; 7 4 8; 13 8 9; 14 12 13; 15 9 10; 10 4 12
 16. 19 14 15; 18 10 11; 17 13 14; 16 14 10; 8 5 16; 20 16 17; 22 19 20
 17. 23 20 21; 9 6 22; 24 22 23; 12 6 24; 25 24 25; 26 17 23; 27 20 25
 18. 21 17 18; 11 5 19; 2 2 200; 200 200 3; 5 5 500; 500 500 6
 19. MEMBER PROPERTY AMER
 20. 13 TO 19 24 25 TABLE ST TUB30203
 21. 20 TO 23 26 27 TABLE ST TUB40408
 22. 7 TO 12 TABLE ST TUB80805
 23. 1 TO 6 200 500 TABLE ST PIPE OD 31. ID 30.5
 24. MEMBER RELEASE
 25. 13 14 20 22 24 25 START MX MY MZ
 26. CONSTANTS
 27. E STEEL ALL
 28. POISSON STEEL ALL
 29. DENSITY STEEL ALL
 30. BETA 90. MEMB 13 14 18 19 24 25
 31. ALPHA 0.00000919 MEMB 1 TO 6 200 500 7 TO 12
 32. SUPPORTS
 33. 11 15 FIXED BUT MZ
 34. 18 21 23 25 FIXED
 35. ****************************************
 36. LOAD 1 DW
 37. JOINT LOAD
 38. 1 7 FY -1539.
 39. 2 3 FY -2250.
 40. MEMBER LOAD
 41. 1 TO 6 200 500 UNI Y -14.66
```

```
42. ***************************************
43. LOAD 2 DW+TH+VACUUM
44. JOINT LOAD
45. 1 7 FY -1539.
46. 2 3 FY -4354.
47. ***  UNBALANCED VACUUM LOAD W/DW @ ION PUMPS
48. 500 FZ 1042.
49. ***  UNBALANCED VACUUM LOAD @ PUMP
50. 200 FZ 382.
51. ***  UNBALANCED VACUUM LOAD @ PUMP
52. 7 FX 33779.996
53. ***  UNBALANCED VACUUM LOAD @ BELLOWS
54. MEMBER LOAD
55. 1 TO 6 200 500 UNI Y -14.66
56. TEMPERATURE LOAD
57. 1 TO 6 200 500 7 TO 12 TEMP 330.
58. ***************************************
59. LOAD 3 DW+TH+VACUUM+SEIS-AXIAL
60. JOINT LOAD
61. 1 7 FY -1539.
62. 2 3 FY -4354.
63. 500 FZ 1042.
64. 200 FZ 382.
65. 2 3 FX -126.5
66. 2 3 MZ 4542.
67. 1 FX -86.5
68. 7 FX 33779.996
69. MEMBER LOAD
70. 1 TO 6 200 500 UNI Y -14.66
71. 1 TO 6 200 500 UNI X -0.825
72. TEMPERATURE LOAD
73. 1 TO 6 200 500 7 TO 12 TEMP 330.
74. ***************************************
75. LOAD 4 DW+TH+VACUUM+SEIS-LAT
76. JOINT LOAD
77. 1 7 FY -1539.
78. 2 3 FY -4354.
79. 500 FZ 1042.
80. 200 FZ 382.
81. 2 3 FZ 126.5
82. 2 3 MX 4542.
83. 1 7 FZ 86.5
84. 7 FX 33779.996
85. MEMBER LOAD
86. 1 TO 6 200 500 UNI Y -14.66
87. 1 TO 6 200 500 UNI Z 0.825
88. TEMPERATURE LOAD
89. 1 TO 6 200 500 7 TO 12 TEMP 330.
90. ***************************************
91. LOAD 5 THERM DISPL "BAKEOUT"
92. TEMPERATURE LOAD
93. 1 TO 6 200 500 7 TO 12 TEMP 330.
94. PERFORM ANALYSIS
```

```
      P R O B L E M   S T A T I S T I C S
      -----------------------------------

   NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS =     27/    29/     6
   ORIGINAL/FINAL BAND-WIDTH =   24/     5
   TOTAL PRIMARY LOAD CASES  =     5, TOTAL DEGREES OF FREEDOM =    128
   SIZE OF STIFFNESS MATRIX =    3840 DOUBLE PREC. WORDS
   REQRD/AVAIL. DISK SPACE =  12.07/  954.3 MB,  EXMEM = 14.83 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.              14: 7:29
++ PROCESSING GLOBAL STIFFNESS MATRIX.               14: 7:29
++ PROCESSING TRIANGULAR FACTORIZATION.              14: 7:29
++ CALCULATING JOINT DISPLACEMENTS.                  14: 7:29
++ CALCULATING MEMBER  FORCES.                       14: 7:29

   95. PRINT MATERIAL PROPERTIES ALL
```

```
MATERIAL PROPERTIES.
--------------------
ALL UNITS ARE - POUN INCH

MEMBER            E             G            DEN          ALPHA

   1        29000000.0    11153846.0    0.28299999   0.00000919
   3        29000000.0    11153846.0    0.28299999   0.00000919
   4        29000000.0    11153846.0    0.28299999   0.00000919
   6        29000000.0    11153846.0    0.28299999   0.00000919
   7        29000000.0    11153846.0    0.28299999   0.00000919
  13        29000000.0    11153846.0    0.28299999   0.00000000
  14        29000000.0    11153846.0    0.28299999   0.00000000
  15        29000000.0    11153846.0    0.28299999   0.00000000
  10        29000000.0    11153846.0    0.28299999   0.00000919
  19        29000000.0    11153846.0    0.28299999   0.00000000
  18        29000000.0    11153846.0    0.28299999   0.00000000
  17        29000000.0    11153846.0    0.28299999   0.00000000
  16        29000000.0    11153846.0    0.28299999   0.00000000
   8        29000000.0    11153846.0    0.28299999   0.00000919
  20        29000000.0    11153846.0    0.28299999   0.00000000
  22        29000000.0    11153846.0    0.28299999   0.00000000
  23        29000000.0    11153846.0    0.28299999   0.00000000
   9        29000000.0    11153846.0    0.28299999   0.00000919
  24        29000000.0    11153846.0    0.28299999   0.00000000
  12        29000000.0    11153846.0    0.28299999   0.00000919
  25        29000000.0    11153846.0    0.28299999   0.00000000
  26        29000000.0    11153846.0    0.28299999   0.00000000
  27        29000000.0    11153846.0    0.28299999   0.00000000
  21        29000000.0    11153846.0    0.28299999   0.00000000
  11        29000000.0    11153846.0    0.28299999   0.00000919
   2        29000000.0    11153846.0    0.28299999   0.00000919
 200        29000000.0    11153846.0    0.28299999   0.00000919
   5        29000000.0    11153846.0    0.28299999   0.00000919
 500        29000000.0    11153846.0    0.28299999   0.00000919

 ************ END OF DATA FROM INTERNAL STORAGE ************

  96. PRINT MEMBER INFORMATION ALL
```

```
 MEMBER INFORMATION
 ------------------

 MEMBER      START     END          LENGTH      BETA
             JOINT    JOINT         (INCH)      (DEG)       RELEASES

    1          1        2           72.000       0.00
    3          3        4           12.000       0.00
    4          4        5          136.000       0.00
    6          6        7           91.000       0.00
    7          4        8           17.250       0.00
   13          8        9           21.125      90.00     000111000000
   14         12       13           21.125      90.00     000111000000
   15          9       10            2.500       0.00
   10          4       12           17.250       0.00
   19         14       15           48.875      90.00
   18         10       11           48.875      90.00
   17         13       14            2.500       0.00
   16         14       10           29.500       0.00
    8          5       16           17.250       0.00
   20         16       17            9.000       0.00     000111000000
   22         19       20            9.000       0.00     000111000000
   23         20       21           61.000       0.00
    9          6       22           17.250       0.00
   24         22       23           70.000      90.00     000111000000
   12          6       24           17.250       0.00
   25         24       25           70.000      90.00     000111000000
   26         17       23          120.569       0.00
   27         20       25          120.569       0.00
   21         17       18           61.000       0.00
   11          5       19           17.250       0.00
    2          2      200           24.000       0.00
  200        200        3           24.000       0.00
    5          5      500           70.000       0.00
  500        500        6           34.000       0.00

 ************ END OF DATA FROM INTERNAL STORAGE ************


  97. PRINT JOINT COORDINATES ALL
```

```
 JOINT COORDINATES
 -----------------
 COORDINATES ARE INCH UNIT

 JOINT            X              Y              Z

    1         -24.000          0.000          0.000
    2          48.000          0.000          0.000
    3          96.000          0.000          0.000
    4         108.000          0.000          0.000
    5         244.000          0.000          0.000
    6         348.000          0.000          0.000
    7         439.000          0.000          0.000
    8         108.000          0.000        -17.250
    9         108.000        -21.125        -17.250
   10         108.000        -21.125        -14.750
   11         108.000        -70.000        -14.750
   12         108.000          0.000         17.250
   13         108.000        -21.125         17.250
   14         108.000        -21.125         14.750
   15         108.000        -70.000         14.750
   16         244.000          0.000        -17.250
   17         244.000         -9.000        -17.250
   18         244.000        -70.000        -17.250
   19         244.000          0.000         17.250
   20         244.000         -9.000         17.250
   21         244.000        -70.000         17.250
   22         348.000          0.000        -17.250
   23         348.000        -70.000        -17.250
   24         348.000          0.000         17.250
   25         348.000        -70.000         17.250
  200          72.000          0.000          0.000
  500         314.000          0.000          0.000

 ************ END OF DATA FROM INTERNAL STORAGE ************

  98. PRINT SUPPORT INFORMATION ALL


 SUPPORT INFORMATION (1=FIXED, 0=RELEASED)
 -------------------
 UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

 JOINT   FORCE-X/   FORCE-Y/   FORCE-Z/   MOM-X/   MOM-Y/   MOM-Z/
            KFX        KFY        KFZ       KMX      KMY      KMZ

   11        1          1          1         1        1        0
                0.0        0.0        0.0      0.0      0.0      0.0
```

```
 15       1            1            1           1          1          0
              0.0          0.0          0.0        0.0        0.0        0.0
 18       1            1            1           1          1          1
              0.0          0.0          0.0        0.0        0.0        0.0
 21       1            1            1           1          1          1
              0.0          0.0          0.0        0.0        0.0        0.0
 23       1            1            1           1          1          1
              0.0          0.0          0.0        0.0        0.0        0.0
 25       1            1            1           1          1          1
              0.0          0.0          0.0        0.0        0.0        0.0

************ END OF DATA FROM INTERNAL STORAGE ************

 99. PRINT ANALYSIS RESULTS
```

```
 JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
 ------------------

JOINT  LOAD   X-TRANS   Y-TRANS   Z-TRANS   X-ROTAN   Y-ROTAN   Z-ROTAN

    1    1    0.00026  -0.10593   0.00000   0.00000   0.00000   0.00072
         2   -0.71979  -0.15027   0.02723   0.00006  -0.00032   0.00098
         3   -0.72191  -0.15157   0.02723   0.00006  -0.00032   0.00099
         4   -0.71979  -0.15027   0.13331   0.00014  -0.00008   0.00098
         5   -0.81323  -0.00583  -0.00001   0.00000   0.00000   0.00002
    2    1    0.00026  -0.05452   0.00000   0.00000   0.00000   0.00066
         2   -0.50144  -0.08021   0.05009   0.00006  -0.00032   0.00092
         3   -0.50354  -0.08081   0.05008   0.00006  -0.00032   0.00093
         4   -0.50144  -0.08021   0.13946   0.00014  -0.00009   0.00092
         5   -0.59488  -0.00419  -0.00001   0.00000   0.00000   0.00002
    3    1    0.00026  -0.02444   0.00000   0.00000   0.00000   0.00050
         2   -0.35587  -0.03754   0.06528   0.00006  -0.00032   0.00073
         3   -0.35795  -0.03774   0.06528   0.00006  -0.00032   0.00074
         4   -0.35587  -0.03754   0.14374   0.00014  -0.00010   0.00073
         5   -0.44931  -0.00310   0.00000   0.00000   0.00000   0.00002
    4    1    0.00026  -0.01818   0.00000   0.00000   0.00000   0.00044
         2   -0.31948  -0.02831   0.06909   0.00006  -0.00032   0.00065
         3   -0.32155  -0.02843   0.06908   0.00006  -0.00032   0.00066
         4   -0.31948  -0.02831   0.14489   0.00013  -0.00010   0.00065
         5   -0.41292  -0.00283   0.00000   0.00000   0.00000   0.00002
    5    1    0.00026   0.00150   0.00000   0.00000   0.00000   0.00000
         2    0.09297   0.00521   0.11442   0.00003  -0.00035   0.00001
         3    0.09099   0.00519   0.11442   0.00003  -0.00035   0.00001
         4    0.09297   0.00521   0.16429   0.00006  -0.00019   0.00001
         5   -0.00047  -0.00019   0.00000   0.00000   0.00000   0.00001
    6    1    0.00026  -0.00569   0.00000   0.00000   0.00000  -0.00017
         2    0.41336  -0.00468   0.15286   0.00002  -0.00037  -0.00021
         3    0.41136  -0.00469   0.15285   0.00002  -0.00037  -0.00021
         4    0.41336  -0.00468   0.18789   0.00004  -0.00024  -0.00021
         5    0.31491   0.00017   0.00000   0.00000   0.00000   0.00000
    7    1    0.00026  -0.02865   0.00000   0.00000   0.00000  -0.00027
         2    0.69372  -0.03117   0.18651   0.00002  -0.00037  -0.00031
         3    0.69172  -0.03116   0.18650   0.00002  -0.00037  -0.00031
         4    0.69372  -0.03117   0.20982   0.00004  -0.00024  -0.00031
         5    0.59088   0.00029   0.00000   0.00000   0.00000   0.00000
    8    1    0.00026  -0.01247  -0.00002   0.00034   0.00000   0.00044
         2   -0.31395  -0.01897   0.01676   0.00055  -0.00032   0.00065
         3   -0.31603  -0.01905   0.01675   0.00055  -0.00032   0.00066
         4   -0.31769  -0.01733   0.09255   0.00064  -0.00010   0.00065
         5   -0.41292  -0.00288  -0.05229   0.00000   0.00000   0.00002
    9    1    0.00018  -0.00982   0.00008  -0.00095   0.00000   0.00000
         2   -0.21969  -0.01512   0.04414  -0.00200  -0.00018   0.00449
         3   -0.22114  -0.01518   0.04414  -0.00200  -0.00018   0.00452
         4   -0.22197  -0.01331   0.09254  -0.00121  -0.00006   0.00454
         5   -0.28830  -0.00290  -0.00019  -0.00137   0.00000   0.00590
   10    1    0.00018  -0.00613   0.00007  -0.00094   0.00000   0.00000
         2   -0.22015  -0.00850   0.04413  -0.00175  -0.00018   0.00450
         3   -0.22160  -0.00854   0.04413  -0.00175  -0.00018   0.00453
```

```
JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
------------------

JOINT  LOAD   X-TRANS    Y-TRANS    Z-TRANS    X-ROTAN    Y-ROTAN    Z-ROTAN

        4   -0.22212   -0.00840    0.09252   -0.00111   -0.00006    0.00454
        5   -0.28830    0.00006   -0.00017   -0.00100    0.00000    0.00590
  11    1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00451
        3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00454
        4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00455
        5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00590
  12    1    0.00026   -0.01247    0.00002   -0.00034    0.00000    0.00044
        2   -0.32500   -0.02175    0.12139   -0.00039   -0.00032    0.00065
        3   -0.32708   -0.02183    0.12139   -0.00039   -0.00032    0.00066
        4   -0.32127   -0.02339    0.19719   -0.00029   -0.00010    0.00065
        5   -0.41292   -0.00288    0.05228    0.00000    0.00000    0.00002
  13    1    0.00018   -0.00982   -0.00008    0.00095    0.00000    0.00000
        2   -0.22644   -0.01823    0.04428    0.00342   -0.00018    0.00464
        3   -0.22789   -0.01829    0.04427    0.00343   -0.00018    0.00467
        4   -0.22416   -0.02003    0.09267    0.00421   -0.00006    0.00459
        5   -0.28830   -0.00290    0.00018    0.00137    0.00000    0.00590
  14    1    0.00018   -0.00613   -0.00007    0.00094    0.00000    0.00000
        2   -0.22597   -0.00856    0.04427    0.00289   -0.00018    0.00463
        3   -0.22742   -0.00860    0.04427    0.00290   -0.00018    0.00466
        4   -0.22401   -0.00866    0.09266    0.00353   -0.00006    0.00458
        5   -0.28830    0.00006    0.00016    0.00100    0.00000    0.00590
  15    1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00462
        3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00465
        4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00458
        5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00590
  16    1    0.00026    0.00042    0.00000   -0.00006    0.00000    0.00000
        2    0.08186    0.00465    0.06209   -0.00003    0.00066    0.00001
        3    0.08023    0.00458    0.06209   -0.00004    0.00064    0.00001
        4    0.07963    0.00470    0.11194   -0.00003    0.00079    0.00001
        5   -0.00039   -0.00007   -0.05230    0.00001    0.00000    0.00001
  17    1    0.00022    0.00037    0.00000    0.00000    0.00000   -0.00001
        2    0.02084    0.00459    0.05069    0.00124    0.00008   -0.00503
        3    0.02043    0.00452    0.05068    0.00124    0.00008   -0.00493
        4    0.02034    0.00462    0.09138    0.00224    0.00015   -0.00489
        5   -0.00012   -0.00006   -0.04269   -0.00105   -0.00007    0.00002
  18    1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
        5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
  19    1    0.00026    0.00042    0.00000    0.00006    0.00000    0.00000
        2    0.07190    0.00397    0.16669    0.00007   -0.00124    0.00001
        3    0.07027    0.00390    0.16669    0.00007   -0.00121    0.00001
        4    0.07413    0.00391    0.21654    0.00008   -0.00111    0.00001
        5   -0.00039   -0.00007    0.05230   -0.00001    0.00000    0.00001
  20    1    0.00022    0.00037    0.00000    0.00000    0.00000   -0.00001
```

```
 JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
 ------------------

JOINT  LOAD   X-TRANS   Y-TRANS   Z-TRANS   X-ROTAN   Y-ROTAN   Z-ROTAN

         2    0.01826   0.00394   0.13607   0.00334   0.00022  -0.00442
         3    0.01786   0.00387   0.13607   0.00334   0.00022  -0.00432
         4    0.01877   0.00390   0.17676   0.00433   0.00029  -0.00456
         5   -0.00012  -0.00006   0.04269   0.00105   0.00007   0.00002
  21     1    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         2    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         3    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         4    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         5    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  22     1    0.00026  -0.00345   0.00000   0.00013   0.00000  -0.00017
         2    0.41963  -0.00260   0.10054   0.00012  -0.00036  -0.00021
         3    0.41764  -0.00261   0.10054   0.00012  -0.00036  -0.00021
         4    0.41733  -0.00238   0.13557   0.00013  -0.00023  -0.00021
         5    0.31483   0.00011  -0.05231   0.00000   0.00000   0.00000
  23     1    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         2    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         3    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         4    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         5    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  24     1    0.00026  -0.00345   0.00000  -0.00013   0.00000  -0.00017
         2    0.40688  -0.00307   0.20516  -0.00010  -0.00038  -0.00021
         3    0.40488  -0.00308   0.20516  -0.00010  -0.00038  -0.00021
         4    0.40918  -0.00329   0.24019  -0.00008  -0.00024  -0.00021
         5    0.31483   0.00011   0.05231   0.00000   0.00000   0.00000
  25     1    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         2    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         3    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         4    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
         5    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
 200     1    0.00026  -0.03857   0.00000   0.00000   0.00000   0.00060
         2   -0.42865  -0.05779   0.05771   0.00006  -0.00032   0.00085
         3   -0.43075  -0.05817   0.05770   0.00006  -0.00032   0.00086
         4   -0.42865  -0.05779   0.14157   0.00014  -0.00009   0.00085
         5   -0.52209  -0.00365   0.00000   0.00000   0.00000   0.00002
 500     1    0.00026  -0.00149   0.00000   0.00000   0.00000  -0.00010
         2    0.30861   0.00096   0.14030   0.00003  -0.00037  -0.00013
         3    0.30662   0.00093   0.14030   0.00003  -0.00037  -0.00013
         4    0.30861   0.00096   0.17993   0.00005  -0.00023  -0.00013
         5    0.21180   0.00015   0.00000   0.00000   0.00000   0.00000
```

```
SUPPORT REACTIONS -UNIT POUN INCH    STRUCTURE TYPE = SPACE
-----------------

JOINT  LOAD   FORCE-X    FORCE-Y    FORCE-Z     MOM-X      MOM-Y      MOM Z

  11    1       0.00    5960.82    -127.81   -2062.40       0.00       0.00
        2       0.12    8270.78    -481.19   -9788.79      91.89       0.00
        3       0.12    8309.23    -482.01   -9801.83      91.89       0.00
        4       0.04    8177.02    -662.98  -14950.03      29.74       0.00
        5       0.00     -54.65    -134.68   -2162.30       0.01       0.00
  15    1       0.00    5960.82     127.81    2062.40       0.00       0.00
        2      -0.12    8333.55     146.57     319.15      91.89       0.00
        3      -0.12    8372.00     147.40     332.72      91.89       0.00
        4      -0.04    8427.31     -35.22   -4842.08      29.74       0.00
        5       0.00     -54.64     134.70    2162.88       0.01       0.00
  18    1      -1.01   -1119.63       0.00       0.00       0.00      61.78
        2    2436.00  -13876.25    -235.24  -14439.37    -331.71  -44898.11
        3    2386.84  -13664.87    -235.23  -14438.51    -331.69  -43989.33
        4    2365.65  -13982.56    -424.10  -26031.64    -598.01  -43582.10
        5     -10.75     182.70     198.14   12162.38     279.40     193.43
  21    1      -1.01   -1119.63       0.00       0.00       0.00      61.78
        2    2141.97  -11905.02    -631.52  -38763.48    -890.49  -39490.16
        3    2092.81  -11693.68    -631.51  -38762.61    -890.48  -38581.38
        4    2212.31  -11798.70    -820.38  -50355.74   -1156.80  -40806.12
        5     -10.76     182.75    -198.13  -12161.73    -279.39     193.75
  23    1       1.01    2341.60       0.00       0.00       0.00      36.45
        2  -20406.73   14483.24     -68.87   -6848.31   -1805.11  -19908.13
        3  -19996.96   14233.43     -68.87   -6847.98   -1805.01  -19390.53
        4  -19823.21   13967.93    -102.20  -10809.24   -3254.31  -19150.23
        5      10.75    -128.03      42.45    4679.21    1520.46    5690.51
  25    1       1.01    2341.60       0.00       0.00       0.00      36.45
        2  -17951.24   13267.28    -153.77  -16206.61   -4845.96  -16839.85
        3  -17541.46   13017.46    -153.76  -16206.28   -4845.85  -16322.24
        4  -18534.73   13782.58    -187.10  -20167.54   -6295.14  -17597.72
        5      10.90    -128.14     -42.45   -4679.09   -1520.38    5690.70
```

```
  MEMBER END FORCES    STRUCTURE TYPE = SPACE
  -----------------
  ALL UNITS ARE -- POUN INCH

 MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y     MOM-Z

          2     4   -252.69  -8679.79     5.24      0.01    -90.50 -149726.41
                8    252.69   8679.79    -5.24     -0.01     -0.86       0.07
          3     4   -254.76  -8718.23     5.22      0.01    -90.20 -150389.39
                8    254.76   8718.23    -5.22     -0.01      0.17      -0.03
          4     4   -433.84  -9038.10     1.77      0.01    -29.74 -155907.41
                8    433.84   9038.10    -1.77     -0.01     -1.01       0.13
          5     4    392.82     54.67     0.02      0.00      0.20     943.08
                8   -392.82    -54.67    -0.02      0.00     -0.03       0.00

   13     1     8   5960.82    340.90     0.00      0.00      0.00       0.00
                9  -5960.82   -340.90     0.00      0.00      0.00    7201.57
          2     8   8679.79    252.45    -5.23      0.00      0.00       0.00
                9  -8679.79   -252.45     5.23      0.00    110.38    5333.00
          3     8   8718.23    254.64    -5.23      0.00      0.00       0.00
                9  -8718.23   -254.64     5.23      0.00    110.39    5379.27
          4     8   9038.11    434.24    -1.69      0.00      0.00       0.00
                9  -9038.11   -434.24     1.69      0.00     35.73    9173.30
          5     8    -54.67   -392.80     0.00      0.00      0.00       0.00
                9     54.67    392.80     0.00      0.00     -0.01   -8297.98

   14     1    12   5960.82   -340.90     0.00      0.00      0.00       0.00
               13  -5960.82    340.90     0.00      0.00      0.00   -7201.57
          2    12   7924.53     82.18     5.22      0.00      0.00       0.00
               13  -7924.53    -82.18    -5.22      0.00   -110.38    1735.95
          3    12   7963.00     79.97     5.22      0.00      0.00       0.00
               13  -7963.00    -79.97    -5.22      0.00   -110.37    1689.30
          4    12   7566.21    263.96     1.69      0.00      0.00       0.00
               13  -7566.21   -263.96    -1.69      0.00    -35.72    5576.24
          5    12    -54.62    392.78     0.00      0.00      0.00       0.00
               13     54.62   -392.78     0.00      0.00     -0.01    8297.54

   15     1     9    340.90  -5960.82     0.00      0.00      0.00   -7201.57
               10   -340.90   5960.82     0.00      0.00      0.00   -7700.48
          2     9    252.51  -8679.79    -5.22   -110.38     -0.05   -5332.99
               10   -252.51   8679.79     5.22    110.38     13.01  -16366.47
          3     9    254.69  -8718.22    -5.26   -110.39      0.02   -5379.27
               10   -254.69   8718.22     5.26    110.39     13.09  -16416.29
          4     9    434.00  -9038.11    -1.68    -35.73     -0.03   -9173.29
               10   -434.00   9038.11     1.68     35.73      4.19  -13422.00
          5     9   -392.80     54.67    -0.05     -0.01      0.07    8297.98
               10    392.80    -54.67     0.05      0.01      0.05   -8161.30

   10     1     4   -340.90  -5960.82     0.00      0.00      0.00 -102824.15
               12    340.90   5960.82     0.00      0.00      0.00       0.00
          2     4     82.21  -7924.51     5.10      0.01    -88.83 -136698.03
               12    -82.21   7924.51    -5.10     -0.01      0.93       0.12
          3     4     79.96  -7963.01     5.16     -0.01    -89.56 -137361.89
               12    -79.96   7963.01    -5.16      0.01      0.71      -0.10
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z

         4     4    263.55  -7566.19     1.69      0.00    -28.51 -130516.98
              12   -263.55   7566.19    -1.69      0.00      0.19       0.16
         5     4    392.82     54.62    -0.03      0.00     -0.03     942.15
              12   -392.82    -54.62     0.03      0.00     -0.09       0.00

  19     1    14   5960.82   -127.81     0.00      0.00      0.00   -4184.54
              15  -5960.82    127.81     0.00      0.00      0.00   -2062.40
         2    14   8333.55   -146.57    -0.12     91.89      5.82   -6844.37
              15  -8333.55    146.57     0.12    -91.89      0.00    -319.15
         3    14   8372.00   -147.40    -0.12     91.89      5.82   -6871.56
              15  -8372.00    147.40     0.12    -91.89      0.00    -332.72
         4    14   8427.31     35.22    -0.04     29.74      1.88   -3120.69
              15  -8427.31    -35.22     0.04    -29.74      0.00    4842.08
         5    14    -54.64   -134.70     0.00      0.01      0.00   -4420.63
              15     54.64    134.70     0.00     -0.01      0.00   -2162.88

  18     1    10   5960.82    127.81     0.00      0.00      0.00    4184.54
              11  -5960.82   -127.81     0.00      0.00      0.00    2062.40
         2    10   8270.78    481.19     0.12     91.89     -5.82   13729.56
              11  -8270.78   -481.19    -0.12    -91.89      0.00    9788.79
         3    10   8309.23    482.01     0.12     91.89     -5.83   13756.36
              11  -8309.23   -482.01    -0.12    -91.89      0.00    9801.83
         4    10   8177.02    662.98     0.04     29.74     -1.89   17453.24
              11  -8177.02   -662.98    -0.04    -29.74      0.00   14950.03
         5    10    -54.65    134.68     0.00      0.01      0.00    4420.21
              11     54.65   -134.68     0.00     -0.01      0.00    2162.30

  17     1    13    340.90  -5960.82     0.00      0.00      0.00   -7201.57
              14   -340.90   5960.82     0.00      0.00      0.00   -7700.48
         2    13    -82.11  -7924.53    -5.31   -110.38      0.06    1735.96
              14     82.11   7924.53     5.31    110.38     13.12  -21547.28
         3    13    -79.93  -7963.01    -5.28   -110.37      0.08    1689.30
              14     79.93   7963.01     5.28    110.37     13.15  -21596.84
         4    13   -263.88  -7566.19    -1.66    -35.71     -0.03    5576.26
              14    263.88   7566.19     1.66     35.71      4.22  -24491.76
         5    13   -392.78     54.62    -0.01      0.00      0.06    8297.54
              14    392.78    -54.62     0.01      0.00      0.06   -8161.00

  16     1    14    213.09      0.00     0.00      0.00      0.00    3515.93
              10   -213.09      0.00     0.00      0.00      0.00   -3515.93
         2    14   -228.74    409.02    -5.34   -104.56     78.82   14702.91
              10    228.74   -409.02     5.34    104.56     78.82   -2636.92
         3    14   -227.38    408.99    -5.34   -104.56     78.82   14725.26
              10    227.38   -408.99     5.34    104.56     78.82   -2659.93
         4    14   -228.75    861.10    -1.73    -33.84     25.51   21371.08
              10    228.75   -861.10     1.73     33.84     25.51    4031.25
         5    14   -527.48     -0.02     0.00     -0.01      0.01    3740.37
              10    527.48      0.02     0.00      0.01      0.01   -3741.10
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z


     8    1     5      0.00   1120.58    -0.07      0.00       1.15   19329.99
               16      0.00  -1120.58     0.07      0.00       0.00       0.00
          2     5   -255.86   1157.43 17864.58      0.00-308164.63   19965.62
               16    255.86  -1157.43-17864.58      0.00       0.37      -0.01
          3     5   -255.68   1202.48 17504.55      0.00-301953.38   20742.69
               16    255.68  -1202.48-17504.55      0.00      -0.03       0.01
          4     5   -461.00   1629.09 17352.06      0.00-299323.22   28101.73
               16    461.00  -1629.09-17352.06      0.00      -0.11       0.01
          5     5    215.45   -126.12   -79.63      0.00    1373.48   -2175.64
               16   -215.45    126.12    79.63      0.00       0.19       0.01

    20    1    16  -1120.58     -0.07     0.00      0.00       0.00       0.00
               17   1120.58      0.07     0.00      0.00       0.00      -0.60
          2    16  -1157.43  17864.64   255.79      0.00       0.00       0.00
               17   1157.43 -17864.64  -255.79      0.00   -2302.11  160781.72
          3    16  -1202.47  17504.54   255.77      0.00       0.00       0.00
               17   1202.47 -17504.54  -255.77      0.00   -2301.97  157540.78
          4    16  -1629.10  17352.04   461.13      0.00       0.00       0.00
               17   1629.10 -17352.04  -461.13      0.00   -4150.25  156168.41
          5    16    126.12    -79.61  -215.45      0.00       0.00       0.00
               17   -126.12     79.61   215.45      0.00    1939.03    -716.48

    22    1    19  -1120.58     -0.07     0.00      0.00       0.00       0.00
               20   1120.58      0.07     0.00      0.00       0.00      -0.60
          2    19   -722.54  15706.40   686.67      0.00       0.00       0.00
               20    722.54 -15706.40  -686.67      0.00   -6180.07  141357.53
          3    19   -767.63  15346.29   686.67      0.00       0.00       0.00
               20    767.63 -15346.29  -686.67      0.00   -6179.94  138116.63
          4    19   -250.88  16218.96   892.05      0.00       0.00       0.00
               20    250.88 -16218.96  -892.05      0.00   -8028.44  145970.64
          5    19    126.07    -79.74   215.44      0.00       0.00       0.00
               20   -126.07     79.74  -215.44      0.00   -1938.95    -717.64

    23    1    20  -1119.63      1.01     0.00      0.00       0.00       0.05
               21   1119.63     -1.01     0.00      0.00       0.00      61.78
          2    20 -11905.02  -2141.97   631.52   -890.49     240.74  -91169.97
               21  11905.02   2141.97  -631.52    890.49  -38763.48  -39490.16
          3    20 -11693.68  -2092.81   631.51   -890.48     240.74  -89079.74
               21  11693.68   2092.81  -631.51    890.48  -38762.61  -38581.38
          4    20 -11798.70  -2212.31   820.38  -1156.80     312.75  -94145.08
               21  11798.70   2212.31  -820.38   1156.80  -50355.74  -40806.12
          5    20    182.75     10.76   198.13   -279.39      75.53     462.89
               21   -182.75    -10.76  -198.13    279.39  -12161.73     193.75

     9    1     6      0.00  -2342.55     0.07      0.00      -1.15  -40408.94
               22      0.00   2342.55    -0.07      0.00       0.00       0.00
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z

          2    6    -48.28  -1764.42   106.10      0.00  -1830.79  -30436.28
              22     48.28   1764.42  -106.10      0.00     -0.40      -0.01
          3    6    -48.40  -1771.04   105.63      0.00  -1821.88  -30550.42
              22     48.40   1771.04  -105.63      0.00     -0.29       0.01
          4    6    -65.12  -1614.45   105.57      0.00  -1820.47  -27849.33
              22     65.12   1614.45  -105.57      0.00     -0.43       0.00
          5    6     25.15     71.45    79.59      0.00  -1372.64    1232.56
              22    -25.15    -71.45   -79.59      0.00      0.41       0.00

    24    1   22   2342.55      0.00    -0.07      0.00      0.00       0.00
              23  -2342.55      0.00     0.07      0.00      4.66       0.00
          2   22   1764.42     48.32  -106.10      0.00      0.00       0.00
              23  -1764.42    -48.32   106.10      0.00   7426.98    3382.57
          3   22   1771.04     48.32  -105.60      0.00      0.00       0.00
              23  -1771.04    -48.32   105.60      0.00   7391.65    3382.45
          4   22   1614.45     65.16  -105.52      0.00      0.00       0.00
              23  -1614.45    -65.16   105.52      0.00   7386.28    4561.13
          5   22    -71.45    -25.14   -79.60      0.00      0.00       0.00
              23     71.45     25.14    79.60      0.00   5572.12   -1759.99

    12    1    6      0.00  -2342.55    -0.07      0.00      1.15  -40408.93
              24      0.00   2342.55     0.07      0.00      0.00       0.01
          2    6     98.45  -2084.80  -102.88      0.00   1774.91  -35962.76
              24    -98.45   2084.80   102.88      0.00      0.49       0.00
          3    6     98.51  -2091.40  -102.40      0.00   1766.00  -36076.66
              24    -98.51   2091.40   102.40      0.00      0.19      -0.01
          4    6    115.36  -2234.76  -103.36      0.00   1783.94  -38549.69
              24   -115.36   2234.76   103.36      0.00     -0.74      -0.01
          5    6     25.09     71.46   -79.54      0.00   1372.72    1232.72
              24    -25.09    -71.46    79.54      0.00     -0.39       0.00

    25    1   24   2342.55      0.00    -0.07      0.00      0.00       0.00
              25  -2342.55      0.00     0.07      0.00      4.66       0.00
          2   24   2084.80     98.61  -102.87      0.00      0.00       0.00
              25  -2084.80    -98.61   102.87      0.00   7201.23    6902.60
          3   24   2091.40     98.61  -102.37      0.00      0.00       0.00
              25  -2091.40    -98.61   102.37      0.00   7165.90    6902.48
          4   24   2234.76    115.45  -103.46      0.00      0.00       0.00
              25  -2234.76   -115.45   103.46      0.00   7241.92    8081.15
          5   24    -71.46     25.14   -79.60      0.00      0.00       0.00
              25     71.46    -25.14    79.60      0.00   5572.11    1760.03

    26    1   17     -1.41      0.27     0.00      0.00      0.00       0.55
              23      1.41     -0.27     0.00      0.00      0.00      31.78
          2   17  23945.64   -700.17    20.55   2076.19    833.21  -57083.81
              23 -23945.64    700.17   -20.55  -2076.19  -3310.47  -27335.11
          3   17  23462.88   -686.04    20.55   2076.06    833.16  -55933.15
              23 -23462.88    686.04   -20.55  -2076.06  -3310.28  -26782.18
```

```
MEMBER END FORCES    STRUCTURE TYPE = SPACE
-----------------
ALL UNITS ARE -- POUN INCH

MEMBER  LOAD    JT      AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z

           4    17   23257.98   -679.96    37.04   3743.00   1502.12  -55445.77
                23  -23257.98    679.96   -37.04  -3743.00  -5968.20  -26536.52
           5    17    -106.57      3.09   -17.31  -1748.79   -701.82     254.34
                23     106.57     -3.09    17.31   1748.79   2788.43     118.39

    27     1    20      -1.41      0.27     0.00      0.00      0.00       0.55
                25       1.41     -0.27     0.00      0.00      0.00      31.78
           2    20   21053.10   -615.65    55.16   5573.66   2236.80  -50187.57
                25  -21053.10    615.65   -55.16  -5573.66  -8887.19  -24041.08
           3    20   20570.34   -601.52    55.16   5573.54   2236.75  -49036.90
                25  -20570.34    601.52   -55.16  -5573.54  -8886.99  -23488.15
           4    20   21740.74   -635.86    71.65   7240.48   2905.72  -51825.55
                25  -21740.74    635.86   -71.65  -7240.48 -11544.91  -24839.64
           5    20    -106.74      3.10    17.31   1748.69    701.78     254.75
                25     106.74     -3.10   -17.31  -1748.69  -2788.28     118.59

    21     1    17   -1119.63      1.01     0.00      0.00      0.00       0.05
                18    1119.63     -1.01     0.00      0.00      0.00      61.78
           2    17  -13876.25  -2436.00   235.24   -331.71     89.68 -103697.87
                18   13876.25   2436.00  -235.24    331.71 -14439.37  -44898.11
           3    17  -13664.87  -2386.84   235.23   -331.69     89.67 -101607.64
                18   13664.87   2386.84  -235.23    331.69 -14438.51  -43989.33
           4    17  -13982.56  -2365.65   424.10   -598.01    161.67 -100722.64
                18   13982.56   2365.65  -424.10    598.01 -26031.64  -43582.10
           5    17     182.70     10.75  -198.14    279.40    -75.54     462.14
                18    -182.70    -10.75   198.14   -279.40  12162.38     193.43

    11     1     5       0.00   1120.58     0.07      0.00     -1.15   19329.99
                19       0.00  -1120.58    -0.07      0.00      0.00       0.00
           2     5     686.71    722.54-15706.39      0.00 270935.03   12463.80
                19    -686.71   -722.54 15706.39      0.00      0.26       0.01
           3     5     686.71    767.61-15346.26      0.00 264723.28   13241.39
                19    -686.71   -767.61 15346.26      0.00     -0.11      -0.03
           4     5     891.91    250.88-16218.97      0.00 279777.34    4327.67
                19    -891.91   -250.88 16218.97      0.00      0.03       0.01
           5     5     215.45   -126.08    79.72      0.00  -1375.21   -2174.87
                19    -215.45    126.08   -79.72      0.00      0.06      -0.01

     2     1     2       0.00  -4844.51     0.00      0.01      0.00  148806.33
               200       0.00   5196.35     0.00     -0.01      0.00 -269297.47
           2     2       0.73  -6948.55    -0.01     -0.01      0.06  148806.34
               200      -0.73   7300.39     0.01      0.01     -0.28 -319793.97
           3     2    -273.19  -6948.53     0.03     -0.03      0.07  153348.03
               200     292.97   7300.37    -0.03      0.03     -0.16 -324335.44
           4     2       0.73  -6948.53   272.49   4542.06   8365.39  148806.78
               200      -0.73   7300.37  -292.29  -4542.06 -15142.68 -319793.75
           5     2       1.71      0.00     0.00      0.00      0.01      -0.01
               200      -1.71      0.00     0.00      0.00     -0.01       0.03
```

```
  MEMBER END FORCES    STRUCTURE TYPE = SPACE
  -----------------
  ALL UNITS ARE -- POUN INCH

 MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z


    200    1   200      0.00  -5196.37     0.00      0.03      0.00  269297.09
                 3      0.00   5548.21     0.00     -0.03      0.00 -398231.84
           2   200     -0.49  -7300.39   382.03     -0.07     -0.53  319793.06
                 3      0.49   7652.23  -382.03      0.07  -9167.61 -499225.03
           3   200   -291.99  -7300.34   382.04      0.01      0.39  324335.22
                 3    311.77   7652.18  -382.04     -0.01  -9168.50 -503765.72
           4   200     -1.46  -7300.40   674.24   4541.95  15139.85  319792.63
                 3      1.46   7652.24  -694.04  -4541.95 -31559.80 -499225.03
           5   200     -0.24      0.00     0.00      0.00     -0.06       0.00
                 3      0.24      0.00     0.00      0.00      0.14      -0.05

      5    1     5      0.13   -287.39     0.00      0.00      0.00   91578.41
               500     -0.13   1313.59     0.00      0.00      0.00 -147613.03
           2     5 -33571.04    548.48  -895.06   5526.48  57603.73  178509.39
               500  33571.04    477.72   895.06  -5526.48   5051.29 -176032.75
           3     5 -33411.13    535.26  -895.07   5526.25  57604.52  177134.55
               500  33468.99    490.94   895.07  -5526.25   5051.24 -175583.31
           4     5 -33571.04    548.48 -1108.77  10700.35  86676.05  178509.42
               500  33571.04    477.72  1051.02 -10700.35 -11082.44 -176032.78
           5     5    159.18    142.92     0.00     -0.16      0.07   14863.18
               500   -159.18   -142.92     0.00      0.16      0.06   -4859.12

    500    1   500      0.13  -1313.59     0.00      0.00      0.00  147613.03
                 6     -0.13   1812.03     0.00      0.00      0.00 -200748.69
           2   500 -33570.80   -477.72   146.88   5526.49  -5050.80  176032.78
                 6  33570.80    976.16  -146.88  -5526.49     54.86 -200748.70
           3   500 -33468.99   -490.94   146.93   5526.25  -5051.62  175583.30
                 6  33497.07    989.38  -146.93  -5526.25     55.53 -200748.70
           4   500 -33570.55   -477.72    -9.05  10700.35  11082.52  176032.80
                 6  33570.55    976.16   -19.00 -10700.35 -11252.36 -200748.70
           5   500    159.91    142.92     0.02     -0.16     -0.44    4859.12
                 6   -159.91   -142.92    -0.02      0.16     -0.20       0.00


  ************** END OF LATEST ANALYSIS RESULT **************


  100. PRINT MEMBER STRESSES ALL
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB    LD  SECT     AXIAL     BEND-Y     BEND-Z   COMBINED  SHEAR-Y  SHEAR-Z


   1     1    .0       0.0 C      0.0        0.0        0.0    106.2      0.0
           1.00        0.0 C      0.0      808.0      808.0    179.0      0.0
         2    .0       0.0 T      0.0        0.0        0.0    106.2      0.0
           1.00        0.0 T      0.0      808.0      808.0    179.0      0.0
         3    .0       3.6 T      0.0        0.0        3.6    106.2      0.0
           1.00        6.0 T      0.0      808.0      814.0    179.0      0.0
         4    .0       0.0 T      0.0        0.0        0.0    106.2      6.0
           1.00        0.0 T     45.4      808.0      809.3    179.0     10.1
         5    .0       0.0 T      0.0        0.0        0.0      0.0      0.0
           1.00        0.0 T      0.0        0.0        0.0      0.0      0.0

   3     1    .0       0.0 T      0.0     2162.2     2162.2    538.2      0.0
           1.00        0.0 T      0.0     2676.1     2676.1    550.3      0.0
         2    .0       0.1 T     49.8     2710.6     2711.1    828.6     26.4
           1.00        0.1 T     74.7     3498.6     3499.5    840.7     26.4
         3    .0      18.1 T     49.8     2759.9     2778.5    828.5     26.4
           1.00       18.6 T     74.7     3547.9     3567.3    840.7     26.4
         4    .0       0.0 T    171.3     2710.6     2716.0    828.6     56.6
           1.00        0.0 T    225.1     3498.6     3505.8    840.7     57.3
         5    .0       0.0        0.0        0.0        0.0      0.0      0.0
           1.00        0.0        0.0        0.0        0.0      0.0      0.0

   4     1    .0       0.0 C      0.0     2676.1     2676.1    272.4      0.0
           1.00        0.0 C      0.0      497.2      497.2    134.8      0.0
         2    .0       0.0       75.6     3498.6     3499.4    305.2      3.3
           1.00        0.0      110.6      969.2      975.5    167.6      3.3
         3    .0      18.5 T     75.6     3547.9     3567.3    310.5      3.3
           1.00       23.2 T    110.6      961.8      991.3    172.9      3.3
         4    .0       0.0      225.5     3498.6     3505.8    305.2      9.1
           1.00        0.0      364.5      969.2     1035.5    167.6     16.9
         5    .0       0.0        0.0        0.0        0.0      7.5      0.0
           1.00        0.0        0.0       80.7       80.7      7.5      0.0

   6     1    .0       0.0 T      0.0     1090.0     1090.0    198.3      0.0
           1.00        0.0 T      0.0        0.0        0.0    106.2      0.0
         2    .0    1398.7 T      0.0     1090.0     2488.7    198.3      0.0
           1.00     1398.7 T      0.0        0.0     1398.7    106.2      0.0
         3    .0    1395.6 T      0.0     1090.0     2485.6    198.3      0.0
           1.00     1398.7 T      0.0        0.0     1398.7    106.2      0.0
         4    .0    1398.7 T     61.3     1090.0     2490.4    198.3     11.2
           1.00     1398.7 T      0.0        0.0     1398.7    106.2      6.0
         5    .0       0.0        0.0        0.0        0.0      0.0      0.0
           1.00        0.0        0.0        0.0        0.0      0.0      0.0

   7     1    .0      36.4 T      0.0     4524.7     4561.1   1192.2      0.0
           1.00       36.4 T      0.0        0.0       36.4   1192.2      0.0
         2    .0      27.0 T      4.0     6588.6     6619.6   1736.0      1.0
           1.00       27.0 T      0.0        0.0       27.0   1736.0      1.0
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB    LD  SECT     AXIAL     BEND-Y      BEND-Z    COMBINED   SHEAR-Y   SHEAR-Z

         3    .0      27.2 T        4.0     6617.8     6649.0    1743.6       1.0
            1.00      27.2 T        0.0        0.0       27.2    1743.6       1.0
         4    .0      46.4 T        1.3     6860.6     6908.3    1807.6       0.4
            1.00      46.4 T        0.0        0.0       46.4    1807.6       0.4
         5    .0      42.0 C        0.0       41.5       83.5      10.9       0.0
            1.00      42.0 C        0.0        0.0       42.0      10.9       0.0

   13    1    .0    3634.6 C        0.0        0.0     3634.6     303.0       0.0
            1.00    3634.6 C        0.0     5685.5     9320.1     303.0       0.0
         2    .0    5292.6 C        0.0        0.0     5292.6     224.4      10.5
            1.00    5292.6 C      110.4     4210.3     9613.2     224.4      10.5
         3    .0    5316.0 C        0.0        0.0     5316.0     226.3      10.5
            1.00    5316.0 C      110.4     4246.8     9673.2     226.3      10.5
         4    .0    5511.0 C        0.0        0.0     5511.0     386.0       3.4
            1.00    5511.0 C       35.7     7242.1    12788.8     386.0       3.4
         5    .0      33.3 T        0.0        0.0       33.3     349.2       0.0
            1.00      33.3 T        0.0     6551.0     6584.4     349.2       0.0

   14    1    .0    3634.6 C        0.0        0.0     3634.6     303.0       0.0
            1.00    3634.6 C        0.0     5685.5     9320.1     303.0       0.0
         2    .0    4832.0 C        0.0        0.0     4832.0      73.0      10.4
            1.00    4832.0 C      110.4     1370.5     6312.9      73.0      10.4
         3    .0    4855.5 C        0.0        0.0     4855.5      71.1      10.4
            1.00    4855.5 C      110.4     1333.7     6299.5      71.1      10.4
         4    .0    4613.5 C        0.0        0.0     4613.5     234.6       3.4
            1.00    4613.5 C       35.7     4402.3     9051.6     234.6       3.4
         5    .0      33.3 T        0.0        0.0       33.3     349.1       0.0
            1.00      33.3 T        0.0     6550.7     6584.0     349.1       0.0

   15    1    .0     207.9 C        0.0     5685.5     5893.3    5298.5       0.0
            1.00     207.9 C        0.0     6079.3     6287.2    5298.5       0.0
         2    .0     154.0 C        0.1     4210.3     4364.3    7715.4      10.4
            1.00     154.0 C       13.0    12920.9    13087.9    7715.4      10.4
         3    .0     155.3 C        0.0     4246.8     4402.1    7749.5      10.5
            1.00     155.3 C       13.1    12960.2    13128.6    7749.5      10.5
         4    .0     264.6 C        0.0     7242.1     7506.7    8033.9       3.4
            1.00     264.6 C        4.2    10596.3    10865.1    8033.9       3.4
         5    .0     239.5 T        0.1     6551.0     6790.6      48.6       0.1
            1.00     239.5 T        0.1     6443.1     6682.7      48.6       0.1

   10    1    .0      36.4 T        0.0     4524.7     4561.1    1192.2       0.0
            1.00      36.4 T        0.0        0.0       36.4    1192.2       0.0
         2    .0       8.8 C        3.9     6015.3     6028.0    1584.9       1.0
            1.00       8.8 C        0.0        0.0        8.8    1584.9       1.0
         3    .0       8.5 C        3.9     6044.5     6057.0    1592.6       1.0
            1.00       8.5 C        0.0        0.0        8.6    1592.6       1.0
         4    .0      28.2 C        1.3     5743.3     5772.7    1513.2       0.3
            1.00      28.2 C        0.0        0.0       28.2    1513.2       0.3
         5    .0      42.0 C        0.0       41.5       83.4      10.9       0.0
            1.00      42.0 C        0.0        0.0       42.0      10.9       0.0
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB    LD  SECT     AXIAL      BEND-Y      BEND-Z    COMBINED   SHEAR-Y  SHEAR-Z


  19     1    .0   3634.6 C        0.0      3303.6      6938.2     113.6       0.0
            1.00   3634.6 C        0.0      1628.2      5262.9     113.6       0.0
         2    .0   5081.4 C        5.8      5403.5     10490.7     130.3       0.2
            1.00   5081.4 C        0.0       252.0      5333.4     130.3       0.2
         3    .0   5104.9 C        5.8      5424.9     10535.6     131.0       0.2
            1.00   5104.9 C        0.0       262.7      5367.6     131.0       0.2
         4    .0   5138.6 C        1.9      2463.7      7604.2      31.3       0.1
            1.00   5138.6 C        0.0      3822.7      8961.3      31.3       0.1
         5    .0     33.3 T        0.0      3490.0      3523.3     119.7       0.0
            1.00     33.3 T        0.0      1707.5      1740.9     119.7       0.0

  18     1    .0   3634.6 C        0.0      3303.6      6938.2     113.6       0.0
            1.00   3634.6 C        0.0      1628.2      5262.9     113.6       0.0
         2    .0   5043.2 C        5.8     10839.1     15888.1     427.7       0.2
            1.00   5043.2 C        0.0      7728.0     12771.2     427.7       0.2
         3    .0   5066.6 C        5.8     10860.3     15932.7     428.5       0.2
            1.00   5066.6 C        0.0      7738.3     12804.9     428.5       0.2
         4    .0   4986.0 C        1.9     13778.9     18766.8     589.3       0.1
            1.00   4986.0 C        0.0     11802.7     16788.6     589.3       0.1
         5    .0     33.3 T        0.0      3489.6      3523.0     119.7       0.0
            1.00     33.3 T        0.0      1707.1      1740.4     119.7       0.0

  17     1    .0    207.9 C        0.0      5685.5      5893.3    5298.5       0.0
            1.00    207.9 C        0.0      6079.3      6287.2    5298.5       0.0
         2    .0     50.1 T        0.1      1370.5      1420.6    7044.0      10.6
            1.00     50.1 T       13.1     17011.0     17074.2    7044.0      10.6
         3    .0     48.7 T        0.1      1333.7      1382.5    7078.2      10.6
            1.00     48.7 T       13.1     17050.1     17112.0    7078.2      10.6
         4    .0    160.9 T        0.0      4402.3      4563.2    6725.5       3.3
            1.00    160.9 T        4.2     19335.6     19500.7    6725.5       3.3
         5    .0    239.5 T        0.1      6550.7      6790.3      48.5       0.0
            1.00    239.5 T        0.1      6442.9      6682.5      48.5       0.0

  16     1    .0    129.9 C        0.0      2775.7      2905.7       0.0       0.0
            1.00    129.9 C        0.0      2775.7      2905.7       0.0       0.0
         2    .0    139.5 T       78.8     11607.6     11825.9     363.6      10.7
            1.00    139.5 T       78.8      2081.8      2300.1     363.6      10.7
         3    .0    138.6 T       78.8     11625.2     11842.7     363.6      10.7
            1.00    138.6 T       78.8      2099.9      2317.4     363.6      10.7
         4    .0    139.5 T       25.5     16871.9     17036.9     765.4       3.5
            1.00    139.5 T       25.5      3182.6      3347.6     765.4       3.5
         5    .0    321.6 T        0.0      2952.9      3274.6       0.0       0.0
            1.00    321.6 T        0.0      2953.5      3275.1       0.0       0.0

   8     1    .0      0.0 T        0.1       850.6       850.7     224.1       0.0
            1.00      0.0 T        0.0         0.0         0.0     224.1       0.0
         2    .0     27.3 T    13560.6       878.6     14466.5     231.5    3572.9
            1.00     27.3 T        0.0         0.0        27.4     231.5    3572.9
```

```
    MEMBER STRESSES
    ---------------
    ALL UNITS ARE POUN/SQ INCH

  MEMB    LD  SECT      AXIAL     BEND-Y       BEND-Z     COMBINED    SHEAR-Y    SHEAR-Z

           3     .0     27.3 T   13287.3       912.8     14227.4      240.5     3500.9
               1.00     27.3 T       0.0         0.0        27.3      240.5     3500.9
           4     .0     49.3 T   13171.5      1236.6     14457.4      325.8     3470.4
               1.00     49.3 T       0.0         0.0        49.3      325.8     3470.4
           5     .0     23.0 C      60.4        95.7       179.2       25.2       15.9
               1.00     23.0 C       0.0         0.0        23.0       25.2       15.9

     20    1     .0    176.2 T       0.0         0.0       176.2        0.0        0.0
               1.00    176.2 T       0.0         0.1       176.3        0.0        0.0
           2     .0    182.0 T       0.0         0.0       182.0     4466.2       63.9
               1.00    182.0 T     374.3     26143.4     26699.7     4466.2       63.9
           3     .0    189.1 T       0.0         0.0       189.1     4376.1       63.9
               1.00    189.1 T     374.3     25616.4     26179.8     4376.1       63.9
           4     .0    256.1 T       0.0         0.0       256.1     4338.0      115.3
               1.00    256.1 T     674.8     25393.2     26324.2     4338.0      115.3
           5     .0     19.8 C       0.0         0.0        19.8       19.9       53.9
               1.00     19.8 C     315.3       116.5       451.6       19.9       53.9

     22    1     .0    176.2 T       0.0         0.0       176.2        0.0        0.0
               1.00    176.2 T       0.0         0.1       176.3        0.0        0.0
           2     .0    113.6 T       0.0         0.0       113.6     3926.6      171.7
               1.00    113.6 T    1004.9     22985.0     24103.5     3926.6      171.7
           3     .0    120.7 T       0.0         0.0       120.7     3836.6      171.7
               1.00    120.7 T    1004.9     22458.0     23583.6     3836.6      171.7
           4     .0     39.4 T       0.0         0.0        39.4     4054.7      223.0
               1.00     39.4 T    1305.4     23735.1     25079.9     4054.7      223.0
           5     .0     19.8 C       0.0         0.0        19.8       19.9       53.9
               1.00     19.8 C     315.3       116.7       451.8       19.9       53.9

     23    1     .0    176.0 T       0.0         0.0       176.1        0.3        0.0
               1.00    176.0 T       0.0        10.0       186.1        0.3        0.0
           2     .0   1871.9 T      39.1     14824.4     16735.4      535.5      157.9
               1.00   1871.9 T    6303.0      6421.2     14596.0      535.5      157.9
           3     .0   1838.6 T      39.1     14484.5     16362.3      523.2      157.9
               1.00   1838.6 T    6302.9      6273.4     14414.9      523.2      157.9
           4     .0   1855.1 T      50.9     15308.1     17214.1      553.1      205.1
               1.00   1855.1 T    8187.9      6635.1     16678.2      553.1      205.1
           5     .0     28.7 C      12.3        75.3       116.3        2.7       49.5
               1.00     28.7 C    1977.5        31.5      2037.8        2.7       49.5

      9    1     .0      0.0 T       0.1      1778.2      1778.2      468.5        0.0
               1.00      0.0 T       0.0         0.0         0.0      468.5        0.0
           2     .0      5.2 T      80.6      1339.3      1425.1      352.9       21.2
               1.00      5.2 T       0.0         0.0         5.2      352.9       21.2
           3     .0      5.2 T      80.2      1344.4      1429.7      354.2       21.1
               1.00      5.2 T       0.0         0.0         5.2      354.2       21.1
           4     .0      7.0 T      80.1      1225.5      1312.6      322.9       21.1
               1.00      7.0 T       0.0         0.0         7.0      322.9       21.1
           5     .0      2.7 C      60.4        54.2       117.3       14.3       15.9
               1.00      2.7 C       0.0         0.0         2.7       14.3       15.9
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB    LD  SECT     AXIAL     BEND-Y      BEND-Z    COMBINED   SHEAR-Y   SHEAR-Z


  24     1    .0   1428.4 C       0.0         0.0     1428.4       0.0       0.1
            1.00   1428.4 C       4.7         0.0     1433.0       0.0       0.1
         2    .0   1075.9 C       0.0         0.0     1075.9      43.0     212.2
            1.00   1075.9 C    7427.0      2670.5    11173.3      43.0     212.2
         3    .0   1079.9 C       0.0         0.0     1079.9      43.0     211.2
            1.00   1079.9 C    7391.7      2670.4    11141.9      43.0     211.2
         4    .0    984.4 C       0.0         0.0      984.4      57.9     211.0
            1.00    984.4 C    7386.3      3600.9    11971.6      57.9     211.0
         5    .0     43.6 T       0.0         0.0       43.6      22.3     159.2
            1.00     43.6 T    5572.1      1389.5     7005.2      22.3     159.2

  12     1    .0      0.0 T       0.1      1778.2     1778.2     468.5       0.0
            1.00      0.0 T       0.0         0.0        0.0     468.5       0.0
         2    .0     10.5 C      78.1      1582.5     1671.1     417.0      20.6
            1.00     10.5 C       0.0         0.0       10.5     417.0      20.6
         3    .0     10.5 C      77.7      1587.5     1675.8     418.3      20.5
            1.00     10.5 C       0.0         0.0       10.5     418.3      20.5
         4    .0     12.3 C      78.5      1696.4     1787.2     447.0      20.7
            1.00     12.3 C       0.0         0.0       12.4     447.0      20.7
         5    .0      2.7 C      60.4        54.2      117.3      14.3      15.9
            1.00      2.7 C       0.0         0.0        2.7      14.3      15.9

  25     1    .0   1428.4 C       0.0         0.0     1428.4       0.0       0.1
            1.00   1428.4 C       4.7         0.0     1433.0       0.0       0.1
         2    .0   1271.2 C       0.0         0.0     1271.2      87.7     205.7
            1.00   1271.2 C    7201.2      5449.4    13921.9      87.7     205.7
         3    .0   1275.2 C       0.0         0.0     1275.2      87.7     204.7
            1.00   1275.2 C    7165.9      5449.3    13890.5      87.7     204.7
         4    .0   1362.7 C       0.0         0.0     1362.7     102.6     206.9
            1.00   1362.7 C    7241.9      6379.9    14984.4     102.6     206.9
         5    .0     43.6 T       0.0         0.0       43.6      22.3     159.2
            1.00     43.6 T    5572.1      1389.5     7005.2      22.3     159.2

  26     1    .0      0.2 T       0.0         0.1        0.3       0.1       0.0
            1.00      0.2 T       0.0         5.2        5.4       0.1       0.0
         2    .0   3765.0 C     135.5      9281.9    13182.4     175.0       5.1
            1.00   3765.0 C     538.3      4444.7     8748.1     175.0       5.1
         3    .0   3689.1 C     135.5      9094.8    12919.4     171.5       5.1
            1.00   3689.1 C     538.3      4354.8     8582.2     171.5       5.1
         4    .0   3656.9 C     244.2      9015.6    12916.7     170.0       9.3
            1.00   3656.9 C     970.4      4314.9     8942.2     170.0       9.3
         5    .0     16.8 T     114.1        41.4      172.2       0.8       4.3
            1.00     16.8 T     453.4        19.3      489.4       0.8       4.3

  27     1    .0      0.2 T       0.0         0.1        0.3       0.1       0.0
            1.00      0.2 T       0.0         5.2        5.4       0.1       0.0
         2    .0   3310.2 C     363.7      8160.6    11834.5     153.9      13.8
            1.00   3310.2 C    1445.1      3909.1     8664.4     153.9      13.8
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB   LD  SECT    AXIAL     BEND-Y      BEND-Z    COMBINED   SHEAR-Y   SHEAR-Z

        3   .0    3234.3 C    363.7      7973.5    11571.5    150.4      13.8
           1.00   3234.3 C   1445.0      3819.2     8498.6    150.4      13.8
        4   .0    3418.4 C    472.5      8426.9    12317.7    159.0      17.9
           1.00   3418.4 C   1877.2      4039.0     9334.5    159.0      17.9
        5   .0      16.8 T    114.1        41.4      172.3      0.8       4.3
           1.00     16.8 T    453.4        19.3      489.4      0.8       4.3

  21    1   .0     176.0 T      0.0         0.0      176.1      0.3       0.0
           1.00    176.0 T      0.0        10.0      186.1      0.3       0.0
        2   .0    2181.8 T     14.6     16861.4    19057.8    609.0      58.8
           1.00   2181.8 T   2347.9      7300.5    11830.2    609.0      58.8
        3   .0    2148.6 T     14.6     16521.6    18684.7    596.7      58.8
           1.00   2148.6 T   2347.7      7152.7    11649.0    596.7      58.8
        4   .0    2198.5 T     26.3     16377.7    18602.5    591.4     106.0
           1.00   2198.5 T   4232.8      7086.5    13517.8    591.4     106.0
        5   .0      28.7 C     12.3        75.1      116.2      2.7      49.5
           1.00     28.7 C   1977.6        31.5     2037.8      2.7      49.5

  11    1   .0       0.0 C      0.1       850.6      850.7    224.1       0.0
           1.00      0.0 C      0.0         0.0        0.0    224.1       0.0
        2   .0      73.4 C  11922.3       548.5    12544.2    144.5    3141.3
           1.00     73.4 C      0.0         0.0       73.4    144.5    3141.3
        3   .0      73.4 C  11649.0       582.7    12305.0    153.5    3069.3
           1.00     73.4 C      0.0         0.0       73.4    153.5    3069.3
        4   .0      95.3 C  12311.4       190.4    12597.2     50.2    3243.8
           1.00     95.3 C      0.0         0.0       95.3     50.2    3243.8
        5   .0      23.0 C     60.5        95.7      179.2     25.2      15.9
           1.00     23.0 C      0.0         0.0       23.0     25.2      15.9

   2    1   .0       0.0 C      0.0       808.0      808.0    334.3       0.0
           1.00      0.0 C      0.0      1462.2     1462.2    358.6       0.0
        2   .0       0.0 C      0.0       808.0      808.0    479.5       0.0
           1.00      0.0 C      0.0      1736.4     1736.4    503.8       0.0
        3   .0      11.3 T      0.0       832.6      843.9    479.5       0.0
           1.00     12.1 T      0.0      1761.0     1773.1    503.8       0.0
        4   .0       0.0 C     45.4       808.0      809.3    479.5      18.8
           1.00      0.0 C     82.2      1736.4     1738.3    503.8      20.2
        5   .0       0.1 C      0.0         0.0        0.1      0.0       0.0
           1.00      0.1 C      0.0         0.0        0.1      0.0       0.0

 200    1   .0       0.0 T      0.0      1462.2     1462.2    358.6       0.0
           1.00      0.0 T      0.0      2162.2     2162.2    382.9       0.0
        2   .0       0.0 T      0.0      1736.3     1736.4    503.8      26.4
           1.00      0.0 T     49.8      2710.6     2711.1    528.1      26.4
        3   .0      12.1 T      0.0      1761.0     1773.1    503.8      26.4
           1.00     12.9 T     49.8      2735.2     2748.6    528.1      26.4
        4   .0       0.1 T     82.2      1736.3     1738.4    503.8      46.5
           1.00      0.1 T    171.4      2710.6     2716.1    528.1      47.9
        5   .0       0.0 T      0.0         0.0        0.0      0.0       0.0
           1.00      0.0 T      0.0         0.0        0.0      0.0       0.0
```

```
MEMBER STRESSES
---------------
ALL UNITS ARE POUN/SQ INCH

MEMB   LD  SECT    AXIAL    BEND-Y     BEND-Z   COMBINED  SHEAR-Y  SHEAR-Z


   5    1    .0      0.0 C      0.0      497.2      497.2     19.8      0.0
           1.00      0.0 C      0.0      801.5      801.5     90.7      0.0
        2    .0   1390.0 T    312.8      969.2     2408.5     37.9     61.8
           1.00   1390.0 T     27.4      955.8     2346.2     33.0     61.8
        3    .0   1383.4 T    312.8      961.8     2394.8     36.9     61.8
           1.00   1385.8 T     27.4      953.3     2339.6     33.9     61.8
        4    .0   1390.0 T    470.6      969.2     2467.5     37.9     76.5
           1.00   1390.0 T     60.2      955.8     2347.7     33.0     72.5
        5    .0      6.6 C      0.0       80.7       87.3      9.9      0.0
           1.00      6.6 C      0.0       26.4       33.0      9.9      0.0

 500    1    .0      0.0 C      0.0      801.5      801.5     90.7      0.0
           1.00      0.0 C      0.0     1090.0     1090.0    125.0      0.0
        2    .0   1390.0 T     27.4      955.8     2346.2     33.0     10.1
           1.00   1390.0 T      0.3     1090.0     2480.0     67.4     10.1
        3    .0   1385.8 T     27.4      953.3     2339.6     33.9     10.1
           1.00   1387.0 T      0.3     1090.0     2477.0     68.3     10.1
        4    .0   1390.0 T     60.2      955.8     2347.7     33.0      0.6
           1.00   1390.0 T     61.1     1090.0     2481.7     67.4      1.3
        5    .0      6.6 C      0.0       26.4       33.0      9.9      0.0
           1.00      6.6 C      0.0        0.0        6.6      9.9      0.0


  ************** END OF LATEST ANALYSIS RESULT **************


  101. PARAMETER
  102. CODE AISC
  103. FYLD 45999.969 MEMB 13 TO 27
  104. WSTR 21000. MEMB 13 TO 27
  105. LY 70. MEMB 18 TO 27
  106. UNL 70. MEMB 13 TO 27
  107. WMIN 0.188 MEMB 13 TO 27
  108. CB 1. MEMB 13 TO 27
  109. CMY 1. MEMB 13 TO 27
  110. MAIN 0. MEMB 13 TO 27
  111. RATIO 1. MEMB 13 TO 27
  112. CHECK CODE MEMB 13 TO 27
```

```
                        STAAD-III CODE CHECKING - (AISC)
                        ***********************

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER      TABLE          RESULT/   CRITICAL COND/       RATIO/      LOADING/
                              FX            MY              MZ        LOCATION
=======================================================================


    13   ST   TUB 30203       PASS     AISC- H1-2          0.463           4
                   9038.11 C             35.73          9173.30        21.13
    14   ST   TUB 30203       PASS     AISC- H1-3          0.349           1
                   5960.82 C              0.00         -7201.57        21.13
    15   ST   TUB 30203       PASS     AISC- H1-3          0.476           3
                    254.69 C             13.09        -16416.29         2.50
    16   ST   TUB 30203       PASS     AISC- H2-1          0.617           4
                    228.75 T             25.51         21371.08         0.00
    17   ST   TUB 30203       PASS     AISC- H2-1          0.707           4
                    263.88 T              4.22        -24491.76         2.50
    18   ST   TUB 30203       PASS     AISC- H1-1          0.761           4
                   8177.02 C             -1.89         17453.24         0.00
    19   ST   TUB 30203       PASS     AISC- H1-1          0.492           3
                   8372.00 C              5.82         -6871.56         0.00
    20   ST   TUB 40408       PASS     AISC- H2-1          0.967           2
                   1157.43 T          -2302.11        160781.72         9.00
    21   ST   TUB 40408       PASS     AISC- H2-1          0.691           2
                  13876.25 T             89.68       -103697.87         0.00
    22   ST   TUB 40408       PASS     AISC- H2-1          0.909           4
                    250.88 T          -8028.44        145970.64         9.00
    23   ST   TUB 40408       PASS     AISC- H2-1          0.624           4
                  11798.70 T            312.75        -94145.08         0.00
    24   ST   TUB 30203       PASS     AISC- H1-3          0.458           4
                   1614.45 C           7386.28          4561.13        70.00
    25   ST   TUB 30203       PASS     AISC- H1-3          0.577           4
                   2234.76 C           7241.92          8081.15        70.00
    26   ST   TUB 40408       PASS     AISC- H1-1          0.581           2
                  23945.64 C            833.21        -57083.81         0.00
    27   ST   TUB 40408       PASS     AISC- H1-1          0.534           4
                  21740.74 C           2905.72        -51825.55         0.00
  113. SELECT WELD MEMB 13 TO 27
```

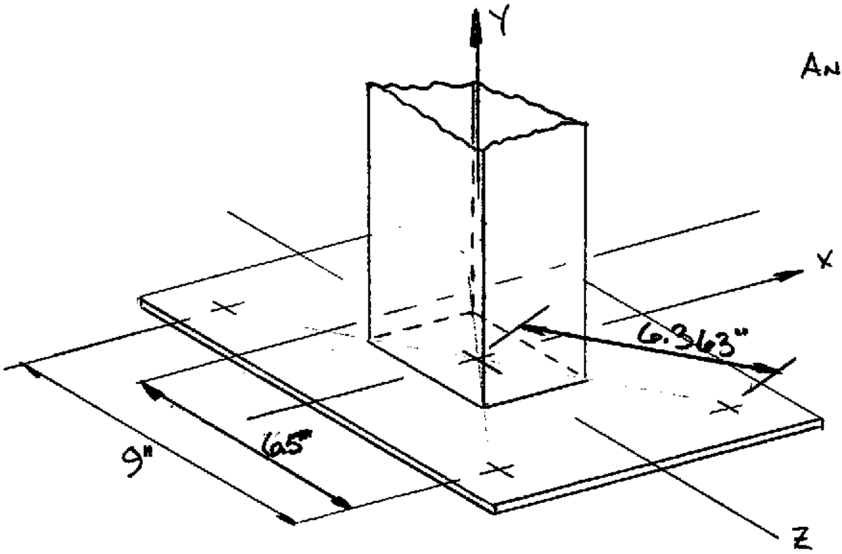
```
                         STAAD-III WELD DESIGN
                         *********************

ALL UNITS ARE - INCH POUN

MEMBER   LOCATION/    WELD TYPE/      WELD SIZE/       COMB STRESS/
         LOADING      HOR STRESS     VERT STRESS        DIR STRESS
=====================================================================


   13      STA            1             3/16              4825.89
            4               0.90          231.59          4820.33

   13      END            1             3/16             10284.94
            4               0.90          231.59         10282.34

   14      STA            1             3/16              4247.15
            3               2.79           42.65          4246.93

   14      END            1             3/16              7448.92
            1               0.00          181.81          7446.70

   15      STA            1             3/16              7446.12
            4              14.62         4829.48          5667.51

   15      END            1             3/16             10925.75
            3              45.19         4677.98          9873.53

   16      STA            1             3/16             12813.45
            4              13.92          467.91         12804.90

   16      END            1             3/16              2572.39
            4              13.92          467.91          2529.44

   17      STA            1             3/16              5468.45
            1               0.00         3179.10          4449.41

   17      END            1             3/16             15205.21
            4              14.60         4044.45         14657.44

   18      STA            1             3/16             14709.55
            4              11.44          361.20         14705.11

   18      END            1             3/16             13225.29
            4              11.44          361.20         13220.35

   19      STA            1             3/16              8542.02
            3              35.35          102.14          8541.34

   19      END            1             3/16              7364.00
            4              11.44           26.40          7363.95

   20      STA            1             3/16              5967.97
            2              85.26         5954.88           385.81

   20      END            1             6/16             20792.71
            2              42.63         2977.44         20578.38
```

```
                        STAAD-III WELD DESIGN
                        *********************

ALL UNITS ARE - INCH POUN

MEMBER   LOCATION/     WELD TYPE/       WELD SIZE/        COMB STRESS/
         LOADING       HOR STRESS       VERT STRESS        DIR STRESS
===================================================================

  21       STA            1               5/16              18350.67
            2              71.93           512.08           18343.38

  21       END            1               4/16              16561.67
            4             162.09           647.48           16548.22

  22       STA            1               3/16               5415.14
            4             297.35          5406.32              83.63

  22       END            1               6/16              19480.73
            4             148.67          2703.16           19291.70

  23       STA            1               4/16              20673.48
            4             313.54           661.53           20660.52

  23       END            1               4/16              20055.89
            4             313.54           661.53           20042.52

  24       STA            1               3/16               1249.36
            1               0.04             0.00            1249.36

  24       END            1               3/16               8936.02
            4              56.28            34.75            8935.78

  25       STA            1               3/16               1249.36
            1               0.04             0.00            1249.36

  25       END            1               3/16              11247.86
            4              55.18            61.57           11247.56

  26       STA            1               4/16              16851.09
            2             199.78           369.68           16845.85

  26       END            1               3/16              15901.27
            4             480.22           694.53           15878.84

  27       STA            1               3/16              20980.09
            4             928.94          1117.01           20929.73

  27       END            1               3/16              16407.50
            4             928.94          1117.01           16343.05

****************** END OF TABULATED WELD DESIGN ******************
```

```
 114. LOAD LIST ALL
 115. FINISH

          *************** END OF STAAD-III ***************

            **** DATE= SEP 20,1996   TIME= 14: 7:31 ****

      ********************************************************
      *        For questions on  STAAD-III,   contact:       *
      *              Research Engineers, Inc at              *
      *       Ph: (714) 974-2500   Fax:  (714) 921-2543      *
      ********************************************************
```

DESIGN BASEPLATE & ANCHOR BOLTS 12" × 12" PL

DESIGN ANCHOR BOLTS AND BASEPLATE
FOR: 4"×4" T.S. ATTACHMENT JT. 18 & 21 (MEM 21 & 23)



ANCHOR BOLTS

TRY 1" Φ HILTI HVA
@ 8 1/4" EMB'T
$f'c = 3000$ psi

$T_{ALL} = 10960.$ lbs

$V_{ALL} = 7630.$ lbs.

SUPPORT REACTIONS (WORST CASE JT 21 L.C. #4)

$F_X = 2212.$ lbs.	$M_X = 50356.$ in-lbs
$F_Y = 11799.$ lbs (up)	$M_Y = 1157.$ in-lbs.
$F_Z = 820.$ lbs.	$M_Z = 40806$ in-lbs.

TENSION

$$T_{MAX} : \frac{11799 \text{ lbs}}{4 \text{ BOLTS}} + \frac{50356 \text{ in-lbs}}{(2 \text{ BOLTS})(6.5 \text{ in})} + \frac{40806 \text{ in-lbs}}{(2 \text{ BOLTS})(6.5 \text{ in})}$$

$$= 9962. \text{ lbs/BOLT}$$ (NO PRYING DUE TO PLATE THKS.)

SHEAR

$$V_{MAX} = \frac{2212 \text{ lbs} + 820 \text{ lbs}}{4 \text{ BOLTS}} + \frac{1157 \text{ in-lbs}}{(4 \text{ BOLTS})(6.363 \text{ in})}$$

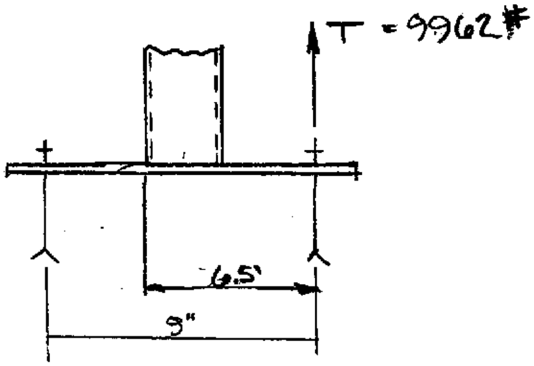
$$= 803 \text{ lbs/BOLT}$$

BOLT INTERACTION

$$\frac{9962}{10960} + \frac{810}{7630} = 1.0 \leq 1.0 \therefore$$

1" Φ HILTI HVA
@ 8 1/4" EMB'T O.K.

PLATE THICKNESS



$F_Y = 36000\ psi$

$F_{Y_b} = .75(36000 psi)$

$= 27000 psi$

$$f_b = \frac{M}{S} = \frac{T(7.5in)}{S} \Rightarrow S\ REQ'D = \frac{M}{f_b} = \frac{M}{F_{Y_b}}$$

$$S_{REQ'D} = \frac{9962^*(6.5in)}{27000\ psi} = 2.40$$

$$S = \frac{bd^2}{6} \Longrightarrow \sqrt{\frac{6(S)}{b}} = d\ req'd$$

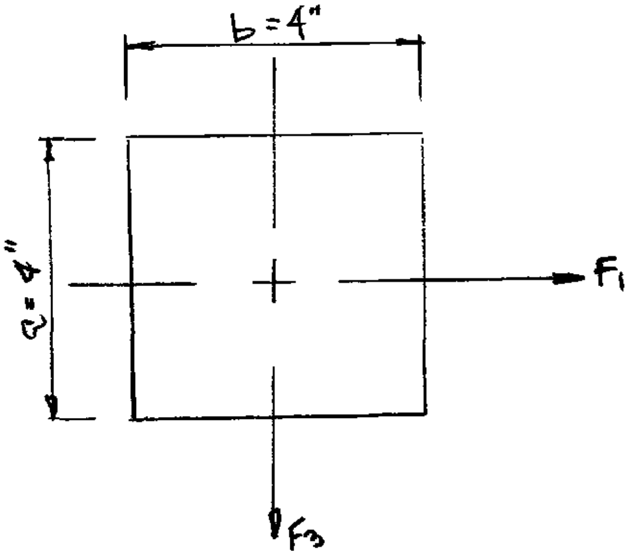
$$d\ req'd = \sqrt{\frac{6(2.40in^3)}{12.0in}} = 1.09\ in$$

$$\boxed{USE\ PL\ 1\tfrac{3}{8}''\ THK}$$

Filename: B-5 ANCHOR

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part MEM 21 & 23 and BASEPLTS



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
2212.00	11799.00	820.00	50356.00	1157.00	40806.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90ø>á<120ø)
4.000	4.000	21000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
16.000	21.333	21.333	85.333	2.000	2.000

EFFECTIVE THROAT CORRECTION FACTOR

Mf

1.00

MAXIMUM WELD LOAD (f) - #/INCH

f=

5014

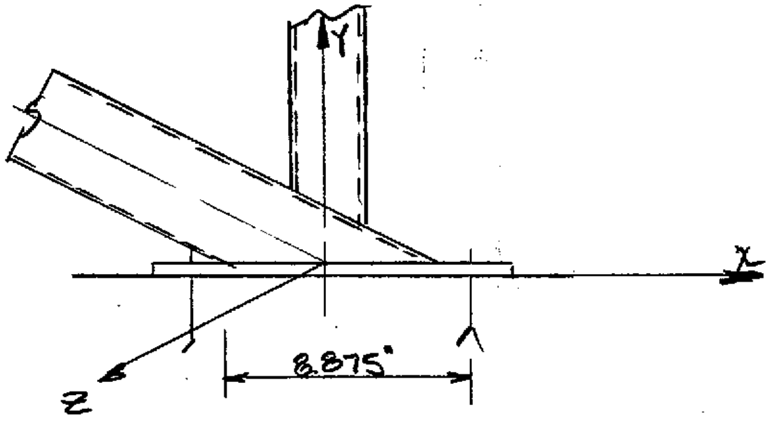
REQUIRED FILLET WELD SIZE (INCHES)

w=

0.338 USE 3/8" allaround fillet

DESIGN BASEPLATE & ANCHOR BOLTS 12"x12" ℞

DESIGN ANCHOR AND BASEPLATE FOR 3"x2" ATTACHMENT JT 23 & 25 (MEM 24 & 25)



ANCHOR BOLTS

TRY 1"Φ HILTI HVA @ 8¼" EMB'T
$f'_c = 3000$ psi

TALL = 10960

VALL = 7630

SUPPORT REACTIONS (JT 25 L.C. # 4)

Fx = 18535. lbs. Mx = 20168. in-lbs
FY = COMPRESSI lbs. My = 6295. in-lbs
Fz = 187. lbs. Mz = 17598. in-lbs

TENSION

$$T_{MAX} = \frac{20168 \text{ in-lbs}}{(2 \text{ BOLTS})(6 \text{ in})} + \frac{17598 \text{ in-lbs}}{(2 \text{ BOLTS})(8.875 \text{ in})}$$

$$= 2672. \text{ lbs/BOLT}$$ (No Prying due to ℞ thk's)

SHEAR

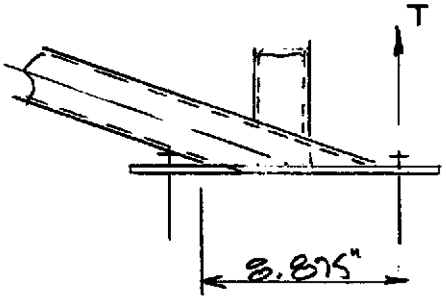
$$V_{MAX} = \frac{18535.+187}{4 \text{ BOLTS}} + \frac{6295. \text{ in-lbs}}{(4 \text{ BOLTS})(6.363 \text{ in})} = 4928 \text{ \#/BOLT}$$

INTERACTION

$$\frac{2672.}{10960} + \frac{4928}{7630} = 0.89 < 1.0 \therefore$$ 1"Φ HILTI HVA @ 8¼" EMB'T

BASEPLATE THICKNESS

$F_Y = 36000$ psi
$F_{Y_b} = .75\, F_Y = 27000$ psi



$T = 2672.$ lbs.

$$f_b = \frac{M}{S} = \frac{T(6\text{in})}{S} \Rightarrow S_{\text{REQ'D}} = \frac{M}{f_b} = \frac{M}{F_{Y_b}}$$

$$S_{\text{REQ'D}} = \frac{2672.\text{lbs}(8.875")}{27000\text{ psi}} = .878\text{ in}^3$$

$$S = \frac{bd^2}{6} \Rightarrow d = \sqrt{\frac{S(6)}{b}}$$

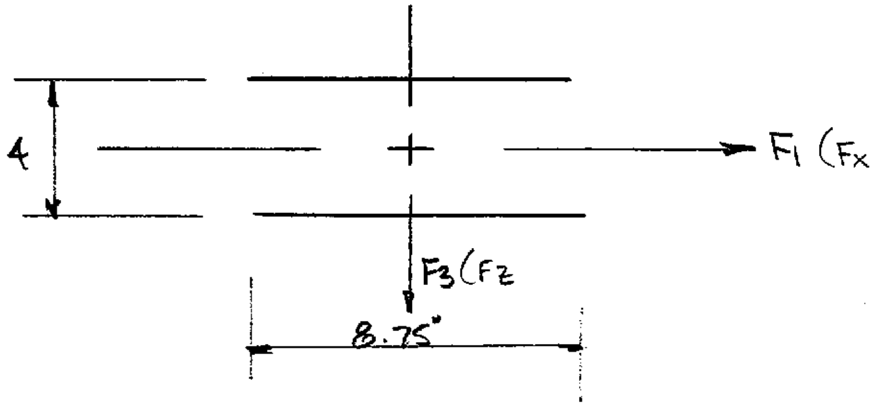
$$= \sqrt{\frac{(.878\text{ in}^3)(6)}{12\text{in}}} = .66\text{ in}$$

$$\boxed{\text{USE PL } 1\tfrac{3}{8}\text{" THK}}$$

filename: B-5,3,&2

HORIZONTAL FILLET WELDS PARALLEL TO F1 AXIS

Between part BASEPLATE & JT 23/MEM24 JT 25/MEM 25



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
18535.00	0.00	187.00	20168.00	6295.00	17598.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)
4.000	8.750	21000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
17.500	35.000	25.521	181.654	2.000	4.375

MAXIMUM WELD LOAD (f) - #/INCH

f
1704

REQUIRED FILLET WELD SIZE (INCHES)

w
0.115

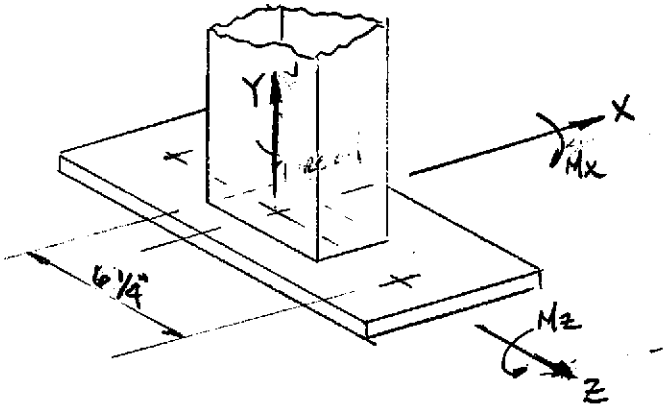
DESIGN BASEPLATE & ANCHOR BOLTS - PL 6" x 12"

DESIGN ANCHOR BOLTS & BASEPLATE (USING WORST CASE LOADING @ JT 11 & 15 .)
13 9

ANCHOR BOLTS - TRY 1"φ HILTI HVA @ 8¼" EMBEDMENT
for f'c = 3000psi

TALLOW = 10960 lbs.

VALLOW = 7630 lbs



SEE Pg. 24
ENVELOPE OF SUPPORT REACTIONS

Fx = 0.0 lbs.
Fy = 8177. lbs Compression
Fz = 663. lbs.

Mx = 14950. IN-lbs
My = 30.0 IN-lbs
Mz = 0.0

REF. STAAD3 OUTPUT

0 = Compression

$$T_{MAX} = \frac{\cancel{8177.}\text{ lbs}}{2\text{ BOLTS}} + \frac{14950.\ ^{\text{IN-lbs}}}{(6.25\text{ IN})(1\text{ BOLT})} = 2392.\text{ lbs / BOLT}$$

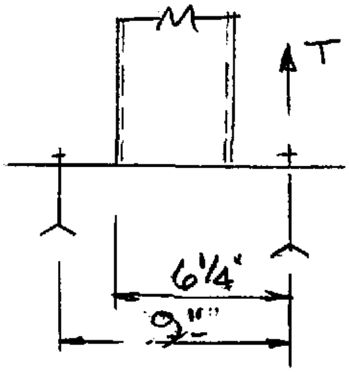
$$V_{MAX} = \frac{663.\text{ lbs}}{2\text{ BOLTS}} + \frac{30.0\text{ IN-lbs}}{(2\text{ BOLTS})(4.75\text{ IN})} = 335.\text{ lbs/BOLT}$$

$$\frac{T_{MAX}}{T_{ALL}} + \frac{V_{MAX}}{V_{ALL}} \Rightarrow \frac{2392(1.2)}{10960.} + \frac{335.}{7630.} = 0.31 < 1.0$$

∴ O.K.

USE 1"φ
HILTI HVA
@ 8½" EMB'D.

BASEPLATE



$F_y = 36000 \text{ lb/in}^2$

$F_{y_b} = .75\,(36000 \text{ lb/in}^2)$

$= 27000 \text{ lb/in}^2$

$$f_b = \frac{M}{S} = \frac{T\,(4.5")}{S} \Rightarrow S_{req'd} = \frac{M}{f_b} = \frac{M}{F_{y_b}}$$

PRYING FACTOR

$$S_{req'd} = \frac{2392\,(6.25")\,(1.2)}{27000} = 0.664 \text{ in}^3$$

$$S = bd^2/6 \Rightarrow \sqrt{\frac{6\,(S)}{b}} = d_{req'd}$$

where b = 6 in

$$d_{req'd} = \sqrt{\frac{6\,(.664 \text{ in}^3)}{9.0"}} = 0.67 \text{ THICK}$$

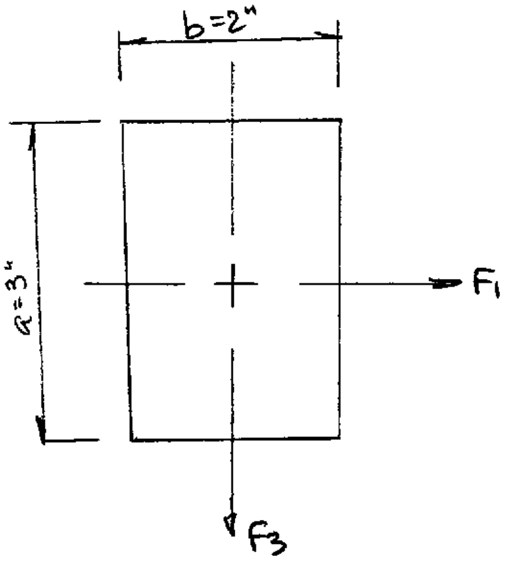
USE 1" THK PLATE

(USE 1 3/8" THK PL
STD THKS)

Filename: B-5 SUPPORT

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part MEM 18 & 19 and BASEPLTS



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
		663.00	14950.00		

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90ø>á<120ø)
3.000	2.000	21000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
10.000	9.000	7.333	20.833	1.500	1.000
12					

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

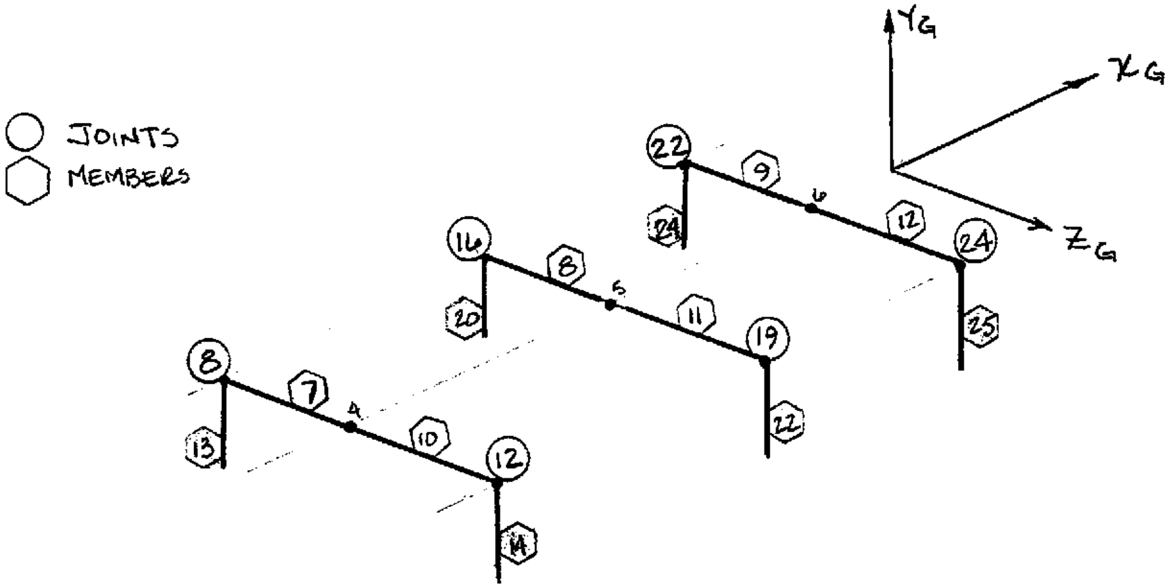
f=
1662

REQUIRED FILLET WELD SIZE (INCHES)

w=
0.112 USE 3/16" fillet

DESIGN BOLTED CONNECTION

B-5 MODE CLEANER TUBE TO SUPPORT LEG

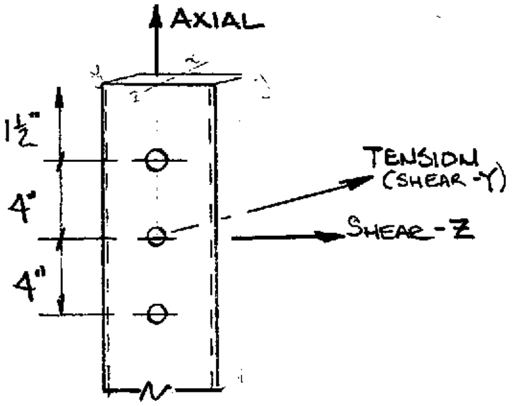


TRY 5/8" Φ A325 BOLTS

$F_T = 44$ KSI $A_g = .307 in^2$ ⇒ $F_{T_{ALLOW}} = 44 KSI (.307 in^2)$
= 13.5 KIPS
= 13508. lbs

$F_V = 17$ KSI $A_g = .307 in^2$ ⇒ $F_{V_{ALLOW}} = 17 KSI (.307 in^2)$
= 5.2 KIPS
= 5219. lbs.

MEMBER END FORCES @ member 20 ~~JT~~ JT 16 (WORST CASE)



MAX AXIAL = 1629. lbs

MAX SHEAR-Z = 461. lbs

TENSION MAX = 17352 lbs
(SHEAR-Y)

BOLT FORCES

$$\text{SHEAR} = V = \left((1629.0\ \text{lbs})^2 + (461.\ \text{lbs})^2 \right)^{1/2}$$

$$V = 1693.\ \text{lbs} / 3\ \text{BOLTS} = 564.\ \text{lbs/BOLT}$$

$$\text{TENSION} \quad T = 17352\ \text{lbs}\ (1.2\ \text{PRYING})$$

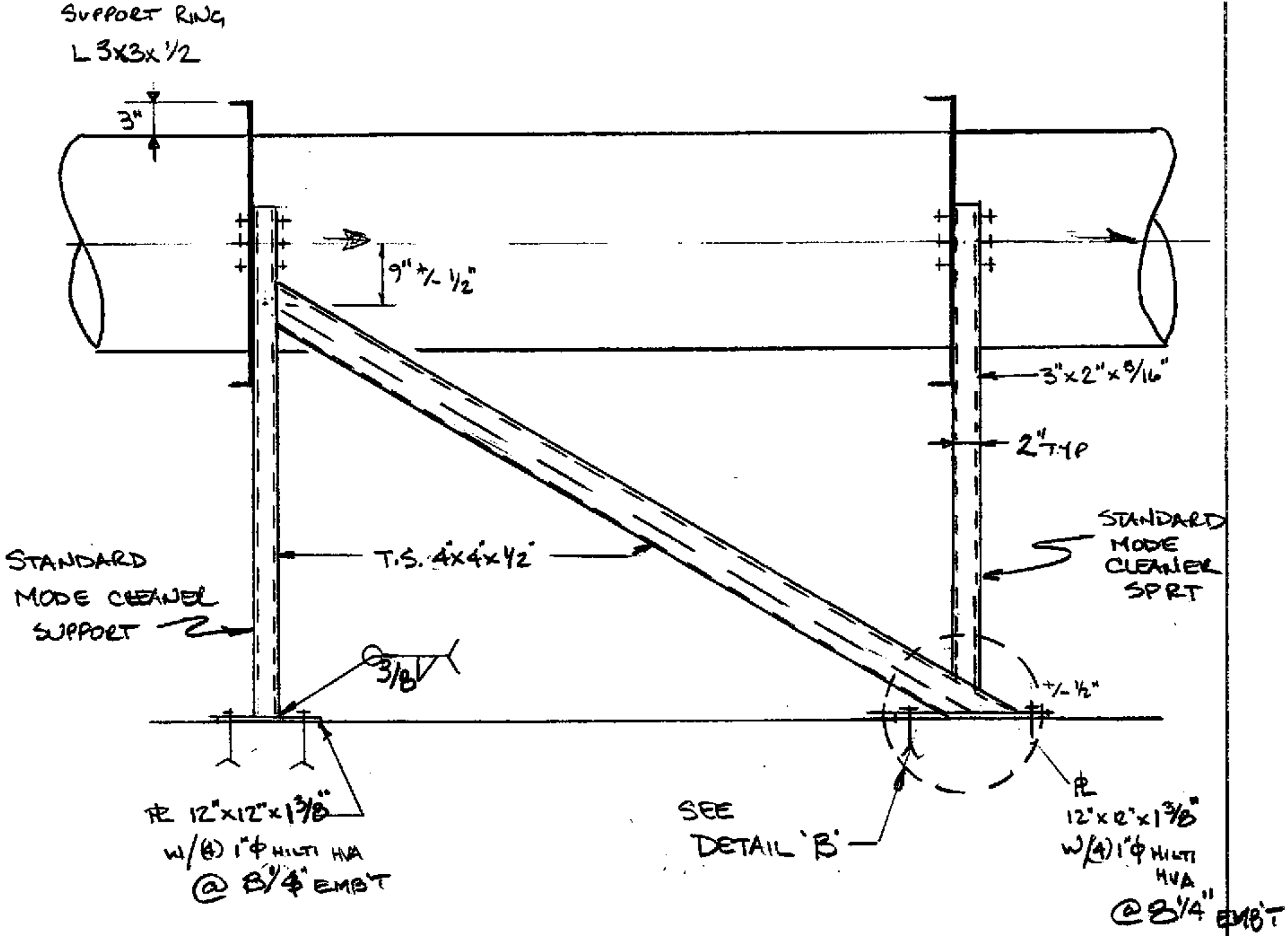
$$T = 20822\ \text{lbs} / 3\ \text{BOLTS} = 6941\ \text{lbs/BOLT}$$

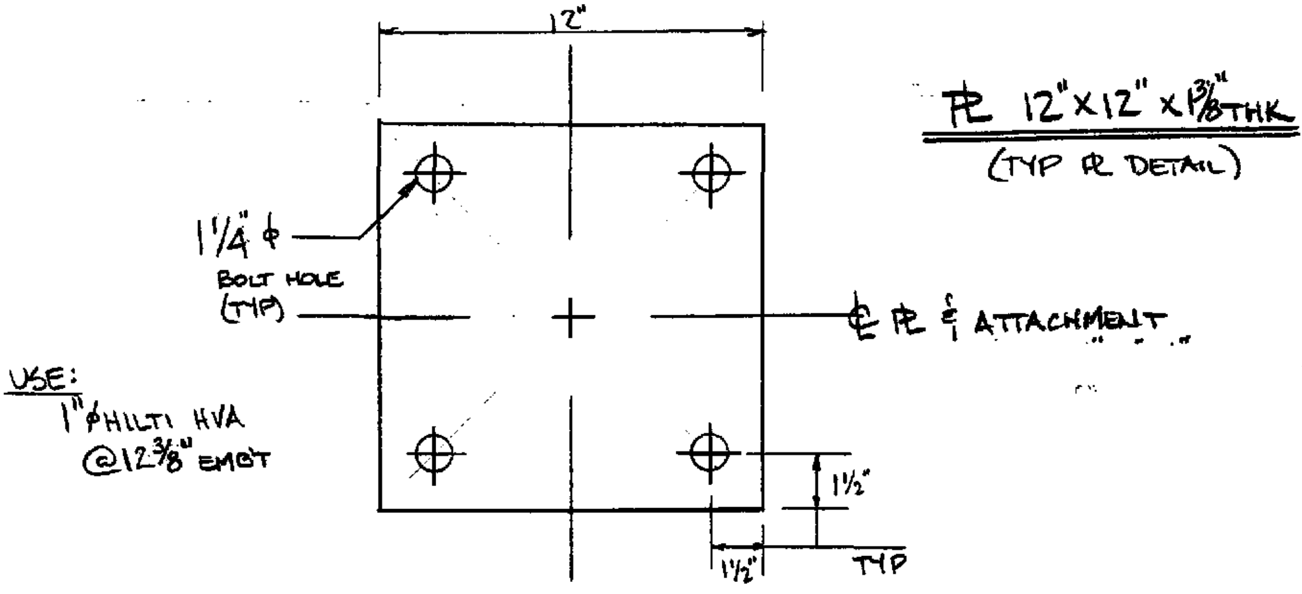
$$\frac{V}{V_{all}} + \frac{T}{T_{all}} = \frac{564.\ \text{lbs}}{5219\ \text{lbs}} + \frac{6941\ \text{lbs.}}{13508\ \text{lbs.}} = .62 < 1.0$$

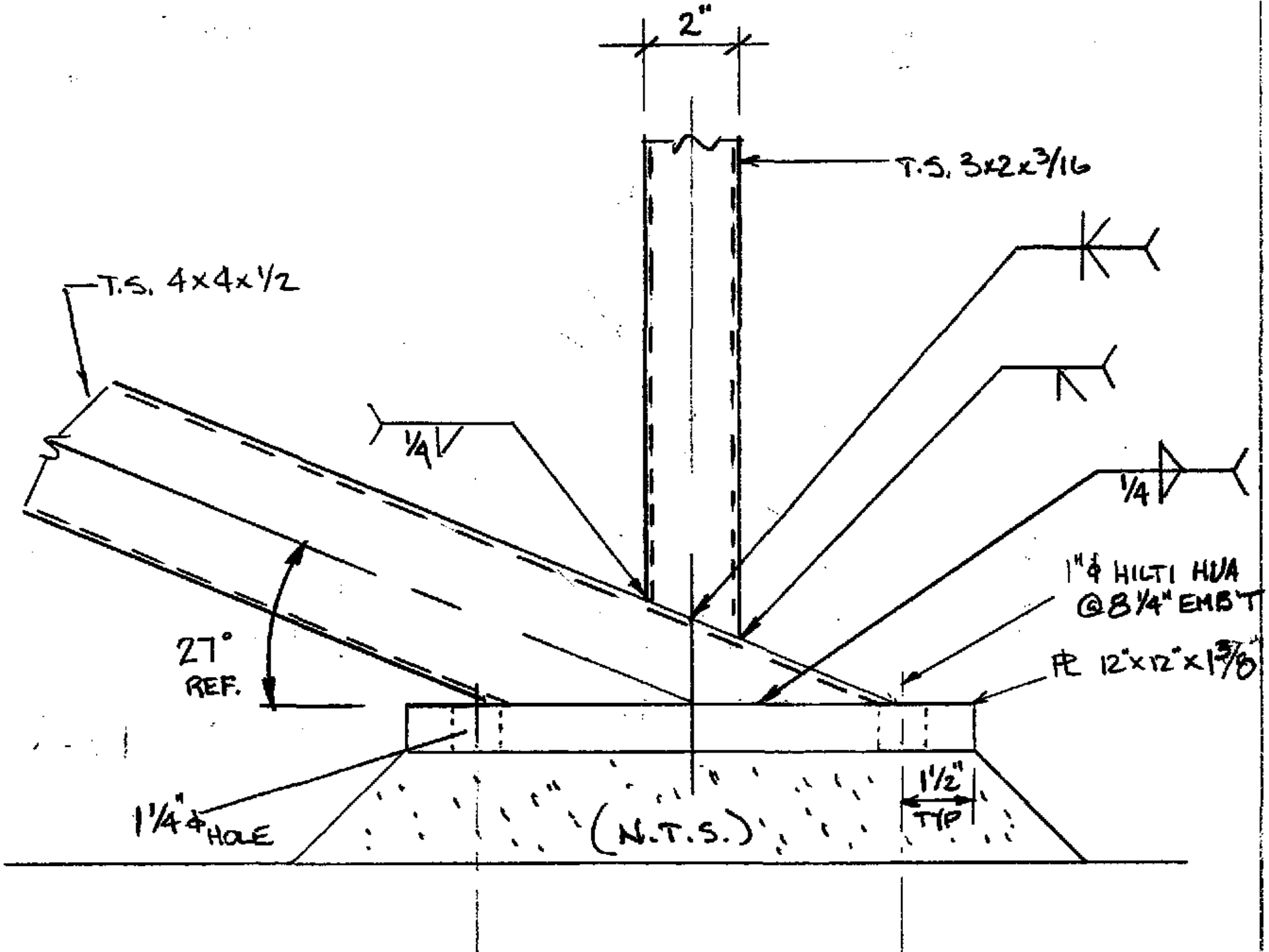
$\therefore$ 5/8"φ O.K.

USE 5/8"φ BOLTS A325

ANCHOR — MODE CLEANER TUBE

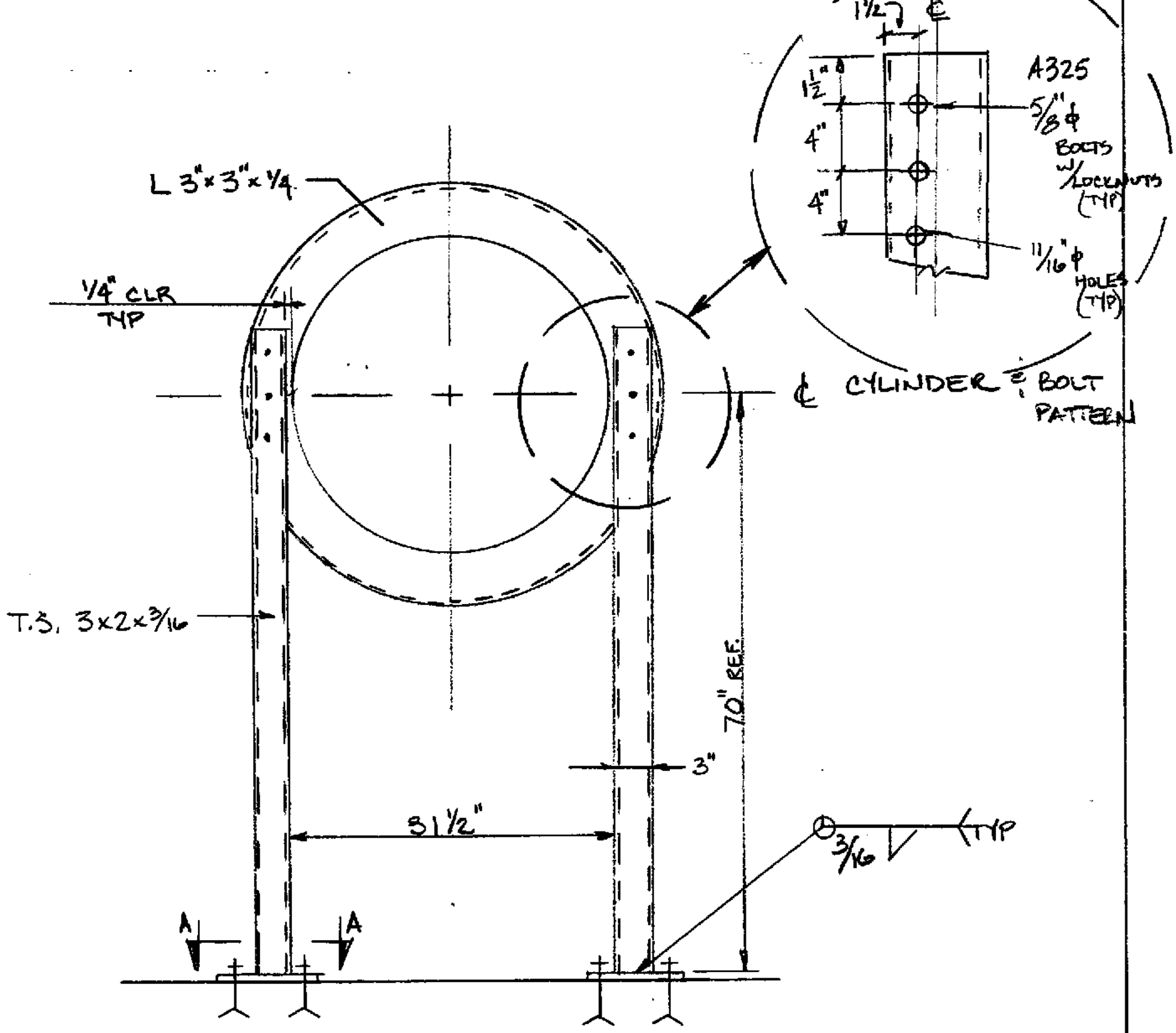


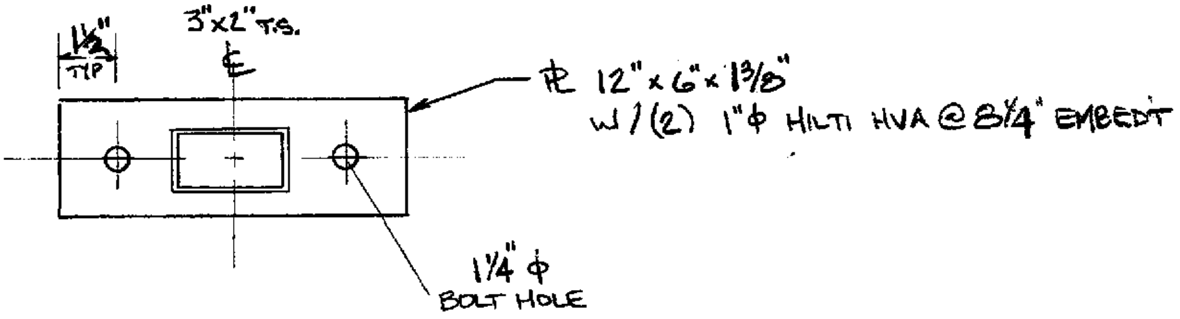

12"
PL 12"x12"x1 3/8" THK
(TYP PL DETAIL)
1 1/4" ϕ
BOLT HOLE
(TYP)
℄ PL & ATTACHMENT
USE:
1" ϕ HILTI HVA
@ 12 3/8" EMB'T
1 1/2"
1 1/2"
TYP


2"
T.S. 3x2x3/16
T.S. 4x4x1/2
1/4
1/4
1" ϕ HILTI HVA
@ 8 1/4" EMB'T
PL 12"x12"x1 3/8"
27°
REF.
1 1/4" ϕ HOLE
(N.T.S.)
1 1/2"
TYP

DETAIL 'B'

STANDARD MODE CLEANER TUBE SUPPORT

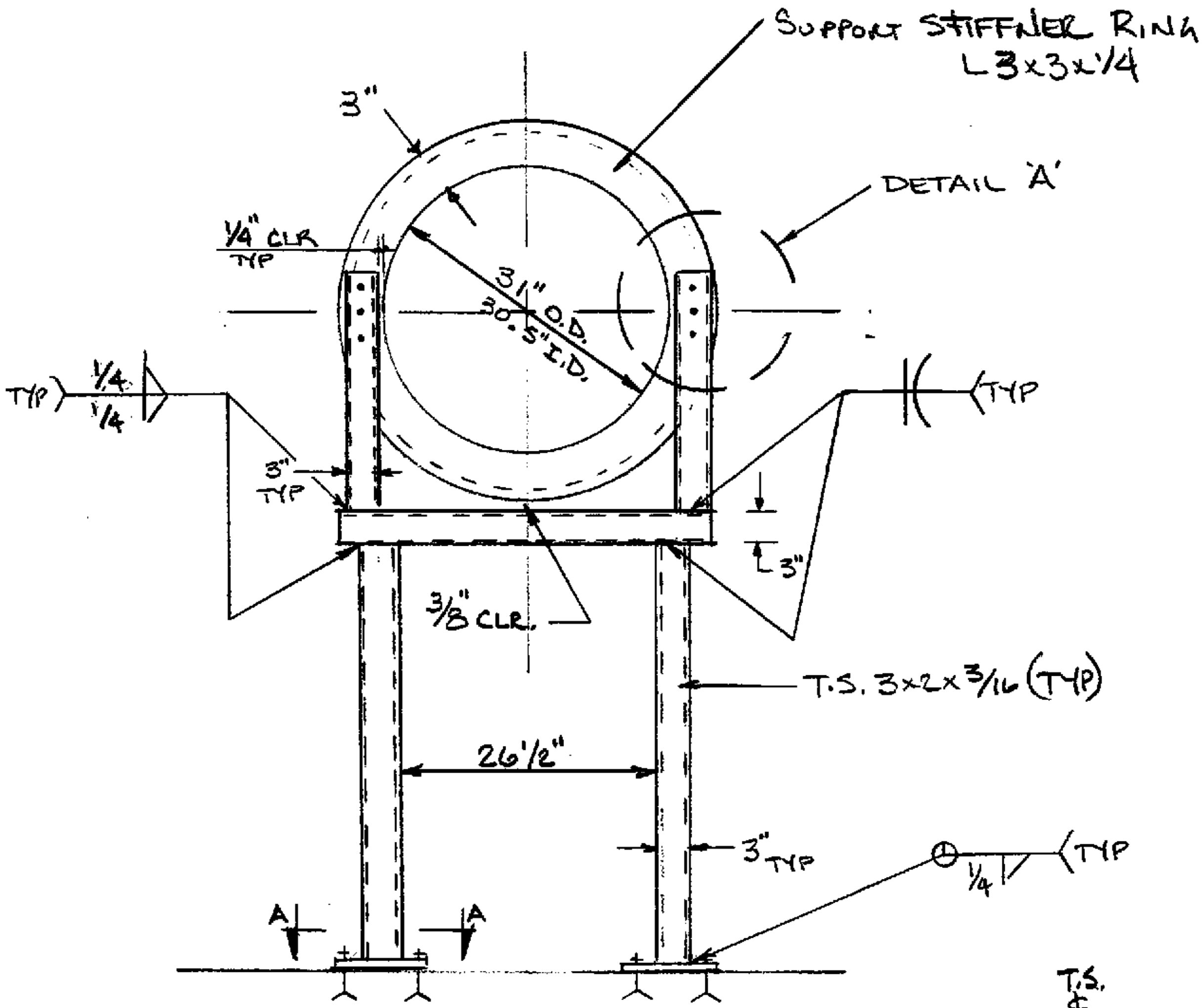


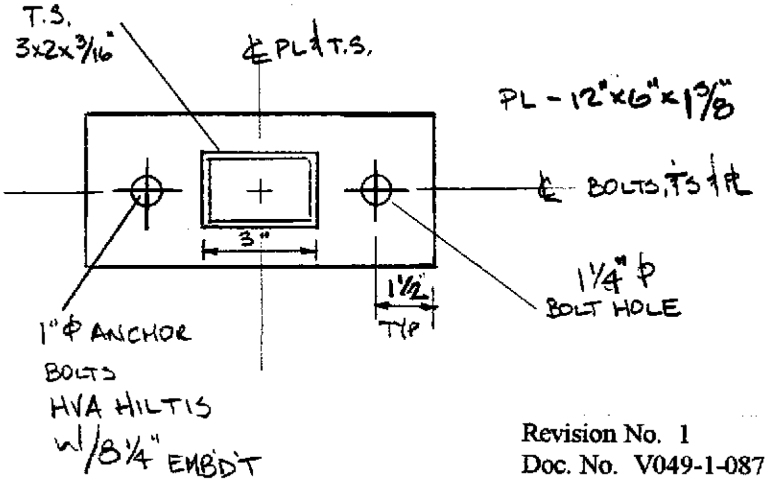


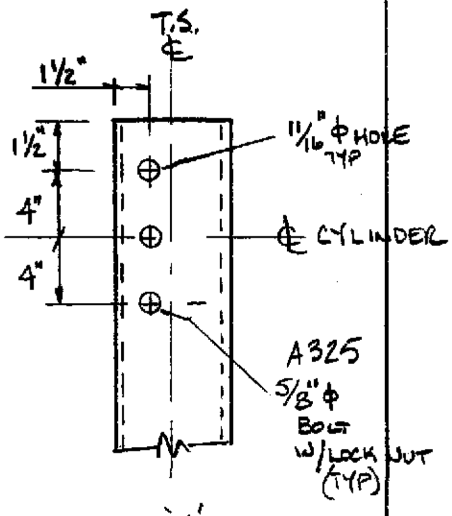
SECTION A-A

NON-STANDARD SUPPORT

MODE CLEANER TUBE B-5







DETAIL 'A'

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-088
PAGE 1 OF 53

REV.	DEO #	DATE	BY:	CHECK
0	0139	4/24/96	WDB	AGR
1	0293	9/19/96	WDB	DJ

TITLE:
Design of Generic Support Scheme for;
Beam Tube Manifold BE-5

BY: W. Bilynsky
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. The purpose of this calculation is to design a generic support scheme for the Beam Tube Manifold (BTM) BE-5 and the related spool pieces i.e. B-1,and B-8. The support scheme as designed allows for thermal axial growth. The axial growth is restricted by means of a flexible support.

METHOD: Supports were located based on acceptable thermal displacements. The "flex-support" was designed for the AISC code allowable stresses, additionally the bellows on A-13 and BE-5 are designed for a max displacement of +/- 2-1/4 inches. A STAAD model of BTM BE-5 was generated and used for design. Baseplates, anchor bolts and thru-bolted connections were designed using classical hand calculations and STAAD computer output. Load cases included; DW, Thermal, Vacuum and Seismic (static g load). DW included the weight of the vessel and its flanges, Thermal included a temperature loa along the length of the vessel, unbalanced vacuum loads occur due to the difference in size between the bellows spool pieces at A-13 and spool B-8. Seismic factors were applied for horizontal loads.

ASSUMPTIONS: See Calculation

INPUTS:
1. Vessel wght = 16.15 lb/in,
2. Thermal Coeff of Expansion = 9.19E-06 in/in F
3. Seismic Acceleration = 0.05625 g.
4. Unbalanced Vacuum Load = 18640. lbs

REFERENCES:
1. STAAD-III release 21, Research Engineers
2. ASD - AISC 9th edition
3. COMPRESS computer aided design Version 5.53
4. Doc. No. V049-1-066 - LIGO Vacuum Equipment Structural Design Criteria

CALCULATIONS:

V049-1-085 - Beam Manifold Tube BE-5 (Vessel Design)
V049-1-032 - Component Interface Loads

CONCLUSIONS: The requirements of the AISC Code and the LIGO Vacuum Equipment Structural Design Criteria are met.

NOTES: STAAD-III Computer file: BE5BTMR1.*

TABLE OF CONTENTS

PROCESS SYSTEMS INTERNATIONAL, INC. **WESTBOROUGH, MA**	**ENGINEERING** **CALCULATIONS**	**NO: V049-1-088** **Rev. No. 1** **PAGE 3 OF 53**
PROJECT: LIGO VACUUM EQUIPMENT	**PROJECT NO: V59049**	
CALCULATION TITLE: Design of Generic Support Scheme for Beam Tube Manifold BE-5		

REVISION HISTORY

Rev. 0 Original Issue
April 24, 1996

Rev. 1 Issue Date
September 19, 1996

- Added unbalanced vacuum axial load to all pertinent load cases.
- Released moments at pinned connections to stiffener ring in STAAD model.
- Revised Structural Tube Steel members from 4" x 2" x 5/16" thk to 4" x 4" x 1/2" thk.
- Revised body of calc to reflect changes due to new vacuum load.
- Added additional weld calculations
- Revised design details to reflect change in members.
- Revised stiffener/support ring to 4" x 3" x 3/8" & 4 x 3 x 1/2
- Revised anchor bolts and base plate sizes

DISCUSSION

Beam Tube Manifold (BE-5)

Support Scheme

Step 1 - BE-5 support/anchorage assembly includes BE-5, B-1 and B-8 and portions of A-13. Anchorage was preferred at the midspan of BE-5, however due to the overall length of the BE-5 support/anchorage assembly, the anchor and flexible support locations were selected to facilitate the expected thermal growth.

Step 2 - Flexible supports were located based on a maximum allowable thermal displacement A maximum allowable displacement of 1/2" was established. This in turn determined the maximum spacing between anchor and flexible support.

Step 3 - A finite element model which includes the properties of the beam tube manifold shell and the support frame were generated using the STAAD structural design computer program.

Step 4 - Applicable loading conditions were determined. These included; deadweight for vessel and flanges, uniform thermal load for the Beam Tube Manifold, unbalanced vacuum loads at the roughing pumps and seismic factors. Additionally,an unbalanced vacuum load acts on the Beam Tube Manifold due to the disparity at the A-13 bellows to B-8 Manifold interface.

Step 5 - Computer output results were evaluated.

Step 6 - Using computer generated forces and reactions, anchors, baseplates, bolted connections (support legs to vessel stiffener rings), and welded connections were designed.

THERMAL DISPLACEMENTS

ANCHOR TO FLEX SUPPORT

$$\delta_{THERM} = \alpha \Delta T L$$

$$= (9.19 \times 10^{-6} \text{ IN/IN°F})(330 \text{°F})(239.813 \text{ IN})$$

$$= 0.727 \text{ IN.}$$

ANCHOR TO BELLOWS ON A-13

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330 \text{°F})(186.187 \text{ IN})$$

$$= 0.56 \text{ IN.}$$

ANCHOR TO BELLOWS ON BE-5

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330 \text{°F})(409.813 \text{ IN})$$

$$= 1.24 \text{ IN.}$$

LOADS ACTING ON BE-5 (B-1) BEAM TUBE MANIFOLD

- VESSEL D.W.

$$w = \left(\frac{490^{\#}}{FT^3}\right)\left(\frac{1\ FT^3}{1728\ IN^3}\right)\left(\frac{\pi\left[(72.75_{IN})^2-(72.25_{IN})^2\right]}{4}\right)$$

$$w = 16.15\ lbs/IN$$

- FLANGE WEIGHT

REDUCING FLANGE @ A-13 TO B-8 (JT. #2)

72¼" ID FLANGE = 370. lbs ref. V049-1-085
72¼" ID × 60½" ID = 1381. lbs

TOTAL WEIGHT FOR 2 FLG'S = 1751. lbs

MATING FLANGE @ B-8 TO B-1 (JT #3)

72¼" I.D. FLANGE = 370 lbs
2 REQD ∴ 2 (370 lbs) = 740. lbs.

MATING FLANGES @ B-1 TO BE-5 (JT #5)

WT = 740 lbs.

- STATIC SEISMIC LOAD

g = 0.05625 Ref. V049-1-066

SEISMIC LOAD APPLIED FOR HORIZONTAL DIRECTION ONLY

$\therefore F_{HOR} = 0.05625\ (16.15^{\#}/_{IN}) = 0.908^{\#}/_{IN}$

- $F_{HOR} = 0.05625\ (1751^{\#}) = 98.5$ lbs.
- $F_{HOR} = 0.05625\ (740^{\#}) = 41.6$ lbs ≈ 42. lbs.

- UNBALANCED VACUUM LOADS

6" ϕ NOZZLE (JT # 6)

$$F = PA = (14.7\#/in^2)(\pi D^2/4)$$

$$= (14.7\#/in^2)(\pi (5.75 in)^2/4)$$

$$F_{6''\phi} = 382. lbs.$$

10" ϕ NOZZLE (JT # 7)

$$F = PA = (14.7\#/in^2)(\pi D^2/4)$$

$$= (14.7\#/in^2)(\pi (9.5 in)^2/4)$$

$$F_{10''\phi} = 1042. lbs.$$

BELLOWS

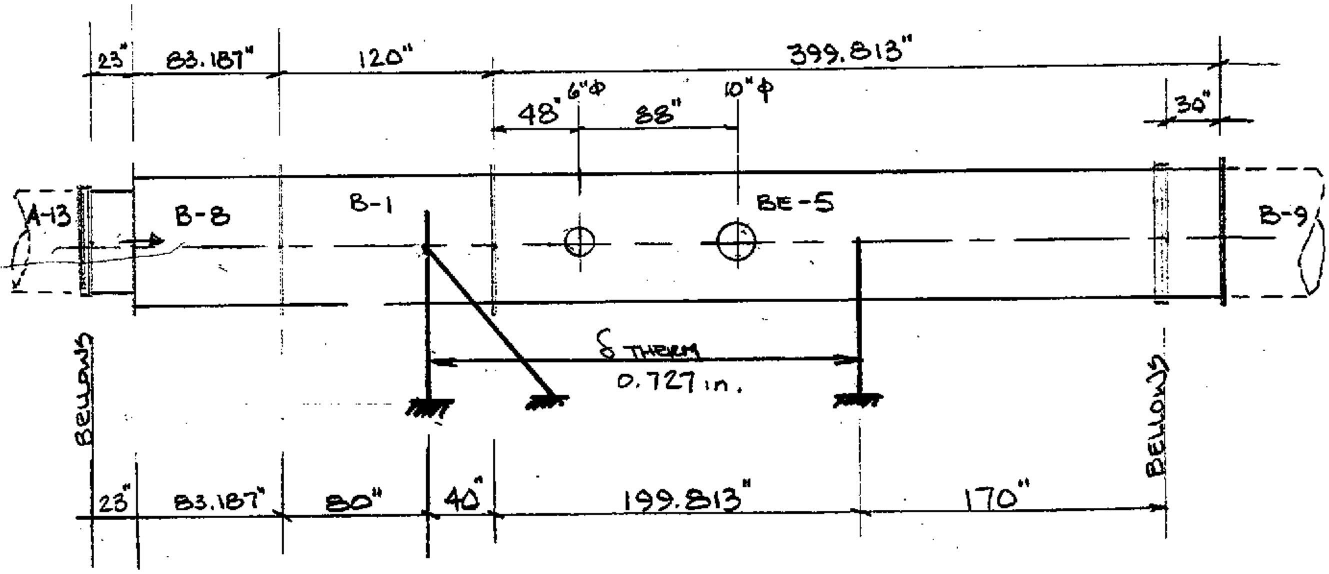
FORCE IS THE DIFFERENCE BETWEEN 60.5 in & 72.25 in DIAMETER BELLOWS FORCES.

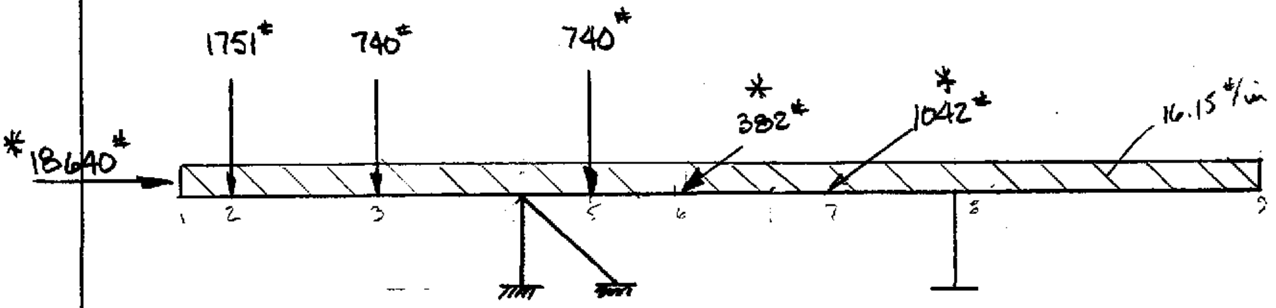
$$\therefore F = \overset{\swarrow 72.25''\phi}{64.1 \text{ KIPS}} - \overset{\swarrow 60.5''\phi}{45.46 \text{ KIPS}} \quad *$$

$$= 18.64 \text{ KIPS} = 18640 \text{ lbs.} @ \text{A-13 (JT \#1)}$$

* REF CALC V049-1-032, PP 4 TO 5

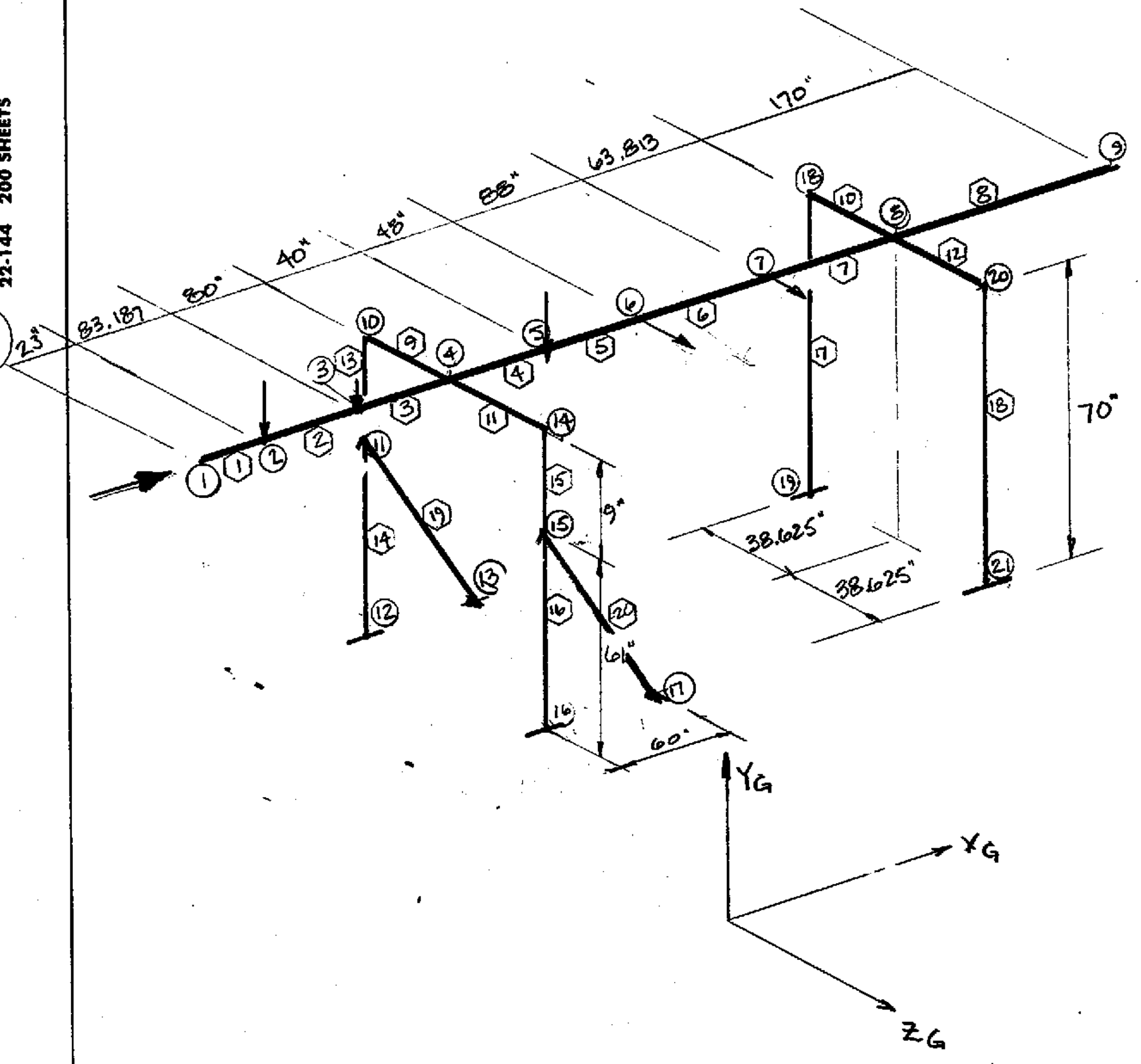
BEAM TUBE MANIFOLD AT BE-5





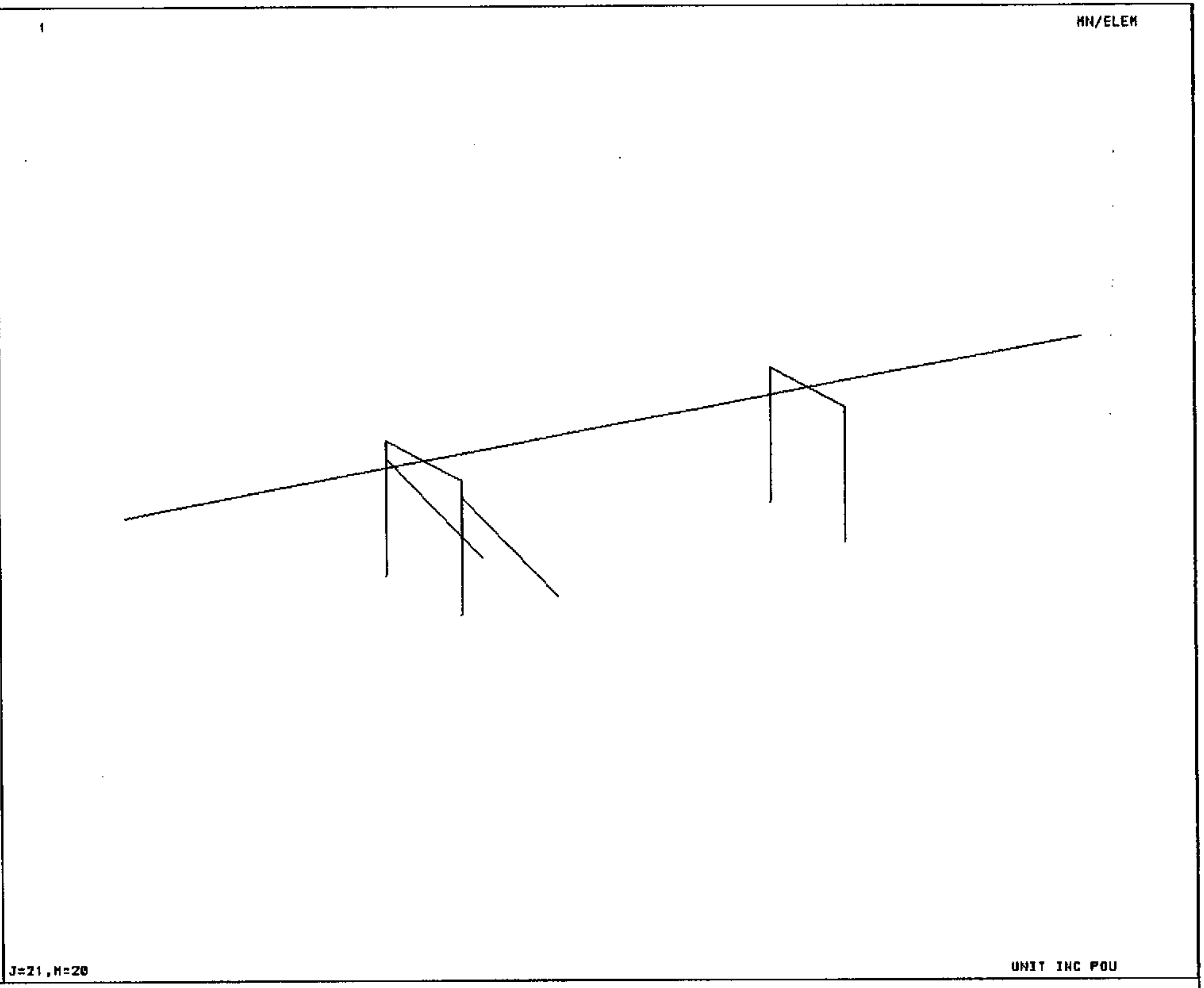
* UNBALANCED VACUUM FORCES.

STAAD MODEL



STRUCTURE DATA

TYPE = SPACE
NJ = 21
NM = 20
NE = 0
NS = 6
NL = 5
XMAX= 596.0
YMAX= 70.0
ZMAX= 77.3



S T A A D P O S T - P L O T (REV: 21.0)
DATE: SEP 26, 1996

USER ID:PROCESS SYSTEMS INTERNATIONAL IN
TITLE: BE-5 BEAM TUBE MANIFOLD SUPPORT

```
 **************************************************
 *                                                *
 *           S T A A D - III                      *
 *           Revision 21.0                        *
 *           Proprietary Program of               *
 *           Research Engineers, Inc.             *
 *           Date=    SEP 26, 1996                *
 *           Time=    15:11:41                    *
 *                                                *
 *      USER ID: PROCESS SYSTEMS INTERNATIONAL IN *
 **************************************************

  1. STAAD SPACE BE-5 BEAM TUBE MANIFOLD SUPPORT
  2. INPUT WIDTH 72
  3. UNIT INCHES POUND
  4. JOINT COORDINATES
  5. 1 0. 0. 0.; 2 23. 0. 0.; 3 106.187 0. 0.; 4 186.187 0. 0.
  6. 5 226.187 0. 0.; 6 274.187 0. 0.; 7 362.187 0. 0.; 8 426. 0. 0.
  7. 9 596. 0. 0.; 10 186.187 0. -38.625; 11 186.187 -9. -38.625
  8. 12 186.187 -70. -38.625; 13 246.187 -70. -38.625; 14 186.187 0. 38.625
  9. 15 186.187 -9. 38.625; 16 186.187 -70. 38.625; 17 246.187 -70. 38.625
 10. 18 426. 0. -38.625; 19 426. -70. -38.625; 20 426. 0. 38.625
 11. 21 426. -70. 38.625
 12. MEMBER INCIDENCES
 13. 1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 5 6; 6 6 7; 7 7 8; 8 8 9; 9 4 10; 10 8 18
 14. 11 4 14; 12 8 20; 13 11 10; 14 12 11; 15 15 14; 16 16 15; 17 19 18
 15. 18 21 20; 19 13 11; 20 17 15
 16. MEMBER PROPERTY AMER
 17. 17 18 TABLE ST TUB40203
 18. 13 TO 16 19 20 TABLE ST TUB40408
 19. 9 TO 12 TABLE ST TUB80805
 20. 1 TO 8 TABLE ST PIPE OD 72.75 ID 72.25
 21. MEMBER RELEASE
 22. 13 15 17 18 END MX MY MZ
 23. CONSTANTS
 24. E STEEL ALL
 25. POISSON STEEL ALL
 26. DENSITY STEEL ALL
 27. BETA 90. MEMB 13 TO 18
 28. ALPHA 0.00000919 MEMB 1 TO 12
 29. SUPPORTS
 30. 19 21 FIXED BUT MZ
 31. 12 13 16 17 FIXED
 32. **********************************
 33. LOAD 1 DW
 34. JOINT LOAD
 35. 2 FY -1751.
 36. ** FLG WT = 370.# + 1381# = 1751.#
 37. 3 5 FY -740.
 38. ** FLG WT = 2 (370#)= 740.#
 39. MEMBER LOAD
 40. 1 TO 8 UNI Y -16.15
 41. **********************************
```

```
42. LOAD 2 DW+TH+VACUUM(+)
43. JOINT LOAD
44. 1 FX 18639.992
45. ** UNBALANCED VACUUM LOAD @ BELLOWS
46. 2 FY -1751.
47. 3 5 FY -740.
48. 6 FZ 382.
49. ** UNBALANCED VACUUM LOAD @ 6" NOZZLE
50. 7 FZ 1042.
51. ** UNBALANCED VACUUM LOAD @ 10" NOZZLE
52. MEMBER LOAD
53. 1 TO 8 UNI Y -16.15
54. TEMPERATURE LOAD
55. 1 TO 12 TEMP 330.
56. **********************************
57. LOAD 3 DW+TH+VACUUM(+)+SEIS-AXIAL
58. JOINT LOAD
59. 1 FX 18639.992
60. 2 FY -1751.
61. 2 FX 98.5
62. ** SEISMIC LOAD = 0.05625(1751#)=98.5#
63. 3 5 FY -740.
64. 3 5 FX 42.
65. ** SEISMIC LOAD = 0.05625(740.#)=42.#
66. 6 FZ 382.
67. 7 FZ 1042.
68. MEMBER LOAD
69. 1 TO 8 UNI Y -16.15
70. 1 TO 8 UNI X 0.908
71. ** SEISMIC LOAD = 0.05625(16.15)=0.908
72. TEMPERATURE LOAD
73. 1 TO 12 TEMP 330.
74. **********************************
75. LOAD 4 DW+TH+VACUUM(+)+SEIS-LAT
76. JOINT LOAD
77. 1 FX 18639.992
78. 2 FY -1751.
79. 2 FZ 98.5
80. 3 5 FY -740.
81. 3 5 FZ 42.
82. 6 FZ 382.
83. 7 FZ 1042.
84. MEMBER LOAD
85. 1 TO 8 UNI Y -16.15
86. 1 TO 8 UNI Z 0.908
87. TEMPERATURE LOAD
88. 1 TO 12 TEMP 330.
89. **********************************
90. LOAD 5 THERMAL DISP "BAKEOUT"
91. TEMPERATURE LOAD
92. 1 TO 12 TEMP 330.
93. **********************************
94. PERFORM ANALYSIS
```

```
       P R O B L E M   S T A T I S T I C S
       -----------------------------------

   NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS =     21/    20/     6
   ORIGINAL/FINAL BAND-WIDTH =     12/     4
   TOTAL PRIMARY LOAD CASES  =      5, TOTAL DEGREES OF FREEDOM =      92
   SIZE OF STIFFNESS MATRIX =     2208 DOUBLE PREC. WORDS
   REQRD/AVAIL. DISK SPACE =  12.05/  951.8 MB,  EXMEM = 14.83 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.                 15:11:43
++ PROCESSING GLOBAL STIFFNESS MATRIX.                  15:11:43
++ PROCESSING TRIANGULAR FACTORIZATION.                 15:11:43
++ CALCULATING JOINT DISPLACEMENTS.                     15:11:43
++ CALCULATING MEMBER  FORCES.                          15:11:43

  95. PRINT MATERIAL PROPERTIES ALL
```

```
MATERIAL PROPERTIES.
--------------------
ALL UNITS ARE - POUN INCH

MEMBER           E             G            DEN         ALPHA

   1       29000000.0    11153846.0    0.28299999   0.00000919
   2       29000000.0    11153846.0    0.28299999   0.00000919
   3       29000000.0    11153846.0    0.28299999   0.00000919
   4       29000000.0    11153846.0    0.28299999   0.00000919
   5       29000000.0    11153846.0    0.28299999   0.00000919
   6       29000000.0    11153846.0    0.28299999   0.00000919
   7       29000000.0    11153846.0    0.28299999   0.00000919
   8       29000000.0    11153846.0    0.28299999   0.00000919
   9       29000000.0    11153846.0    0.28299999   0.00000919
  10       29000000.0    11153846.0    0.28299999   0.00000919
  11       29000000.0    11153846.0    0.28299999   0.00000919
  12       29000000.0    11153846.0    0.28299999   0.00000919
  13       29000000.0    11153846.0    0.28299999   0.00000000
  14       29000000.0    11153846.0    0.28299999   0.00000000
  15       29000000.0    11153846.0    0.28299999   0.00000000
  16       29000000.0    11153846.0    0.28299999   0.00000000
  17       29000000.0    11153846.0    0.28299999   0.00000000
  18       29000000.0    11153846.0    0.28299999   0.00000000
  19       29000000.0    11153846.0    0.28299999   0.00000000
  20       29000000.0    11153846.0    0.28299999   0.00000000

************ END OF DATA FROM INTERNAL STORAGE ************

  96. PRINT MEMBER INFORMATION ALL
```

```
MEMBER INFORMATION
------------------

MEMBER    START    END         LENGTH    BETA
          JOINT    JOINT       (INCH)    (DEG)      RELEASES

   1        1        2         23.000    0.00
   2        2        3         83.187    0.00
   3        3        4         80.000    0.00
   4        4        5         40.000    0.00
   5        5        6         48.000    0.00
   6        6        7         88.000    0.00
   7        7        8         63.813    0.00
   8        8        9        170.000    0.00
   9        4       10         38.625    0.00
  10        8       18         38.625    0.00
  11        4       14         38.625    0.00
  12        8       20         38.625    0.00
  13       11       10          9.000   90.00    000000000111
  14       12       11         61.000   90.00
  15       15       14          9.000   90.00    000000000111
  16       16       15         61.000   90.00
  17       19       18         70.000   90.00    000000000111
  18       21       20         70.000   90.00    000000000111
  19       13       11         85.563    0.00
  20       17       15         85.563    0.00

************ END OF DATA FROM INTERNAL STORAGE ************

 97. PRINT JOINT COORDINATES ALL
```

```
JOINT COORDINATES
-----------------
COORDINATES ARE INCH UNIT

JOINT          X              Y              Z

  1           0.000          0.000          0.000
  2          23.000          0.000          0.000
  3         106.187          0.000          0.000
  4         186.187          0.000          0.000
  5         226.187          0.000          0.000
  6         274.187          0.000          0.000
  7         362.187          0.000          0.000
  8         426.000          0.000          0.000
  9         596.000          0.000          0.000
 10         186.187          0.000        -38.625
 11         186.187         -9.000        -38.625
 12         186.187        -70.000        -38.625
 13         246.187        -70.000        -38.625
 14         186.187          0.000         38.625
 15         186.187         -9.000         38.625
 16         186.187        -70.000         38.625
 17         246.187        -70.000         38.625
 18         426.000          0.000        -38.625
 19         426.000        -70.000        -38.625
 20         426.000          0.000         38.625
 21         426.000        -70.000         38.625

************ END OF DATA FROM INTERNAL STORAGE ************


 98. PRINT SUPPORT INFORMATION ALL


SUPPORT INFORMATION (1=FIXED, 0=RELEASED)
--------------------
UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

JOINT    FORCE-X/    FORCE-Y/    FORCE-Z/    MOM-X/    MOM-Y/    MOM-Z/
           KFX         KFY         KFZ        KMX       KMY       KMZ

  19        1           1           1          1         1         0
               0.0         0.0         0.0       0.0       0.0       0.0
  21        1           1           1          1         1         0
               0.0         0.0         0.0       0.0       0.0       0.0
  12        1           1           1          1         1         1
               0.0         0.0         0.0       0.0       0.0       0.0
  13        1           1           1          1         1         1
               0.0         0.0         0.0       0.0       0.0       0.0
```

```
 16        1            1            1          1          1          1
                0.0          0.0          0.0        0.0        0.0        0.0
 17        1            1            1          1          1          1
                0.0          0.0          0.0        0.0        0.0        0.0

************ END OF DATA FROM INTERNAL STORAGE ************

 99. PRINT ANALYSIS RESULTS
```

```
 JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
 ------------------

JOINT  LOAD   X-TRANS   Y-TRANS   Z-TRANS   X-ROTAN   Y-ROTAN   Z-ROTAN

    1    1  -0.00197  -0.07671   0.00000   0.00000   0.00000   0.00020
         2  -0.44606  -0.06997   0.01436   0.00001  -0.00048   0.00018
         3  -0.44145  -0.06971   0.01436   0.00001  -0.00048   0.00018
         4  -0.44606  -0.06997   0.06874   0.00001  -0.00052   0.00018
         5  -0.56465   0.00000   0.00000   0.00000   0.00000   0.00000
    2    1  -0.00197  -0.07218   0.00000   0.00000   0.00000   0.00020
         2  -0.37657  -0.06581   0.02541   0.00001  -0.00048   0.00018
         3  -0.37196  -0.06556   0.02541   0.00001  -0.00048   0.00018
         4  -0.37657  -0.06581   0.08062   0.00001  -0.00052   0.00018
         5  -0.49490   0.00000   0.00000   0.00000   0.00000   0.00000
    3    1  -0.00197  -0.05546   0.00000   0.00000   0.00000   0.00019
         2  -0.12522  -0.05040   0.06537   0.00001  -0.00048   0.00017
         3  -0.12062  -0.05021   0.06537   0.00001  -0.00048   0.00017
         4  -0.12522  -0.05040   0.12359   0.00001  -0.00052   0.00017
         5  -0.24262   0.00000   0.00000   0.00000   0.00000   0.00000
    4    1  -0.00197  -0.04047   0.00000   0.00000   0.00000   0.00016
         2   0.11649  -0.03667   0.10381   0.00001  -0.00048   0.00014
         3   0.12108  -0.03653   0.10380   0.00001  -0.00048   0.00014
         4   0.11649  -0.03667   0.16498   0.00001  -0.00052   0.00014
         5   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
    5    1  -0.00197  -0.03502   0.00000   0.00000   0.00000   0.00014
         2   0.23780  -0.03186   0.12320   0.00001  -0.00048   0.00012
         3   0.24240  -0.03174   0.12320   0.00001  -0.00048   0.00012
         4   0.23780  -0.03186   0.18598   0.00001  -0.00052   0.00012
         5   0.12131   0.00000   0.00000   0.00000   0.00000   0.00000
    6    1  -0.00197  -0.02922   0.00000   0.00000   0.00000   0.00012
         2   0.38337  -0.02682   0.14661   0.00001  -0.00049   0.00010
         3   0.38797  -0.02673   0.14661   0.00001  -0.00049   0.00010
         4   0.38337  -0.02682   0.21137   0.00001  -0.00053   0.00010
         5   0.26688   0.00000   0.00000   0.00000   0.00000   0.00000
    7    1  -0.00197  -0.02019   0.00000   0.00000   0.00000   0.00010
         2   0.65025  -0.01918   0.18955   0.00001  -0.00049   0.00008
         3   0.65487  -0.01914   0.18955   0.00001  -0.00049   0.00008
         4   0.65025  -0.01918   0.25805   0.00001  -0.00053   0.00008
         5   0.53376   0.00000   0.00000   0.00000   0.00000   0.00000
    8    1  -0.00197  -0.01455   0.00000   0.00000   0.00000   0.00008
         2   0.84377  -0.01455   0.22045   0.00001  -0.00049   0.00007
         3   0.84840  -0.01455   0.22045   0.00001  -0.00049   0.00007
         4   0.84377  -0.01455   0.29173   0.00001  -0.00053   0.00007
         5   0.72728   0.00000   0.00000   0.00000   0.00000   0.00000
    9    1  -0.00197  -0.00283   0.00000   0.00000   0.00000   0.00007
         2   1.35933  -0.00551   0.30293   0.00001  -0.00049   0.00005
         3   1.36397  -0.00562   0.30292   0.00001  -0.00049   0.00005
         4   1.35933  -0.00551   0.38179   0.00001  -0.00053   0.00005
         5   1.24284   0.00000   0.00000   0.00000   0.00000   0.00000
   10    1  -0.00197  -0.00183   0.00000   0.00137   0.00000   0.00016
         2   0.04902   0.00254  -0.01332   0.00139   0.00257   0.00014
         3   0.05073   0.00269  -0.01333   0.00139   0.00267   0.00014
```

```
  JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
  ------------------

 JOINT  LOAD   X-TRANS    Y-TRANS    Z-TRANS    X-ROTAN    Y-ROTAN    Z-ROTAN

          4    0.04958    0.00259    0.04781    0.00139    0.00256    0.00014
          5    0.00000    0.00000   -0.11706    0.00000    0.00000    0.00000
   11     1   -0.00161   -0.00160    0.00000    0.00000    0.00000    0.00004
          2    0.01468    0.00278   -0.01087   -0.00027   -0.00003   -0.00276
          3    0.01522    0.00293   -0.01087   -0.00027   -0.00003   -0.00285
          4    0.01486    0.00283    0.03901    0.00095    0.00010   -0.00279
          5    0.00000    0.00000   -0.09552   -0.00234   -0.00025    0.00000
   12     1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   13     1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   14     1   -0.00197   -0.00183    0.00000   -0.00137    0.00000    0.00016
          2    0.03522    0.00138    0.22079   -0.00135   -0.00270    0.00014
          3    0.03693    0.00152    0.22079   -0.00135   -0.00281    0.00014
          4    0.03467    0.00133    0.28193   -0.00135   -0.00271    0.00014
          5    0.00000    0.00000    0.11706    0.00000    0.00000    0.00000
   15     1   -0.00161   -0.00160    0.00000    0.00000    0.00000    0.00004
          2    0.01028    0.00161    0.18017    0.00441    0.00047   -0.00200
          3    0.01083    0.00176    0.18017    0.00441    0.00047   -0.00209
          4    0.01010    0.00156    0.23006    0.00563    0.00060   -0.00197
          5    0.00000    0.00000    0.09552    0.00234    0.00025    0.00000
   16     1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   17     1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          2    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          3    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          4    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
          5    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
   18     1   -0.00197   -0.00190    0.00000    0.00045    0.00000    0.00008
          2    0.86251   -0.00186    0.10330    0.00045   -0.00049    0.00007
          3    0.86714   -0.00186    0.10330    0.00045   -0.00049    0.00007
          4    0.86420   -0.00185    0.17457    0.00045   -0.00053    0.00007
          5    0.72728    0.00000   -0.11712    0.00000    0.00000    0.00000
   19     1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00003
          2    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01232
          3    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01239
          4    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01235
          5    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01039
   20     1   -0.00197   -0.00190    0.00000   -0.00045    0.00000    0.00008
```

```
 JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
 ------------------

JOINT  LOAD   X-TRANS    Y-TRANS    Z-TRANS    X-ROTAN    Y-ROTAN    Z-ROTAN

         2    0.82503   -0.00193    0.33754   -0.00045   -0.00049    0.00007
         3    0.82966   -0.00193    0.33754   -0.00045   -0.00049    0.00007
         4    0.82334   -0.00194    0.40881   -0.00045   -0.00053    0.00007
         5    0.72728    0.00000    0.11712    0.00000    0.00000    0.00000
   21    1    0.00000    0.00000    0.00000    0.00000    0.00000    0.00003
         2    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01179
         3    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01185
         4    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01176
         5    0.00000    0.00000    0.00000    0.00000    0.00000   -0.01039
```

```
 SUPPORT REACTIONS -UNIT POUN INCH    STRUCTURE TYPE = SPACE
 -----------------

JOINT  LOAD   FORCE-X    FORCE-Y    FORCE-Z     MOM-X      MOM-Y      MOM Z

  19     1       0.00    1586.45       0.00       0.00       0.00       0.00
         2       0.00    1554.13    -101.76   -7123.49       0.00       0.00
         3       0.00    1554.13    -101.76   -7123.39       0.00       0.00
         4       0.00    1551.53    -171.98 -12038.33       0.00       0.00
         5       0.00       0.00     115.38    8076.84       0.00       0.00
  21     1       0.00    1586.45       0.00       0.00       0.00       0.00
         2       0.00    1618.77    -332.53 -23276.78       0.00       0.00
         3       0.00    1618.77    -332.52 -23276.69       0.00       0.00
         4       0.00    1621.37    -402.74 -28191.63       0.00       0.00
         5       0.00       0.00    -115.38   -8076.45       0.00       0.00
  12     1       7.50    4828.55       0.00       0.00       0.00    -460.01
         2    1276.65   -8400.25      50.66    3101.16     112.09  -22809.53
         3    1319.14   -8844.31      50.67    3101.67     112.11  -23557.82
         4    1290.48   -8542.19    -181.79  -11128.71    -402.23  -23053.33
         5       0.00       0.02     445.10   27247.65     984.83       0.03
  13     1      -7.50      13.20       0.00       0.00       0.00    -331.93
         2  -12057.81   13274.32      12.90    1347.70     661.69  -18968.28
         3  -12461.32   13718.38      12.90    1347.92     661.80  -19592.26
         4  -12189.15   13418.86     -46.28   -4836.32   -2374.53  -19171.55
         5       0.02      -0.02     113.31   11841.30    5813.82       0.03
  16     1       7.50    4828.55       0.00       0.00       0.00    -460.01
         2     932.59   -4870.66    -839.55  -51394.09   -1857.57  -16746.98
         3     975.09   -5314.70    -839.54  -51393.59   -1857.55  -17495.23
         4     918.76   -4728.74   -1072.00  -65623.96   -2371.89  -16503.20
         5       0.01      -0.06    -445.10  -27247.60    -984.83      -0.11
  17     1      -7.50      13.20       0.00       0.00       0.00    -331.93
         2   -8791.80    9680.09    -213.73  -22334.88  -10965.95  -13913.56
         3   -9195.30   10124.13    -213.72  -22334.66  -10965.84  -14537.51
         4   -8660.47    9535.56    -272.90  -28518.90  -14002.17  -13710.31
         5      -0.06       0.07    -113.31  -11841.28   -5813.81      -0.09
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z


    1    1     1      0.00      0.09     0.00      0.00      0.00       1.01
               2      0.00    371.36     0.00      0.00      0.00   -4271.04
         2     1  18638.67     -0.09    -0.04     -0.04      3.03      -0.88
               2 -18638.67    371.54     0.04      0.04      0.11   -4271.73
         3     1  18642.09      0.02    -0.02      0.02     -0.65       2.04
               2 -18662.60    371.43     0.02     -0.02      1.82   -4269.75
         4     1  18640.13      0.03     0.02     -0.02      1.41       0.58
               2 -18640.13    371.42   -20.91      0.02   -240.37   -4269.77
         5     1     -0.49      0.00     0.00      0.00     -0.06      -0.01
               2      0.49      0.00     0.00      0.00      0.10       0.01

    2    1     2      0.01  -2122.44     0.00      0.00      0.00    4271.54
               3     -0.01   3465.91     0.00      0.00      0.00 -236711.19
         2     2  18641.11  -2122.43     0.00     -0.01     -1.56    4273.11
               3 -18641.11   3465.90     0.00      0.01      1.27 -236708.94
         3     2  18759.76  -2122.45     0.01      0.00     -0.17    4270.59
               3 -18834.96   3465.92    -0.01      0.00     -1.37 -236711.69
         4     2  18641.11  -2122.43   119.27      0.00    247.13    4272.93
               3 -18641.11   3465.90  -194.80      0.00 -13311.55 -236710.00
         5     2      0.00      0.00     0.00      0.00     -0.14      -0.01
               3      0.00      0.00     0.00      0.00     -0.27       0.00

    3    1     3      0.00  -4205.95     0.00      0.00      0.00  236709.42
               4      0.00   5497.95     0.00      0.00      0.00 -624865.88
         2     3  18641.11  -4205.92    -0.02      0.01      0.58  236711.33
               4 -18641.11   5497.92     0.02     -0.01      1.14 -624865.50
         3     3  18876.95  -4205.91    -0.03     -0.01      1.02  236712.23
               4 -18949.22   5497.91     0.03      0.01      1.07 -624864.25
         4     3  18640.62  -4205.94   236.90      0.00  13313.71  236710.25
               4 -18640.62   5497.94  -309.54      0.00 -35168.86 -624865.19
         5     3      0.98      0.00     0.00      0.00      0.52       0.00
               4     -0.98      0.00     0.00      0.00     -0.81      -0.01

    4    1     4      0.00   4185.57     0.00      0.00      0.00  624865.81
               5      0.00  -3539.57     0.00      0.00      0.00 -470363.28
         2     4      0.49   4185.58  -989.64   2496.66 112860.13  624864.94
               5     -0.49  -3539.58   989.64  -2496.66 -73275.72 -470362.84
         3     4   -413.09   4185.56  -989.78   2496.69 112859.82  624865.13
               5    376.95  -3539.56   989.78  -2496.69 -73269.63 -470362.72
         4     4      0.00   4185.58 -1263.25   2697.49 157102.39  624865.25
               5      0.00  -3539.58  1226.93  -2697.49-107296.86 -470362.66
         5     4      0.98      0.00     0.02     -0.06     -1.86       0.01
               5     -0.98      0.00    -0.02      0.06      0.95      -0.01

    5    1     5      0.00   2799.59     0.00     -0.01      0.00  470362.72
               6      0.00  -2024.39     0.00      0.01      0.00 -354586.97
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z

          2     5    -0.98   2799.54  -989.86   2496.69  73272.34  470361.56
                6     0.98  -2024.34   989.86  -2496.69 -25762.29 -354588.13
          3     5  -338.38   2799.54  -989.71   2496.71  73273.55  470362.22
                6   294.43  -2024.34   989.71  -2496.71 -25765.56 -354588.88
          4     5    -0.49   2799.58 -1184.79   2697.48 107300.30  470362.56
                6     0.49  -2024.38  1141.20  -2697.48 -51473.47 -354587.13
          5     5     0.49      0.00     0.01     -0.06     -2.01       0.01
                6    -0.49      0.00    -0.01      0.06      1.30      -0.01

     6    1     6     0.00   2024.37     0.00      0.00      0.00  354587.63
                7     0.00   -603.17     0.00      0.00      0.00 -238975.75
          2     6     0.00   2024.39  -607.71   2496.71  25766.02  354588.00
                7     0.00   -603.19   607.71  -2496.71  27715.12 -238974.73
          3     6  -291.50   2024.39  -607.75   2496.71  25764.40  354588.06
                7   211.43   -603.19   607.75  -2496.71  27713.20 -238975.02
          4     6     0.98   2024.37  -759.47   2697.50  51460.80  354587.00
                7    -0.98   -603.17   679.57  -2697.50  11857.90 -238975.70
          5     6     0.00      0.00     0.01     -0.06     -1.47       0.01
                7     0.00      0.00    -0.01      0.06      0.24      -0.01

     7    1     7     0.00    603.17     0.00      0.00      0.00  238975.28
                8     0.00    427.41     0.00      0.00      0.00 -233367.66
          2     7    -0.98    603.17   434.34   2496.71 -27713.45  238975.25
                8     0.98    427.41  -434.34  -2496.71     -1.53 -233367.08
          3     7  -213.38    603.17   434.30   2496.70 -27715.13  238975.55
                8   155.76    427.41  -434.30  -2496.70      0.21 -233367.58
          4     7    -0.49    603.18   362.53   2697.48 -11860.19  238975.56
                8     0.49    427.40  -420.48  -2697.48 -13125.60 -233366.84
          5     7    -0.98      0.00     0.01     -0.06     -0.37      -0.10
                8     0.98      0.00    -0.01      0.06     -0.11       0.09

     8    1     8     0.00   2745.50     0.00      0.00      0.00  233367.36
                9     0.00      0.00     0.00      0.00      0.00       0.17
          2     8    -0.49   2745.50     0.00      0.01     -1.90  233367.59
                9     0.49      0.00     0.00     -0.01      1.44       0.06
          3     8  -153.81   2745.50     0.00      0.01     -2.95  233367.30
                9    -0.49      0.00     0.00     -0.01      1.16      -0.07
          4     8     0.49   2745.50  -154.33      0.00  13120.28  233367.59
                9    -0.49      0.00    -0.03      0.00     -1.67       0.11
          5     8     0.00      0.00     0.00      0.00     -0.47      -0.02
                9     0.00      0.00     0.00      0.00     -0.12       0.02

     9    1     4     0.00  -4841.75     0.00      0.00      0.00 -187012.44
               10     0.00   4841.75     0.00      0.00      0.00       0.01
          2     4    63.60  -4874.07 10781.16      0.00-416422.44 -188260.83
               10   -63.60   4874.07-10781.16      0.00     -0.03      -0.01
          3     4    63.54  -4874.07 11142.18      0.00-430366.72 -188260.81
               10   -63.54   4874.07-11142.18      0.00     -0.04       0.03
```

```
MEMBER END FORCES    STRUCTURE TYPE = SPACE
-----------------
ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z    TORSION     MOM-Y      MOM-Z

         4     4   -228.09  -4876.67 10898.67       0.00-420961.00 -188361.25
              10    228.09   4876.67-10898.67       0.00       0.02      -0.02
         5     4    558.47      0.00    -0.01       0.00       0.57       0.02
              10   -558.47      0.00     0.01       0.00       0.00       0.00

  10     1     8      0.00  -1586.45     0.00       0.00       0.00  -61276.76
              18      0.00   1586.45     0.00       0.00       0.00       0.00
         2     8   -101.68  -1554.13     0.08       0.00      -0.68  -60028.42
              18    101.68   1554.13    -0.08       0.00      -0.96       0.01
         3     8   -101.87  -1554.13     0.05       0.00      -1.10  -60028.45
              18    101.87   1554.13    -0.05       0.00      -0.84       0.00
         4     8   -171.87  -1551.54     0.04       0.00      -0.98  -59928.03
              18    171.87   1551.54    -0.04       0.00      -1.18       0.00
         5     8    115.36      0.00     0.00       0.00      -0.19      -0.02
              18   -115.36      0.00     0.00       0.00      -0.08       0.00

  11     1     4      0.00  -4841.75     0.00       0.00       0.00 -187012.44
              14      0.00   4841.75     0.00       0.00       0.00       0.01
         2     4   1053.22  -4809.43 -7859.20       0.00 303561.94 -185764.14
              14  -1053.22   4809.43  7859.20       0.00      -0.27       0.02
         3     4   1053.22  -4809.43 -8220.19       0.00 317505.34 -185764.09
              14  -1053.22   4809.43  8220.19       0.00      -0.40      -0.03
         4     4   1344.79  -4806.83 -7741.71       0.00 299023.88 -185663.77
              14  -1344.79   4806.83  7741.71       0.00      -0.08      -0.01
         5     4    558.41      0.00    -0.05       0.00       2.07      -0.03
              14   -558.41      0.00     0.05       0.00       0.05       0.00

  12     1     8      0.00  -1586.45     0.00       0.00       0.00  -61276.75
              20      0.00   1586.45     0.00       0.00       0.00       0.01
         2     8    332.64  -1618.77    -0.02       0.00       0.36  -62525.10
              20   -332.64   1618.77     0.02       0.00       0.25       0.01
         3     8    332.70  -1618.77    -0.06       0.00       0.54  -62525.15
              20   -332.70   1618.77     0.06       0.00       0.89      -0.01
         4     8    402.65  -1621.37    -0.05       0.00       0.87  -62625.52
              20   -402.65   1621.37     0.05       0.00       0.54      -0.01
         5     8    115.36      0.00    -0.03       0.00       0.50       0.03
              20   -115.36      0.00     0.03       0.00       0.61       0.00

  13     1    11   4841.74      0.00     0.00       0.00       0.00       0.00
              10  -4841.74      0.00     0.00       0.00       0.00       0.00
         2    11   4874.07     63.56-10781.16       0.00  97030.46     572.00
              10  -4874.07    -63.56 10781.16       0.00       0.00       0.00
         3    11   4874.07     63.57-11142.18       0.00 100279.63     572.09
              10  -4874.07    -63.57 11142.18       0.00       0.00       0.00
         4    11   4876.67   -228.07-10898.67       0.00  98088.03   -2052.64
              10  -4876.67    228.07 10898.67       0.00       0.00       0.00
         5    11      0.00    558.42     0.01       0.00      -0.13    5025.67
              10      0.00   -558.42    -0.01       0.00       0.00       0.00
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z


  14     1    12   4828.55      0.00     7.50      0.00   -460.01       0.00
              11  -4828.55      0.00    -7.50      0.00      2.32       0.00
         2    12  -8400.25     50.66  1276.65    112.09 -22809.53    3101.16
              11   8400.25    -50.66 -1276.65   -112.09 -55065.82     -10.97
         3    12  -8844.31     50.67  1319.14    112.11 -23557.82    3101.67
              11   8844.31    -50.67 -1319.14   -112.11 -56909.83     -10.97
         4    12  -8542.19   -181.79  1290.48   -402.23 -23053.33  -11128.71
              11   8542.19    181.79 -1290.48    402.23 -55666.02      39.37
         5    12      0.02    445.10     0.00    984.83      0.03   27247.65
              11     -0.02   -445.10     0.00   -984.83      0.07     -96.38

  15     1    15   4841.75      0.00     0.00      0.00      0.00       0.00
              14  -4841.75      0.00     0.00      0.00      0.00       0.00
         2    15   4809.43  -1053.26 -7859.21      0.00  70732.88   -9479.43
              14  -4809.43   1053.26  7859.21      0.00      0.00       0.00
         3    15   4809.42  -1053.27 -8220.21      0.00  73981.91   -9479.38
              14  -4809.42   1053.27  8220.21      0.00      0.00       0.00
         4    15   4806.83  -1344.96 -7741.70      0.00  69675.31  -12104.64
              14  -4806.83   1344.96  7741.70      0.00      0.00       0.00
         5    15      0.00   -558.41    -0.05      0.00      0.48   -5025.68
              14      0.00    558.41     0.05      0.00      0.00       0.00

  16     1    16   4828.55      0.00     7.50      0.00   -460.01       0.00
              15  -4828.55      0.00    -7.50      0.00      2.32       0.00
         2    16  -4870.66   -839.55   932.59  -1857.57 -16746.98  -51394.09
              15   4870.66    839.55  -932.59   1857.57 -40141.09     181.80
         3    16  -5314.70   -839.54   975.09  -1857.55 -17495.23  -51393.59
              15   5314.70    839.54  -975.09   1857.55 -41985.00     181.79
         4    16  -4728.74  -1072.00   918.76  -2371.89 -16503.20  -65623.96
              15   4728.74   1072.00  -918.76   2371.89 -39540.96     232.13
         5    16     -0.06   -445.10     0.01   -984.83     -0.11  -27247.60
              15      0.06    445.10    -0.01    984.83     -0.27      96.40

  17     1    19   1586.45      0.00     0.00      0.00      0.00       0.00
              18  -1586.45      0.00     0.00      0.00      0.00       0.00
         2    19   1554.13   -101.76     0.00      0.00      0.00   -7123.49
              18  -1554.13    101.76     0.00      0.00      0.00       0.00
         3    19   1554.13   -101.76     0.00      0.00      0.00   -7123.39
              18  -1554.13    101.76     0.00      0.00      0.00       0.00
         4    19   1551.53   -171.98     0.00      0.00      0.00  -12038.33
              18  -1551.53    171.98     0.00      0.00      0.00       0.00
         5    19      0.00    115.38     0.00      0.00      0.00    8076.84
              18      0.00   -115.38     0.00      0.00      0.00       0.00

  18     1    21   1586.45      0.00     0.00      0.00      0.00       0.00
              20  -1586.45      0.00     0.00      0.00      0.00       0.00
```

```
 MEMBER END FORCES    STRUCTURE TYPE = SPACE
 -----------------
 ALL UNITS ARE -- POUN INCH

MEMBER  LOAD  JT     AXIAL   SHEAR-Y  SHEAR-Z   TORSION     MOM-Y      MOM-Z

         2    21   1618.77   -332.53     0.00      0.00      0.00  -23276.78
              20  -1618.77    332.53     0.00      0.00      0.00       0.00
         3    21   1618.77   -332.52     0.00      0.00      0.00  -23276.69
              20  -1618.77    332.52     0.00      0.00      0.00       0.00
         4    21   1621.37   -402.74     0.00      0.00      0.00  -28191.63
              20  -1621.37    402.74     0.00      0.00      0.00       0.00
         5    21      0.00   -115.38     0.00      0.00      0.00   -8076.45
              20      0.00    115.38     0.00      0.00      0.00       0.00

    19   1    13     14.67      3.91     0.00      0.00      0.00     331.93
              11    -14.67     -3.91     0.00      0.00      0.00       2.32
         2    13  17919.01    712.14   -12.90   -473.32   1424.82   18968.28
              11 -17919.01   -712.14    12.90    473.32   -321.37   41964.64
         3    13  18518.56    735.86   -12.90   -473.40   1425.05   19592.26
              11 -18518.56   -735.86    12.90    473.40   -321.42   43369.79
         4    13  18114.16    719.86    46.28   1698.55  -5113.06   19171.55
              11 -18114.16   -719.86   -46.28  -1698.55   1153.26   42422.00
         5    13     -0.02      0.00  -113.31  -4158.75  12518.85      -0.03
              11      0.02      0.00   113.31   4158.75  -2823.65      -0.06

    20   1    17     14.67      3.91     0.00      0.00      0.00     331.93
              15    -14.67     -3.91     0.00      0.00      0.00       2.32
         2    17  13066.35    520.15   213.73   7844.18 -23612.87   13913.56
              15 -13066.35   -520.15  -213.73  -7844.18   5325.93   30591.84
         3    17  13665.86    543.86   213.72   7844.10 -23612.64   14537.51
              15 -13665.86   -543.86  -213.72  -7844.10   5325.87   31996.92
         4    17  12871.22    512.43   272.90  10016.05 -30150.74   13710.31
              15 -12871.22   -512.43  -272.90 -10016.05   6800.56   30134.54
         5    17      0.09      0.00   113.31   4158.75 -12518.83       0.09
              15     -0.09      0.00  -113.31  -4158.75   2823.65       0.21


 ************** END OF LATEST ANALYSIS RESULT **************


 100. PRINT MEMBER STRESSES ALL
```

```
MEMBER STRESSES
---------------
ALL UNITS ARE POUN/SQ INCH

MEMB    LD  SECT    AXIAL     BEND-Y     BEND-Z   COMBINED  SHEAR-Y  SHEAR-Z


   1     1    .0      0.0 C      0.0        0.0       0.0      0.0      0.0
            1.00      0.0 C      0.0        4.2       4.2     10.9      0.0
         2    .0    327.3 C      0.0        0.0     327.3      0.0      0.0
            1.00    327.3 C      0.0        4.2     331.5     10.9      0.0
         3    .0    327.4 C      0.0        0.0     327.4      0.0      0.0
            1.00    327.8 C      0.0        4.2     331.9     10.9      0.0
         4    .0    327.4 C      0.0        0.0     327.4      0.0      0.0
            1.00    327.4 C      0.2        4.2     331.5     10.9      0.6
         5    .0      0.0 T      0.0        0.0       0.0      0.0      0.0
            1.00      0.0 T      0.0        0.0       0.0      0.0      0.0

   2     1    .0      0.0 C      0.0        4.2       4.2     62.1      0.0
            1.00      0.0 C      0.0      230.1     230.1    101.4      0.0
         2    .0    327.4 C      0.0        4.2     331.5     62.1      0.0
            1.00    327.4 C      0.0      230.1     557.5    101.4      0.0
         3    .0    329.5 C      0.0        4.2     333.6     62.1      0.0
            1.00    330.8 C      0.0      230.1     560.9    101.4      0.0
         4    .0    327.4 C      0.2        4.2     331.5     62.1      3.5
            1.00    327.4 C     12.9      230.1     557.9    101.4      5.7
         5    .0      0.0        0.0        0.0       0.0      0.0      0.0
            1.00      0.0        0.0        0.0       0.0      0.0      0.0

   3     1    .0      0.0 C      0.0      230.1     230.1    123.1      0.0
            1.00      0.0 C      0.0      607.5     607.5    160.9      0.0
         2    .0    327.4 C      0.0      230.1     557.5    123.1      0.0
            1.00    327.4 C      0.0      607.5     934.9    160.9      0.0
         3    .0    331.5 C      0.0      230.1     561.7    123.1      0.0
            1.00    332.8 C      0.0      607.5     940.3    160.9      0.0
         4    .0    327.4 C     12.9      230.1     557.9    123.1      6.9
            1.00    327.4 C     34.2      607.5     935.9    160.9      9.1
         5    .0      0.0 C      0.0        0.0       0.0      0.0      0.0
            1.00      0.0 C      0.0        0.0       0.0      0.0      0.0

   4     1    .0      0.0 C      0.0      607.5     607.5    122.5      0.0
            1.00      0.0 C      0.0      457.3     457.3    103.6      0.0
         2    .0      0.0 C    109.7      607.5     617.4    122.5     29.0
            1.00      0.0 C     71.2      457.3     462.8    103.6     29.0
         3    .0      7.3 T    109.7      607.5     624.6    122.5     29.0
            1.00      6.6 T     71.2      457.3     469.5    103.6     29.0
         4    .0      0.0      152.7      607.5     626.4    122.5     37.0
            1.00      0.0      104.3      457.3     469.1    103.6     35.9
         5    .0      0.0 C      0.0        0.0       0.0      0.0      0.0
            1.00      0.0 C      0.0        0.0       0.0      0.0      0.0

   5     1    .0      0.0 C      0.0      457.3     457.3     81.9      0.0
            1.00      0.0 C      0.0      344.8     344.8     59.3      0.0
         2    .0      0.0 T     71.2      457.3     462.8     81.9     29.0
            1.00      0.0 T     25.0      344.8     345.7     59.3     29.0
```

```
   MEMBER STRESSES
   ---------------
   ALL UNITS ARE POUN/SQ INCH

 MEMB    LD  SECT     AXIAL     BEND-Y      BEND-Z   COMBINED   SHEAR-Y   SHEAR-Z

          3    .0      5.9 T       71.2       457.3      468.8      81.9      29.0
             1.00      5.2 T       25.1       344.8      350.8      59.3      29.0
          4    .0      0.0 T      104.3       457.3      469.1      81.9      34.7
             1.00      0.0 T       50.0       344.8      348.4      59.3      33.4
          5    .0      0.0 C        0.0         0.0        0.0       0.0       0.0
             1.00      0.0 C        0.0         0.0        0.0       0.0       0.0

     6    1    .0      0.0 T        0.0       344.8      344.8      59.3       0.0
             1.00      0.0 T        0.0       232.3      232.3      17.7       0.0
          2    .0      0.0         25.1       344.8      345.7      59.3      17.8
             1.00      0.0         26.9       232.3      233.9      17.7      17.8
          3    .0      5.1 T       25.0       344.8      350.8      59.3      17.8
             1.00      3.7 T       26.9       232.3      237.6      17.7      17.8
          4    .0      0.0 C       50.0       344.8      348.4      59.3      22.2
             1.00      0.0 C       11.5       232.3      232.7      17.7      19.9
          5    .0      0.0          0.0         0.0        0.0       0.0       0.0
             1.00      0.0          0.0         0.0        0.0       0.0       0.0

     7    1    .0      0.0 C        0.0       232.3      232.3      17.7       0.0
             1.00      0.0 C        0.0       226.9      226.9      12.5       0.0
          2    .0      0.0 T       26.9       232.3      233.9      17.7      12.7
             1.00      0.0 T        0.0       226.9      226.9      12.5      12.7
          3    .0      3.7 T       26.9       232.3      237.7      17.7      12.7
             1.00      2.7 T        0.0       226.9      229.6      12.5      12.7
          4    .0      0.0 T       11.5       232.3      232.6      17.7      10.6
             1.00      0.0 T       12.8       226.9      227.3      12.5      12.3
          5    .0      0.0 T        0.0         0.0        0.0       0.0       0.0
             1.00      0.0 T        0.0         0.0        0.0       0.0       0.0

     8    1    .0      0.0 C        0.0       226.9      226.9      80.4       0.0
             1.00      0.0 C        0.0         0.0        0.0       0.0       0.0
          2    .0      0.0 T        0.0       226.9      226.9      80.4       0.0
             1.00      0.0 T        0.0         0.0        0.0       0.0       0.0
          3    .0      2.7 T        0.0       226.9      229.6      80.4       0.0
             1.00      0.0 T        0.0         0.0        0.0       0.0       0.0
          4    .0      0.0 C       12.8       226.9      227.3      80.4       4.5
             1.00      0.0 C        0.0         0.0        0.0       0.0       0.0
          5    .0      0.0          0.0         0.0        0.0       0.0       0.0
             1.00      0.0          0.0         0.0        0.0       0.0       0.0

     9    1    .0      0.0 T        0.0      8229.4     8229.4     968.3       0.0
             1.00      0.0 T        0.0         0.0        0.0     968.3       0.0
          2    .0      6.8 C    18324.4      8284.3    26615.5     974.8    2156.2
             1.00      6.8 C        0.0         0.0        6.8     974.8    2156.2
          3    .0      6.8 C    18938.0      8284.3    27229.1     974.8    2228.4
             1.00      6.8 C        0.0         0.0        6.8     974.8    2228.4
          4    .0     24.4 T    18524.1      8288.7    26837.2     975.3    2179.7
             1.00     24.4 T        0.0         0.0       24.4     975.3    2179.7
          5    .0     59.7 C        0.0         0.0       59.7       0.0       0.0
             1.00     59.7 C        0.0         0.0       59.7       0.0       0.0
```

```
   MEMBER STRESSES
   ---------------
   ALL UNITS ARE POUN/SQ INCH

 MEMB   LD  SECT     AXIAL     BEND-Y      BEND-Z   COMBINED  SHEAR-Y  SHEAR-Z


   10    1    .0       0.0 C       0.0     2696.4     2696.4    317.3      0.0
            1.00       0.0 C       0.0        0.0        0.0    317.3      0.0
         2    .0      10.9 T       0.0     2641.5     2652.4    310.8      0.0
            1.00      10.9 T       0.0        0.0       10.9    310.8      0.0
         3    .0      10.9 T       0.0     2641.5     2652.4    310.8      0.0
            1.00      10.9 T       0.0        0.0       10.9    310.8      0.0
         4    .0      18.4 T       0.0     2637.1     2655.5    310.3      0.0
            1.00      18.4 T       0.1        0.0       18.4    310.3      0.0
         5    .0      12.3 C       0.0        0.0       12.3      0.0      0.0
            1.00      12.3 C       0.0        0.0       12.3      0.0      0.0

   11    1    .0       0.0 C       0.0     8229.4     8229.4    968.3      0.0
            1.00       0.0 C       0.0        0.0        0.0    968.3      0.0
         2    .0     112.5 C   13358.1     8174.4    21645.0    961.9   1571.8
            1.00     112.5 C       0.0        0.0      112.5    961.9   1571.8
         3    .0     112.5 C   13971.6     8174.4    22258.6    961.9   1644.0
            1.00     112.5 C       0.0        0.0      112.5    961.9   1644.0
         4    .0     143.7 C   13158.4     8170.0    21472.1    961.4   1548.3
            1.00     143.7 C       0.0        0.0      143.7    961.4   1548.3
         5    .0      59.7 C       0.1        0.0       59.8      0.0      0.0
            1.00      59.7 C       0.0        0.0       59.7      0.0      0.0

   12    1    .0       0.0 T       0.0     2696.4     2696.4    317.3      0.0
            1.00       0.0 T       0.0        0.0        0.0    317.3      0.0
         2    .0      35.5 C       0.0     2751.4     2786.9    323.8      0.0
            1.00      35.5 C       0.0        0.0       35.5    323.8      0.0
         3    .0      35.5 C       0.0     2751.4     2787.0    323.8      0.0
            1.00      35.5 C       0.0        0.0       35.6    323.8      0.0
         4    .0      43.0 C       0.0     2755.8     2798.9    324.3      0.0
            1.00      43.0 C       0.0        0.0       43.0    324.3      0.0
         5    .0      12.3 C       0.0        0.0       12.3      0.0      0.0
            1.00      12.3 C       0.0        0.0       12.4      0.0      0.0

   13    1    .0     761.3 C       0.0        0.0      761.3      0.0      0.0
            1.00     761.3 C       0.0        0.0      761.3      0.0      0.0
         2    .0     766.4 C   15777.3       93.0    16636.7     15.9   2695.3
            1.00     766.4 C       0.0        0.0      766.4     15.9   2695.3
         3    .0     766.4 C   16305.6       93.0    17165.0     15.9   2785.5
            1.00     766.4 C       0.0        0.0      766.4     15.9   2785.5
         4    .0     766.8 C   15949.3      333.8    17049.8     57.0   2724.7
            1.00     766.8 C       0.0        0.0      766.8     57.0   2724.7
         5    .0       0.0 T       0.0      817.2      817.2    139.6      0.0
            1.00       0.0 T       0.0        0.0        0.0    139.6      0.0

   14    1    .0     759.2 C      74.8        0.0      834.0      0.0      1.9
            1.00     759.2 C       0.4        0.0      759.6      0.0      1.9
         2    .0    1320.8 T    3708.9      504.3     5533.9     12.7    319.2
            1.00    1320.8 T    8953.8        1.8    10276.4     12.7    319.2
```

```
  MEMBER STRESSES
  ---------------
  ALL UNITS ARE POUN/SQ INCH

 MEMB    LD  SECT     AXIAL     BEND-Y     BEND-Z   COMBINED   SHEAR-Y   SHEAR-Z

          3    .0   1390.6 T    3830.5      504.3     5725.5      12.7     329.8
             1.00   1390.6 T    9253.6        1.8    10646.0      12.7     329.8
          4    .0   1343.1 T    3748.5     1809.5     6901.2      45.4     322.6
             1.00   1343.1 T    9051.4        6.4    10400.9      45.4     322.6
          5    .0      0.0 C       0.0     4430.5     4430.5     111.3       0.0
             1.00      0.0 C       0.0       15.7       15.7     111.3       0.0

   15     1    .0    761.3 C       0.0        0.0      761.3       0.0       0.0
             1.00    761.3 C       0.0        0.0      761.3       0.0       0.0
          2    .0    756.2 C   11501.3     1541.4    13798.8     263.3    1964.8
             1.00    756.2 C       0.0        0.0      756.2     263.3    1964.8
          3    .0    756.2 C   12029.6     1541.4    14327.1     263.3    2055.1
             1.00    756.2 C       0.0        0.0      756.2     263.3    2055.1
          4    .0    755.8 C   11329.3     1968.2    14053.3     336.2    1935.4
             1.00    755.8 C       0.0        0.0      755.8     336.2    1935.4
          5    .0      0.0 C       0.1      817.2      817.3     139.6       0.0
             1.00      0.0 C       0.0        0.0        0.0     139.6       0.0

   16     1    .0    759.2 C      74.8        0.0      834.0       0.0       1.9
             1.00    759.2 C       0.4        0.0      759.6       0.0       1.9
          2    .0    765.8 T    2723.1     8356.8    11845.7     209.9     233.1
             1.00    765.8 T    6527.0       29.6     7322.4     209.9     233.1
          3    .0    835.6 T    2844.8     8356.7    12037.1     209.9     243.8
             1.00    835.6 T    6826.8       29.6     7692.0     209.9     243.8
          4    .0    743.5 T    2683.4    10670.6    14097.5     268.0     229.7
             1.00    743.5 T    6429.4       37.7     7210.7     268.0     229.7
          5    .0      0.0 T       0.0     4430.5     4430.5     111.3       0.0
             1.00      0.0 T       0.0       15.7       15.7     111.3       0.0

   17     1    .0    785.4 C       0.0        0.0      785.4       0.0       0.0
             1.00    785.4 C       0.0        0.0      785.4       0.0       0.0
          2    .0    769.4 C       0.0     3653.1     4422.4      67.8       0.0
             1.00    769.4 C       0.0        0.0      769.4      67.8       0.0
          3    .0    769.4 C       0.0     3653.0     4422.4      67.8       0.0
             1.00    769.4 C       0.0        0.0      769.4      67.8       0.0
          4    .0    768.1 C       0.0     6173.5     6941.6     114.7       0.0
             1.00    768.1 C       0.0        0.0      768.1     114.7       0.0
          5    .0      0.0 C       0.0     4142.0     4142.0      76.9       0.0
             1.00      0.0 C       0.0        0.0        0.0      76.9       0.0

   18     1    .0    785.4 C       0.0        0.0      785.4       0.0       0.0
             1.00    785.4 C       0.0        0.0      785.4       0.0       0.0
          2    .0    801.4 C       0.0    11936.8    12738.2     221.7       0.0
             1.00    801.4 C       0.0        0.0      801.4     221.7       0.0
          3    .0    801.4 C       0.0    11936.8    12738.1     221.7       0.0
             1.00    801.4 C       0.0        0.0      801.4     221.7       0.0
          4    .0    802.7 C       0.0    14457.2    15259.9     268.5       0.0
             1.00    802.7 C       0.0        0.0      802.7     268.5       0.0
          5    .0      0.0 T       0.0     4141.8     4141.8      76.9       0.0
             1.00      0.0 T       0.0        0.0        0.0      76.9       0.0
```

```
 MEMBER STRESSES
 ---------------
 ALL UNITS ARE POUN/SQ INCH

MEMB   LD  SECT    AXIAL    BEND-Y     BEND-Z   COMBINED  SHEAR-Y  SHEAR-Z


   19   1   .0       2.3 C      0.0       54.0      56.3      1.0      0.0
           1.00      2.3 C      0.0        0.4       2.7      1.0      0.0
        2   .0    2817.5 C    231.7     3084.3    6133.4    178.0      3.2
           1.00   2817.5 C     52.3     6823.5    9693.2    178.0      3.2
        3   .0    2911.7 C    231.7     3185.7    6329.2    184.0      3.2
           1.00   2911.7 C     52.3     7052.0   10016.0    184.0      3.2
        4   .0    2848.1 C    831.4     3117.3    6796.9    180.0     11.6
           1.00   2848.1 C    187.5     6897.9    9933.5    180.0     11.6
        5   .0       0.0 T   2035.6        0.0    2035.6      0.0     28.3
           1.00      0.0 T    459.1        0.0     459.1      0.0     28.3

   20   1   .0       2.3 C      0.0       54.0      56.3      1.0      0.0
           1.00      2.3 C      0.0        0.4       2.7      1.0      0.0
        2   .0    2054.5 C   3839.5     2262.4    8156.3    130.0     53.4
           1.00   2054.5 C    866.0     4974.3    7894.7    130.0     53.4
        3   .0    2148.7 C   3839.5     2363.8    8352.0    136.0     53.4
           1.00   2148.7 C    866.0     5202.8    8217.5    136.0     53.4
        4   .0    2023.8 C   4902.6     2229.3    9155.7    128.1     68.2
           1.00   2023.8 C   1105.8     4899.9    8029.5    128.1     68.2
        5   .0       0.0 C   2035.6        0.0    2035.6      0.0     28.3
           1.00      0.0 C    459.1        0.0     459.2      0.0     28.3

   ************** END OF LATEST ANALYSIS RESULT **************


   101. PARAMETER
   102. CODE AISC
   103. FYLD 45999.969 MEMB 13 TO 20
   104. WSTR 21000. MEMB 13 TO 20
   105. WMIN 0.188 MEMB 13 TO 20
   106. CB 1. MEMB 13 TO 20
   107. CMY 1. MEMB 13 TO 20
   108. MAIN 0. MEMB 13 TO 20
   109. RATIO 1. MEMB 13 TO 20
   110. CHECK CODE MEMB 13 TO 20
```

```
                          STAAD-III CODE CHECKING - (AISC)
                          ***********************

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER      TABLE        RESULT/   CRITICAL COND/      RATIO/     LOADING/
                           FX            MY               MZ       LOCATION
=======================================================================

    13  ST  TUB 40408       PASS     AISC- H1-3          0.622         3
                    4874.07 C      100279.63         572.09         0.00
    14  ST  TUB 40408       PASS     AISC- H2-1          0.386         3
                    8844.31 T     -56909.83          -10.97        61.00
    15  ST  TUB 40408       PASS     AISC- H1-3          0.520         3
                    4809.42 C      73981.91        -9479.38         0.00
    16  ST  TUB 40408       PASS     AISC- H2-1          0.511         4
                    4728.74 T     -16503.20       -65623.96         0.00
    17  ST  TUB 40203       PASS     AISC- H1-3          0.269         4
                    1551.53 C          0.00       -12038.33         0.00
    18  ST  TUB 40203       PASS     AISC- H1-3          0.572         4
                    1621.37 C          0.00       -28191.63         0.00
    19  ST  TUB 40408       PASS     AISC- H1-3          0.396         3
                   18518.56 C       -321.42        43369.79        85.56
    20  ST  TUB 40408       PASS     AISC- H1-3          0.355         4
                   12871.22 C     -30150.74        13710.31         0.00
  111. SELECT WELD MEMB 13 TO 20
```

```
                              STAAD-III WELD DESIGN
                              *********************

ALL UNITS ARE - INCH POUN

MEMBER    LOCATION/      WELD TYPE/       WELD SIZE/       COMB STRESS/
          LOADING        HOR STRESS      VERT STRESS        DIR STRESS
=======================================================================

   13       STA              1             4/16              20320.05
             3            2785.54            15.89           20128.21

   13       END              1             3/16               4053.92
             3            3714.06            21.19            1624.69

   14       STA              1             3/16              11403.57
             4             480.44           110.88           11392.91

   14       END              1             3/16              17184.32
             3             453.73            30.90           17178.30

   15       STA              1             4/16              16978.23
             3            2055.05           263.32           16851.35

   15       END              1             3/16               3193.95
             3            2740.07           351.09            1603.14

   16       STA              1             4/16              16594.43
             4             452.05           490.36           16581.03

   16       END              1             3/16              12336.50
             3             557.22           512.04           12313.26

   17       STA              1             3/16               5505.44
             4               0.00            76.43            5504.91

   17       END              1             3/16                705.09
             1               0.00             0.00             705.09

   18       STA              1             3/16              11998.60
             4               0.00           178.99           11997.26

   18       END              1             3/16                742.51
             4               0.00           178.99             720.61

   19       STA              1             3/16              12119.79
             4             227.75           452.27           12109.21

   19       END              1             3/16              17098.48
             3              63.47           304.46           17095.65

   20       STA              1             3/16              15380.62
             4            1342.97          1422.82           15255.67

   20       END              1             3/16              13974.13
             3            1051.75          1161.80           13885.98
```

```
                      STAAD-III WELD DESIGN
                      *********************

ALL UNITS ARE - INCH POUN

MEMBER   LOCATION/     WELD TYPE/       WELD SIZE/       COMB STRESS/
         LOADING       HOR STRESS      VERT STRESS        DIR STRESS
=====================================================================


****************** END OF TABULATED WELD DESIGN ******************

112. STEEL TAKE OFF
```

```
STEEL TAKE-OFF
--------------

PROFILE                   LENGTH(INCH)       WEIGHT(POUN)

ST   PIP E                   596.00            9604.186
ST   TUB 80805               154.50             409.252
ST   TUB 40408               311.13             559.989
ST   TUB 40203               140.00              80.032
                                           ----------------
                                 TOTAL =      10653.46

************ END OF DATA FROM INTERNAL STORAGE ************

113. FINISH

          *************** END OF STAAD-III ***************

            **** DATE= SEP 26,1996   TIME= 15:11:45 ****

      ********************************************************
      *        For questions on  STAAD-III,   contact:        *
      *              Research Engineers, Inc at               *
      *       Ph: (714) 974-2500   Fax:  (714) 921-2543       *
      ********************************************************
```

DESIGN ANCHOR BOLTS, BASEPLATES AND BOLTED CONNECTIONS

ANCHOR BOLTS

1"ϕ HILTI HVA @ 8¼" EMBEDMENT

$f'_c = 3000$ PSI

$T_{ALL} = 10960$ lbs. $V_{ALLOW} = 7630$ lbs.

SUPPORT REACTIONS (JOINTS 19 & 21)

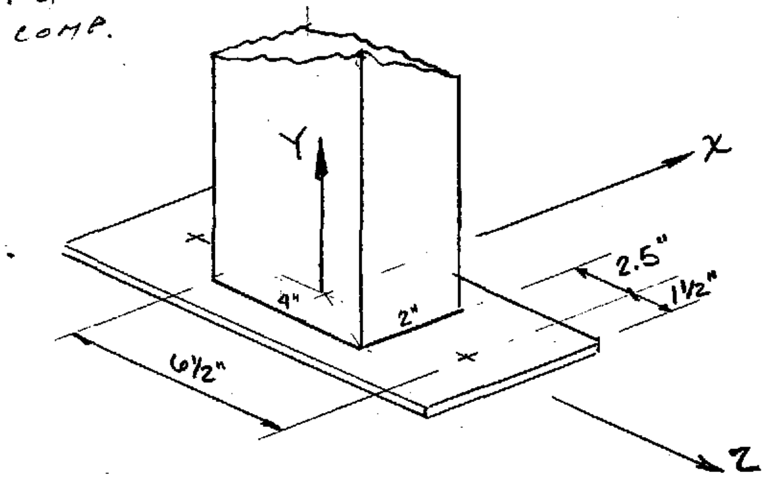
WORST CASE ENVELOPE LOADS (GLOBAL AXIS)

$F_X = 0.0$ $M_X = 28192.0$ in-lbs

$F_Y = 1552.$ lbs* (COMPRESS) $M_Y = 0.0$ in-lbs.

$F_Z = 403.$ lbs $M_Z = 0.0$ in-lbs

* 1622 LB - P. 21
SAY OK - COMP.



SHEAR

$$V = \frac{403.0 \text{ lbs}}{2 \text{ BOLTS}}$$

$V = 201.5$ lbs/BOLT

TENSION

$$T = \frac{1552.\text{ lbs}}{2 \text{ BOLTS}} + \frac{28192 \text{ in-lbs}}{1 \text{ BOLT } (6.5 \text{ in})}$$

$$T = 5113.\text{lbs} \overset{\text{PRYING FACTOR}}{(1.2)} = 6136.\text{lbs.}$$

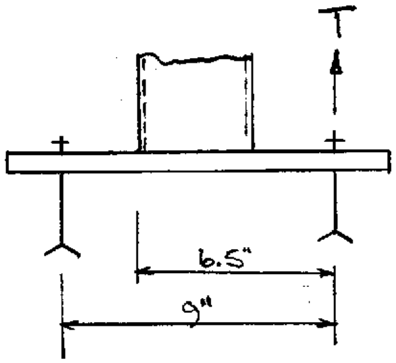
ANCHOR BOLT INTERACTION

$$\frac{V}{V_{ALL}} + \frac{T}{T_{ALL}} = \frac{201.5}{7630} + \frac{6136.}{10960.} = .59 < 1.0$$

∴ OK.

$$\boxed{\text{USE } 1'' \phi \text{ HILTI HVA @ } 8\tfrac{1}{4}'' \text{ EMB'T}}$$

BASEPLATE



$F_Y = 36000 \ \#/in^2$

$F_{Y_b} = .75(F_Y) = 27000 \ \#/in^2$

$T = 6136 \ \#/BOLT$

$$f_b = \frac{M}{S} = \frac{T(6.5 \, in)}{S} \Rightarrow S_{REQ'D} = \frac{M}{f_b} = \frac{M}{F_{Y_b}}$$

$$S_{REQ'D} = \frac{(6136^{\#})(6.5 \, in)}{27000. \ \#/in^2} = 1.48 \, in^3$$

$$S = \frac{bd^2}{6} \quad \therefore \quad d = \sqrt{\frac{S \ 6}{b}}$$

$$d_{req'd} = \sqrt{\frac{(1.49 \, in^3)(6)}{9}}$$

$$= 0.99 \ in$$

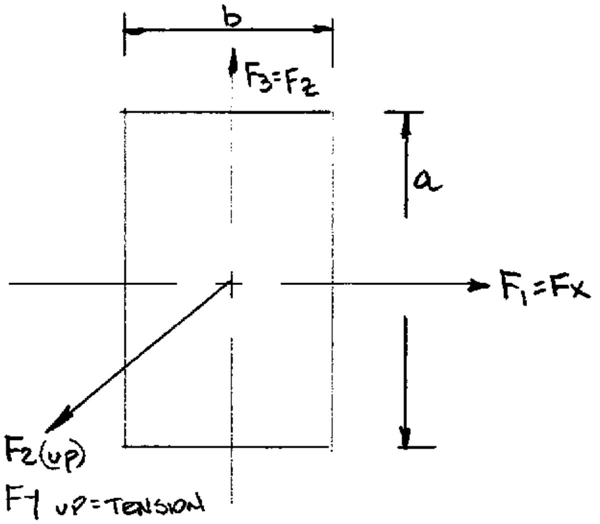
USE THICKNESS = 1.375"

∴ PL = 6" × 12" × 1 3/8"

Filename: BE-5 SUPPORT

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part Joint 19/21 and BASEPLTS



4x2 T.S.

LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
	1552.00	403.00	28192.00	0.00	0.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90ø>â<120ø)
4.000	2.000	21000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
12.000	13.333	9.333	36.000	2.000	1.000

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

f=
2244

REQUIRED FILLET WELD SIZE (INCHES)

w=
0.151 USE 1/4" fillet all-around

PL 12"x12" (JT 12 & 16)

WORST LOAD CASE IS at JT 16 L.C.# 4 ✓

Fx = 919. lbs Mx = 65624. in-lbs

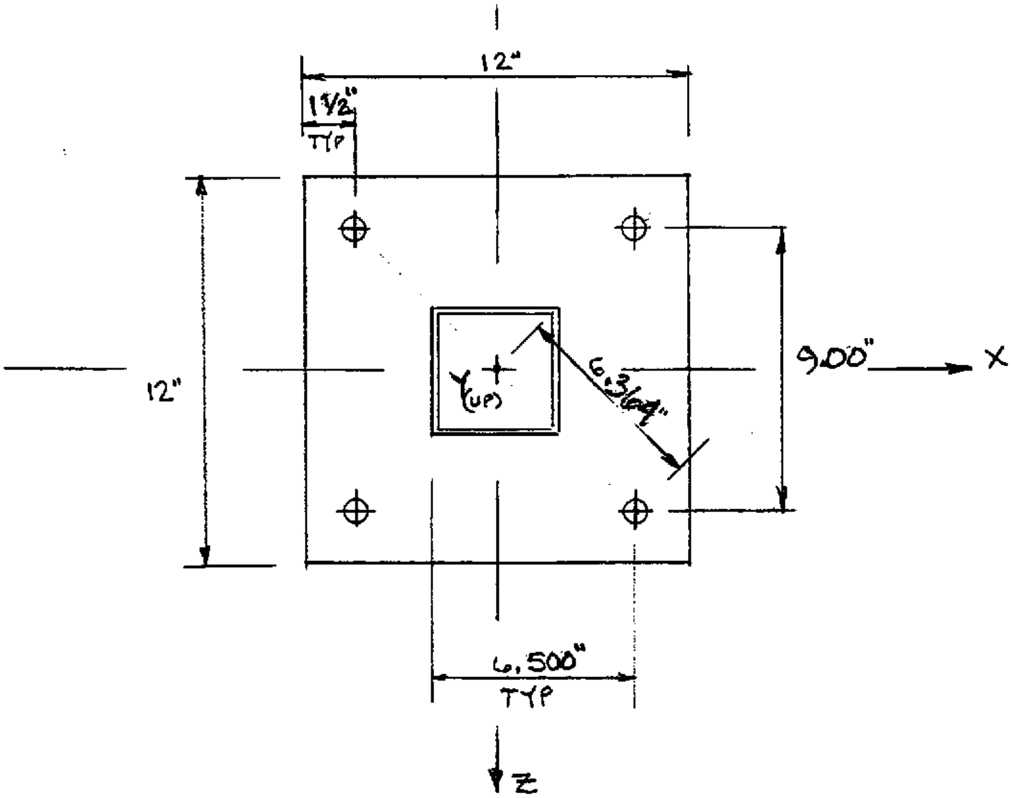
Fy = 4729. lbs. (TENSION) My = 2372. in-lbs.

Fz = 1072. lbs Mz = 16503. in-lbs.

TRY 1" ϕ HILTI HVA @ 8¼" EMBT

TALL = 10960 lbs

VALL = 7630 lbs.



PL 12"x12"

ANCHOR BOLTS

SHEAR

$$V = \frac{919\text{ lbs} + 1072\text{ lbs}}{4\text{ BOLTS}} + \frac{2372\text{ in-lbs}}{(4\text{ BOLTS})(6.364\text{ in})}$$

$$= 591.0\text{ lbs / BOLT}$$

TENSION

$$T = \frac{4729\text{ lbs}}{4\text{ BOLTS}} + \frac{65624\text{ in-lbs}}{(2\text{ BOLTS})(6.5\text{ in})} + \frac{16503\text{ in-lbs}}{(2\text{ BOLTS})(6.5\text{ in})}$$

$$= 7500\text{ lbs}$$

BOLT INTERACTION

$$\frac{V}{V_{ALL}} + \frac{T}{T_{ALL}} < 1.0$$

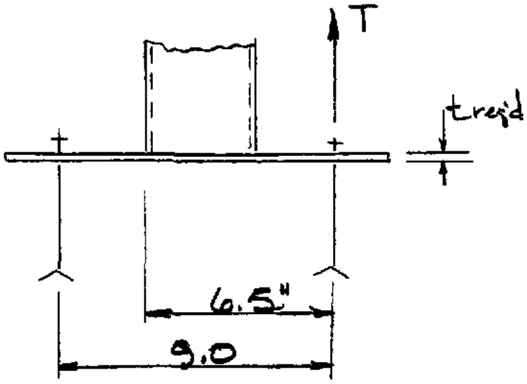
$$\frac{591\text{ lbs}}{7630\text{ lbs}} + \frac{7500\text{ lbs}}{10960\text{ lbs}} = 0.08 + 0.68 = 0.76 < 1.0$$

$\therefore$ O.K.

USE 1"ϕ HILTI HVA @ 8¼" EMBEDMENT

PL 12"×12"

DETERMINE REQUIRED PLATE THICKNESS



$T = 7500 \text{ lbs.}$

$F_Y = 36000 \text{ psi}$

$F_{Yb} = .75\ (F_Y)$

$= 27000 \text{ psi}$

$f_b = \frac{M}{S} = \frac{T\ (6.5\text{in})}{S}$

$S = \frac{T\ (6.5\text{in})}{f_b}$

$S_{req'd} = \frac{(7500\text{lbs})(6.50\text{in})}{27000.\text{ psi}}$

$S_{req'd} = 1.805\text{in}^3$

$S = bd^2/6$

$d^2 = \frac{6\ S}{b} \Rightarrow d = \sqrt{\frac{6\ S_{req'd}}{b}}$

$t_{req'd} = d = \sqrt{\frac{6\ (1.805\text{in}^3)}{12.00\text{in}}}$

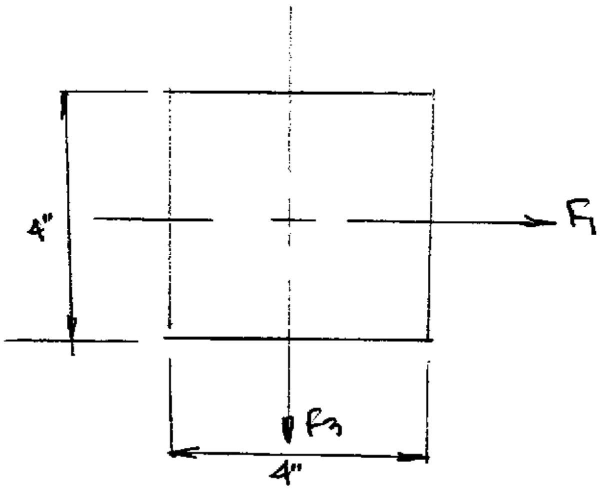
$t_{req'd} = 0.95\text{in}$

$\boxed{\text{USE: PL } 12" \times 12" \times 1\tfrac{3}{8}" \text{ THKs.}}$

Filename: BE-5 SUPPORT

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part Jts. 12 & 16 and BASEPLTS



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
919.00	4729.00	1072.00	65624.00	2372.00	16503.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90ø>â<120ø)
4.000	4.000	21000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
16.000	21.333	21.333	85.333	2.000	2.000

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

f=
4149

REQUIRED FILLET WELD SIZE (INCHES)

w=
0.279 USE 1/4" fillet allaround.

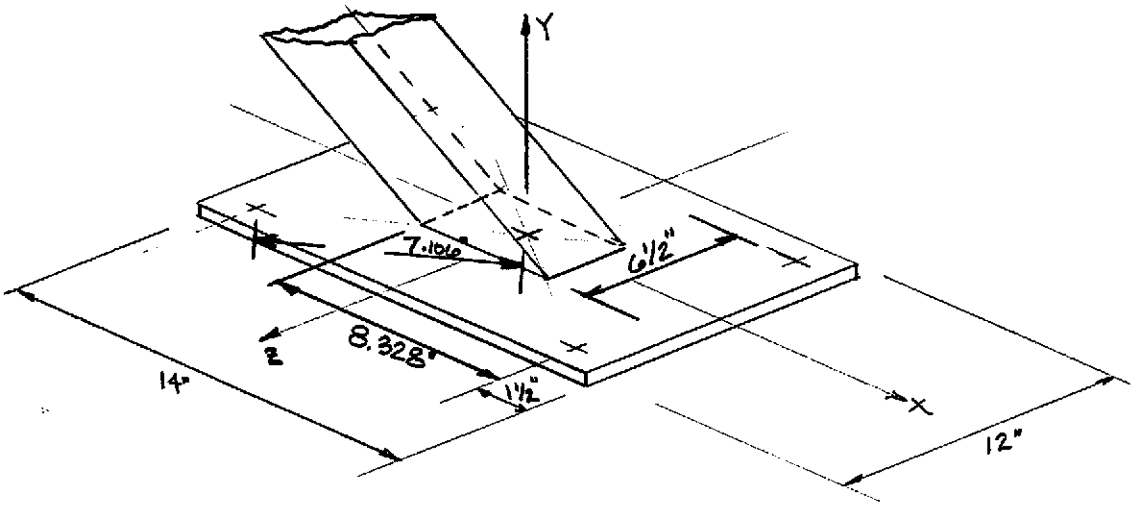
PL 14"x12" (JTS 13 & 17)

SUPPORT REACTIONS @ JT 17 @ L.C.#4

Fx = 8661. lbs. Mx = 28519. in-lbs

FY = 9536. lbs. (compression) MY = 14002. in-lbs

FZ = 273. lbs. MZ = 13710. in-lbs



SHEAR

$$V = \frac{8661.\text{lbs} + 273.\text{ lbs}}{4 \text{ BOLTS}} + \frac{14002 \text{ in-lbs}}{(4 \text{ BOLTS})(7.106 \text{ in})}$$

$$= 2726.\text{ lbs/BOLT}$$

TENSION

$$T = \frac{\cancel{9536 \text{ lbs}}}{\cancel{4 \text{ BOLTS}}}\overset{0=\text{Compression}}{} + \frac{28519 \text{ in-lbs}}{(2 \text{ BOLTS})(6.5 \text{ in})} + \frac{1371.0 \text{ in-lbs}}{(2 \text{ BOLTS})(8.328 \text{ in})}$$

$$T = 3017.0 \text{ lbs/BOLT}$$

BOLT INTERACTION

$T_{ALL} = 10960 \ \#/\text{BOLT}$

$V_{ALL} = 7630 \ \#/\text{BOLT}$

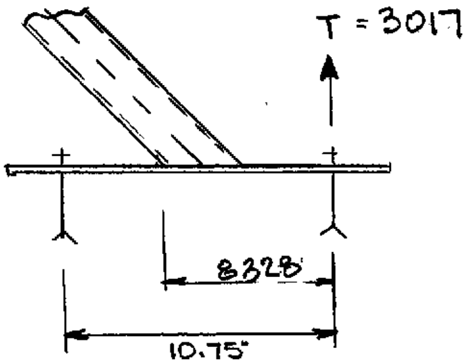
$$\frac{2726 \ \#/\text{BOLT}}{7630 \ \#/\text{BOLT}} + \frac{3017 \ \#/\text{BOLT}}{10960 \ \#/\text{BOLT}} = .63 < 1.0$$

∴ O.K.

$$\boxed{\text{USE: } 1"\phi \text{ HILTI HVA}}$$

@ 8¼" EMBEDMENT

BASEPLATE THICKNESS



$F_y = 36000$ psi

$F_{y_b} = .75 (F_y) = 27000$ psi

$$f_b = \frac{M}{S} = \frac{T(8.328 \text{in})}{S}$$

therefore: $$S_{req'd} = \frac{(3017 \text{ lbs})(8.328)}{27000 \text{ psi}}$$

$$= 0.93$$

$S = bd^2/6$

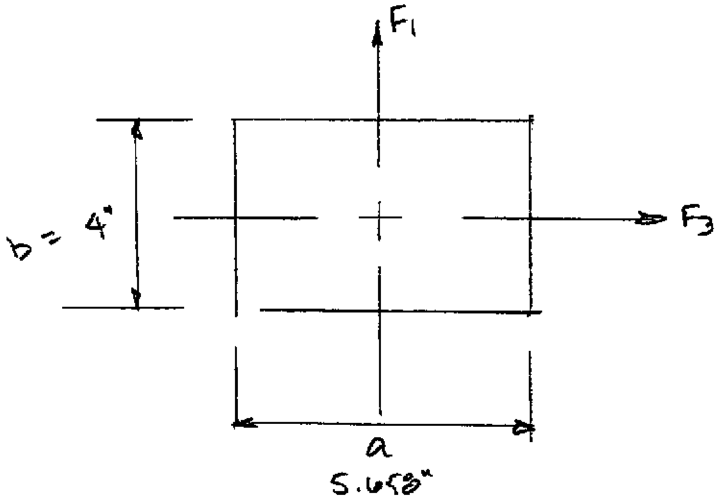
$$\therefore d = \sqrt{\frac{(S)6}{b}} \Rightarrow d_{req'd} = \sqrt{\frac{(0.93 \text{ in}^3)(6)}{12.0 \text{ in}}} = 0.68 \text{ in}$$

USE PL 14"x12" x 1⅜" THK
w/(4) - 1"φ HILTI HVA @8¼" EMB'T

Filename: BE-5 SUPPORT

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part Jts. 13 & 17 and BASEPLTS



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
273.00		8661.00	13710.00	14002.00	28519.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90ø>â<120ø)
5.658	4.000	21000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
19.316	33.303	27.965	150.145	2.829	2.000

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

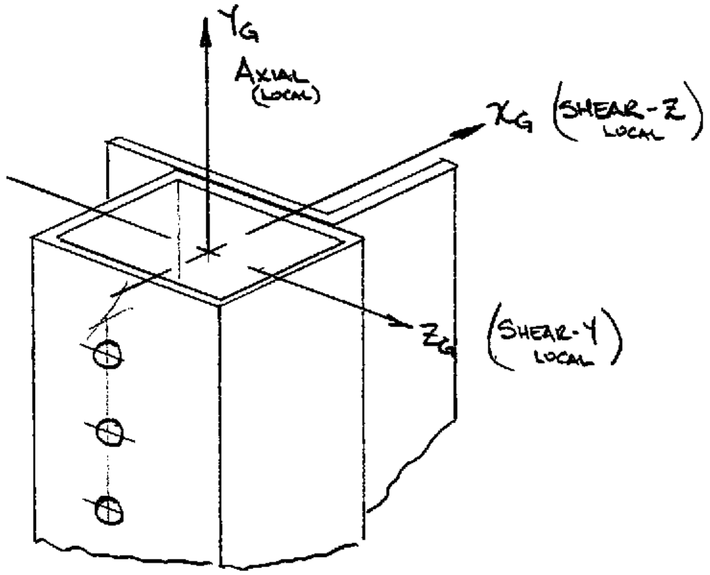
MAXIMUM WELD LOAD (f) - #/INCH

f=
1590

REQUIRED FILLET WELD SIZE (INCHES)

w=
0.107 Use 1/4" fillet all around

BOLTED CONNECTIONS



BOLTED CONNECTIONS @ JT'S 10, 14, 18 & 20
(END OF MEM'S 13, 15, 17, 18)

ENVELOPE LOAD CASES

FAXIAL = 4877. lbs MEM. 13, JT 10 L.C. # 4

SHEAR-Y = 1345. lbs. MEM 15, JT. 14 L.C. # 4

SHEAR-Z = 11142. lbs. MEM 13, JT. 10, L.C. # 3

SHEAR

$$V = \frac{4877 \text{ lbs} + 1345 \text{ lbs}}{3 \text{ BOLTS}} = 2074 \text{ lbs/BOLT}$$

TENSION

$$T = 11142 \text{ lbs}/3 \text{ BOLTS} = 3714 \text{ lbs/BOLT } \overset{\text{PRYING}}{\downarrow}(1.2)$$

$$T = 4457 \text{ lbs/BOLT}$$

BOLTED CONNECTIONS

TRY 5/8" ϕ A325 BOLTS

$T_{ALL} = 13500$ lbs.

$V_{ALL} = 5220$ lbs.

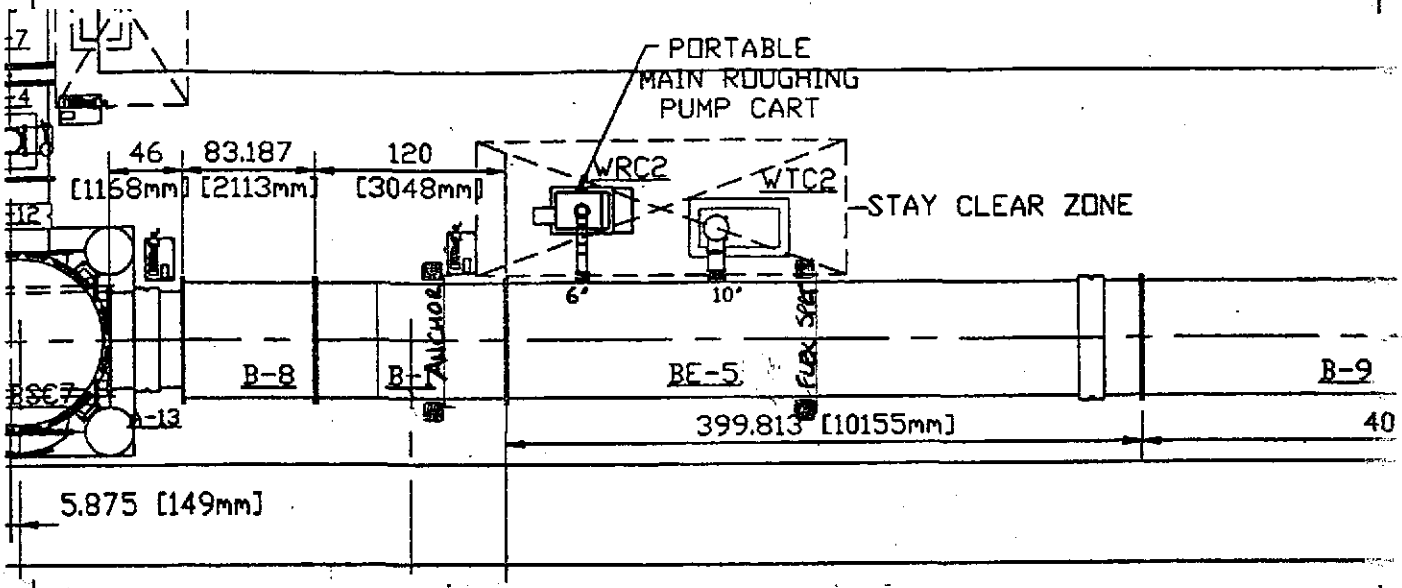
BOLT INTERACTION

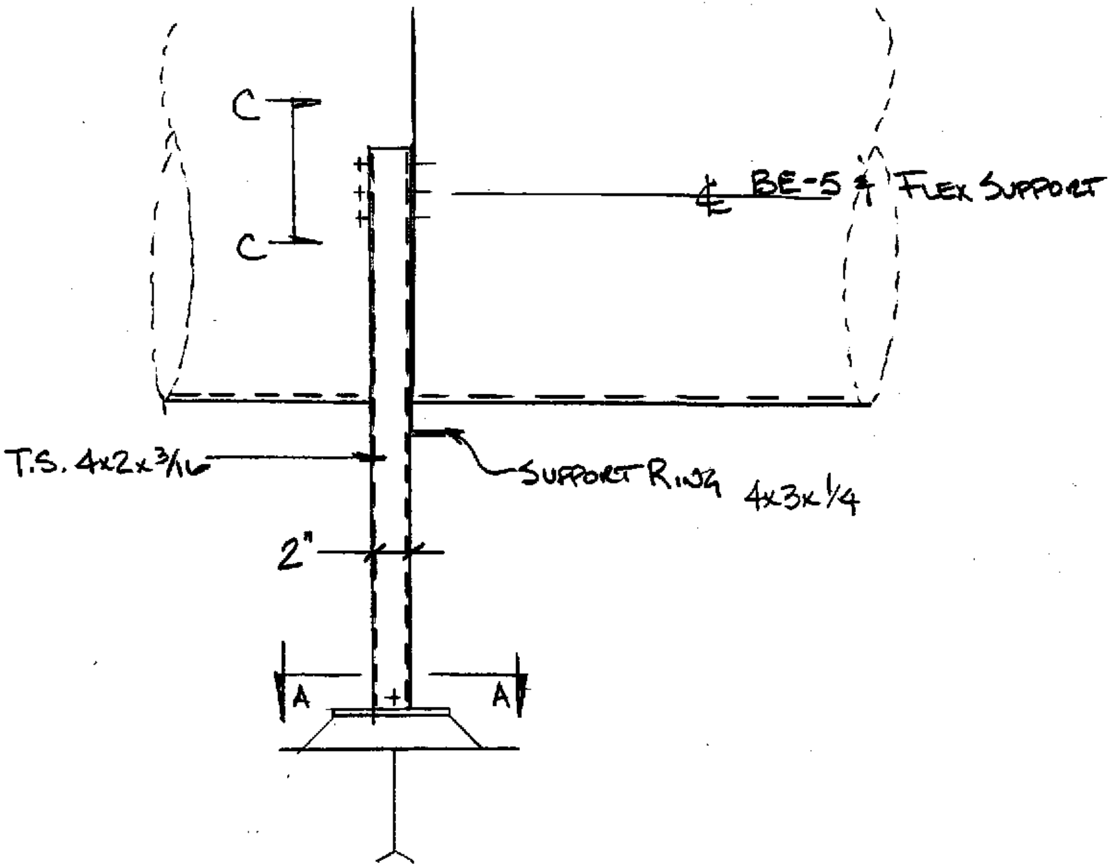
$$\frac{T}{T_{ALL}} + \frac{V}{V_{ALL}} < 1.0$$

$$\frac{4457 \text{ lbs}}{13500 \text{ lbs}} + \frac{2074 \text{ lbs}}{5220 \text{ lbs.}} = .73 < 1.0 \quad \therefore \underline{OK}$$

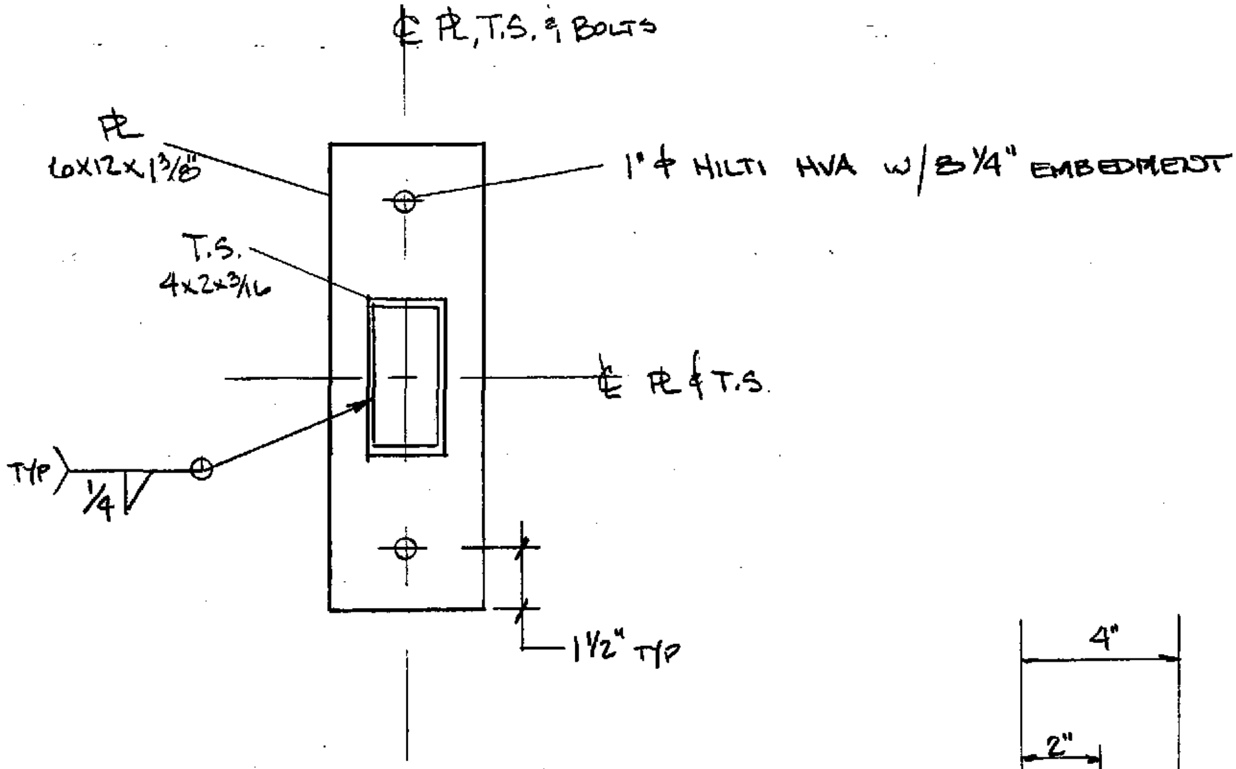
USE: $\boxed{5/8" \phi \text{ A325 BOLTS}}$

BE-5 GENERIC SUPPORT SCHEME

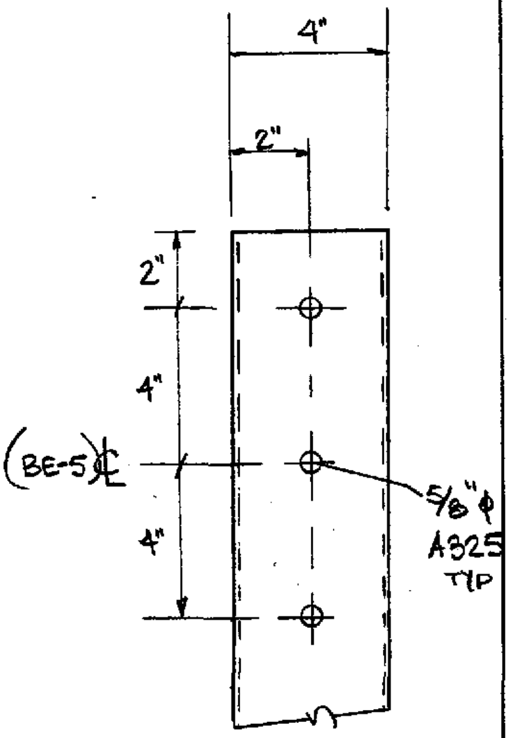




FLEX SUPPORT



SECTION A-A

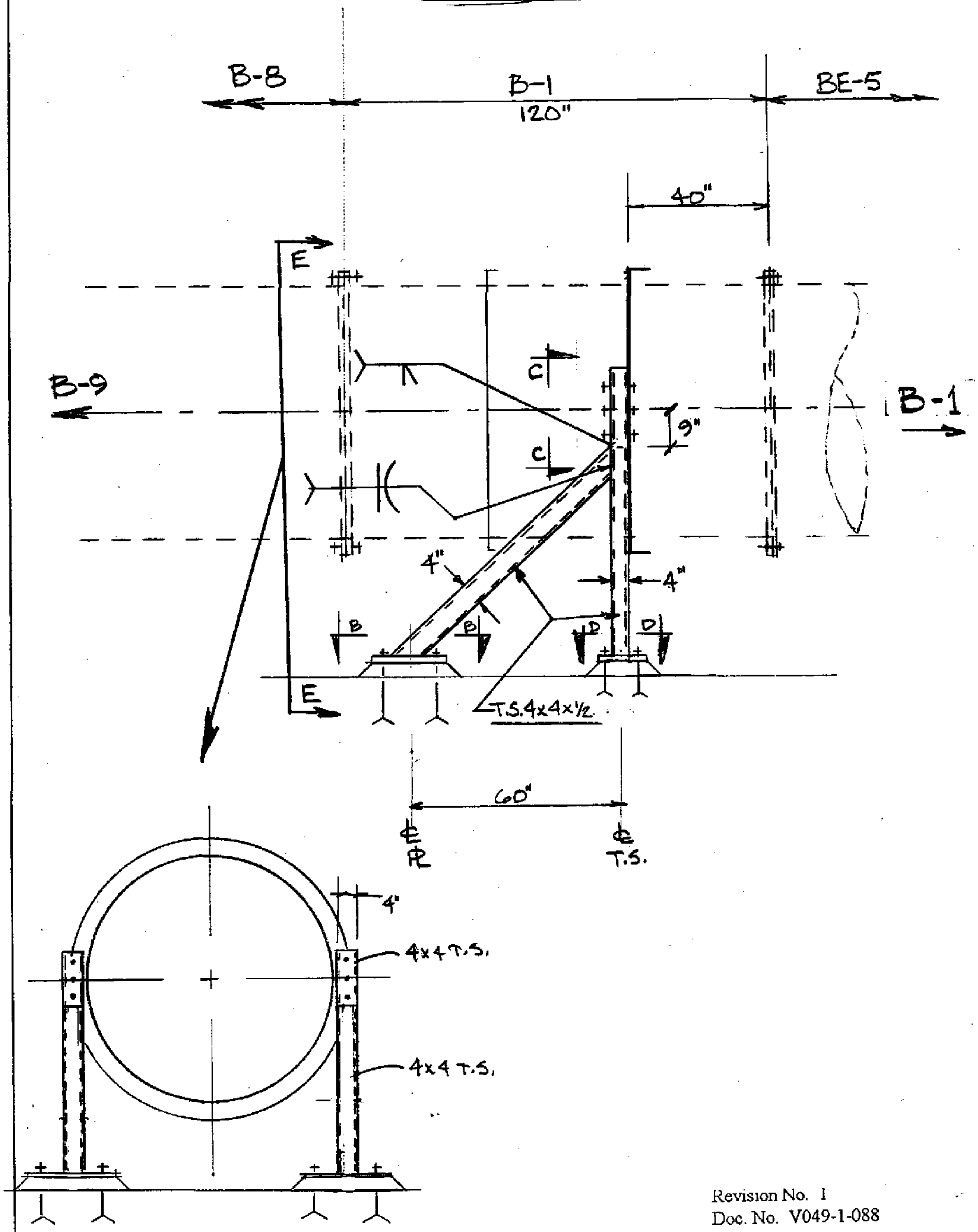


SECTION C-C

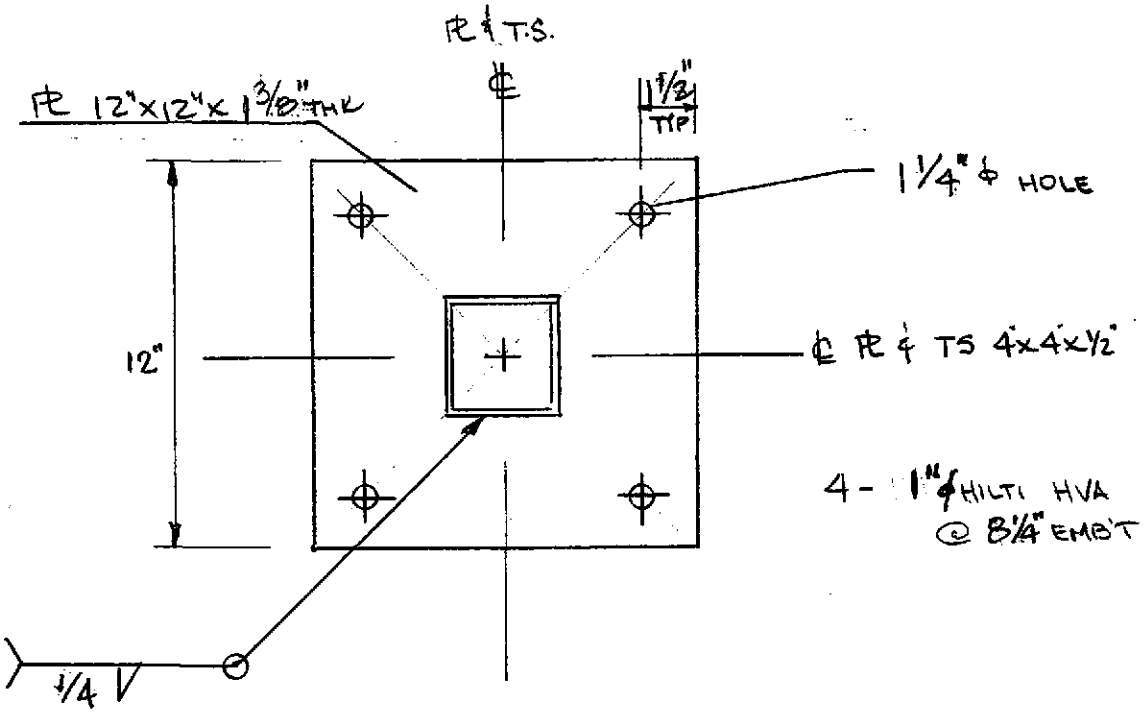
BEAM TUBE MANIFOLD SUPPORT

BE-5

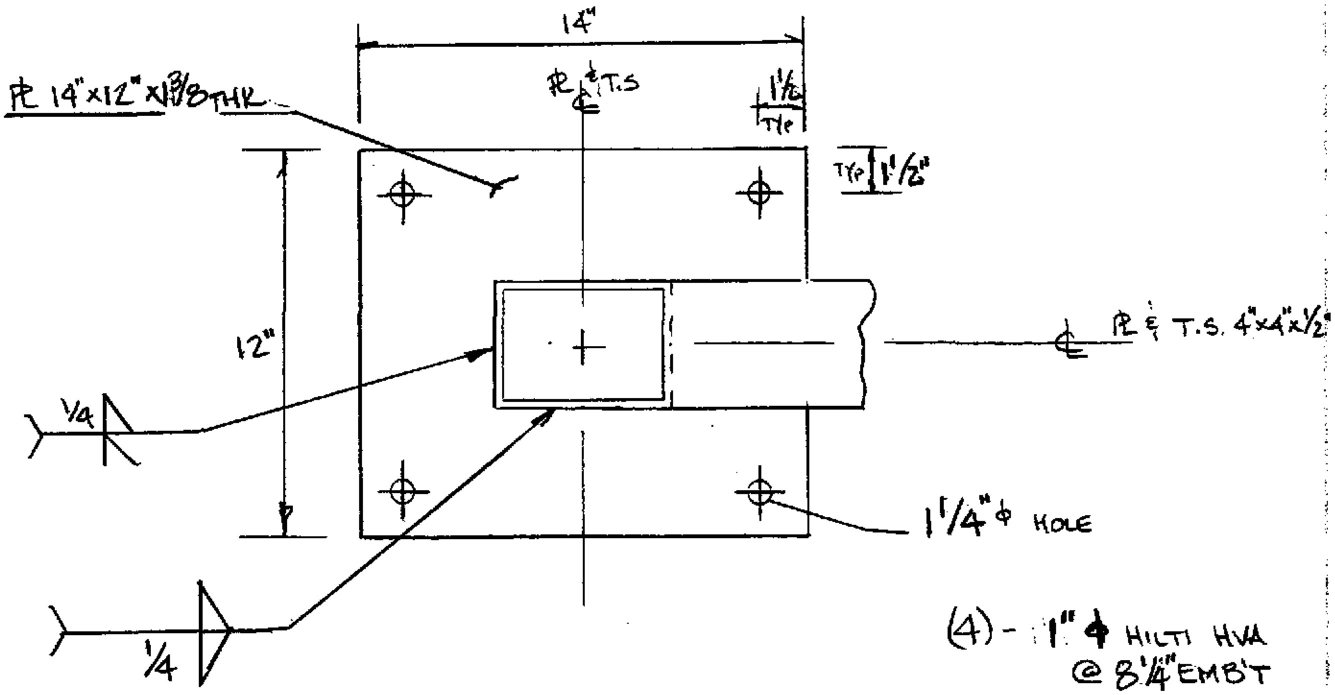
ANCHOR



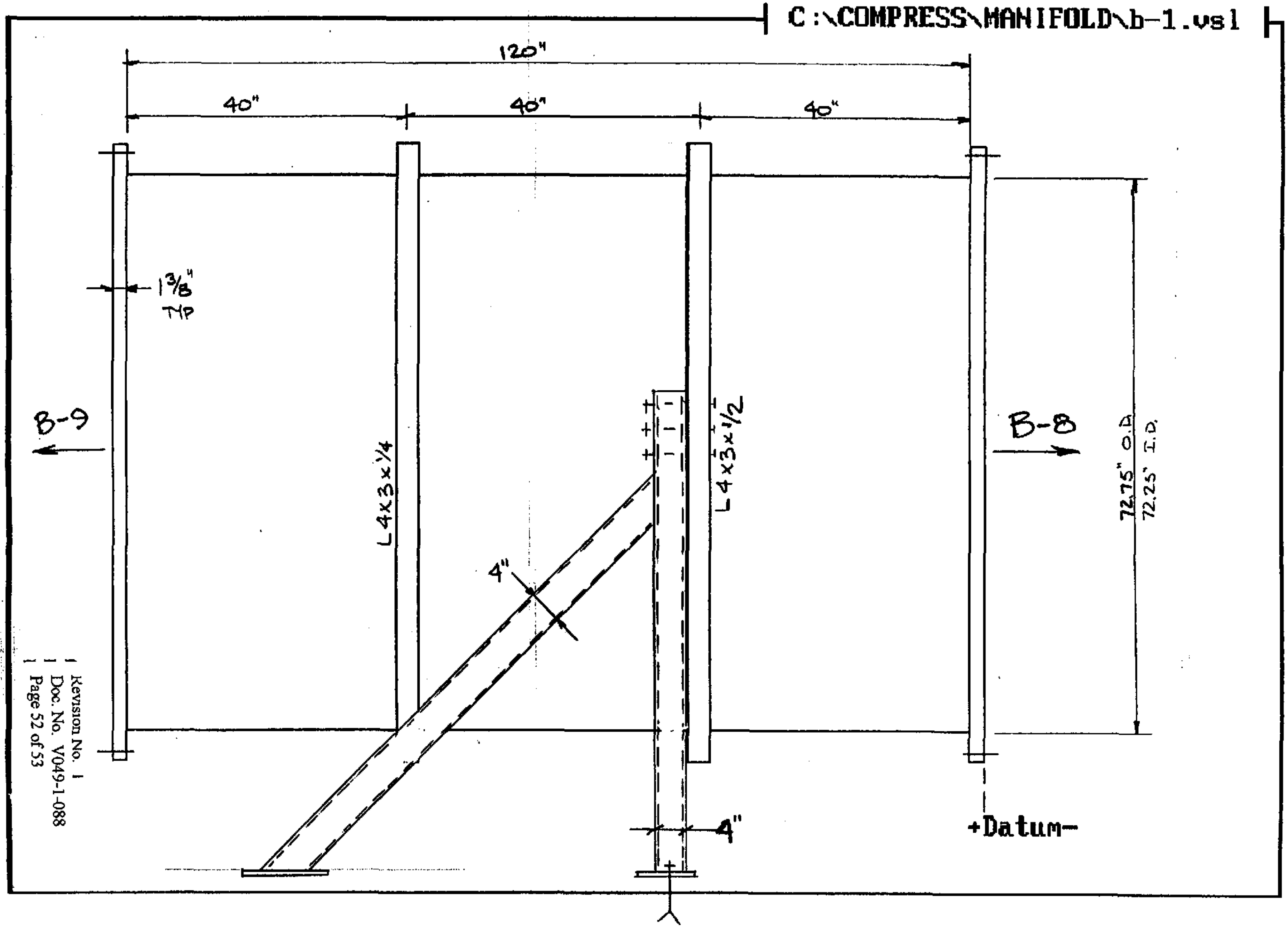
SECTION E-E

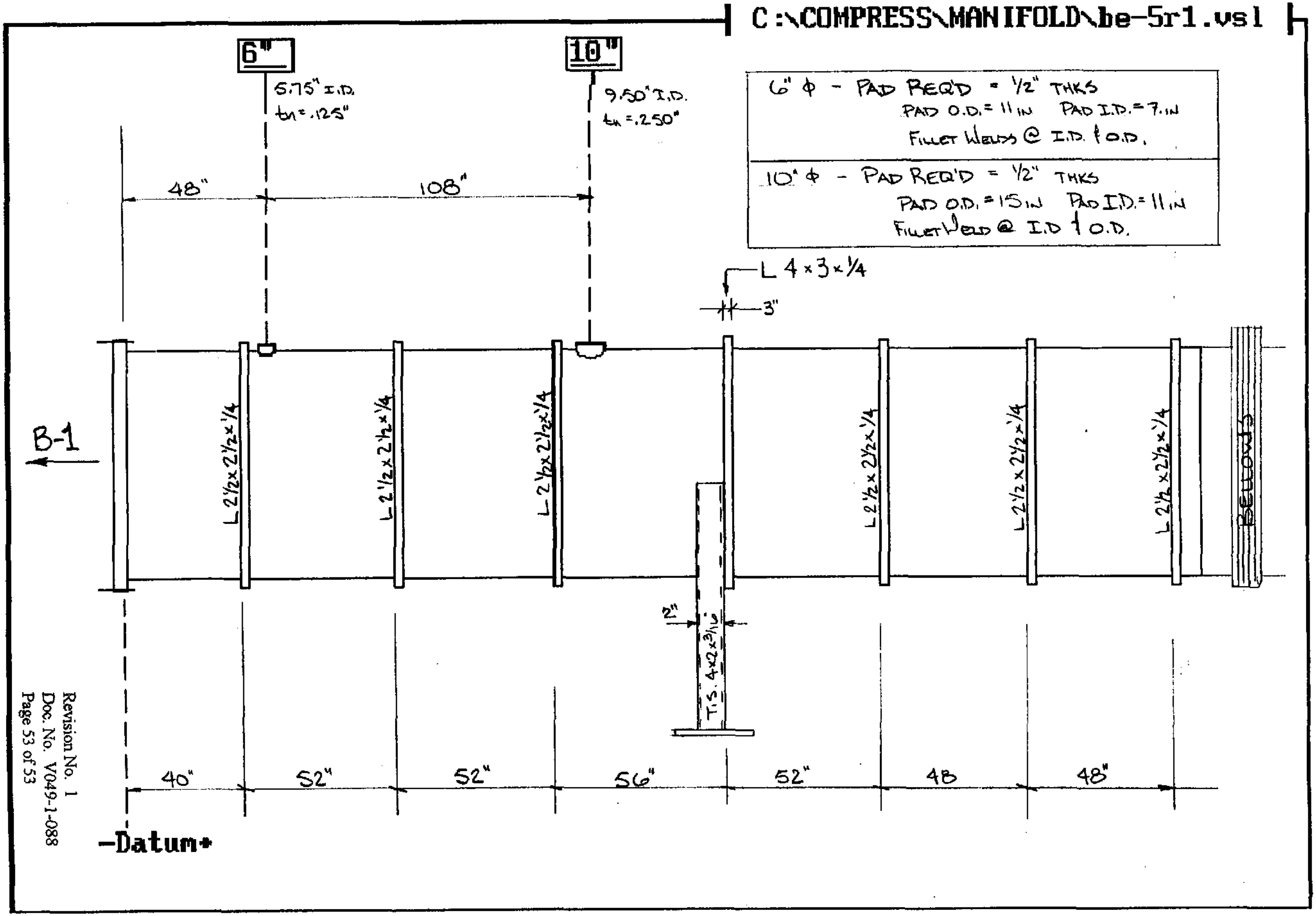


SECTION D-D



SECTION B-B


C:\COMPRESS\MANIFOLD\b-1.vsl
120"
40"
40"
40"
1 3/8" TYP
B-9
B-8
L 4x3x1/4
L 4x3x1/2
4"
4"
72.75" O.D
72.25" I.D.
+Datum-



6" φ - PAD REQ'D = 1/2" THKS
PAD O.D. = 11 IN PAD I.D. = 7. IN
FILLET WELDS @ I.D. & O.D.

10" φ - PAD REQ'D = 1/2" THKS
PAD O.D. = 15 IN PAD I.D. = 11 IN
FILLET WELD @ I.D & O.D.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-089
PAGE 1 OF 49

REV.	DEO #	DATE	BY:	CHECK
0	0139	4/24/96	WDB	AGR
1	0253	9/11/96	WDB	RD ✓

TITLE:
Design of Generic Support Scheme for;
Beam Tube Manifold B-9

BY: W. Bilynsky
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. The purpose of this calculation is to design a generic support scheme for the B-9 Beam Tube Manifold (BTM). The design of BTM B-9 is governed by the thermal axial growth which occurs during "bakeout" conditions and the unbalanced vacuum load due to the disparity of bellows at A-1 and. BE-5. The support scheme for BTM B-9 is made up of one anchor and one flexible support

METHOD: Thermal growth is one of the governing design factors. Therefore, support locations were established using a maximum displacement of 1/2" at the flex support. Additionally, the bellows at BE-5 is limited to an overall displacement of +/- 2-1/2". A STAAD model of BTM B-9 was generated and used for design. Baseplates, anchor bolts and thru-bolted connections were designed using AISC standards and STAAD computer output. Load cases included; DW, Thermal, Vacuum and Seismic (static g load). DW included the weight of the vessel and its flanges, Thermal included a temperature load along the length of the vessel, Vacuum loads occur due to the difference in size of bellows spool pieces at A-1 & BE-5

ASSUMPTIONS Assume anchor points are fixed but released for Mz (about the out-of-plane moment)

INPUTS: Vessel wght = 6437.0 lb.
Seismic Acceleration = 0.05625 g.
Unbalanced vacuum load = 38.13 kips
Flange wght = 1539.0 lb.

REFERENCES:
1. STAAD-III release 21, Research Engineers
2. ASD - AISC 9th edition
3. Doc. No. V049-1-066 - LIGO Vacuum Equipment Structural Design Criteria
4. COMPRESS - Computer Aided Vessel Design version 5.53

CALCULATIONS:

V049-1- 088	Design of Generic Support Scheme for Beam Tube Manifold BE-5
V049-1- 061	Beam Tube Manifold B9
V049-1- 032	Component Interface Loads
V049-1- 042	Bolted Flange Analysis for Tensile Forces

CONCLUSIONS: The requirements of the AISC Code and the LIGO Vacuum Equipment Structural Design Criteria are met.

NOTES: STAAD-III Computer file: B9BTMR1.*

TABLE OF CONTENTS

REVISION HISTORY

Rev. 0 Original Issue

April 24, 1996

Rev. 1 Issue Date

September 17, 1996

- Added unbalanced vacuum axial load.
- Released moments at pinned connections to stiffener ring in STAAD model.
- Revised Structural Tube Steel members from 4" x 2" x 5/16" thk to 4" x 4" x 1/2" thk.
- Checked for punching shear using STAAD analysis.
- Revised body of calc to reflect changes due to new vacuum load.
- Added additional weld calculations to calculation text.
- Revised design details to reflect change in members.
- Revised stiffener/support ring to 4" x 3" x 1/2"

DISCUSSION

Beam Tube Manifold (B-9)

Support Scheme

Step 1 - B-9 due to its length which includes portions of BE-5 and A-1 experiences a large overall thermal growth. Anchorage was preferred at midspan but due to the potential large thermal displacements, an optimum location for anchors and flexible supports was required.

Step 2 - Flexible supports were located based on max allowable displacement (due to thermal growth). A maximum allowable displacement of 1/2" was established. This in turn determined the maximum spacing between anchor and flexible support.

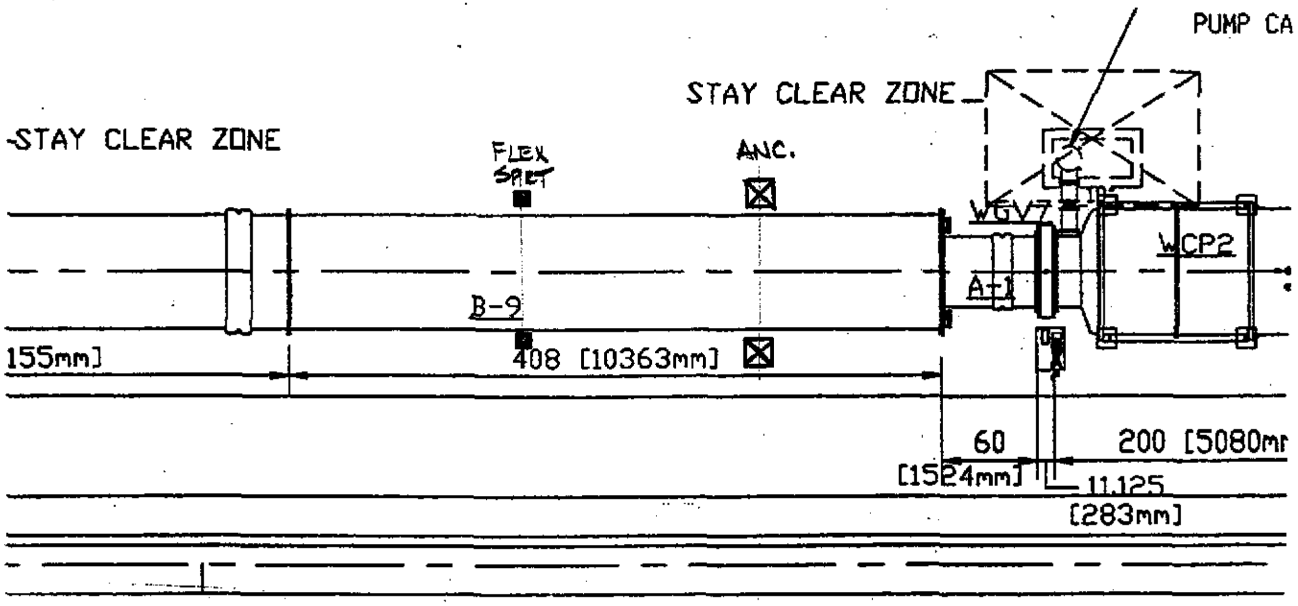
Step 3 - A finite element model which includes the properties of the beam tube manifold shell and the support frame was generated using the STAAD structural design computer program.

Step 4 - Applicable loading conditions were determined. These included; deadweight for vessel and flanges, uniform thermal load for the Beam Tube Manifold, and seismic factors. Additionally, an unbalanced vacuum load acts on the Beam Tube Manifold due to the disparity of bellows at A-1 and BE-5.

Step 5 - Computer output results were evaluated.

Step 6 - Using computer generated forces and reactions, anchors, baseplates, bolted connections (support legs to vessel stiffener rings), and welded connections were designed.

BEAM TUBE MANIFOLD B-9



DETERMINE SPAN LENGTH - ANCHOR TO FLEX SUPPORT

1. Calculate Max Allowable Displacement (δ_{max})
   ASSUME STIFFENER RING RESTRAINS AGAINST ROTATION

$$fb = \frac{M_y}{S_y} \Rightarrow M_y = \frac{6EI_y\delta}{L^2}$$

FOR MEMBER FIXED AT BOTH ENDS

ref. GERE & WEAVER TABLE B-4

$$M_y = fb(S_y) \leftarrow \text{TS } 4 \times 2 \times 3/16$$

$$\frac{6EI_y\delta}{L^2} = fb(S_y)$$

$$\therefore \delta_{max} = \frac{fb(S_y)(L)^2}{6EI_y}$$

$$\delta_{max} = \frac{.6(36000\#/\text{in}^2)(1.29\,\text{in}^3)(70\,\text{in})^2}{6(29E06\#/\text{in}^2)(1.29\,\text{in}^4)} = 0.608 \text{ IN.}$$

$\delta_{max} = 0.608 in$

LIMIT MAX DISPLACEMENT TO 0.50 IN. (@ FLEX SUPPORT)

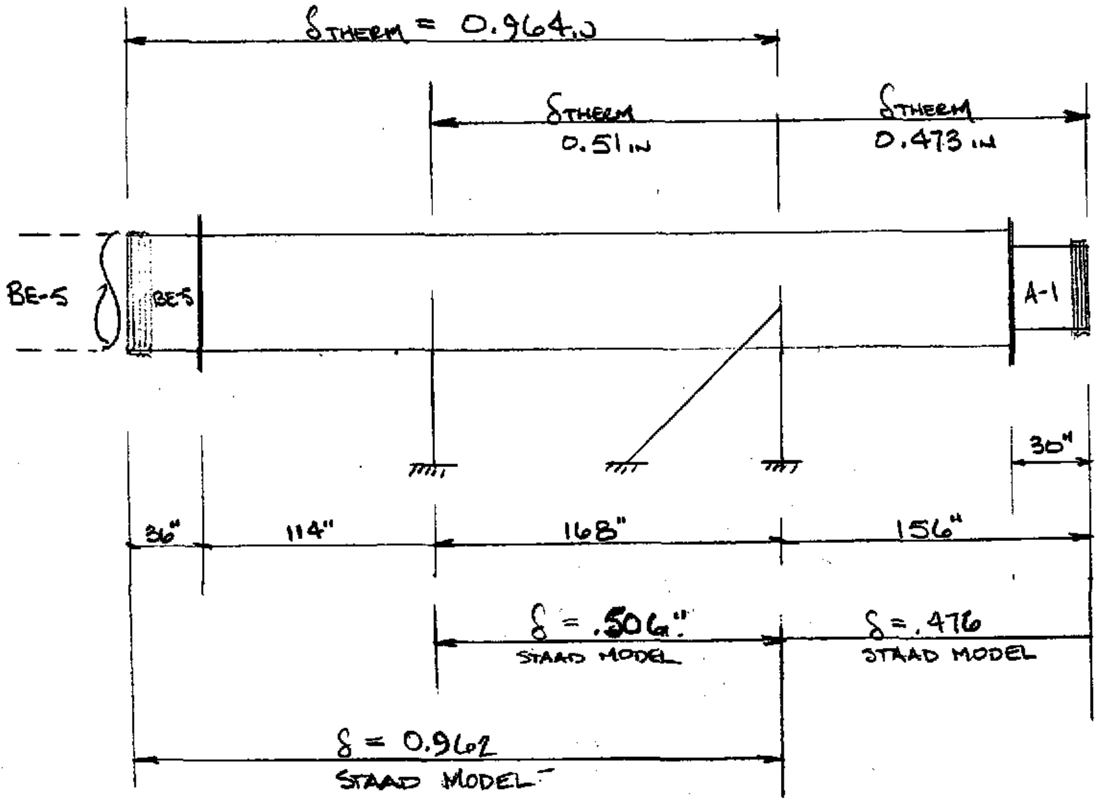
THERFORE, MAX SPAN;

$$L_{MAX} = \frac{\delta_{max}}{\alpha \ \Delta T} = \frac{.50 IN}{(9.19 \times 10^{-6} IN/IN^{\circ}F)(330^{\circ}F)}$$

$$L_{MAX} = 165 IN.$$

MANIFOLD B-9 - SUPPORT WAS LOCATED AS CLOSE TO MIDSPAN AS POSSIBLE. MANIFOLD B-9 INCLUDES 1/2 OF ADAPTER A-1 (30" LONG) AND THE BELLOWS PORTION OF BE-5 (36" LONG).

ANCHOR LOCATION WAS CHOSEN TO ALLOW THERMAL GROWTH IN TWO DIRECTIONS (OPPOSITE TO ONE ANOTHER)

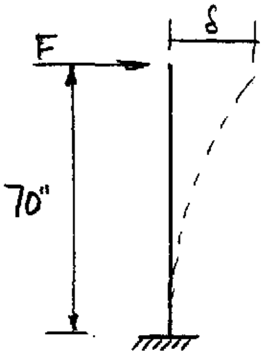


FOR FLEXIBLE SUPPORT

Max δ_{THERM} @ 168 in. Span

$$\delta_{THERM} = \alpha \ \Delta T \ L$$
$$= (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(168 \text{ IN})$$
$$= .51 \text{ IN.}$$

EQUIVALENT STATIC FORCE DUE TO THERMAL DISPLACEMENT



T.S. 4 x 2 x 3/16

$$I_y = 1.29 \text{ IN}^4$$

$$\delta = \frac{P L^3}{3 E I_y} \Rightarrow P = \frac{(\delta) 3 E I_y}{L^3}$$

$$F = P = \frac{\delta \ (3)(29E6 \text{ lb/IN}^2)(1.29 \text{ IN}^4)}{(70 \text{ IN})^3}$$

@ $\delta = 0.509$ IN

$P = 167$ lbs. ($P \cong 160.$ lbs STAAD MODEL)

Max δ_{THERM} @ A-1 BELLOWS

$$\delta_{THERM} = \alpha \ \Delta T \ L$$
$$= (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(156 \text{ IN})$$
$$= 0.473 \text{ IN}$$

($\delta = 0.476$ STAAD MODEL)

Max δ_{THERM} @ BE-5 BELLOWS

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(318 \text{ IN.})$$
$$= 0.964 \text{ IN}$$

($\delta = 0.962"$ STAAD MODEL)