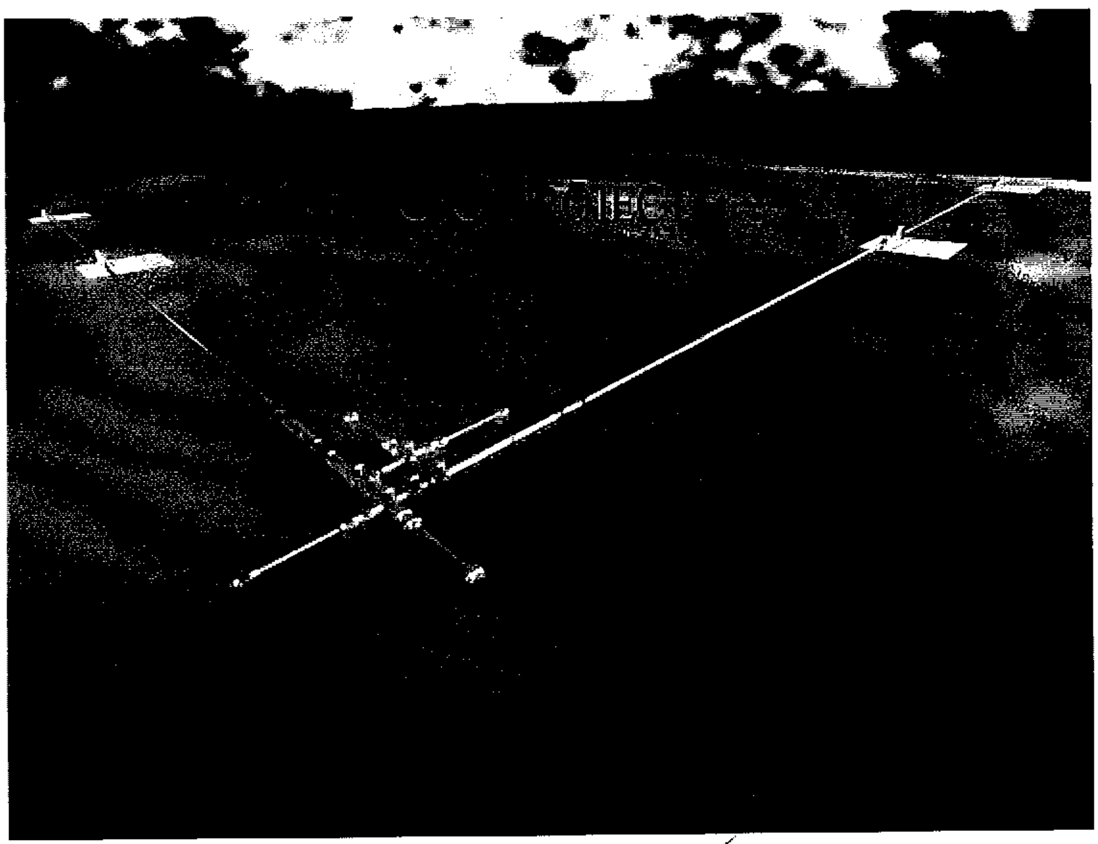
LIGO VACUUM EQUIPMENT FINAL DESIGN REPORT

VOLUME II ATTACHMENT 3 - CALCULATIONS

CONTRACT NO: PC175730

CDRL NO: 03

PSI DOCUMENT NO: V049-1-097



CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO PROJECT

PROCESS SYSTEMS INTERNATIONAL
20 WALKUP DRIVE
WESTBOROUGH, MASSACHUSETTS 01581

VOLUME II ATTACHMENTS
ATTACHMENT 3

I. STRUCTURAL CALCULATIONS

TITLE	DOCUMENT NO.	REV.
Spool B-5 (30 in)	V049-1-057	0
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-2 (60 in)	V049-1-050	0
Spool BE-3 & BE-3A(60 in)	V049-1-049	0
Spool BE-4 (44 in)	V049-1-076	0
Spool BE-5 (44 in)	V049-1-085	0
Generic Spool Design	V049-1-077	0
Supports		
Design of Flexible Support for Adapter A-7	V049-1-062	0
Design of Gate Valve Support	V049-1-086	0
Support Design for Mode Cleaner Tubes (B-5)	V049-1-087	0
Support Design for Beam Tube Manifold (BE-5)	V049-1-088	0
Support Design for Beam Tube Manifold (B-9)	V049-1-089	0
Support Design for Beam Tube Manifold (B-6/B-7)	V049-1-095	0
Turbo Cart Frame Extension	V049-1-098	0

TITLE	DOCUMENT NO.	REV.
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	0

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-057 PAGE 1 OF 56
REV.	DEO #	DATE	BY:	CHECK	TITLE:	
0	0131	4/19/96	WDB	RDC	SPOOL B-5 (30 in)	
					BY: WD [signature]	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

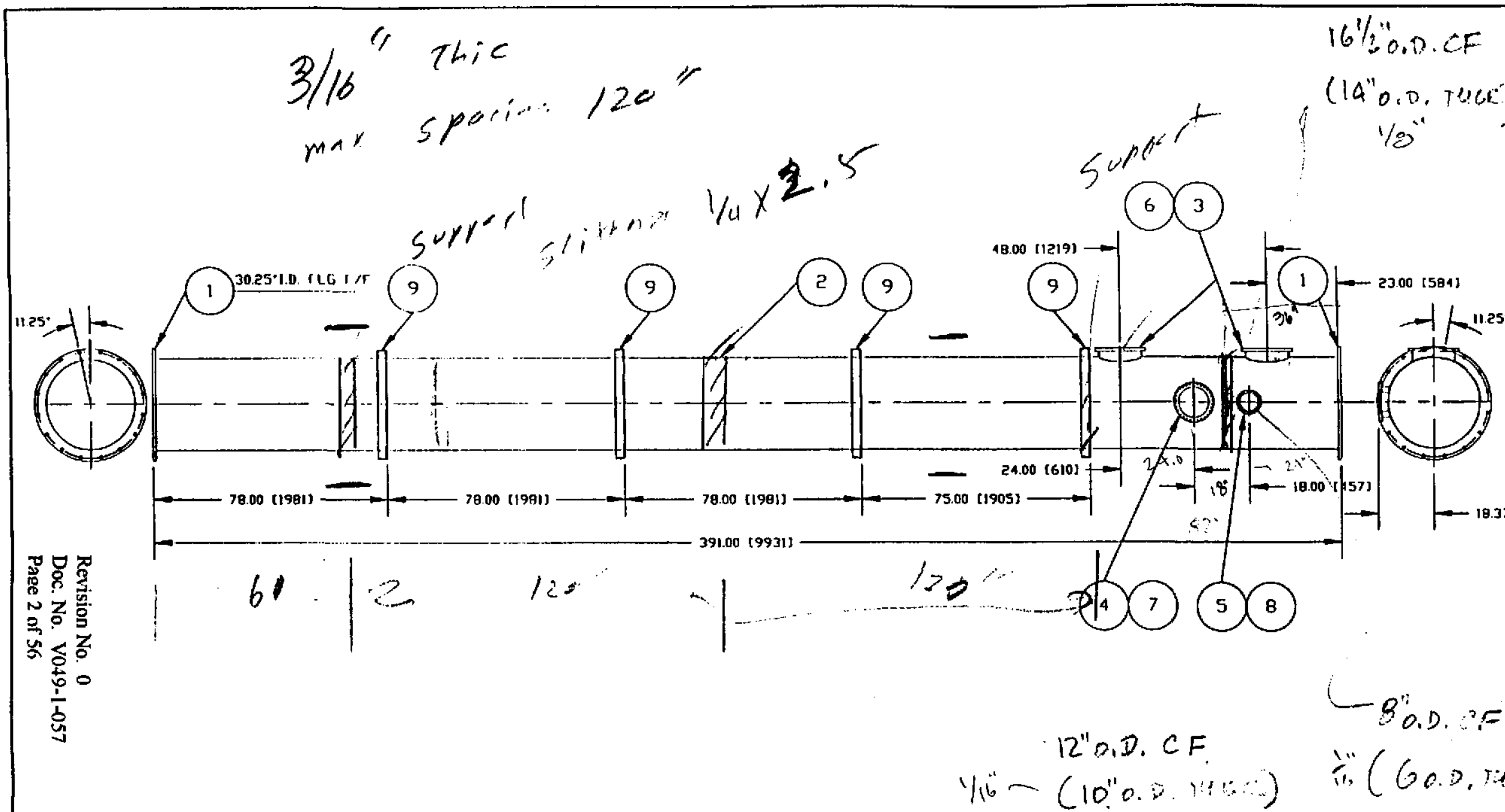
Pr = 2250.0 lbs
Mc = Ml = 4542.0 in-lbs
Vc = Vl = 126.5 lbs

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. V049-1-066, LIGO Vac. Equip. Struct. Design Criteria

CALCULATIONS: (SEE ATTACHED)

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



Revision No. 0
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PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

DO NOT SCALE THIS DWG

USED ON

NEXT ASS'Y

REV	DESCRIPTION	CHKD	DRVN	DATE	DEO
	ISSUE DESCRIPTION				

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

SPOOL B-5
30"
LIGO VACUUM EQUIPMENT

CAD FILE	SIZE	DWG NO.	REV.
B5	B	V049-4-B5	0
SCALE 3/8"=1'-0"		SHEET 1 OF 1	

Dec 19, 1995 - 104622

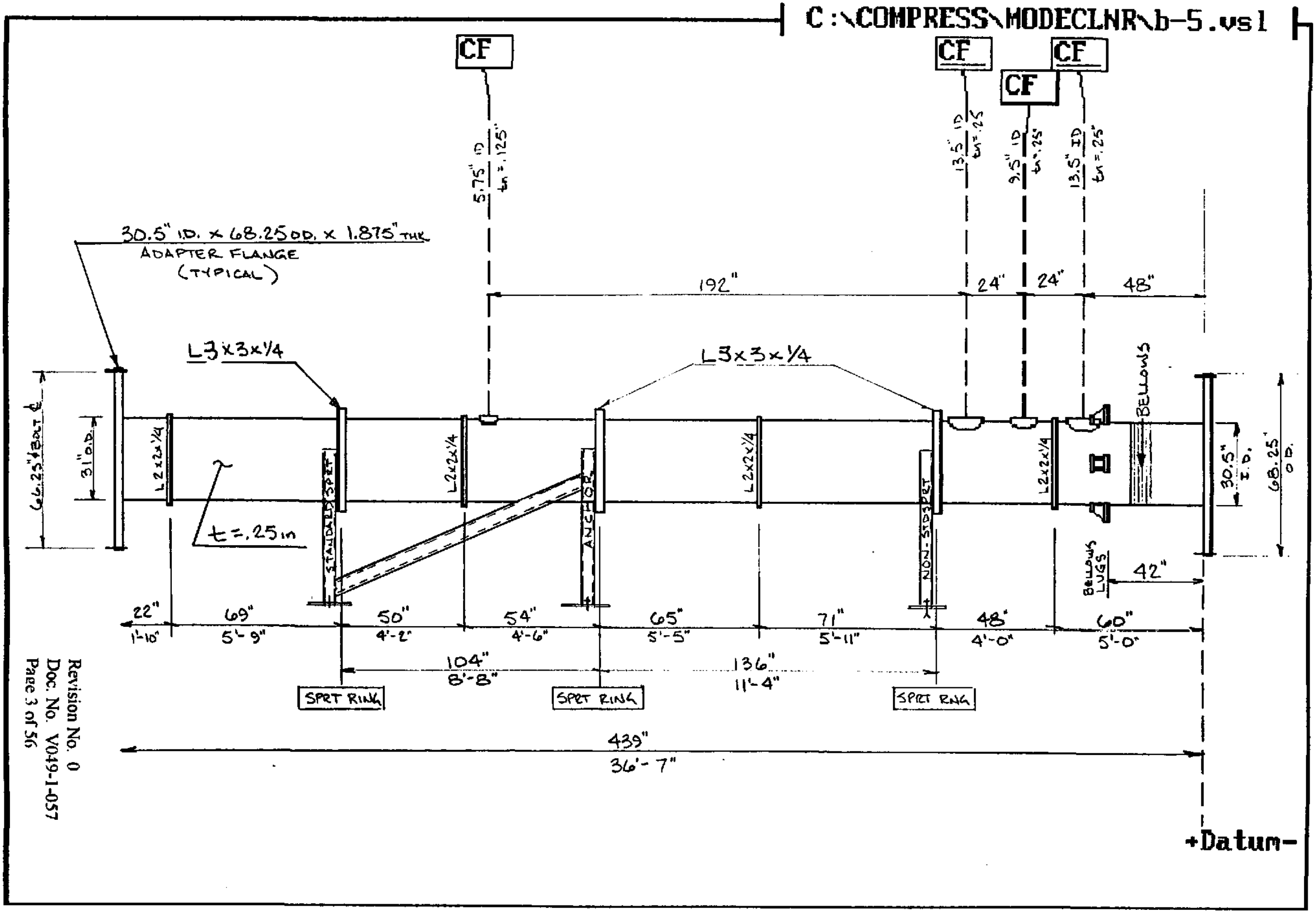
C:\COMPRESS\MODECLNR\b-5.vsl
CF
CF
CF
CF
5.75" ID
tn=.125"
13.5" ID
tn=.25
9.5" ID
tn=.25
13.5" ID
tn=.25
30.5" I.D. x 68.25 OD. x 1.875" THK
ADAPTER FLANGE
(TYPICAL)
192"
24"
24"
48"
L3x3x1/4
L3x3x1/4
BELLOWS
66.25" BOLT ℄
31" O.D.
L2x2x1/4
L2x2x1/4
L2x2x1/4
L2x2x1/4
t=.25in
STANDARD SPRT
ANCHOR
NON-STD SPRT
30.5" I.D.
68.25" O.D.
BELLOWS LUGS
42"
22"
1'-10"
69"
5'-9"
50"
4'-2"
54"
4'-6"
65"
5'-5"
71"
5'-11"
48"
4'-0"
60"
5'-0"
104"
8'-8"
136"
11'-4"
SPRT RING
SPRT RING
SPRT RNG
439"
36'-7"
+Datum-

TABLE OF CONTENTS

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-5	0.0	0.0	230.4	230.4	51.5	1.000		Not applicable	0.000
CF 16-1/2" od	0.0	0.0	148.2	148.1	14.7	1.000		Not applicable	0.000
CF 16-1/2" o.d.	0.0	0.0	148.2	148.1	14.7	1.000		Not applicable	0.000
CF 8"od CF	0.0	0.0	136.2	136.2	14.7	1.000		Not applicable	0.000
CF 12"od CF	0.0	0.0	154.4	154.4	14.7	1.000		Not applicable	0.000
Stiffner Rings					14.7				
Support Rings					14.7				
Support Ring					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	10.2	10.2		1.000		Not applicable	0.000

Vessel MAWP hot & corroded is 10.26 psi @ 0 degrees F.

Vessel MAP new & cold is 10.26 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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
Spool b-5	3075	3075	0	0	0	0	0	0	239	0	11580	24
Whan-5 end conn	1539	1539	0	0	0	0	0	0	0	0	0	0
Whan-6 end conn	1539	1539	0	0	0	0	0	0	0	0	0	0
	6153	6153	0	0	0	0	0	0	239	0	11580	24

Weight (lbs) Contributed by Vessel Elements

Vessel operating weight, corroded:	6,416 lbs
Vessel empty weight, corroded:	6,416 lbs
Vessel empty weight, new:	6,416 lbs
Vessel test weight, new:	17,996 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	6,416 lbs
Center of gravity to seam:	219.4 in

Nozzle Summary

Nozzle mark	OD (in)	tn (in)	Req tn (in)	A1?	A2?	Nom t (in)	Req t (in)	User t (in)	Corr (in)	Aa/Ar (%)
CF	14.00	0.2500	0.1361	y	y	0.2500	0.1446	0.2500	0.0000	100.0
CF	14.00	0.2500	0.1361	y	y	0.2500	0.1446	0.2500	0.0000	100.0
CF	6.00	0.1250	0.1250	y	y	0.2500	0.1446	0.2500	0.0000	117.6
CF	10.00	0.2500	0.1418	y	y	0.2500	0.1446	0.2500	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
CF	16-1/2" od	13.50 IDx0.25	SA 240 304L HIGH	n	n				
CF	16-1/2" o.d.	13.50 IDx0.25	SA 240 304L HIGH	n	n				
CF	8"od cf	5.75 IDx0.12	SA 240 304L HIGH	n	n				
CF	12"od cf	9.50 IDx0.25	SA 240 304L HIGH	n	n				

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (in)
Spool b-5	30.50	439.00	0.2500	0.1446	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-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 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

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

L/Do = 71/31 =2.2903 Do/t = 31/0.14461 = 214.3697
From table G: A = 0.000181
From table HA-3: B = 2382.1

Pa= 4*B/(3*Do/t)
= 4*2382.1/(3*31/0.14461)
= 14.8162 psi

Design thickness for external pressure Pa = 14.8162 psi:

= t + Corrosion
= 0.14461 + 0
= 0.14461 in

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

L/Do = 71/31 =2.2903 Do/t = 31/0.25 = 124
From table G: A = 0.000404
From table HA-3: B = 4791.6

Spool B-5

Pa= 4*B/(3*Do/t)
 = 4*4791.6/(3*31/0.25)
 = 51.5226 psi

16-1/2" od

Opening CF 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 ->| |
twl->| |<        | |
     |/| |  v    | |\
-----.-| |--     | |-.-----
------\|_|_tw2   |_|/------
          ^
<---- L ---->|
```

```
corrosion allow = 0 in
noz thick new tn= .25 in
nozzle id. new d= 13.5 in
fillet weld twl = .25 in
groove weld tw2 = .1875 in

To datum L= 48 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)
= 148.293*6.75/(16700*1 - 0.6*148.293)
= 0.0603 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 148.293*15.25/(16700*1 - 0.6*148.293)
= 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 MAWP = 148.293 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 = 0.0603 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 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*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).

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

16-1/2" od

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 148.1006*6.75/(16700*1 - 0.6*148.1006)
= *0.0602 in*

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 148.1006*15.25/(16700*1 - 0.6*148.1006)
= 0.136 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*0.136*1 + 2*0.25*0.136*1*(1 - 1)
= 1.836 in^2

Area available

A1 = larger of the following = 1.539 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.136) - 2*0.25*(1*0.25-1*0.136)*(1-1)
= 1.539 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*0.136) - 2*0.25*(1*0.25-1*0.136)*(1-1)
= .114 in^2

A2 = smaller of the following = 0.237 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0602)*1*0.25
= .237 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0602)*1*0.25
= .237 in^2

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

Area = A1 + A2 + A41
= 1.539 + 0.237 + 0.063
= 1.839 in^2

As Area > A the reinforcement is adequate for MAP = 148.1006 at 0 Deg F

16-1/2" od

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 = 0.0602 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.136 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 = 0.136 in
The lesser of tr4 or tr5:	tr6 = 0.136 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.136 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
 = (1.836 - (13.5 - 2*0.25)*(1*0.25 - 1*0.136))*16700
 = 5911.801 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 = 5911.801 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).

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) = .1446 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*0.1446*1 + 2*0.25*0.1446*1*(1 - 1))
= .9761 in^2

Area available

A1 = larger of the following = 1.423 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= 1.423 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*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= .105 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
= 1.423 + 0.276 + 0.063
= 1.762 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.

16-1/2" od

Applied Loads

Radial load	Pr = 2250 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

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

Maximum combined stress =-19254 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-3663 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

16-1/2" od

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	1.5557	0.398					-911	-911	-911	-911
4C*	4.3911	0.398	-2570	-2570	-2570	-2570				
1C	0.0648	0.398					-13997	13997	-13997	13997
2C-1	0.0065	0.398	-1404	1404	-1404	1404				
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*										
Total circ stress			-5019	-1087	-2929	-1245	-19254	16898	-10562	9274
Primary membrane circ stress*			-3053	-3053	-2087	-2087	-1178	-1178	-644	-644
3C*	1.5557	0.398	-911	-911	-911	-911				
4C*	4.3911	0.398					-2570	-2570	-2570	-2570
1C-1	0.0160	0.398	-3456	3456	-3456	3456				
2C	0.0300	0.398					-6480	6480	-6480	6480
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*										
Total long stress			-5771	3391	-2963	1699	-11759	4433	-6341	3387
Primary membrane long stress*			-1190	-1190	-632	-632	-3663	-3663	-1477	-1477
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			-5772	4478	-2975	2944	-19254	16898	-10562	9274

16-1/2" o.d.

Opening CF 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 ->| |
twl->|  |<|       | |
     |/ | |  v    | |\
-----.- | |  -    | |-.-----
-----\|_|_|_tw2   |_|/-----
             ^
<--- L --->|
```

```
corrosion allow = 0 in
noz thick new tn= .25 in
nozzle id. new d= 13.5 in
fillet weld twl = .25 in
groove weld tw2 = .1875 in

To datum L= 96 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)
= 148.293*6.75/(16700*1 - 0.6*148.293)
= 0.0603 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 148.293*15.25/(16700*1 - 0.6*148.293)
= 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

16-1/2" o.d.

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 = 148.293 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 = 0.0603 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 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*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).

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

16-1/2" o.d.

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 148.1006*6.75/(16700*1 - 0.6*148.1006)
= 0.0602 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 148.1006*15.25/(16700*1 - 0.6*148.1006)
= 0.136 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*0.136*1 + 2*0.25*0.136*1*(1 - 1)
= 1.836 in^2

Area available

A1 = larger of the following = 1.539 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.136) - 2*0.25*(1*0.25-1*0.136)*(1-1)
= 1.539 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*0.136) - 2*0.25*(1*0.25-1*0.136)*(1-1)
= .114 in^2

A2 = smaller of the following = 0.237 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0602)*1*0.25
= .237 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0602)*1*0.25
= .237 in^2

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

Area = A1 + A2 + A41
= 1.539 + 0.237 + 0.063
= 1.839 in^2

As Area > A the reinforcement is adequate for MAP = 148.1006 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 = 0.0602 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.136 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 = 0.136 in
The lesser of tr4 or tr5:	tr6 = 0.136 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.136 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
= (1.836 - (13.5 - 2*0.25)*(1*0.25 - 1*0.136))*16700
= 5911.801 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 = 5911.801 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).

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) = .1446 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*0.1446*1 + 2*0.25*0.1446*1*(1 - 1))
= .9761 in^2

Area available

A1 = larger of the following = 1.423 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.5*(1*0.25-1*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= 1.423 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*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= .105 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
= 1.423 + 0.276 + 0.063
= 1.762 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.

16-1/2" o.d.

Applied Loads

Radial load	Pr = 2250 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

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

Maximum combined stress =-19254 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-3663 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

16-1/2" o.d.

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	1.5557	0.398					-911	-911	-911	-911
4C*	4.3911	0.398	-2570	-2570	-2570	-2570				
1C	0.0648	0.398					-13997	13997	-13997	13997
2C-1	0.0065	0.398	-1404	1404	-1404	1404				
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*										
Total circ stress			-5019	-1087	-2929	-1245	-19254	16898	-10562	9274
Primary membrane circ stress*			-3053	-3053	-2087	-2087	-1178	-1178	-644	-644
3C*	1.5557	0.398	-911	-911	-911	-911				
4C*	4.3911	0.398					-2570	-2570	-2570	-2570
1C-1	0.0160	0.398	-3456	3456	-3456	3456				
2C	0.0300	0.398					-6480	6480	-6480	6480
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*										
Total long stress			-5771	3391	-2963	1699	-11759	4433	-6341	3387
Primary membrane long stress*			-1190	-1190	-632	-632	-3663	-3663	-1477	-1477
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			-5772	4478	-2975	2944	-19254	16898	-10562	9274

8"od CF

Opening CF 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:	90 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 ->|    | |
twl->|  | |<       |    | |
     |/ | |  v     |    | |\
_____.-| |  _      |    | |-._____
_____\|_|_|_tw2    |_|/______
             ^
<---- L ---->|
```

```
corrosion allow = 0 in
noz thick new tn= .125 in
nozzle id. new d= 5.75 in
fillet weld twl = .25 in
groove weld tw2 = .1875 in

To datum L= 288 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)
= 136.2469*2.875/(16700*1 - 0.6*136.2469)
= 0.0236 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 136.2469*15.25/(16700*1 - 0.6*136.2469)
= 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

8"od CF

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 5.75*0.125*1 + 2*0.125*0.125*1*(1 - 1)
= .7188 in^2

Area available

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

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
= 0.719 + 0.063 + 0.063
= .845 in^2

As Area > A the reinforcement is adequate for MAWP = 136.2469 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 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*0.25*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

(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
= (0.7188 - (5.75 - 2*0.125)*(1*0.25 - 1*0.125))*16700
= 522.7101 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 = 522.7101 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 = 522.7101 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 Nozzle MAP

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

8"od CF

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
 = 136.2634*2.875/(16700*1 - 0.6*136.2634)
 = 0.0236 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
 = 136.2634*15.25/(16700*1 - 0.6*136.2634)
 = 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)
 = 5.75*0.125*1 + 2*0.125*0.125*1*(1 - 1)
 = .7188 in^2

Area available

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

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
 = 0.719 + 0.063 + 0.063
 = .845 in^2

As Area > A the reinforcement is adequate for MAP = 136.2634 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

(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
= (0.7188 - (5.75 - 2*0.125)*(1*0.25 - 1*0.125))*16700
= 522.7101 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 = 522.7101 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 = 522.7101 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 = 5.75 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

L/Do = 2.625/6 = .4375 Do/t = 6/0.01409 = 425.8339
From table G: A = 0.000361
From table HA-3: B = 4697.7

Pa= 4*B/(3*Do/t)
= 4*4697.7/(3*6/0.01409)
= 14.709 psi

Nozzle required thickness trn = .01409 in

Required thickness tr from UG-37(d)(1) = .1446 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*0.1446*1 + 2*0.125*0.1446*1*(1 - 1))
= .4157 in^2

Area available

A1 = larger of the following = .606 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.1446) - 2*0.125*(1*0.25-1*0.1446)*(1-1)
= .606 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*0.1446) - 2*0.125*(1*0.25-1*0.1446)*(1-1)
= .079 in^2

A2 = smaller of the following = 0.069 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.125 - 0.01409)*1*0.25
= .139 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.125 - 0.01409)*1*0.125
= .069 in^2

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

Area = A1 + A2 + A41
= 0.606 + 0.069 + 0.063
= .738 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 = 0.01409 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.

12"od CF

Opening CF 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:	90 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
twl->| |<         | |               nozzle id. new d= 9.5 in
     |/|  v       | |\              fillet weld twl = .25 in
_____.-| |-       | |-._____        groove weld tw2 = .1875 in
_____\|_|_tw2     |_|/_____
          ^
<---- L ---->|                      To datum L= 72 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)
= 154.4154*4.75/(16700*1 - 0.6*154.4154)
= 0.0442 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 154.4154*15.25/(16700*1 - 0.6*154.4154)
= 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

12"od CF

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

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

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
 = 1.028 + 0.257 + 0.063
 = 1.348 in^2

As Area > A the reinforcement is adequate for MAWP = 154.4154 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 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*0.1875*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 Nozzle MAP

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"od CF

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 154.4724*4.75/(16700*1 - 0.6*154.4724)
= 0.0442 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 154.4724*15.25/(16700*1 - 0.6*154.4724)
= 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)
= 9.5*0.1418*1 + 2*0.25*0.1418*1*(1 - 1)
= 1.3471 in^2

Area available

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

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
= 1.028 + 0.257 + 0.063
= 1.348 in^2

As Area > A the reinforcement is adequate for MAP = 154.4724 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

(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 = 9.5 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 = 2.625/10 = .2625 Do/t = 10/0.02173 = 460.1933
From table G: A = 0.00056
From table HA-3: B = 5075

Pa= 4*B/(3*Do/t)
= 4*5075/(3*10/0.02173)
= 14.704 psi

Nozzle required thickness trn = .02173 in

Required thickness tr from UG-37(d)(1) = .1446 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*0.1446*1 + 2*0.25*0.1446*1*(1 - 1))
= .6869 in^2

Area available

A1 = larger of the following = 1.001 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= 1.001 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)

12"od CF

= 2*(0.25+0.25)*(1*0.25-1*0.1446) - 2*0.25*(1*0.25-1*0.1446)*(1-1)
= .105 in^2

A2 = smaller of the following = 0.285 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02173)*1*0.25
= .285 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02173)*1*0.25
= .285 in^2

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

Area = A1 + A2 + A41
= 1.001 + 0.285 + 0.063
= 1.349 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 = 0.02173 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.

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:		4
Distance first ring to datum line:		60 in
Ring spacing:		119 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 60 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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 =	56.27083 in

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*31/(0.14461 + 0.938/56.27083))
 = 2119.149

From table HA-3 (ring) A = 1.612017E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
 = (31^2*56.27083*(0.14461 + 0.938/56.27083)*1.612017E-04)/10.9
 = .1289819 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 = 56.27083 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
= 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 179 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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 =	68 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14461 + 0.938/68))
= 2157.614

From table HA-3 (ring) A = 1.640997E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*68*(0.14461 + 0.938/68)*1.640997E-04)/10.9
= .1558404 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)

Stiffner Rings

= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 68 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 298 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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/(0.14461 + 0.938/52))
= 2101.311

From table HA-3 (ring) A = 1.598576E-04

Required moment of inertia of the combined ring-shell section

Stiffner Rings

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*52*(0.14461 + 0.938/52)*1.598576E-04)/10.9
= .119202 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 417 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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

Stiffner Rings

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*31/(0.14461 + 0.938/45.5))
 = 2068.538

From table HA-3 (ring) A = 1.57388E-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*(0.14461 + 0.938/45.5)*1.57388E-04)/10.9
 = .1043174 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

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

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:		108 in
Ring spacing:		136 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 108 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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 =	59.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14461 + 1.44/59.5))
= 2024.593

From table HA-3 (ring) A = 1.540758E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*59.5*(0.14461 + 1.44/59.5)*1.540758E-04)/10.9
= .1364428 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 = 59.5 in

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

Distance to the ring neutral axis

Support Rings

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.

Calculations for ring 244 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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 =	59.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14461 + 1.44/59.5))
= 2024.593

From table HA-3 (ring) A = 1.540758E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*59.5*(0.14461 + 1.44/59.5)*1.540758E-04)/10.9
= .1364428 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)

Support Rings

= 1.1*Sqr(31*0.25)
= 3.06227 in

W = Ls = 59.5 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
= 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

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Identifier:		Support Ring
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		1
Distance first ring to datum line:		348 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 348 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.14461 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 =	59.5 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*31/(0.14461 + 1.44/59.5))
= 2024.593

From table HA-3 (ring) A = 1.540758E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (31^2*59.5*(0.14461 + 1.44/59.5)*1.540758E-04)/10.9
= .1364428 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 = 59.5 in

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

Distance to the ring neutral axis

Y2 = Ring NA + ts/2

Support Ring

= 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.

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		= 4
Angular position, first lug		= 90 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

BELLOWS LUGS

Longitudinal moment	ML =0 lbf-ft
Longitudinal shear	VL = 1604 lbf
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 = +- 25050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = 0 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

BELLOWS LUGS

From Fig.	Value read	beta	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

<table>
<tr><td colspan="5">PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA</td><td>ENGINEERING
CALCULATIONS</td><td>NO: V049-1-058
PAGE 1 OF 21</td></tr>
<tr><td>REV.</td><td>DEO #</td><td>DATE</td><td>BY:</td><td>CHECK</td><td colspan="2" rowspan="5">TITLE:

SPOOL B-6 (48 in)</td></tr>
<tr><td>0</td><td>0136</td><td>4/22/[illegible]</td><td>WDB</td><td>RDC</td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td>BY: W. Bilynsky</td><td>DEPT.: 744</td></tr>
<tr><td colspan="5"><u>PROJECT:</u> LIGO Vacuum Equipment</td><td colspan="2"><u>PROJECT NO:</u> V59049</td></tr>
</table>

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

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

<u>ASSUMPTIONS:</u> None

<u>INPUTS:</u>
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

<u>REFERENCES:</u>
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

<u>CALCULATIONS:</u> (SEE ATTACHED)

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

<u>NOTES:</u> 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

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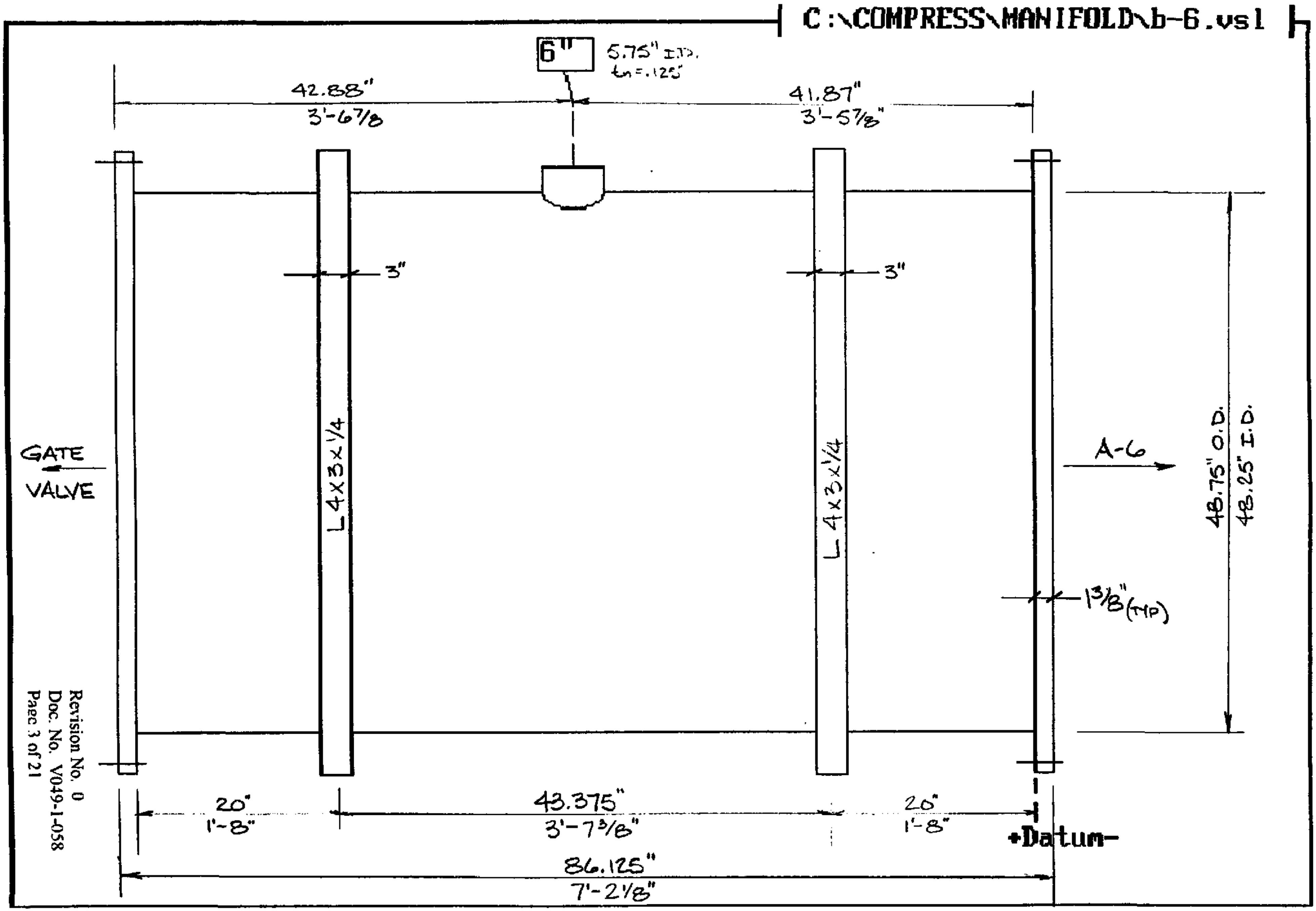

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Pressure Summary

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 New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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 mark	OD (in)	tn (in)	Req tn (in)	A1?	A2?	Nom t (in)	Req t (in)	User t (in)	Corr (in)	Aa/Ar (%)
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 mark	Service	Size	Materials Nozzle	Impact?	Norm?	Pad	Impact?	Norm?	Flange
6"	od cf	5.75 IDx0.12	SA 240 304L HIGH	n	n				

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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 ->| |<-
        _ |<- d ->| _
 twl->| | <|        | |
      |/|  v        | |\
 ____.-| | _        | |-.____
 ____\|_|_tw2       |_|/____
           ^
<--- L --->|
```

```
corrosion allow = 0 in
noz thick new tn= .125 in
nozzle id. new d= 5.75 in
fillet weld twl = .125 in
groove weld tw2 = .1875 in

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

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/(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

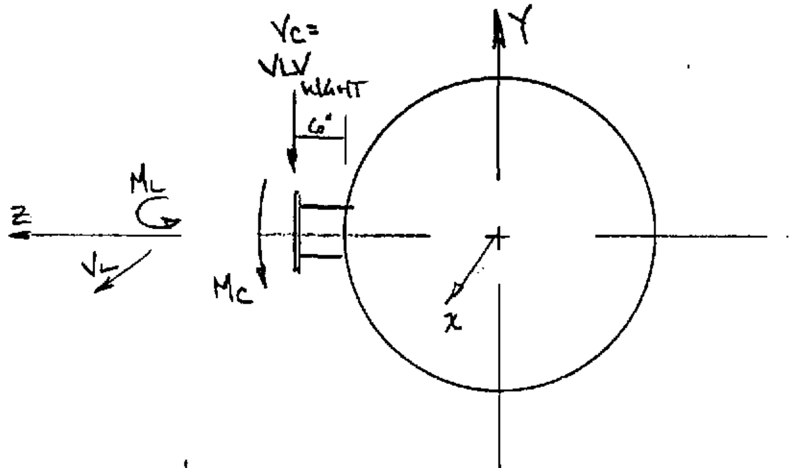
· UNBALANCED VACUUM LOAD

$$F = PA$$

$$= (14.7 \text{ \#/in}^2)(\pi (6)^2/4)$$

$$= 416 \text{ lbs.}$$

· VALVE WEIGHT < 150 lbs   USE: 150 lbs FOR DESIGN
6" NOZZLE EXTENSION



FOR WRC-107

$P_R = 416$ lbs

$V_C = 150$ lbs.

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

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

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

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-059 PAGE 1 OF 21
REV.	DEO #	DATE	BY:	CHECK	TITLE: **SPOOL B-7 (48 in)**	
0	0136	1/22/96	WDB	RDC		
					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

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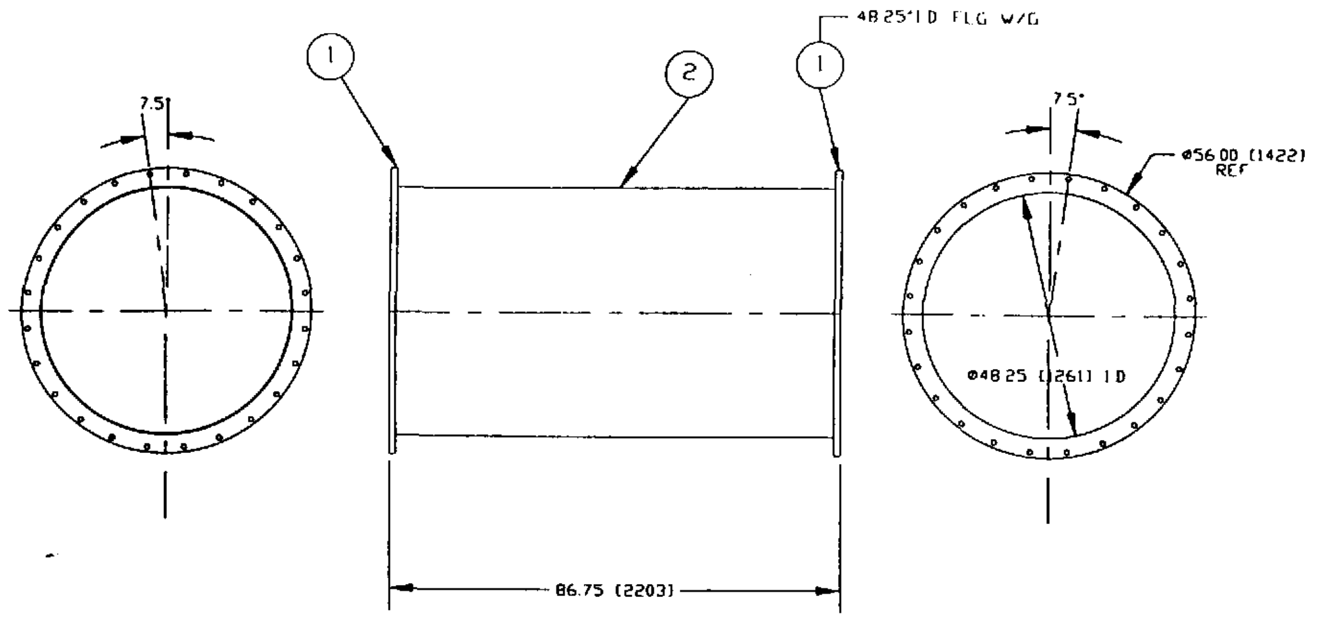

1 REQ'D

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UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± [illegible]
ANGULAR/MACH [illegible] BEND ±[illegible]
TWO PLACE DECIMAL ± [illegible]
THREE PLACE DECIMAL ± [illegible]
FINISHED SURFACE [illegible]
BREAK CORNERS [illegible] OUT
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.

USED ON:

NEXT ASS'Y:

REV	DESCRIPTION	CHKD	DRWN	DATE	DCO#
X	X	X	X	X	X

ISSUE DESCRIPTION

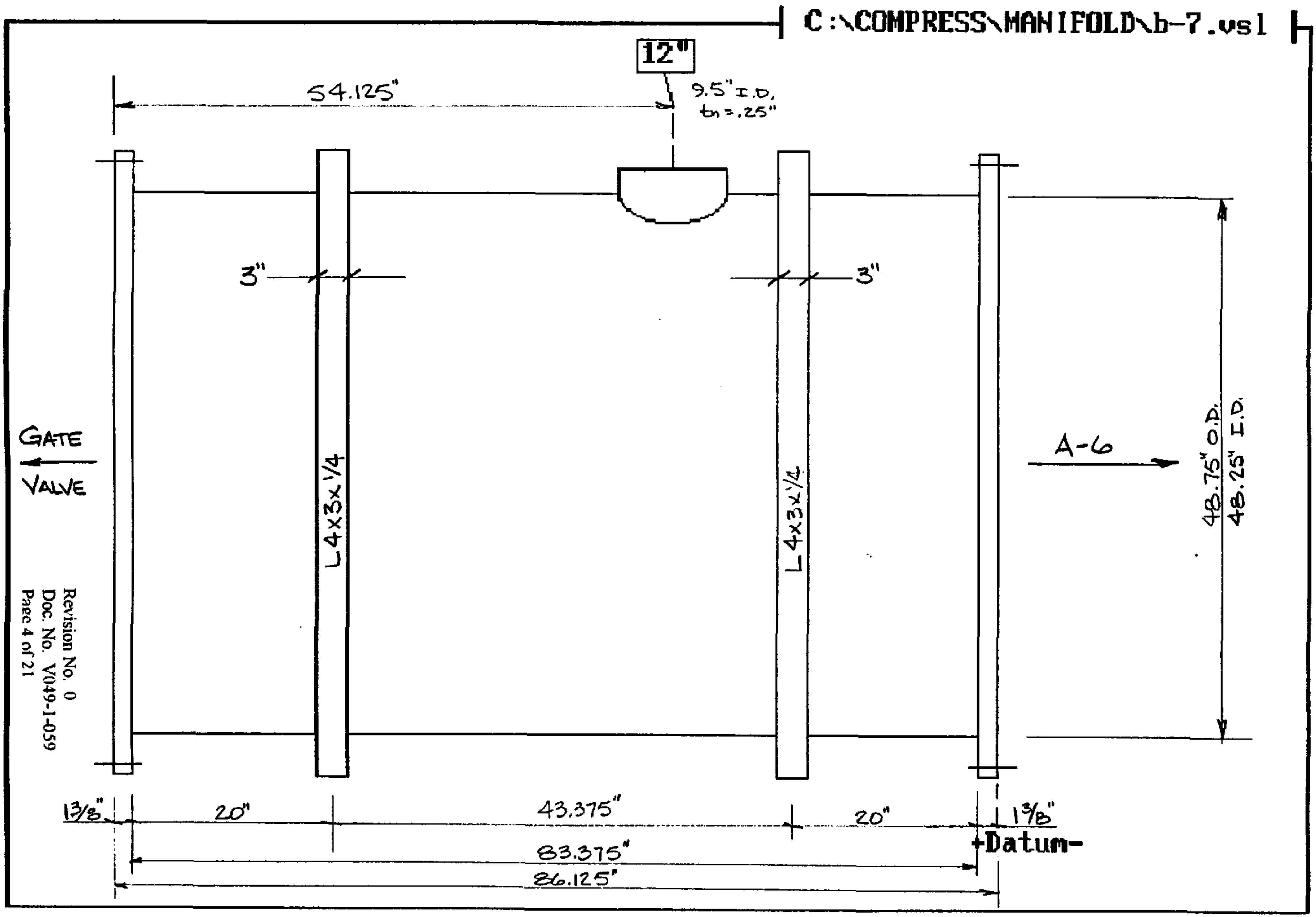
PROCESS SYSTEMS INTERNATIONAL, INC.
20 WALKUP DR. WESTBOROUGH, MASSACHUSETTS 01581 USA

SPOOL B-7
48"
LIGO VACUUM EQUIPMENT

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

Jan 17, 1996 - 14:46:38

4 3 2 1


C:\COMPRESS\MANIFOLD\b-7.vsl
12"
54.125"
9.5" I.D.
tn=.25"
3"
3"
GATE
VALVE
L4x3x1/4
L4x3x1/4
A-6
48.75" O.D.
48.25" I.D.
1 3/8"
20"
43.375"
20"
1 3/8"
Datum
83.375"
86.125"

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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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 mark	OD (in)	tn (in)	Req tn (in)	A1?	A2?	Nom t (in)	Req t (in)	User t (in)	Corr (in)	Aa/Ar (%)
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 mark	Service	Size	Materials Nozzle	Impact?	Norm?	Pad	Impact?	Norm?	Flange
12"	cf	9.50 IDx0.25	SA 240 304L HIGH	n	n				

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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 ->| |<-
          _       _                  corrosion allow = 0 in
         | |<- d ->| |               noz thick new tn= .25 in
twl->|  |<        | |                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

12" CF

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.

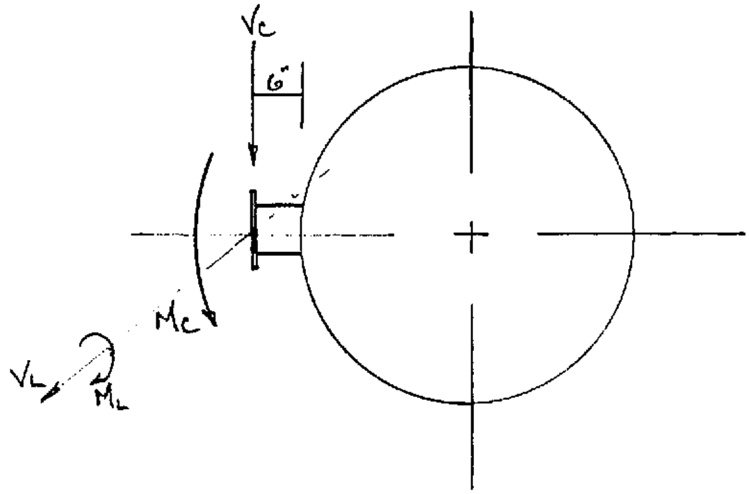
LOADS @ 12" CF (10" O.D. NOZZLE)

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 ft-lbs

V_L = 150 lbs (0.05625) ≅ 10 lbs

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

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-060 PAGE 1 OF 11
REV.	DEO #	DATE	BY:	CHECK	TITLE:	
0	013C	4/22/96	WDB	PAC	**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

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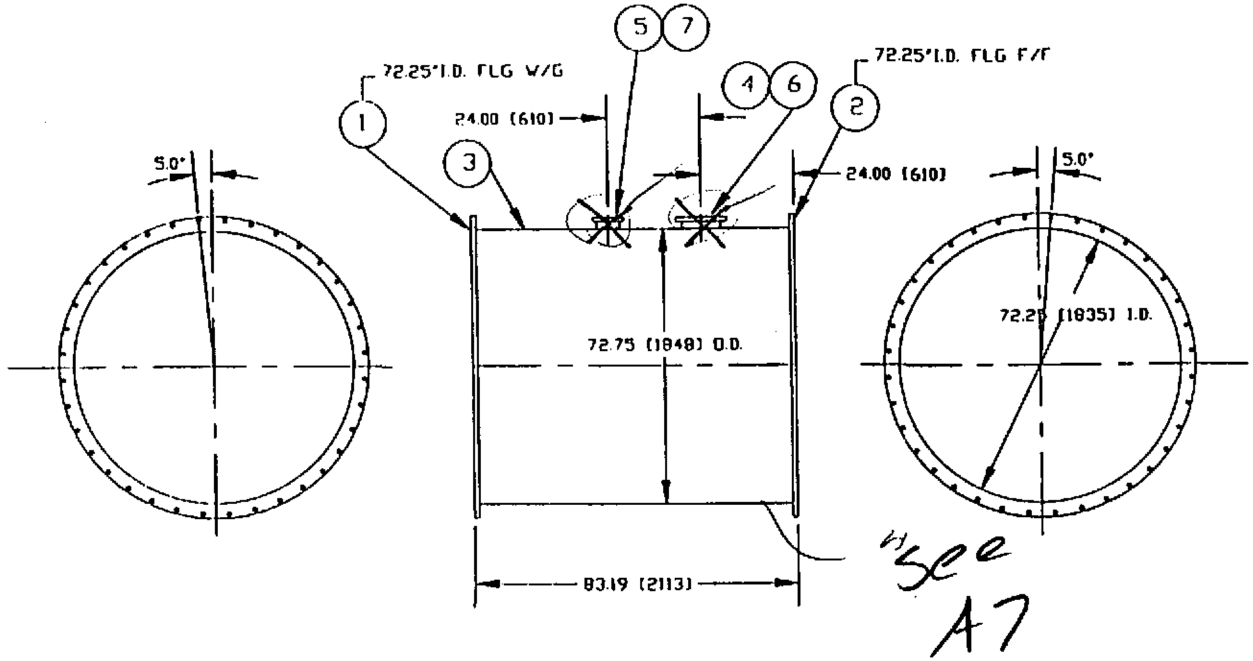

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR/MACH 10°-30° BEND 10°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE
BREAK CORNERS
REMOVE ALL BURRS

DO NOT SCALE THIS DWG.

USED ON

NEXT ASS'Y:

REV	DESCRIPTION	CHKD	DRWN	DATE	ECO#
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	SIZE	DWG. NO.	REV.
B8	B	V049-4-B8	0
SCALE 3/8"=1'-0"		SHEET 1 OF 1	

4 3 2 1

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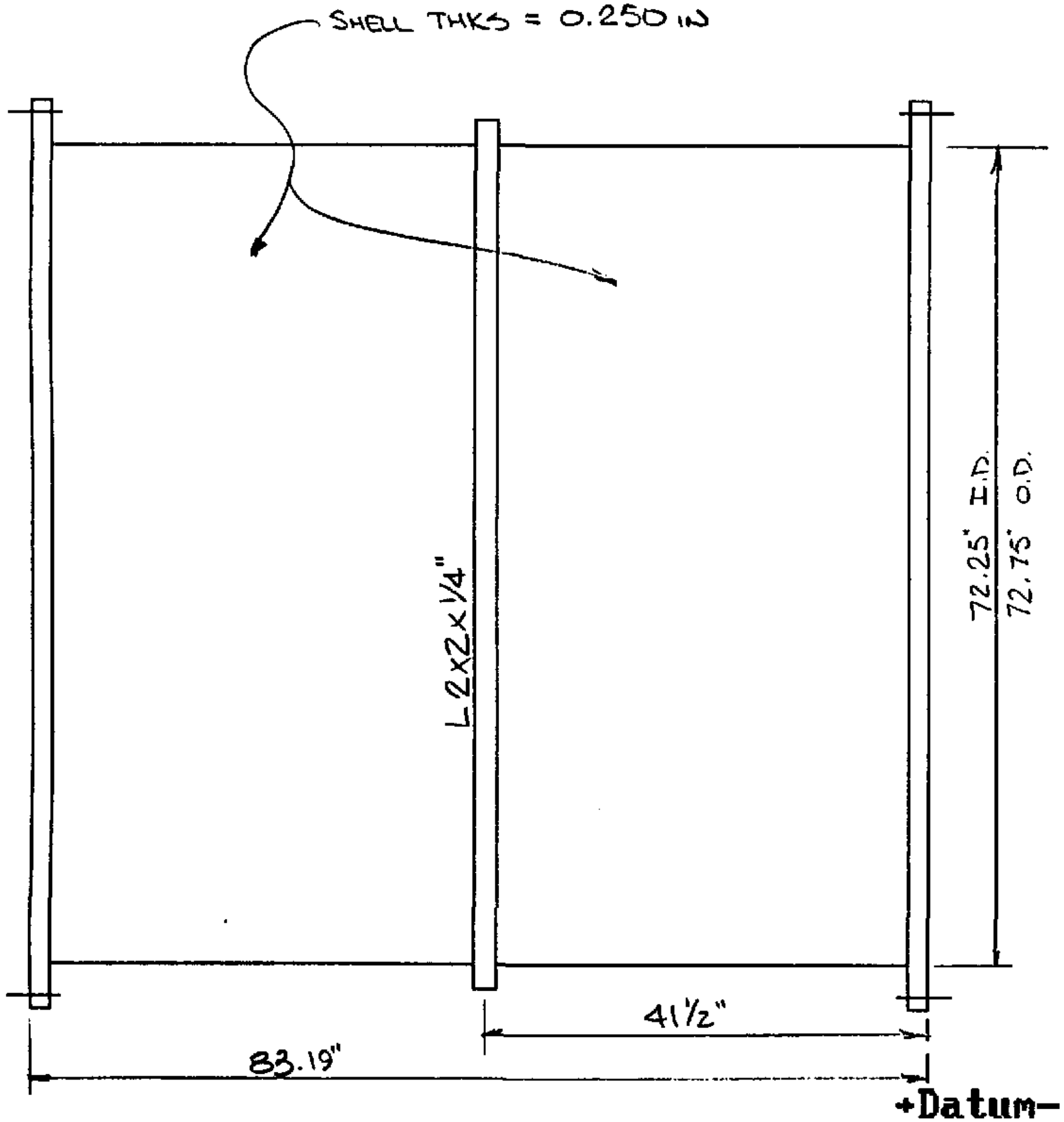

Pressure Summary

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-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 ----------------------------

Component	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

Spool B-8

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: **SPOOL B-9 (72 in)**	
0	0136	4/22/96	WDB	RPC		
					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

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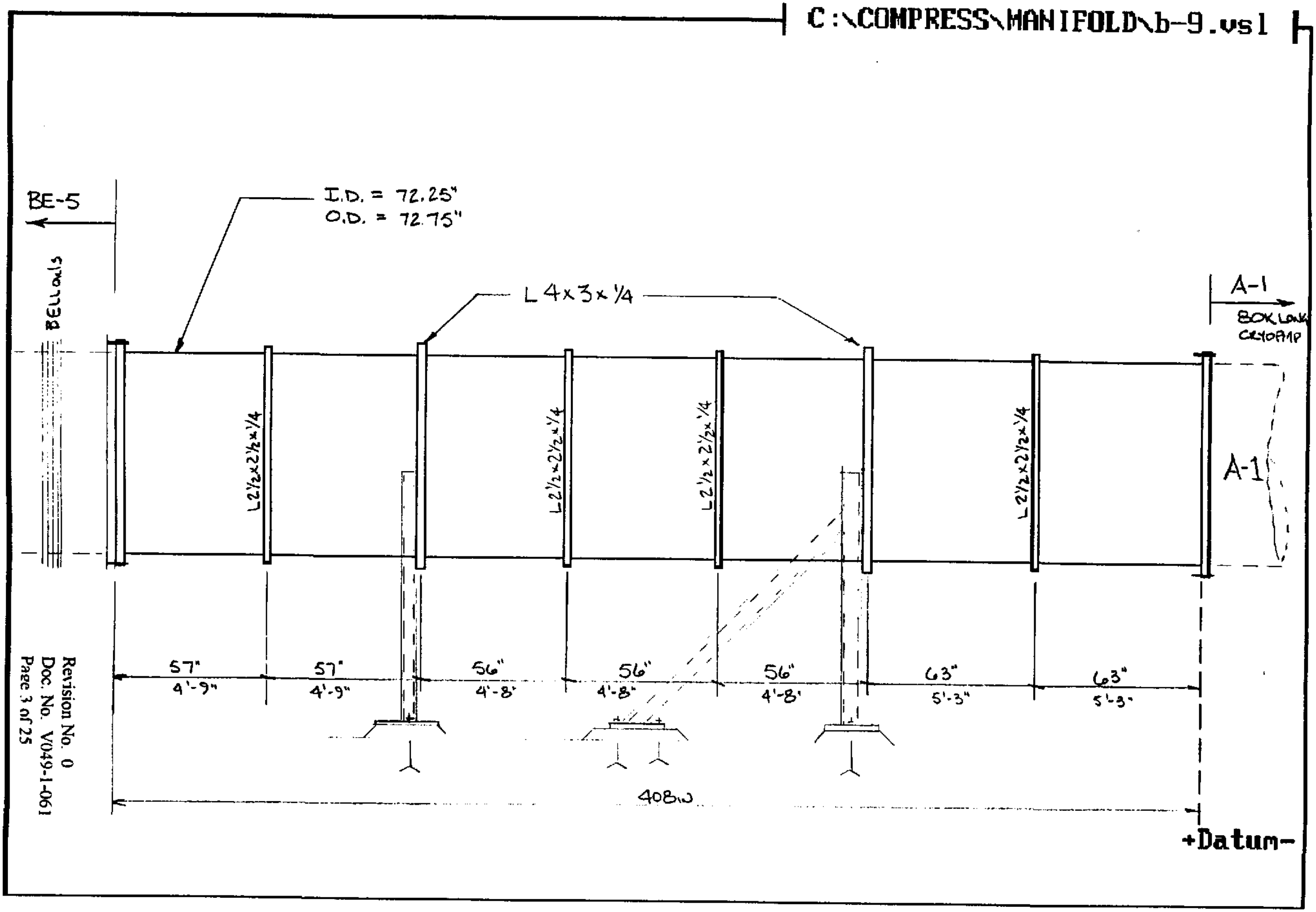

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Pressure Summary

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-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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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

Weight (lbs) Contributed by Vessel Elements

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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

Spool B-9

Pa= 4*B/(3*Do/t)
= 4*3633.7/(3*72.75/0.25)
= 16.6493 psi

Stiffner Rings

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

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.

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

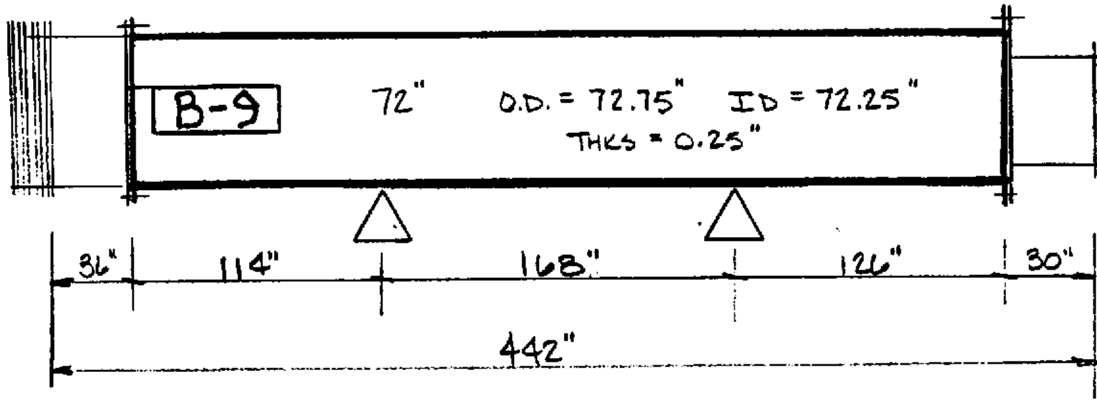
I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

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"



<u>MATERIAL – TYPE 304L</u>

E = 28.3 x10⁶ PSI @ 70°F

E = 26.5 x10⁶ PSI @ 400°F

<u>PROPERTIES OF BEAM TUBE MANIFOLD</u>

$$A = \frac{\pi}{4}\left(D_o^2 - d_i^2\right) = 0.7854\left[(72.75\,in)^2 - (72.25\,in)^2\right]$$

$$A = 56.94\ in^2$$

$$I = \frac{\pi}{64}\left(D_o^4 - d_i^4\right) = 0.049\left[(72.75\,in)^4 - (72.25\,in)^4\right]$$

$$I = 37412.7\ in^4$$

$$S = \frac{\pi}{32}\left(D_o^4 - d_i^4\right) / D_o$$

$$= 0.098\left[(72.75\,in)^4 - (72.25\,in)^4 / 72.75\right]$$

$$= 1028.5\ in^3$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

REFERENCE: ASME CODE UG-23

SECTION VIII, DIVISION 1

$$A = \frac{0.125}{(R_o/t)} = \left(\frac{0.125}{36.375''/.25''}\right)$$

$$A = 0.000859$$

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

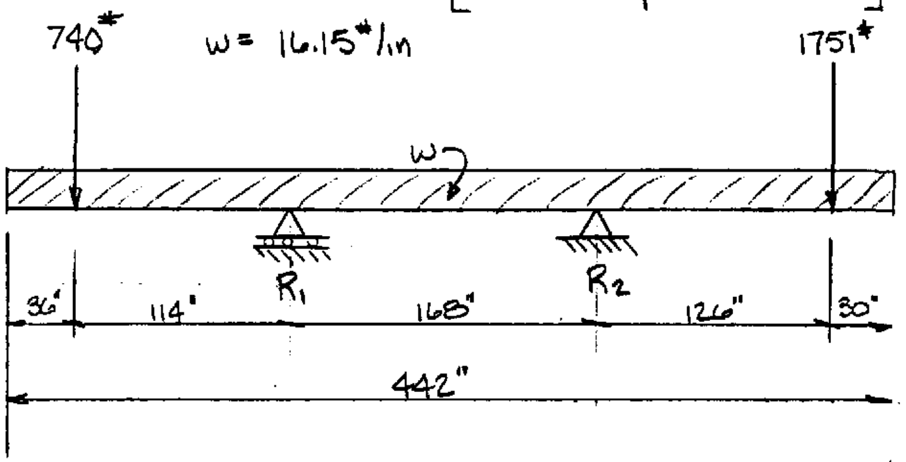
$$f_a = \frac{PR_o}{2t} + \frac{Mc}{I}$$

$$= \frac{(14.7\ \#/in^2)(36.375\ in)}{2(.250\ in)} + \frac{Mc}{I}$$

$$\frac{Mc}{I} = \frac{M}{S}$$

DETERMINE M_{MAX}

$$w = (490\ \#/FT^3)\left[\frac{(\pi)\left((72.75\ in)^2 - (72.25\ in)^2\right)}{4}\right](1\ FT^3/1728\ in^3)$$



CONSERVATIVELY ASSUME TWO PINNED SUPPORTS

from overhang @ $M_{R2} = (1751\#)(126\ in) + \frac{(16.15\#/in)(156\ in)^2}{2} = 417139.2$ in-lbs

from overhang @ $M_{R1} = (740\#)(114\ in) + \frac{(16.15\#/in)(150\ in)^2}{2} = 266047.5$ in-lbs

Between Supports $M = \frac{wL^2}{8} = \frac{(16.15\#/in)(168\ in)^2}{8} = 56977.2$ in-lbs

$M_{MAX} = 417139.2$ in-lbs.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

$$f_a = \frac{(14.7\ \#/in^2)(36.375\ in)}{2\ (.250\ in)} + \frac{417139.2\ in\text{-}lb}{1028.5\ in^3}$$

$$= 1069.4\ \#/in^2 + 405.6\ \#/in^2$$

$$f_a = 1475\ \#/IN^2$$

$$F_{allow} = 5400\ lb/in^2$$

$\therefore$ 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.

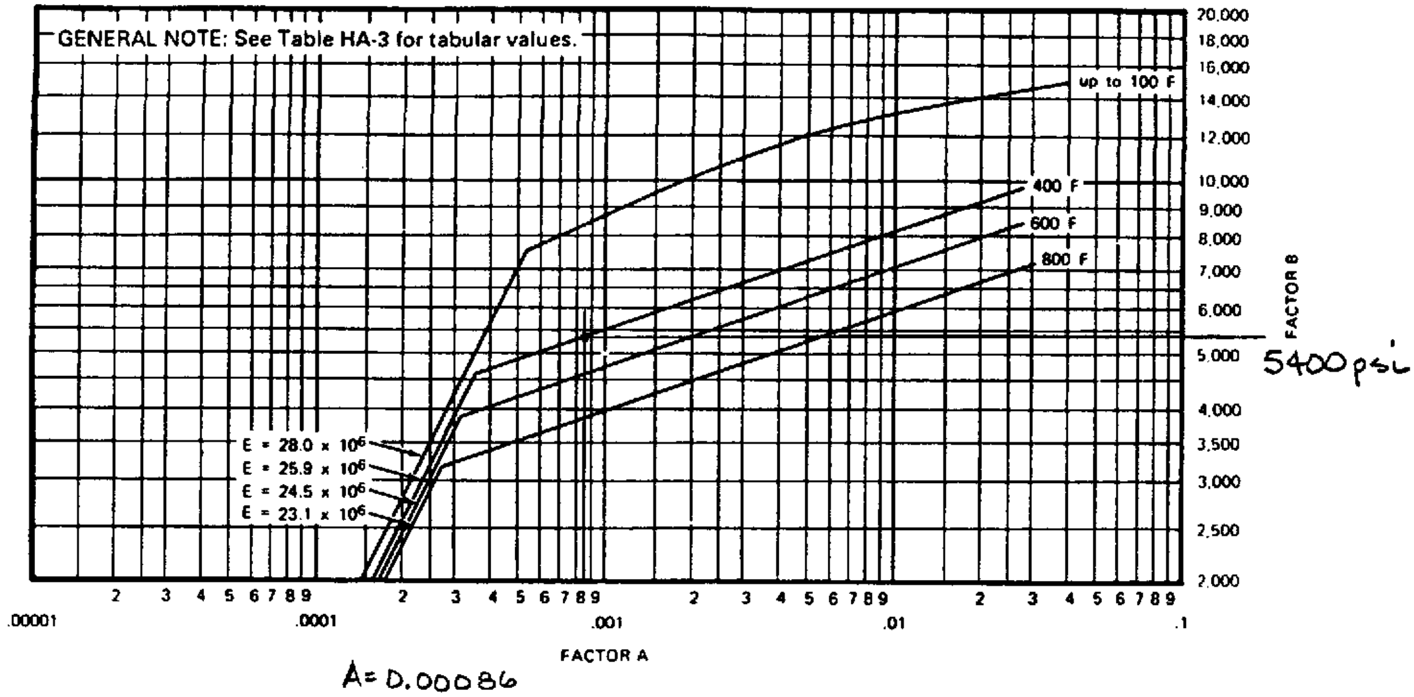


FIG. HA-3 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–0.035 MAXIMUM CARBON, TYPE 304L) [NOTE (1)]

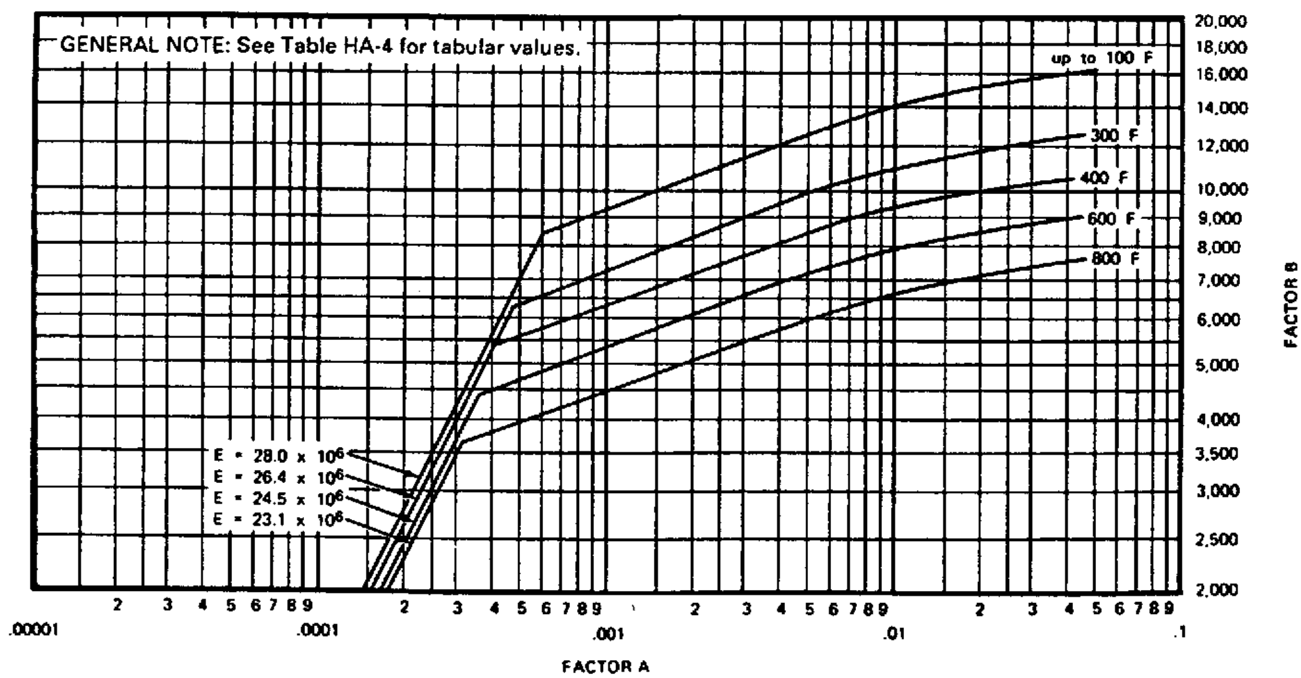


FIG. HA-4 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–Mo–0.035 MAXIMUM CARBON, TYPES 316L AND 317L) [NOTE (1)]

TABLE HA-3
TABULAR VALUES FOR FIG. HA-3

Temp., °F	A	B, psi
100	0.100 −04	0.139 +03
	0.524 −03	0.767 +04
	0.200 −02	0.103 +05
	0.600	0.125
	0.100 −01	0.144
	0.100 +00	0.153
400	0.100 −04	0.128 +03
	0.352 −03	0.468 +04
	0.100 −02	0.562
	0.100 −01	0.834
	0.100 +00	0.987
600	0.100 −04	0.121 +03
	0.313 −03	0.393 +04
	0.100 −02	0.484
	0.100 −01	0.722
	0.100 +00	0.855
800	0.100 −04	0.114 +03
	0.270 −03	0.322 +04
	0.150 −02	0.435
	0.100 −01	0.606
	0.100 +00	0.736

0.859 -03 →

TABLE HA-4
TABULAR VALUES FOR FIG. HA-4

Temp., °F	A	B, psi
100	0.100 −04	0.140 +03
	0.587 −03	0.857 +04
	0.700 −02	0.135 +05
	0.100 −01	0.143
	0.200	0.155
	0.500	0.166
	0.100 +00	0.166
300	0.100 −04	0.133 +03
	0.466 −03	0.638 +04
	0.500 −02	0.102 +05
	0.600	0.104
	0.100 −01	0.112
	0.500	0.129
	0.100 +00	0.129
400	0.100 −04	0.133 +03
	0.402 −03	0.547 +04
	0.700 −02	0.916
	0.100 −01	0.958
	0.400	0.108 +05
	0.100 +00	0.108
600	0.100 −04	0.122 +03
	0.355 −03	0.448 +04
	0.500 −02	0.738
	0.100 −01	0.812
	0.500	0.936
	0.100 +00	0.936
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	TITLE: **SPOOL BE-2 (60 in)**	
0	0136	4/23/96	WDB	RPC		
					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.

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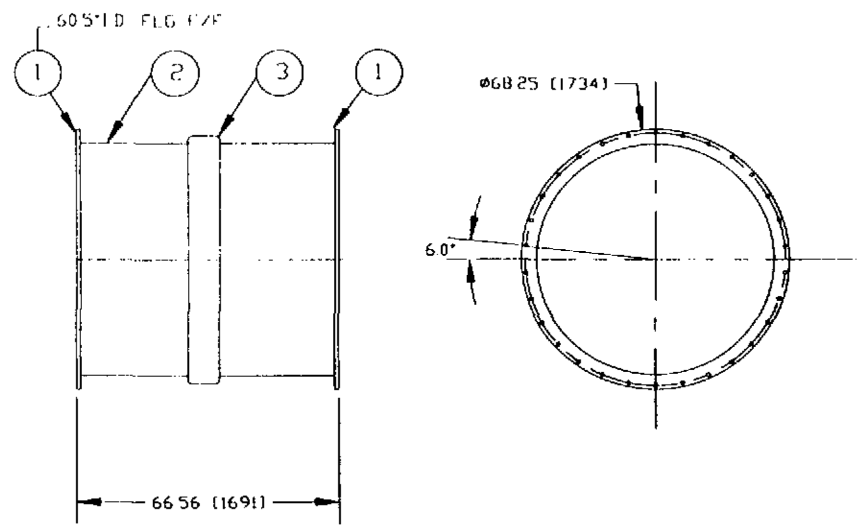

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR MACH ±0°-30' BEND ±2°
TWO PLACE DECIMAL ± .010
THREE PLACE DECIMAL ± .005
FINISHED SURFACE RMS
BREAK CORNERS: IN OUT
REMOVE ALL BURRS

DO NOT SCALE THIS DWG
USED ON
NEXT ASS'Y

REV	DESCRIPTION					CHKD	DRWN	DATE	DEO#
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	SIZE	DWG NO	REV
BE2	B	V049-4-BE2	0

SCALE 3/8"=1'-0"   SHEET 1 OF 1

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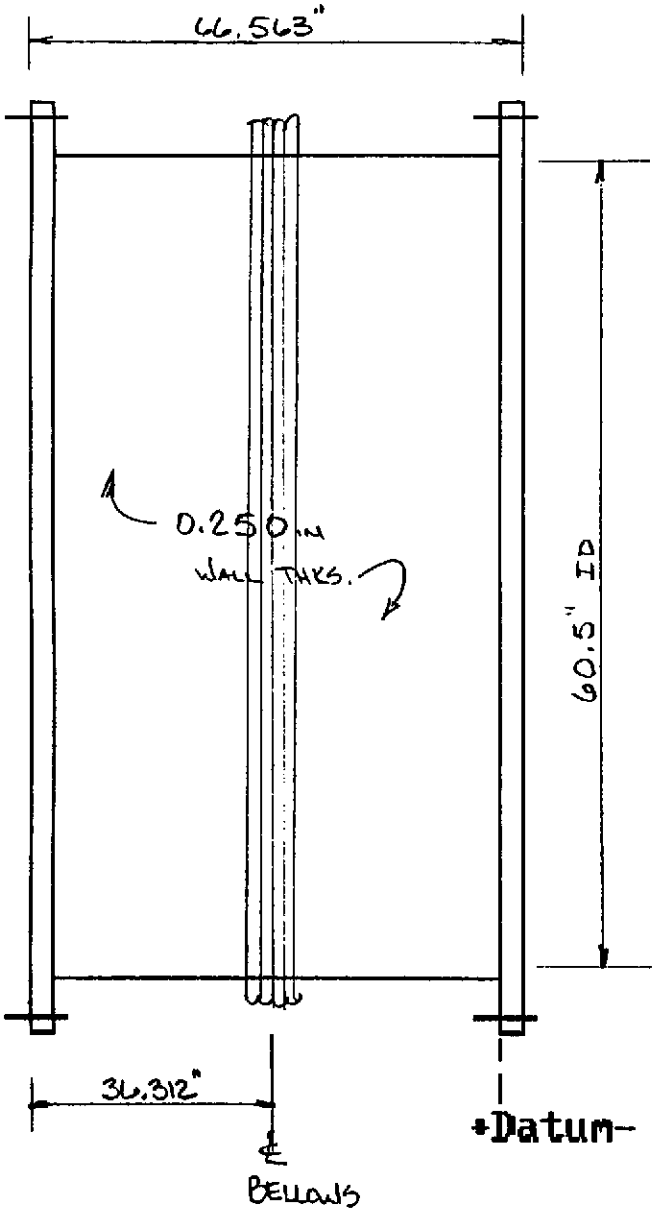

Pressure Summary

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)	Exemption or Stress Reduction	Corrosion Allowance (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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & flg
	Weight (lbs) Contributed by Vessel Elements											
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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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	TITLE:	
0	139	4.24.96	WDB	AGR	**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.

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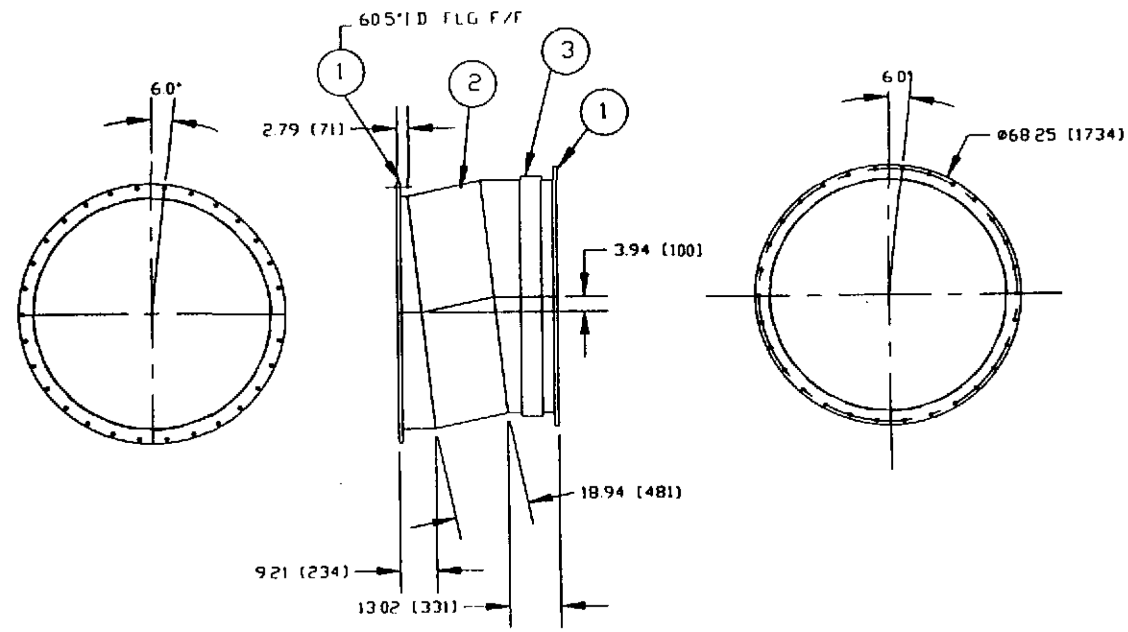

ELEVATION

6 ~~4~~ REQ'D

Revision No. 0
Doc. No. V049-1-049
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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					CHK'D	DRWN	DATE	DED#
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
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SCALE 3/8"=1'-0" SHEET 1 OF 1

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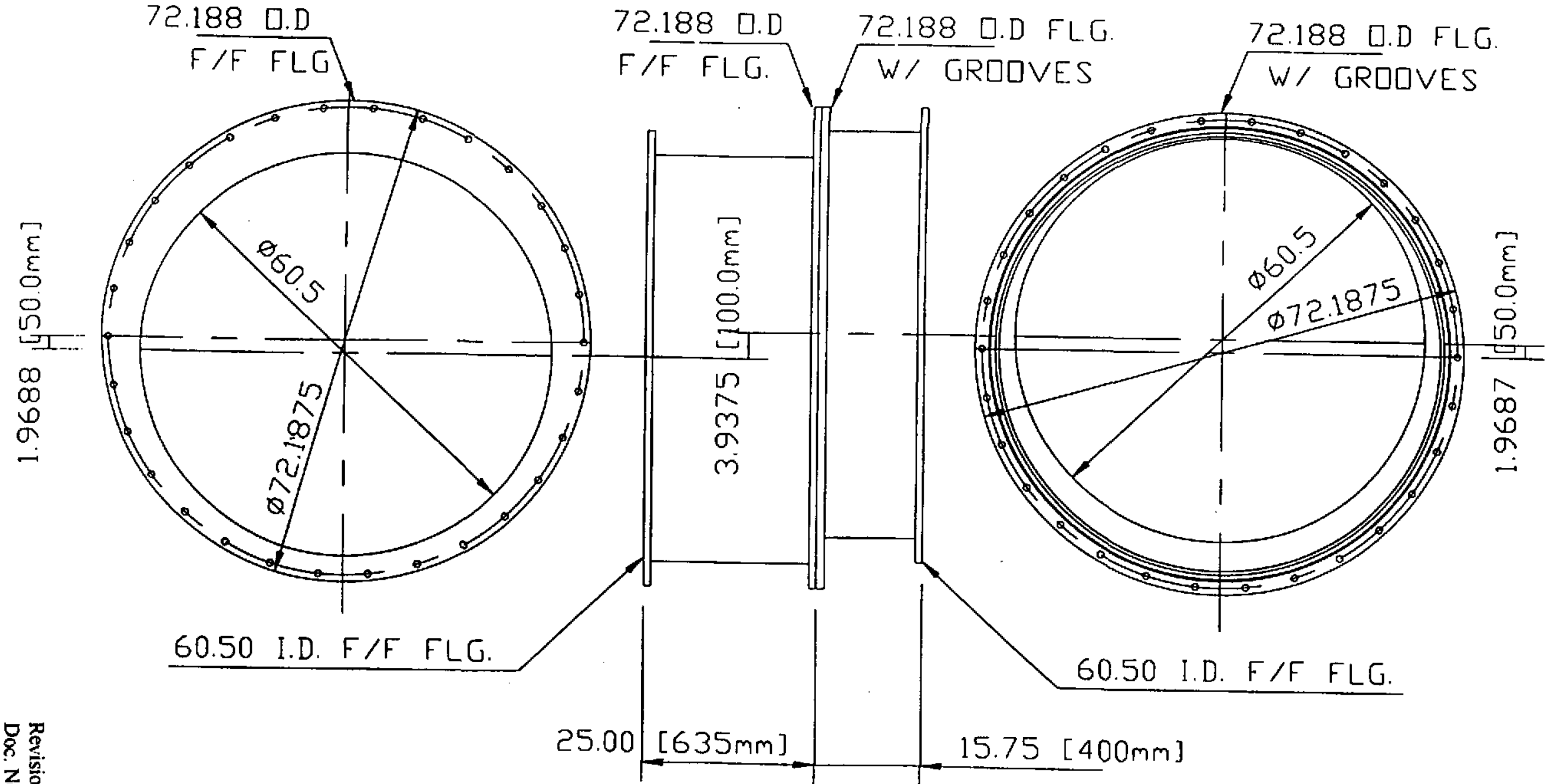
BE-3A


72.188 O.D
F/F FLG
ø60.5
ø72.1875
1.9688 [50.0mm]
72.188 O.D
F/F FLG.
72.188 O.D FLG.
W/ GROOVES
3.9375 [100.0mm]
72.188 O.D FLG.
W/ GROOVES
ø60.5
ø72.1875
1.9687 [50.0mm]
60.50 I.D. F/F FLG.
60.50 I.D. F/F FLG.
25.00 [635mm]
15.75 [400mm]

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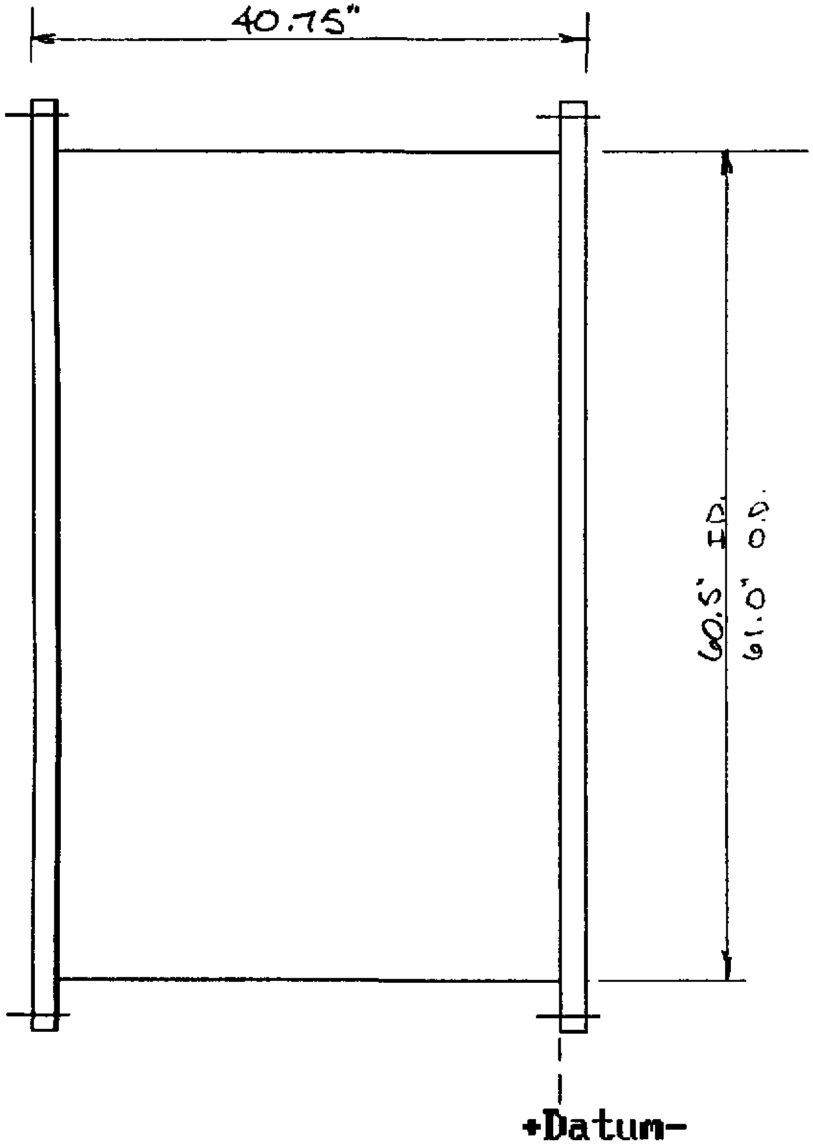


NOTE: THE MODEL USED FOR THE DESIGN OF THE SHELL WALL THICKNESS IS CONSERVATIVELY MODELLED AS A STRAIGHT RUN. IN REALITY THE PLATE FOR FIT UP OF ECCENTRIC SPOOLS (WHICH IS AT MIDPOINT) ACTS AS A STIFFENER. NO STIFFENER WAS USED FOR SHELL WALL DESIGN. THE BELLOWS SECTION IS MODELLED AS CONTINUOUS SHELL.

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)	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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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

Weight (lbs) Contributed by Vessel Elements

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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

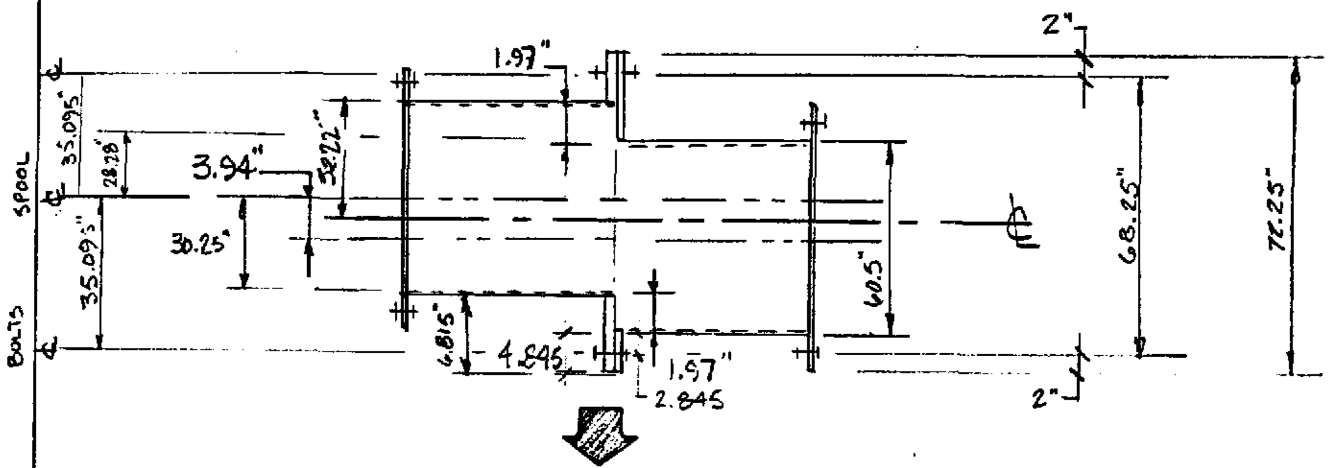
BE-3

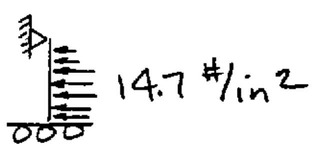
Pa = 4*B/(3*Do/t)
= 4*4887.2/(3*61/0.25)
= 26.706 psi

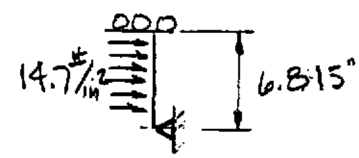
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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.





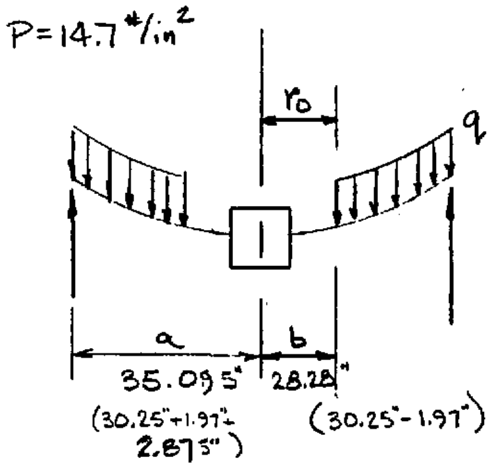


FOR QUICK REVIEW:

ASSUME ANNULAR PLATE WITH 2 in BEARING SURFACE. CONSIDER OUTER EDGE SIMPLY SUPPORTED, INNER EDGE GUIDED. CONSIDER DISTRIBUTED LOAD ACTING ON ONE SIDE ONLY.
REF. 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

$$Q_a = -\frac{14.7\ \#/in^2/in}{2\,(35.095\,in)}\left[(35.095\,in)^2 - (28.28\,in)^2\right]$$

$$= 90.45 \text{ lbs}$$

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
$b = 28.28\,in$
$a = 35.095\,in$

$$C_8 = 0.8773$$

$$L_{17} = \tfrac{1}{4}\left[1 - \frac{1-\nu}{4}\left\{1 - \left(\frac{r_o}{a}\right)^4\right\} - \left(\frac{r_o}{a}\right)^2\left\{1 + (1+\nu)\ln\frac{a}{r_o}\right\}\right]$$

$$= \tfrac{1}{4}\left[1 - \frac{1-.3}{4}\left\{1 - \left(\frac{28.28}{35.095}\right)^4\right\} - \left(\frac{28.28}{35.095}\right)^2\left\{1 + (1+.3)\ln\frac{35.095}{28.28}\right\}\right]$$

$$L_{17} = 0.0168$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

$$M_{rb} = \frac{(14.7\ \#/in^2/in)(35.095\ in)^2}{0.8773}(0.0168)$$

$$M_{MAX} = M_{rb} = 346.7\ lb\text{-}in$$

ASSUME 1" THK PLATE

$$\sigma_{max} = \frac{6 M_{rb}}{t^2} = \frac{6(346.7\ lb\text{-}in)}{(1.00\ in)^2} = 2080\ \#/in^2$$

Shear Stress & Bending Stress are relatively small and therefore eccentricity is acceptable.

Additionally 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.

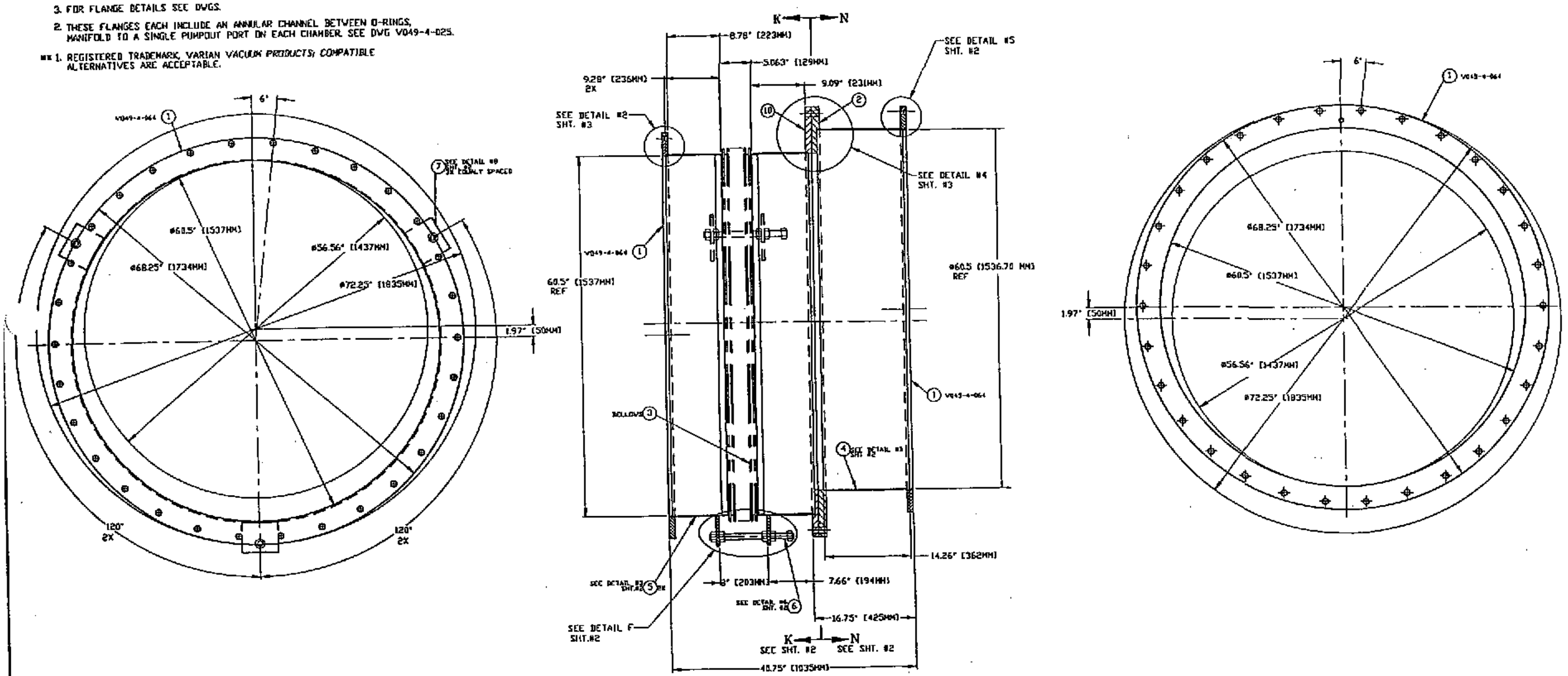
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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)

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

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

DO NOT SCALE THIS DRAWING

USED ON | NEXT ASS'Y

DWG. NO. | DESCRIPTION | DWG. NO. | DESCRIPTION — REFERENCE DRAWINGS

REV | DESCRIPTION | CHKD | DRWN | DATE | ECO# — ISSUE DESCRIPTION

PROCESS SYSTEMS INTERNATIONAL INC.

ADAPTER BE-3A
60.5 ID 3.94 OFFSET
LIGO VACUUM EQUIPMENT

CAD FILE: 49BE3AS1 | SIZE: D | DWG. NO.: V049-4-BE3A | REV.: P1

SCALE: NONE | SHEET: 1 OF 1

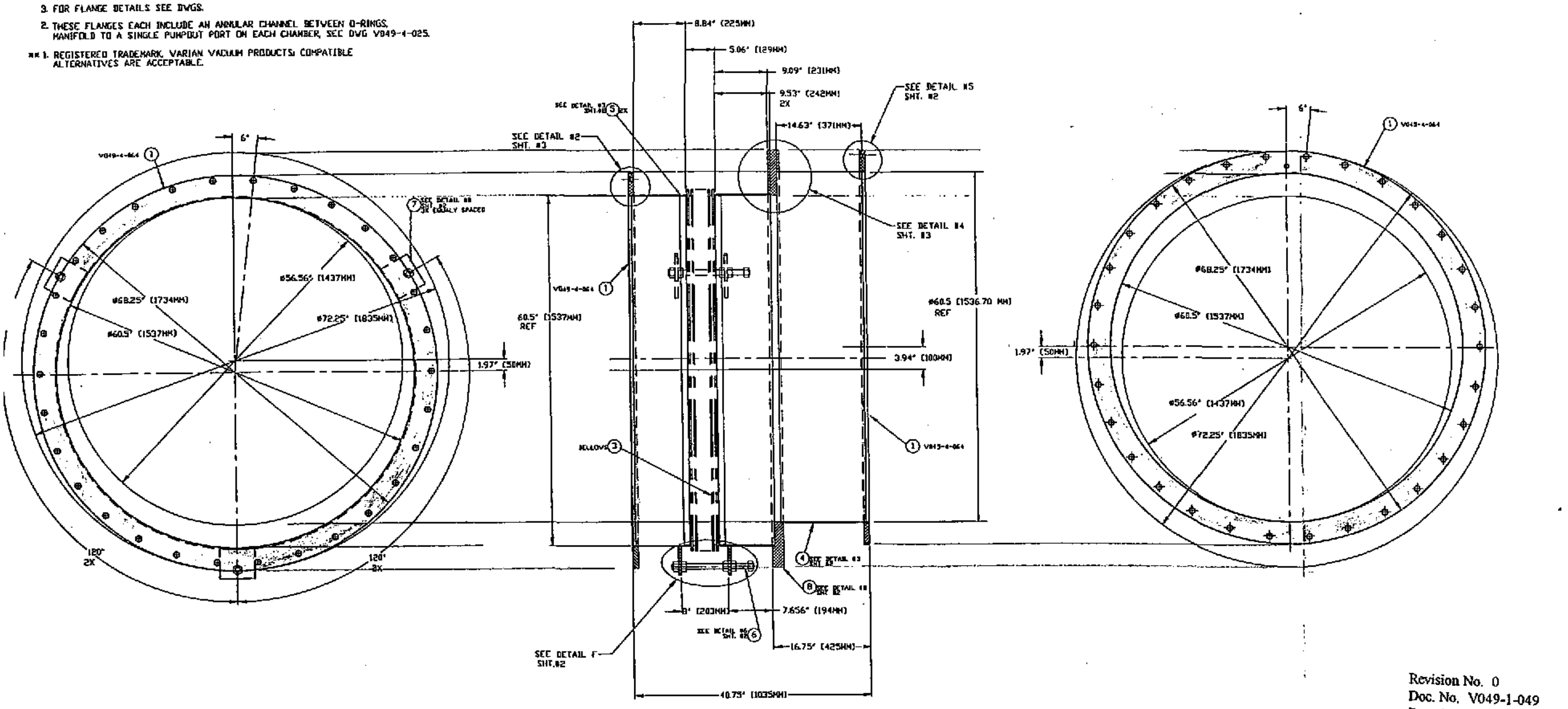
Dec 07, 1994

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	-	-	-	-	
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.



Revision No. 0
Doc. No. V049-1-049
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PROCESS SYSTEMS INTERNATIONAL INC.

ADAPTER BE-3
60.5 ID 3.94 OFFSET
LIGO VACUUM EQUIPMENT

CAD FILE: V049-4-BE3 | SIZE: D | DWG. NO.: V049-4-BE3 | REV.: P1
SCALE: NONE | SHEET: 1 OF 1

DO NOT SCALE THIS DRAWING

REFERENCE DRAWINGS | DWG. NO. | DESCRIPTION

ISSUE DESCRIPTION | REV | DESCRIPTION | CHKD | DRWN | DATE | ECN

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-096
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 8
?	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

ASSUMPTIONS: SEE CALCS

INPUTS: "STRUCTURAL DESIGN CRITERIA" DOC. NO. V049-1-066

REFERENCES: LIGO DWG. V049-4-324
DOC. NO. V049-1-066, LIGO VAC. EQUIP. STRUCT. DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

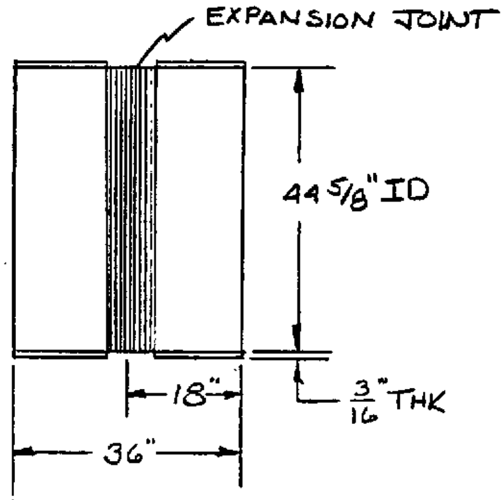
CONCLUSIONS: SPOOL PIECE BE-4, AS SHOWN IN SKETCH, IS IN CONFORMANCE WITH ASME VIII REQUIREMENTS

NOTES: COMPRESS FILE NAME: SP_B4 FILED IN DIRECTORY :\41896

DESIGN SKETCH

SK-V049-1-076 RO

SPOOL BE-4



REV 0
Doc. No. V049-1-076
P. 2 OF 8

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

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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 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	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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

SPOOL BE-4

```
Pa= 4*B/(3*Do/t)
  = 4*4528.5/(3*45/0.1875)
  = 25.1583 psi
```

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-085 PAGE 1 OF 46
REV.	DEO #	DATE	BY:	CHECK	TITLE:	
0	0141	4.24.96	WDB	AGR	**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

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.

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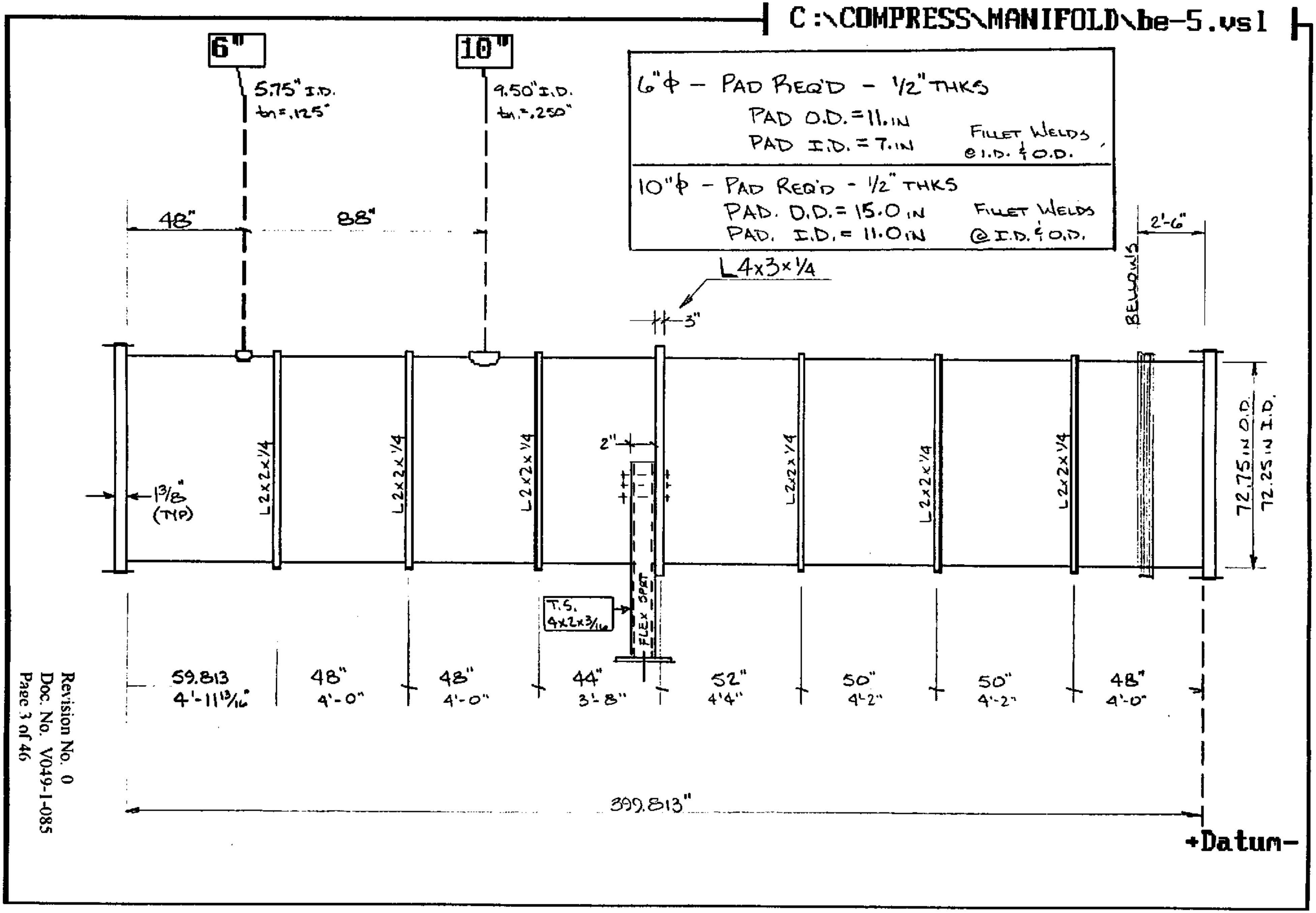

C:\COMPRESS\MANIFOLD\be-5.vsl
6"
5.75" I.D.
tn=.125"
10"
9.50" I.D.
tn=.250"
6"φ - PAD REQ'D - 1/2" THKS
PAD O.D. = 11. IN
PAD I.D. = 7. IN
FILLET WELDS
@ I.D. & O.D.
10"φ - PAD REQ'D - 1/2" THKS
PAD. O.D. = 15.0 IN
PAD. I.D. = 11.0 IN
FILLET WELDS
@ I.D. & O.D.
48"
88"
2'-6"
L4x3x1/4
3"
BELLOWS
1 3/8" (TYP)
L2x2x1/4
2"
72.75 IN O.D.
72.25 IN I.D.
T.S. 4x2x3/16
FLEX SPRT
59.813
4'-11 13/16"
48"
4'-0"
44"
3'-8"
52"
4'4"
50"
4'-2"
399.813"
+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 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
BE-5	0.0	400.0	86.1	97.8	20.0	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
Stiffner Rings					14.7				
Support Ring					14.7				
Stiffner Rings @ no					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	Metal New	Metal Corr	Trays & sup	Packed Beds	Insul	Lining	Piping	Ladder & plat	Rings & Misc	Oper Liquid	Test Liquid	Nozzle & 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

Weight (lbs) Contributed by Vessel Elements

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:	198.7 in

Nozzle Summary

Nozzle mark	OD (in)	tn (in)	Req tn (in)	A1?	A2?	Nom t (in)	Req t (in)	User t (in)	Corr (in)	Aa/Ar (%)
6"	6.00	0.1250	0.0625	y	y	0.2500	0.2193		0.0000	186.7
10"	10.00	0.2500	0.0625	y	y	0.2500	0.2193		0.0000	112.8

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
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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (in)
Be-5	72.25	360.00	0.2500	0.2192	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 = 59.81299/72.75 =0.8222 Do/t = 72.75/0.21929 = 331.7525
From table G: A = 0.000277
From table HA-3: B = 3660.4

Pa= 4*B/(3*Do/t)
= 4*3660.4/(3*72.75/0.21929)
= 14.7114 psi

Design thickness for external pressure Pa = 14.7114 psi:

= t + Corrosion
= 0.21929 + 0
= 0.21929 in

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

L/Do = 59.81299/72.75 =0.8222 Do/t = 72.75/0.25 = 291
From table G: A = 0.00033
From table HA-3: B = 4368.1

Pa= 4*B/(3*Do/t)
= 4*4368.1/(3*72.75/0.25)
= 20.0142 psi

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 ->| _|twl |          nozzle id. new d= 5.75 in
->| |<tw2 | |        |>| |<-|           pad diameter dp = 9 in
__|   ___/| |        | |\___            pad thickness te= .25 in
te|/|     | |        | |    |\          fillet weld twl = .25 in
_________|_|_v       | |________        fillet weld tw2 = .25 in
________/|_|_tw3     |_|\_______        groove weld tw3 = .25 in
             ^
<---- L ---->|                          To datum L= 312 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
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

6" Roughing Pmp

Outer Fillet: tmin = lesser of 0.75 or te or t, tmin = 0.25 in
tw(min) = 0.5*tmin = 0.125 in
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) = .2193 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*0.2193*1 + 2*0.125*0.2193*1*(1 - 1))
= .6305 in^2

Area available

A1 = larger of the following = .177 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 5.75*(1*0.25-1*0.2193) - 2*0.125*(1*0.25-1*0.2193)*(1-1)
= .177 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*0.2193) - 2*0.125*(1*0.25-1*0.2193)*(1-1)
= .023 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
= 0.177 + 0.124 + 0.063 + 0.063 + 0.75
= 1.177 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 = 0 psi

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

Maximum combined stress = ~~1447~~ psi
Allowable combined stress = +-1.5*S = +- 22050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-264 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Max Combined Stress
Does Not Include Local
Stresses Therefore,

$$\sigma_L = \frac{(14.7\ \#/in^2)(36.25\ in)}{2\ (.50\ in)} = 533\ \#/in^2$$

$$\sigma_C = \frac{(14.7\ \#/in^2)(36.25\ in)}{.50\ in} = 1066\ \#/in^2$$

Max Combined (ENVELOPE)

$$\sigma_{TOTAL} = 533\ \#/in^2 + 2.046(1066\ \#/in^2) + 1447\ \#/in^2$$

$$\sigma_{TOT} = 4161\ \#/in^2$$

$$4161\ \#/in^2 < 22050\ \#/in^2$$

$\therefore$ O.K

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*										
Total circ stress			-1127	599	-1127	599	-1424	946	-1424	946
Primary membrane circ stress*			-264	-264	-264	-264	-239	-239	-239	-239
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*										
Total long stress			-1447	969	-1447	969	-1108	580	-1108	580
Primary membrane long stress*			-239	-239	-239	-239	-264	-264	-264	-264
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-1447	969	-1447	969	-1424	946	-1424	946

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 = [redacted]

Local long. pressure stress = P*Rm/2t = [redacted]

Maximum combined stress =-[redacted] psi
Allowable combined stress = +-1.5*S = +- 22050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-843 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Max Combined stress
(CONSERVATIVELY USE ENVELOPE)

σ_C = 1066 #/in² (1.375)
= 1466 #/in²

σ_L = 533 #/in²

σ_{TOTAL} = 533#/in² + 1466#/in² + 3264#/in²
= 5263 #/in²

5263 #/in² < 22050 #/in²
∴ OK

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*										
Total circ stress			-2328	642	-2328	642	-3264	2170	-3264	2170
Primary membrane circ stress*			-843	-843	-843	-843	-547	-547	-547	-547
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*										
Total long stress			-3209	2115	-3209	2115	-2446	760	-2446	760
Primary membrane long stress*			-547	-547	-547	-547	-843	-843	-843	-843
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-3209	2115	-3209	2115	-3264	2170	-3264	2170

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 ->| |<-
dp->|      _  |          _ |<-  corrosion allow = 0 in
    |     | |<- d ->| |twl |    noz thick new tn= .25 in
->| |<tw2 | |       |>| |<-|    nozzle id. new d= 9.5 in
__|  __/  | |       | |\___     pad diameter dp = 12 in
te|/|     | |       | |    |\   pad thickness te= .25 in
_______|_|_v        | |_______  fillet weld twl = .25 in
______/|_|_tw3      |_|\______  fillet weld tw2 = .1875 in
           ^                    groove weld tw3 = .25 in
<---- L ---->|                  To datum L= 224 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

10" Roughing Pmp

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 = 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

10" Roughing Pmp

Outer Fillet: tmin = lesser of 0.75 or te or t, tmin = 0.25 in
tw(min) = 0.5*tmin = 0.125 in
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

10" Roughing Pmp

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) = .2193 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*0.2193*1 + 2*0.25*0.2193*1*(1 - 1))
= 1.0417 in^2

Area available

A1 = larger of the following = .292 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 9.5*(1*0.25-1*0.2193) - 2*0.25*(1*0.25-1*0.2193)*(1-1)
= .292 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*0.2193) - 2*0.25*(1*0.25-1*0.2193)*(1-1)
= .031 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
= 0.292 + 0.285 + 0.063 + 0.035 + 0.5
= 1.175 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

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

Maximum combined stress = -2692 psi
Allowable combined stress = +-1.5*S = +- 22050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = -644 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Max Combined Stress does not include local stresses Therefore;

$$\sigma_L = \frac{(14.7\#/in^2)(36.25 in)}{2(.50 in)} = 533\#/in^2$$

$$\sigma_C = \frac{(14.7\#/in^2)(36.25 in)}{.50 in} = 1066\#/in^2$$

Max Combined Stress
Conservatively using envelope stresses

$$\sigma_{tot} = (1066\#/in^2)(2.117) + 533\#/in^2 + 2692\#/in^2$$

$$\sigma_{TOT} = 5482\#/in^2$$

$$5482\#/in^2 < 22050\#/in^2$$

∴ OK

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*										
Total circ stress			-2019	731	-2019	731	-2680	1722	-2680	1722
Primary membrane circ stress*			-644	-644	-644	-644	-479	-479	-479	-479
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*										
Total long stress			-2692	1734	-2692	1734	-2057	769	-2057	769
Primary membrane long stress*			-479	-479	-479	-479	-644	-644	-644	-644
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-2692	1734	-2692	1734	-2680	1722	-2680	1722

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

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

Maximum combined stress =-7218 psi
Allowable combined stress = +-1.5*S = +- 22050 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-1998 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Max Combined Stress does not include local stresses therefore;

$$\sigma_L = \frac{(14.7\#/in^2)(36.25 in)}{2(.50 in)} = 533\#/in^2$$

$$\sigma_c = \frac{(14.7\#/in^2)(36.25 in)}{.50 in} = 1066\#/in^2$$

Max Combined Stress (conservatively use envelope of max stresses)

$$\sigma_{combined} = 533\#/in^2 + 1066\#/in^2(1.702) + 7218\#/in^2 = 9565\#/in^2$$

$$9565\#/in^2 < 22050\#/in^2 \therefore O.K.$$

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*										
Total circ stress			-4589	593	-4589	593	-7218	5146	-7218	5146
Primary membrane circ stress*			-1998	-1998	-1998	-1998	-1036	-1036	-1036	-1036
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*										
Total long stress			-6508	4436	-6508	4436	-5699	1703	-5699	1703
Primary membrane long stress*			-1036	-1036	-1036	-1036	-1998	-1998	-1998	-1998
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-6508	4436	-6508	4436	-7218	5146	-7218	5146

Stiffner Rings

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Identifier:		Stiffner Rings
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		3
Distance first ring to datum line:		15 in
Ring spacing:		50 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 15 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	36.51042 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21929 + 1.19/36.51042))
= 3184.285

From table HA-3 (ring) A = 2.412903E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*36.51042*(0.21929 + 1.19/36.51042)*2.412903E-04)/10.9
= 1.077447 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 = 36.51042 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 65 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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/(0.21929 + 1.19/50))
= 3299.472

From table HA-3 (ring) A = 2.499343E-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*(0.21929 + 1.19/50)*2.499343E-04)/10.9
= 1.475035 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 = 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.

Calculations for ring 115 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	47.5935 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21929 + 1.19/47.5935))
= 3283.219

From table HA-3 (ring) A = 2.487147E-04

Required moment of inertia of the combined ring-shell section

Stiffner Rings

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*47.5935*(0.21929 + 1.19/47.5935)*2.487147E-04)/10.9
= 1.404108 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 = 47.5935 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 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:		160.187 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 160.187 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	44.5935 in

B = .75*(P*Do/(t + As/Ls))
 = .75*(14.7*72.75/(0.21929 + 1.69/44.5935))
 = 3118.61

From table HA-3 (ring) A = 2.363605E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
 = (72.75^2*44.5935*(0.21929 + 1.69/44.5935)*2.363605E-04)/10.9
 = 1.316244 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 = 44.5935 in

Shell area A1 = W*ts = 1.172787 in^2

Distance to the ring neutral axis

Y2 = Ring NA + ts/2

Support Ring

= 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.

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1995 Edition, A95 Addenda

Identifier:		Stiffner Rings @ nozzles
Ring material specification:		SA 240 304L HIGH
Number of rings in this group:		3
Distance first ring to datum line:		204.187 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 204.187 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	46 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21929 + 1.19/46))
= 3271.619

From table HA-3 (ring) A = 2.478443E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*46*(0.21929 + 1.19/46)*2.478443E-04)/10.9
= 1.357142 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 = 46 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 252.187 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	48.00001 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21929 + 1.19/48.00001))
= 3286.067

From table HA-3 (ring) A = 2.489284E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*48.00001*(0.21929 + 1.19/48.00001)*2.489284E-04)/10.9
= 1.416089 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 = 48.00001 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 300.187 in from datum

Shell material specification:		SA 240 304L HIGH
Required shell thickness:	t =	0.21929 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 =	53.9065 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*72.75/(0.21929 + 1.19/53.9065))
= 3323.05

From table HA-3 (ring) A = 2.517032E-04

Required moment of inertia of the combined ring-shell section

Stiffner Rings @ nozzles

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (72.75^2*53.9065*(0.21929 + 1.19/53.9065)*2.517032E-04)/10.9
= 1.590172 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 = 53.9065 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

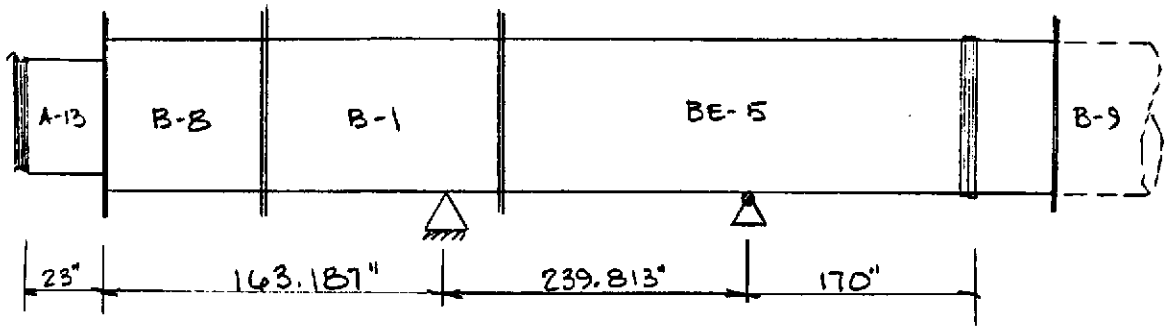
I2 = Ir + As*(NA - Y2)^2
= 0.703 + 1.19*(0.9609499 - 1.908)^2
= 1.770316 in^4

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

$$A = \frac{\pi (D_o^2 - D_i^2)}{4} = \frac{\pi}{4}\left[(72.75\text{in})^2 - (72.25\text{in})^2\right]$$

$$A = 56.94 \text{ in}^2$$

$$I = \frac{\pi}{64}(D_o^4 - D_i^4) = \frac{\pi}{4}\left[(72.75\text{in})^4 - (72.25\text{in})^4\right]$$

$$I = 37412.7 \text{ in}^4$$

$$S = \frac{\pi}{32}(D_o^4 - D_i^4)/D_o = \frac{\pi}{32}\left[\frac{(72.75\text{in})^4 - (72.25\text{in})^4}{72.75\text{in}}\right]$$

$$S = 1028.5 \text{ in}^3$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

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

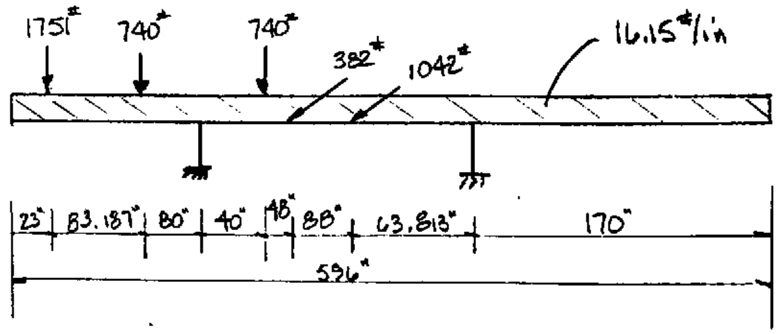
$$\sigma_{all} \hat{=} 5400 \text{ psi}$$

AXIAL BENDING & VACUUM STRESS

$$f_a = \frac{PR_o}{2t} + \frac{Mc}{I}$$

$$= \frac{(14.7\ \#/in^2)(36.375\ in)}{(2)(0.250\ in)} + \frac{M}{S}$$

M MAX



$$w = \left(\frac{490\ lbs}{FT^3}\right)\left(\frac{FT^3}{1728\ in^3}\right)\left[\frac{\pi\left((72.75\ in)^2 - (72.25\ in)^2\right)}{4}\right] = 16.15\ \#/in$$

CONSERVATIVELY ASSUME TWO PINNED SUPPORTS

BENDING MOMENT @ LEFT END

$$M_L = \frac{(16.15\#/in)(186.187in)^2}{2} + (1751\#)(163.187in) + (740\#)(80^{IN})$$

$$= 624865 \text{ IN-lbs}$$

BENDING MOMENT BETWEEN SUPPORTS

$$M = \frac{(16.15\#/in)(239.813in)^2}{8} + \frac{740 lbs(40)(199.813)}{239.813in} +$$

$$\frac{382 lbs(88in)(151.813)}{239.813in} + \frac{1042 lbs(176in)(63.813in)}{239.813in}$$

$$M = 210843. \text{ IN-lbs}$$

BENDING MOMENT @ RIGHT END

$$M_R = \frac{(16.15\#/in)(170in)^2}{2}$$

$$M_R = 233368. \text{ IN-lbs}$$

$$\therefore M_{MAX} = 624865 \text{ IN-lbs.}$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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(c), 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.

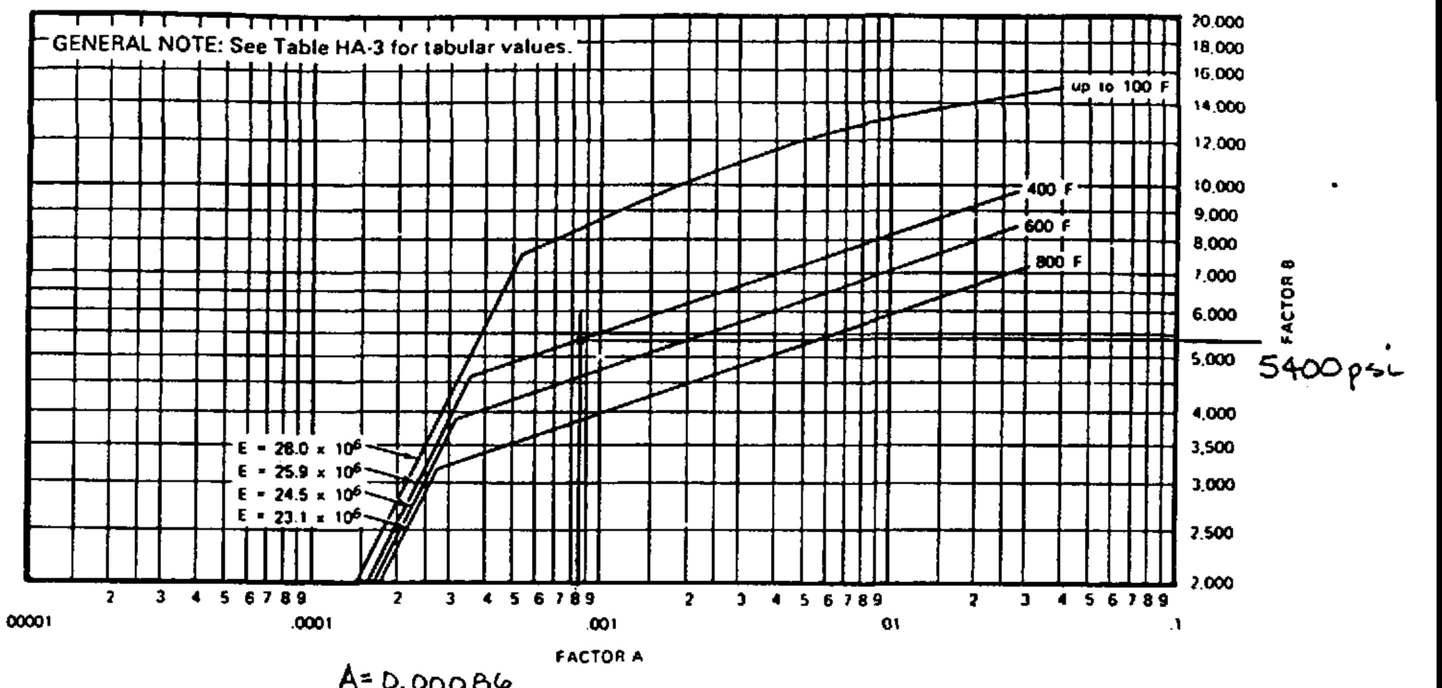


FIG. HA-3 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–0.035 MAXIMUM CARBON, TYPE 304L) [NOTE (1)]

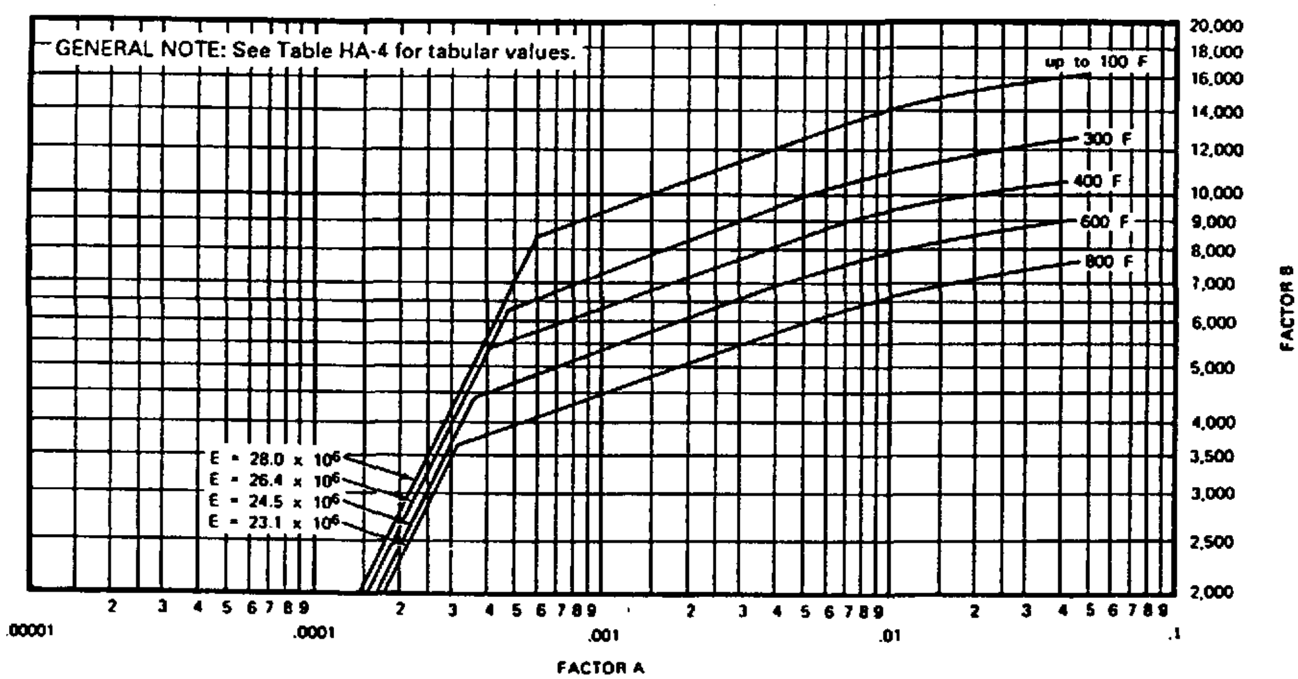


FIG. HA-4 CHART FOR DETERMINING SHELL THICKNESS OF COMPONENTS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18Cr–8Ni–Mo–0.035 MAXIMUM CARBON, TYPES 316L AND 317L) [NOTE (1)]

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

$$f_a = \frac{(14.7\ \#/in^2)(36.375\ in)}{2(.250\ in)} + \frac{624865\ in\text{-}lbs}{1028.5\ in^3}$$

$$= 1069.4\ \#/in^2 + 607.5\ lb/in^2$$

$$f_a = 1676.925\ lb/in^2$$

$$F_a = 5400\ lb/in^2$$

$$f_a < F_a \quad \therefore \quad \underline{O.K}$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-077
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 56
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_.....

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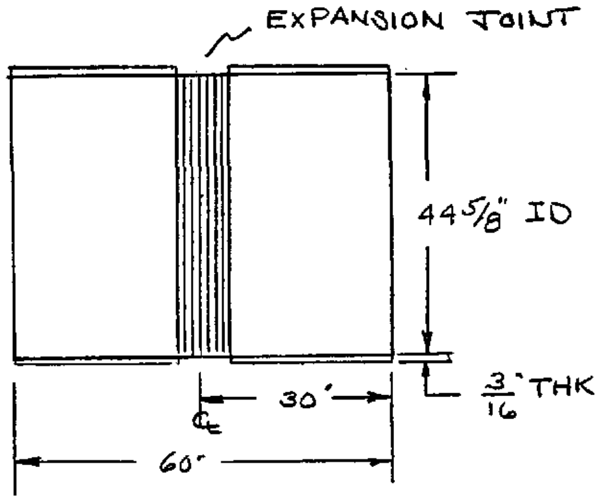
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

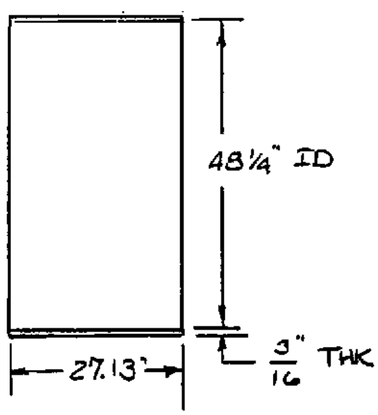
1.0 DESIGN SKETCH

SK-V049-1-077 REVO SHT 1 OF 4

1.1- ADAPTER / SPOOL A-1 REF: DWG. V049-4-A1



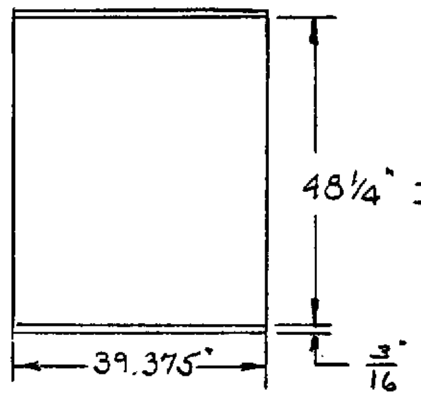
1.2. - ADAPTER / SPOOL A-2 REF: DWG. V049-4-A2



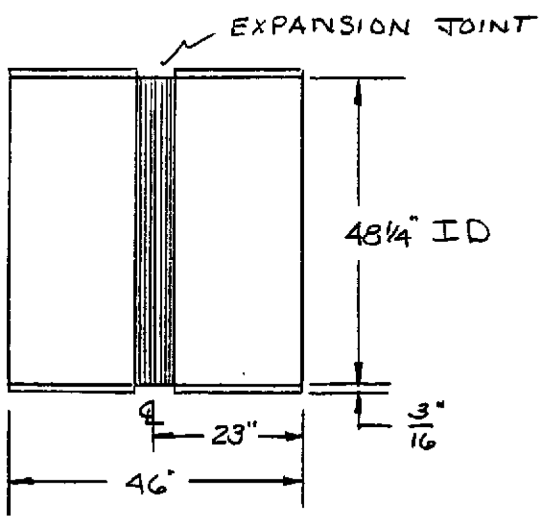
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

SK-V049-1-077 REV O 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

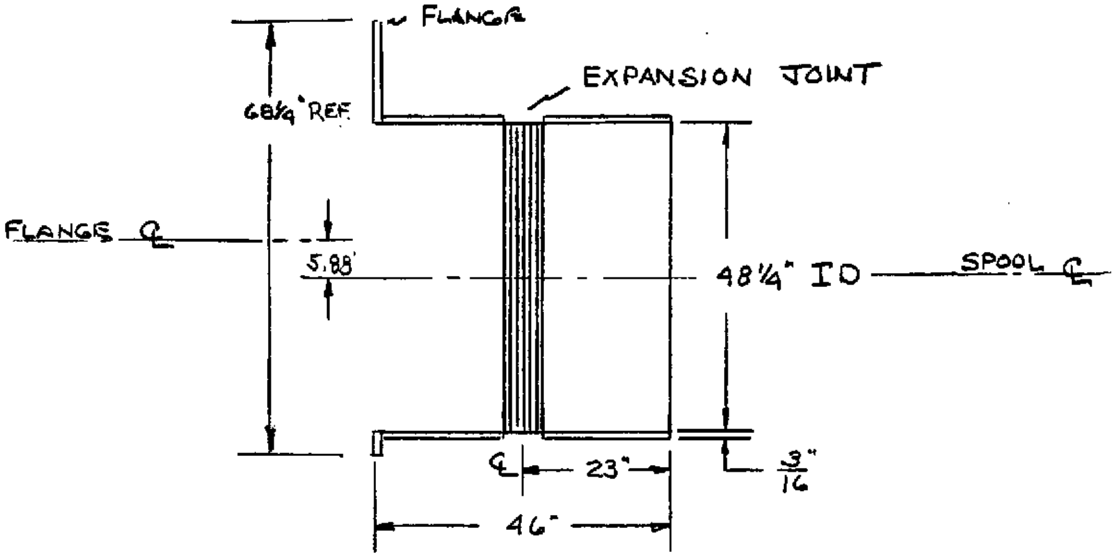


22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

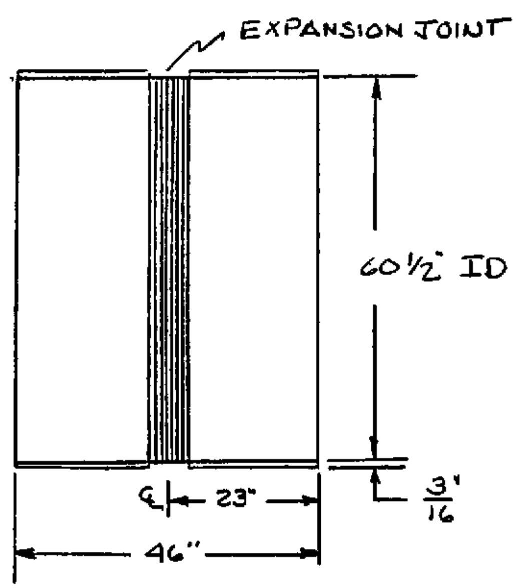
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

SK-V049-1-077 REVO SHT 3 OF 4

1.5. - ADAPTER/SPOOL A-12 REF: DWG. V049-4-A12



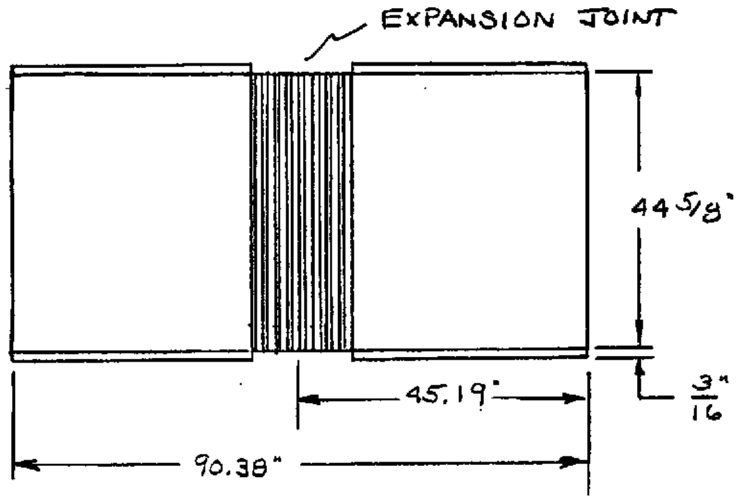
1.6. - ADAPTER / SPOOL A-13 REF: DWG. V049-4-A13



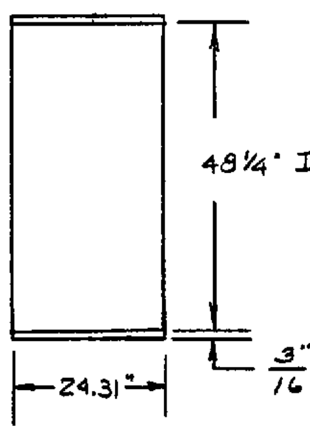
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

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



AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

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 PROJECTED EXPANSION JOINT AXIAL COMPRESSIVE CYLINDER/SPOOL PIECE STRESS VERSUS MAXIMUM ALLOWABLE LONGITUDINAL COMPRESSIVE STRESS PER ASME VIII, SECTION UG-23.

- PROJECTED 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 OF THE FOLLOWING:

1.- MAXIMUM ALLOWABLE TENSILE STRESS PER ASME II, PART D, SUBPART 1 σ_{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

σ_{ALLOW} = 5,800 PSI AT 400°F - FROM FIG. HA-3, ASME II, PART D, SUBPART 3

$\therefore \sigma_{APPLIED}$ = 536 PSI < σ_{ALLOW} = 5,800 PSI ∴ OK

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

2.2 • 48 1/4" ID FOR SPOOLS: A-2, A-3, A-6, A-12 + A-15

- WORSE CASE LENGTH = 46" FOR SPOOLS A-6 + A-12
- APPLIED LONGITUDINAL STRESS σ_{APP}:

$$\sigma_{APP} = \frac{\pi D_o (L \ldots)}{A_{METAL}} = \frac{\pi(48.25 + .375)(100)}{\pi/4(48.625^2 - 48.25^2)} = 535 \text{ PSI}$$

- ALLOWABLE LONGITUDINAL STRESS: σ_{ALLOW}

$\sigma_{ALLOW} = 5800 \text{ PSI} > \sigma_{APP} = 535 \text{ PSI} \therefore OK$

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 • 60 1/2" ID FOR SPOOL A-13

$$-\sigma_{APP} = \frac{\pi D_o \times 100}{A_{METAL}} = \frac{\pi(60.5 + .375)(100)}{\pi/4(60.875^2 - 60.5^2)} = 535 \text{ PSI}$$

$-\sigma_{ALLOW} = 6{,}700 \text{ PSI} > \sigma_{APP} = 535 \text{ PSI} \therefore OK$

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

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3.1

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-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.

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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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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
```

SPOOL A-1

```
Pa= 4*B/(3*Do/t)
  = 4*2954/(3*45/0.1875)
  = 16.4111 psi
```

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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	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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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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
```

SPOOL A-2

```
Pa= 4*B/(3*Do/t)
  = 4*4783.3/(3*48.625/0.1875)
  = 24.5928 psi
```

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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-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	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-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

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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
```

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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-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	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

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

Thickness Summary

Component Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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```
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
```

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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

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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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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
```

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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-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

Weight (lbs) Contributed by Vessel Elements

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	Load	Governing Status	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

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```
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
```

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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-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	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-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

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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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

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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 MDMT (deg F)	UCS-66 Exemption or Stress Reduction	Corrosion Allowance (in)
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	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-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 Identifier	ID (in)	Length (in)	Nom t (in)	Req t (in)	Joint E	Load	Governing Status	Stress	Deflect (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 17
REV.	DEO #	DATE	BY:	CHECK	TITLE: Design of Flexible Support	
0	002	4/12/96	ROC	WDB		
					BY:	DEPT.: 744

PROJECT: LIGO Vacuum Equipment	PROJECT NO: V59049

PURPOSE:. Analyze and evaluate supports for thermal expansion, weight, and seismic forces. Ensure that requirements of AISC Specification are met

METHOD: 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 .05625g.
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 Equip., Structural Design Criteria.

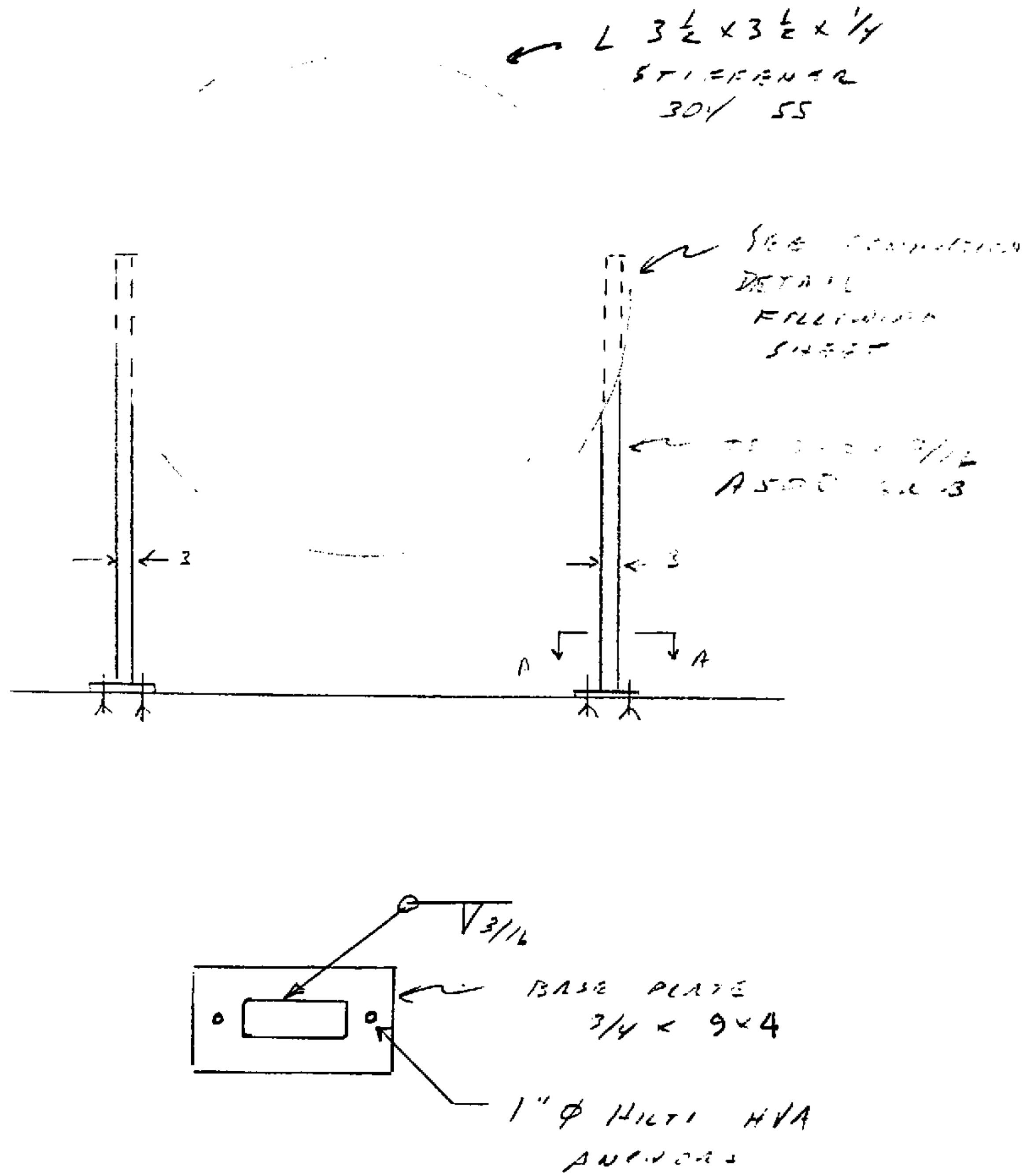
CALCULATIONS: (SEE ATTACHED)

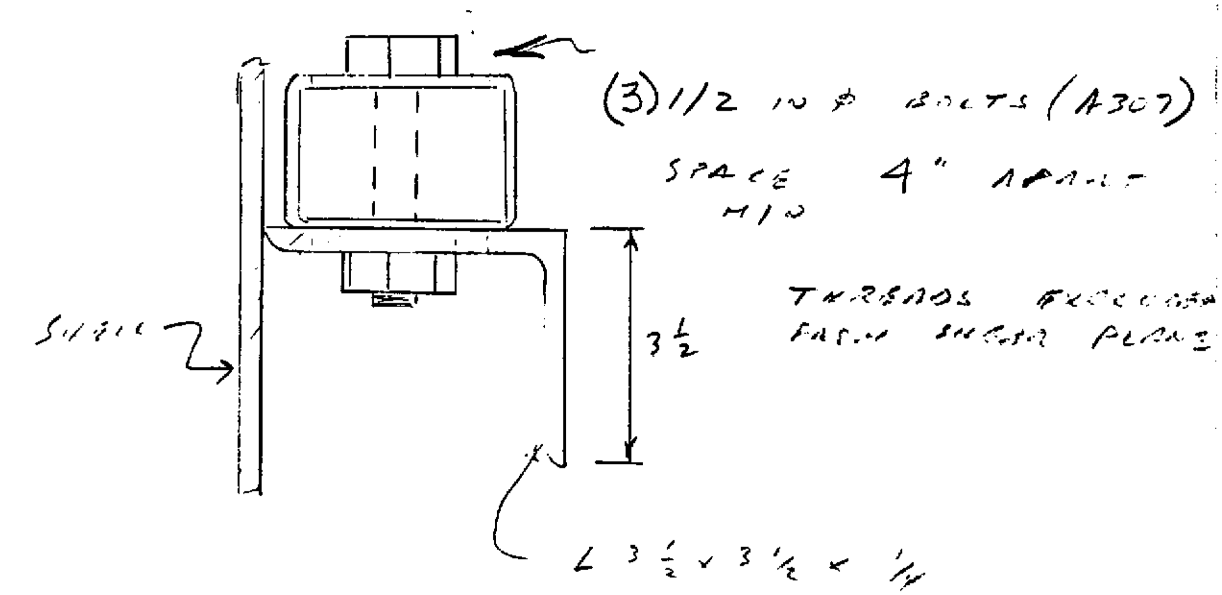
CONCLUSIONS: The requirements of the AISC Code are met. Axial growth of the shell is allowed by bending of the support leg columns without imposing stresses that are beyond the limits of the Code.

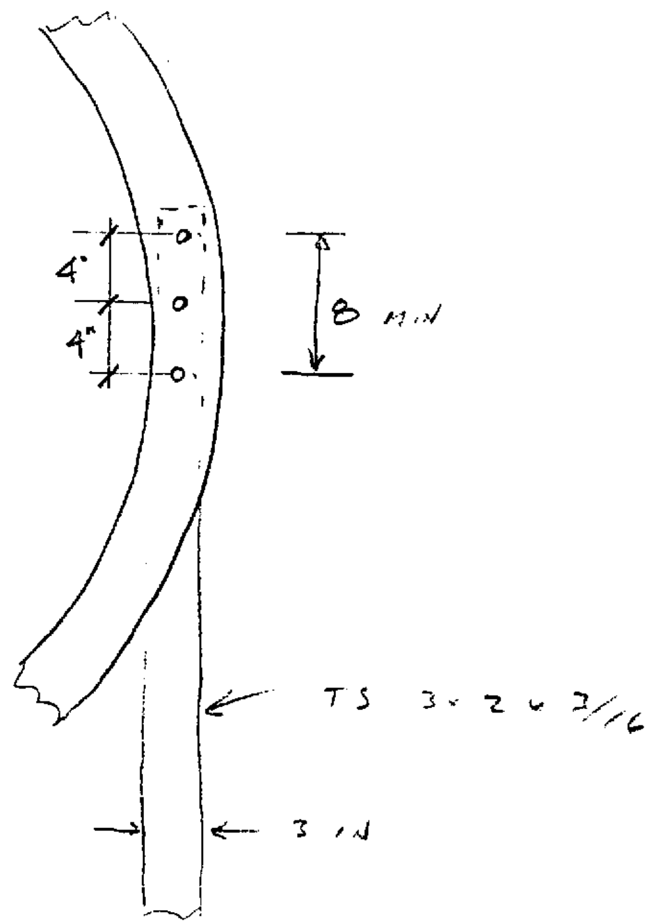
NOTES:

FILED:\F:\TEMPLATE\ENGFORMS\ENGCALC

SUPPORT LEGS ...
ADAPTER A-7




(3) 1/2 IN ⌀ BOLTS (A307)
SPACE 4" APART MIN
THREADS EXCLUDED FROM SHEAR PLANE
SHELL
3 1/2
∠ 3 1/2 x 3 1/2 x 1/4


4"
4"
8 MIN
TS 3 x 2 x 3/16
3 IN

ESTIMATED WT OF ADAPTER A-1

1 IN PLATE FOR 72.25 IN FLANGE

OD = 80.0 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

ASSUMED LENGTH IS FROM ABOVE PLATE TO END OF ADAPTER BEYOND THROUGH 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

42-141 50 SHEETS
42-142 100 SHEETS
42-144 200 SHEETS

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

$L_{A1} = 60$

$L_{A7} = 167$

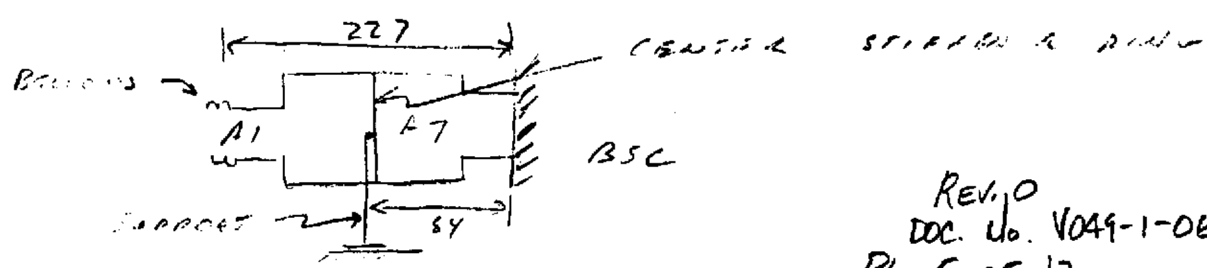
$L_T = 167 + 60 = 227$ IN

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



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Pg. 6 OF 17

100 SHEETS 200 SHEETS

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

$$f_b = \frac{M r_o}{I}$$

$$= \frac{419200\left(36.31 + \frac{.375}{2}\right)}{56400}$$

$$= 270 \text{ psi}$$

LOW

THERMAL GROWTH AT SUPPORT FROM CENTER OF BSC.

MAX TEMP

$$T = 400\,^{\circ}F$$

FROM ROOM TEMP

$$\Delta T = 400 - 70 = 330\,^{\circ}F$$

FROM PIPE AT 6[illegible] IN APART TO BSC ℄ THE DISTANCE IS

$$S = \frac{113.75}{2}$$ REF DWG V0[illegible]

$$= 57 \text{ IN}$$

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 *

$$\alpha = 9.19(10)^{-6} \frac{\text{IN}}{\text{IN}\,^{\circ}F}$$

$$\delta = 9.15(10)^{-6}(141)(330)$$

$$= .43 \text{ IN}$$

* ASME B&PV CODE SECT II TABLE TE-1 FOR 18 Cr - 8 Ni

REV. 0
Doc. No. V049-1-062

ASSUME THAT THE SUPPORT AT THE CENTER OF A7 RESISTS THE FULL WEIGHT LOAD, 9291 LB. ADD THE ION PUMP WT, 2250 LB. $W_T = 9291 + 2250 = 11541$ LB

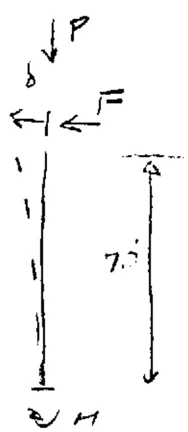
$$P = \frac{11541}{2} = 5770.5 \text{ LB IN EA. LEG}$$

$$= 5.77^K$$

TRY A TUBE STEEL COLUMN, TS 3x2x3/16

$$A = 1.64 \text{ in}^2$$

BEND IT ABOUT WEAK AXIS



$$I_y = .977$$

P_a = 26 K FOR KL = 6 FT
REF: AISC [illegible]

$$\delta = \frac{F l^3}{3EI}$$

$$F = \frac{3(29)(10)^6(.977)(.43)}{70^3}$$

$$= 107 \text{ LB}$$

$$M = F l = 107(70) = 7490 \text{ in-LB}$$

ALTERNATIVELY, IF THE STIFFENER RING RESTRAINS THE COLUMN FROM ROTATION, THE BENDING MOMENT WILL BE GREATER

$$M = \frac{6EI\delta}{l^2}$$

REF: GERE & WEAVER TABLE B-4

$$= \frac{6(29)(10)^6(.977)(.43)}{70^2}$$

$$= 14918 \text{ in LB}$$

42-142 100 SHEETS
42-144 200 SHEETS

BENDING STRESS IN COL

$$f_{b_y} = \frac{M}{S_y}$$

$$S_y = .977$$

$$f_{b_y} = \frac{14918}{.977} = 15.3 \text{ KSI}$$

FOR WEAK AXIS BENDING, ALLOWABLE STRESS IS

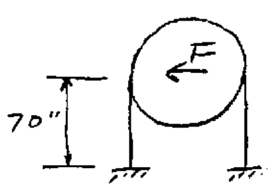
$$F_{b_y} = .66 F_y$$

$F_y = 46$ KSI FOR A500 GR B

$$F_{b_y} = .66(46)$$
$$= 30.4 \text{ KSI}$$

$$\frac{f_{b_y}}{F_{b_y}} = \frac{15.3}{30.4} = .50$$

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

$W_T = 11541$

$F = .05625(11541)$
$= 650$ LB

FOR EACH SUPPORT LEG THE LATERAL FORCE IS

$$F = \frac{650}{2} = 325 \text{ LB}$$

THE MAXIMUM BENDING MOMENT IS

$$M = 325(70)$$

$$= 22750 \text{ IN-LB}$$

FOR STRONG AXIS BENDING

$S_y = 1.24$ FOR TS 3x2x3/16

$$f_{by} = \frac{M}{S_y}$$

$$= \frac{22750}{1.24}$$

$$= 18350 \text{ psi}$$

MAX LATERAL DEFLECTION

$$\Delta = \frac{F L^3}{3 E I_y}$$

$I_y = 1.86 \text{ IN}^4$

$$\Delta = \frac{325(70)^3}{3(29)(10)^6(1.86)}$$

$$= .69 \text{ IN}$$ 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

$$M = 14918 + 5770(.43)$$

$$= 14918 + 2438$$

$$= 17405$$

$$f_{b_y} = \frac{M}{S_y}$$

$$= \frac{17356}{.977} =$$

$$= 17,800 \text{ psi} = 17.8 \text{ ksi}$$

$$\frac{f_a}{F_a} = \frac{P}{P_{cr}} = \frac{5.8}{26} = .22 > .15$$

∴ USE EQ H1-1 & H1-2 OF AISC CODE

$$\frac{f_a}{.60 F_y} + \frac{f_b}{F_{bx}} + \frac{f_{b_y}}{F_{b_y}} < 1.0 \quad (H1-2)$$

$$f_a = \frac{P}{A}$$

$$A = 1.64$$

$$f_a = \frac{5.8}{1.64} = 3.5 \text{ ksi}$$

$$\frac{3.5}{.60(46)} + 0 + \frac{17.8}{30.4}$$

$$= .13 + 0 + .63 = .76 < 1.0 \quad (H1-2)$$

OK

Rev. O
Doc No V049-1-062

50 SHEETS 100 SHEETS 200 SHEETS

AMPLIFICATION FACTOR FOR EQ H1-1

$$\frac{K\ell_b}{r_b} = \frac{1.0\,(70)}{.771} \quad K = 1.0 \text{ CONSERVATIVE}$$

$r_b = r_y$ FOR PLANE OF BENDING.

$$\frac{K\ell_b}{r_b} = 91$$

$F'_e = 18.03$ KSI TABLE 8, AISC

$$\frac{f_a}{F'_{ey}} = \frac{3.5}{18.03} = .19$$

$$1 - \frac{f_a}{F'_{ey}} = 1 - .19 = .81$$

$$C_{my} = 1.0$$

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_{by}} \le 1.0 \quad \text{EQ H1-1}$$

$$.22 + 0 + \frac{1.0\,(19.1)}{(.81)\,30.4}$$

$$= .22 + 0 + .78 = 1.0 \quad \text{OK}$$

∴ TS 3x2x3/16 IS ACCEPTABLE FOR NORMAL LOAD CONDITION

50 SHEETS
42-142 100 SHEETS
42-144 200 SHEETS

EVALUATE TUBE STEEL SUPPORT LEGS FOR NORMAL PLUS SEISMIC LOAD

ADD P-Δ EFFECT FOR SEISMIC FORCE

$$M = 22700 + 11541(.68)$$

$$= 22700 + 7848$$

$$= 30600$$

$$f_{bx} = \frac{30600}{1.24}$$

$$= 24676 \text{ psi}$$

$$\frac{KL_b}{r_b} = \frac{1.0(70)}{1.38} = 50.7$$

$$F'_e = 58$$

$$\frac{f_a}{F'_{ex}} = \frac{3.5}{58} = .06$$

$$1 - \frac{f_a}{F'_{ex}} = .94$$

GET F_{bx}

$$\frac{b}{t} = \frac{2}{3/16} = 10.67 < \frac{190}{\sqrt{F_y}} = \frac{190}{\sqrt{46}} = 28$$

FROM AISC, TABLE B5.1, TS 3×3×3/16 is COMPACT

FROM AISC, EQ F3-2

$$L_{c_{MIN}} = 1950\frac{b}{F_y} = \frac{1950(2)}{46} = 85$$

$$> L_b = 70$$

$$\therefore \quad F_{bx} = .66 F_y$$

100 SHEETS 200 SHEETS

$F_{by} = .66(46)$ FOR A500 GR B

$= 30.4$ KSI

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F'_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F'_{ey}}\right) F_{by}} < 1.33$$

$C_{mx} = 1.0$

$$.22 + \frac{1.0(24.7)}{.94(30.4)} + .72$$

$$.22 + .86 + .72 = 1.80 > 1.33$$

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

$$C_{my} = .6 - .4(1.0) = .2$$

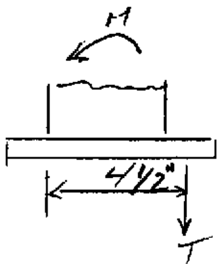
$$.22 + .86 + .2(.72) = 1.22 < 1.33$$ OK

ALSO NOTE - THE PROBABILITY OF AN EARTHQUAKE DURING BAKEOUT IS EXTREMELY LOW

50 SHEETS 100 SHEETS 200 SHEETS

ANCHOR BOLT

THE ANCHOR RESISTS THE STRONG AXIS SEISMIC MOMENT



$M = 30600$

$4\frac{1}{2}T = M$

$T = 6.8\ K$

ADD 20% TO ACCOUNT FOR PRYING

$T = 1.2(6.8)$

$= 8.16\ K$

USE 1 IN HILTI HVA ADHESIVE ANCHORS

$T_{ALL} = 10.96\ K > T = 8.16$

SEE CALC V049-1-[illegible], P. 27

MAX SHEAR

$V = \frac{325}{2} = .163\ K$

$V << V_{ALL} = 7.63\ K$ ok

BOLTS FOR UPPER CONNECTION OF [illegible]
TO STIFFENER

TRY 3 - 1/2" Ø BOLTS IN BEARING
WITH THREADS EXCLUDED FROM SHEAR
PLANE

$$A_B = \pi(.25)^2$$
$$= .196 \text{ SHEAR AREA}$$

FOR WEIGHT

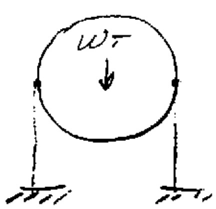
$$f_v = \frac{P}{3A_B}$$
$$= \frac{5.7}{3(.196)}$$
$$9.69 \text{ KSI} < 14$$

OK FOR A307

BEARING

$$A_p = 1/4\,(1/2) = .125$$

$$f_p = \frac{5.7}{3(.125)} = 15.2 \text{ KSI} < .9\,F_y \text{ OK}$$



SEISMIC STRESSES ARE LOW

BOLTS CONT

FOR BENDING DUE TO THERMAL EXP

$M = 14918$ (NO P-Δ AT TOP OF LEG)

FOR 8 IN SPACING BOLT TENSION IS

$$T = \frac{M}{8(1)} = \frac{14918}{8(1)}$$

$= 1.86$ K PER BOLT

TENSILE STRESS AREA

$A_T = .142\ \text{in}^2$ AISC P 4-47

$$f_t = \frac{1.86}{.142} =$$

$= 13.1$ KSI ok

$13.1 < 20.0$ KSI

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-086
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 9
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:

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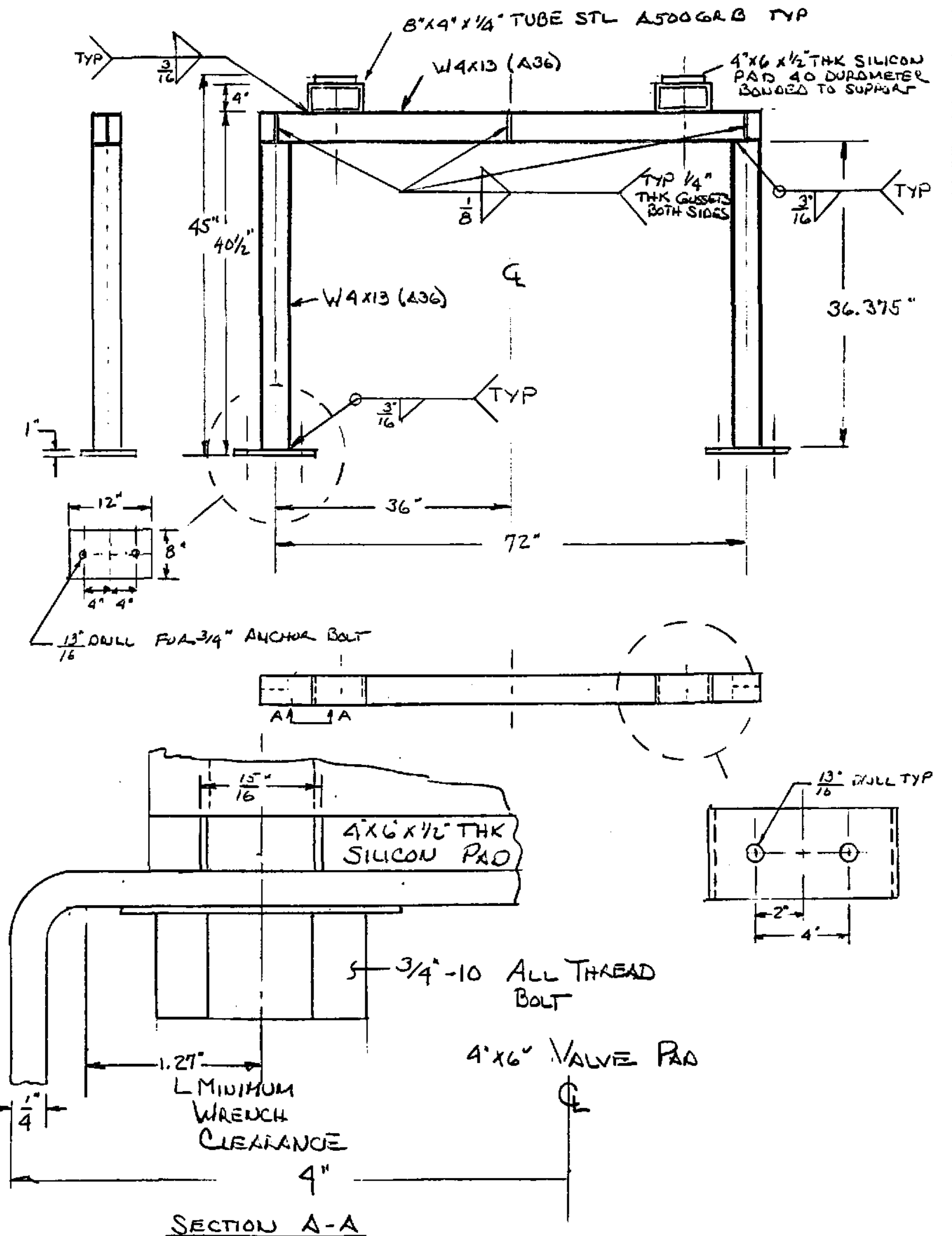
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

1.0 - DESIGN SKETCH
SK-V049-1-086, REV 0



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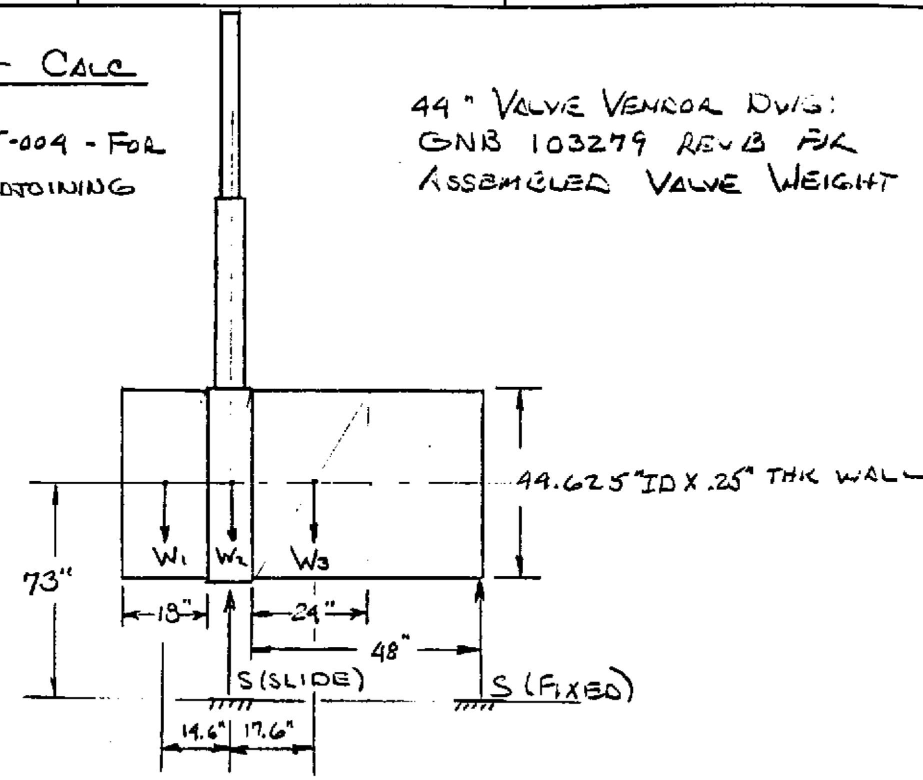
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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



$W_1 = \pi/4\,(45.125^2 - 44.625^2)(18)(.283) = 180$#

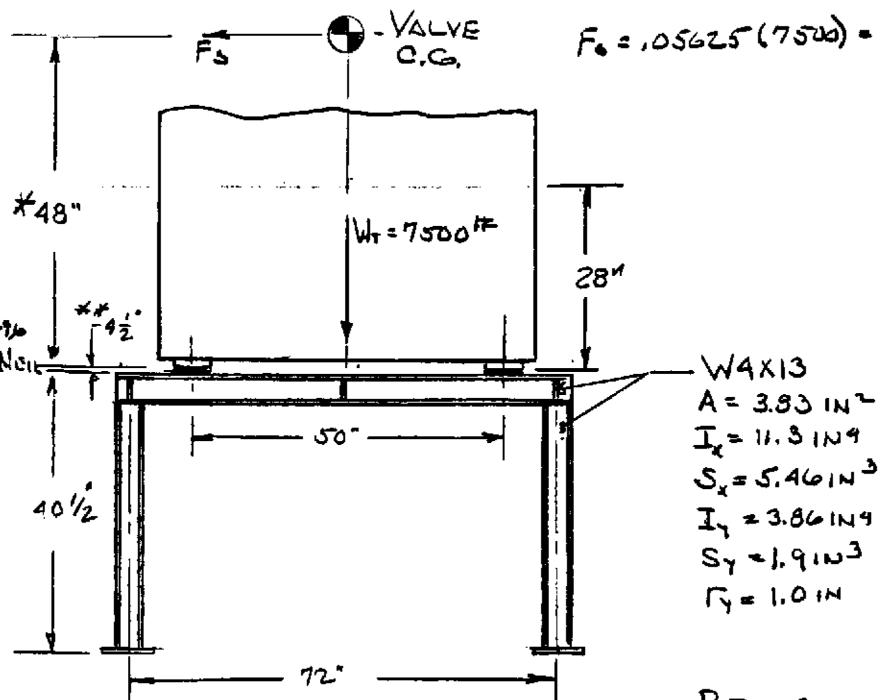
$W_2 = 7000$# (ASSEMBLED VALVE WEIGHT)

$W_3 = \pi/4\,(45.125^2 - 44.625^2)(24)(.283) = 239$#

$\Sigma W = 180 + 7000 + 239 = 7{,}419$#

- USE 7500# FOR SUPPORT DESIGN

$F_s = .05625(7500) = 422$#



* NOTE:
48" C.G. LOCATION FOR 44" VALVE IS PER TELECON ON 4-11-96 WITH GNB SHAWN McNEIL

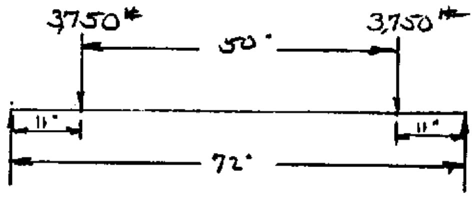
** SEE DESIGN SKETCH FOR ACTUAL SUPPORT DETAIL

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

3. – HORIZONTAL W4X13 BEAM SUPPORT

MODEL:

· DEADWEIGHT



REF: BLODGETT, CASE 3AC, P. 8.1-6

$M_{MAX} = 11(3750) = 41,250$ IN-#

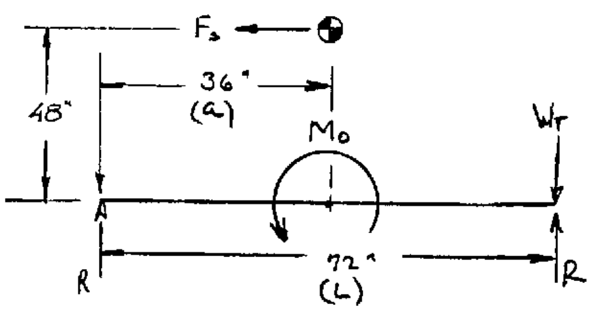
$\sigma_{MAX} = .6 S_y = .6(36,000) = 21,600$ PSI

$\therefore\ S_{REQ} = \dfrac{M_{MAX}}{\sigma_{MAX}} = \dfrac{41,250}{21,600} = 1.91\ IN^3$

$S_{ACTUAL} = 5.46\ IN^3 > 1.91\ IN^3$ ∴ OK

$\sigma_{ACTUAL} = \dfrac{41,250}{5.46} = 7,555$ PSI $= \sigma_{DW}$

· LATERAL SEISMIC



$M_o = 48(422) = 20,256$ IN-#

WHERE: $F_s = 422$#

$R = M_o/L = 20,256/72 = 281$#

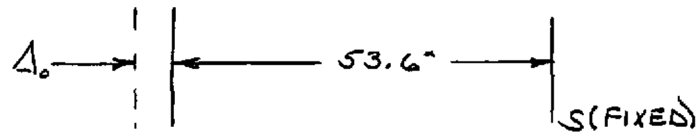
$W_T = 7419/2 - 281 = 3428$# (COMPRESSION)

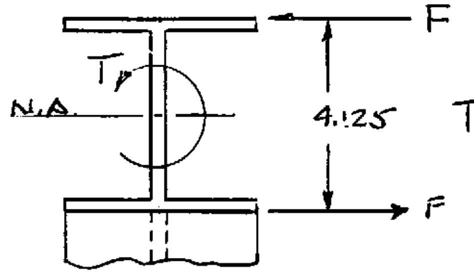
REF: BLODGETT, CASE 3Eb, P. 8.1-10

$M_{MAX} = \dfrac{M_o a}{L} = \dfrac{(20,256)(36)}{(72)} = 10,128$ IN-#

$\sigma_{SEIS} = \dfrac{10128}{5.46} = 1,855$ PSI

• Torsion Due To Thermal Expansion Loads





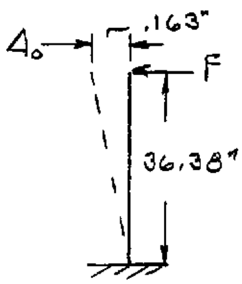
$T = 4.125 F_{TH} = 4.125(2274) = 9380$ IN-#

$\Delta_o = \alpha L \Delta T = 9.19 \times 10^{-6} (53.6)(330) = .163"$

WHERE: $\alpha = 9.19 \times 10^{-6}$ IN/IN/°F AT 400°F

MODEL: - DEFLECTION DUE TO THERMAL MOVEMENT: .163"

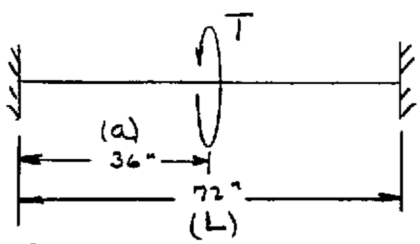
REF: BLODGETT, CASE 1Aa, P. 3.1-3



$\Delta_o = \frac{FL^3}{3EI}$

$F_{TH} = \frac{3EI\Delta_o}{L^3} = \frac{3(29 \times 10^6)(2 \times 3.86)(.163)}{(36.38)^3} = 2274$ #

MODEL: - TORSIONAL STRESS



REF: BLODGETT, CASE 3, P. 8.2-1

$\tau_T = \frac{Ta}{L} = \frac{9380(36)}{72} = 4690$ PSI.

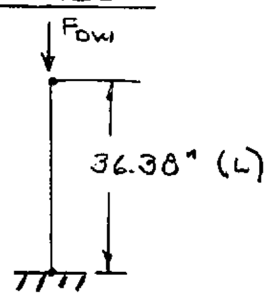
- COMBINING STRESSES - FOR HORIZONTAL BEAM SUPPORT
  - BY SUPERPOSITION:

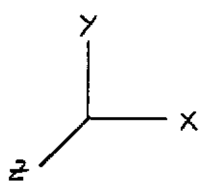
$\sigma = \sigma_{DW} + \sigma_{SEISMIC} = 7555 + 1855 = 9410 < .6S_Y \therefore OK$

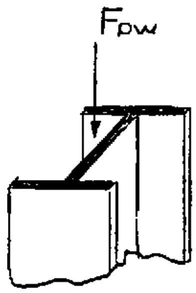
$\tau = 4{,}690\ PSI < .4S_Y = 14{,}400\ PSI \therefore OK$

4. - VERTICAL W4X13 COLUMN SUPPORT

MODEL:







$$\frac{KL}{r} = \frac{(1.0)(36.38)}{1.0} = 36.38$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

4. - 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

$$\frac{KL}{r} = 36.38$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2(\pi^2)(29 \times 10^6)}{(36{,}000)}} = 126$$

$KL/r < C_c$

$$\therefore F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right]F_y}{\frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}}$$

$$F_a = \frac{\left[1 - \frac{(36.38)^2}{2(126)^2}\right](36{,}000)}{\frac{5}{3} + \frac{3(36.38)}{8(126)} - \frac{(36.38)^3}{8(126)^3}} = 19{,}470 \text{ PSI} > \sigma_A = 979 \text{ PSI}$$

$\therefore$ 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

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

<table>
<tr><td colspan="5">PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA</td><td>ENGINEERING
CALCULATIONS</td><td>NO: V049-1-087
PAGE 1 OF 48</td></tr>
<tr><td>REV.</td><td>DEO #</td><td>DATE</td><td>BY:</td><td>CHECK</td><td colspan="2" rowspan="4">TITLE:
Design of Generic Support Scheme for:
Mode Cleaner Tubes B-5, B-2 & B-3</td></tr>
<tr><td>0</td><td>0024</td><td>4/5/96</td><td>WDB</td><td>AGR</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>BY: W. [signature]</td><td>DEPT.: 744</td></tr>
<tr><td colspan="5">PROJECT: LIGO Vacuum Equipment</td><td colspan="2">PROJECT NO: V59049</td></tr>
</table>

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 Assume anchor points are fixed but released for Mz (about the out-of-plane moment)

INPUTS: Vessel wght = 6437.0 lbs, Flange wght = 1539.0 lbs
External Nozzle Loads:
Pr = 2250.0 lbs, Mc = Ml = 4542.0 in-lbs, Vc = Vl = 126.5 lbs,
Seismic Acceleration = 0.05625 g.

REFERENCES:
1. STAAD-III release 21, Research Engineers
2. COMPRESS - Computer Aided Vessel Design program - version 5.53
3. ASD - AISC 9th edition
4. Doc. No. V049-1-066, LIGO Vacuum Equip., Struct. Des. Criteria

CALCULATIONS: V049-1-057 - 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: B5MDCLNR.*

DISCUSSION

Mode Cleaner Tubes

Support Scheme

Step 1 - B-5 due to its external loading from ion pumps and portable roughing pumps was used for designing generic support schemes for all mode cleaner tubes i.e. B-5, B-2 & B-3. Anchorage was preferred at midspan but due to limited space at the pipe bridge the anchor location was not at mid span but rather as near to the pipe bridge as permissible due to the " stay clear zone ".

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.

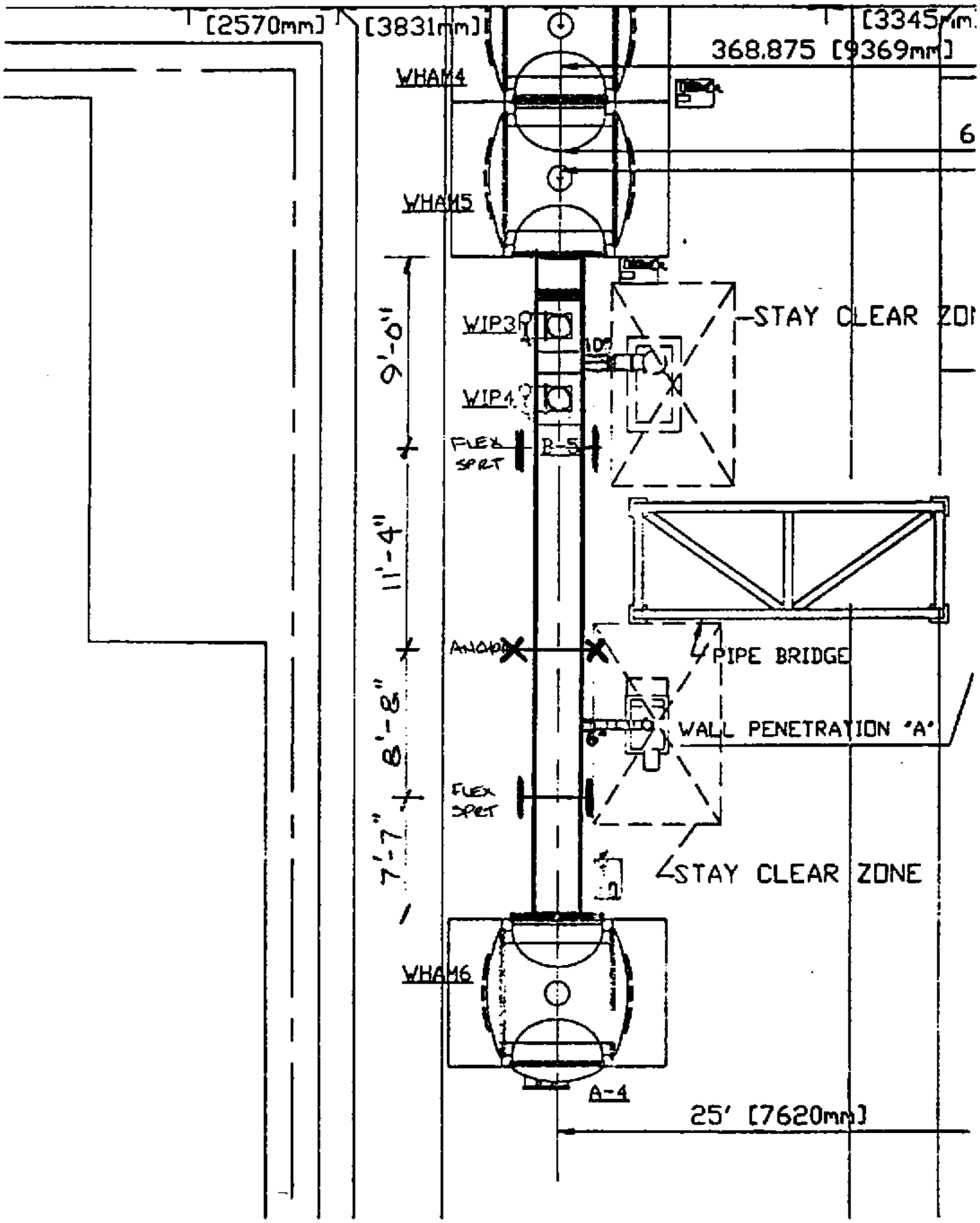
Step 3 - A finite element model which includes the properties of the mode cleaner tube shell and the support frame was generated using the STAAD structural design computer program.

Step 4 - Applicable loading conditions were determined. These included; deadweight for vessel and flanges, unbalanced vacuum pressure loads at pump nozzles, uniform thermal load for the Mode Cleaner Tube, and seismic factors.

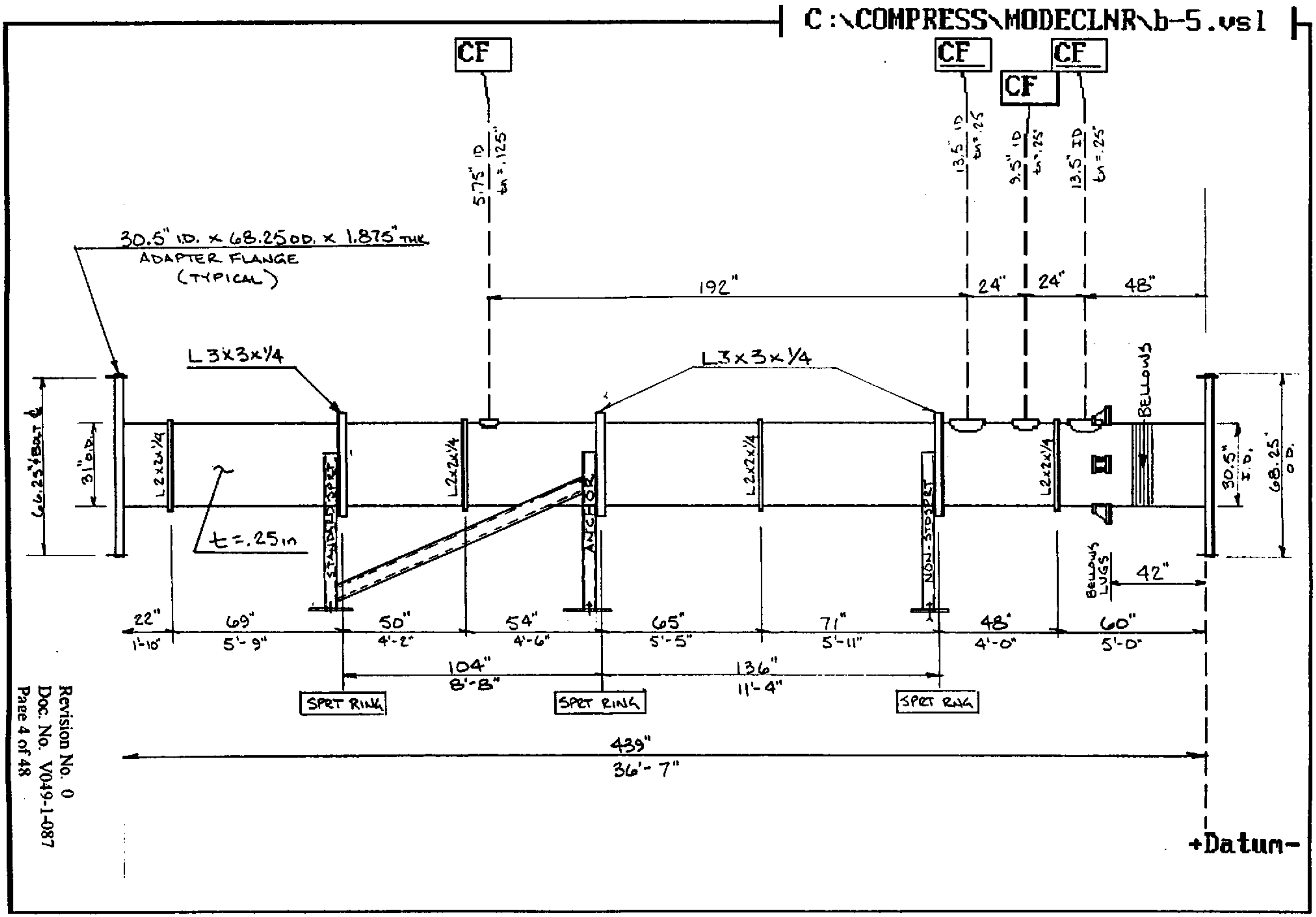
Step 5 - Computer output results were evaluated.

Step 6 - Using computer generated forces and reactions, anchors, baseplates and bolted connections (support legs to vessel stiffener rings) were designed.

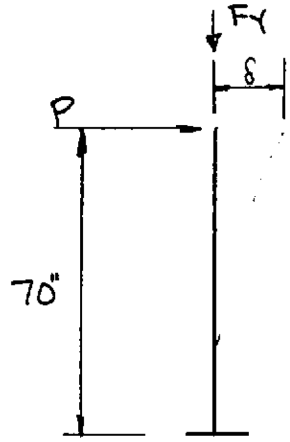
MODE CLEANER TUBE B-5



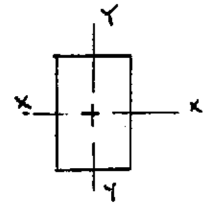
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS


C:\COMPRESS\MODECLNR\b-5.vsl
CF
CF
CF
CF
5.75" ID
tn = .125"
13.5" ID
tn = .25
9.5" ID
tn = .25
13.5" ID
tn = .25"
30.5" I.D. x 68.25 OD. x 1.875" THK
ADAPTER FLANGE
(TYPICAL)
192"
24"
24"
48"
L3x3x1/4
L3x3x1/4
BELLOWS
66.25" BOLT ℄
31" O.D.
L2x2x1/4
L2x2x1/4
L2x2x1/4
L2x2x1/4
t = .25in
STANDOFF SPRT
ANCHOR
NON-STDSPRT
30.5" I.D.
68.25" O.D.
BELLOWS LUGS
42"
22"
1'-10"
69"
5'-9"
50"
4'-2"
54"
4'-6"
65"
5'-5"
71"
5'-11"
48"
4'-0"
60"
5'-0"
104"
8'-8"
136"
11'-4"
SPRT RING
SPRT RING
SPRT RING
439"
36'-7"
+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.

$$f_b = \frac{M_y}{S_y} \Rightarrow M_y = \frac{6 E I_y \delta}{L^2}$$

ref. Gere & Weaver
Table B-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 PTS. 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".

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(104")$$

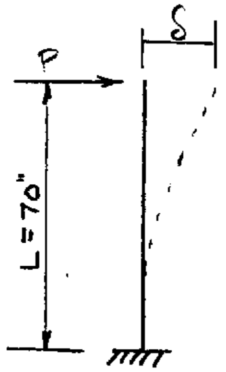
$$= .315 \text{ IN.} \quad (0.30858 \text{ STAAD MODEL})$$

δ_{THERM} WHERE L = 136 IN

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ IN/IN°F})(330°F)(136 \text{ IN})$$

$$= .412 \text{ IN} \quad (0.41925 \text{ STAAD MODEL})$$

EQUIVALENT FORCE DUE TO DISPLACEMENT ASSUMING A CANTILEVER



USING T.S. 3x2x3/16

$I_{yy} = .977 \text{ IN}^4$

$$\delta = \frac{PL^3}{3 E I_y} \Rightarrow P = \frac{(\delta) 3 E I_y}{L^3}$$

$$P = \frac{\delta (3)(29000000. \text{\#/in}^2)(.977 \text{ IN}^4)}{(70 \text{ IN})^3}$$

δ .315 in $\Rightarrow$ P = 78 lbs.

δ .412 in $\Rightarrow$ P = 102 lbs.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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#/in

= FLANGE WEIGHT = 1539. lbs

2. D.W + VACUUM + THERMAL

VACUUM PRESSURE = UNBALANCED LOADS @ PORTABLE MAIN ROUGHING PUMPS

@ 10" φ NOZZLE

$$F = PA = (14.7\#/in^2)(\pi D^2/4)$$
$$= (14.7\#/in^2)(\pi (9.5 in)^2/4)$$
$$= 1042 \text{ lbs}$$

@ 6" φ NOZZLE

$$F = (14.7\#/in^2)(\pi (5.75 in)^2/4)$$
$$= 382. \text{ lbs.}$$

D.W = LOAD CASE #1

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)(0.5625 g) = 0.825
(UNIFORM LOAD for Shell)

SEISMIC AXIAL = 126.5#. @ NOZZLES 16"φ = Fx
= 4542 in·lbs @ NOZZLES 16"φ = Mz

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

4. D.W. + VACUUM PRESSURE + THERMAL + SEISMIC LATERAL

D.W. + VACUUM PRESSURE + THERMAL DISP = LOAD CASE #2

SEISMIC LATERAL = 0.825 factor for uniform LOAD LATERAL @ SHELL

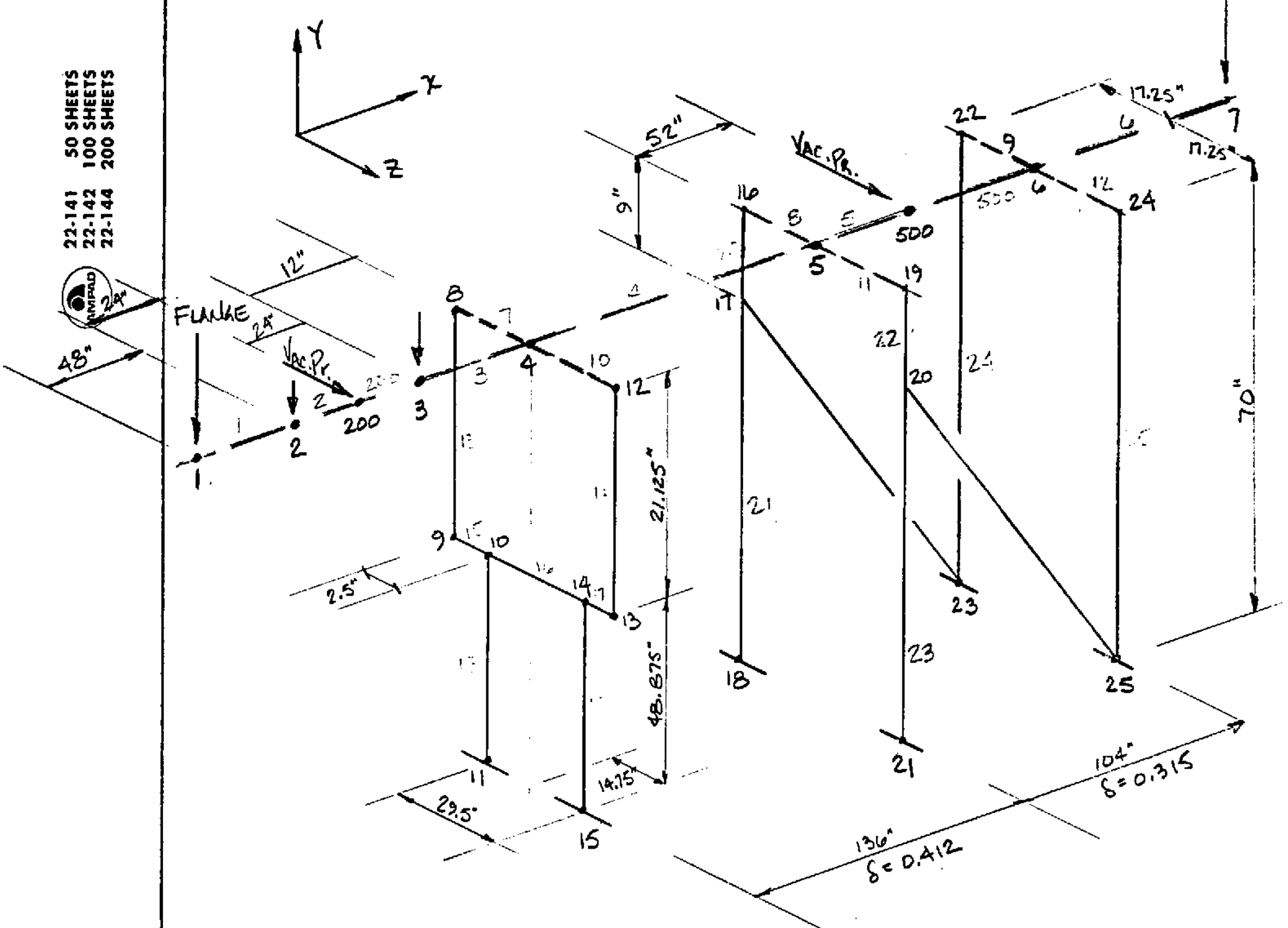
SEISMIC LATERAL = 126.5* @ 16" NOZZLES (2) = Fz

= 4542 in-lbs @ 16" NOZZLES (2) = Mx

STAAD MODEL

———— = VESSEL

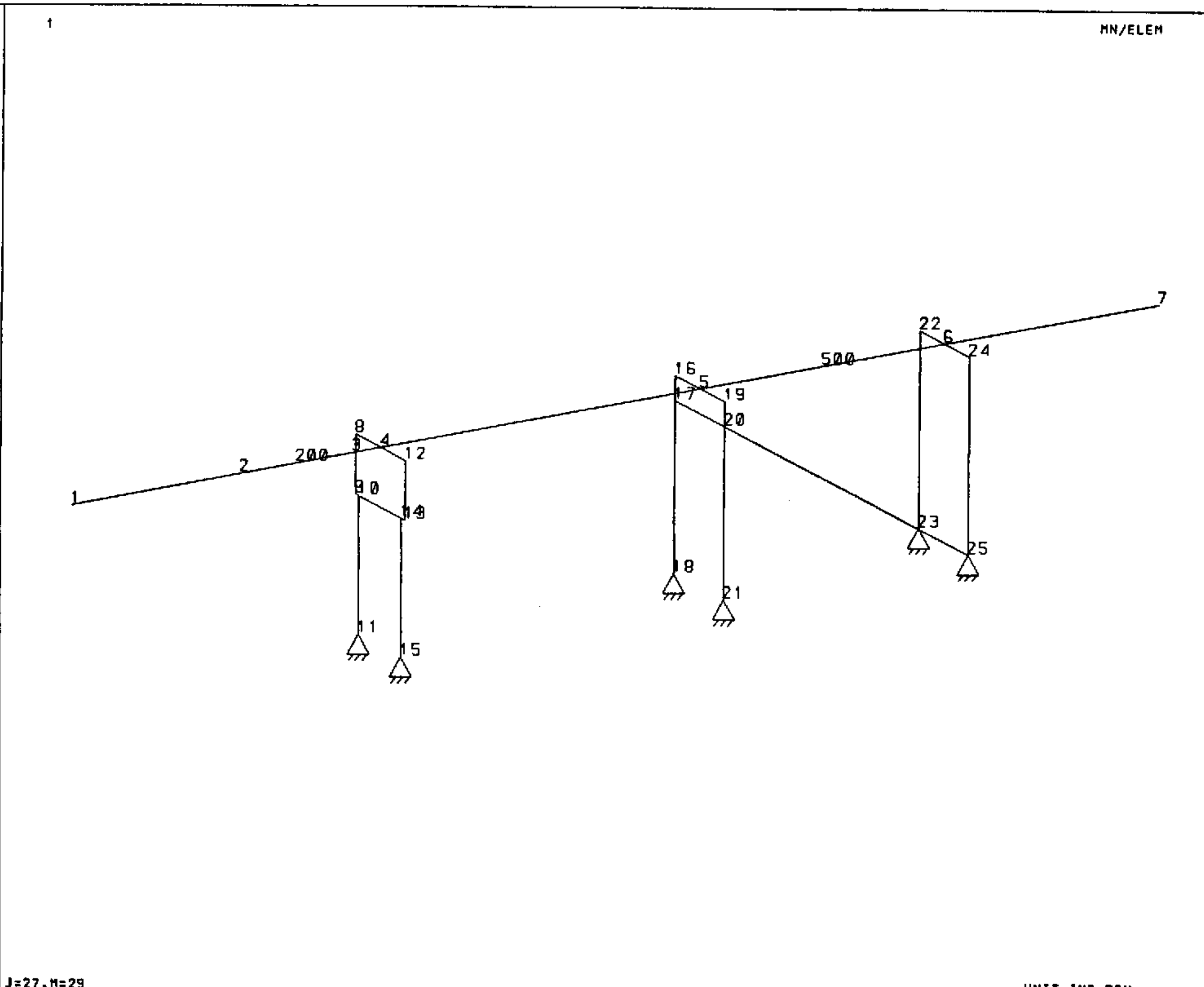
———— = STRUCTURAL MEMBERS (FRAME SUPPORT)



22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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

S T A A D P O S T - P L O T (REV: 21.0)

TITLE: B5 MODE CLEANER TUBE SUPPORTS

DATE: MAR 28, 1996

```
**************************************************
*                                                *
*           S T A A D - III                      *
*           Revision 21.0                        *
*           Proprietary Program of               *
*           Research Engineers, Inc.             *
*           Date=    APR  4, 1996                *
*           Time=    11: 7:46                    *
*                                                *
*      USER ID: Process Systems International    *
**************************************************
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 1. STAAD SPACE B5 MODE CLEANER TUBE SUPPORT
 2. INPUT WIDTH 72
 3. UNIT INCHES POUND
 4. JOINT COORDINATES
 5. 1 -24. 0. 0.; 2 48. 0. 0.; 3 96. 0. 0.; 4 108. 0. 0.; 5 244. 0. 0.
 6. 6 348. 0. 0.; 7 439. 0. 0.; 8 108. 0. -17.25; 9 108. -21.125 -17.25
 7. 10 108. -21.125 -14.75; 11 108. -70. -14.75; 12 108. 0. 17.25
 8. 13 108. -21.125 17.25; 14 108. -21.125 14.75; 15 108. -70. 14.75
 9. 16 244. 0. -17.25; 17 244. -9. -17.25; 18 244. -70. -17.25
10. 19 244. 0. 17.25; 20 244. -9. 17.25; 21 244. -70. 17.25
11. 22 348. 0. -17.25; 23 348. -70. -17.25; 24 348. 0. 17.25
12. 25 348. -70. 17.25; 200 72. 0. 0.; 500 296. 0. 0.
13. MEMBER INCIDENCES
14. 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
15. 19 14 15; 18 10 11; 17 13 14; 16 14 10; 8 5 16; 20 16 17; 22 19 20
16. 23 20 21; 9 6 22; 24 22 23; 12 6 24; 25 24 25; 26 17 23; 27 20 25
17. 21 17 18; 11 5 19; 2 2 200; 200 200 3; 5 5 500; 500 500 6
18. MEMBER PROPERTY AMER
19. 13 TO 15 19 18 17 16 20 22 TO 27 21 TABLE ST TUB30203
20. 7 10 8 9 12 11 TABLE ST TUB80805
21. 1 TO 6 200 500 TABLE ST PIPE OD 31. ID 30.5
22. MEMBER RELEASE
23. 13 14 20 22 24 25 START MX MY MZ
24. 7 TO 12 END MX MY MZ
25. CONSTANTS
26. E STEEL ALL
27. POISSON STEEL ALL
28. DENSITY STEEL ALL
29. BETA 90. MEMB 13 14 19 18 20 22 TO 25 21
30. ALPHA 0.00000919 MEM 1 TO 6 200 500 7 TO 12
31. SUPPORTS
32. 11 15 18 21 23 25 FIXED BUT MZ
33. LOAD 1 DW
34. JOINT LOAD
35. 1 7 FY -1539.
36. 2 3 FY -2250.
37. MEMBER LOAD
38. 1 TO 6 200 500 UNI Y -14.66
39. LOAD 2 DW+TH+VACUUM
40. JOINT LOAD
41. 1 7 FY -1539.
```

```
42. 2 3 FY -2250.
43. 200 FZ 1042.
44. 500 FZ 382.
45. MEMBER LOAD
46. 1 TO 6 200 500 UNI Y -14.66
47. TEMPERATURE LOAD
48. 1 TO 6 200 500 7 TO 12 TEMP 330.
49. LOAD 3 DW+TH+VACUUM+SEIS-AXIAL
50. JOINT LOAD
51. 1 7 FY -1539.
52. 2 3 FY -2250.
53. 200 FZ 1042.
54. 500 FZ 382.
55. 2 3 FX -126.5
56. 2 3 MZ 4542.
57. 1 7 FX -86.5
58. MEMBER LOAD
59. 1 TO 6 200 500 UNI Y -14.66
60. 1 TO 6 200 500 UNI X -0.825
61. TEMPERATURE LOAD
62. 1 TO 6 200 500 7 TO 12 TEMP 330.
63. LOAD 4 DW+TH+VACUUM+SEIS-LAT
64. JOINT LOAD
65. 1 7 FY -1539.
66. 2 3 FY -2250.
67. 200 FZ 1042.
68. 500 FZ 382.
69. 2 3 FZ 126.5
70. 2 3 MX 4542.
71. 1 7 FZ 86.5
72. MEMBER LOAD
73. 1 TO 6 200 500 UNI Y -14.66
74. 1 TO 6 200 500 UNI Z 0.825
75. TEMPERATURE LOAD
76. 1 TO 6 200 500 7 TO 12 TEMP 330.
77. LOAD 5 THERM DISPL "BAKEOUT"
78. TEMPERATURE LOAD
79. 1 TO 6 200 500 7 TO 12 TEMP 330.
80. 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 =   132
SIZE OF STIFFNESS MATRIX =    4092 DOUBLE PREC. WORDS
REQRD/AVAIL. DISK SPACE =  12.07/  486.9 MB,  EXMEM =  1.02 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.                 11: 7:47
++ PROCESSING GLOBAL STIFFNESS MATRIX.                  11: 7:47
++ PROCESSING TRIANGULAR FACTORIZATION.                 11: 7:47
++ CALCULATING JOINT DISPLACEMENTS.                     11: 7:47
++ CALCULATING MEMBER  FORCES.                          11: 7:47
```

81. 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 ************

82. PRINT MEMBER INFORMATION ALL

MEMBER INFORMATION

MEMBER	START JOINT	END JOINT	LENGTH (INCH)	BETA (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	000000000111
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	000000000111
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	000000000111
20	16	17	9.000	90.00	000111000000
22	19	20	9.000	90.00	000111000000
23	20	21	61.000	90.00	
9	6	22	17.250	0.00	000000000111
24	22	23	70.000	90.00	000111000000
12	6	24	17.250	0.00	000000000111
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	90.00	
11	5	19	17.250	0.00	000000000111
2	2	200	24.000	0.00	
200	200	3	24.000	0.00	
5	5	500	52.000	0.00	
500	500	6	52.000	0.00	

************ END OF DATA FROM INTERNAL STORAGE ************

83. 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	296.000	0.000	0.000

************ END OF DATA FROM INTERNAL STORAGE ************

84. PRINT SUPPORT INFORMATION ALL

SUPPORT INFORMATION (1=FIXED, 0=RELEASED)

UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

JOINT	FORCE-X/ KFX	FORCE-Y/ KFY	FORCE-Z/ KFZ	MOM-X/ KMX	MOM-Y/ KMY	MOM-Z/ 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		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
23	1		1		1		1		1		0	
		0.0		0.0		0.0		0.0		0.0		0.0
25	1		1		1		1		1		0	
		0.0		0.0		0.0		0.0		0.0		0.0

************ END OF DATA FROM INTERNAL STORAGE ************

85. PRINT ANALYSIS RESULTS

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

)INT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
1	1	0.00087	-0.10696	0.00000	0.00000	0.00000	0.00073
	2	-0.81870	-0.11270	0.32934	0.00020	0.00068	0.00075
	3	-0.83546	-0.11381	0.32934	0.00020	0.00068	0.00076
	4	-0.81870	-0.11270	0.44981	0.00033	0.00071	0.00075
	5	-0.81957	-0.00573	-0.00001	0.00000	0.00000	0.00002
2	1	0.00087	-0.05491	0.00000	0.00000	0.00000	0.00067
	2	-0.60034	-0.05906	0.28059	0.00020	0.00068	0.00069
	3	-0.61709	-0.05959	0.28059	0.00020	0.00068	0.00070
	4	-0.60035	-0.05906	0.39876	0.00033	0.00071	0.00069
	5	-0.60122	-0.00415	-0.00001	0.00000	0.00000	0.00002
3	1	0.00087	-0.02440	0.00000	0.00000	0.00000	0.00051
	2	-0.45477	-0.02751	0.24797	0.00020	0.00067	0.00053
	3	-0.47150	-0.02771	0.24797	0.00020	0.00067	0.00054
	4	-0.45478	-0.02751	0.36483	0.00032	0.00069	0.00053
	5	-0.45565	-0.00310	-0.00001	0.00000	0.00000	0.00002
4	1	0.00087	-0.01804	0.00000	0.00000	0.00000	0.00045
	2	-0.41838	-0.02088	0.23984	0.00020	0.00067	0.00047
	3	-0.43510	-0.02102	0.23984	0.00020	0.00067	0.00047
	4	-0.41839	-0.02088	0.35645	0.00032	0.00069	0.00047
	5	-0.41925	-0.00284	0.00000	0.00000	0.00000	0.00002
5	1	0.00087	0.00246	0.00000	0.00000	0.00000	-0.00001
	2	-0.00593	0.00218	0.15250	0.00010	0.00062	0.00001
	3	-0.02256	0.00198	0.15251	0.00010	0.00062	0.00001
	4	-0.00594	0.00218	0.26959	0.00017	0.00060	0.00001
	5	-0.00681	-0.00028	0.00000	0.00000	0.00000	0.00001
6	1	0.00087	-0.00554	0.00000	0.00000	0.00000	-0.00018
	2	0.30945	-0.00538	0.08811	0.00007	0.00062	-0.00018
	3	0.29280	-0.00543	0.08811	0.00007	0.00062	-0.00018
	4	0.30945	-0.00538	0.20852	0.00012	0.00058	-0.00018
	5	0.30858	0.00016	0.00000	0.00000	0.00000	0.00000
7	1	0.00087	-0.02938	0.00000	0.00000	0.00000	-0.00028
	2	0.58543	-0.02902	0.03165	0.00007	0.00062	-0.00028
	3	0.56876	-0.02888	0.03165	0.00007	0.00062	-0.00028
	4	0.58543	-0.02902	0.15612	0.00012	0.00057	-0.00028
	5	0.58456	0.00036	0.00001	0.00000	0.00000	0.00000
8	1	0.00087	-0.01237	-0.00002	0.00000	0.00000	0.00000
	2	-0.42991	-0.01051	0.18749	0.00000	0.00000	0.00000
	3	-0.44663	-0.01061	0.18749	0.00000	0.00000	0.00000
	4	-0.43020	-0.00791	0.30408	0.00000	0.00000	0.00000
	5	-0.41925	-0.00289	-0.05229	0.00000	0.00000	0.00000
9	1	0.00061	-0.00974	0.00008	-0.00094	0.00000	-0.00001
	2	-0.29916	-0.00731	0.15343	0.00015	0.00038	0.00613
	3	-0.31083	-0.00738	0.15343	0.00014	0.00038	0.00637
	4	-0.29933	-0.00448	0.22782	0.00137	0.00039	0.00614
	5	-0.29273	-0.00291	-0.00019	-0.00138	0.00000	0.00599
10	1	0.00061	-0.00608	0.00007	-0.00093	0.00000	-0.00001
	2	-0.29820	-0.00595	0.15340	0.00005	0.00038	0.00611
	3	-0.30987	-0.00599	0.15341	0.00004	0.00038	0.00635

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	4	-0.29835	-0.00576	0.22778	0.00104	0.00039	0.00611
	5	-0.29273	0.00005	-0.00017	-0.00100	0.00000	0.00599
11	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00610
	3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00634
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00610
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00599
12	1	0.00087	-0.01237	0.00002	0.00000	0.00000	0.00000
	2	-0.40685	-0.02001	0.29211	0.00000	0.00000	0.00000
	3	-0.42358	-0.02010	0.29211	0.00000	0.00000	0.00000
	4	-0.40657	-0.02261	0.40870	0.00000	0.00000	0.00000
	5	-0.41926	-0.00289	0.05228	0.00000	0.00000	0.00000
13	1	0.00061	-0.00974	-0.00008	0.00094	0.00000	-0.00001
	2	-0.28508	-0.01800	0.15363	0.00479	0.00038	0.00582
	3	-0.29676	-0.01808	0.15363	0.00479	0.00038	0.00606
	4	-0.28491	-0.02083	0.22802	0.00601	0.00039	0.00582
	5	-0.29273	-0.00291	0.00018	0.00138	0.00000	0.00599
14	1	0.00061	-0.00608	-0.00007	0.00093	0.00000	-0.00001
	2	-0.28604	-0.00611	0.15360	0.00392	0.00038	0.00585
	3	-0.29772	-0.00615	0.15360	0.00393	0.00038	0.00608
	4	-0.28590	-0.00629	0.22797	0.00491	0.00039	0.00584
	5	-0.29273	0.00005	0.00016	0.00100	0.00000	0.00599
15	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00586
	3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00609
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00585
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00599
16	1	0.00087	0.00149	0.00000	0.00000	0.00000	0.00000
	2	-0.01635	0.00229	0.10019	0.00000	0.00000	0.00000
	3	-0.03260	0.00204	0.10019	0.00000	0.00000	0.00000
	4	-0.01600	0.00296	0.21727	0.00000	0.00000	0.00000
	5	-0.00677	-0.00017	-0.05231	0.00000	0.00000	0.00000
17	1	0.00076	0.00130	0.00000	0.00000	0.00000	-0.00001
	2	-0.00001	0.00197	0.08152	0.00204	0.00014	0.00147
	3	-0.00164	0.00170	0.08152	0.00204	0.00014	0.00265
	4	0.00033	0.00255	0.17679	0.00443	0.00031	0.00147
	5	-0.00024	-0.00015	-0.04257	-0.00107	-0.00007	0.00068
18	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00072
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00127
	4	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00073
	5	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00033
19	1	0.00087	0.00149	0.00000	0.00000	0.00000	0.00000
	2	0.00457	0.00035	0.20481	0.00000	0.00000	0.00000
	3	-0.01168	0.00009	0.20481	0.00000	0.00000	0.00000
	4	0.00420	-0.00032	0.32189	0.00000	0.00000	0.00000
	5	-0.00677	-0.00017	0.05231	0.00000	0.00000	0.00000
20	1	0.00076	0.00130	0.00000	0.00000	0.00000	-0.00001

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

ɪINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	2	0.00106	0.00033	0.16666	0.00417	0.00029	-0.00014
	3	-0.00057	0.00007	0.16666	0.00417	0.00029	0.00105
	4	0.00072	-0.00025	0.26193	0.00656	0.00045	-0.00013
	5	-0.00024	-0.00015	0.04257	0.00107	0.00007	0.00068
21	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00004
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00050
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00005
	5	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00033
22	1	0.00087	-0.00336	0.00000	0.00000	0.00000	0.00000
	2	0.29872	-0.00250	0.03580	0.00000	0.00000	0.00000
	3	0.28207	-0.00252	0.03580	0.00000	0.00000	0.00000
	4	0.29940	-0.00202	0.15621	0.00000	0.00000	0.00000
	5	0.30854	0.00010	-0.05231	0.00000	0.00000	0.00000
23	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00218
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00242
	4	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00218
	5	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00198
24	1	0.00087	-0.00336	0.00000	0.00000	0.00000	0.00000
	2	0.32011	-0.00402	0.14042	0.00000	0.00000	0.00000
	3	0.30347	-0.00405	0.14042	0.00000	0.00000	0.00000
	4	0.31942	-0.00450	0.26083	0.00000	0.00000	0.00000
	5	0.30854	0.00010	0.05232	0.00000	0.00000	0.00000
25	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	2	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00182
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00206
	4	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00181
	5	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00198
200	1	0.00087	-0.03874	0.00000	0.00000	0.00000	0.00061
	2	-0.52756	-0.04237	0.26434	0.00020	0.00068	0.00063
	3	-0.54430	-0.04272	0.26435	0.00020	0.00068	0.00064
	4	-0.52756	-0.04237	0.38181	0.00033	0.00070	0.00063
	5	-0.52843	-0.00363	-0.00001	0.00000	0.00000	0.00002
500	1	0.00087	0.00056	0.00000	0.00000	0.00000	-0.00008
	2	0.15176	0.00061	0.12038	0.00009	0.00062	-0.00007
	3	0.13512	0.00046	0.12039	0.00009	0.00062	-0.00007
	4	0.15176	0.00061	0.23890	0.00014	0.00059	-0.00007
	5	0.15089	0.00005	0.00000	0.00000	0.00000	0.00000

SUPPORT REACTIONS -UNIT POUN INCH STRUCTURE TYPE = SPACE

›INT	LOAD	FORCE-X	FORCE-Y	FORCE-Z	MOM-X	MOM-Y	MOM Z
11	1	0.00	5913.56	-126.80	-2046.04	0.00	0.00
	2	-0.25	5785.97	-843.38	-20665.39	-191.80	0.00
	3	-0.25	5832.70	-844.38	-20681.71	-191.80	0.00
	4	-0.25	5607.32	-1121.99	-28585.48	-196.55	0.00
	5	0.00	-50.05	-134.78	-2163.86	0.01	0.00
15	1	0.00	5913.56	126.80	2046.04	0.00	0.00
	2	0.25	5941.04	-320.19	-12244.95	-191.80	0.00
	3	0.25	5987.78	-319.20	-12228.94	-191.80	0.00
	4	0.25	6119.69	-598.81	-20165.04	-196.55	0.00
	5	0.00	-50.05	134.80	2164.49	0.01	0.00
18	1	0.00	-1011.51	0.00	0.00	0.00	0.00
	2	-34.18	-1532.81	-55.37	-3532.34	-56.91	0.00
	3	-61.16	-1325.19	-55.38	-3532.38	-56.91	0.00
	4	-34.25	-1988.58	-120.09	-7660.36	-123.42	0.00
	5	-15.70	115.46	28.91	1844.39	29.72	0.00
21	1	0.00	-1011.51	0.00	0.00	0.00	0.00
	2	2.79	-259.30	-113.20	-7221.14	-116.35	0.00
	3	-24.19	-51.68	-113.20	-7221.19	-116.35	0.00
	4	2.84	196.61	-177.91	-11349.17	-182.86	0.00
	5	-15.70	115.45	-28.91	-1844.42	-29.72	0.00
23	1	0.00	2280.74	0.00	0.00	0.00	0.00
	2	310.78	1511.45	-19.56	-1713.21	-188.20	0.00
	3	741.58	1257.08	-19.56	-1713.24	-188.21	0.00
	4	311.59	1185.20	-80.19	-6358.92	-408.15	0.00
	5	15.61	-65.39	26.37	2025.57	98.27	0.00
25	1	0.00	2280.74	0.00	0.00	0.00	0.00
	2	-279.55	2919.24	-72.31	-5764.62	-384.74	0.00
	3	151.24	2664.88	-72.31	-5764.65	-384.75	0.00
	4	-280.09	3245.33	-132.94	-10410.33	-604.69	0.00
	5	15.64	-65.42	-26.38	-2025.85	-98.27	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
1	1	1	0.00	-1538.99	0.00	0.00	0.00	0.29
		2	0.00	2594.51	0.00	0.00	0.00	-148806.89
	2	1	-0.24	-1539.00	-0.09	0.01	2.98	0.04
		2	0.24	2594.52	0.09	-0.01	2.20	-148806.64
	3	1	-85.69	-1539.00	-0.02	-0.02	0.98	-0.15
		2	145.02	2594.52	0.02	0.02	0.62	-148806.72
	4	1	-0.73	-1539.00	86.51	0.01	-1.95	0.06
		2	0.73	2594.52	-145.91	-0.01	-8368.94	-148806.34
	5	1	0.24	0.00	0.00	0.00	0.00	-0.02
		2	-0.24	0.00	0.00	0.00	0.00	-0.03
3	1	3	0.00	-7798.17	0.00	-0.01	0.00	398232.13
		4	0.00	7974.09	0.00	0.01	0.00	-492865.88
	2	3	1.22	-7798.21	1042.03	-0.06	25009.52	398232.19
		4	-1.22	7974.13	-1042.03	0.06	-37511.00	-492866.16
	3	3	-438.23	-7798.20	1041.90	0.02	25010.51	407315.97
		4	448.24	7974.12	-1041.90	-0.02	-37512.93	-501949.59
	4	3	-4.88	-7798.22	1479.77	9084.16	47402.25	398232.19
		4	4.88	7974.14	-1489.67	-9084.16	-65224.27	-492866.13
	5	3	-1.71	0.00	-0.03	0.01	1.16	0.06
		4	1.71	0.00	0.03	-0.01	-0.77	-0.04
4	1	4	0.00	3853.00	0.00	0.00	0.00	492866.00
		5	0.00	-1859.24	0.00	0.00	0.00	-104434.26
	2	4	-0.24	3752.89	-121.58	46252.23	37136.16	492865.97
		5	0.24	-1759.13	121.58	-46252.23	-20600.34	-118048.43
	3	4	-448.49	3846.36	-121.58	46252.68	37135.84	501949.78
		5	560.55	-1852.60	121.58	-46252.68	-20600.58	-114420.29
	4	4	-0.24	3752.90	-230.38	73231.97	64838.85	492865.97
		5	0.24	-1759.14	118.18	-73231.97	-41136.70	-118047.36
	5	4	0.00	-100.10	0.00	-0.92	-0.27	0.02
		5	0.00	100.10	0.00	0.92	0.42	-13614.13
6	1	6	0.00	2873.06	0.00	0.00	0.00	200748.73
		7	0.00	-1539.00	0.00	0.00	0.00	0.03
	2	6	-0.49	2873.06	0.00	0.00	-0.02	200748.72
		7	0.49	-1539.00	0.00	0.00	-0.15	0.02
	3	6	161.38	2873.06	0.00	0.00	0.64	200748.69
		7	-86.43	-1539.00	0.00	0.00	0.10	-0.04
	4	6	-0.49	2873.06	-161.57	0.00	11287.95	200748.75
		7	0.49	-1539.00	86.50	0.00	0.22	-0.05
	5	6	-0.24	0.00	0.00	0.00	0.05	0.00
		7	0.24	0.00	0.00	0.00	-0.03	0.00
7	1	4	-338.20	-5913.56	0.00	0.00	0.00	-102008.95
		8	338.20	5913.56	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	4	-527.40	-7204.15	-10.93	0.00	188.36	-124271.57
		8	527.40	7204.15	10.93	0.00	0.00	0.00
	3	4	-530.15	-7250.90	-10.86	0.00	187.30	-125077.99
		8	530.15	7250.90	10.86	0.00	0.00	0.00
	4	4	-805.97	-7722.87	-11.10	0.00	191.21	-133219.53
		8	805.97	7722.87	11.10	0.00	0.00	0.00
	5	4	392.58	50.08	-0.03	0.00	0.71	863.86
		8	-392.58	-50.08	0.03	0.00	0.00	0.00
13	1	8	5913.56	338.20	0.00	0.00	0.00	0.00
		9	-5913.56	-338.20	0.00	0.00	0.00	7144.47
	2	8	7204.15	527.45	10.91	0.00	0.00	0.00
		9	-7204.15	-527.45	-10.91	0.00	-230.41	11142.48
	3	8	7250.90	530.13	10.91	0.00	0.00	0.00
		9	-7250.90	-530.13	-10.91	0.00	-230.38	11199.03
	4	8	7722.87	806.07	11.18	0.00	0.00	0.00
		9	-7722.87	-806.07	-11.18	0.00	-236.10	17028.20
	5	8	-50.08	-392.54	0.00	0.00	0.00	0.00
		9	50.08	392.54	0.00	0.00	-0.01	-8292.44
14	1	12	5913.56	-338.20	0.00	0.00	0.00	0.00
		13	-5913.56	338.20	0.00	0.00	0.00	-7144.47
	2	12	4522.85	636.12	-10.91	0.00	0.00	0.00
		13	-4522.85	-636.12	10.91	0.00	230.39	13437.95
	3	12	4569.58	633.45	-10.91	0.00	0.00	0.00
		13	-4569.58	-633.45	10.91	0.00	230.40	13381.59
	4	12	4004.15	914.73	-11.18	0.00	0.00	0.00
		13	-4004.15	-914.73	11.18	0.00	236.10	19323.66
	5	12	-50.03	392.52	0.00	0.00	0.00	0.00
		13	50.03	-392.52	0.00	0.00	-0.05	8291.98
15	1	9	338.20	-5913.56	0.00	0.00	0.00	-7144.47
		10	-338.20	5913.56	0.00	0.00	0.00	-7639.42
	2	9	527.39	-7204.15	10.88	230.40	0.03	-11142.49
		10	-527.39	7204.15	-10.88	-230.40	-27.22	-6867.89
	3	9	530.33	-7250.90	10.95	230.39	-0.07	-11199.05
		10	-530.33	7250.90	-10.95	-230.39	-27.36	-6928.20
	4	9	806.17	-7722.87	11.12	236.09	0.04	-17028.19
		10	-806.17	7722.87	-11.12	-236.09	-27.84	-2278.98
	5	9	-392.54	50.08	-0.01	-0.02	0.04	8292.45
		10	392.54	-50.08	0.01	0.02	0.02	-8167.26
10	1	4	-338.20	-5913.56	0.00	0.00	0.00	-102008.95
		12	338.20	5913.56	0.00	0.00	0.00	0.00
	2	4	636.29	-4522.86	-10.93	0.00	188.07	-78019.33
		12	-636.29	4522.86	10.93	0.00	0.00	0.00
	3	4	633.61	-4569.58	-10.90	0.00	188.20	-78825.30
		12	-633.61	4569.58	10.90	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
	4	4	915.28	-4004.15	-11.30	0.00	194.40	-69071.54
		12	-915.28	4004.15	11.30	0.00	0.00	0.00
	5	4	392.64	50.03	0.00	0.00	0.44	862.93
		12	-392.64	-50.03	0.00	0.00	0.00	0.00
19	1	14	5913.56	-126.80	0.00	0.00	0.00	-4151.36
		15	-5913.56	126.80	0.00	0.00	0.00	-2046.04
	2	14	5941.04	320.19	0.25	-191.80	-12.15	3404.55
		15	-5941.04	-320.19	-0.25	191.80	0.00	12244.95
	3	14	5987.78	319.20	0.25	-191.80	-12.16	3371.86
		15	-5987.78	-319.20	-0.25	191.80	0.00	12228.94
	4	14	6119.69	598.81	0.25	-196.55	-12.45	9101.76
		15	-6119.69	-598.81	-0.25	196.55	0.00	20165.04
	5	14	-50.05	-134.80	0.00	0.01	0.00	-4423.87
		15	50.05	134.80	0.00	-0.01	0.00	-2164.49
18	1	10	5913.56	126.80	0.00	0.00	0.00	4151.36
		11	-5913.56	-126.80	0.00	0.00	0.00	2046.04
	2	10	5785.97	843.38	-0.25	-191.80	12.15	20554.57
		11	-5785.97	-843.38	0.25	191.80	0.00	20665.39
	3	10	5832.70	844.38	-0.25	-191.80	12.15	20587.49
		11	-5832.70	-844.38	0.25	191.80	0.00	20681.71
	4	10	5607.32	1121.99	-0.25	-196.55	12.46	26251.79
		11	-5607.32	-1121.99	0.25	196.55	0.00	28585.48
	5	10	-50.05	134.78	0.00	0.01	0.00	4423.41
		11	50.05	-134.78	0.00	-0.01	0.00	2163.86
17	1	13	338.20	-5913.56	0.00	0.00	0.00	-7144.47
		14	-338.20	5913.56	0.00	0.00	0.00	-7639.42
	2	13	-636.51	-4522.85	10.70	230.39	0.24	13437.97
		14	636.51	4522.85	-10.70	-230.39	-27.03	-24745.09
	3	13	-633.41	-4569.58	10.80	230.39	0.13	13381.62
		14	633.41	4569.58	-10.80	-230.39	-27.11	-24805.55
	4	13	-914.55	-4004.15	11.17	236.10	0.00	19323.66
		14	914.55	4004.15	-11.17	-236.10	-27.89	-29334.04
	5	13	-392.52	50.03	-0.02	-0.01	0.05	8291.98
		14	392.52	-50.03	0.02	0.01	0.05	-8166.91
16	1	14	211.40	0.00	0.00	0.00	0.00	3488.05
		10	-211.40	0.00	0.00	0.00	0.00	-3488.06
	2	14	-315.94	1418.18	11.15	218.24	-164.53	28149.66
		10	315.94	-1418.18	-11.15	-218.24	-164.52	13686.66
	3	14	-314.25	1418.19	11.16	218.24	-164.54	28177.41
		10	314.25	-1418.19	-11.16	-218.24	-164.54	13659.29
	4	14	-315.93	2115.55	11.43	223.65	-168.61	38435.82
		10	315.93	-2115.55	-11.43	-223.65	-168.62	23972.82
	5	14	-527.32	-0.03	0.00	-0.01	0.01	3743.04
		10	527.32	0.03	0.00	0.01	0.01	-3743.84

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	1011.51	0.00	0.00	0.00	17448.52
		16	0.00	-1011.51	0.00	0.00	0.00	0.00
	2	5	-57.74	1718.98	-313.64	0.00	5410.24	29652.45
		16	57.74	-1718.98	313.64	0.00	0.00	0.00
	3	5	-57.86	1783.17	-708.85	0.00	12227.71	30759.67
		16	57.86	-1783.17	708.85	0.00	0.00	0.00
	4	5	-124.94	2175.25	-314.37	0.00	5422.85	37523.11
		16	124.94	-2175.25	314.37	0.00	0.00	0.00
	5	5	30.15	-115.52	-42.85	0.00	739.22	-1992.76
		16	-30.15	115.52	42.85	0.00	0.00	0.00
20	1	16	-1011.51	0.00	0.00	0.00	0.00	0.00
		17	1011.51	0.00	0.00	0.00	0.00	0.00
	2	16	-1718.98	57.73	313.63	0.00	0.00	0.00
		17	1718.98	-57.73	-313.63	0.00	-2822.71	519.61
	3	16	-1783.17	57.73	708.86	0.00	0.00	0.00
		17	1783.17	-57.73	-708.86	0.00	-6379.73	519.59
	4	16	-2175.25	125.20	314.40	0.00	0.00	0.00
		17	2175.25	-125.20	-314.40	0.00	-2829.62	1126.76
	5	16	115.52	-30.14	42.83	0.00	0.00	0.00
		17	-115.52	30.14	-42.83	0.00	-385.48	-271.30
22	1	19	-1011.51	0.00	0.00	0.00	0.00	0.00
		20	1011.51	0.00	0.00	0.00	0.00	0.00
	2	19	-73.02	118.02	-227.96	0.00	0.00	0.00
		20	73.02	-118.02	227.96	0.00	2051.66	1062.19
	3	19	-137.19	118.02	167.26	0.00	0.00	0.00
		20	137.19	-118.02	-167.26	0.00	-1505.32	1062.17
	4	19	383.23	185.49	-228.49	0.00	0.00	0.00
		20	-383.23	-185.49	228.49	0.00	2056.43	1669.38
	5	19	115.49	30.14	42.86	0.00	0.00	0.00
		20	-115.49	-30.14	-42.86	0.00	-385.75	271.31
23	1	20	-1011.51	0.00	0.00	0.00	0.00	0.00
		21	1011.51	0.00	0.00	0.00	0.00	0.00
	2	20	-259.30	113.20	2.79	-116.35	-169.96	-315.85
		21	259.30	-113.20	-2.79	116.35	0.00	7221.14
	3	20	-51.68	113.20	-24.19	-116.35	1475.46	-315.85
		21	51.68	-113.20	24.19	116.35	0.00	7221.19
	4	20	196.61	177.91	2.84	-182.86	-172.97	-496.41
		21	-196.61	-177.91	-2.84	182.86	0.00	11349.17
	5	20	115.45	28.91	-15.70	-29.72	957.65	-80.67
		21	-115.45	-28.91	15.70	29.72	0.00	1844.42
9	1	6	0.00	-2280.74	0.00	0.00	0.00	-39342.77
		22	0.00	2280.74	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	6	-17.27	-1697.62	37.03	0.00	-638.81	-29283.99
		22	17.27	1697.62	-37.03	0.00	0.00	0.00
	3	6	-17.21	-1715.06	28.43	0.00	-490.31	-29584.80
		22	17.21	1715.06	-28.43	0.00	0.00	0.00
	4	6	-75.07	-1371.87	37.06	0.00	-639.57	-23664.71
		22	75.07	1371.87	-37.06	0.00	0.00	0.00
	5	6	25.09	65.44	42.89	0.00	-740.17	1128.91
		22	-25.09	-65.44	-42.89	0.00	0.00	0.00
24	1	22	2280.74	0.00	0.00	0.00	0.00	0.00
		23	-2280.74	0.00	0.00	0.00	0.00	0.00
	2	22	1697.62	17.21	-37.03	0.00	0.00	0.00
		23	-1697.62	-17.21	37.03	0.00	2592.21	1204.36
	3	22	1715.06	17.21	-28.44	0.00	0.00	0.00
		23	-1715.06	-17.21	28.44	0.00	1990.51	1204.38
	4	22	1371.87	75.08	-37.06	0.00	0.00	0.00
		23	-1371.87	-75.08	37.06	0.00	2594.24	5255.41
	5	22	-65.44	-25.14	-42.92	0.00	0.00	0.00
		23	65.44	25.14	42.92	0.00	3004.14	-1759.88
12	1	6	0.00	-2280.74	0.00	0.00	0.00	-39342.76
		24	0.00	2280.74	0.00	0.00	0.00	0.00
	2	6	67.50	-2732.95	-48.76	0.00	841.05	-47143.43
		24	-67.50	2732.95	48.76	0.00	0.00	0.00
	3	6	67.44	-2750.40	-40.22	0.00	693.24	-47444.39
		24	-67.44	2750.40	40.22	0.00	0.00	0.00
	4	6	125.55	-3058.72	-48.78	0.00	841.18	-52762.90
		24	-125.55	3058.72	48.78	0.00	0.00	0.00
	5	6	25.15	65.46	-42.91	0.00	740.24	1129.21
		24	-25.15	-65.46	42.91	0.00	0.00	0.00
25	1	24	2280.74	0.00	0.00	0.00	0.00	0.00
		25	-2280.74	0.00	0.00	0.00	0.00	0.00
	2	24	2732.95	67.49	-48.80	0.00	0.00	0.00
		25	-2732.95	-67.49	48.80	0.00	3416.05	4724.39
	3	24	2750.40	67.49	-40.21	0.00	0.00	0.00
		25	-2750.40	-67.49	40.21	0.00	2814.36	4724.41
	4	24	3058.72	125.36	-48.77	0.00	0.00	0.00
		25	-3058.72	-125.36	48.77	0.00	3413.66	8775.44
	5	24	-65.46	25.15	-42.92	0.00	0.00	0.00
		25	65.46	-25.15	42.92	0.00	3004.09	1760.15
26	1	17	0.00	0.00	0.00	0.00	0.00	0.00
		23	0.00	0.00	0.00	0.00	0.00	0.00
	2	17	-394.21	-15.38	2.36	343.70	135.61	737.66
		23	394.21	15.38	-2.36	-343.70	-419.78	-2592.21
	3	17	-895.90	5.46	2.36	343.71	135.62	2649.24
		23	895.90	-5.46	-2.36	-343.71	-419.79	-1990.51

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	-395.18	-15.37	5.11	745.36	294.10	740.56
		23	395.18	15.37	-5.11	-745.36	-910.36	-2594.24
	5	17	-50.46	-29.66	-1.23	-179.46	-70.81	-572.05
		23	50.46	29.66	1.23	179.46	219.19	-3004.14
27	1	20	0.00	0.00	0.00	0.00	0.00	0.00
		25	0.00	0.00	0.00	0.00	0.00	0.00
	2	20	293.28	-43.94	4.82	702.63	277.23	-1881.70
		25	-293.28	43.94	-4.82	-702.63	-858.16	-3416.05
	3	20	-208.40	-23.09	4.82	702.63	277.24	29.85
		25	208.40	23.09	-4.82	-702.63	-858.16	-2814.36
	4	20	293.95	-43.93	7.57	1104.29	435.72	-1883.45
		25	-293.95	43.93	-7.57	-1104.29	-1348.73	-3413.66
	5	20	-50.49	-29.66	1.23	179.46	70.81	-571.90
		25	50.49	29.66	-1.23	-179.46	-219.19	-3004.09
21	1	17	-1011.51	0.00	0.00	0.00	0.00	0.00
		18	1011.51	0.00	0.00	0.00	0.00	0.00
	2	17	-1532.81	55.37	-34.18	-56.91	2085.05	-154.50
		18	1532.81	-55.37	34.18	56.91	0.00	3532.34
	3	17	-1325.19	55.38	-61.16	-56.91	3730.50	-154.51
		18	1325.19	-55.38	61.16	56.91	0.00	3532.38
	4	17	-1988.58	120.09	-34.25	-123.42	2089.06	-335.06
		18	1988.58	-120.09	34.25	123.42	0.00	7660.36
	5	17	115.46	-28.91	-15.70	29.72	957.52	80.67
		18	-115.46	28.91	15.70	-29.72	0.00	-1844.39
11	1	5	0.00	1011.51	0.00	0.00	0.00	17448.51
		19	0.00	-1011.51	0.00	0.00	0.00	0.00
	2	5	117.98	73.02	-227.90	0.00	3931.35	1259.66
		19	-117.98	-73.02	227.90	0.00	0.00	0.00
	3	5	118.04	137.19	167.31	0.00	-2886.02	2366.58
		19	-118.04	-137.19	-167.31	0.00	0.00	0.00
	4	5	185.24	-383.23	-228.56	0.00	3942.72	-6610.68
		19	-185.24	383.23	228.56	0.00	0.00	0.00
	5	5	30.15	-115.49	42.87	0.00	-739.51	-1992.14
		19	-30.15	115.49	-42.87	0.00	0.00	0.00
2	1	2	0.00	-4844.50	0.00	0.00	0.00	148806.67
		200	0.00	5196.34	0.00	0.00	0.00	-269296.88
	2	2	1.46	-4844.52	0.10	0.01	-0.40	148806.98
		200	-1.46	5196.36	-0.10	-0.01	-1.77	-269297.41
	3	2	-272.22	-4844.56	0.19	0.13	-3.07	153348.59
		200	291.99	5196.40	-0.19	-0.13	-2.55	-273840.09
	4	2	0.98	-4844.46	272.76	4542.08	8363.74	148807.13
		200	-0.98	5196.30	-292.56	-4542.08	-15143.74	-269297.28
	5	2	5.62	0.00	0.00	0.00	0.00	-0.04
		200	-5.62	0.00	0.00	0.00	0.00	-0.02

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	0.01	0.00	269296.56
		3	0.00	5548.21	0.00	-0.01	0.00	-398231.75
	2	200	0.24	-5196.37	1042.09	0.01	1.05	269297.19
		3	-0.24	5548.21	-1042.09	-0.01	-25009.27	-398232.06
	3	200	-292.24	-5196.36	1042.01	0.01	-0.74	273839.50
		3	312.01	5548.20	-1042.01	-0.01	-25009.58	-402774.00
	4	200	-0.24	-5196.36	1334.21	4542.01	15143.17	269297.16
		3	0.24	5548.20	-1354.01	-4542.01	-47399.98	-398231.94
	5	200	-0.24	0.00	0.00	0.01	0.65	0.05
		3	0.24	0.00	0.00	-0.01	-0.61	-0.03
5	1	5	0.00	-163.78	0.00	0.00	0.00	104434.26
		500	0.00	926.10	0.00	0.00	0.00	-132771.16
	2	5	85.69	-32.87	-297.30	17859.44	11259.05	118048.42
		500	-85.69	795.19	297.30	-17859.44	4201.05	-139578.25
	3	5	315.92	-67.76	-297.30	17859.60	11258.26	114420.30
		500	-272.95	830.08	297.30	-17859.60	4199.86	-137764.19
	4	5	85.94	-32.89	-428.90	29098.18	31771.08	118047.34
		500	-85.94	795.21	386.00	-29098.18	-10582.25	-139577.72
	5	5	85.69	130.91	0.00	-0.30	-0.22	13614.13
		500	-85.69	-130.91	0.00	0.30	0.11	-6807.07
500	1	500	0.00	-926.10	0.00	0.00	0.00	132771.16
		6	0.00	1688.42	0.00	0.00	0.00	-200748.69
	2	500	85.94	-795.19	84.68	17859.44	-4201.02	139578.25
		6	-85.94	1557.51	-84.68	-17859.44	-202.72	-200748.67
	3	500	272.95	-830.08	84.70	17859.61	-4201.68	137764.20
		6	-229.98	1592.40	-84.70	-17859.61	-202.95	-200748.67
	4	500	85.94	-795.20	-4.04	29098.18	10583.94	139577.72
		6	-85.94	1557.52	-38.86	-29098.18	-11488.01	-200748.67
	5	500	85.69	130.91	0.01	-0.30	-0.20	6807.07
		6	-85.69	-130.91	-0.01	0.30	-0.10	0.00

************** END OF LATEST ANALYSIS RESULT **************

86. PRINT MEMBER STRESSES ALL

MEMBER STRESSES

LL 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	3.5	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	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
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	C	135.8	2162.2	2166.6	538.2	71.9
		1.00	0.1	C	203.7	2676.1	2683.9	550.3	71.9
	3	.0	18.1	T	135.8	2211.6	2233.9	538.2	71.9
		1.00	18.6	T	203.7	2725.4	2751.5	550.3	71.9
	4	.0	0.2	T	257.4	2162.2	2177.7	538.2	102.1
		1.00	0.2	T	354.1	2676.1	2699.6	550.3	102.8
	5	.0	0.1	T	0.0	0.0	0.1	0.0	0.0
		1.00	0.1	T	0.0	0.0	0.1	0.0	0.0
4	1	.0	0.0	C	0.0	2676.1	2676.1	265.9	0.0
		1.00	0.0	C	0.0	567.0	567.0	128.3	0.0
	2	.0	0.0	T	201.6	2676.1	2683.7	259.0	8.4
		1.00	0.0	T	111.9	641.0	650.7	121.4	8.4
	3	.0	18.6	T	201.6	2725.4	2751.4	265.4	8.4
		1.00	23.2	T	111.9	621.3	654.5	127.8	8.4
	4	.0	0.0	T	352.0	2676.1	2699.1	259.0	15.9
		1.00	0.0	T	223.4	640.9	678.8	121.4	8.2
	5	.0	0.0		0.0	0.0	0.0	6.9	0.0
		1.00	0.0		0.0	73.9	73.9	6.9	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	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
	3	.0	6.7	C	0.0	1090.0	1096.7	198.3	0.0
		1.00	3.6	C	0.0	0.0	3.6	106.2	0.0
	4	.0	0.0	T	61.3	1090.0	1091.7	198.3	11.2
		1.00	0.0	T	0.0	0.0	0.0	106.2	6.0
	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
7	1	.0	36.1	T	0.0	4488.8	4525.0	1182.7	0.0
		1.00	36.1	T	0.0	0.0	36.1	1182.7	0.0
	2	.0	56.3	T	8.3	5468.5	5533.1	1440.8	2.2
		1.00	56.3	T	0.0	0.0	56.3	1440.8	2.2

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	3	.0	56.6 T	8.2	5504.0	5568.9	1450.2	2.2
		1.00	56.6 T	0.0	0.0	56.6	1450.2	2.2
	4	.0	86.1 T	8.4	5862.2	5956.8	1544.6	2.2
		1.00	86.1 T	0.0	0.0	86.1	1544.6	2.2
	5	.0	41.9 C	0.0	38.0	80.0	10.0	0.0
		1.00	41.9 C	0.0	0.0	41.9	10.0	0.0
13	1	.0	3605.8 C	0.0	0.0	3605.8	300.6	0.0
		1.00	3605.8 C	0.0	5640.4	9246.2	300.6	0.0
	2	.0	4392.8 C	0.0	0.0	4392.8	468.8	21.8
		1.00	4392.8 C	230.4	8796.7	13419.9	468.8	21.8
	3	.0	4421.3 C	0.0	0.0	4421.3	471.2	21.8
		1.00	4421.3 C	230.4	8841.3	13493.0	471.2	21.8
	4	.0	4709.1 C	0.0	0.0	4709.1	716.5	22.4
		1.00	4709.1 C	236.1	13443.3	18388.5	716.5	22.4
	5	.0	30.5 T	0.0	0.0	30.5	348.9	0.0
		1.00	30.5 T	0.0	6546.7	6577.2	348.9	0.0
14	1	.0	3605.8 C	0.0	0.0	3605.8	300.6	0.0
		1.00	3605.8 C	0.0	5640.4	9246.2	300.6	0.0
	2	.0	2757.8 C	0.0	0.0	2757.8	565.4	21.8
		1.00	2757.8 C	230.4	10608.9	13597.1	565.4	21.8
	3	.0	2786.3 C	0.0	0.0	2786.3	563.1	21.8
		1.00	2786.3 C	230.4	10564.4	13581.1	563.1	21.8
	4	.0	2441.6 C	0.0	0.0	2441.6	813.1	22.4
		1.00	2441.6 C	236.1	15255.5	17933.2	813.1	22.4
	5	.0	30.5 T	0.0	0.0	30.5	348.9	0.0
		1.00	30.5 T	0.1	6546.3	6576.9	348.9	0.0
15	1	.0	206.2 C	0.0	5640.4	5846.6	5256.5	0.0
		1.00	206.2 C	0.0	6031.1	6237.3	5256.5	0.0
	2	.0	321.6 C	0.0	8796.7	9118.3	6403.7	21.8
		1.00	321.6 C	27.2	5422.0	5770.8	6403.7	21.8
	3	.0	323.4 C	0.1	8841.4	9164.8	6445.2	21.9
		1.00	323.4 C	27.4	5469.6	5820.4	6445.2	21.9
	4	.0	491.6 C	0.0	13443.3	13934.9	6864.8	22.2
		1.00	491.6 C	27.8	1799.2	2318.6	6864.8	22.2
	5	.0	239.4 T	0.0	6546.7	6786.1	44.5	0.0
		1.00	239.4 T	0.0	6447.8	6687.2	44.5	0.0
10	1	.0	36.1 T	0.0	4488.8	4525.0	1182.7	0.0
		1.00	36.1 T	0.0	0.0	36.1	1182.7	0.0
	2	.0	68.0 C	8.3	3433.2	3509.4	904.6	2.2
		1.00	68.0 C	0.0	0.0	68.0	904.6	2.2
	3	.0	67.7 C	8.3	3468.7	3544.6	913.9	2.2
		1.00	67.7 C	0.0	0.0	67.7	913.9	2.2
	4	.0	97.8 C	8.6	3039.5	3145.8	800.8	2.3
		1.00	97.8 C	0.0	0.0	97.8	800.8	2.3
	5	.0	41.9 C	0.0	38.0	79.9	10.0	0.0
		1.00	41.9 C	0.0	0.0	41.9	10.0	0.0

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
19	1	.0	3605.8	C	0.0	3277.4	6883.2	112.7	0.0
		1.00	3605.8	C	0.0	1615.3	5221.1	112.7	0.0
	2	.0	3622.6	C	12.2	2687.8	6322.5	284.6	0.5
		1.00	3622.6	C	0.0	9667.1	13289.7	284.6	0.5
	3	.0	3651.1	C	12.2	2662.0	6325.2	283.7	0.5
		1.00	3651.1	C	0.0	9654.4	13305.5	283.7	0.5
	4	.0	3731.5	C	12.5	7185.6	10929.6	532.3	0.5
		1.00	3731.5	C	0.0	15919.8	19651.3	532.3	0.5
	5	.0	30.5	T	0.0	3492.5	3523.1	119.8	0.0
		1.00	30.5	T	0.0	1708.8	1739.3	119.8	0.0
18	1	.0	3605.8	C	0.0	3277.4	6883.2	112.7	0.0
		1.00	3605.8	C	0.0	1615.3	5221.1	112.7	0.0
	2	.0	3528.0	C	12.2	16227.3	19767.5	749.7	0.5
		1.00	3528.0	C	0.0	16314.8	19842.8	749.7	0.5
	3	.0	3556.5	C	12.1	16253.3	19822.0	750.6	0.5
		1.00	3556.5	C	0.0	16327.7	19884.2	750.6	0.5
	4	.0	3419.1	C	12.5	20725.1	24156.7	997.3	0.5
		1.00	3419.1	C	0.0	22567.5	25986.6	997.3	0.5
	5	.0	30.5	T	0.0	3492.2	3522.7	119.8	0.0
		1.00	30.5	T	0.0	1708.3	1738.8	119.8	0.0
17	1	.0	206.2	C	0.0	5640.4	5846.6	5256.5	0.0
		1.00	206.2	C	0.0	6031.1	6237.3	5256.5	0.0
	2	.0	388.1	T	0.2	10608.9	10997.3	4020.3	21.4
		1.00	388.1	T	27.0	19535.6	19950.7	4020.3	21.4
	3	.0	386.2	T	0.1	10564.4	10950.8	4061.8	21.6
		1.00	386.2	T	27.1	19583.3	19996.7	4061.8	21.6
	4	.0	557.7	T	0.0	15255.5	15813.2	3559.2	22.3
		1.00	557.7	T	27.9	23158.5	23744.0	3559.2	22.3
	5	.0	239.3	T	0.0	6546.3	6785.7	44.5	0.0
		1.00	239.3	T	0.1	6447.6	6687.0	44.5	0.0
16	1	.0	128.9	C	0.0	2753.7	2882.6	0.0	0.0
		1.00	128.9	C	0.0	2753.7	2882.6	0.0	0.0
	2	.0	192.6	T	164.5	22223.4	22580.6	1260.6	22.3
		1.00	192.6	T	164.5	10805.3	11162.4	1260.6	22.3
	3	.0	191.6	T	164.5	22245.3	22601.5	1260.6	22.3
		1.00	191.6	T	164.5	10783.6	11139.8	1260.6	22.3
	4	.0	192.6	T	168.6	30344.1	30705.3	1880.5	22.9
		1.00	192.6	T	168.6	18925.9	19287.2	1880.5	22.9
	5	.0	321.5	T	0.0	2955.0	3276.6	0.0	0.0
		1.00	321.5	T	0.0	2955.7	3277.2	0.0	0.0
8	1	.0	0.0	C	0.0	767.8	767.8	202.3	0.0
		1.00	0.0	C	0.0	0.0	0.0	202.3	0.0
	2	.0	6.2	T	238.1	1304.8	1549.1	343.8	62.7
		1.00	6.2	T	0.0	0.0	6.2	343.8	62.7

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	3	.0	6.2	T	538.1	1353.6	1897.8	356.6	141.8
		1.00	6.2	T	0.0	0.0	6.2	356.6	141.8
	4	.0	13.3	T	238.6	1651.2	1903.2	435.1	62.9
		1.00	13.3	T	0.0	0.0	13.3	435.1	62.9
	5	.0	3.2	C	32.5	87.7	123.4	23.1	8.6
		1.00	3.2	C	0.0	0.0	3.2	23.1	8.6
20	1	.0	616.8	T	0.0	0.0	616.8	0.0	0.0
		1.00	616.8	T	0.0	0.0	616.8	0.0	0.0
	2	.0	1048.2	T	0.0	0.0	1048.2	51.3	627.3
		1.00	1048.2	T	2822.7	410.2	4281.1	51.3	627.3
	3	.0	1087.3	T	0.0	0.0	1087.3	51.3	1417.7
		1.00	1087.3	T	6379.7	410.2	7877.2	51.3	1417.7
	4	.0	1326.4	T	0.0	0.0	1326.4	111.3	628.8
		1.00	1326.4	T	2829.6	889.5	5045.5	111.3	628.8
	5	.0	70.4	C	0.0	0.0	70.4	26.8	85.7
		1.00	70.4	C	385.5	214.2	670.1	26.8	85.7
22	1	.0	616.8	T	0.0	0.0	616.8	0.0	0.0
		1.00	616.8	T	0.0	0.0	616.8	0.0	0.0
	2	.0	44.5	T	0.0	0.0	44.5	104.9	455.9
		1.00	44.5	T	2051.7	838.6	2934.8	104.9	455.9
	3	.0	83.7	T	0.0	0.0	83.7	104.9	334.5
		1.00	83.7	T	1505.3	838.6	2427.5	104.9	334.5
	4	.0	233.7	C	0.0	0.0	233.7	164.9	457.0
		1.00	233.7	C	2056.4	1317.9	3608.0	164.9	457.0
	5	.0	70.4	C	0.0	0.0	70.4	26.8	85.7
		1.00	70.4	C	385.7	214.2	670.4	26.8	85.7
23	1	.0	616.8	T	0.0	0.0	616.8	0.0	0.0
		1.00	616.8	T	0.0	0.0	616.8	0.0	0.0
	2	.0	158.1	T	170.0	249.4	577.4	100.6	5.6
		1.00	158.1	T	0.0	5700.9	5859.0	100.6	5.6
	3	.0	31.5	T	1475.5	249.4	1756.3	100.6	48.4
		1.00	31.5	T	0.0	5700.9	5732.5	100.6	48.4
	4	.0	119.9	C	173.0	391.9	684.8	158.1	5.7
		1.00	119.9	C	0.0	8959.9	9079.8	158.1	5.7
	5	.0	70.4	C	957.7	63.7	1091.7	25.7	31.4
		1.00	70.4	C	0.0	1456.1	1526.5	25.7	31.4
9	1	.0	0.0	C	0.0	1731.3	1731.3	456.1	0.0
		1.00	0.0	C	0.0	0.0	0.0	456.1	0.0
	2	.0	1.8	T	28.1	1288.6	1318.6	339.5	7.4
		1.00	1.8	T	0.0	0.0	1.8	339.5	7.4
	3	.0	1.8	T	21.6	1301.9	1325.3	343.0	5.7
		1.00	1.8	T	0.0	0.0	1.8	343.0	5.7
	4	.0	8.0	T	28.1	1041.4	1077.5	274.4	7.4
		1.00	8.0	T	0.0	0.0	8.0	274.4	7.4
	5	.0	2.7	C	32.6	49.7	84.9	13.1	8.6
		1.00	2.7	C	0.0	0.0	2.7	13.1	8.6

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
24	1	.0	1390.7 C	0.0	0.0	1390.7	0.0	0.0
		1.00	1390.7 C	0.0	0.0	1390.7	0.0	0.0
	2	.0	1035.1 C	0.0	0.0	1035.1	15.3	74.1
		1.00	1035.1 C	2592.2	950.8	4578.2	15.3	74.1
	3	.0	1045.8 C	0.0	0.0	1045.8	15.3	56.9
		1.00	1045.8 C	1990.5	950.8	3987.1	15.3	56.9
	4	.0	836.5 C	0.0	0.0	836.5	66.7	74.1
		1.00	836.5 C	2594.2	4149.0	7579.7	66.7	74.1
	5	.0	39.9 T	0.0	0.0	39.9	22.3	85.8
		1.00	39.9 T	3004.1	1389.4	4433.4	22.3	85.8
12	1	.0	0.0 C	0.0	1731.3	1731.3	456.1	0.0
		1.00	0.0 C	0.0	0.0	0.0	456.1	0.0
	2	.0	7.2 C	37.0	2074.5	2118.7	546.6	9.8
		1.00	7.2 C	0.0	0.0	7.2	546.6	9.8
	3	.0	7.2 C	30.5	2087.8	2125.5	550.1	8.0
		1.00	7.2 C	0.0	0.0	7.2	550.1	8.0
	4	.0	13.4 C	37.0	2321.8	2372.2	611.7	9.8
		1.00	13.4 C	0.0	0.0	13.4	611.7	9.8
	5	.0	2.7 C	32.6	49.7	85.0	13.1	8.6
		1.00	2.7 C	0.0	0.0	2.7	13.1	8.6
25	1	.0	1390.7 C	0.0	0.0	1390.7	0.0	0.0
		1.00	1390.7 C	0.0	0.0	1390.7	0.0	0.0
	2	.0	1666.4 C	0.0	0.0	1666.4	60.0	97.6
		1.00	1666.4 C	3416.0	3729.8	8812.3	60.0	97.6
	3	.0	1677.1 C	0.0	0.0	1677.1	60.0	80.4
		1.00	1677.1 C	2814.4	3729.8	8221.2	60.0	80.4
	4	.0	1865.1 C	0.0	0.0	1865.1	111.4	97.5
		1.00	1865.1 C	3413.7	6928.0	12206.7	111.4	97.5
	5	.0	39.9 T	0.0	0.0	39.9	22.4	85.8
		1.00	39.9 T	3004.1	1389.6	4433.6	22.4	85.8
26	1	.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	.0	240.4 T	135.6	582.4	958.3	13.7	4.7
		1.00	240.4 T	419.8	2046.5	2706.6	13.7	4.7
	3	.0	546.3 T	135.6	2091.5	2773.4	4.9	4.7
		1.00	546.3 T	419.8	1571.5	2537.5	4.9	4.7
	4	.0	241.0 T	294.1	584.7	1119.7	13.7	10.2
		1.00	241.0 T	910.4	2048.1	3199.4	13.7	10.2
	5	.0	30.8 T	70.8	451.6	553.2	26.4	2.5
		1.00	30.8 T	219.2	2371.7	2621.6	26.4	2.5
27	1	.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
	2	.0	178.8 C	277.2	1485.6	1941.6	39.1	9.6
		1.00	178.8 C	858.2	2696.9	3733.9	39.1	9.6

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	3	.0	127.1 T	277.2	23.6	427.9	20.5	9.6
		1.00	127.1 T	858.2	2221.9	3207.1	20.5	9.6
	4	.0	179.2 C	435.7	1486.9	2101.9	39.1	15.1
		1.00	179.2 C	1348.7	2695.0	4223.0	39.1	15.1
	5	.0	30.8 T	70.8	451.5	553.1	26.4	2.5
		1.00	30.8 T	219.2	2371.7	2621.6	26.4	2.5
21	1	.0	616.8 T	0.0	0.0	616.8	0.0	0.0
		1.00	616.8 T	0.0	0.0	616.8	0.0	0.0
	2	.0	934.6 T	2085.1	122.0	3141.7	49.2	68.4
		1.00	934.6 T	0.0	2788.7	3723.3	49.2	68.4
	3	.0	808.0 T	3730.5	122.0	4660.5	49.2	122.3
		1.00	808.0 T	0.0	2788.7	3596.8	49.2	122.3
	4	.0	1212.5 T	2089.1	264.5	3566.1	106.7	68.5
		1.00	1212.5 T	0.0	6047.7	7260.2	106.7	68.5
	5	.0	70.4 C	957.5	63.7	1091.6	25.7	31.4
		1.00	70.4 C	0.0	1456.1	1526.5	25.7	31.4
11	1	.0	0.0 C	0.0	767.8	767.8	202.3	0.0
		1.00	0.0 C	0.0	0.0	0.0	202.3	0.0
	2	.0	12.6 C	173.0	55.4	241.0	14.6	45.6
		1.00	12.6 C	0.0	0.0	12.6	14.6	45.6
	3	.0	12.6 C	127.0	104.1	243.7	27.4	33.5
		1.00	12.6 C	0.0	0.0	12.6	27.4	33.5
	4	.0	19.8 C	173.5	290.9	484.2	76.6	45.7
		1.00	19.8 C	0.0	0.0	19.8	76.6	45.7
	5	.0	3.2 C	32.5	87.7	123.4	23.1	8.6
		1.00	3.2 C	0.0	0.0	3.2	23.1	8.6
2	1	.0	0.0 T	0.0	808.0	808.0	334.3	0.0
		1.00	0.0 T	0.0	1462.2	1462.2	358.6	0.0
	2	.0	0.1 C	0.0	808.0	808.0	334.3	0.0
		1.00	0.1 C	0.0	1462.2	1462.2	358.6	0.0
	3	.0	11.3 T	0.0	832.6	843.9	334.3	0.0
		1.00	12.1 T	0.0	1486.8	1498.9	358.6	0.0
	4	.0	0.0 C	45.4	808.0	809.3	334.3	18.8
		1.00	0.0 C	82.2	1462.2	1464.5	358.6	20.2
	5	.0	0.2 C	0.0	0.0	0.2	0.0	0.0
		1.00	0.2 C	0.0	0.0	0.2	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 C	0.0	1462.2	1462.2	358.6	71.9
		1.00	0.0 C	135.8	2162.2	2166.5	382.9	71.9
	3	.0	12.1 T	0.0	1486.8	1498.9	358.6	71.9
		1.00	12.9 T	135.8	2186.9	2204.0	382.9	71.9
	4	.0	0.0 T	82.2	1462.2	1464.5	358.6	92.1
		1.00	0.0 T	257.4	2162.2	2177.5	382.9	93.4
	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

LL 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	567.0	567.0	11.3	0.0
		1.00	0.0 C	0.0	720.9	720.9	63.9	0.0
	2	.0	3.5 C	61.1	641.0	647.4	2.3	20.5
		1.00	3.5 C	22.8	757.9	761.7	54.9	20.5
	3	.0	13.1 C	61.1	621.3	637.3	4.7	20.5
		1.00	11.3 C	22.8	748.0	759.7	57.3	20.5
	4	.0	3.6 C	172.5	640.9	667.3	2.3	29.6
		1.00	3.6 C	57.5	757.9	763.6	54.9	26.6
	5	.0	3.5 C	0.0	73.9	77.5	9.0	0.0
		1.00	3.5 C	0.0	37.0	40.5	9.0	0.0
500	1	.0	0.0 C	0.0	720.9	720.9	63.9	0.0
		1.00	0.0 C	0.0	1090.0	1090.0	116.5	0.0
	2	.0	3.6 C	22.8	757.9	761.8	54.9	5.8
		1.00	3.6 C	1.1	1090.0	1093.5	107.5	5.8
	3	.0	11.3 C	22.8	748.0	759.7	57.3	5.8
		1.00	9.5 C	1.1	1090.0	1099.5	109.9	5.8
	4	.0	3.6 C	57.5	757.9	763.6	54.9	0.3
		1.00	3.6 C	62.4	1090.0	1095.3	107.5	2.7
	5	.0	3.5 C	0.0	37.0	40.5	9.0	0.0
		1.00	3.5 C	0.0	0.0	3.5	9.0	0.0

************** END OF LATEST ANALYSIS RESULT **************

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87. PARAMETER
88. CODE AISC
89. FYLD 45999.969 MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
90. WSTR 21000. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
91. LY 70. MEMB 19 18 20 22 TO 27 21
92. UNL 70. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
93. WMIN 0.188 MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
94. CB 1. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
95. CMY 1. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
96. MAIN 0. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
97. RATIO 1. MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
98. CHECK CODE MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21
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STAAD-III CODE CHECKING - (AISC)
****

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER	TABLE	RESULT/ FX	CRITICAL COND/ MY	RATIO/ MZ	LOADING/ LOCATION
13	ST TUB 30203	PASS	AISC- H1-2	0.666	4
		7722.87 C	-236.10	17028.20	21.13
14	ST TUB 30203	PASS	AISC- H1-3	0.657	4
		4004.15 C	236.10	19323.66	21.13
15	ST TUB 30203	PASS	AISC- H1-3	0.505	4
		806.17 C	0.04	-17028.19	0.00
19	ST TUB 30203	PASS	AISC- H1-1	0.745	4
		6119.69 C	0.00	20165.04	48.88
18	ST TUB 30203	PASS	AISC- H1-2	0.942	4
		5607.32 C	0.00	28585.48	48.88
17	ST TUB 30203	PASS	AISC- H2-1	0.860	4
		914.55 T	-27.89	-29334.04	2.50
* 16	ST TUB 30203	FAIL	AISC- H2-1	1.113	4
		315.93 T	-168.61	38435.82	0.00
20	ST TUB 30203	PASS	AISC- H2-1	0.285	3
		1783.17 T	-6379.73	519.59	9.00
22	ST TUB 30203	PASS	AISC- H1-3	0.137	4
		383.23 C	2056.43	1669.38	9.00
23	ST TUB 30203	PASS	AISC- H1-3	0.332	4
		196.61 C	0.00	11349.17	61.00
24	ST TUB 30203	PASS	AISC- H1-3	0.295	4
		1371.87 C	2594.24	5255.41	70.00
25	ST TUB 30203	PASS	AISC- H1-3	0.489	4
		3058.72 C	3413.66	8775.44	70.00
26	ST TUB 30203	PASS	AISC- H2-1	0.116	4
		395.18 T	-910.36	-2594.24	120.57
27	ST TUB 30203	PASS	AISC- H1-3	0.162	4
		293.95 C	-1348.73	-3413.66	120.57
21	ST TUB 30203	PASS	AISC- H2-1	0.263	4
		1988.58 T	0.00	7660.36	61.00

99. SELECT WELD MEMB 13 TO 15 19 18 17 16 20 22 TO 27 21

* RATIO = 1.113

THIS IS FOR LOADCASE #4 WHICH INCLUDES SEISMIC LOADING, THEREFORE THE ALLOWABLE RATIO WOULD BE INCREASED TO 1.33 > 1.113 ∴ OK

ALL MEMBERS ARE WITHIN CODE ALLOWABLES.

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS
13	STA 4	1 5.96	3/16 429.90	4141.24 4118.86
13	END 4	1 5.96	3/16 429.90	14387.78 14381.36
14	STA 1	1 0.00	3/16 180.37	3159.05 3153.90
14	END 4	1 5.96	3/16 487.86	13766.96 13758.31
15	STA 4	1 96.59	3/16 4179.30	11320.89 10520.77
15	END 3	1 94.31	3/16 3926.12	5903.97 4408.34
19	STA 4	1 75.61	3/16 369.68	8674.74 8666.53
19	END 4	1 75.61	3/16 369.68	15218.17 15213.49
18	STA 4	1 75.61	3/16 648.71	18567.74 18556.25
18	END 4	1 75.61	3/16 648.71	19940.82 19930.12
17	STA 4	1 96.62	3/16 2195.99	12139.49 11938.82
17	END 4	1 96.62	3/16 2195.99	18025.70 17891.18
16	STA 4	1 68.98	4/16 889.16	17323.90 17300.93
16	END 4	1 91.98	3/16 1185.55	14545.93 14497.24
20	STA 4	1 167.68	3/16 66.77	1174.09 1160.14
20	END 3	1 378.06	3/16 30.79	5910.92 5898.73

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS
22	STA 1	1 0.00	3/16 0.00	539.47 539.47
22	END 4	1 121.86	3/16 98.93	2693.81 2689.23
23	STA 3	1 57.58	3/16 90.16	1292.23 1287.80
23	END 4	1 71.73	3/16 141.70	6832.14 6830.29
24	STA 1	1 0.00	3/16 0.00	1216.39 1216.39
24	END 4	1 19.77	3/16 40.04	5732.87 5732.70
25	STA 4	1 26.01	3/16 66.86	1632.89 1631.32
25	END 4	1 26.01	3/16 66.86	9314.51 9314.24
26	STA 3	1 133.24	3/16 90.90	2152.41 2146.36
26	END 4	1 288.95	3/16 199.01	2435.57 2410.16
27	STA 4	1 428.08	3/16 306.13	1674.62 1589.78
27	END 4	1 428.08	3/16 306.13	3204.10 3160.58
21	STA 3	1 54.47	3/16 44.10	3512.12 3511.42
21	END 4	1 65.66	3/16 95.64	5601.25 5600.05

****************** END OF TABULATED WELD DESIGN ******************

```
100. LOAD LIST ALL
101. FINISH

          *************** END OF STAAD-III ***************

            **** DATE= APR  4,1996   TIME= 11: 7:47 ****

      **********************************************************
      *        For questions on  STAAD-III,   contact:          *
      *              Research Engineers, Inc at                 *
      *       Ph: (714) 974-2500   Fax:  (714) 921-2543         *
      **********************************************************
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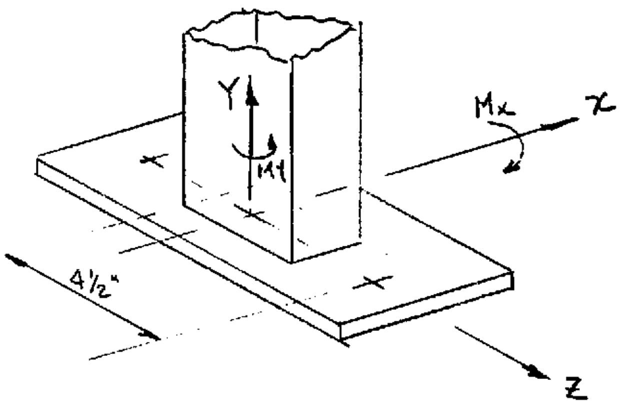
DESIGN BASEPLATE & ANCHOR BOLTS

DESIGN ANCHOR BOLTS & BASEPLATE (USING WORST CASE LOADING @ ANY SPRT.)

ANCHOR BOLTS - TRY 1"Φ HILTI HVA @ 8¼" EMBEDMENT
for f'c=3000psi

T_{ALLOW} = 10960 lbs.

V_{ALLOW} = 7630 lbs



ENVELOPE LOADS

Fx = 742.0 lbs
FY = 1989.0 lbs (TENSION)
FZ = 1122.0 lbs

Mx = 28586. IN-lbs
MY = 605 IN-lbs.
MZ = 0. (RELEASED)

REF. STAAD3 OUTPUT

$$T_{MAX} = \frac{1989.^{\#}}{2\ BOLTS} + \frac{28586.^{\ IN\cdot lbs}}{(4.5_{in})(1\ BOLT)} = 7347.\ lbs/BOLT$$

$$V_{MAX} = \frac{742.0^{\#} + 1122.0^{\#}}{2\ BOLTS} + \frac{605.\ IN\cdot lbs}{(2\ BOLTS)(3_{in})} = 1134.\ lbs/BOLT$$

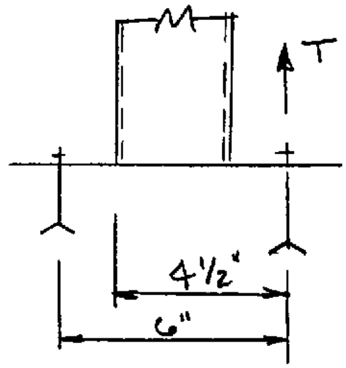
$$\frac{T_{MAX}}{T_{ALL}} + \frac{V_{MAX}}{V_{ALL}} \Rightarrow \frac{7347.}{10960.} + \frac{1134.}{7630.} = 0.82 < 1.0$$

∴ O.K.

USE 1"Φ HILTI HVA @ 8½" EMB'D.

NOTE: ULTRA CONSERVATIVE BY ENVELOPING LOADCASES.

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

$$S_{req'd} = \frac{7347.^{\#}(4.5")(1.2)}{27000} = 1.469\ \text{in}^3$$

$$S = bd^2/6 \Rightarrow \sqrt{\frac{6\,(S)}{b}} = d_{req'd} \qquad \text{where } b = 6\,\text{in}$$

$$d_{req'd} = \sqrt{\frac{6\,(1.469\ \text{in}^3)}{6\,\text{in.}}} = 1.21"\ \text{THICK}$$

USE 1" THK PLATE

NOTE:

$$\text{ACTUAL MAX TENSION} = \frac{28586.\ \text{in-lbs}}{(4.5\ \text{in})(1\ \text{BOLT})} = 6352\ \text{lbs/BOLT}$$

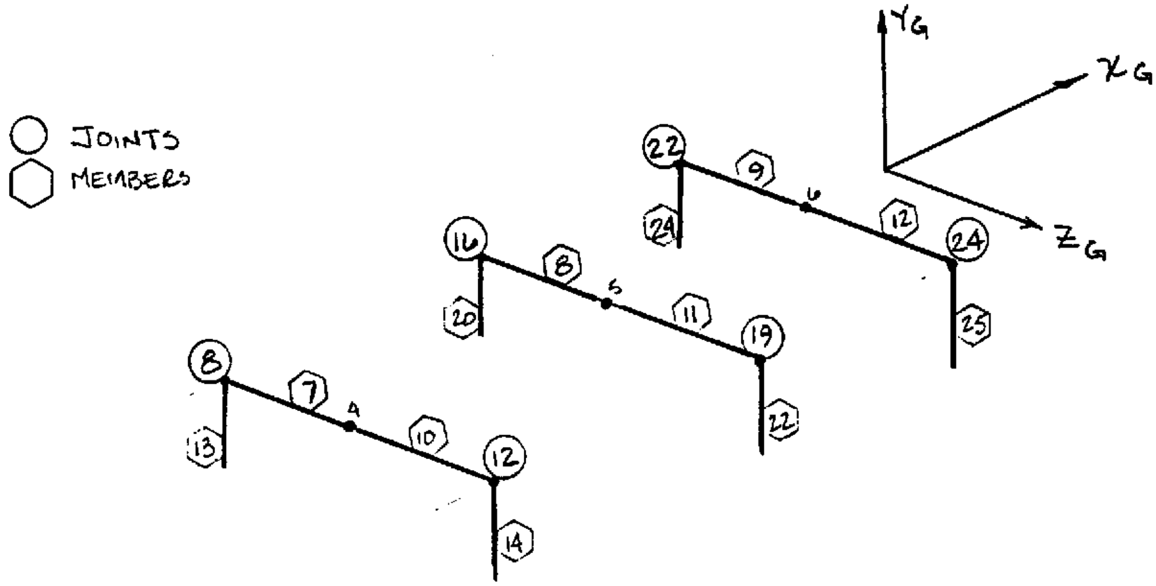
6352 lbs INCLUDES SEISMIC LOADING
∴ A 33% IN ALLOWABLE Fbe Fb

∴ 1" THK PLATE O.K.

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

DESIGN BOLTED CONNECTION

B-5 MODE CLEANER TUBE TO SUPPORT LEG

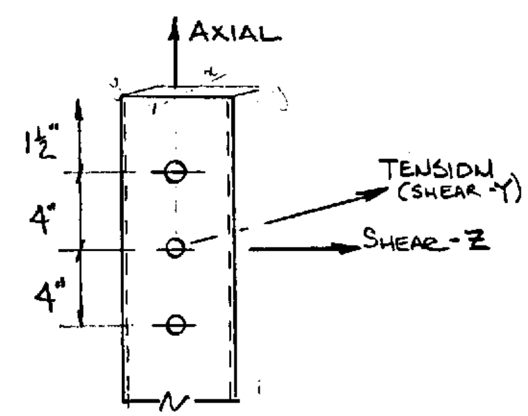


TRY 5/8" ϕ A307 BOLTS

$F_T = 20$ KSI $A_g = .307 in^2 \Rightarrow F_{T_{ALLOW}} = 20 ksi (.307 in^2)$
$= 6.1$ KIPS
$= 6100$ lbs

$F_V = 10$ KSI $A_g = .307 in^2 \Rightarrow F_{V_{ALLOW}} = 10 ksi (.307 in^2)$
$= 3.1$ KIPS
$= 3070$ lbs.

MEMBER END FORCES @ 13, 14, 20, 22, 24 & 25 **ENVELOPE LOADS**



MAX AXIAL = 7723.0 lbs (MEM 13)

MAX SHEAR-Z = 709.0 (MEM 20)

TENSION MAX (SHEAR-Y) = 915.0 (MEM 14)

22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS AMPAD

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

BOLT FORCES

$$\text{SHEAR} = V = \left((7723.0 \text{ lbs})^2 + (709. \text{ lbs})^2 \right)^{1/2}$$
$$= 7756. \text{ lbs}$$
$$V = 7756. \text{ lbs} / 3 \text{ BOLTS} = 2585. \text{ lbs/BOLT}$$

$$\text{TENSION} \quad T = 915. \text{ lbs}$$
$$T = 915. \text{ lbs} / 3 \text{ BOLTS} = 305 \text{ lbs/BOLT}$$

$$\frac{V}{V_{all}} + \frac{T}{T_{all}} = \frac{2585. \text{ lbs}}{3100. \text{ lbs}} + \frac{305 \text{ lbs.}}{6100 \text{ lbs}} = .88 < 1.0$$

$\therefore$ 5/8" ϕ O.K.

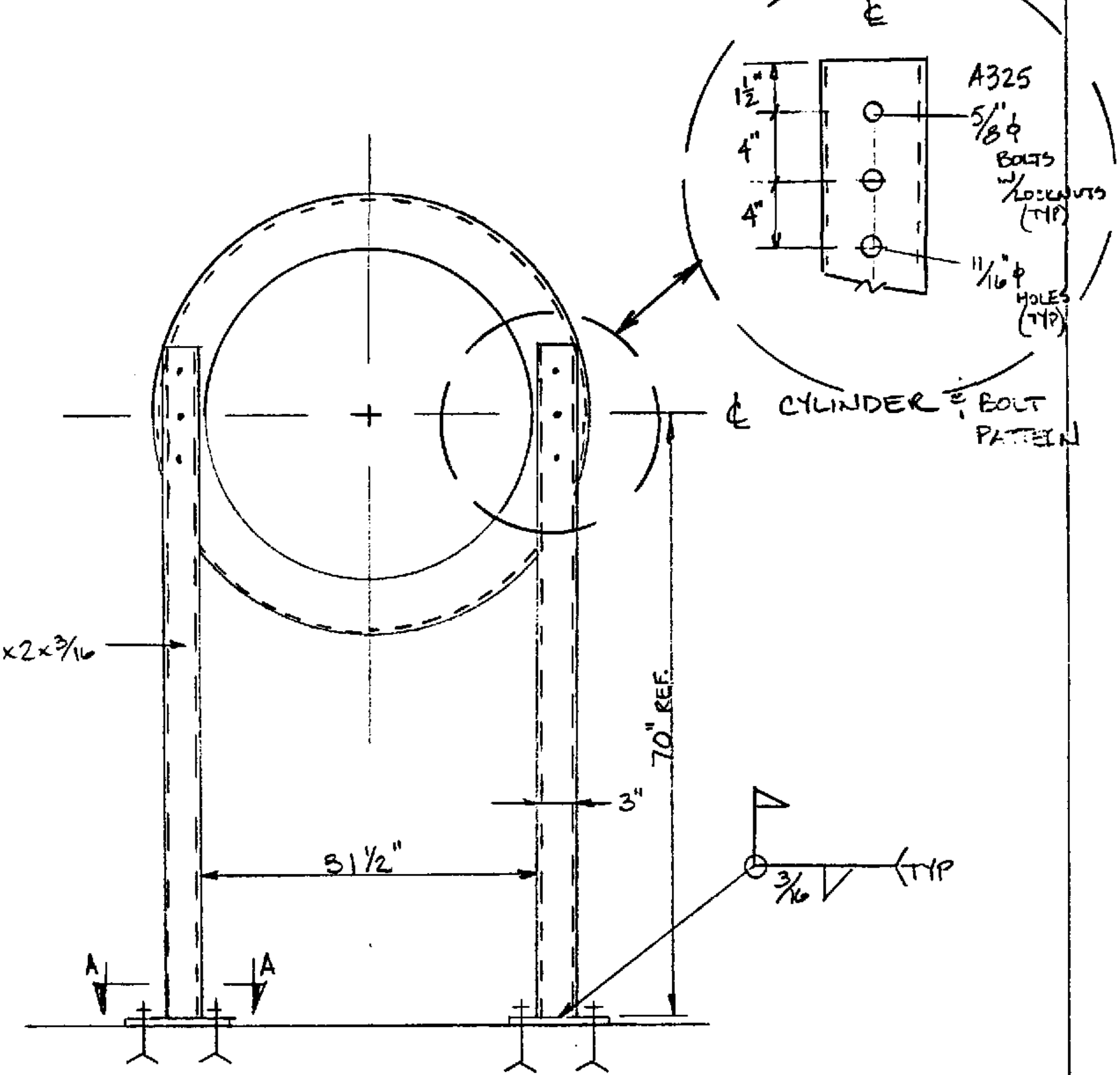
USE 5/8" ϕ BOLTS A325 *

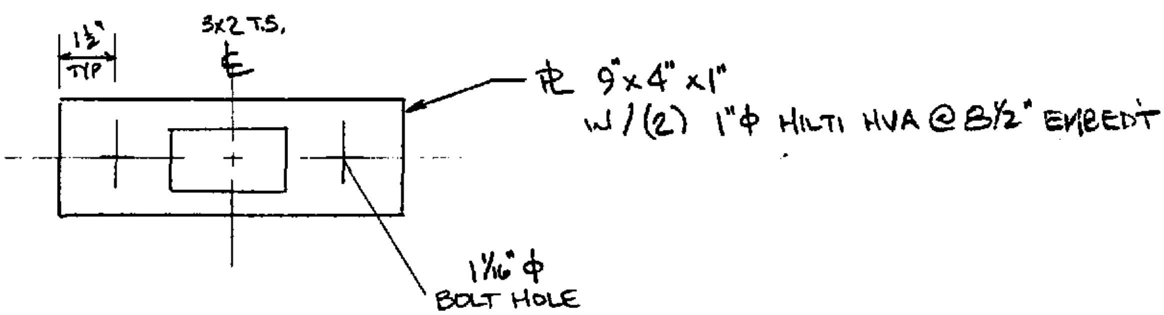
NOTE: CONSERVATISM EXISTS DUE TO LOAD COMBINATIONS INCLUDE SEISMIC LOADS WHICH ALLOW FOR SOME MARGIN OF INCREASE.

* USE A325 FOR INSTALLATION TO ACCOUNT FOR LOCAL BENDING AT CONNECTIONS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

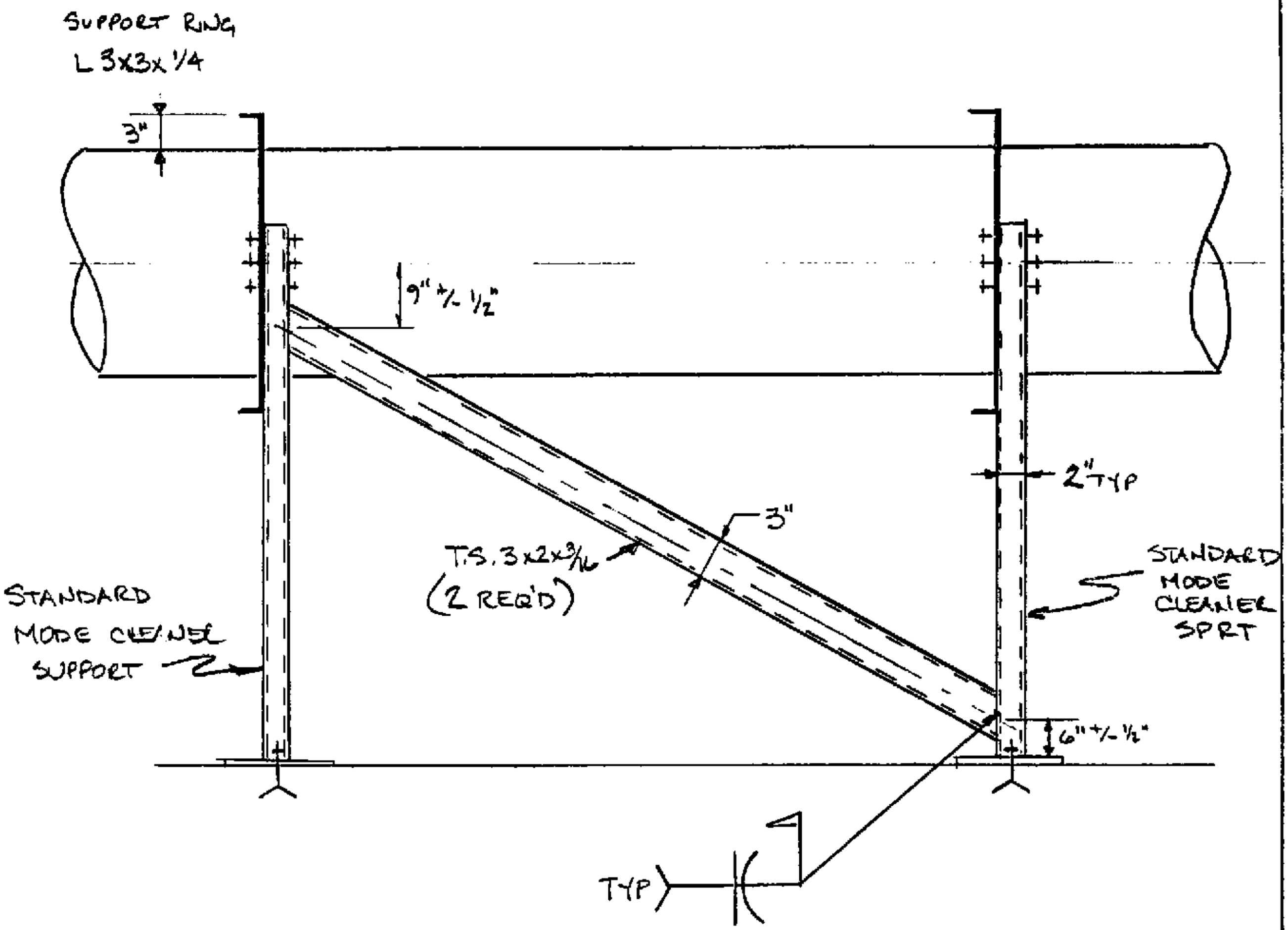
STANDARD MODE CLEANER TUBE SUPPORT





SECTION A-A

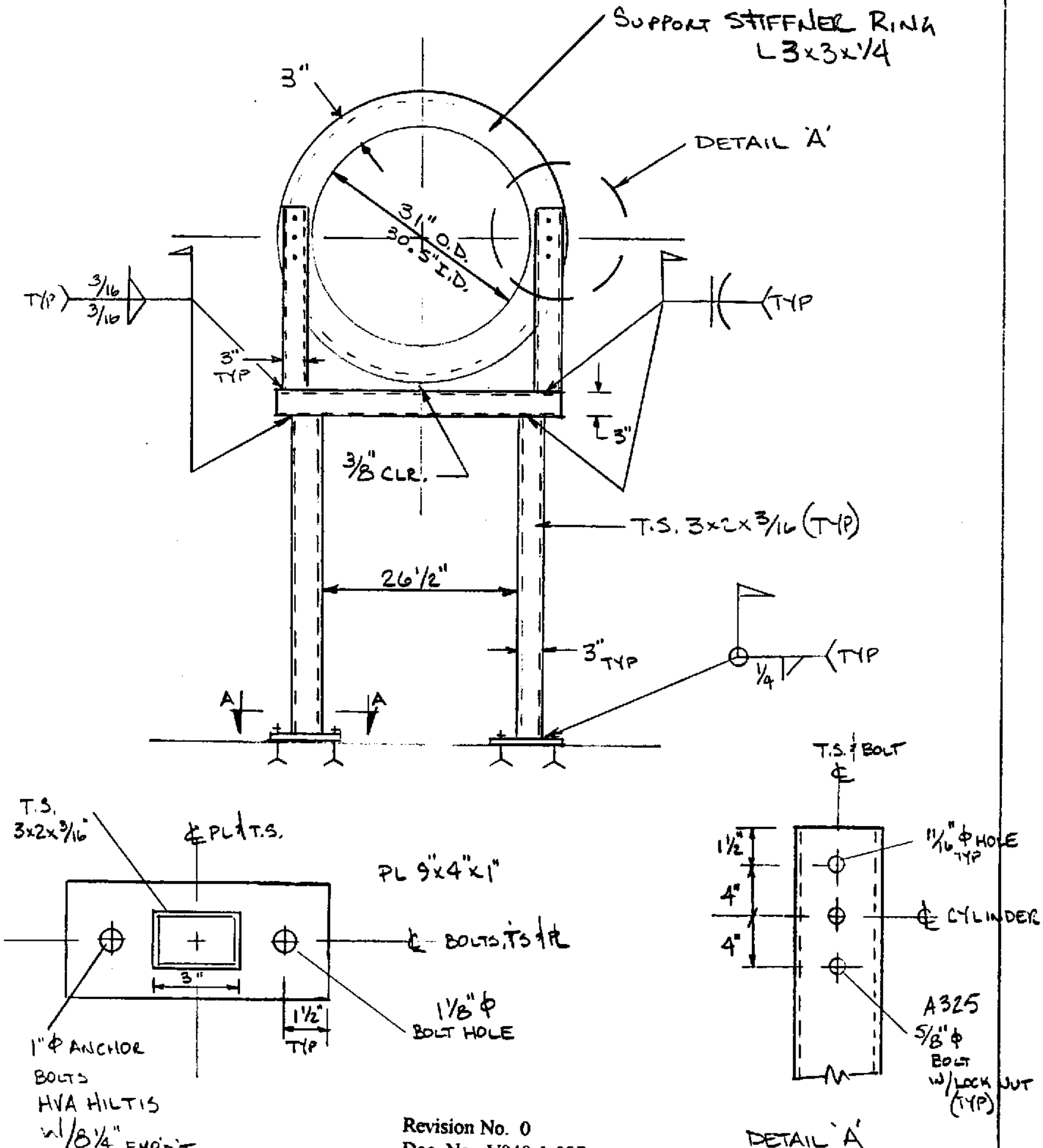
ANCHOR – MODE CLEANER TUBE



22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

NON-STANDARD SUPPORT

MODE CLEANER TUBE B-5



PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-089 PAGE 1 OF 39
REV.	DEO #	DATE	BY:	CHECK	TITLE: Design of Generic Support Scheme for: Beam Tube Manifold B-9	
0	0739	4.24.96	WDB	AGR		
					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. The support scheme for BTM B-9 is made up of one anchor and one flexible support.

METHOD:

Thermal growth is the governing design factor, supports were located using a maximum displacement of 1/2in. at the flex support. Additionally, the bellows connections at the end of the spool piece 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, 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

ASSUMPTIONS Assume anchor points are fixed but released for Mz (about the out-of-plane moment)

INPUTS:

Vessel wght = 6437.0 lbs, Flange wght = 1539.0 lbs
Seismic Acceleration = 0.05625 g.

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

CONCLUSIONS: The requirements of the AISC Code and the LIGO Vacuum Equipment Structural Design Criteria are met.

NOTES: STAAD-III Computer file: B9MANFOLD.*

TABLE OF CONTENTS

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.

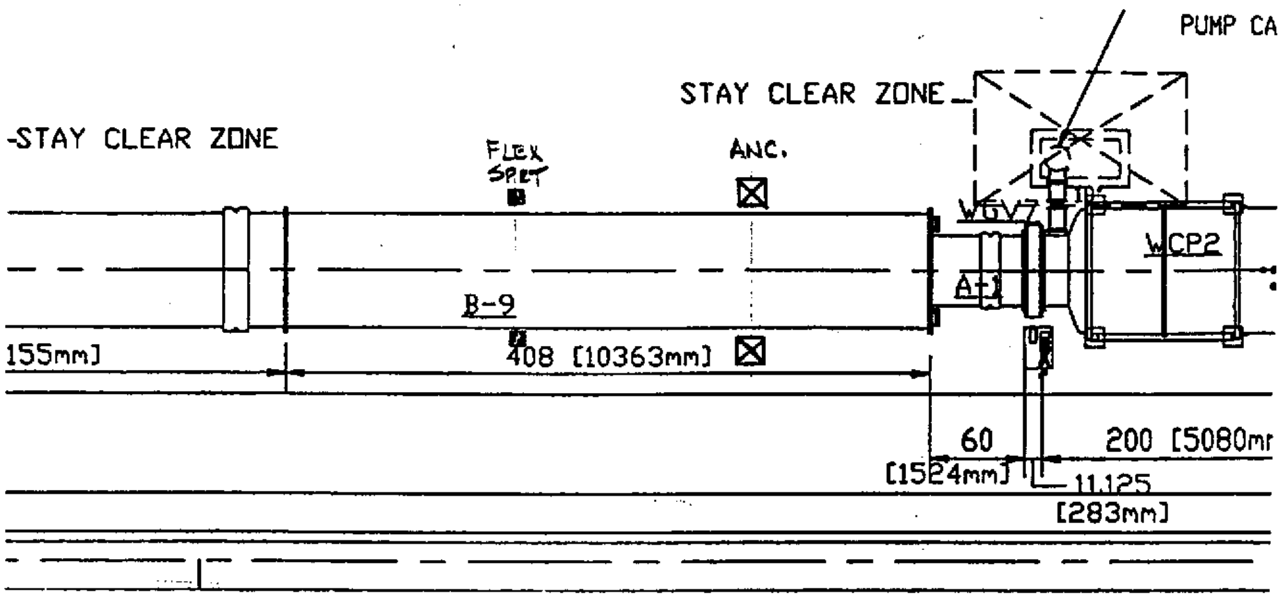
Step 4 - Applicable loading conditions were determined. These included; deadweight for vessel and flanges, uniform thermal load for the Beam Tube Manifold, and seismic factors.

Step 5 - Computer output results were evaluated.

Step 6 - Using computer generated forces and reactions, anchors, baseplates and bolted connections (support legs to vessel stiffener rings) were designed.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

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

$$f_b = \frac{M_y}{S_y} \Rightarrow M_y = \frac{6 E I_y \delta}{L^2}$$

ref. GERE & WEAVER TABLE B-4

$$M_y = f_b (S_y)$$

$$\frac{6 E I_y \delta}{L^2} = f_b (S_y)$$

$$\therefore \delta_{max} = \frac{f_b (S_y)(L)^2}{6 E I_y}$$

$$\delta_{max} = \frac{.6(36000 \#/in^2)(1.29 in^3)(70 in)^2}{6(29E06 \#/in^2)(1.29 in^4)} = 0.608 \text{ IN.}$$

$\delta_{max} = 0.608 in$

LIMIT MAX DISPLACEMENT TO 0.50 IN. (@ FLEX SUPPORT)

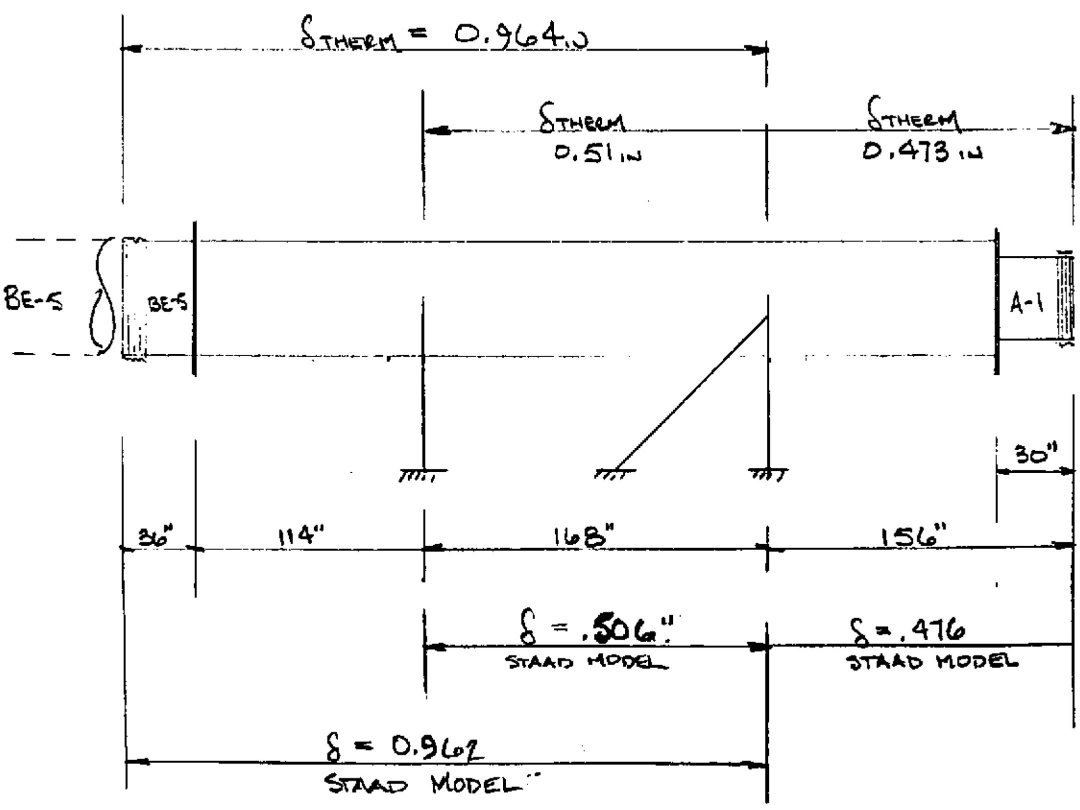
THEREFORE, MAX SPAN;

$$L_{MAX} = \frac{\delta_{max}}{\alpha \Delta T} = \frac{.50 in}{(9.19 \times 10^{-6} in/in{\cdot}°F)(330°F)}$$

$$L_{MAX} = 165 \text{ in.}$$

<u>MANIFOLD B-9</u> - SUPPORT WAS LOCATED AS CLOSE TO MID SPAN 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)



AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

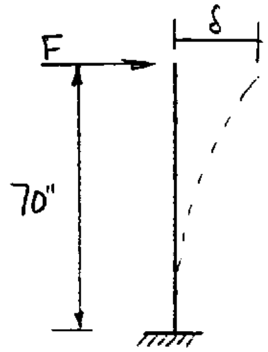
FOR FLEXIBLE SUPPORT

Max δ_{THERM} @ 168 in. Span

$$\delta_{THERM} = \alpha \, \Delta T \, L$$
$$= (9.19 \times 10^{-6} \text{ in/in°F})(330°\text{F})(168 \text{ in})$$
$$= .51 \text{ in.}$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

EQUIVALENT STATIC FORCE DUE TO THERMAL DISPLACEMENT



T.S. 4 × 2 × 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

$$\delta_{THERM} = \alpha \, \Delta T \, L$$
$$= (9.19 \times 10^{-6} \text{ in/in°F})(330°\text{F})(156 \text{ in})$$
$$= 0.473 \text{ in}$$

($\delta = 0.476$ in STAAD MODEL)

Max δ_{THERM} @ BE-5 BELLOWS

$$\delta_{THERM} = (9.19 \times 10^{-6} \text{ in/in°F})(330°\text{F})(318 \text{ in.})$$
$$= 0.964 \text{ in}$$

($\delta = 0.962$" STAAD MODEL)

DETERMINE LOADING CONDITIONS

BEAM MANIFOLD B-9 WAS DESIGNED USING THE COMPUTER AIDED DESIGN PROGRAM COMPRESS. THE WEIGHT SUMMARY INCLUDES THE WEIGHT OF VESSEL (INCLUDING STIFFENER RINGS, SUPPORT RINGS) ADDITIONALLY FLANGES WERE MODELED TO OBTAIN THEIR RESPECTIVE WEIGHTS.

VESSEL WEIGHT = 6737 lbs

$$\frac{6737 \text{ lbs}}{408 \text{ in}} = 16.5 \text{ lbs/in.}$$

FLANGE WEIGHTS

@ BE-5 BELLOWS - 2 FLANGES

370 lbs + 370 lbs = 740 lbs.

@ A-1 BELLOWS - 2 FLANGES (ONE REDUCING)

1381 lbs + 370 lbs. = 1751 lbs.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

"COMPRESS" - WEIGHT SUMMARY

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

File View Title Block

C:\COMPRESS\MANIFOLD\b-9.vsl:Weight summary

Component	Weight (lbs) Metal New	Metal Corr	Trays & sup	Packed Beds	Contribute Insul	Lin
Spool b-9	6737	6737	0	0	0	
Reducing flg	370	370	0	0	0	
Adapter flg	370	370	0	0	0	
	7477	7477	0	0	0	

Vessel operating weight, corroded: 7,895 lbs
Vessel empty weight, corroded: 7,895 lbs
Vessel empty weight, new: 7,895 lbs
Vessel test weight, new: 68,289 lbs

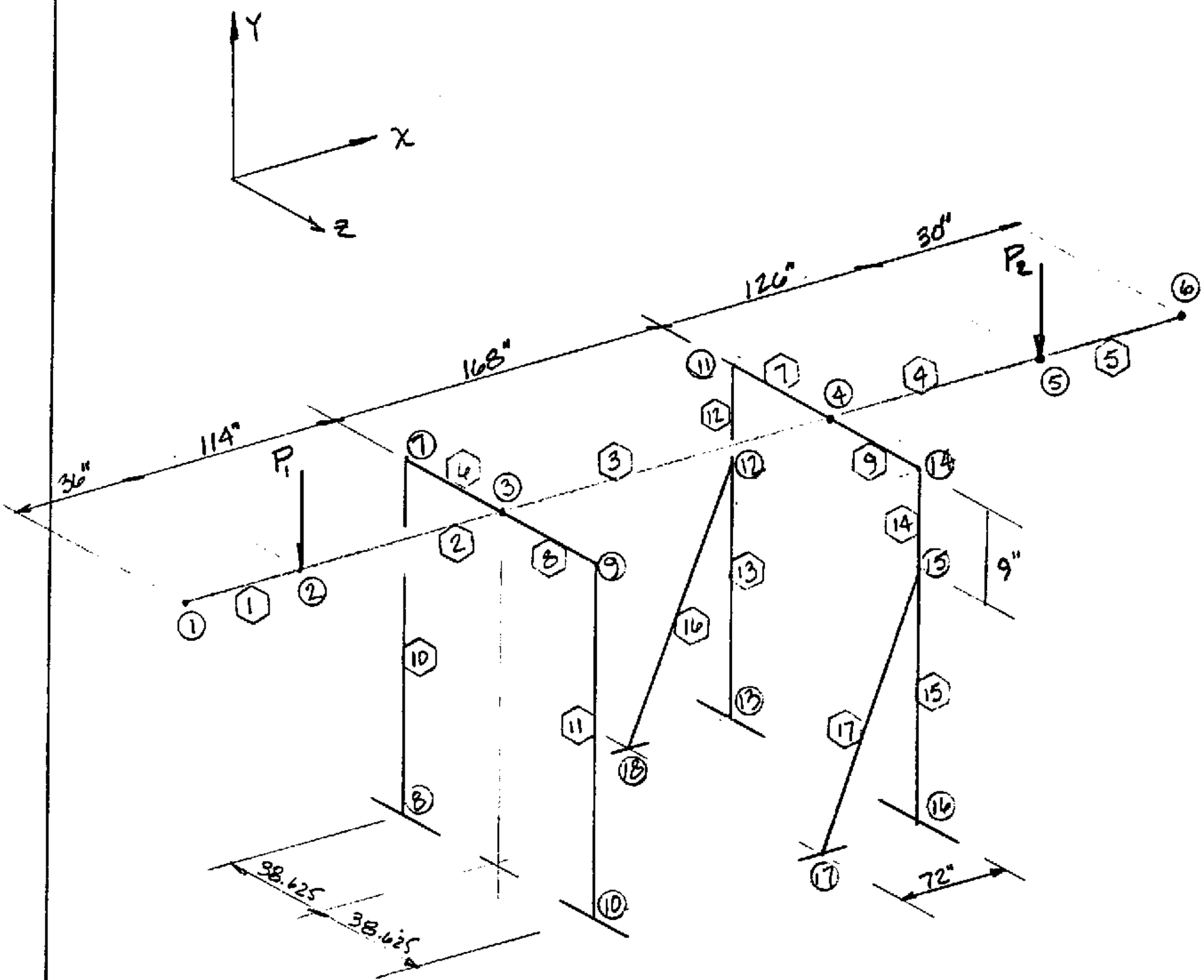
File View Title Block

C:\COMPRESS\MANIFOLD\b-9.vsl:Weight summary

Component	Weight (lbs) Metal New	Metal Corr	Trays & sup	Packed Beds	Contribute Insul	Lin
Spool b-9	6737	6737	0	0	0	
Reducing flg	1381	1381	0	0	0	
Adapter flg	370	370	0	0	0	
	8488	8488	0	0	0	

Vessel operating weight, corroded: 8,906 lbs
Vessel empty weight, corroded: 8,906 lbs
Vessel empty weight, new: 8,906 lbs
Vessel test weight, new: 69,300 lbs

B-9 BEAM TUBE MANIFOLD SUPPORT SCHEME



P1 = 740 lbs P2 = 1751 lbs

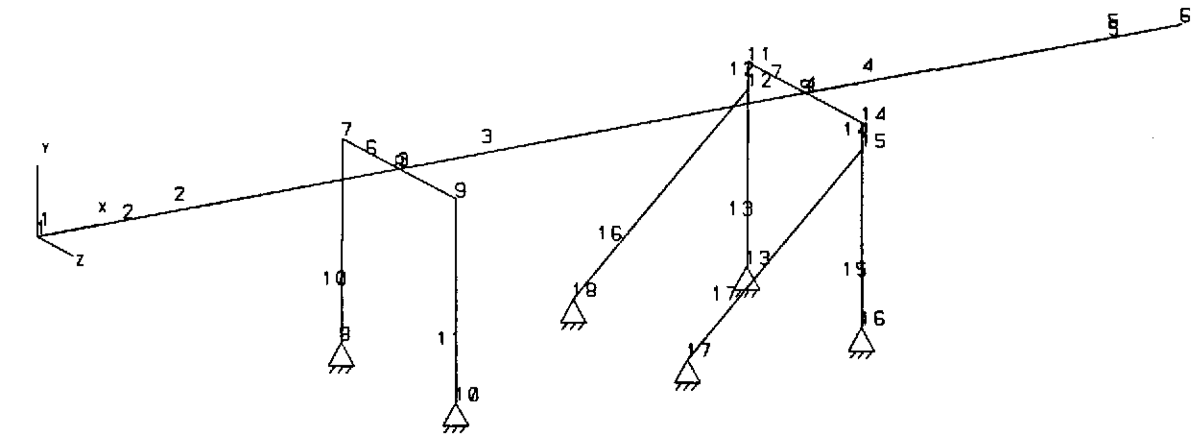
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

1

MN/ELEM

STRUCTURE DATA

TYPE = SPACE
NJ = 18
NM = 17
NE = 0
NS = 6
NL = 4
XMAX= 474.0
YMAX= 70.0
ZMAX= 77.3



J=18,M=17

UNIT INC POU

USER ID:Process Systems International

S T A A D P O S T - P L O T (REV: 21.0)

TITLE: BS MODE CLEANER TUBE SUPPORTS

DATE: MAR 29, 1996

```
**************************************************
*                                                *
*             S T A A D - III                    *
*             Revision 21.0                      *
*             Proprietary Program of             *
*             Research Engineers, Inc.           *
*             Date=    APR  8, 1996              *
*             Time=    10: 6:58                  *
*                                                *
*     USER ID: Process Systems International     *
**************************************************
```

```
 1. STAAD SPACE B-9 BEAM TUBE MANIFOLD SUPPORT
 2. INPUT WIDTH 72
 3. UNIT INCHES POUND
 4. JOINT COORDINATES
 5. 1 0. 0. 0.; 2 36. 0. 0.; 3 150. 0. 0.; 4 318. 0. 0.; 5 444. 0. 0.
 6. 6 474. 0. 0.
 7. 7 150. 0. -38.625; 8 150. -70. -38.625; 9 150. 0. 38.625
 8. 10 150. -70.0 38.625; 11 318. 0. -38.625; 12 318. -9. -38.625
 9. 13 318. -70. -38.625; 14 318. 0. 38.625; 15 318. -9. 38.625
10. 16 318. -70. 38.625; 17 246. -70. 38.625; 18 246. -70. -38.625
11. MEMBER INCIDENCES
12. 1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 5 6; 6 3 7; 7 4 11; 8 3 9; 9 4 14; 10 8 7
13. 11 10 9; 12 12 11; 13 13 12; 14 15 14; 15 16 15; 16 18 12; 17 17 15
14. MEMBER PROPERTY AMER
15. 10 TO 17 TABLE ST TUB40203
16. 6 TO 9 TABLE ST TUB80805
17. 1 TO 5 TABLE ST PIPE OD 72.75 ID 72.25
18. MEMBER RELEASE
19. ***10 11 12 14 END MX MY MZ
20. *** 6 TO 9     END MX MY MZ
21. CONSTANTS
22. E STEEL ALL
23. POISSON STEEL ALL
24. DENSITY STEEL ALL
25. BETA 90. MEMB 10 TO 15
26. ALPHA 0.00000919 MEM 1 TO 5 6 TO 9
27. SUPPORTS
28. 8 10 13 16 FIXED BUT MZ
29. 17 18 FIXED
30. LOAD 1 DW
31. JOINT LOAD
32. 2 FY -740.
33. 5 FY -1751.
34. MEMBER LOAD
35. 1 TO 5  UNI Y -16.15
36. LOAD 2 DW+TH
37. JOINT LOAD
38. 2 FY -740.
39. 5 FY -1751.
40. MEMBER LOAD
41. 1 TO 5 UNI Y -16.15
```

```
 42. TEMPERATURE LOAD
 43. 1 TO 5 TEMP 330.
 44. LOAD 3 DW+TH+SEIS-AXIAL
 45. JOINT LOAD
 46. 2 FY -740.
 47. 5 FY -1751.
 48. 2 FX -42.
 49. 5 FX -98.
 50. MEMBER LOAD
 51. 1 TO 5 UNI Y -16.15
 52. 1 TO 5 UNI X -0.908
 53. TEMPERATURE LOAD
 54. 1 TO 5 TEMP 330.
 55. LOAD 4 DW+TH+SEIS-LAT
 56. JOINT LOAD
 57. 2 FY -740.
 58. 5 FY -1751.
 59. 2 FZ 42.
 60. 5 FZ 98.
 61. MEMBER LOAD
 62. 1 TO 5 UNI Y -16.15
 63. 1 TO 5 UNI Z 0.908
 64. TEMPERATURE LOAD
 65. 1 TO 5 TEMP 330.
 66. LOAD 5 THERMAL DISPL "BAKEOUT"
 67. TEMPERATURE LOAD
 68. 1 TO 5 TEMP 330.
 69. 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 =    18/   17/    6
   ORIGINAL/FINAL BAND-WIDTH =   10/     5
   TOTAL PRIMARY LOAD CASES  =    5, TOTAL DEGREES OF FREEDOM =    76
   SIZE OF STIFFNESS MATRIX =    2736 DOUBLE PREC. WORDS
   REQRD/AVAIL. DISK SPACE =  12.05/  482.9 MB,  EXMEM =  1.02 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.                 10: 6:58
++ PROCESSING GLOBAL STIFFNESS MATRIX.                  10: 6:58
++ PROCESSING TRIANGULAR FACTORIZATION.                 10: 6:58
++ CALCULATING JOINT DISPLACEMENTS.                     10: 6:58
++ CALCULATING MEMBER  FORCES.                          10: 6:58


 70. PRINT MATERIAL PROPERTIES ALL
```

MATERIAL PROPERTIES.

ᐠLL 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	0.00000000
11	29000000.0	11153846.0	0.28299999	0.00000000
12	29000000.0	11153846.0	0.28299999	0.00000000
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

************ END OF DATA FROM INTERNAL STORAGE ************

71. PRINT MEMBER INFORMATION ALL

MEMBER INFORMATION

MEMBER	START JOINT	END JOINT	LENGTH (INCH)	BETA (DEG)	RELEASES
1	1	2	36.000	0.00	
2	2	3	114.000	0.00	
3	3	4	168.000	0.00	
4	4	5	126.000	0.00	
5	5	6	30.000	0.00	
6	3	7	38.625	0.00	
7	4	11	38.625	0.00	
8	3	9	38.625	0.00	
9	4	14	38.625	0.00	
10	8	7	70.000	90.00	
11	10	9	70.000	90.00	
12	12	11	9.000	90.00	
13	13	12	61.000	90.00	
14	15	14	9.000	90.00	
15	16	15	61.000	90.00	
16	18	12	94.366	0.00	
17	17	15	94.366	0.00	

************ END OF DATA FROM INTERNAL STORAGE ************

72. PRINT JOINT COORDINATES ALL

JOINT COORDINATES

COORDINATES ARE INCH UNIT

JOINT	X	Y	Z
1	0.000	0.000	0.000
2	36.000	0.000	0.000
3	150.000	0.000	0.000
4	318.000	0.000	0.000
5	444.000	0.000	0.000
6	474.000	0.000	0.000
7	150.000	0.000	-38.625
8	150.000	-70.000	-38.625
9	150.000	0.000	38.625
10	150.000	-70.000	38.625
11	318.000	0.000	-38.625
12	318.000	-9.000	-38.625
13	318.000	-70.000	-38.625
14	318.000	0.000	38.625
15	318.000	-9.000	38.625
16	318.000	-70.000	38.625
17	246.000	-70.000	38.625
18	246.000	-70.000	-38.625

************ END OF DATA FROM INTERNAL STORAGE ************

73. PRINT SUPPORT INFORMATION ALL

SUPPORT INFORMATION (1=FIXED, 0=RELEASED)

UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

JOINT	FORCE-X/ KFX	FORCE-Y/ KFY	FORCE-Z/ KFZ	MOM-X/ KMX	MOM-Y/ KMY	MOM-Z/ KMZ
8	1	1	1	1	1	0
	0.0	0.0	0.0	0.0	0.0	0.0
10	1	1	1	1	1	0
	0.0	0.0	0.0	0.0	0.0	0.0
13	1	1	1	1	1	0
	0.0	0.0	0.0	0.0	0.0	0.0
16	1	1	1	1	1	0
	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
18	1	1	1	1	1	1
	0.0	0.0	0.0	0.0	0.0	0.0

************ END OF DATA FROM INTERNAL STORAGE ************

74. 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	0.00375	-0.00956	0.00000	0.00000	0.00000	-0.00004
	2	-0.95788	-0.01113	0.00000	0.00000	0.00000	-0.00004
	3	-0.96295	-0.01163	0.00000	0.00000	0.00000	-0.00003
	4	-0.95788	-0.01113	0.02708	-0.00001	-0.00004	-0.00004
	5	-0.96163	-0.00156	0.00000	0.00000	0.00000	0.00001
2	1	0.00375	-0.01108	0.00000	0.00000	0.00000	-0.00004
	2	-0.84870	-0.01239	0.00000	0.00000	0.00000	-0.00004
	3	-0.85378	-0.01279	0.00000	0.00000	0.00000	-0.00003
	4	-0.84870	-0.01239	0.02849	-0.00001	-0.00004	-0.00004
	5	-0.85246	-0.00132	0.00000	0.00000	0.00000	0.00001
3	1	0.00375	-0.01576	0.00000	0.00000	0.00000	-0.00006
	2	-0.50297	-0.01629	0.00000	0.00000	0.00000	-0.00005
	3	-0.50804	-0.01639	0.00000	0.00000	0.00000	-0.00005
	4	-0.50297	-0.01629	0.03298	-0.00001	-0.00004	-0.00005
	5	-0.50673	-0.00053	0.00000	0.00000	0.00000	0.00001
4	1	0.00375	-0.02833	0.00000	0.00000	0.00000	-0.00010
	2	0.00649	-0.02795	0.00000	0.00000	0.00000	-0.00010
	3	0.00145	-0.02759	0.00000	0.00000	0.00000	-0.00009
	4	0.00649	-0.02795	0.03990	-0.00001	-0.00004	-0.00010
	5	0.00273	0.00037	0.00000	0.00000	0.00000	0.00001
5	1	0.00375	-0.04422	0.00000	0.00000	0.00000	-0.00012
	2	0.38861	-0.04322	0.00000	0.00000	0.00000	-0.00012
	3	0.38355	-0.04248	0.00000	0.00000	0.00000	-0.00012
	4	0.38861	-0.04322	0.04539	-0.00001	-0.00004	-0.00012
	5	0.38485	0.00101	0.00000	0.00000	0.00000	0.00001
6	1	0.00375	-0.04799	0.00000	0.00000	0.00000	-0.00012
	2	0.47959	-0.04683	0.00000	0.00000	0.00000	-0.00012
	3	0.47453	-0.04600	0.00000	0.00000	0.00000	-0.00012
	4	0.47959	-0.04683	0.04669	-0.00001	-0.00004	-0.00012
	5	0.47583	0.00116	0.00000	0.00000	0.00000	0.00001
7	1	0.00375	-0.00216	0.00001	0.00047	0.00000	-0.00006
	2	-0.50171	-0.00224	0.00001	0.00048	-0.00004	0.00022
	3	-0.50676	-0.00225	0.00001	0.00049	-0.00005	0.00022
	4	-0.50017	-0.00211	0.03297	0.00051	-0.00008	0.00022
	5	-0.50546	-0.00007	0.00000	0.00002	-0.00004	0.00027
8	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00005
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.01060
	3	0.00000	0.00000	0.00000	0.00000	0.00000	0.01070
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.01057
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.01065
9	1	0.00375	-0.00216	-0.00001	-0.00047	0.00000	-0.00006
	2	-0.50171	-0.00224	-0.00001	-0.00048	0.00004	0.00022
	3	-0.50676	-0.00225	-0.00001	-0.00049	0.00005	0.00022
	4	-0.50325	-0.00236	0.03295	-0.00046	0.00001	0.00022
	5	-0.50546	-0.00007	0.00000	-0.00002	0.00004	0.00027
10	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00005
	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.01060
	3	0.00000	0.00000	0.00000	0.00000	0.00000	0.01070

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

JOINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.01063
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.01065
11	1	0.00368	-0.00390	0.00002	0.00084	0.00000	-0.00010
	2	0.00516	-0.00398	0.00002	0.00082	0.00005	-0.00012
	3	0.00235	-0.00370	0.00002	0.00082	-0.00003	-0.00007
	4	0.00605	-0.00390	0.03989	0.00086	0.00003	-0.00013
	5	0.00148	-0.00008	0.00000	-0.00002	0.00004	-0.00002
12	1	0.00288	-0.00340	-0.00558	0.00043	0.00006	-0.00008
	2	0.00341	-0.00348	-0.00548	0.00042	0.00009	-0.00016
	3	0.00236	-0.00321	-0.00545	0.00042	0.00003	-0.00001
	4	0.00366	-0.00343	0.03227	0.00083	0.00000	-0.00021
	5	0.00053	-0.00009	0.00010	-0.00001	0.00003	-0.00008
13	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00003
	2	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00005
	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00003
14	1	0.00368	-0.00390	-0.00002	-0.00084	0.00000	-0.00010
	2	0.00516	-0.00398	-0.00002	-0.00082	-0.00005	-0.00012
	3	0.00235	-0.00370	-0.00002	-0.00082	0.00003	-0.00007
	4	0.00427	-0.00405	0.03986	-0.00079	-0.00007	-0.00010
	5	0.00148	-0.00008	0.00000	0.00002	-0.00004	-0.00002
15	1	0.00288	-0.00340	0.00558	-0.00043	-0.00006	-0.00008
	2	0.00341	-0.00348	0.00548	-0.00042	-0.00009	-0.00016
	3	0.00236	-0.00321	0.00545	-0.00042	-0.00003	-0.00001
	4	0.00315	-0.00354	0.04323	-0.00002	-0.00018	-0.00011
	5	0.00053	-0.00009	-0.00010	0.00001	-0.00003	-0.00008
16	1	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00003
	2	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00001
	3	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00005
	4	0.00000	0.00000	0.00000	0.00000	0.00000	-0.00003
	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00003
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	0.00000	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

SUPPORT REACTIONS -UNIT POUN INCH STRUCTURE TYPE = SPACE

JOINT	LOAD	FORCE-X	FORCE-Y	FORCE-Z	MOM-X	MOM-Y	MOM Z
8	1	0.04	1810.44	63.79	1475.71	0.01	0.00
	2	159.73	1871.21	65.93	1525.23	27.13	0.00
	3	161.27	1881.96	66.31	1533.99	27.39	0.00
	4	159.24	1767.26	-58.70	-2880.48	51.15	0.00
	5	159.69	60.77	2.14	49.55	27.12	0.00
10	1	0.04	1810.44	-63.79	-1475.71	-0.01	0.00
	2	159.73	1871.21	-65.93	-1525.25	-27.13	0.00
	3	161.27	1881.96	-66.31	-1534.01	-27.39	0.00
	4	160.22	1975.16	-190.57	-5930.97	-3.11	0.00
	5	159.69	60.77	-2.14	-49.53	-27.12	0.00
13	1	0.94	3261.84	109.65	2544.30	-39.08	0.00
	2	3.03	3344.98	107.82	2501.55	-60.69	0.00
	3	-0.81	3078.34	107.08	2484.94	-20.89	0.00
	4	4.45	3291.69	-40.89	-2783.89	1.19	0.00
	5	2.09	83.01	-1.83	-42.77	-21.59	0.00
16	1	0.94	3261.84	-109.65	-2544.30	39.08	0.00
	2	3.03	3344.98	-107.82	-2501.54	60.69	0.00
	3	-0.81	3078.34	-107.08	-2484.92	20.89	0.00
	4	1.61	3398.28	-256.53	-7786.98	122.57	0.00
	5	2.09	83.00	1.83	42.74	21.59	0.00
17	1	-0.98	0.77	-8.92	-85.73	355.19	151.36
	2	-162.75	-143.14	-8.15	-64.67	340.58	-2.07
	3	124.63	112.75	-9.18	-98.94	353.60	271.87
	4	-56.38	-48.22	-20.00	-597.06	794.61	109.56
	5	-161.62	-143.77	0.76	21.04	-14.60	-153.28
18	1	-0.98	0.77	8.92	85.73	-355.19	151.36
	2	-162.75	-143.14	8.15	64.67	-340.58	-2.07
	3	124.64	112.76	9.18	98.95	-353.60	271.87
	4	-269.13	-238.07	-3.70	-467.72	113.46	-113.71
	5	-161.62	-143.78	-0.76	-21.04	14.60	-153.29

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	-0.01	0.00	0.00	0.00	-0.24
		2	0.00	581.41	0.00	0.00	0.00	-10465.29
	2	1	2.93	0.00	0.00	0.00	0.00	0.09
		2	-2.93	581.40	0.00	0.00	0.00	-10465.02
	3	1	0.49	0.00	0.00	0.00	0.00	-0.12
		2	32.23	581.40	0.00	0.00	0.00	-10465.11
	4	1	-1.46	0.00	-0.01	-0.01	0.24	-0.01
		2	1.46	581.40	-32.68	0.01	-588.33	-10465.13
	5	1	0.00	0.00	0.00	0.00	0.00	-0.01
		2	0.00	0.00	0.00	0.00	0.00	-0.02
2	1	2	0.00	-1321.40	0.00	0.00	0.00	10465.26
		3	0.00	3162.50	0.00	0.00	0.00	-266047.47
	2	2	0.00	-1321.40	0.00	0.00	0.00	10465.27
		3	0.00	3162.50	0.00	0.00	0.00	-266047.38
	3	2	-74.22	-1321.40	0.00	0.00	0.00	10465.24
		3	177.73	3162.50	0.00	0.00	0.00	-266047.44
	4	2	0.49	-1321.40	74.69	0.00	588.33	10464.97
		3	-0.49	3162.50	-178.20	0.00	-15003.03	-266047.63
	5	2	0.00	0.00	0.00	0.00	0.00	0.01
		3	0.00	0.00	0.00	0.00	0.00	0.01
3	1	3	0.09	458.38	0.00	0.00	0.00	266053.50
		4	-0.09	2254.82	0.00	0.00	0.00	-416953.81
	2	3	319.34	579.92	0.00	-0.02	0.40	288409.91
		4	-319.34	2133.28	0.00	0.02	0.01	-418892.31
	3	3	144.04	601.42	0.00	-0.02	-0.27	288625.34
		4	8.30	2111.78	0.00	0.02	0.02	-415496.09
	4	3	319.82	579.92	-71.07	607.32	15089.10	288409.84
		4	-319.82	2133.28	-81.48	-607.32	-15963.33	-418891.84
	5	3	319.34	121.55	0.00	0.02	-0.06	22356.33
		4	-319.34	-121.55	0.00	-0.02	0.10	-1936.46
4	1	4	0.00	4270.40	0.00	0.00	0.00	417139.28
		5	0.00	-2235.50	0.00	0.00	-0.01	-7267.25
	2	4	0.00	4270.40	0.00	-0.01	-0.12	417139.88
		5	0.00	-2235.50	0.00	0.01	0.00	-7267.47
	3	4	239.26	4270.40	0.01	0.01	-0.80	417139.34
		5	-125.00	-2235.50	-0.01	-0.01	0.12	-7267.56
	4	4	-0.49	4270.40	-239.66	-0.01	23397.32	417138.88
		5	0.49	-2235.50	125.26	0.01	-406.91	-7267.96
	5	4	0.00	0.00	0.00	0.00	0.23	-0.03
		5	0.00	0.00	0.00	0.00	-0.05	-0.03
5	1	5	0.03	484.52	0.00	-0.01	0.01	7268.38
		6	-0.03	-0.02	0.00	0.01	-0.01	1.13

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	-1.46	484.51	0.00	-0.01	0.01	7267.58
		6	1.46	-0.01	0.00	0.01	-0.04	0.90
	3	5	28.81	484.51	0.01	0.01	-0.14	7267.81
		6	-1.46	-0.01	-0.01	-0.01	-0.01	0.74
	4	5	0.98	484.49	-27.22	-0.02	409.01	7267.81
		6	-0.98	0.01	-0.02	0.02	-0.11	0.38
	5	5	2.44	0.00	0.00	0.00	0.05	0.01
		6	-2.44	0.00	0.00	0.00	0.00	0.03
6	1	3	63.79	-1810.44	-0.04	3.06	1.69	-66938.70
		7	-63.79	1810.44	0.04	-3.06	0.01	-2989.63
	2	3	65.93	-1871.21	-159.74	11181.18	6142.48	-69185.51
		7	-65.93	1871.21	159.74	-11181.18	27.18	-3089.96
	3	3	66.31	-1881.96	-161.27	11288.84	6201.90	-69582.86
		7	-66.31	1881.96	161.27	-11288.84	27.80	-3107.71
	4	3	-58.69	-1767.26	-159.24	11147.07	6099.43	-69489.18
		7	58.69	1767.26	159.24	-11147.07	51.14	1228.76
	5	3	2.14	-60.77	-159.66	11178.16	6140.42	-2247.03
		7	-2.14	60.77	159.66	-11178.16	26.79	-100.37
7	1	4	118.56	-3262.61	0.04	92.78	-249.40	-120348.70
		11	-118.56	3262.61	-0.04	-92.78	247.71	-5669.46
	2	4	115.97	-3201.84	159.70	-876.34	-6354.47	-118119.23
		11	-115.97	3201.84	-159.70	876.34	186.24	-5551.72
	3	4	116.26	-3191.09	-123.83	821.58	4496.02	-117701.28
		11	-116.26	3191.09	123.83	-821.58	286.96	-5554.62
	4	4	-44.57	-3053.62	264.68	-1500.28	-10071.75	-117815.63
		11	44.57	3053.62	-264.68	1500.28	-151.52	-130.35
	5	4	-2.59	60.77	159.53	-968.23	-6099.84	2229.66
		11	2.59	-60.77	-159.53	968.23	-62.03	117.74
8	1	3	63.79	-1810.44	0.04	-3.06	-1.69	-66938.71
		9	-63.79	1810.44	-0.04	3.06	-0.01	-2989.63
	2	3	65.93	-1871.21	159.75	-11181.18	-6142.83	-69185.52
		9	-65.93	1871.21	-159.75	11181.18	-27.36	-3089.99
	3	3	66.31	-1881.96	161.26	-11288.84	-6201.25	-69582.88
		9	-66.31	1881.96	-161.26	11288.84	-27.37	-3107.72
	4	3	190.53	-1975.16	160.21	-11215.27	-6185.21	-68881.87
		9	-190.53	1975.16	-160.21	11215.27	-2.66	-7408.75
	5	3	2.14	-60.77	159.67	-11178.17	-6140.33	-2247.01
		9	-2.14	60.77	-159.67	11178.17	-26.81	-100.35
9	1	4	118.56	-3262.61	-0.04	-92.78	249.40	-120348.70
		14	-118.56	3262.61	0.04	92.78	-247.71	-5669.46
	2	4	115.97	-3201.84	-159.71	876.34	6354.61	-118119.23
		14	-115.97	3201.84	159.71	-876.34	-185.81	-5551.73
	3	4	116.26	-3191.09	123.80	-821.52	-4495.26	-117701.26
		14	-116.26	3191.09	-123.80	821.52	-286.34	-5554.55

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	276.50	-3350.06	-54.78	252.44	2638.33	-118422.95
		14	-276.50	3350.06	54.78	-252.44	-522.49	-10973.21
	5	4	-2.59	60.77	-159.52	968.25	6099.49	2229.64
		14	2.59	-60.77	159.52	-968.25	61.93	117.70
10	1	8	1810.44	63.79	0.04	0.01	0.00	1475.71
		7	-1810.44	-63.79	-0.04	-0.01	-3.06	2989.64
	2	8	1871.21	65.93	159.73	27.13	0.00	1525.23
		7	-1871.21	-65.93	-159.73	-27.13	-11181.18	3089.98
	3	8	1881.96	66.31	161.27	27.39	0.00	1533.99
		7	-1881.96	-66.31	-161.27	-27.39	-11288.84	3107.73
	4	8	1767.26	-58.70	159.24	51.15	0.01	-2880.48
		7	-1767.26	58.70	-159.24	-51.15	-11147.07	-1228.77
	5	8	60.77	2.14	159.69	27.12	0.00	49.55
		7	-60.77	-2.14	-159.69	-27.12	-11178.17	100.37
11	1	10	1810.44	-63.79	0.04	-0.01	0.00	-1475.71
		9	-1810.44	63.79	-0.04	0.01	-3.06	-2989.64
	2	10	1871.21	-65.93	159.73	-27.13	0.00	-1525.25
		9	-1871.21	65.93	-159.73	27.13	-11181.18	-3089.99
	3	10	1881.96	-66.31	161.27	-27.39	0.00	-1534.01
		9	-1881.96	66.31	-161.27	27.39	-11288.84	-3107.74
	4	10	1975.16	-190.57	160.22	-3.11	0.00	-5930.97
		9	-1975.16	190.57	-160.22	3.11	-11215.28	-7408.74
	5	10	60.77	-2.14	159.69	-27.12	0.01	-49.53
		9	-60.77	2.14	-159.69	27.12	-11178.17	-100.35
12	1	12	3262.61	118.56	-0.04	247.71	93.17	-4602.41
		11	-3262.61	-118.56	0.04	-247.71	-92.78	5669.49
	2	12	3201.84	115.97	-159.71	185.69	561.10	-4508.03
		11	-3201.84	-115.97	159.71	-185.69	876.29	5551.77
	3	12	3191.09	116.26	123.82	286.81	-292.82	-4508.25
		11	-3191.09	-116.26	-123.82	-286.81	-821.52	5554.63
	4	12	3053.62	-44.59	-264.67	-151.42	881.79	-531.65
		11	-3053.62	44.59	264.67	151.42	1500.28	130.34
	5	12	-60.77	-2.59	-159.54	-61.97	467.55	94.39
		11	60.77	2.59	159.54	61.97	968.27	-117.74
13	1	13	3261.84	109.65	0.94	-39.08	0.00	2544.30
		12	-3261.84	-109.65	-0.94	39.08	-57.15	4144.24
	2	13	3344.98	107.82	3.03	-60.69	0.00	2501.55
		12	-3344.98	-107.82	-3.03	60.69	-184.84	4075.42
	3	13	3078.34	107.08	-0.81	-20.89	0.00	2484.94
		12	-3078.34	-107.08	0.81	20.89	49.48	4046.92
	4	13	3291.69	-40.89	4.45	1.19	0.00	-2783.89
		12	-3291.69	40.89	-4.45	-1.19	-271.41	289.35
	5	13	83.01	-1.83	2.09	-21.59	0.00	-42.77
		12	-83.01	1.83	-2.09	21.59	-127.58	-68.85

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	15	3262.61	-118.56	-0.04	-247.71	93.17	4602.41
		14	-3262.61	118.56	0.04	247.71	-92.78	-5669.49
	2	15	3201.84	-115.97	-159.72	-185.70	561.12	4508.02
		14	-3201.84	115.97	159.72	185.70	876.33	-5551.77
	3	15	3191.09	-116.26	123.85	-286.81	-292.97	4508.24
		14	-3191.09	116.26	-123.85	286.81	-821.65	-5554.61
	4	15	3350.06	-276.53	-54.76	-522.79	240.44	8484.41
		14	-3350.06	276.53	54.76	522.79	252.39	-10973.18
	5	15	-60.77	2.59	-159.54	61.96	467.59	-94.37
		14	60.77	-2.59	159.54	-61.96	968.28	117.70
15	1	16	3261.84	-109.65	0.94	39.08	0.00	-2544.30
		15	-3261.84	109.65	-0.94	-39.08	-57.15	-4144.24
	2	16	3344.98	-107.82	3.03	60.69	0.00	-2501.54
		15	-3344.98	107.82	-3.03	-60.69	-184.85	-4075.42
	3	16	3078.34	-107.08	-0.81	20.89	0.00	-2484.92
		15	-3078.34	107.08	0.81	-20.89	49.47	-4046.91
	4	16	3398.28	-256.53	1.61	122.57	0.00	-7786.98
		15	-3398.28	256.53	-1.61	-122.57	-98.30	-7861.49
	5	16	83.00	1.83	2.09	21.59	0.00	42.74
		15	-83.00	-1.83	-2.09	-21.59	-127.58	68.83
16	1	18	-0.25	1.22	8.92	-164.19	-326.42	151.36
		12	0.25	-1.22	-8.92	164.19	-514.98	-36.03
	2	18	-216.70	-4.01	8.15	-170.81	-301.66	-2.07
		12	216.70	4.01	-8.15	170.81	-467.63	-376.28
	3	18	167.99	5.46	9.18	-153.08	-333.75	271.87
		12	-167.99	-5.46	-9.18	153.08	-532.99	243.41
	4	18	-359.24	-7.67	-3.70	-283.52	388.91	-113.71
		12	359.24	7.67	3.70	283.52	-40.19	-610.42
	5	18	-216.26	-5.23	-0.76	-6.61	24.74	-153.29
		12	216.26	5.23	0.76	6.61	47.32	-339.95
17	1	17	-0.25	1.22	-8.92	164.19	326.42	151.36
		15	0.25	-1.22	8.92	-164.19	514.98	-36.03
	2	17	-216.70	-4.01	-8.15	170.81	301.66	-2.07
		15	216.70	4.01	8.15	-170.81	467.63	-376.29
	3	17	167.98	5.46	-9.18	153.08	333.75	271.87
		15	-167.98	-5.46	9.18	-153.08	532.99	243.39
	4	17	-74.19	-0.35	-20.00	58.10	992.23	109.56
		15	74.19	0.35	20.00	-58.10	895.06	-142.18
	5	17	-216.25	-5.23	0.76	6.61	-24.74	-153.28
		15	216.25	5.23	-0.76	-6.61	-47.32	-339.93

************** END OF LATEST ANALYSIS RESULT **************

75. PRINT MEMBER STRESSES ALL

MEMBER STRESSES

.LL 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	10.2	10.2	17.0	0.0
	2	.0	0.1 C	0.0	0.0	0.1	0.0	0.0
		1.00	0.1 C	0.0	10.2	10.2	17.0	0.0
	3	.0	0.0 C	0.0	0.0	0.0	0.0	0.0
		1.00	0.6 C	0.0	10.2	10.7	17.0	0.0
	4	.0	0.0 T	0.0	0.0	0.0	0.0	0.0
		1.00	0.0 T	0.6	10.2	10.2	17.0	1.0
	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
2	1	.0	0.0 C	0.0	10.2	10.2	38.7	0.0
		1.00	0.0 C	0.0	258.7	258.7	92.6	0.0
	2	.0	0.0	0.0	10.2	10.2	38.7	0.0
		1.00	0.0	0.0	258.7	258.7	92.6	0.0
	3	.0	1.3 T	0.0	10.2	11.5	38.7	0.0
		1.00	3.1 T	0.0	258.7	261.8	92.6	0.0
	4	.0	0.0 C	0.6	10.2	10.2	38.7	2.2
		1.00	0.0 C	14.6	258.7	259.1	92.6	5.2
	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	258.7	258.7	13.4	0.0
		1.00	0.0 C	0.0	405.4	405.4	66.0	0.0
	2	.0	5.6 C	0.0	280.4	286.0	17.0	0.0
		1.00	5.6 C	0.0	407.3	412.9	62.4	0.0
	3	.0	2.5 C	0.0	280.6	283.1	17.6	0.0
		1.00	0.1 C	0.0	404.0	404.1	61.8	0.0
	4	.0	5.6 C	14.7	280.4	286.4	17.0	2.1
		1.00	5.6 C	15.5	407.3	413.2	62.4	2.4
	5	.0	5.6 C	0.0	21.7	27.3	3.6	0.0
		1.00	5.6 C	0.0	1.9	7.5	3.6	0.0
4	1	.0	0.0 T	0.0	405.6	405.6	125.0	0.0
		1.00	0.0 T	0.0	7.1	7.1	65.4	0.0
	2	.0	0.0	0.0	405.6	405.6	125.0	0.0
		1.00	0.0	0.0	7.1	7.1	65.4	0.0
	3	.0	4.2 C	0.0	405.6	409.8	125.0	0.0
		1.00	2.2 C	0.0	7.1	9.3	65.4	0.0
	4	.0	0.0 T	22.7	405.6	406.2	125.0	7.0
		1.00	0.0 T	0.4	7.1	7.1	65.4	3.7
	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
5	1	.0	0.0 C	0.0	7.1	7.1	14.2	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	2	.0	0.0 T	0.0	7.1	7.1	14.2	0.0
		1.00	0.0 T	0.0	0.0	0.0	0.0	0.0

MEMBER STRESSES

ⱢL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	3	.0	0.5 C	0.0	7.1	7.6	14.2	0.0
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	4	.0	0.0 C	0.4	7.1	7.1	14.2	0.8
		1.00	0.0 C	0.0	0.0	0.0	0.0	0.0
	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	6.8 C	0.1	2945.6	2952.5	362.1	0.0
		1.00	6.8 C	0.0	131.6	138.4	362.1	0.0
	2	.0	7.0 C	270.3	3044.5	3321.8	374.2	31.9
		1.00	7.0 C	1.2	136.0	144.2	374.2	31.9
	3	.0	7.1 C	272.9	3062.0	3341.9	376.4	32.3
		1.00	7.1 C	1.2	136.8	145.1	376.4	32.3
	4	.0	6.3 T	268.4	3057.8	3332.5	353.5	31.8
		1.00	6.3 T	2.3	54.1	62.6	353.5	31.8
	5	.0	0.2 C	270.2	98.9	369.3	12.2	31.9
		1.00	0.2 C	1.2	4.4	5.8	12.2	31.9
7	1	.0	12.7 C	11.0	5295.9	5319.5	652.5	0.0
		1.00	12.7 C	10.9	249.5	273.0	652.5	0.0
	2	.0	12.4 C	279.6	5197.8	5489.8	640.4	31.9
		1.00	12.4 C	8.2	244.3	264.9	640.4	31.9
	3	.0	12.4 C	197.8	5179.4	5389.6	638.2	24.8
		1.00	12.4 C	12.6	244.4	269.5	638.2	24.8
	4	.0	4.8 T	443.2	5184.4	5632.4	610.7	52.9
		1.00	4.8 T	6.7	5.7	17.2	610.7	52.9
	5	.0	0.3 T	268.4	98.1	366.8	12.2	31.9
		1.00	0.3 T	2.7	5.2	8.2	12.2	31.9
8	1	.0	6.8 C	0.1	2945.6	2952.5	362.1	0.0
		1.00	6.8 C	0.0	131.6	138.4	362.1	0.0
	2	.0	7.0 C	270.3	3044.5	3321.8	374.2	32.0
		1.00	7.0 C	1.2	136.0	144.2	374.2	32.0
	3	.0	7.1 C	272.9	3062.0	3341.9	376.4	32.3
		1.00	7.1 C	1.2	136.8	145.0	376.4	32.3
	4	.0	20.4 C	272.2	3031.1	3323.6	395.0	32.0
		1.00	20.4 C	0.1	326.0	346.5	395.0	32.0
	5	.0	0.2 C	270.2	98.9	369.3	12.2	31.9
		1.00	0.2 C	1.2	4.4	5.8	12.2	31.9
9	1	.0	12.7 C	11.0	5295.9	5319.5	652.5	0.0
		1.00	12.7 C	10.9	249.5	273.0	652.5	0.0
	2	.0	12.4 C	279.6	5197.8	5489.8	640.4	31.9
		1.00	12.4 C	8.2	244.3	264.9	640.4	31.9
	3	.0	12.4 C	197.8	5179.4	5389.6	638.2	24.8
		1.00	12.4 C	12.6	244.4	269.4	638.2	24.8
	4	.0	29.5 C	116.1	5211.1	5356.8	670.0	11.0
		1.00	29.5 C	23.0	482.9	535.4	670.0	11.0
	5	.0	0.3 T	268.4	98.1	366.8	12.2	31.9
		1.00	0.3 T	2.7	5.2	8.2	12.2	31.9

MEMBER STRESSES

ᒪL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
10	1	.0	896.3	C	0.0	756.8	1653.0	42.5	0.1
		1.00	896.3	C	2.4	1533.1	2431.8	42.5	0.1
	2	.0	926.3	C	0.0	782.2	1708.5	44.0	319.5
		1.00	926.3	C	8600.9	1584.6	11111.9	44.0	319.5
	3	.0	931.7	C	0.0	786.7	1718.3	44.2	322.5
		1.00	931.7	C	8683.7	1593.7	11209.1	44.2	322.5
	4	.0	874.9	C	0.0	1477.2	2352.1	39.1	318.5
		1.00	874.9	C	8574.7	630.1	10079.7	39.1	318.5
	5	.0	30.1	C	0.0	25.4	55.5	1.4	319.4
		1.00	30.1	C	8598.6	51.5	8680.1	1.4	319.4
11	1	.0	896.3	C	0.0	756.8	1653.0	42.5	0.1
		1.00	896.3	C	2.4	1533.1	2431.8	42.5	0.1
	2	.0	926.3	C	0.0	782.2	1708.5	44.0	319.5
		1.00	926.3	C	8600.9	1584.6	11111.9	44.0	319.5
	3	.0	931.7	C	0.0	786.7	1718.3	44.2	322.5
		1.00	931.7	C	8683.7	1593.7	11209.1	44.2	322.5
	4	.0	977.8	C	0.0	3041.5	4019.3	127.0	320.4
		1.00	977.8	C	8627.1	3799.4	13404.3	127.0	320.4
	5	.0	30.1	C	0.0	25.4	55.5	1.4	319.4
		1.00	30.1	C	8598.6	51.5	8680.1	1.4	319.4
12	1	.0	1615.2	C	71.7	2360.2	4047.0	79.0	0.1
		1.00	1615.2	C	71.4	2907.4	4594.0	79.0	0.1
	2	.0	1585.1	C	431.6	2311.8	4328.5	77.3	319.4
		1.00	1585.1	C	674.1	2847.1	5106.2	77.3	319.4
	3	.0	1579.7	C	225.2	2311.9	4116.9	77.5	247.6
		1.00	1579.7	C	631.9	2848.5	5060.2	77.5	247.6
	4	.0	1511.7	C	678.3	272.6	2462.6	29.7	529.3
		1.00	1511.7	C	1154.1	66.8	2732.6	29.7	529.3
	5	.0	30.1	T	359.7	48.4	438.1	1.7	319.1
		1.00	30.1	T	744.8	60.4	835.3	1.7	319.1
13	1	.0	1614.8	C	0.0	1304.8	2919.5	73.1	1.9
		1.00	1614.8	C	44.0	2125.3	3784.0	73.1	1.9
	2	.0	1655.9	C	0.0	1282.8	2938.8	71.9	6.1
		1.00	1655.9	C	142.2	2090.0	3888.1	71.9	6.1
	3	.0	1523.9	C	0.0	1274.3	2798.3	71.4	1.6
		1.00	1523.9	C	38.1	2075.3	3637.3	71.4	1.6
	4	.0	1629.5	C	0.0	1427.6	3057.2	27.3	8.9
		1.00	1629.5	C	208.8	148.4	1986.7	27.3	8.9
	5	.0	41.1	C	0.0	21.9	63.0	1.2	4.2
		1.00	41.1	C	98.1	35.3	174.5	1.2	4.2
14	1	.0	1615.2	C	71.7	2360.2	4047.0	79.0	0.1
		1.00	1615.2	C	71.4	2907.4	4593.9	79.0	0.1
	2	.0	1585.1	C	431.6	2311.8	4328.5	77.3	319.4
		1.00	1585.1	C	674.1	2847.1	5106.2	77.3	319.4

MEMBER STRESSES

LL UNITS ARE POUN/SQ INCH

..EMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	3	.0	1579.8	C	225.4	2311.9	4117.0	77.5	247.7
		1.00	1579.8	C	632.0	2848.5	5060.3	77.5	247.7
	4	.0	1658.4	C	185.0	4351.0	6194.4	184.4	109.5
		1.00	1658.4	C	194.1	5627.3	7479.9	184.4	109.5
	5	.0	30.1	T	359.7	48.4	438.2	1.7	319.1
		1.00	30.1	T	744.8	60.4	835.3	1.7	319.1
15	1	.0	1614.8	C	0.0	1304.8	2919.5	73.1	1.9
		1.00	1614.8	C	44.0	2125.3	3784.0	73.1	1.9
	2	.0	1655.9	C	0.0	1282.8	2938.8	71.9	6.1
		1.00	1655.9	C	142.2	2090.0	3888.1	71.9	6.1
	3	.0	1523.9	C	0.0	1274.3	2798.2	71.4	1.6
		1.00	1523.9	C	38.1	2075.3	3637.3	71.4	1.6
	4	.0	1682.3	C	0.0	3993.3	5675.6	171.0	3.2
		1.00	1682.3	C	75.6	4031.5	5789.5	171.0	3.2
	5	.0	41.1	C	0.0	21.9	63.0	1.2	4.2
		1.00	41.1	C	98.1	35.3	174.5	1.2	4.2
16	1	.0	0.1	T	251.1	77.6	328.8	0.8	17.8
		1.00	0.1	T	396.1	18.5	414.7	0.8	17.8
	2	.0	107.3	T	232.0	1.1	340.4	2.7	16.3
		1.00	107.3	T	359.7	193.0	660.0	2.7	16.3
	3	.0	83.2	C	256.7	139.4	479.3	3.6	18.4
		1.00	83.2	C	410.0	124.8	618.0	3.6	18.4
	4	.0	177.8	T	299.2	58.3	535.3	5.1	7.4
		1.00	177.8	T	30.9	313.0	521.8	5.1	7.4
	5	.0	107.1	T	19.0	78.6	204.7	3.5	1.5
		1.00	107.1	T	36.4	174.3	317.8	3.5	1.5
17	1	.0	0.1	T	251.1	77.6	328.8	0.8	17.8
		1.00	0.1	T	396.1	18.5	414.7	0.8	17.8
	2	.0	107.3	T	232.0	1.1	340.4	2.7	16.3
		1.00	107.3	T	359.7	193.0	660.0	2.7	16.3
	3	.0	83.2	C	256.7	139.4	479.3	3.6	18.4
		1.00	83.2	C	410.0	124.8	618.0	3.6	18.4
	4	.0	36.7	T	763.3	56.2	856.2	0.2	40.0
		1.00	36.7	T	688.5	72.9	798.2	0.2	40.0
	5	.0	107.1	T	19.0	78.6	204.7	3.5	1.5
		1.00	107.1	T	36.4	174.3	317.8	3.5	1.5

************** END OF LATEST ANALYSIS RESULT **************

76. PARAMETER
77. CODE AISC
78. FYLD 45999.969 MEMB 10 TO 17
79. WSTR 21000. MEMB 10 TO 17
80. WMIN 0.188 MEMB 10 TO 17

81. CB 1. MEMB 10 TO 17
82. CMY 1. MEMB 10 TO 17
83. MAIN 0. MEMB 10 TO 17
84. RATIO 1. MEMB 10 TO 17
85. CHECK CODE MEMB 10 TO 17

STAAD-III CODE CHECKING - (AISC)
****

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER	TABLE	RESULT/ FX	CRITICAL COND/ MY	RATIO/ MZ	LOADING/ LOCATION
10	ST TUB 40203	PASS	AISC- H1-3	0.428	3
		1881.96 C	-11288.84	3107.73	70.00
11	ST TUB 40203	PASS	AISC- H1-3	0.508	4
		1975.16 C	-11215.28	-7408.74	70.00
12	ST TUB 40203	PASS	AISC- H1-3	0.187	2
		3201.84 C	876.29	5551.77	9.00
13	ST TUB 40203	PASS	AISC- H1-3	0.169	2
		3344.98 C	-184.84	4075.42	61.00
14	ST TUB 40203	PASS	AISC- H1-3	0.273	4
		3350.06 C	252.39	-10973.18	9.00
15	ST TUB 40203	PASS	AISC- H1-3	0.239	4
		3398.28 C	-98.30	-7861.49	61.00
16	ST TUB 40203	PASS	AISC- H1-3	0.027	3
		167.99 C	-532.99	243.41	94.37
17	ST TUB 40203	PASS	AISC- H2-1	0.031	4
		74.19 T	992.23	109.56	0.00

86. SELECT WELD MEMB 10 TO 17

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS
10	STA 4	1 85.93	3/16 33.67	1939.84 1937.65
10	END 3	1 79.79	3/16 33.53	8530.72 8530.28
11	STA 4	1 72.13	3/16 85.16	3252.15 3250.24
11	END 4	1 72.13	3/16 85.16	10250.68 10250.07
12	STA 2	1 126.00	3/16 79.05	3550.00 3546.88
12	END 2	1 126.00	3/16 79.05	4147.15 4144.49
13	STA 4	1 2.33	3/16 18.35	2576.60 2576.53
13	END 2	1 19.33	3/16 56.91	3223.01 3222.45
14	STA 4	1 179.24	3/16 200.35	5027.27 5020.07
14	END 4	1 179.24	3/16 200.35	6028.41 6022.41
15	STA 4	1 37.03	3/16 132.17	4627.18 4625.14
15	END 4	1 37.03	3/16 132.17	4713.11 4711.11
16	STA 4	1 85.65	3/16 45.41	438.24 427.38
16	END 2	1 54.23	3/16 27.09	517.60 514.04
17	STA 4	1 26.10	3/16 8.76	644.37 643.78
17	END 4	1 26.10	3/16 8.76	601.94 601.31

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS

****************** END OF TABULATED WELD DESIGN ******************

87. LOAD LIST ALL
88. FINISH

*************** END OF STAAD-III ***************

**** DATE= APR 8,1996 TIME= 10: 6:58 ****

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**********************************************************
*        For questions on  STAAD-III,  contact:          *
*              Research Engineers, Inc at                *
*       Ph: (714) 974-2500   Fax:  (714) 921-2543        *
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AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

DESIGN ANCHOR BOLTS, BASEPLATES AND BOLTED CONNECTIONS.

NOTE: ALL WELDED CONNECTIONS (U.N.O.) ARE 3/16 IN. FILLET (ALL AROUND FILLET)

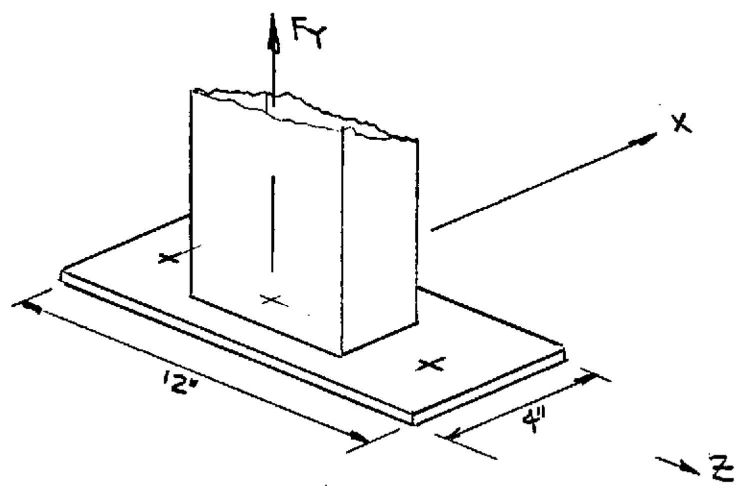
ANCHOR BOLTS – TRY 1" φ HILTI HVA @ 8¼" EMBED'T

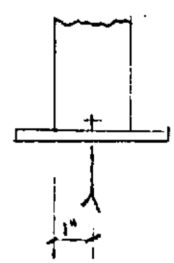
$f'_c = 3000$ PSI

$T_{ALLOW} = 10960$ lbs $V_{ALLOW} = 7630$ lbs.

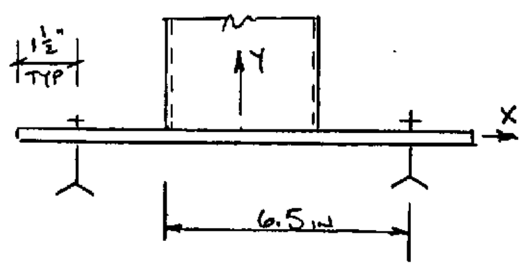
ENVELOPE OF LOADS @ SUPPORTS

$F_X = 269.$ lbs $M_X = 7787.0$ IN-lbs
$F_Y = 238.0$ lbs. (MAX TENSION) $M_Y = 795.0$ IN-lbs
$F_Z = 257.$ lbs. $M_Z = 272.0$ IN-lbs





WORST CASE SCENARIO



BOLT/TENSION

$$T = \frac{7787.0 \text{ IN-lbs}}{(1 \text{ BOLT})(6.5 \text{ IN})} + \frac{272.0 \text{ IN-lbs}}{2 \text{ BOLTS } (1")}$$

$$= 1334. \text{ lbs/BOLT}$$

SHEAR/BOLT

$$V = \frac{(269. + 257.)}{2 \text{ BOLTS}} + \frac{795.0 \text{ IN-lbs}}{1 \text{ BOLT } (2 \text{ IN})}$$

$$V = 661 \text{ lb/BOLT}$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

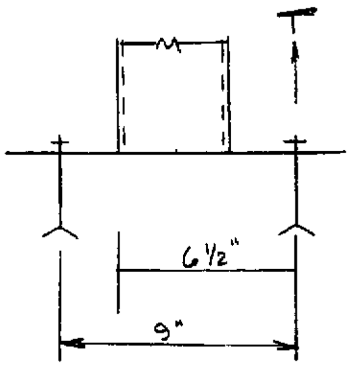
BOLT INTERACTION

$$\frac{T}{T_{ALL}} + \frac{V}{V_{ALL}} = \frac{1334.\ \text{lbs}}{10960\ \text{lbs}} \cdot \frac{661.\ \text{lbs}}{7630\ \text{lbs}} = 0.21 < 1.0$$

∴ 1"ϕ ANCHORS O.K.

DESIGN BASEPLATE

$F_Y = 36000\ \text{lb/in}^2$
$F_{by} = .75\,(36000.\ \text{lb/in}^2) = 27000\ \text{lb/in}^2$



$$f_b = \frac{M}{S} = \frac{T\,(6.5\text{in})}{S} \Rightarrow$$

$$S_{REQ'D} = \frac{M}{f_b} = \frac{M}{F_{Y_b}}$$

PRYING FACTOR

$$S_{REQ'D} = \frac{1334\ \text{lbs}\,(6.5\text{in})(1.2)}{27000\ \#/\text{in}^2}$$

$$= 0.385\ \text{in}^3$$

$$S = \frac{bd^2}{6} \Rightarrow d = \sqrt{\frac{6\,(S)}{b}}$$

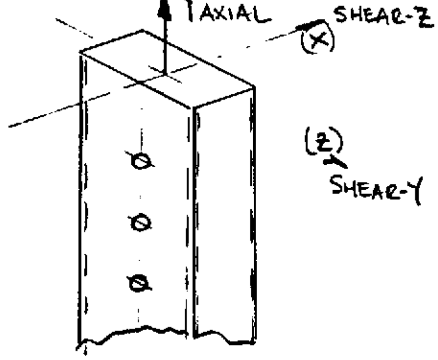
$$d = \sqrt{\frac{6\,(.595\,\text{in}^3)}{9\text{in}}} = 0.50\ \text{in}$$

USE 1" THK PL

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

DESIGN BOLTED CONNECTIONS

MEMBER END FORCES @ 10, 11, 12 & 14



ENVELOPE (WORST CASE) LOADS

Fy = Axial = 3351. (MEM 14)

Fx = Shear-Z = 265. (MEM 12)

Fz = Shear-Y = 277. (MEM 14)

NOTE: MEMBERS WHERE MODELLED W/ RIGID JOINTS TO PRODUCE MAX SUPPORT/ANCHOR LOADS. MEMBERS ARE PINNED AT B-9 BOLT CONNECTION ∴ NO MOMENTS.

My = TORSION = 523 in. lbs

Mx = Mom-Z = 10973.

Mz = Mom-Y = 11289. in-lbs.

$$\text{MAX SHEAR} = V_{MAX} = \frac{3351.\ \text{lbs} + 277.\ \text{lbs.}}{3\ \text{BOLTS}}$$

$$V_{MAX} = 1209\ \#/\text{BOLT}$$

$$\text{MAX TENSION} = T_{MAX} = 285\ \text{lbs.}/3\ \text{BOLTS} = 95\#/\text{BOLT}$$

USE 5/8" ϕ A307 BOLTS

ALLOWABLE = V_{MAX} = 3100 lbs

ALLOWABLE = T_{MAX} = 6100 lbs

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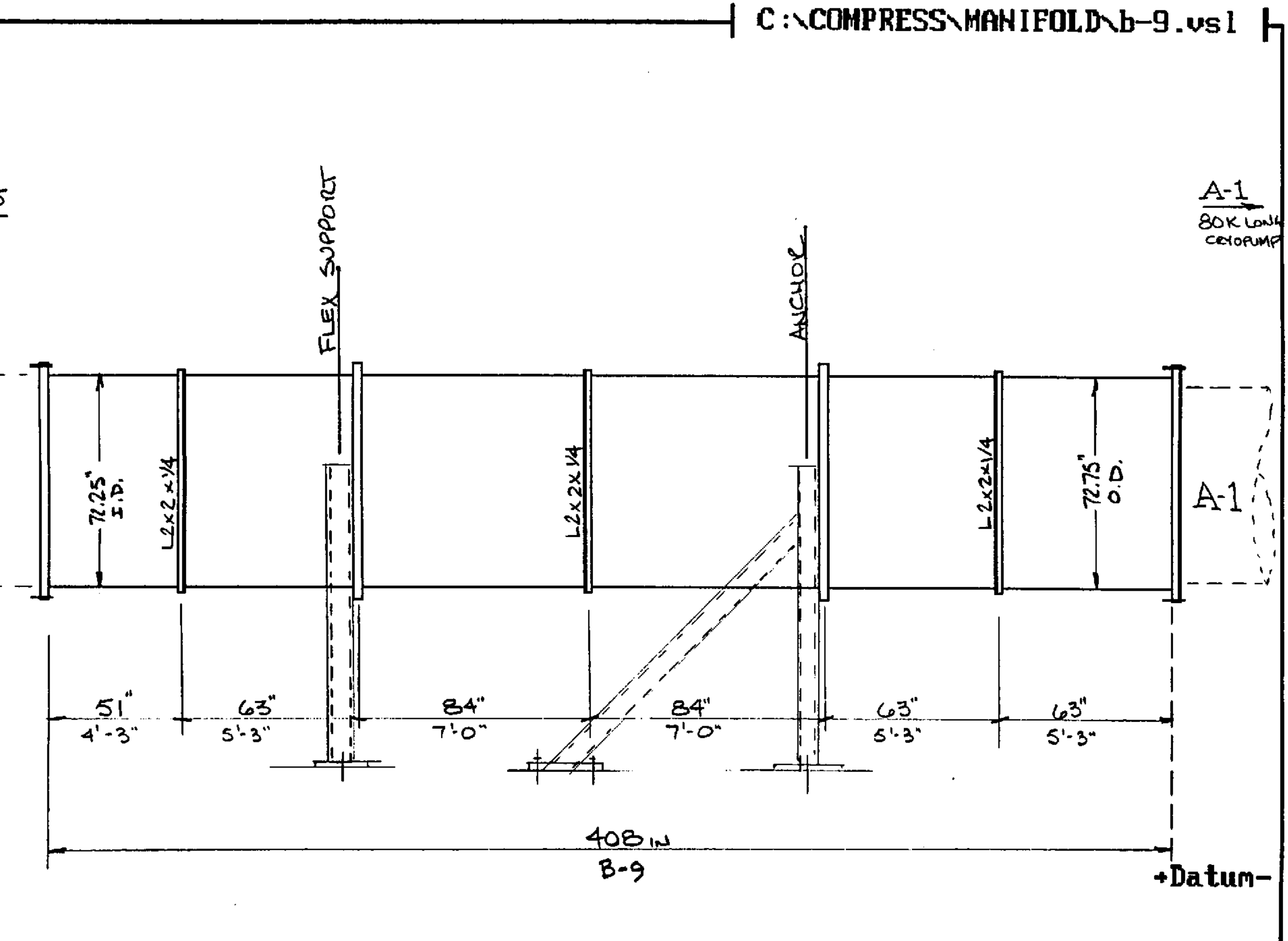
BOLT INTERACTION

$$\frac{V_{MAX}}{V_{MAX\ ALLOW}} + \frac{T_{MAX}}{T_{MAX\ ALLOW}} = \frac{1209}{3100} + \frac{95}{6100} = .40$$

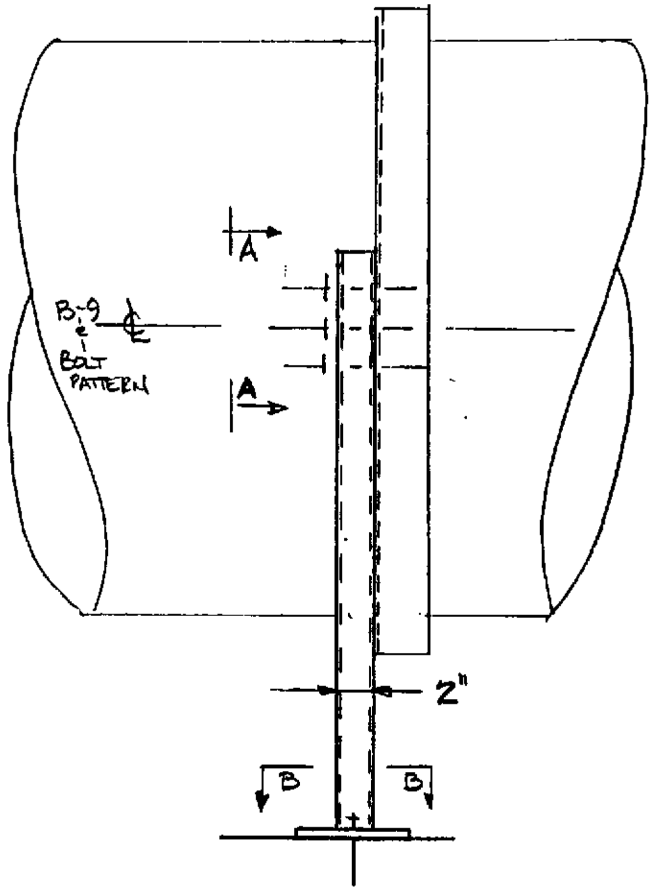
$$= 0.40 < 1.0 \therefore OK$$

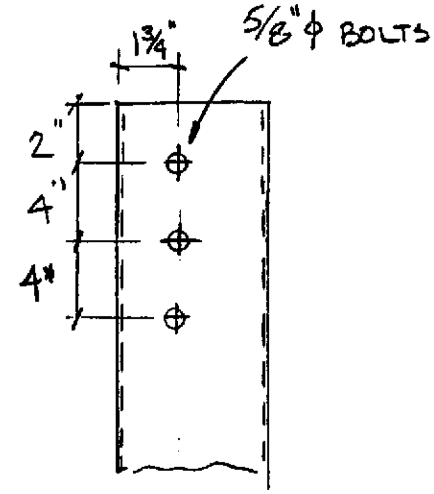
NOTE: TO ACCOUNT FOR ANY LOCAL PRYING AFFECTS AT THE BOLTED CONNECTIONS →

USE 5/8" ϕ A325 BOLTS

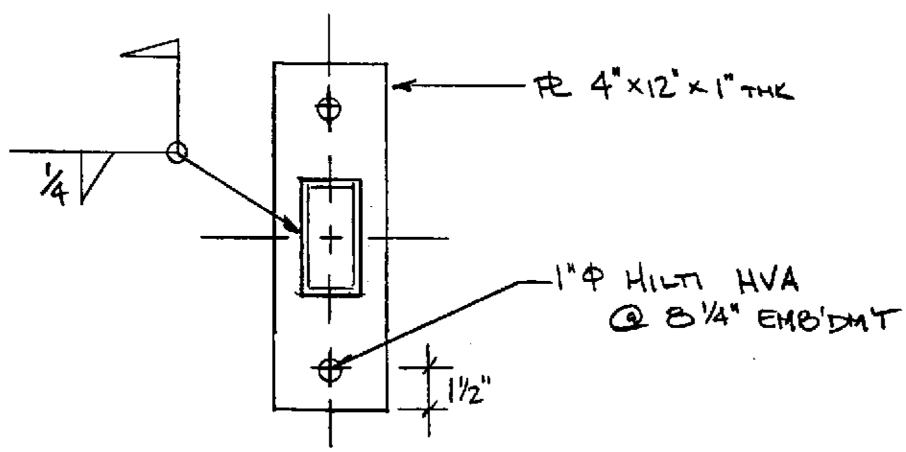

C:\COMPRESS\MANIFOLD\b-9.vsl
BE-5
BELLOWS
FLEX SUPPORT
ANCHOR
A-1
80K LONG
CRYOPUMP
72.25" I.D.
L2x2x1/4
L2x2x1/4
L2x2x1/4
72.75" O.D.
A-1
51"
4'-3"
63"
5'-3"
84"
7'-0"
84"
7'-0"
63"
5'-3"
63"
5'-3"
408 IN
B-9
+Datum-

B-9 FLEX SUPPORT





SECTION A-A



SECTION B-B

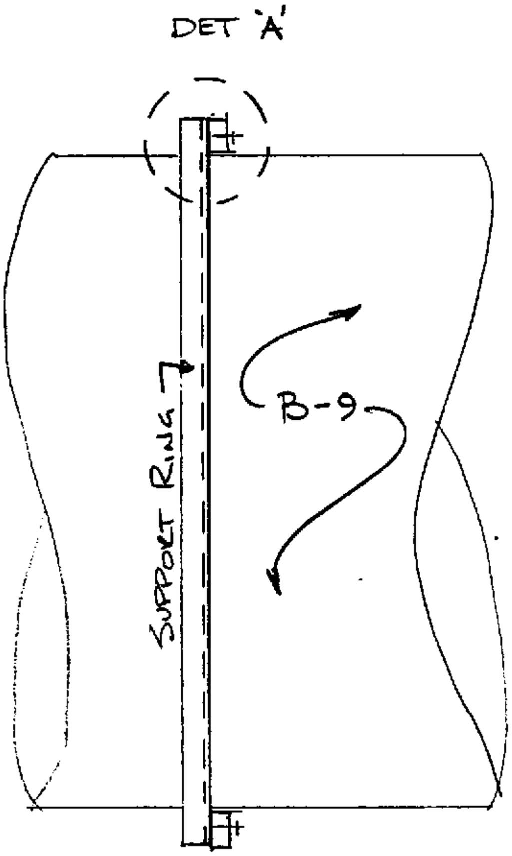
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

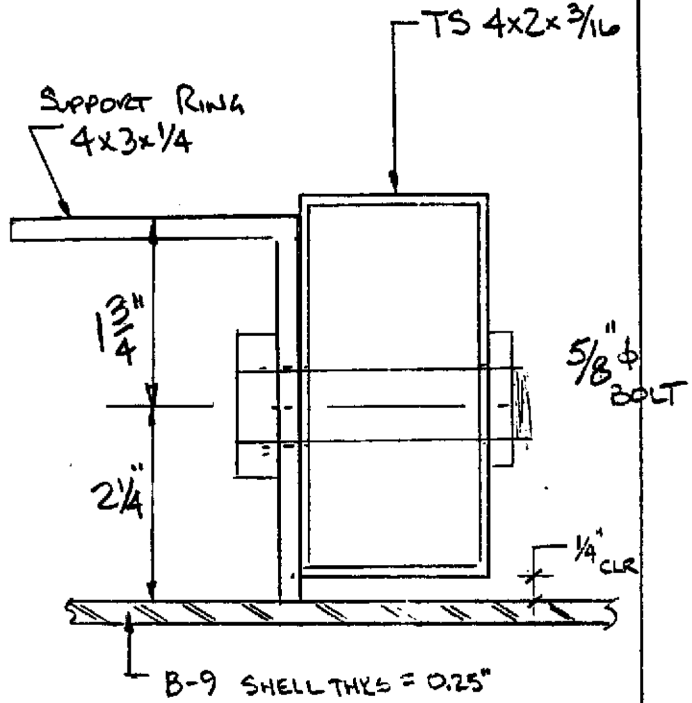
BEAM TUBE MANIFOLD SUPPORTS

B-9

FLEX SUPPORT



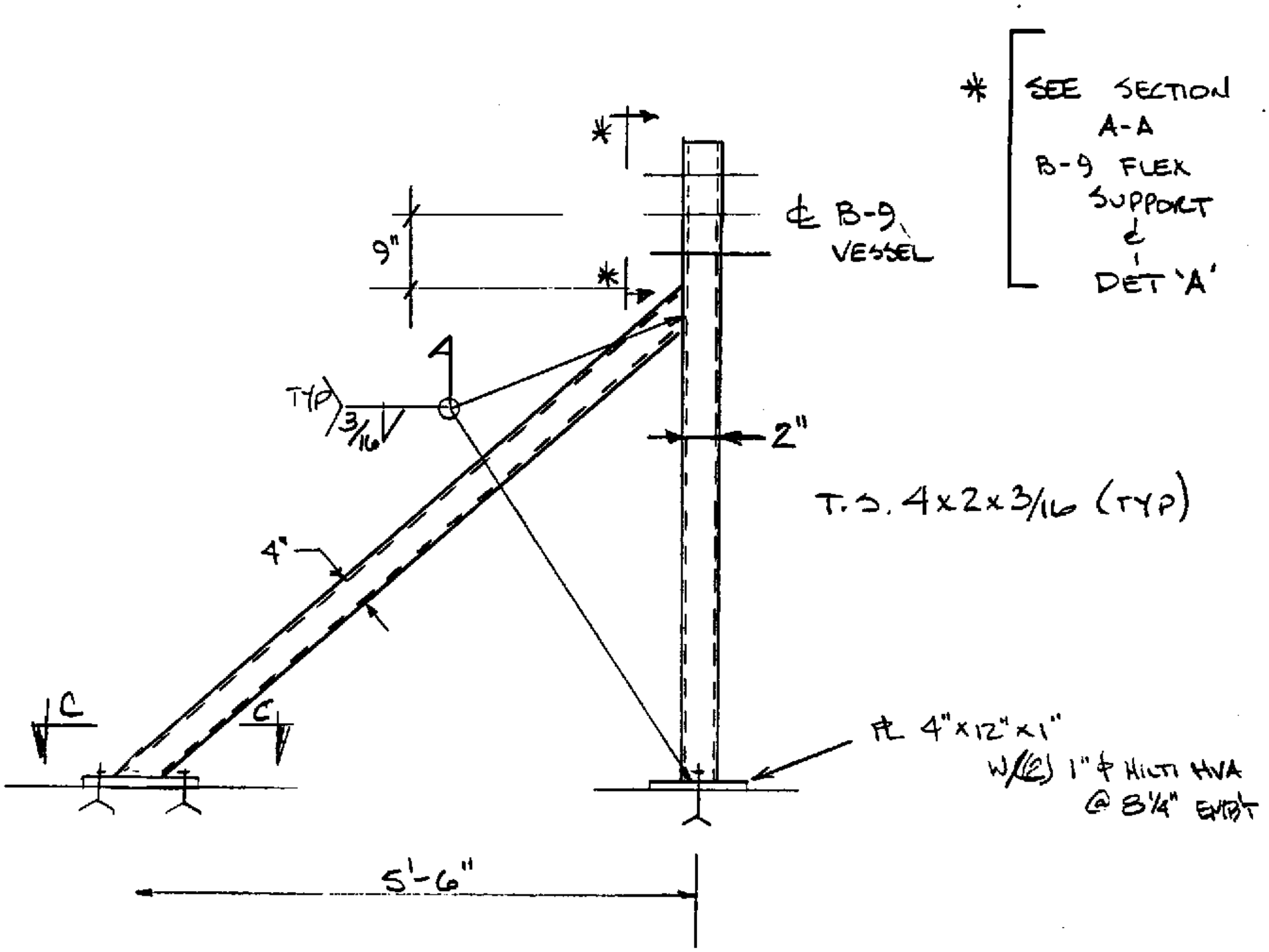
PLAN VIEW

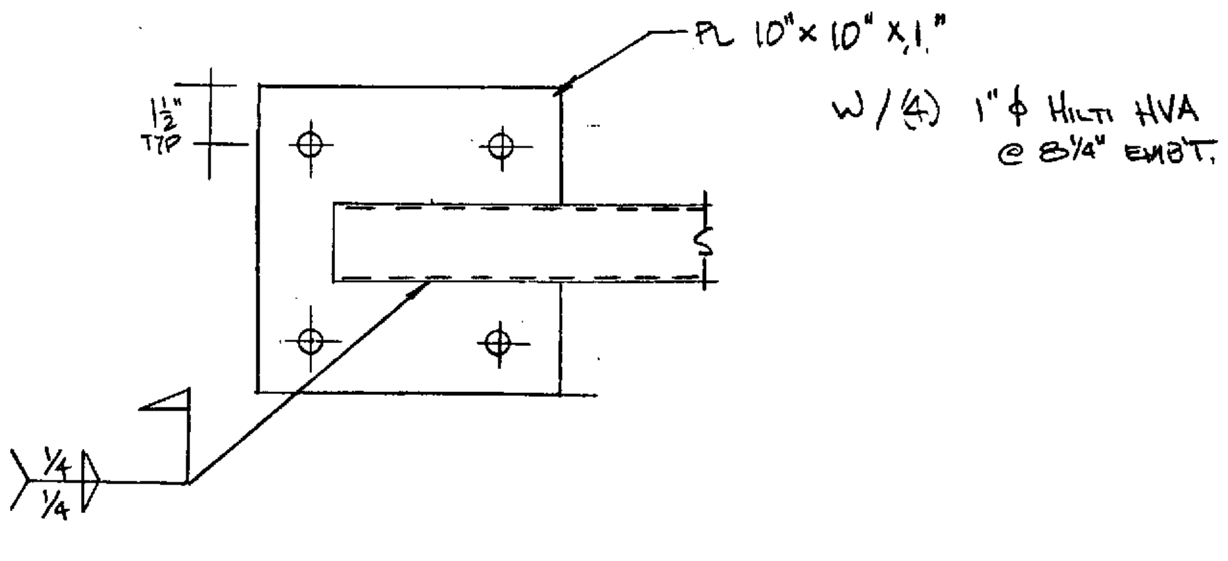


DETAIL 'A'

BEAM TUBE MANIFOLD SUPPORTS

B-9 ANCHOR





22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

<table>
<tr><td colspan="5">PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA</td><td>ENGINEERING
CALCULATIONS</td><td>NO: V049-1-095
PAGE 1 OF 40</td></tr>
<tr><td>REV.</td><td>DEO #</td><td>DATE</td><td>BY:</td><td>CHECK</td><td colspan="2" rowspan="5">TITLE:
Design of Generic Support Scheme for:
Beam Tube Manifold B-6 & B-7</td></tr>
<tr><td>0</td><td>139</td><td>4/24/96</td><td>WDB</td><td>AGK</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5"></td><td>BY: W. Bilynsky</td><td>DEPT.: 744</td></tr>
<tr><td colspan="5">PROJECT: LIGO Vacuum Equipment</td><td colspan="2">PROJECT NO: V59049</td></tr>
</table>

PURPOSE:

The purpose of this calculation is to design a generic support for B-6/B-7 Beam Tube Manifolds (BTM). The design of BTM B-6/B-7 is governed by the gate valve's vacuum load which occurs during system regeneration.

METHOD:

A STAAD model of BTM B-6/B-7 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 from the gate valves opening/closing. An additional unbalanced vacuum load occurs at the turbo pump nozzle opening.

ASSUMPTIONS See Calculation

INPUTS:

Vessel weight = 1083.0 lbs, Flange weight = 253.0 lbs
Seismic Acceleration = 0.05625 g.
Vacuum Load @ Gate Valve = 29500.0 lbs
Vacuum Load @ Turbo Pump = 1155.0 lbs

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

CALCULATIONS:

V049-1- 058 Design of Spool B-6
V049-1- 059 Design of Spool B-7

CONCLUSIONS: The requirements of the AISC Code and the LIGO Vacuum Equipment Structural Design Criteria are met.

NOTES: STAAD-III Computer file: B67MNFOLD.*

TABLE OF CONTENTS

LOAD CONDITIONS

- DEADWEIGHT

VESSEL WEIGHT - REF COMPRESS OUTPUT, CALC No. V049-1-058 & 059

$1589^{\#} - (2)(253^{\#}) = 1083 \text{ lbs}$

$\text{uniform load} = \frac{1083 \text{ lbs}}{83.375 \text{in}} = 12.99 \approx 13.0^{\#}/\text{in}$

FLANGE WEIGHT = 253 lbs.
(2 FLANGES)

VALVE = 150 lbs.

- THERMAL

"BAKEOUT" @ 400°F ⇒ $\Delta T = 400°F - 70°F$

$\Delta T = 330°F$

- VACUUM

VACUUM LOAD FROM GATE VALVE = 29.5 KIPS
(REF CALC No. V049-1-032)

VACUUM LOAD FROM UNBALANCED CONDITION @ TURBO PUMP (10" φ).

$F = PA$

$= (14.7^{\#}/\text{in}^2) \frac{(10\text{in})^2 \pi}{4}$

$= 1155. \text{ lbs.}$

- SEISMIC -

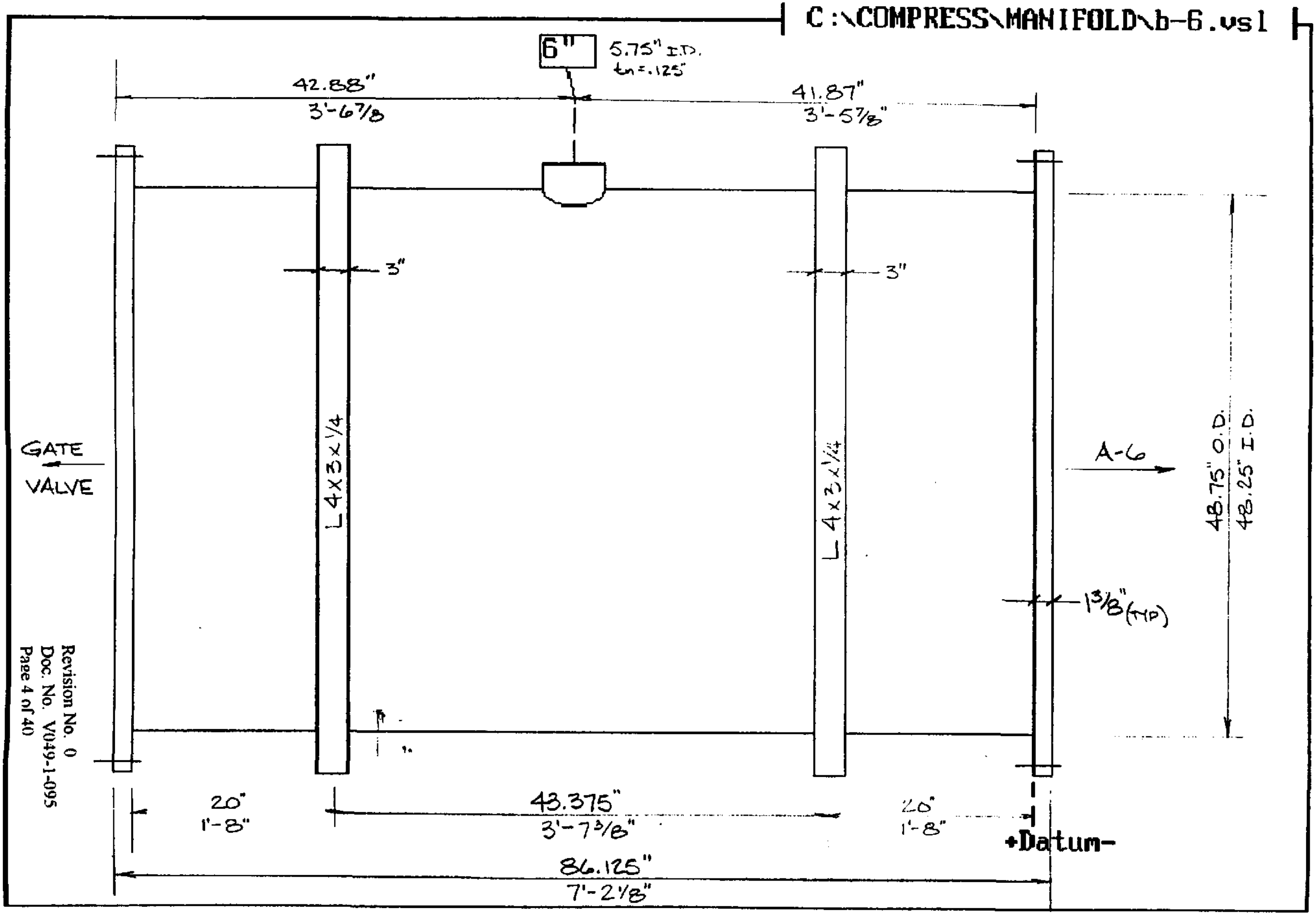
SEISMIC (HORIZONTAL ONLY) - ONE DIRECTION

VESSEL = $F_H = (13.0^{\#}/\text{in})(0.05625g) = 0.73^{\#}/\text{in}$

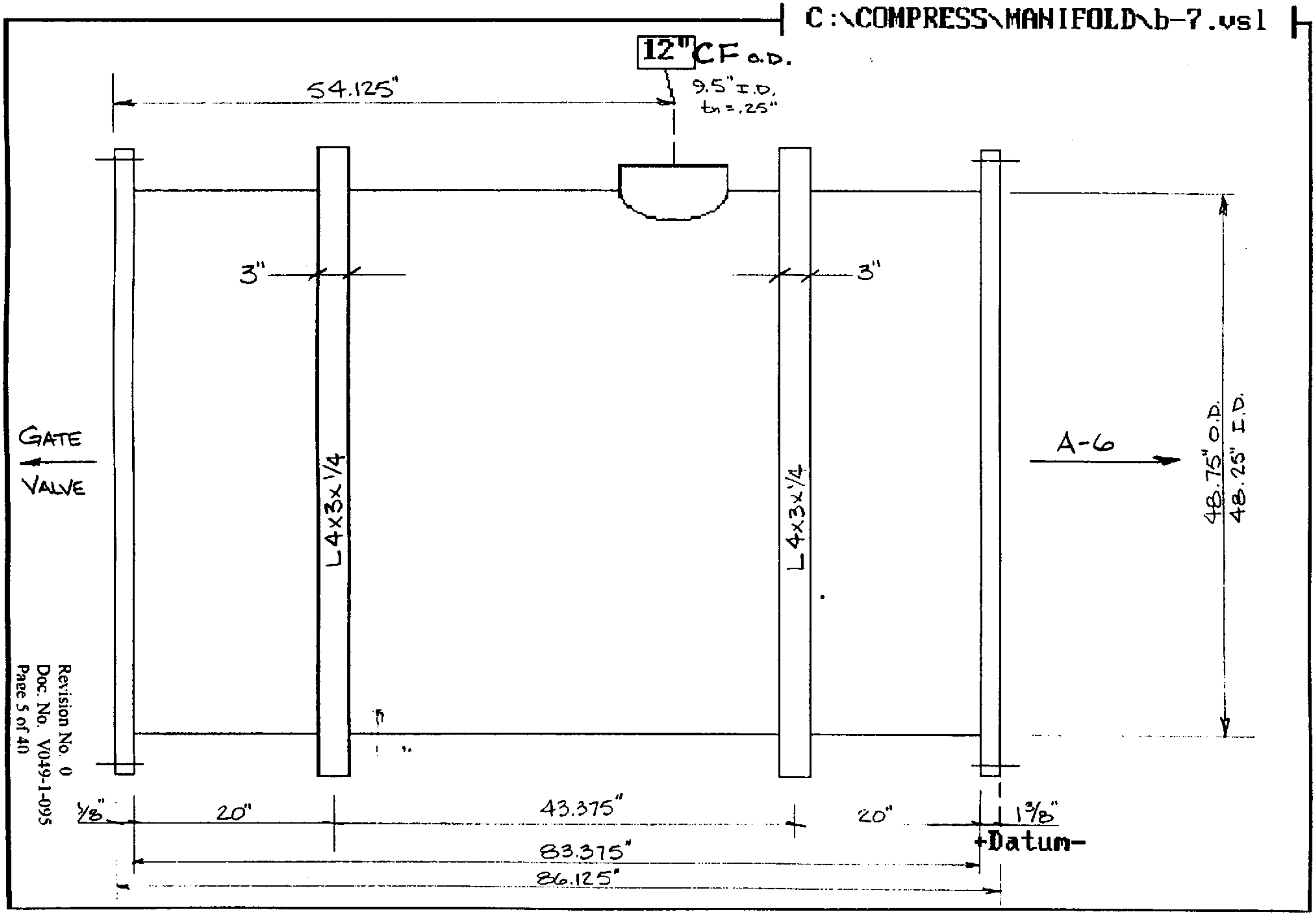
FLANGE = $253. \text{ lbs} (0.05625g) = 14.23 \text{ lbs} = F_{HOR.}$

VALVE = $150. \text{ lbs} (0.05625g) = 8.4 \text{ lbs} = F_{HOR.}$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS



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"



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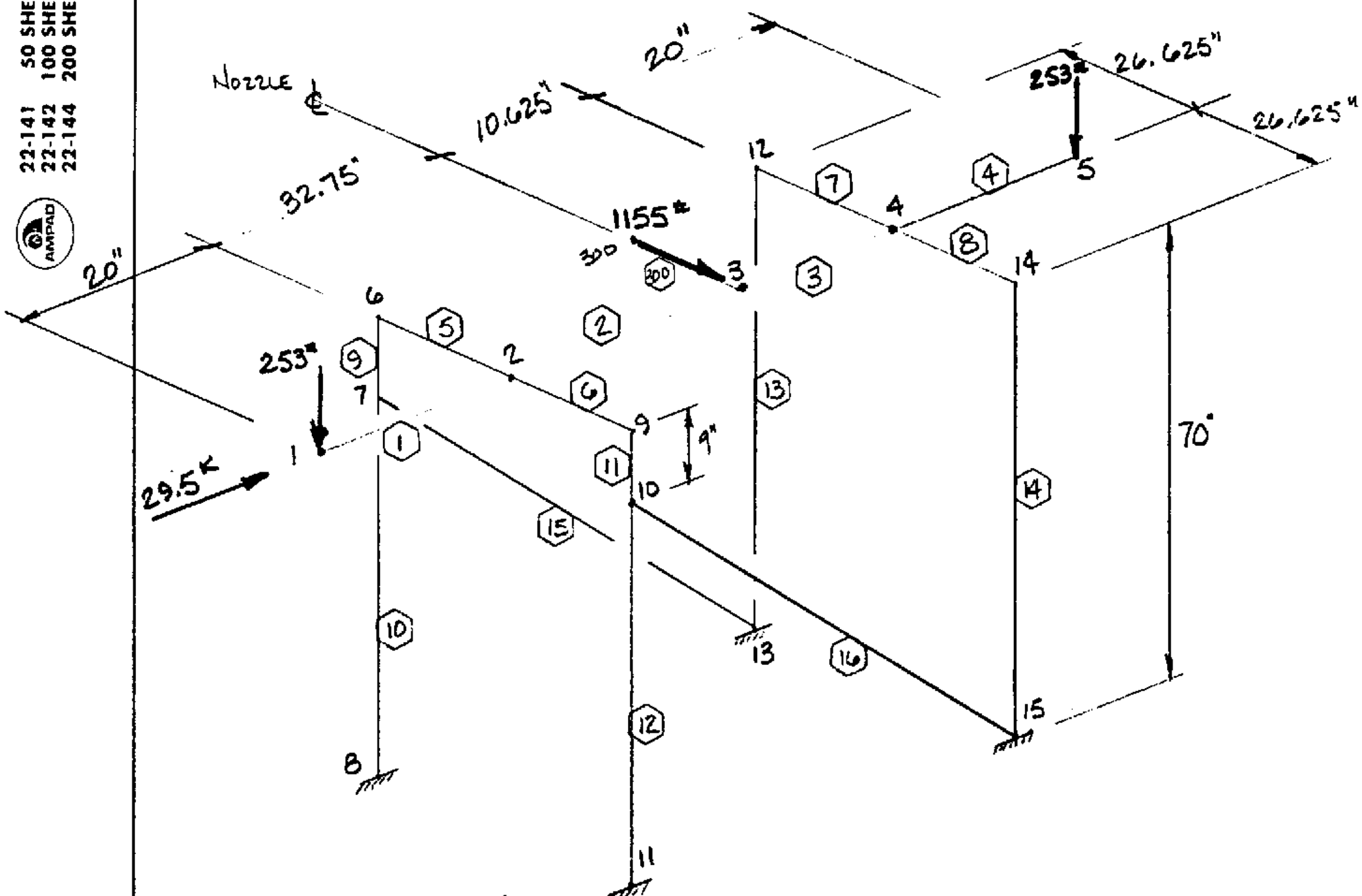
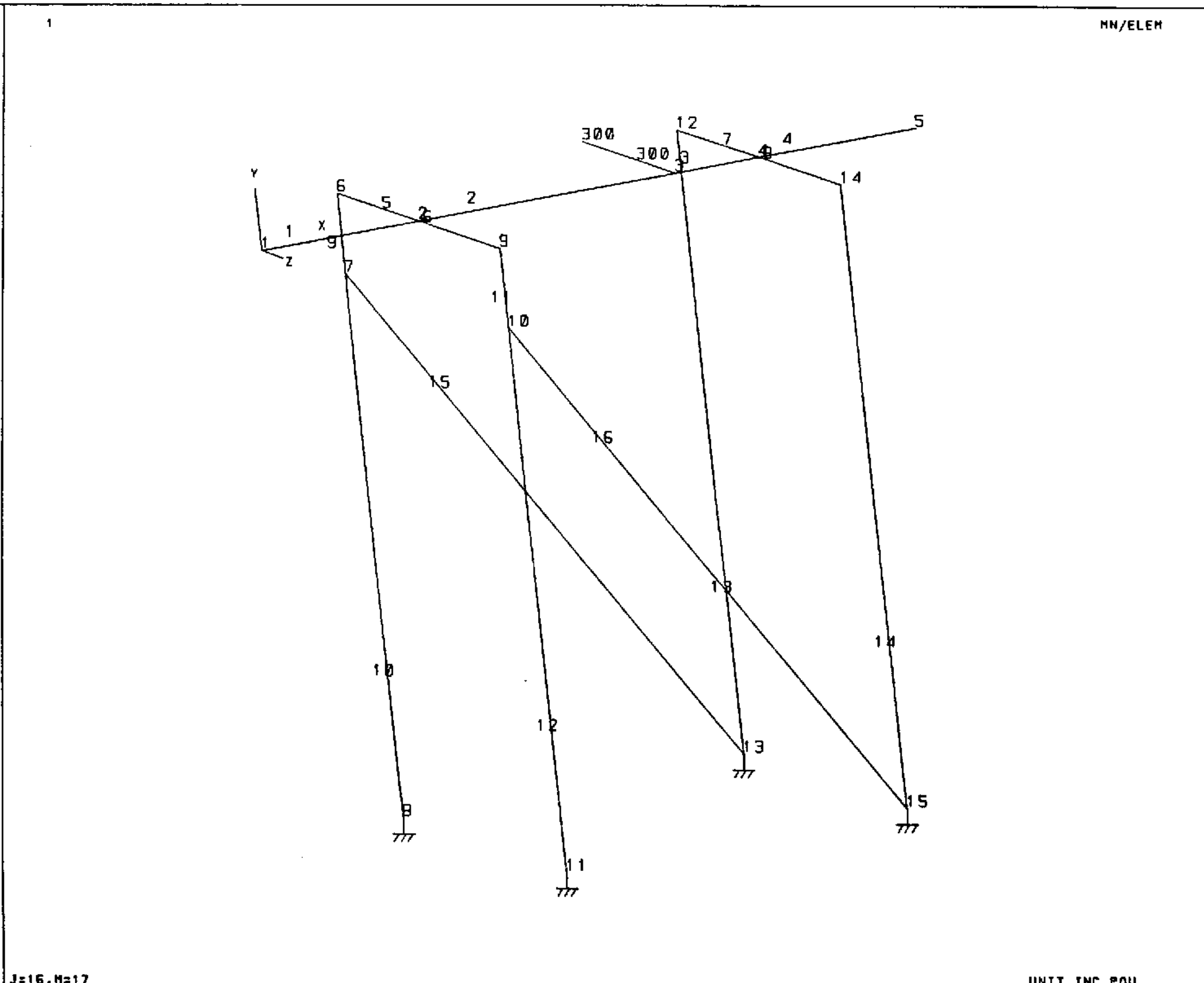
B6 & B7 STAAD MODEL

B6 & B7 = 48 in ϕ = 48.25 in I.D. / 48.75 in. O.D.





STRUCTURE DATA

TYPE = SPACE

NJ =	16
NM =	17
NE =	0
NS =	4
NL =	8
XMAX=	83.4
YMAX=	70.0
ZMAX=	57.0

USER ID:Process Systems International

S T A A D P O S T - P L O T (REV: 21.0)

TITLE: B6 & B7 MANIFOLD SUPPORT

DATE: APR 17, 1996

```
************************************************
*                                              *
*            S T A A D - III                   *
*            Revision 21.0                     *
*            Proprietary Program of            *
*            Research Engineers, Inc.          *
*            Date=    APR 17, 1996             *
*            Time=    10: 4:48                 *
*                                              *
*       USER ID: Process Systems International *
************************************************
```

```
 1. STAAD SPACE B6 & B7 MANIFOLD SUPPORT
 2. INPUT WIDTH 72
 3. UNIT INCHES POUND
 4. JOINT COORDINATES
 5. 1 0. 0. 0.; 2 20.0 0. 0.; 3 52.75 0. 0.; 4 63.375 0. 0.; 5 83.375 0. 0.
 6. 6 20.0 0. -26.625; 7 20.0 -9. -26.625; 8 20.0 -70. -26.625
 7. 9 20.0 0. 26.625; 10 20.0 -9. 26.625; 11 20.0 -70. 26.625
 8. 12 63.375 0. -26.625; 13 63.375 -70. -26.625; 14 63.375 0. 26.625
 9. 15 63.375 -70. 26.625;300 52.75 0. -30.375
10. MEMBER INCIDENCES
11. 1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 2 6; 6 2 9; 7 4 12; 8 4 14; 9 7 6;10 8 7
12. 11 10 9; 12 11 10; 13 13 12; 14 15 14; 15 7 13; 16 10 15;300 3 300
13. MEMBER PROPERTY AMER
14. 9 TO 12 15 16 TABLE ST TUB40408
15. 13 14 TABLE ST TUB40203
16. 5 TO 8 TABLE ST TUB80805
17. 1 TO 4 TABLE ST PIPE OD 48.75 ID 48.25
18. 300 TABLE ST PIPE OD 10. ID 9.50
19. MEMBER RELEASE
20. 9 11 13 14 END MX MY MZ
21. CONSTANTS
22. E STEEL ALL
23. POISSON STEEL ALL
24. DENSITY STEEL ALL
25. BETA 90. MEMB 13 14
26. ALPHA 0.00000919 MEMB 1 TO 8
27. SUPPORTS
28. 8 11 13 15 FIXED
29. LOAD 1 DEADWEIGHT
30. JOINT LOAD
31. 1 5 FY -506.
32. * FLANGE WEIGHT = 2 @ 253 LBS.
33. 300 FY -150.
34. * VALVE WEIGHT
35. MEMBER LOAD
36. 1 TO 4 UNI Y -13.00
37. * UNIFORM  1083.#/83.375" = 13.0
38. LOAD 2 DW+TH
39. JOINT LOAD
40. 1 5 FY -506.
41. 300 FY -150.
```

```
42. 300 FZ 1155.
43. * UNBALANCED VACUUM LOAD @ TURBO PMP
44. MEMBER LOAD
45. 1 TO 4 UNI Y -13.0
46. TEMPERATURE LOAD
47. 1 TO 8 300 TEMP 330.
48. LOAD 3 DW+VACUUM
49. JOINT LOAD
50. 1 FX 29500.
51. * FULL VACUUM LOAD @ GATE VALVE
52. 1 5 FY -506.
53. 300 FY -150.
54. 300 FZ 1155.
55. * UNBALANCED VACUUM LOAD @ TURBO PMP
56. MEMBER LOAD
57. 1 TO 4 UNI Y -13.0
58. LOAD 4 DW+TH+SEIS-AXIAL
59. JOINT LOAD
60. 1 5 FY -506.
61. 300 FY -150.
62. 1 5 FX 14.23
63. * FLANGE WEIGHT X 0.05625
64. 300 FX 8.5
65. * VALVE WEIGHT X 0.05625
66. 300 FZ 1155.
67. * UNBALANCED VACUUM LOAD @ TURBO PMP
68. MEMBER LOAD
69. 1 TO 4 UNI Y -13.0
70. 1 TO 4 UNI X 0.73
71. * UNIFORM WEIGHT X 0.05625
72. TEMPERATURE LOAD
73. 1 TO 8 300 TEMP 330.
74. LOAD 5 DW+VACUUM+SEIS-AXIAL
75. JOINT LOAD
76. 1 FX 29500.
77. 1 5 FY -506.
78. 300 FY -150.
79. 1 5 FX 14.23
80. 300 FX 8.5
81. 300 FZ 1155.
82. * UNBALANCED VACUUM LOAD @ TURBO PMP
83. MEMBER LOAD
84. 1 TO 4 UNI Y -13.0
85. 1 TO 4 UNI X 0.73
86. LOAD 6 DW+TH+SEIS-LAT
87. JOINT LOAD
88. 1 5 FY -502.
89. 300 FY -150.
90. 1 5 FZ 14.23
91. 300 FZ 8.5
92. 300 FZ 1155.
93. * UNBALANCED VACUUM LOAD @ TURBO PMP
94. MEMBER LOAD
95. 1 TO 4 UNI Y -13.0
96. 1 TO 4 UNI Z 0.73
97. TEMPERATURE LOAD
```

```
 98. 1 TO 8 300 TEMP 330.
 99. LOAD 7 DW+VACUUM+SEIS-LAT
100. JOINT LOAD
101. 1 FX 29500.
102. 1 5 FY -502.
103. 300 FY -150.
104. 1 5 FZ 47.925
105. 300 FZ 8.5
106. 300 FZ 1155.
107. MEMBER LOAD
108. 1 TO 4 UNI Y -13.0
109. 1 TO 4 UNI Z 0.73
110. LOAD 8 THERMAL "BAKEOUT"
111. TEMPERATURE LOAD
112. 1 TO 8 300 TEMP 330.
113. 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 =    16/   17/    4
  ORIGINAL/FINAL BAND-WIDTH =   13/    4
  TOTAL PRIMARY LOAD CASES  =     8, TOTAL DEGREES OF FREEDOM =     72
  SIZE OF STIFFNESS MATRIX =    2160 DOUBLE PREC. WORDS
  REQRD/AVAIL. DISK SPACE =  12.05/  485.6 MB,  EXMEM =  1.02 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.                10: 4:48
++ PROCESSING GLOBAL STIFFNESS MATRIX.                 10: 4:48
++ PROCESSING TRIANGULAR FACTORIZATION.                10: 4:48
++ CALCULATING JOINT DISPLACEMENTS.                    10: 4:48
 · CALCULATING MEMBER  FORCES.                         10: 4:48

114. PRINT MATERIAL PROPERTIES ALL
```

MATERIAL PROPERTIES.

\LL 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	0.00000000
10	29000000.0	11153846.0	0.28299999	0.00000000
11	29000000.0	11153846.0	0.28299999	0.00000000
12	29000000.0	11153846.0	0.28299999	0.00000000
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
300	29000000.0	11153846.0	0.28299999	0.00000000

************ END OF DATA FROM INTERNAL STORAGE ************

115. PRINT MEMBER INFORMATION ALL

MEMBER INFORMATION

MEMBER	START JOINT	END JOINT	LENGTH (INCH)	BETA (DEG)	RELEASES
1	1	2	20.000	0.00	
2	2	3	32.750	0.00	
3	3	4	10.625	0.00	
4	4	5	20.000	0.00	
5	2	6	26.625	0.00	
6	2	9	26.625	0.00	
7	4	12	26.625	0.00	
8	4	14	26.625	0.00	
9	7	6	9.000	0.00	000000000111
10	8	7	61.000	0.00	
11	10	9	9.000	0.00	000000000111
12	11	10	61.000	0.00	
13	13	12	70.000	90.00	000000000111
14	15	14	70.000	90.00	000000000111
15	7	13	74.849	0.00	
16	10	15	74.849	0.00	
300	3	300	30.375	0.00	

************ END OF DATA FROM INTERNAL STORAGE ************

116. PRINT JOINT COORDINATES ALL

JOINT COORDINATES

COORDINATES ARE INCH UNIT

JOINT	X	Y	Z
1	0.000	0.000	0.000
2	20.000	0.000	0.000
3	52.750	0.000	0.000
4	63.375	0.000	0.000
5	83.375	0.000	0.000
6	20.000	0.000	-26.625
7	20.000	-9.000	-26.625
8	20.000	-70.000	-26.625
9	20.000	0.000	26.625
10	20.000	-9.000	26.625
11	20.000	-70.000	26.625
12	63.375	0.000	-26.625
13	63.375	-70.000	-26.625
14	63.375	0.000	26.625
15	63.375	-70.000	26.625
300	52.750	0.000	-30.375

************ END OF DATA FROM INTERNAL STORAGE ************

117. PRINT SUPPORT INFORMATION ALL

SUPPORT INFORMATION (1=FIXED, 0=RELEASED)

UNITS FOR SPRING CONSTANTS ARE POUN INCH DEGREES

JOINT	FORCE-X/ KFX	FORCE-Y/ KFY	FORCE-Z/ KFZ	MOM-X/ KMX	MOM-Y/ KMY	MOM-Z/ KMZ
8	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0
11	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0
13	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0
15	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0	1 0.0

************ END OF DATA FROM INTERNAL STORAGE ************

118. 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	-0.00030	-0.00155	0.00003	-0.00001	0.00000	-0.00001
	2	-0.06132	-0.00159	0.08897	0.00000	-0.00017	-0.00001
	3	0.12270	0.01048	0.08897	0.00000	-0.00017	-0.00020
	4	-0.06091	-0.00155	0.08893	0.00000	-0.00017	-0.00001
	5	0.12311	0.01052	0.08893	0.00000	-0.00017	-0.00020
	6	-0.06131	-0.00158	0.09666	0.00000	-0.00018	-0.00001
	7	0.12271	0.01048	0.10197	0.00000	-0.00018	-0.00020
	8	-0.06101	-0.00004	0.00000	0.00000	0.00000	0.00000
2	1	-0.00030	-0.00176	0.00001	-0.00001	0.00000	-0.00001
	2	-0.00066	-0.00178	0.09237	0.00000	-0.00017	-0.00001
	3	0.12217	0.00647	0.09237	0.00000	-0.00017	-0.00020
	4	-0.00025	-0.00175	0.09235	0.00000	-0.00017	-0.00001
	5	0.12258	0.00650	0.09236	0.00000	-0.00017	-0.00020
	6	-0.00066	-0.00178	0.10022	0.00000	-0.00018	-0.00001
	7	0.12217	0.00648	0.10565	0.00000	-0.00018	-0.00020
	8	-0.00036	-0.00002	0.00000	0.00000	0.00000	0.00000
3	1	-0.00030	-0.00222	-0.00002	-0.00001	0.00000	-0.00001
	2	0.09866	-0.00222	0.09808	0.00000	-0.00017	-0.00001
	3	0.12217	-0.00020	0.09808	0.00000	-0.00017	-0.00020
	4	0.09907	-0.00222	0.09812	0.00000	-0.00017	-0.00001
	5	0.12258	-0.00020	0.09812	0.00000	-0.00017	-0.00020
	6	0.09866	-0.00222	0.10623	0.00000	-0.00018	-0.00001
	7	0.12217	-0.00019	0.11185	0.00000	-0.00019	-0.00020
	8	0.09896	-0.00001	0.00000	0.00000	0.00000	0.00000
4	1	-0.00030	-0.00236	-0.00004	-0.00001	0.00000	-0.00001
	2	0.13088	-0.00236	0.09989	0.00000	-0.00017	-0.00001
	3	0.12217	-0.00236	0.09989	0.00000	-0.00017	-0.00020
	4	0.13129	-0.00236	0.09994	0.00000	-0.00017	-0.00001
	5	0.12258	-0.00236	0.09994	0.00000	-0.00017	-0.00020
	6	0.13088	-0.00235	0.10814	0.00000	-0.00018	-0.00001
	7	0.12217	-0.00235	0.11381	0.00000	-0.00019	-0.00020
	8	0.13118	0.00000	0.00000	0.00000	0.00000	0.00000
5	1	-0.00030	-0.00270	-0.00005	-0.00001	0.00000	-0.00001
	2	0.19153	-0.00269	0.10331	0.00000	-0.00017	-0.00001
	3	0.12217	-0.00650	0.10331	0.00000	-0.00017	-0.00020
	4	0.19194	-0.00270	0.10339	0.00000	-0.00017	-0.00001
	5	0.12258	-0.00651	0.10339	0.00000	-0.00017	-0.00021
	6	0.19153	-0.00268	0.11174	0.00000	-0.00018	-0.00001
	7	0.12217	-0.00649	0.11753	0.00000	-0.00019	-0.00020
	8	0.19184	0.00001	0.00000	0.00000	0.00000	0.00000
6	1	-0.00033	-0.00022	0.00001	0.00007	0.00000	-0.00001
	2	0.00241	0.00005	0.01161	0.00009	-0.00010	-0.00001
	3	0.08299	0.00830	0.09232	0.00009	0.00188	-0.00020
	4	0.00270	0.00007	0.01160	0.00009	-0.00010	-0.00001
	5	0.08328	0.00833	0.09231	0.00009	0.00189	-0.00020
	6	0.00256	0.00006	0.01947	0.00009	-0.00011	-0.00001
	7	0.08324	0.00833	0.10559	0.00009	0.00187	-0.00020
	8	-0.00024	-0.00002	-0.08070	0.00000	-0.00001	0.00000

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

INT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
7	1	-0.00027	-0.00019	0.00001	0.00000	0.00000	0.00001
	2	0.00082	0.00008	0.00946	0.00023	0.00003	-0.00013
	3	0.03331	0.00833	0.07518	0.00186	0.00022	-0.00402
	4	0.00094	0.00011	0.00945	0.00023	0.00003	-0.00014
	5	0.03343	0.00836	0.07517	0.00186	0.00022	-0.00404
	6	0.00089	0.00009	0.01585	0.00039	0.00005	-0.00013
	7	0.03342	0.00836	0.08599	0.00212	0.00025	-0.00403
	8	-0.00009	-0.00002	-0.06572	-0.00162	-0.00019	0.00001
8	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
	6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9	1	-0.00028	-0.00019	0.00001	-0.00007	0.00000	-0.00001
	2	-0.00349	-0.00050	0.17302	-0.00006	-0.00009	-0.00001
	3	0.07709	0.00775	0.09232	-0.00006	-0.00207	-0.00020
	4	-0.00324	-0.00048	0.17301	-0.00006	-0.00010	-0.00001
	5	0.07733	0.00778	0.09231	-0.00006	-0.00208	-0.00020
	6	-0.00364	-0.00052	0.18088	-0.00006	-0.00010	-0.00001
	7	0.07684	0.00773	0.10559	-0.00006	-0.00208	-0.00020
	8	-0.00024	-0.00002	0.08070	0.00000	0.00001	0.00000
10	1	-0.00023	-0.00016	0.00001	0.00000	0.00000	0.00001
	2	-0.00151	-0.00048	0.14090	0.00348	0.00041	0.00016
	3	0.03098	0.00778	0.07518	0.00186	0.00022	-0.00373
	4	-0.00141	-0.00046	0.14089	0.00348	0.00041	0.00015
	5	0.03107	0.00780	0.07517	0.00186	0.00022	-0.00375
	6	-0.00157	-0.00050	0.14729	0.00364	0.00042	0.00017
	7	0.03088	0.00775	0.08599	0.00212	0.00025	-0.00372
	8	-0.00009	-0.00002	0.06572	0.00162	0.00019	0.00001
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	0.00000
	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
	6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	1	-0.00033	-0.00074	-0.00004	0.00008	0.00000	-0.00001
	2	0.13530	-0.00069	0.01914	0.00008	-0.00017	-0.00001
	3	0.12660	-0.00069	0.09988	0.00008	-0.00017	-0.00020
	4	0.13575	-0.00069	0.01919	0.00008	-0.00017	-0.00001
	5	0.12705	-0.00069	0.09993	0.00008	-0.00017	-0.00020
	6	0.13554	-0.00069	0.02739	0.00008	-0.00017	-0.00001
	7	0.12700	-0.00069	0.11380	0.00008	-0.00018	-0.00020
	8	0.13106	0.00000	-0.08074	0.00000	0.00001	0.00000

JOINT DISPLACEMENT (INCH RADIANS) STRUCTURE TYPE = SPACE

ˏINT	LOAD	X-TRANS	Y-TRANS	Z-TRANS	X-ROTAN	Y-ROTAN	Z-ROTAN
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
	6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
14	1	-0.00028	-0.00065	-0.00004	-0.00008	0.00000	-0.00001
	2	0.12621	-0.00070	0.18061	-0.00008	-0.00018	-0.00001
	3	0.11750	-0.00070	0.09988	-0.00008	-0.00018	-0.00020
	4	0.12657	-0.00070	0.18067	-0.00008	-0.00018	-0.00001
	5	0.11787	-0.00070	0.09993	-0.00008	-0.00018	-0.00020
	6	0.12597	-0.00070	0.18886	-0.00008	-0.00019	-0.00001
	7	0.11711	-0.00070	0.11380	-0.00008	-0.00019	-0.00020
	8	0.13106	0.00000	0.08074	0.00000	-0.00001	0.00000
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	0.00000
	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
	6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
)00	1	-0.00033	-0.00302	-0.00002	-0.00003	0.00000	-0.00001
	2	0.10385	-0.00284	0.09824	-0.00003	-0.00017	-0.00001
	3	0.12736	-0.00081	0.09824	-0.00003	-0.00017	-0.00020
	4	0.10434	-0.00283	0.09827	-0.00003	-0.00017	-0.00001
	5	0.12785	-0.00080	0.09827	-0.00003	-0.00017	-0.00020
	6	0.10412	-0.00282	0.10639	-0.00003	-0.00018	-0.00001
	7	0.12781	-0.00079	0.11201	-0.00003	-0.00019	-0.00020
	8	0.09896	-0.00001	0.00000	0.00000	0.00000	0.00000

SUPPORT REACTIONS -UNIT POUN INCH STRUCTURE TYPE = SPACE

INT	LOAD	FORCE-X	FORCE-Y	FORCE-Z	MOM-X	MOM-Y	MOM Z
8	1	1.27	585.53	-0.02	-1.53	-0.06	-77.30
	2	55.73	-229.13	-42.82	-2672.73	-108.59	-960.49
	3	1642.93	-25192.56	-340.41	-21245.50	-863.22	-26588.51
	4	61.51	-319.64	-42.78	-2670.19	-108.49	-1053.82
	5	1648.69	-25282.78	-340.37	-21243.12	-863.12	-26681.54 ← 12099.
	6	58.77	-276.85	-71.79	-4480.46	-182.04	-1009.60
	7	1647.94	-25269.92	-389.36	-24300.29	-987.34	-26669.61 ← 12286
	8	-4.63	72.86	297.58	18572.61	754.62	74.80
11	1	1.06	492.85	-0.02	-1.53	-0.06	-64.86
	2	-62.68	1453.54	-638.00	-39818.12	-1617.84	968.25
	3	1524.52	-23509.91	-340.41	-21245.51	-863.22	-24659.79
	4	-57.93	1378.44	-637.95	-39815.58	-1617.73	891.55
	5	1529.25	-23584.76	-340.37	-21243.13	-863.12	-24736.22
	6	-65.73	1497.34	-666.96	-41625.85	-1691.28	1017.94
	7	1519.50	-23436.52	-389.36	-24300.28	-987.34	-24578.16 ← 11543=T
	8	-4.64	72.92	-297.59	-18572.77	-754.62	74.87
13	1	-1.33	622.97	0.02	1.53	-0.37	-71.20
	2	-605.68	1437.63	-36.30	-2866.19	-648.22	2204.50
	3	-16942.98	26401.06	-237.09	-19179.50	-5152.73	-22448.73
	4	-665.31	1528.14	-36.34	-2868.44	-647.61	2125.78
	5	-17002.42	26491.28	-237.13	-19181.88	-5152.15	-22527.20
	6	-637.06	1481.35	-56.23	-4480.98	-1086.66	2163.14
	7	-16994.71	26474.43	-270.75	-21907.20	-5893.61	-22517.02
	8	4.65	-72.86	200.78	16313.16	4504.46	3083.94
15	1	-1.01	544.52	0.02	1.53	-0.37	-59.76
	2	612.86	-416.16	-437.87	-35492.68	-9657.19	3832.68
	3	-15724.46	24547.28	-237.09	-19179.50	-5152.73	-20820.57
	4	563.81	-341.06	-437.91	-35494.93	-9656.58	3767.97
	5	-15773.35	24622.14	-237.13	-19181.88	-5152.15	-20885.06
	6	644.28	-463.96	-457.80	-37107.48	-10095.63	3874.58
	7	-15672.73	24469.89	-270.75	-21907.20	-5893.61	-20751.79
	8	4.70	-72.92	-200.79	-16313.33	-4504.50	3084.00

MEMBER END FORCES STRUCTURE TYPE = SPACE

\LL UNITS ARE -- POUN INCH

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
1	1	1	0.00	-506.00	0.00	0.00	0.00	-0.01
		2	0.00	766.00	0.00	0.00	0.00	-12720.00
	2	1	-0.49	-506.00	-0.12	0.00	2.24	0.03
		2	0.49	766.00	0.12	0.00	-0.17	-12720.02
	3	1	29499.69	-505.99	0.09	0.00	-0.99	-0.26
		2	-29499.69	765.99	-0.09	0.00	-0.74	-12719.67
	4	1	13.67	-506.00	-0.05	0.01	1.30	0.02
		2	-28.32	766.00	0.05	-0.01	-0.22	-12720.01
	5	1	29514.36	-506.00	0.00	0.00	-0.38	0.19
		2	-29528.96	766.00	0.00	0.00	0.58	-12719.91
	6	1	-0.73	-502.00	14.06	0.01	2.47	-0.02
		2	0.73	762.00	-28.66	-0.01	-429.30	-12639.99
	7	1	29499.56	-502.00	48.01	0.00	-1.05	0.09
		2	-29499.56	762.00	-62.61	0.00	-1104.61	-12639.99
	8	1	0.24	0.00	0.01	0.00	-0.17	-0.01
		2	-0.24	0.00	-0.01	0.00	-0.05	0.00
2	1	2	-0.20	318.68	-0.07	2487.18	3.44	12720.03
		3	0.20	107.07	0.07	-2487.18	-1.18	-9254.86
	2	2	85.45	318.68	-958.26	4653.06	29210.48	12719.98
		3	-85.45	107.07	958.26	-4653.06	2170.00	-9254.85
	3	2	80.06	318.68	-958.18	4653.04	29210.90	12720.25
		3	-80.06	107.07	958.18	-4653.04	2169.66	-9255.04
	4	2	16.60	318.68	-958.16	4671.85	29464.64	12720.00
		3	-40.53	107.07	958.16	-4671.85	1913.43	-9254.84
	5	2	11.18	318.68	-958.13	4671.78	29463.92	12719.96
		3	-35.09	107.07	958.13	-4671.78	1913.49	-9254.80
	6	2	85.69	318.68	-1010.95	4764.70	31147.01	12640.02
		3	-85.69	107.07	987.04	-4764.70	1569.09	-9174.85
	7	2	80.19	318.68	-1033.47	4836.97	32795.07	12639.85
		3	-80.19	107.07	1009.57	-4836.97	659.26	-9174.85
	8	2	86.43	0.00	-0.02	0.08	0.73	0.00
		3	-86.43	0.00	0.02	-0.08	0.07	0.01
3	1	3	-0.20	-257.06	-0.07	-2069.07	1.18	9254.93
		4	0.20	395.19	0.07	2069.07	-0.44	-12719.99
	2	3	85.94	-257.06	196.52	96.81	-2168.35	9254.94
		4	-85.94	395.19	-196.52	-96.81	81.84	-12719.98
	3	3	80.76	-257.07	196.52	96.78	-2168.57	9254.42
		4	-80.76	395.19	-196.52	-96.78	79.74	-12719.92
	4	3	50.05	-257.07	196.54	115.62	-2169.55	9254.86
		4	-57.86	395.20	-196.54	-115.62	78.95	-12720.00
	5	3	43.75	-257.07	197.05	115.54	-2170.61	9254.84
		4	-51.50	395.19	-197.05	-115.54	75.42	-12720.22

MEMBER END FORCES STRUCTURE TYPE = SPACE

ALL UNITS ARE -- POUN INCH

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
	6	3	85.94	-257.07	176.32	208.45	-1567.45	9174.86
		4	-85.94	395.19	-184.07	-208.45	-346.29	-12639.94
	7	3	81.75	-257.07	153.93	280.72	-659.24	9174.43
		4	-81.75	395.19	-161.69	-280.72	-1017.70	-12639.70
	8	3	87.40	0.00	-0.02	0.08	-0.44	-0.02
		4	-87.40	0.00	0.02	-0.08	0.61	0.02
4	1	4	0.00	766.00	0.00	-0.01	0.00	12720.01
		5	0.00	-506.00	0.00	0.01	0.00	0.01
	2	4	0.00	766.01	-0.04	0.01	-0.45	12720.08
		5	0.00	-506.01	0.04	-0.01	0.46	0.06
	3	4	0.34	766.01	0.07	0.01	-2.73	12720.11
		5	-0.34	-506.01	-0.07	-0.01	0.37	0.03
	4	4	-29.30	765.99	-0.19	0.01	-0.09	12719.92
		5	14.65	-505.99	0.19	-0.01	2.99	-0.04
	5	4	-28.13	766.00	-0.02	0.00	1.49	12719.89
		5	13.53	-506.00	0.02	0.00	0.31	0.06
	6	4	-0.73	762.00	-28.93	-0.01	429.84	12639.96
		5	0.73	-502.00	14.33	0.01	0.87	0.06
	7	4	1.45	762.00	-62.42	0.01	1103.52	12640.13
		5	-1.45	-502.00	47.82	-0.01	-1.20	-0.10
	8	4	0.98	0.00	-0.02	0.00	-0.03	0.02
		5	-0.98	0.00	0.02	0.00	0.33	-0.01
5	1	2	-0.03	-589.05	0.16	0.00	-4.36	-15683.40
		6	0.03	589.05	-0.16	0.00	0.00	0.00
	2	2	-60.24	-629.72	505.52	0.00	-13459.46	-16766.34
		6	60.24	629.72	-505.52	0.00	0.00	0.00
	3	2	-479.15	-629.72	15258.50	0.00	-406257.41	-16766.33
		6	479.15	629.72	-15258.50	0.00	-0.08	0.00
	4	2	-60.24	-630.07	559.22	0.00	-14889.25	-16775.74
		6	60.24	630.07	-559.22	0.00	0.00	0.00
	5	2	-479.05	-630.07	15312.01	0.00	-407682.31	-16775.68
		6	479.05	630.07	-15312.01	0.00	-0.04	0.01
	6	2	-101.07	-629.82	533.78	0.00	-14211.90	-16768.91
		6	101.07	629.82	-533.78	0.00	0.00	0.00
	7	2	-547.96	-631.17	15305.07	0.00	-407497.50	-16805.03
		6	547.96	631.17	-15305.07	0.00	-0.05	0.01
	8	2	418.82	0.00	-43.06	0.00	1146.41	-0.05
		6	-418.82	0.00	43.06	0.00	0.00	0.00
6	1	2	0.03	-495.63	-0.03	0.00	0.92	-13196.22
		9	-0.03	495.63	0.03	0.00	0.00	0.00
	2	2	897.89	-454.96	591.62	0.00	-15751.92	-12113.28
		9	-897.89	454.96	-591.62	0.00	-0.07	0.00
	3	2	479.07	-454.96	-14161.36	0.00	377046.19	-12113.30
		9	-479.07	454.96	14161.36	0.00	0.02	-0.01

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	2	897.89	-454.61	547.46	0.00	-14575.96	-12103.89
		9	-897.89	454.61	-547.46	0.00	-0.16	0.00
	5	2	479.13	-454.61	-14205.39	0.00	378218.41	-12103.91
		9	-479.13	454.61	14205.39	0.00	0.02	0.01
	6	2	938.72	-450.86	619.93	0.00	-16505.48	-12004.21
		9	-938.72	450.86	-619.93	0.00	-0.24	0.00
	7	2	548.04	-449.50	-14114.79	0.00	375806.13	-11968.08
		9	-548.04	449.50	14114.79	0.00	0.11	0.01
	8	2	418.82	0.00	43.08	0.00	-1147.10	0.03
		9	-418.82	0.00	-43.08	0.00	0.04	0.00
7	1	4	0.03	-619.45	-0.11	0.00	2.87	-16492.93
		12	-0.03	619.45	0.11	0.00	0.00	0.00
	2	4	-18.86	-578.78	44.43	0.00	-1182.91	-15409.99
		12	18.86	578.78	-44.43	0.00	0.06	0.00
	3	4	-98.34	-578.78	41.57	0.00	-1106.93	-15410.00
		12	98.34	578.78	-41.57	0.00	0.01	0.00
	4	4	-18.92	-578.43	44.57	0.00	-1186.80	-15400.59
		12	18.92	578.43	-44.57	0.00	0.11	0.00
	5	4	-98.43	-578.43	41.72	0.00	-1110.78	-15400.62
		12	98.43	578.43	-41.72	0.00	0.07	0.00
	6	4	-27.04	-574.68	44.50	0.00	-1185.06	-15300.91
		12	27.04	574.68	-44.50	0.00	0.01	0.00
	7	4	-112.10	-573.33	41.70	0.00	-1110.19	-15264.79
		12	112.10	573.33	-41.70	0.00	0.14	0.00
	8	4	79.47	0.00	43.02	0.00	-1145.78	0.03
		12	-79.47	0.00	-43.02	0.00	0.04	0.00
8	1	4	-0.03	-541.74	0.09	0.00	-2.42	-14423.86
		14	0.03	541.74	-0.09	0.00	0.00	0.00
	2	4	177.98	-582.41	-41.46	0.00	1103.70	-15506.79
		14	-177.98	582.41	41.46	0.00	0.26	0.01
	3	4	98.49	-582.41	-38.59	0.00	1027.36	-15506.77
		14	-98.49	582.41	38.59	0.00	0.08	0.01
	4	4	177.98	-582.77	-41.57	0.00	1106.68	-15516.21
		14	-177.98	582.77	41.57	0.00	0.05	0.00
	5	4	98.50	-582.77	-38.71	0.00	1030.60	-15516.16
		14	-98.50	582.77	38.71	0.00	0.05	0.00
	6	4	186.04	-582.51	-41.36	0.00	1101.28	-15509.37
		14	-186.04	582.51	41.36	0.00	-0.08	0.01
	7	4	112.10	-583.87	-38.47	0.00	1024.07	-15545.49
		14	-112.10	583.87	38.47	0.00	0.14	0.01
	8	4	79.53	0.00	-43.05	0.00	1146.12	-0.04
		14	-79.53	0.00	43.05	0.00	0.25	0.00
9	1	7	589.05	0.16	-0.03	0.00	0.31	1.48
		6	-589.05	-0.16	0.03	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	7	629.72	505.52	-60.27	0.00	542.45	4549.68
		6	-629.72	-505.52	60.27	0.00	0.00	0.00
	3	7	629.72	15258.49	-479.10	0.00	4311.97	137326.41
		6	-629.72	-15258.49	479.10	0.00	0.00	0.00
	4	7	630.07	559.22	-60.22	0.00	541.94	5032.98
		6	-630.07	-559.22	60.22	0.00	0.00	0.00
	5	7	630.08	15312.01	-479.06	0.00	4311.54	137808.13
		6	-630.08	-15312.01	479.06	0.00	0.00	0.00
	6	7	629.82	533.78	-101.04	0.00	909.36	4804.02
		6	-629.82	-533.78	101.04	0.00	0.00	0.00
	7	7	631.17	15305.07	-547.99	0.00	4931.96	137745.61
		6	-631.17	-15305.07	547.99	0.00	0.00	0.00
	8	7	0.00	-43.06	418.83	0.00	-3769.48	-387.52
		6	0.00	43.06	-418.83	0.00	0.00	0.00
10	1	8	585.53	-1.27	-0.02	-0.06	1.53	-77.30
		7	-585.53	1.27	0.02	0.06	-0.03	-0.44
	2	8	-229.13	-55.73	-42.82	-108.59	2672.73	-960.49
		7	229.13	55.73	42.82	108.59	-60.44	-2439.03
	3	8	-25192.56	-1642.93	-340.41	-863.22	21245.50	-26588.51
		7	25192.56	1642.93	340.41	863.22	-480.42	-73629.99
	4	8	-319.64	-61.51	-42.78	-108.49	2670.19	-1053.82
		7	319.64	61.51	42.78	108.49	-60.38	-2698.17
	5	8	-25282.78	-1648.69	-340.37	-863.12	21243.12	-26681.54
		7	25282.78	1648.69	340.37	863.12	-480.37	-73888.29
	6	8	-276.85	-58.77	-71.79	-182.04	4480.46	-1009.60
		7	276.85	58.77	71.79	182.04	-101.31	-2575.40
	7	8	-25269.92	-1647.94	-389.36	-987.34	24300.29	-26669.61
		7	25269.92	1647.94	389.36	987.34	-549.49	-73854.76
	8	8	72.86	4.63	297.58	754.62	-18572.61	74.80
		7	-72.86	-4.63	-297.58	-754.62	419.97	207.78
11	1	10	495.63	0.03	-0.03	0.00	0.31	0.31
		9	-495.63	-0.03	0.03	0.00	0.00	0.00
	2	10	454.96	-591.63	-897.93	0.00	8081.47	-5324.67
		9	-454.96	591.63	897.93	0.00	0.00	0.00
	3	10	454.96	14161.36	-479.11	0.00	4311.99	127452.24
		9	-454.96	-14161.36	479.11	0.00	0.00	0.00
	4	10	454.61	-547.45	-897.86	0.00	8080.74	-4927.01
		9	-454.61	547.45	897.86	0.00	0.00	0.00
	5	10	454.61	14205.39	-479.07	0.00	4311.59	127848.49
		9	-454.61	-14205.39	479.07	0.00	0.00	0.00
	6	10	450.86	-619.93	-938.68	0.00	8448.22	-5579.41
		9	-450.86	619.93	938.68	0.00	0.00	0.00
	7	10	449.52	14114.78	-548.00	0.00	4932.01	127033.06
		9	-449.52	-14114.78	548.00	0.00	0.00	0.00
	8	10	0.00	-43.09	-418.84	0.00	3769.54	-387.77
		9	0.00	43.09	418.84	0.00	0.00	0.00

MEMBER END FORCES STRUCTURE TYPE = SPACE

\LL UNITS ARE -- POUN INCH

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
12	1	11	492.85	-1.06	-0.02	-0.06	1.53	-64.86
		10	-492.85	1.06	0.02	0.06	-0.03	0.13
	2	11	1453.54	62.68	-638.00	-1617.84	39818.12	968.25
		10	-1453.54	-62.68	638.00	1617.84	-900.38	2855.16
	3	11	-23509.91	-1524.52	-340.41	-863.22	21245.51	-24659.79
		10	23509.91	1524.52	340.41	863.22	-480.40	-68335.85
	4	11	1378.44	57.93	-637.95	-1617.73	39815.58	891.55
		10	-1378.44	-57.93	637.95	1617.73	-900.33	2641.98
	5	11	-23584.76	-1529.25	-340.37	-863.12	21243.13	-24736.22
		10	23584.76	1529.25	340.37	863.12	-480.36	-68548.31
	6	11	1497.34	65.73	-666.96	-1691.28	41625.85	1017.94
		10	-1497.34	-65.73	666.96	1691.28	-941.26	2991.69
	7	11	-23436.52	-1519.50	-389.36	-987.34	24300.28	-24578.16
		10	23436.52	1519.50	389.36	987.34	-549.50	-68111.09
	8	11	72.92	4.64	-297.59	-754.62	18572.77	74.87
		10	-72.92	-4.64	297.59	754.62	-419.98	207.96
13	1	13	619.45	0.03	0.11	0.00	-7.54	2.42
		12	-619.45	-0.03	-0.11	0.00	0.00	0.00
	2	13	578.78	-18.85	-44.43	0.00	3110.18	-1319.82
		12	-578.78	18.85	44.43	0.00	0.00	0.00
	3	13	578.78	-98.39	-41.57	0.00	2910.13	-6887.48
		12	-578.78	98.39	41.57	0.00	0.00	0.00
	4	13	578.43	-18.91	-44.58	0.00	3120.50	-1323.54
		12	-578.43	18.91	44.58	0.00	0.00	0.00
	5	13	578.43	-98.45	-41.72	0.00	2920.42	-6891.24
		12	-578.43	98.45	41.72	0.00	0.00	0.00
	6	13	574.68	-26.98	-44.51	0.00	3115.66	-1888.72
		12	-574.68	26.98	44.51	0.00	0.00	0.00
	7	13	573.33	-112.11	-41.70	0.00	2919.19	-7847.77
		12	-573.33	112.11	41.70	0.00	0.00	0.00
	8	13	0.00	79.54	-43.04	0.00	3012.57	5567.60
		12	0.00	-79.54	43.04	0.00	0.00	0.00
14	1	15	541.74	0.03	0.09	0.00	-6.36	2.42
		14	-541.74	-0.03	-0.09	0.00	0.00	0.00
	2	15	582.41	-177.93	-41.44	0.00	2901.02	-12455.11
		14	-582.41	177.93	41.44	0.00	0.00	0.00
	3	15	582.41	-98.39	-38.59	0.00	2700.98	-6887.48
		14	-582.41	98.39	38.59	0.00	0.00	0.00
	4	15	582.77	-177.98	-41.56	0.00	2909.51	-12458.82
		14	-582.77	177.98	41.56	0.00	0.00	0.00
	5	15	582.77	-98.45	-38.71	0.00	2709.43	-6891.24
		14	-582.77	98.45	38.71	0.00	0.00	0.00
	6	15	582.51	-186.06	-41.37	0.00	2895.58	-13024.00
		14	-582.51	186.06	41.37	0.00	0.00	0.00

MEMBER END FORCES STRUCTURE TYPE = SPACE

\LL UNITS ARE -- POUN INCH

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
	7	15	583.87	-112.11	-38.46	0.00	2691.96	-7847.77
		14	-583.87	112.11	38.46	0.00	0.00	0.00
	8	15	0.00	-79.54	-43.04	0.00	3012.56	-5567.68
		14	0.00	79.54	43.04	0.00	0.00	0.00
15	1	7	3.70	-0.86	0.01	0.21	0.19	-1.03
		13	-3.70	0.86	-0.01	-0.21	-0.94	-63.67
	2	7	1025.18	-40.30	17.45	367.83	329.90	-2110.65
		13	-1025.18	40.30	-17.45	-367.83	-1635.89	-905.68
	3	7	30838.81	-1189.80	138.70	2923.88	2622.38	-63696.38
		13	-30838.81	1189.80	-138.70	-2923.88	-13003.66	-25358.86
	4	7	1133.71	-44.48	17.43	367.48	329.59	-2334.82
		13	-1133.71	44.48	-17.43	-367.48	-1634.34	-994.72
	5	7	30946.98	-1193.97	138.68	2923.55	2622.09	-63919.83
		13	-30946.98	1193.97	-138.68	-2923.55	-13002.21	-25447.62
	6	7	1082.29	-42.50	29.25	616.62	553.03	-2228.62
		13	-1082.29	42.50	-29.25	-616.62	-2742.34	-952.53
	7	7	30932.95	-1193.43	158.64	3344.29	2999.44	-63890.82
		13	-30932.95	1193.43	-158.64	-3344.29	-14873.39	-25436.22
	8	7	-87.01	3.35	-121.25	-2556.03	-2292.46	179.74
		13	87.01	-3.35	121.25	2556.03	11367.67	71.37
16	1	10	2.90	-0.72	0.01	0.21	0.19	-0.44
		15	-2.90	0.72	-0.01	-0.21	-0.94	-53.40
	2	10	-1192.98	45.44	259.94	5479.91	4914.83	2469.44
		15	1192.98	-45.44	-259.94	-5479.91	-24371.34	931.66
	3	10	28620.67	-1104.06	138.70	2923.88	2622.37	-59116.35
		15	-28620.67	1104.06	-138.70	-2923.88	-13003.67	-23521.54
	4	10	-1103.71	42.00	259.93	5479.56	4914.52	2285.02
		15	1103.71	-42.00	-259.93	-5479.56	-24369.78	858.47
	5	10	28709.64	-1107.49	138.68	2923.55	2622.08	-59300.15
		15	-28709.64	1107.49	-138.68	-2923.55	-13002.21	-23594.48
	6	10	-1250.18	47.65	271.74	5728.69	5137.96	2587.55
		15	1250.18	-47.65	-271.74	-5728.69	-25477.79	978.99
	7	10	28526.51	-1100.42	158.64	3344.29	2999.44	-58921.91
		15	-28526.51	1100.42	-158.64	-3344.29	-14873.39	-23443.75
	8	10	-87.09	3.36	121.25	2556.05	2292.48	179.90
		15	87.09	-3.36	-121.25	-2556.05	-11367.77	71.43
300	1	3	0.00	150.00	0.00	0.00	0.00	4556.26
		300	0.00	-150.00	0.00	0.00	0.00	0.01
	2	3	1155.12	150.00	0.01	0.00	-0.02	4556.26
		300	-1155.12	-150.00	-0.01	0.00	-0.05	0.01
	3	3	1154.89	150.00	0.00	0.00	-0.03	4556.26
		300	-1154.89	-150.00	0.00	0.00	-0.03	0.01
	4	3	1155.11	150.00	-8.48	0.00	258.01	4556.24
		300	-1155.11	-150.00	8.48	0.00	-0.23	-0.01

MEMBER END FORCES STRUCTURE TYPE = SPACE

ALL UNITS ARE -- POUN INCH

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
	5	3	1154.93	150.00	-8.51	0.00	258.38	4556.25
		300	-1154.93	-150.00	8.51	0.00	0.19	0.00
	6	3	1163.55	150.00	-0.01	0.00	0.14	4556.26
		300	-1163.55	-150.00	0.01	0.00	0.13	0.01
	7	3	1163.44	150.00	0.02	0.00	-0.31	4556.25
		300	-1163.44	-150.00	-0.02	0.00	-0.31	0.00
	8	3	0.03	0.00	0.02	0.00	-0.26	0.00
		300	-0.03	0.00	-0.02	0.00	-0.30	0.00

************** END OF LATEST ANALYSIS RESULT **************

119. PRINT MEMBER STRESSES ALL

MEMBER STRESSES

'LL UNITS ARE POUN/SQ INCH

..EMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
1	1	.0	0.0 C	0.0	0.0	0.0	22.1	0.0
		1.00	0.0 C	0.0	27.7	27.7	33.5	0.0
	2	.0	0.0 T	0.0	0.0	0.0	22.1	0.0
		1.00	0.0 T	0.0	27.7	27.7	33.5	0.0
	3	.0	774.4 C	0.0	0.0	774.4	22.1	0.0
		1.00	774.4 C	0.0	27.7	802.1	33.5	0.0
	4	.0	0.4 C	0.0	0.0	0.4	22.1	0.0
		1.00	0.7 C	0.0	27.7	28.4	33.5	0.0
	5	.0	774.8 C	0.0	0.0	774.8	22.1	0.0
		1.00	775.2 C	0.0	27.7	802.9	33.5	0.0
	6	.0	0.0 T	0.0	0.0	0.0	22.0	0.6
		1.00	0.0 T	0.9	27.5	27.5	33.3	1.3
	7	.0	774.4 C	0.0	0.0	774.4	22.0	2.1
		1.00	774.4 C	2.4	27.5	802.0	33.3	2.7
	8	.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
2	1	.0	0.0 T	0.0	27.7	27.7	13.9	0.0
		1.00	0.0 T	0.0	20.1	20.1	4.7	0.0
	2	.0	2.2 C	63.6	27.7	71.6	13.9	41.9
		1.00	2.2 C	4.7	20.1	22.9	4.7	41.9
	3	.0	2.1 C	63.6	27.7	71.4	13.9	41.9
		1.00	2.1 C	4.7	20.1	22.8	4.7	41.9
	4	.0	0.4 C	64.1	27.7	70.3	13.9	41.9
		1.00	1.1 C	4.2	20.1	21.6	4.7	41.9
	5	.0	0.3 C	64.1	27.7	70.1	13.9	41.9
		1.00	0.9 C	4.2	20.1	21.5	4.7	41.9
	6	.0	2.2 C	67.8	27.5	75.4	13.9	44.2
		1.00	2.2 C	3.4	20.0	22.5	4.7	43.2
	7	.0	2.1 C	71.4	27.5	78.6	13.9	45.2
		1.00	2.1 C	1.4	20.0	22.1	4.7	44.2
	8	.0	2.3 C	0.0	0.0	2.3	0.0	0.0
		1.00	2.3 C	0.0	0.0	2.3	0.0	0.0
3	1	.0	0.0 T	0.0	20.1	20.1	11.2	0.0
		1.00	0.0 T	0.0	27.7	27.7	17.3	0.0
	2	.0	2.3 C	4.7	20.1	22.9	11.2	8.6
		1.00	2.3 C	0.2	27.7	29.9	17.3	8.6
	3	.0	2.1 C	4.7	20.1	22.8	11.2	8.6
		1.00	2.1 C	0.2	27.7	29.8	17.3	8.6
	4	.0	1.3 C	4.7	20.1	22.0	11.2	8.6
		1.00	1.5 C	0.2	27.7	29.2	17.3	8.6
	5	.0	1.1 C	4.7	20.1	21.8	11.2	8.6
		1.00	1.4 C	0.2	27.7	29.0	17.3	8.6
	6	.0	2.3 C	3.4	20.0	22.5	11.2	7.7
		1.00	2.3 C	0.8	27.5	29.8	17.3	8.1
	7	.0	2.1 C	1.4	20.0	22.2	11.2	6.7
		1.00	2.1 C	2.2	27.5	29.7	17.3	7.1

MEMBER STRESSES

ˉ.L UNITS ARE POUN/SQ INCH

..EMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	8	.0	2.3	C	0.0	0.0	2.3	0.0	0.0
		1.00	2.3	C	0.0	0.0	2.3	0.0	0.0
4	1	.0	0.0	C	0.0	27.7	27.7	33.5	0.0
		1.00	0.0	C	0.0	0.0	0.0	22.1	0.0
	2	.0	0.0		0.0	27.7	27.7	33.5	0.0
		1.00	0.0		0.0	0.0	0.0	22.1	0.0
	3	.0	0.0	C	0.0	27.7	27.7	33.5	0.0
		1.00	0.0	C	0.0	0.0	0.0	22.1	0.0
	4	.0	0.8	T	0.0	27.7	28.5	33.5	0.0
		1.00	0.4	T	0.0	0.0	0.4	22.1	0.0
	5	.0	0.7	T	0.0	27.7	28.4	33.5	0.0
		1.00	0.4	T	0.0	0.0	0.4	22.1	0.0
	6	.0	0.0	T	0.9	27.5	27.5	33.3	1.3
		1.00	0.0	T	0.0	0.0	0.0	22.0	0.6
	7	.0	0.0	C	2.4	27.5	27.7	33.3	2.7
		1.00	0.0	C	0.0	0.0	0.0	22.0	2.1
	8	.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	T	0.2	690.1	690.3	117.8	0.0
		1.00	0.0	T	0.0	0.0	0.0	117.8	0.0
	2	.0	6.4	T	592.3	737.8	1336.5	125.9	101.1
		1.00	6.4	T	0.0	0.0	6.4	125.9	101.1
	3	.0	51.2	T	17877.1	737.8	18666.1	125.9	3051.7
		1.00	51.2	T	0.0	0.0	51.2	125.9	3051.7
	4	.0	6.4	T	655.2	738.2	1399.8	126.0	111.8
		1.00	6.4	T	0.0	0.0	6.4	126.0	111.8
	5	.0	51.2	T	17939.8	738.2	18729.2	126.0	3062.4
		1.00	51.2	T	0.0	0.0	51.2	126.0	3062.4
	6	.0	10.8	T	625.4	737.9	1374.1	126.0	106.8
		1.00	10.8	T	0.0	0.0	10.8	126.0	106.8
	7	.0	58.5	T	17931.7	739.5	18729.7	126.2	3061.0
		1.00	58.5	T	0.0	0.0	58.5	126.2	3061.0
	8	.0	44.7	C	50.4	0.0	95.2	0.0	8.6
		1.00	44.7	C	0.0	0.0	44.7	0.0	8.6
6	1	.0	0.0	C	0.0	580.7	580.7	99.1	0.0
		1.00	0.0	C	0.0	0.0	0.0	99.1	0.0
	2	.0	95.9	C	693.2	533.0	1322.1	91.0	118.3
		1.00	95.9	C	0.0	0.0	95.9	91.0	118.3
	3	.0	51.2	C	16591.7	533.0	17175.9	91.0	2832.3
		1.00	51.2	C	0.0	0.0	51.2	91.0	2832.3
	4	.0	95.9	C	641.4	532.6	1270.0	90.9	109.5
		1.00	95.9	C	0.0	0.0	95.9	90.9	109.5
	5	.0	51.2	C	16643.3	532.6	17227.1	90.9	2841.1
		1.00	51.2	C	0.0	0.0	51.2	90.9	2841.1
	6	.0	100.3	C	726.3	528.2	1354.8	90.2	124.0
		1.00	100.3	C	0.0	0.0	100.3	90.2	124.0

MEMBER STRESSES

~L UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	7	.0	58.6 C	16537.1	526.6	17122.3	89.9	2823.0
		1.00	58.6 C	0.0	0.0	58.6	89.9	2823.0
	8	.0	44.7 C	50.5	0.0	95.2	0.0	8.6
		1.00	44.7 C	0.0	0.0	44.7	0.0	8.6
7	1	.0	0.0 C	0.1	725.8	725.9	123.9	0.0
		1.00	0.0 C	0.0	0.0	0.0	123.9	0.0
	2	.0	2.0 T	52.1	678.1	732.2	115.8	8.9
		1.00	2.0 T	0.0	0.0	2.0	115.8	8.9
	3	.0	10.5 T	48.7	678.1	737.3	115.8	8.3
		1.00	10.5 T	0.0	0.0	10.5	115.8	8.3
	4	.0	2.0 T	52.2	677.7	731.9	115.7	8.9
		1.00	2.0 T	0.0	0.0	2.0	115.7	8.9
	5	.0	10.5 T	48.9	677.7	737.1	115.7	8.3
		1.00	10.5 T	0.0	0.0	10.5	115.7	8.3
	6	.0	2.9 T	52.1	673.3	728.3	114.9	8.9
		1.00	2.9 T	0.0	0.0	2.9	114.9	8.9
	7	.0	12.0 T	48.9	671.7	732.5	114.7	8.3
		1.00	12.0 T	0.0	0.0	12.0	114.7	8.3
	8	.0	8.5 C	50.4	0.0	58.9	0.0	8.6
		1.00	8.5 C	0.0	0.0	8.5	0.0	8.6
8	1	.0	0.0 T	0.1	634.7	634.8	108.3	0.0
		1.00	0.0 T	0.0	0.0	0.0	108.3	0.0
	2	.0	19.0 C	48.6	682.4	749.9	116.5	8.3
		1.00	19.0 C	0.0	0.0	19.0	116.5	8.3
	3	.0	10.5 C	45.2	682.4	738.1	116.5	7.7
		1.00	10.5 C	0.0	0.0	10.5	116.5	7.7
	4	.0	19.0 C	48.7	682.8	750.5	116.6	8.3
		1.00	19.0 C	0.0	0.0	19.0	116.6	8.3
	5	.0	10.5 C	45.4	682.8	738.7	116.6	7.7
		1.00	10.5 C	0.0	0.0	10.5	116.6	7.7
	6	.0	19.9 C	48.5	682.5	750.8	116.5	8.3
		1.00	19.9 C	0.0	0.0	19.9	116.5	8.3
	7	.0	12.0 C	45.1	684.1	741.1	116.8	7.7
		1.00	12.0 C	0.0	0.0	12.0	116.8	7.7
	8	.0	8.5 C	50.4	0.0	58.9	0.0	8.6
		1.00	8.5 C	0.0	0.0	8.5	0.0	8.6
9	1	.0	92.6 C	0.1	0.2	92.9	0.0	0.0
		1.00	92.6 C	0.0	0.0	92.6	0.0	0.0
	2	.0	99.0 C	88.2	739.8	927.0	126.4	15.1
		1.00	99.0 C	0.0	0.0	99.0	126.4	15.1
	3	.0	99.0 C	701.1	22329.5	23129.6	3814.6	119.8
		1.00	99.0 C	0.0	0.0	99.0	3814.6	119.8
	4	.0	99.1 C	88.1	818.4	1005.6	139.8	15.1
		1.00	99.1 C	0.0	0.0	99.1	139.8	15.1
	5	.0	99.1 C	701.1	22407.8	23208.0	3828.0	119.8
		1.00	99.1 C	0.0	0.0	99.1	3828.0	119.8

MEMBER STRESSES

'LL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL	BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	6	.0	99.0 C	147.9	781.1	1028.0	133.4	25.3
		1.00	99.0 C	0.0	0.0	99.0	133.4	25.3
	7	.0	99.2 C	801.9	22397.7	23298.8	3826.3	137.0
		1.00	99.2 C	0.0	0.0	99.2	3826.3	137.0
	8	.0	0.0 C	612.9	63.0	675.9	10.8	104.7
		1.00	0.0 C	0.0	0.0	0.0	10.8	104.7
10	1	.0	92.1 C	0.2	12.6	104.9	0.3	0.0
		1.00	92.1 C	0.0	0.1	92.1	0.3	0.0
	2	.0	36.0 T	434.6	156.2	626.8	13.9	10.7
		1.00	36.0 T	9.8	396.6	442.4	13.9	10.7
	3	.0	3961.1 T	3454.6	4323.3	11739.0	410.7	85.1
		1.00	3961.1 T	78.1	11972.4	16011.6	410.7	85.1
	4	.0	50.3 T	434.2	171.4	655.8	15.4	10.7
		1.00	50.3 T	9.8	438.7	498.8	15.4	10.7
	5	.0	3975.3 T	3454.2	4338.5	11767.9	412.2	85.1
		1.00	3975.3 T	78.1	12014.4	16067.7	412.2	85.1
	6	.0	43.5 T	728.5	164.2	936.2	14.7	17.9
		1.00	43.5 T	16.5	418.8	478.8	14.7	17.9
	7	.0	3973.3 T	3951.3	4336.5	12261.0	412.0	97.3
		1.00	3973.3 T	89.3	12008.9	16071.5	412.0	97.3
	8	.0	11.5 C	3019.9	12.2	3043.6	1.2	74.4
		1.00	11.5 C	68.3	33.8	113.5	1.2	74.4
11	1	.0	77.9 C	0.1	0.1	78.0	0.0	0.0
		1.00	77.9 C	0.0	0.0	77.9	0.0	0.0
	2	.0	71.5 C	1314.1	865.8	2251.4	147.9	224.5
		1.00	71.5 C	0.0	0.0	71.5	147.9	224.5
	3	.0	71.5 C	701.1	20723.9	21496.6	3540.3	119.8
		1.00	71.5 C	0.0	0.0	71.5	3540.3	119.8
	4	.0	71.5 C	1313.9	801.1	2186.6	136.9	224.5
		1.00	71.5 C	0.0	0.0	71.5	136.9	224.5
	5	.0	71.5 C	701.1	20788.4	21560.9	3551.3	119.8
		1.00	71.5 C	0.0	0.0	71.5	3551.3	119.8
	6	.0	70.9 C	1373.7	907.2	2351.8	155.0	234.7
		1.00	70.9 C	0.0	0.0	70.9	155.0	234.7
	7	.0	70.7 C	802.0	20655.8	21528.4	3528.7	137.0
		1.00	70.7 C	0.0	0.0	70.7	3528.7	137.0
	8	.0	0.0 T	612.9	63.1	676.0	10.8	104.7
		1.00	0.0 T	0.0	0.0	0.0	10.8	104.7
12	1	.0	77.5 C	0.2	10.5	88.3	0.3	0.0
		1.00	77.5 C	0.0	0.0	77.5	0.3	0.0
	2	.0	228.5 C	6474.5	157.4	6860.5	15.7	159.5
		1.00	228.5 C	146.4	464.3	839.2	15.7	159.5
	3	.0	3696.5 T	3454.6	4009.7	11160.8	381.1	85.1
		1.00	3696.5 T	78.1	11111.5	14886.2	381.1	85.1
	4	.0	216.7 C	6474.1	145.0	6835.8	14.5	159.5
		1.00	216.7 C	146.4	429.6	792.7	14.5	159.5

MEMBER STRESSES

-L UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	5	.0	3708.3	T	3454.2	4022.2	11184.6	382.3	85.1
		1.00	3708.3	T	78.1	11146.1	14932.5	382.3	85.1
	6	.0	235.4	C	6768.4	165.5	7169.4	16.4	166.7
		1.00	235.4	C	153.1	486.5	874.9	16.4	166.7
	7	.0	3685.0	T	3951.3	3996.4	11632.7	379.9	97.3
		1.00	3685.0	T	89.3	11075.0	14849.3	379.9	97.3
	8	.0	11.5	C	3020.0	12.2	3043.6	1.2	74.4
		1.00	11.5	C	68.3	33.8	113.6	1.2	74.4
13	1	.0	306.7	C	5.8	1.2	313.7	0.0	0.2
		1.00	306.7	C	0.0	0.0	306.7	0.0	0.2
	2	.0	286.5	C	2392.4	676.8	3355.8	12.6	88.9
		1.00	286.5	C	0.0	0.0	286.5	12.6	88.9
	3	.0	286.5	C	2238.6	3532.0	6057.1	65.6	83.1
		1.00	286.5	C	0.0	0.0	286.5	65.6	83.1
	4	.0	286.3	C	2400.4	678.7	3365.5	12.6	89.2
		1.00	286.3	C	0.0	0.0	286.3	12.6	89.2
	5	.0	286.4	C	2246.5	3534.0	6066.8	65.6	83.4
		1.00	286.4	C	0.0	0.0	286.4	65.6	83.4
	6	.0	284.5	C	2396.7	968.6	3649.7	18.0	89.0
		1.00	284.5	C	0.0	0.0	284.5	18.0	89.0
	7	.0	283.8	C	2245.5	4024.5	6553.9	74.7	83.4
		1.00	283.8	C	0.0	0.0	283.8	74.7	83.4
	8	.0	0.0	T	2317.4	2855.2	5172.5	53.0	86.1
		1.00	0.0	T	0.0	0.0	0.0	53.0	86.1
14	1	.0	268.2	C	4.9	1.2	274.3	0.0	0.2
		1.00	268.2	C	0.0	0.0	268.2	0.0	0.2
	2	.0	288.3	C	2231.6	6387.2	8907.1	118.6	82.9
		1.00	288.3	C	0.0	0.0	288.3	118.6	82.9
	3	.0	288.3	C	2077.7	3532.0	5898.0	65.6	77.2
		1.00	288.3	C	0.0	0.0	288.3	65.6	77.2
	4	.0	288.5	C	2238.1	6389.1	8915.7	118.7	83.1
		1.00	288.5	C	0.0	0.0	288.5	118.7	83.1
	5	.0	288.5	C	2084.2	3534.0	5906.6	65.6	77.4
		1.00	288.5	C	0.0	0.0	288.5	65.6	77.4
	6	.0	288.4	C	2227.4	6679.0	9194.7	124.0	82.7
		1.00	288.4	C	0.0	0.0	288.4	124.0	82.7
	7	.0	289.0	C	2070.7	4024.5	6384.3	74.7	76.9
		1.00	289.0	C	0.0	0.0	289.0	74.7	76.9
	8	.0	0.0	C	2317.4	2855.2	5172.6	53.0	86.1
		1.00	0.0	C	0.0	0.0	0.0	53.0	86.1
15	1	.0	0.6	C	0.0	0.2	0.8	0.2	0.0
		1.00	0.6	C	0.2	10.4	11.1	0.2	0.0
	2	.0	161.2	C	53.6	343.2	558.0	10.1	4.4
		1.00	161.2	C	266.0	147.3	574.5	10.1	4.4
	3	.0	4848.9	C	426.4	10357.1	15632.4	297.4	34.7
		1.00	4848.9	C	2114.4	4123.4	11086.7	297.4	34.7

MEMBER STRESSES

ⁱLL UNITS ARE POUN/SQ INCH

MEMB	LD	SECT	AXIAL		BEND-Y	BEND-Z	COMBINED	SHEAR-Y	SHEAR-Z
	4	.0	178.3	C	53.6	379.6	611.5	11.1	4.4
		1.00	178.3	C	265.7	161.7	605.7	11.1	4.4
	5	.0	4865.9	C	426.4	10393.5	15685.7	298.5	34.7
		1.00	4865.9	C	2114.2	4137.8	11117.9	298.5	34.7
	6	.0	170.2	C	89.9	362.4	622.5	10.6	7.3
		1.00	170.2	C	445.9	154.9	771.0	10.6	7.3
	7	.0	4863.7	C	487.7	10388.8	15740.1	298.4	39.7
		1.00	4863.7	C	2418.4	4136.0	11418.1	298.4	39.7
	8	.0	13.7	T	372.8	29.2	415.7	0.8	30.3
		1.00	13.7	T	1848.4	11.6	1873.7	0.8	30.3
16	1	.0	0.5	C	0.0	0.1	0.6	0.2	0.0
		1.00	0.5	C	0.2	8.7	9.3	0.2	0.0
	2	.0	187.6	T	799.2	401.5	1388.3	11.4	65.0
		1.00	187.6	T	3962.8	151.5	4301.9	11.4	65.0
	3	.0	4500.1	C	426.4	9612.4	14538.9	276.0	34.7
		1.00	4500.1	C	2114.4	3824.6	10439.2	276.0	34.7
	4	.0	173.5	T	799.1	371.5	1344.2	10.5	65.0
		1.00	173.5	T	3962.6	139.6	4275.7	10.5	65.0
	5	.0	4514.1	C	426.4	9642.3	14582.8	276.9	34.7
		1.00	4514.1	C	2114.2	3836.5	10464.8	276.9	34.7
	6	.0	196.6	T	835.4	420.7	1452.7	11.9	67.9
		1.00	196.6	T	4142.7	159.2	4498.5	11.9	67.9
	7	.0	4485.3	C	487.7	9580.8	14553.8	275.1	39.7
		1.00	4485.3	C	2418.4	3812.0	10715.7	275.1	39.7
	8	.0	13.7	T	372.8	29.3	415.7	0.8	30.3
		1.00	13.7	T	1848.4	11.6	1873.7	0.8	30.3
300	1	.0	0.0	T	0.0	250.2	250.2	32.6	0.0
		1.00	0.0	T	0.0	0.0	0.0	32.6	0.0
	2	.0	150.8	C	0.0	250.2	401.0	32.6	0.0
		1.00	150.8	C	0.0	0.0	150.8	32.6	0.0
	3	.0	150.8	C	0.0	250.2	401.0	32.6	0.0
		1.00	150.8	C	0.0	0.0	150.8	32.6	0.0
	4	.0	150.8	C	14.2	250.2	401.4	32.6	1.8
		1.00	150.8	C	0.0	0.0	150.9	32.6	1.8
	5	.0	150.8	C	14.2	250.2	401.4	32.6	1.9
		1.00	150.8	C	0.0	0.0	150.8	32.6	1.9
	6	.0	151.9	C	0.0	250.2	402.1	32.6	0.0
		1.00	151.9	C	0.0	0.0	152.0	32.6	0.0
	7	.0	151.9	C	0.0	250.2	402.1	32.6	0.0
		1.00	151.9	C	0.0	0.0	151.9	32.6	0.0
	8	.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

************** END OF LATEST ANALYSIS RESULT **************

```
120. PARAMETER
121. CODE AISC
122. FYLD 45999.969 MEMB 9 TO 16
123. WSTR 21000. MEMB 9 TO 16
124. WMIN 0.188 MEMB 9 TO 16
125. CB 1. MEMB 9 TO 16
126. CMY 1. MEMB 9 TO 16
127. MAIN 0. MEMB 9 TO 16
128. RATIO 1. MEMB 9 TO 16
129. CHECK CODE MEMB 9 TO 16
```

STAAD-III CODE CHECKING - (AISC)
****

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER	TABLE	RESULT/ FX	CRITICAL COND/ MY	RATIO/ MZ	LOADING/ LOCATION
9	ST TUB 40408	PASS	AISC- H1-3	0.844	7
		631.17 C	4931.96	137745.61	0.00
10	ST TUB 40408	PASS	AISC- H2-1	0.582	7
		25269.92 T	-549.49	-73854.76	61.00
11	ST TUB 40408	PASS	AISC- H1-3	0.781	5
		454.61 C	4311.59	127848.49	0.00
12	ST TUB 40408	PASS	AISC- H2-1	0.541	5
		23584.76 T	-480.36	-68548.31	61.00
13	ST TUB 40203	PASS	AISC- H1-3	0.244	7
		573.33 C	2919.19	-7847.77	0.00
14	ST TUB 40203	PASS	AISC- H1-3	0.340	6
		582.51 C	2895.58	-13024.00	0.00
15	ST TUB 40408	PASS	AISC- H1-1	0.592	7
		30932.95 C	2999.44	-63890.82	0.00
16	ST TUB 40408	PASS	AISC- H1-1	0.546	5
		28709.64 C	2622.08	-59300.15	0.00

130. SELECT WELD MEMB 9 TO 16

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS
9	STA 7	1 91.33	6/16 2550.84	18120.56 17939.89
9	END 5	1 159.69	3/16 5104.00	5110.82 210.03
10	STA 7	1 189.90	4/16 504.55	15883.49 15874.34
10	END 7	1 189.90	4/16 504.55	20275.45 20268.28
11	STA 5	1 95.81	5/16 2841.08	20116.80 19914.93
11	END 5	1 159.69	3/16 4735.13	4740.24 151.54
12	STA 7	1 253.20	3/16 629.92	20043.28 20031.78
12	END 5	1 166.01	4/16 463.23	18845.49 18839.07
13	STA 7	1 18.53	3/16 49.83	5062.31 5062.03
13	END 1	1 0.05	3/16 0.02	275.31 275.31
14	STA 6	1 18.38	3/16 82.69	7123.62 7123.11
14	END 6	1 18.38	3/16 82.69	272.40 258.89
15	STA 7	1 353.19	4/16 611.88	20287.46 20275.16
15	END 7	1 470.92	3/16 815.85	20410.13 20388.38
16	STA 5	1 308.75	4/16 550.96	18798.44 18787.83
16	END 7	1 470.92	3/16 784.84	19110.05 19088.12

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS

****************** END OF TABULATED WELD DESIGN ******************

131. FINISH

*************** END OF STAAD-III ***************

**** DATE= APR 17,1996 TIME= 10: 4:48 ****

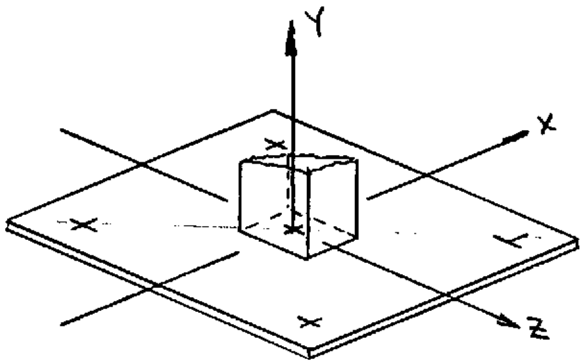
```
**********************************************************
*        For questions on  STAAD-III,   contact:         *
*              Research Engineers, Inc at                *
*       Ph: (714) 974-2500   Fax:  (714) 921-2543        *
**********************************************************
```

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

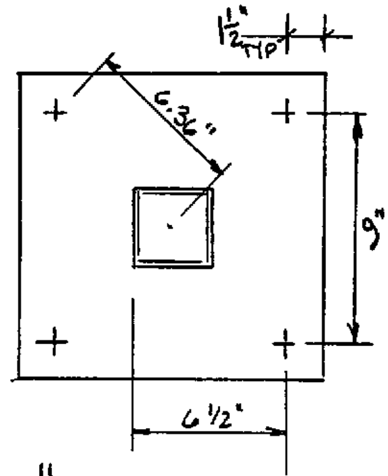
DESIGN ANCHORAGE

TRY 1" ϕ HILTI HVA @ 8¼" EMBEDMENT

$T_{ALLOW} = 10960.^{\#}$ $V_{ALLOW} = 7630.^{\#}$



TRY PL 12" x 12"



CONSERVATIVELY, TRY ENVELOPING LOAD CASES.

Fx = 17002. lbs. Mx = 41626 in-lbs

FY = 25283. lbs (TENSION) My = 10096 in-lbs

Fz = 667. lbs Mz = 26682. in-lbs

SHEAR

$$V = \frac{17002^{\#} + 667 \text{ lbs}}{4 \text{ BOLTS}} + \frac{10096 \text{ in-lbs}}{4 \text{ BOLTS}(6.36 \text{ in})}$$

V = 4814 lbs/BOLT

TENSION

$$T = \frac{25283. \text{ lbs}}{4 \text{ BOLTS}} + \frac{41626 \text{ in-lbs} + 26682 \text{ in-lbs}}{(2 \text{ BOLTS})(6.5 \text{ in})}$$

T = 11575 lbs (1.2) = 13
↑ PRYING

BOLT INTERACTION

$$\frac{V}{V_{ALL}} + \frac{T}{T_{ALL}} = \frac{4814}{7630} + \frac{13890}{10960} = 1.90 > 1.0 \therefore N.G.$$

LOOK AT INDIVIDUAL WORST CASE LOADING

JOINT B L.C. #7

F_x = 1648. lbs M_x = 24300. in-lbs

F_y = 25270 lbs (TENSION) M_y = 987. in-lbs

F_z = 389. lbs. M_z = 26670 in-lbs.

SHEAR

$$V = \frac{1648 \text{ lbs} + 389 \text{ lbs}}{4 \text{ BOLTS}} + \frac{987 \text{ in-lbs}}{(4 \text{ BOLTS})(6.36 \text{ in})}$$

V = 548 lbs / BOLT

TENSION

$$T = \frac{25270 \text{ lbs}}{4 \text{ BOLTS}} + \frac{24300 \text{ in-lbs} + 26670 \text{ in-lbs}}{2 \text{ BOLTS} (6.5 \text{ in})}$$

$\doteq$ (6317.5 lbs/BOLT + 3921. lbs/BOLT) 1.2 (PRYING)

= 12286. lbs/BOLT

BOLT INTERACTION

$$\frac{V}{V_{ALL}} + \frac{T}{T_{ALL}} = \frac{548}{7630} + \frac{12286}{10960} = 1.19 > 1.0$$

USE 1" φ HILTI HVA @ 16½" EMBED'T HAS SUPER (SAE 1410)

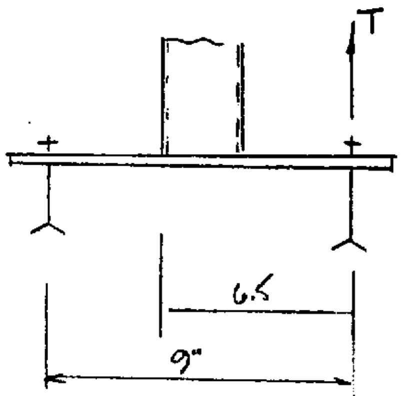
T_{ALL} = 21930 lbs V_{ALL} = 13760 lbs

BOLT INTERACTION:

$$\frac{V}{V_{ALL}} + \frac{T}{T_{ALL}} = \frac{548}{13760} + \frac{12286}{21930} = .60 < 1.0 \therefore OK.$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

DETERMINE PLATE THICKNESS

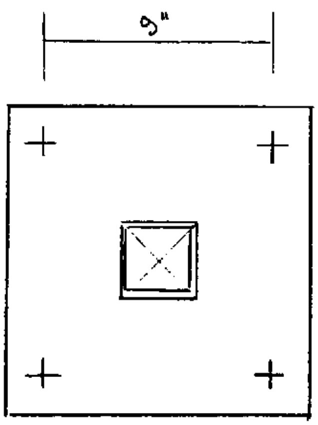


$F_y = 36000\ \#/in^2$

$F_b = .75\ F_y = 27000\ \#/in^2$

$f_b = \frac{M}{S} \Rightarrow S = \frac{M}{f_b}$

$S_{req} = \frac{M}{f_b} = \frac{T\,(6.5 in)}{27000\ \#/in^2} =$



$= \frac{(12286\ lbs)\,(6.5 in)}{27000\ \#/in^2}$

$S_{req'd} = 2.96\ in^3$

$S = bd^2/6 \Rightarrow d = \sqrt{\frac{6S}{b}}$

$= \sqrt{\frac{6\,(2.96 in^3)}{9 in}}$

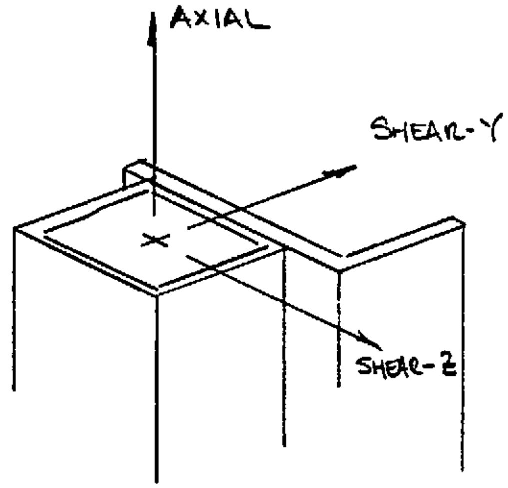
$d = THKS = 1.4\ IN$

USE PL $1\frac{1}{2}$" THK.

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

DESIGN THRU BOLT CONNECTION

MEM 9 JOINT 6
MEM 11 JOINT 9
MEM 13 JOINT 12
MEM 14 JOINT 14



ENVELOPE LOADS

	AXIAL	SHEAR-Y	SHEAR-Z
MEMB 9 JOINT 6	631.	15312.	548
MEM 11 JT 9	455.	14205.	939.
MEM 13 JT 12	619.	112.	45.
MEM 14 JT 14	584.	186.	43.

5/8" A307 T_{ALL} = 6100. lbs V_{ALL} = 3100. lbs

SHEAR

$$V = \frac{631.\text{ lbs} + 939\text{ lbs}}{3\text{ BOLTS}} = 523.\text{ lbs/BOLT}$$

TENSION

$$T = \frac{15312.\text{ lbs}}{3\text{ BOLTS}} = 5104\text{ lbs/BOLT}$$

BOLT INTERACTION:

$$\frac{T}{T_{ALL}} + \frac{V}{V_{ALL}} = \frac{5104}{6100} + \frac{523}{3100} = 1.01 \approx 1.0$$

$\therefore$ OK.

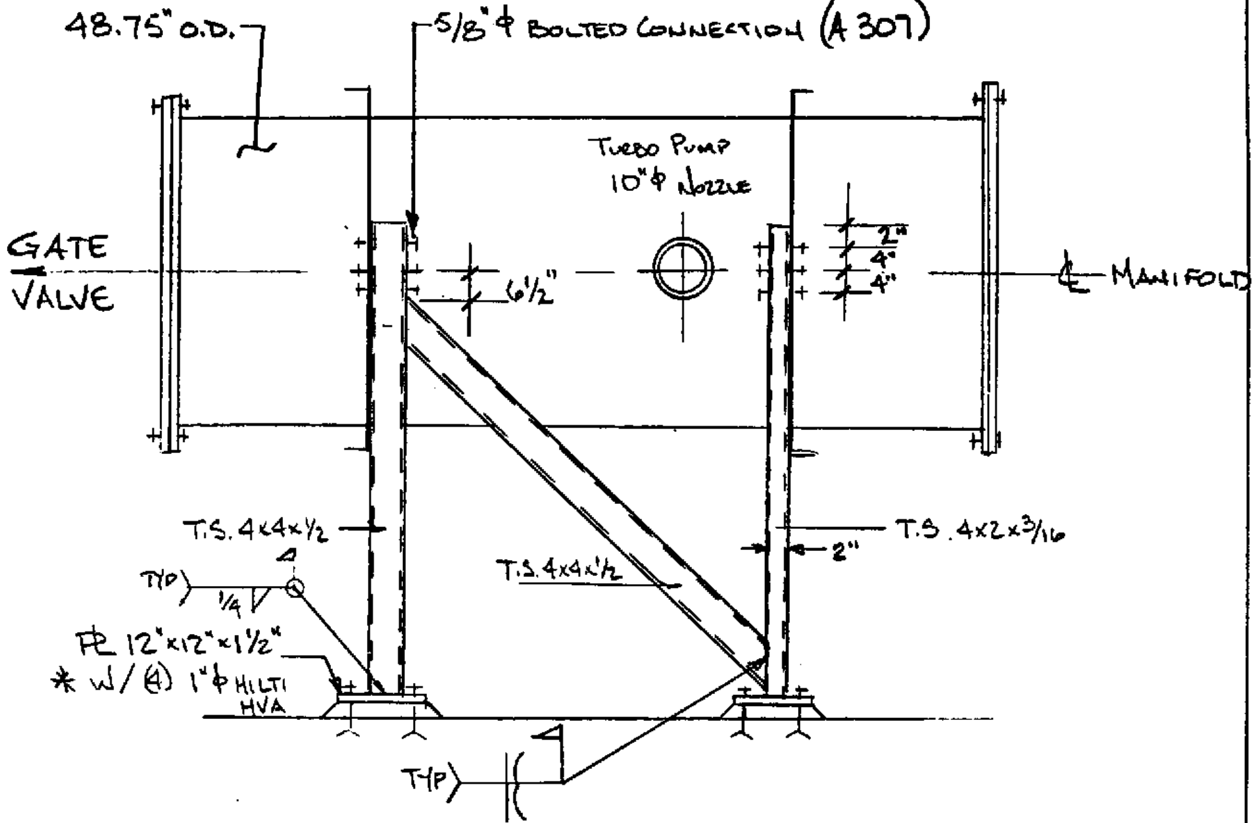
NOTE: LOADS ARE ENVELOPED, ACTUAL LOADS PER LOADCASE RESULT IN LOWER BOLT SHEAR/TENSION INTERACTION

TO ACCOUNT FOR ANY LOCAL PRYING AFFECTS AT THE BOLTED CONNECTIONS →

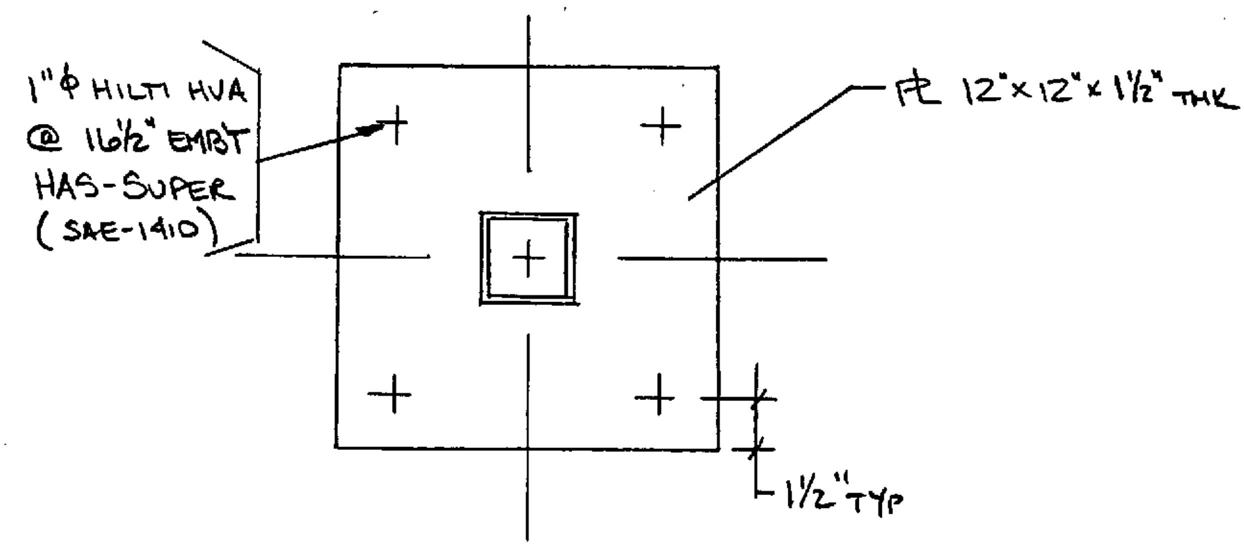
USE 5/8" φ A325 BOLTS.

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

B6 & B7 SUPPORT DETAIL



* 1"φ HILTI HVA (HAS SUPER - SAE 1410) @ 16½" EMBEDMENT



PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-098
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 17
0	139	4-22-96	AGR	RDC	TITLE: MAIN TURBO CART FRAME EXTENSION	
					By: ART ROUSSOPOULOS	DEPT.: 749
PROJECT: LIGO					PROJECT NO: V59049	

PURPOSE: VERIFY THE STRUCTURAL ADEQUACY OF THE FRAME EXTENSION

METHOD: • CLASSICAL STRESS ANALYSIS

ASSUMPTIONS: SEE CALCS

INPUTS: ECWARLS DWG D-4507
PSI DWG V049-4-012

REFERENCES: BLODGETT "DESIGN OF WELDED STRUCTURES" -1982
AISC - SCM - 9TH ED.
ROARK, "FORMULAS OF STRESS + STRAIN, 5TH. ED.
MACHINE DESIGN - THEORY + PRACTICE - 1975

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: THE SUBJECT FRAME CART IS STRUCTURALLY ADEQUATE PER THE DESIGN SKETCHES

NOTES:

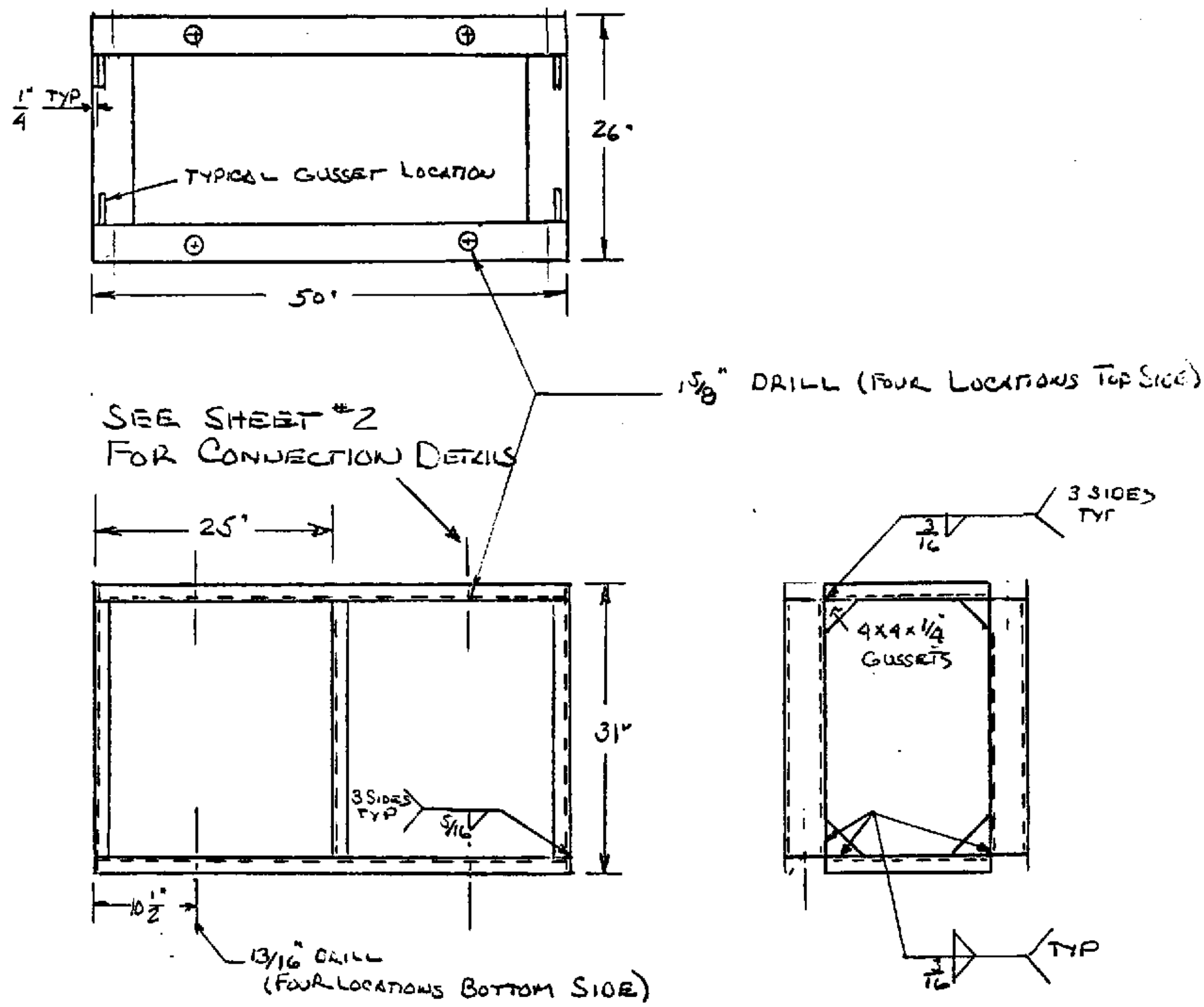
TABLE OF CONTENTS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

1.0 - DESIGN SKETCH

SK-V049-1-098, REV 0 - SHEET 1 OF 2

- ALL MEMBERS ARE C4 x 7.25
- MATERIAL: A36

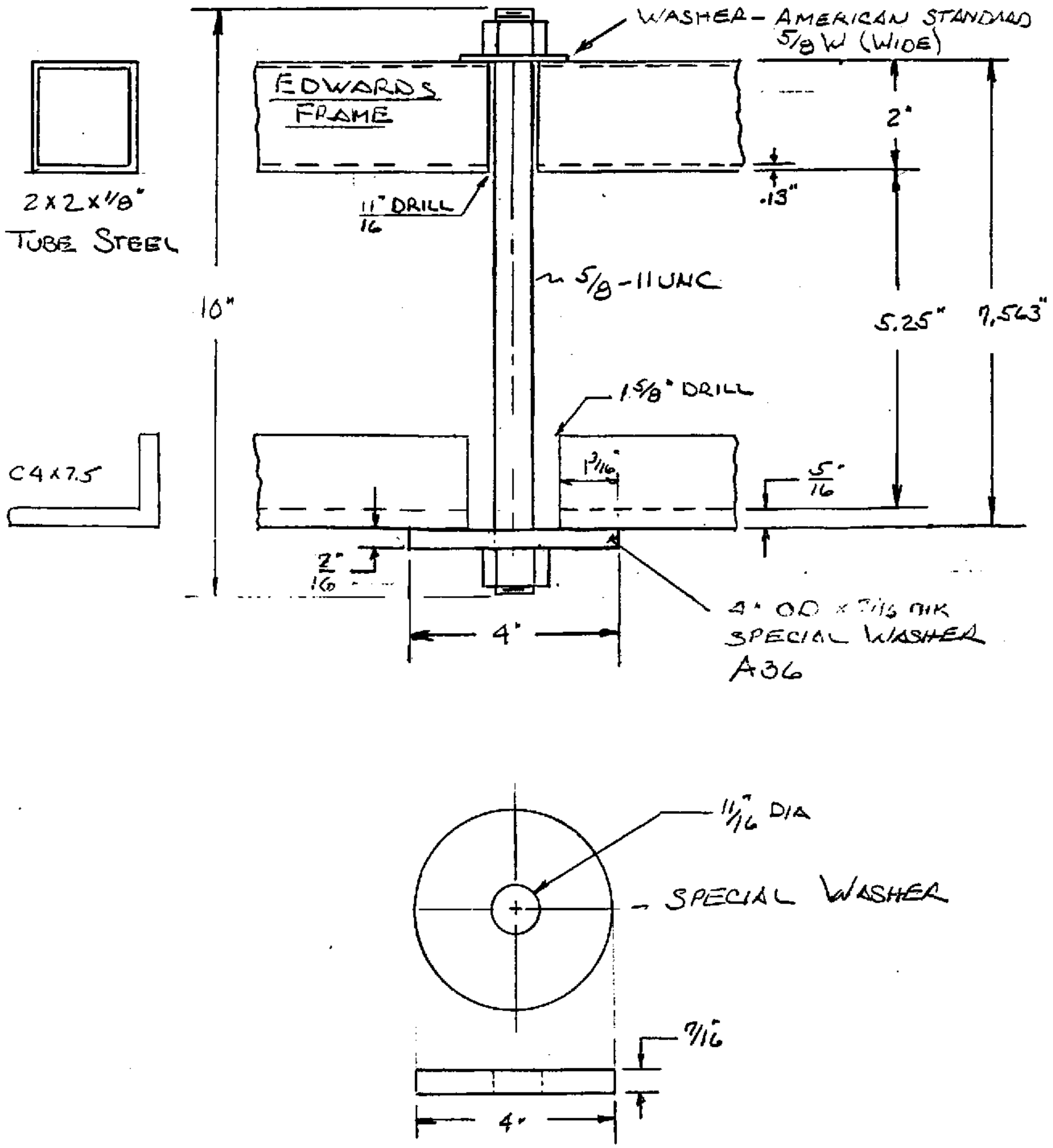


- SPECIFY; HILTI HFA 3/4 FOR 6 5/8" EMBEDMENT DEPTH

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

DESIGN SKETCH

SK-V049-1-098, REV 0 SHEET 2 OF 2



CONNECTION DETAILS

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

2. – DESIGN CRITERIA

- OPERATIONAL LOAD AT ℄ OF TURBO PUMP

$$F = PA = 15 \frac{\#}{IN^2} \times \frac{\pi}{4}(10)^2 \, IN^2 = 1178^{\#}$$

WHERE $P_{ATM} = 15 \ \#/IN^2$

10" = PUMP I.D.

- EXCURSION LOAD

EXCURSION LOAD SHALL BE BASED ON AN ACCIDENT CONDITION OF STALLED TORQUE GENERATING A MOMENT LOAD OF 5200# AT ANCHOR BOLT LOCATIONS IN THE DIRECTION OF ROTATION

- DESIGN TEMP = 100°F

3. – ALLOWABLE STRESSES

- OPERATIONAL LOAD

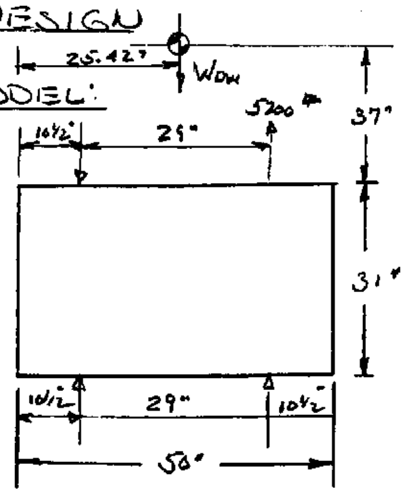
– $\sigma_{ALLOW} = .6 S_Y = .6(36,000) = 21,600$ PSI

- EXCURSION LOAD

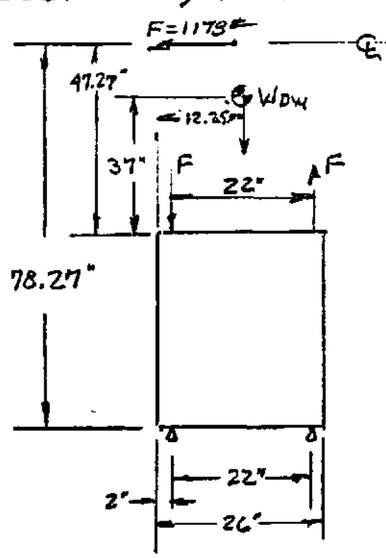
– $\sigma_{ALLOW} = .9 S_Y = .9(36,000) = 32,400$ PSI

4. – DESIGN

4.1 MODEL:



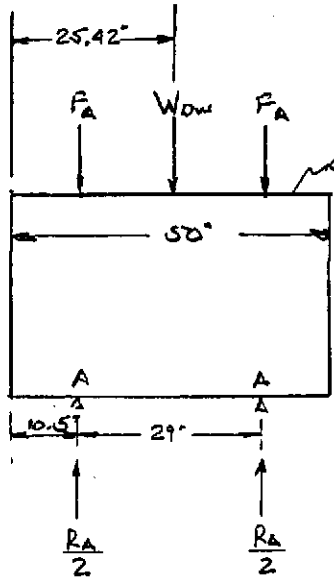
EXCURSION CONDITION

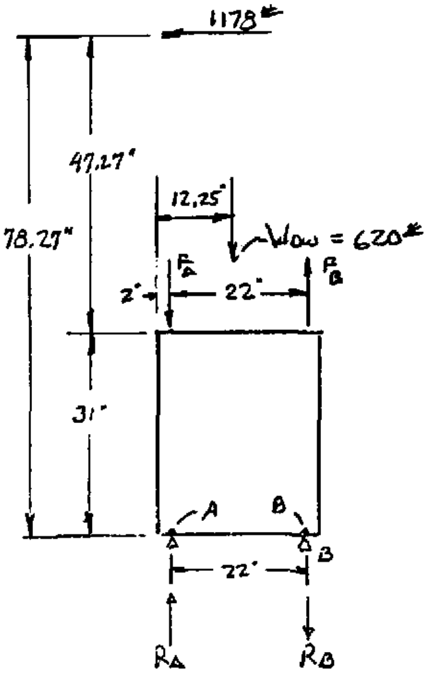


OPERATING CONDITION

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

4.2 OPERATIONAL STRESSES





• REACTION LOADS R_A, R_B

$$\circlearrowleft + \Sigma M_A = 0 = -78.27(1178) + 10.25(620) + 22\,R_B = 0$$

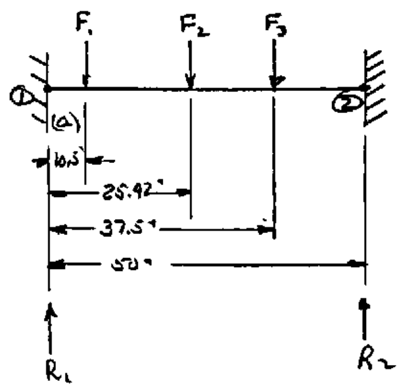
$$R_B = \frac{78.27(1178) - 10.25(620)}{22} = 3902^{\#}$$

$$\circlearrowleft + \Sigma M_B = 0 = -78.27(1178) - 11.75(620) + 22\,R_A = 0$$

$$R_A = \frac{78.27(1178) + 11.75(620)}{22} = 4522^{\#}$$

$$\therefore\ F_A = \frac{R_A}{2} = \frac{4522}{2} = 2261^{\#}$$

4.2.1 • STRESS ON C4x7.25 BEAM 50" LONG - A SIDE



REF. BLODGETT, CASE 4Ab, P. 8.1-11

$$R_1 = \frac{Fb^2(3a+b)}{L^3}\ ;\ R_2 = \frac{Fa^2(a+3b)}{L^3}$$

$$M_1 = \frac{Pab^2}{L^2}\ ;\ M_2 = \frac{Pa^2b}{L^2}\ ;\ M_a = \frac{2Pa^2b^2}{L^3}$$

C4 x 7.25
$S_x = 2.29\ IN^3$, $r_x = .450"$, $r_y = 1.47"$
$A = 2.13\ IN^2$

4.2.1 CONT

- LOAD $F_1 = F_A = 2261\#$

$$R_1 = \frac{2261(50-10.5)^2(3\times10.5+39.5)}{50^3} = 2{,}004\#$$

$$R_2 = 2261 - 2004 = 257\#$$

$$M_1 = 2261(10.5)(39.5)^2/(50)^2 = 14{,}816 \text{ IN-}\#$$

$$M_2 = 2261(10.5)^2(39.5)/(50)^2 = 3{,}939 \text{ IN-}\#$$

$$M_{a_1} = 2(2261)(10.5)^2(39.5)^2/(50)^3 = 6223 \text{ IN-}\#$$

$$\sigma_{a_1} = 6223/2.29 = 2{,}717 \text{ \#/IN}^2$$

- LOAD $F_2 = W_{OW} = 620\#$

$$R_1 = 620(24.58)^2(3\times25.42+24.58)/(50)^3 = 302\#$$

$$R_2 = 620 - 302 = 318\#$$

$$M_1 = 620(25.42)(24.58)^2/(50)^2 = 3{,}809 \text{ IN-}\#$$

$$M_2 = 620(25.42)^2(24.58)/(50)^2 = 3{,}939 \text{ IN-}\#$$

$$M_{a_2} = 2(620)(25.42)^2(24.58)^2/(50)^3 = 3{,}873 \text{ IN-}\#$$

$$\sigma_{a_2} = 3{,}873/2.29 = 1{,}691 \text{ \#/IN}^2$$

- LOAD $F_3 = F_A = 2261\#$

$$R_1 = 2261(12.5)^2(3\times37.5+12.5)/(50)^3 = 353\#$$

$$R_2 = 2261 - 353 = 1908\#$$

$$M_1 = 2261(37.5)(12.5)^2/(50)^2 = 5{,}299 \text{ IN-}\#$$

$$M_2 = 2261(37.5)^2(12.5)/(50)^2 = 15{,}898 \text{ IN-}\#$$

$$M_{a_3} = 2(2261)(37.5)^2(12.5)^2/(50)^3 = 7{,}949 \text{ IN-}\#$$

$$\sigma_{a_3} = 7949/2.29 = 3{,}471 \text{ PSI}$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

4.2.1 CONT

SUMMATION OF MOMENTS BY SUPERPOSITION

- AT ①

$\Sigma M_1 = 14{,}816 + 3809 + 5299 = 23{,}924$ IN-#

$\sigma_1 = 23{,}924 / 2.29 = 10{,}447$ PSI $< .6 S_Y$ ∴ OK

- AT ②

$\Sigma M_2 = 3939 + 3939 + 15898 = 23{,}776$ IN-#

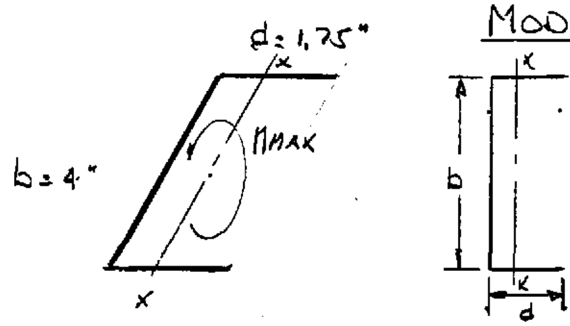
$\sigma_2 = 23{,}776 / 2.29 = 10{,}393$ PSI $< .6 S_Y$ ∴ OK

- AT ⓐ

$\Sigma M_a = 6223 + 3873 + 7949 = 18{,}045$ IN-#

$\sigma_a = 18{,}045 / 2.29 = 7{,}880$ PSI $< .6 S_Y$ ∴ OK

• <u>CHECK WELD FOR WORSE CASE END CONDITION</u>



<u>MODEL</u>: REF: BLODGETT, TABLE 5, P. 7.4-7

$$S_W = \frac{2bd + d^2}{3}$$

$$S_W = \frac{2(4)(1.75) + (1.75)^2}{3}$$

$S_W = 5.69$ IN²

$$f_{MAX} = \frac{23924}{5.69} = 4205 \text{ \#/IN}$$

- ALLOWABLE WELD ROD STRESS:

$.3 S_T = .3(70{,}000) = 21{,}000$ PSI

• ALLOWABLE WELD LOAD IS: $.707(21000) = 14{,}847$ PSI

∴ REQUIRED WELD SIZE IS:

$$\omega = \frac{4205}{14847} = .283 < 5/16 \, (.3125) \therefore OK$$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

4.2.1 CON'T

4.2.2 • CHECK VERTICAL C4X7.25 LEG - FOR BUCKLING

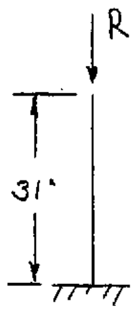
Σ R'S

AT ① $R_{TOT} = 2004 + 302 + 353 = 2659\#$

AT ② $R_{TOT} = 257 + 318 + 1908 = 2483\#$

$R = 2659\#$ - WORSE CASE

MODEL: REF. AISC, E2-1, 2, P.5-42



K = .7 (BOTH ENDS FIXED)

$$\frac{KL}{r} = \frac{(.7)(31)}{1.47} = 14.8$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2\pi^2(29\times10^6)}{(36{,}000)}} = 126$$

$\frac{KL}{r} < C_c \therefore$

$$F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right] F_y}{\frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}}$$

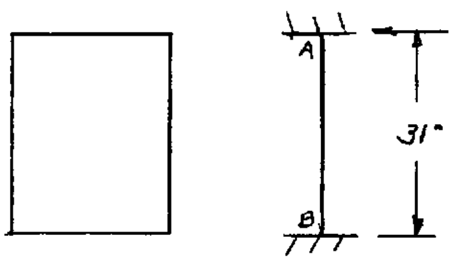
$$F_a = \frac{\left[1 - \frac{14.8^2}{2(126)^2}\right] 36000}{\frac{5}{3} + \frac{3(14.8)}{8(126)} - \frac{(14.8)^3}{8(126)^3}} = 29901\# > 2659\# \therefore OK$$

- COMPRESSIVE STRESS:

$$\sigma = \frac{2659}{2.13} = 1248\ \#/IN^2 \quad \therefore OK$$

• CHECK FOR LATERAL LOAD

← 1178#



REF: ROARK, 5TH. ED., CASE 5d, P. 106

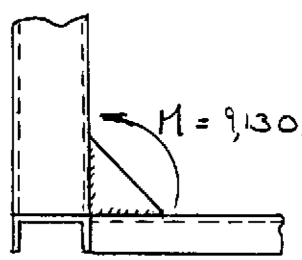
$M_A = M_B$

$\therefore M_{A,B} = \frac{1178(31) = 36\,518\ \text{IN-\#}}{4}$

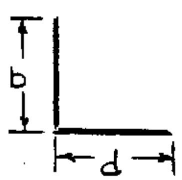
$M_{A\ OR\ B}$ = 9,130 IN-# PER VERTICAL SUPPORT

$\therefore \sigma_{MAX} = \frac{9,130}{2.29} = 3,987$ PSI $< .6S_y$ ∴ OK

DESIGN GUSSET FOR CORNER WELD CONNECTION



MODEL:



REF: BLODGETT, TABLE 5, P. 7.4-7

b = 4"

d = 4"

$$J = \frac{(b+d)^4 - 6b^2d^2}{12(b+d)}$$

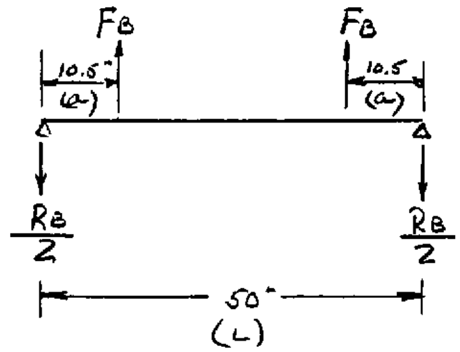
$$J = \frac{(4+4)^4 - 6(4)^2(4)^2}{12(4+4)} = 26.7\ \text{IN}^3$$

$$f = \frac{Tc}{J_w} = \frac{9130(4)}{(26.7)} = 1368\ \text{\#/IN}$$

REQUIRED WELD SIZE:

$$\omega = \frac{1368}{14847} = .0921'' < \quad " \quad \therefore \text{OK}$$

4.2.3 - STRESS ON C4X7.25 BEAM 50" LONG - B SIDE



REF: BLODGETT, CASE 3AC, P. 8.1-6

$R_1, R_2 = F$

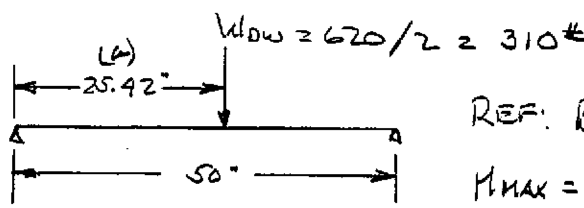
$M_{MAX} = F_B\, a$

$a = 10.5"$

$M_{MAX_1} = 10.5\, F_B = 10.5(1951) = 20{,}486$ IN-#

WHERE: $F_B = \frac{R_B}{2} = \frac{3902}{2} = 1{,}951$ #

$\sigma_{MAX_1} = 20486 / 2.29 = 8{,}946$ PSI



REF: BLODGETT, CASE 4Ab

$M_{MAX} = M_2 = \frac{F a^2 b}{L^2}$

$M_{MAX_2} = \frac{(310)(25.42)^2(24.58)}{50^2} = 1969$ IN-#

$\sigma_{MAX_2} = 1969 / 2.29 = 859$ PSI

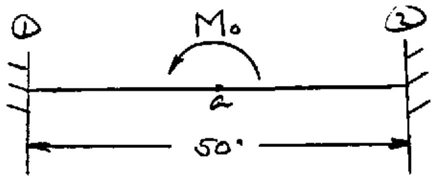
ACTUAL MAX STRESS ON B SIDE

$\sigma_{MAX\ ACTUAL} = 8946 - 859 = 8{,}087$ PSI $< .6 S_Y$ ∴ OK

MAX MOMENT GENERATED ON WELD END CONNECTION IS LESS THAN THE ONE EVALUATED FOR "A" SIDE ∴ "B" SIDE WELD IS OK

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

4.3 EXCURSION STRESSES



$M_o = FL = 5200^{\#} \times 29" = 150,800 \text{ IN-}\#$

REF: BLODGETT, CASE 4E, P. 8.1-14

$M_1 = \frac{M_o b}{L^2}(L - 3a)$; $M_2 = -\frac{M_o a}{L^2}(2L - 3a)$

① - $M_1 = \frac{(150,800)(25)(50 - 3\times 25)}{(50)^2} = 37,700 \text{ IN-}\#$

② - $M_2 = -\frac{(150,800)(25)(2\times 50 - 3\times 25)}{(50)^2} = -37,700 \text{ IN-}\#$

$\sigma_{MAX} = \frac{37,700}{2.29} = 16463 \text{ PSI} < .9S_Y \therefore \text{OK}$

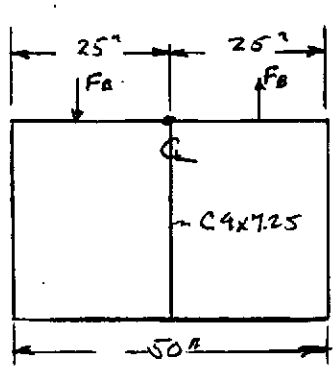
AT CENTER

$M_{MAX} = M_o = 150,800 \text{ IN-}\#$

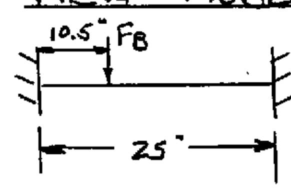
$\sigma_{MAX} = \frac{150,800}{2.29} = 65,851 \text{ PSI} > .9S_Y = 33,400 \text{ PSI} \therefore \text{N.G.}$

SOLUTION:

PROVIDE VERTICAL C4 x 7.25 SUPPORT AT ℄ TO REDUCE MAX MOMENT



NEW MODEL



REF: BLODGETT, CASE 4Ab, P. 8.1-11

4.3 CON'T

$$M_{MAX} = \frac{F a b^2}{L^2} = \frac{5200(10.5)(14.5)^2}{(25)^2} = 18{,}367 \text{ IN-\#}$$

$$\sigma_{MAX} = \frac{18{,}367}{2.29} = 8{,}021 \text{ PSI} < .9S_Y \therefore OK$$

4.4 - CONNECTION DESIGNS

4.4.1 - ANCHOR BOLT SIZING

- LOADS:

MAX TENSILE OPERATING LOAD: $F_B = 1951$#
EXCURSION: 5200#/BOLT

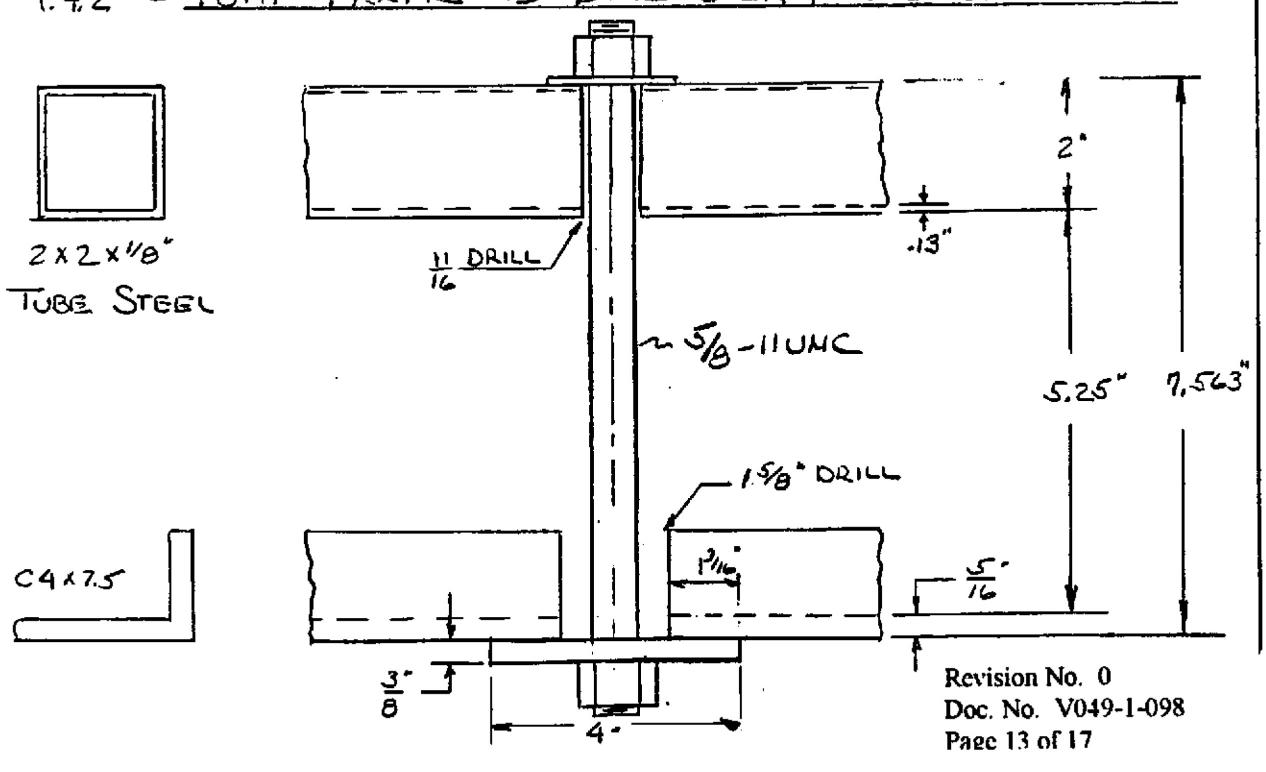
TOTAL TENSILE LOAD = 5200 + 1951 = 7,151#

LATERAL SHEAR LOAD = $\frac{1178}{4}$ = 295#/BOLT

SPECIFY HILTI - HFA 3/4 - 6 5/8" EMBEDMENT DEPTH

HVA ALLOWABLE BOND STRENGTH AND STEEL STRENGTH FOR HFA INSERTS - REF: HILTI PRODUCT TECH GUIDE, P. 87
- BOND STRENGTH (4000 PSI) = 7,260# > 7,150# ∴ OK
- SHEAR STRENGTH = 7315# > 295# ∴ OK

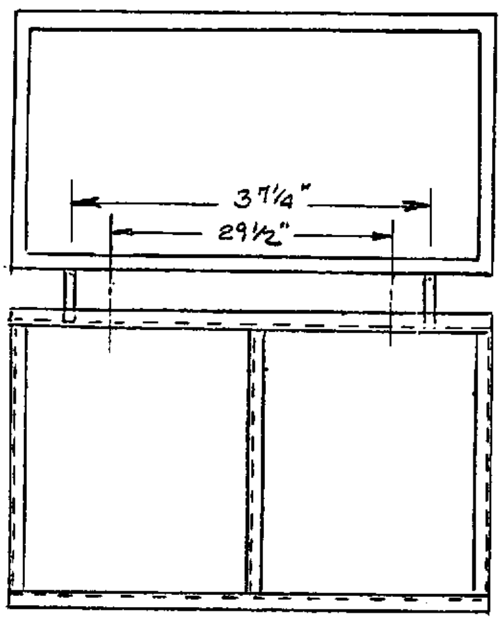
4.4.2 - PUMP FRAME TO EXTENSION FRAME CONNECTION

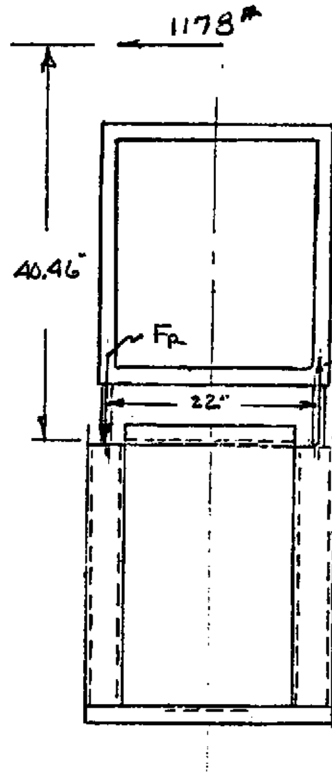


4.4.2 CONT

4.4.2.1 · LOADS

- OPERATIONAL





$$FR = \frac{40.46(1178)}{22} = 2166^{\#}$$

LOAD PER BOLT = 2166 / 2 = 1,083# - TENSILE

SHEAR / SUP LOAD = 1178/4 = 295#

- EXCURSION

LOAD PER BOLT = 5200#

TOTAL LOAD - WORSE CASE = 5200 + 1083 = 6283# TENSILE

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

4.4.2 - CONT

4.4.2.2 • BOLTING: - SPECIFY A36

ALLOWABLE LOADS:

- OPERATIONAL: REF: AISC, TABLE 1-A, P. 4-3.

5/8-11UNC TENSION - 5900# > 1083# ∴ OK
SHEAR - 3000# > 295# ∴ OK

- EXCURSION:

$S_y = 36{,}000$ PSI

$.9S_y = .9(36000) = 32{,}400$ PSI

$\sigma = \frac{F}{A} = \frac{6283}{.202} = 31{,}104$ PSI $< 32{,}400$ PSI ∴ OK

WHERE: $A = .202 \text{ IN}^2$ - ROOT AREA

4.4.2.3 • BOLT PRELOAD

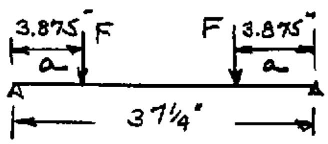
- BOLT PRELOAD SHALL BE BASED ON OPERATIONAL BOLT LOAD PLUS 10%

DESIGN PRELOAD = 1.1 (1083) = 1191# → 1200#

- CHECK EDWARDS FRAME FOR STRUCTURAL ADEQUACY:

2 x 2 x 1/8" $S = \frac{bh^2}{6} = \frac{2(2)^2 - 1.75(1.75)^2}{6} = .515 \text{ IN}^3$

MODEL: REF: BLODGETT, CASE 3AC, P. 8.1-6

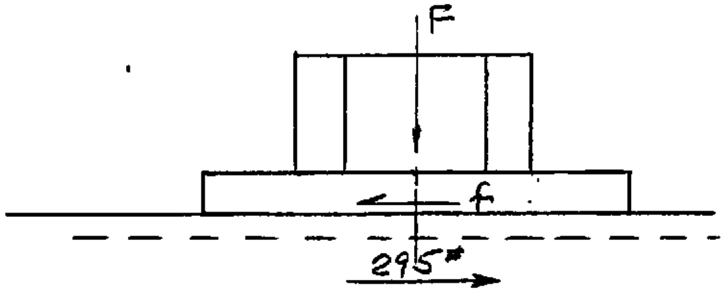


$M_{MAX} = Fa = 1200(3.875) = 4650$ IN-#

$\sigma_{MAX} = \frac{4650}{.515} = 9{,}029$ PSI $< .6S_y$ ∴ OK

4.4.2 CONT

• CHECK FOR SLIP



WASHER - AMERICAN STANDARD TYPE B
5/8 - W (WIDE)

.666" ID
2.25" OD
.160" THK

$F = 1200$ #
$\mu = .2$ (ASSUME)

$f = \mu F = .2(1200) = 240\#$ < 295# ACTUAL SHEAR ∴ N.G.

∴ CRITERIA FOR PRELOAD SHALL BE BASED ON OPERATIONAL SHEAR LOAD PLUS 10%

NEW DESIGN PRELOAD

$(295)(1.1) = 324.5 \rightarrow 325$

$F = \frac{f}{\mu} = \frac{325}{.2} = 1625\#$ PRELOAD

- CHECK EDWARDS 2x2x1/8" FRAME

$\sigma = \frac{(1625)(3.875)}{.515} = 12{,}227$ PSI < .6Sy ∴ OK

4.4.2.4 • BOLT TORQUE REF: MACHINE DESIGN, THEORY + PRACTICE, 1975 P. 816

$T = \mu D F$

$T = .2(.625)(1625) = 203$ IN-# /12 = 17 FT-#

SPECIFY 20FT-# FOR BOLT TORQUE

- CHECK FRAME

$F = \frac{20 \times 12}{.2(.625)} = 1920\#$ $\sigma = \frac{1920(3.875)}{.515} = 14{,}447$ PSI < .6Sy = 21,600 PSI ∴ OK

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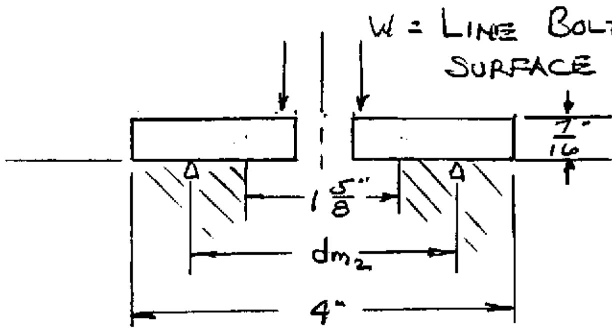
4.4.2.5 SPECIAL WASHER DESIGN

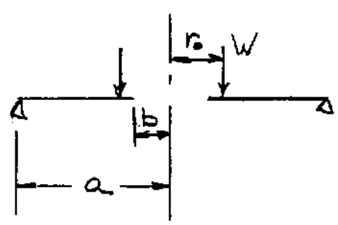


REACTION LOAD IS ASSUMED TO OCCUR AT THE MEAN DIAMETER OF CONTACT SURFACE.

$\therefore \; dm_1 = \dfrac{1.06 - .6875}{2} = .8738"$

$dm_2 = \dfrac{4 + 1.625}{2} = 2.8125"$

MODEL: REF: ROARK, CASE 1a, P. 334



$r_o = \dfrac{dm_1}{2} = \dfrac{.8738}{2} = .4369"$

$a = \dfrac{dm_2}{2} = \dfrac{2.8125}{2} = 1.406"$

$b = \dfrac{.6875}{2} = .3438"$

$M_{MAX} = M_{tb} = K_{Mtb}\, w\, a$

$b/a = .3438/1.406 = .2445 \; ; \; K_{Mtb} = .5423$

$w = \dfrac{W}{\pi dm_1} = \dfrac{1920}{\pi(.8738)} = 699 \text{ \#/IN}$

$\therefore M_{MAX} = .5423(699)(1.406) = 533$

$\sigma = \dfrac{6M}{t^2} = \dfrac{6(533)}{(.4375)^2} = 16{,}708 \text{ PSI} < .6 S_y \;\therefore \text{OK}$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-063 PAGE 1 OF 6
REV.	DEO #	DATE	BY:	CHECK	TITLE: Flange Bolting Analysis of flange bolting for Gate Valves 112 CM & 122 CM	
0	0136	3/11/96	WDB	RDC		
					BY: W.Bilynsky	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Evaluate the gate valves threaded fastening details. Bolts and their mating threaded (tapped) flange section are potential areas of failure due to thread stripping between differing materials.

METHOD:

Hand calculations utilizing standard formulas for Stress Areas and Length of Engagement of Screw Threads as specified in MACHINERY's HANDBOOK

ASSUMPTIONS:

INPUTS:

1. PSI Calc No. V049-1-042
2. GNB Drawings 103098

REFERENCES:

1. Machinery's Handbook. Oberg & Jones 19th Ed. 1973.
2. Standard Handbook for Mechanical Engineers. Baumeister & Marks 7th Ed.
3. Specification for 112 and 122 CM Gate Valves
   PSI - V049-2-005 rev. 3
4. Doc. No. V049-1-066 LIGO Vacuum Equipment Structural Design Criteria

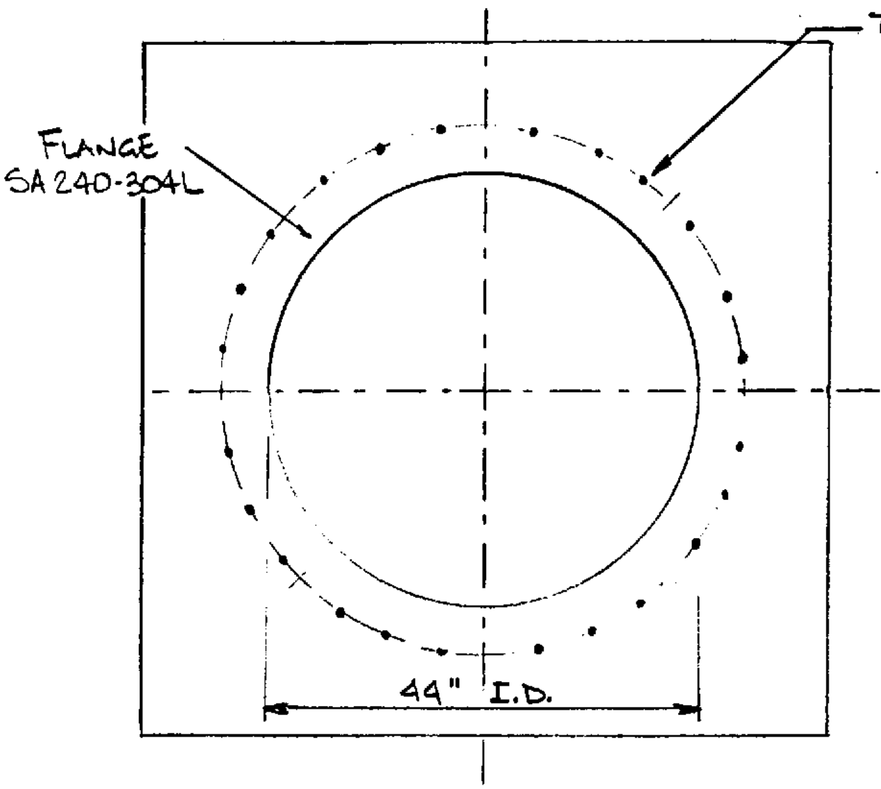
CALCULATIONS:

(See Attached)

CONCLUSIONS: The requirements for proper and adequate bolting as specified in the Machinery's Handbook are satisfactorily met.

NOTES:

BOLTS – 24 REQ'D



7/8" = nom size
9 = no. of threads per inch
UNC = thread series
2B = thread class

UNC = Coarse thread Series

2B = Permits external threads to be plated.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

7/8" BOLT – Ref. Standard Handbook for Mechanical Engineers 7th ed.
Section 8-12

REF. TABLE 1 pg. 8-14

Major Diam, D_{max} = 0.8750 in. (SCREW BASIC DIAMETERS)
Pitch Diam, E_{max} = 0.8028 in.
$E_{s\,min}$ = 0.7946 in.
Basic minor diam, K = 0.7387 in. (EXTERNAL THREADS)
Minor Diam, K_n max = 0.778 in (internal threads)
Minor Diam, K_n min = 0.7547 in. (INTERNAL THREADS)
Minor Diam tolerances
Class 2B = 0.0134 in. (INTERNAL THREADS)

Areas of Section { Basic Min. Minor Diam = 0.4193 in^2
Stress Area = 0.4612 in^2

FORCE ON BOLTS

Ref. PSI CALC No. V049-1-042 $Force_{TENS}$ = 25.37 K on 44"ϕ flange

Ref. SPECIFICATION FOR 112 AND 122 CM GATE VALVES
PSI – V049-2-005 REV. 3
SECTION 4.1.14 = 21.0 K

TOTAL TENSILE FORCE = 46.37 KIPS

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

TENSILE FORCE PER BOLT $= F_{TENS.} = \dfrac{46370 \text{ lbs}}{24 \text{ BOLTS}}$

$F_{TENS.} = 1932.1$ lbs/BOLT

The critical areas of stress of mating screw threads are:

1) The effective cross-sectional area, or tensile stress area, of the external thread.

2) The shear area of the external thread, which depends principally on the minor diameter of the tapped hole.

3) The shear area of the internal thread, which depends principally on the major diameter of the external thread.

To prevent stripping of the external thread, the minimum length of engagement Required is:

$$Le_{MIN.} = \frac{2 \times A_t}{\pi \; K_n max \left[1/2 + 0.57735 n \left(E_s min - K_n max \right) \right]}$$

where: n = no. of threads per inch = 9

$K_n max$ = max. minor diameter of internal threads = .778 in

$E_{s\,min}$ = min. pitch diameter of external thread = .7946 in

A_t = tensile stress area = .4612 in²

$= .7854 \left(D - \frac{0.9743}{n} \right)^2$

$$Le_{min} = \frac{(2)(.4612)}{\pi \; (.778 in) \left[1/2 + .57735(9)[.7946 - .778] \right]}$$

$= .643$ in.

REF. MACHINERY'S HANDBOOK Pg. 1141

AMPAD 22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

STRIPPING OF INTERNAL THREAD.

IF THE INTERNAL THREAD (I.E. TAPPED FLANGE) IS MADE OF MATERIAL OF LOWER STRENGTH THAN THE EXTERNAL THREAD (I.E. BOLT), STRIPPING OF THE INTERNAL THREAD MAY TAKE PLACE BEFORE THE SCREW/BOLT BREAKS (DESIRED FAILURE MODE).

RELATIVE STRENGTH OF THE EXTERNAL AND INTERNAL THREADS IS;

$$J = \frac{A_s \times \text{Tensile strength of external thread mat'l}}{A_n \times \text{Tensile strength of internal thread mat'l}}$$

IF $J \leq 1.0$ the length of engagement $L_{e\,min}$ is adequate

IF $J > 1.0$ the length of engagement to prevent stripping of the internal threads is multiplied by J

OR $Q = J\,L_{e\,min}$

$$A_s = \pi\, n\, L_e\, K_{n\,max}\left[\frac{1}{2n} + 0.57735\left(E_{s\,min} - K_{n\,max}\right)\right]$$

n = number of threads = 9

ref. table 4 Machinery Handbook

L_e = .643 in

$K_{n\,max}$ = .778 in = max minor dia. internal thrds.

$E_{s\,min}$ = .7946 in = min pitch dia. external thrd.

$$A_s = \pi(9)(.643\text{in})(.778\text{in})\left[\tfrac{1}{2(9)} + 0.57735(.7946\text{in} - .778\text{in})\right]$$

$$= .9214\,\text{in}^2$$

$$A_n = \pi\, n\, L_e\, D_{s\,min}\left[\tfrac{1}{2n} + 0.57735\left(D_{s\,min} - E_{n\,max}\right)\right]$$

$D_{s\,min}$ = .8592 in = min major dia of external thrd.

$E_{n\,max}$ = .8110 in = max pitch dia. of internal thrd.

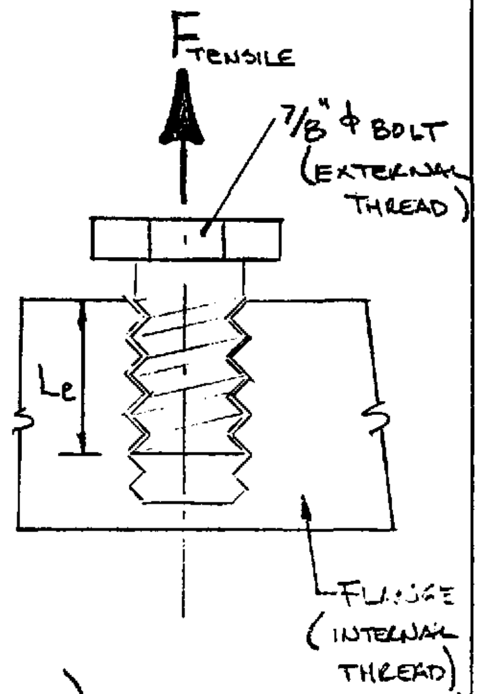
$$A_n = \pi(9)(.643\text{in})(.8592\text{in})\left[\tfrac{1}{2(9)} + 0.57735(.8592\text{in} - .8110\text{in})\right]$$

$$= 1.303\,\text{in}^2$$

- tensile strength of valve flange

material = SA240-304 L

S = 14.7 ksi



- tensile strength of Bolts

material = SA-193-B7

S = 25.0 ksi

$$J = \frac{A_s \times \text{Tensile strength (BOLT)}}{A_n \times \text{Tensile strength (Flange)}}$$

$$= \frac{.9214\ in^2 \times 25.0}{1.303\ in^2 \times 14.7}$$

$J = 1.202$ in ∴ Le = .643 in inadequate

required engagement length

$Q = J\,Le$

$= (1.202\ in)(.643\ in)$

$= .773$ in

.773 in < 1.42 in (actual depth)

∴ Engagement length adequate

Stripping of internal thread is unlikely. Bolts & Flange are adequately sized.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
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Average Thread Stress (SCREW)

$$\sigma_{AVER} = \frac{2\ F_{TENSILE}}{\pi\ K\ Le}$$

$$= \frac{2\ (1932.1\ lbs)}{\pi\ (0.7387 in)(0.643 in)}$$

$$\sigma_{AVER} = 2589.6\ \#/in^2/\text{BOLT}$$

Allow Stress = .6 Sm ref. ASME SECTION VIII DIV. II AD-132.2

$$\sigma_{ALL} = .6\ (14700 psi) \qquad (\text{FOR: SA 240-304 L})$$

$$\sigma_{ALLOW} = 8820\ \#/in^2$$

$$\sigma_{ALL} > \sigma_{AVER} \qquad FS. = 3.4$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-068 PAGE 1 OF 5
REV.	DEO #	DATE	BY:	CHECK	TITLE: Study of Required Bellows Deflections for Installation Fitup	
0	0141	4/19/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine the maximum deformations required of the bellows to facilitate installation of equipment considering component construction tolerances.

METHOD: Hand calculation methods are used to determine the geometric configurations that bellows must assume to connect adjacent components.

ASSUMPTIONS: See calculations attached.

INPUTS: LIGO project drawings and sketches.

REFERENCES: Specification V049-2-017, Bellows Expansion Joints for LIGO Vacuum Equipment

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The required bellows axial and bending deflections have been determined.
Axial deflection....................+/- 2 in.
Bending rotation...................+/- .5°.

NOTES: The above deformations will be included in Specification V049-2-017. Shear deformation of bellows is not required.

MAXIMUM DEFLECTIONS REQUIRED AT ENDS OF BELLOWS

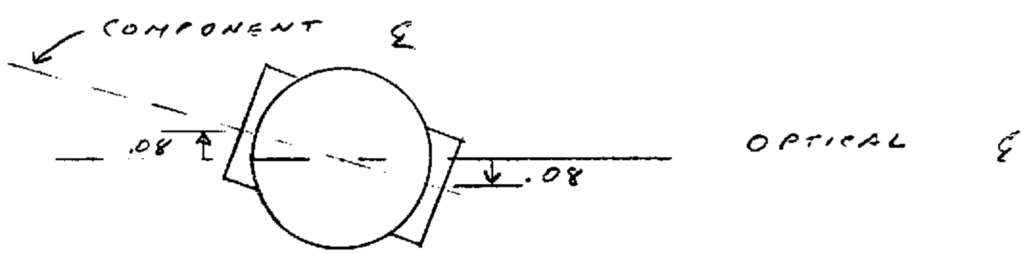
GIVEN:

1. EQUIPMENT TOLERANCES ARE AS SHOWN ON DWGS

2. EQUIPMENT ℄ WILL BE INSTALLED TO WITHIN ± 2mm (±.08 IN) OF THE OPTICAL ℄

ASSUME:

1. EACH MAJOR COMPONENT (BSC, HAM, ION PUMP, ETC) MAY BE INSTALLED AT AN ANGLE TO THE OPTICAL ℄ THAT IS LIMITED BY NO. 2 ABOVE



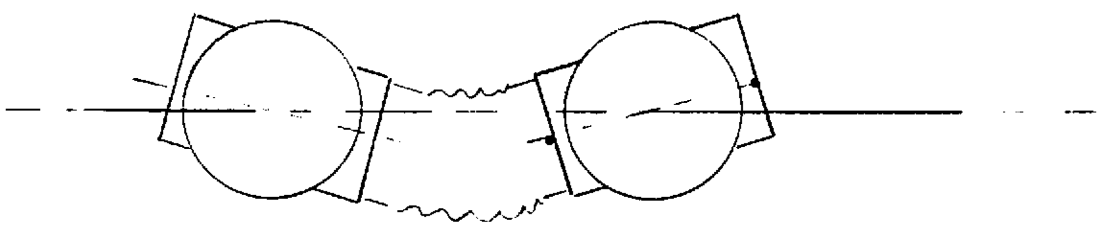
2. THE MISALIGNMENT SHOWN ABOVE CAN OCCUR IN THE HORIZONTAL PLANE AND THE VERTICAL PLANE SIMULTANEOUSLY

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

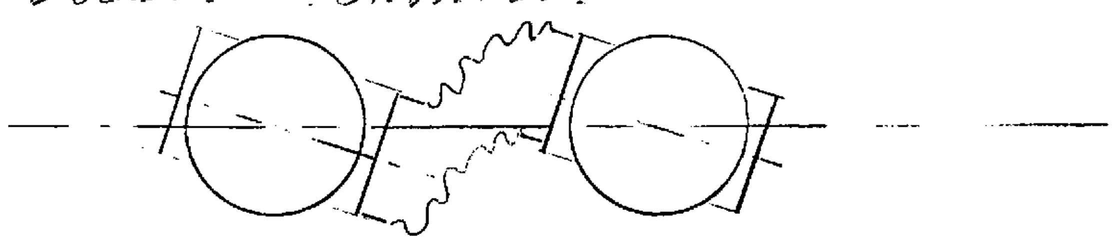
3. ASSUME THAT FLANGE PARALLELISM AND PERPENDICULARITY REQUIREMENTS FOR BSC (DWG V049-4-001) HOLD FOR ALL COMPONENTS.

4 MISALIGNMENT OF 2 ADJACENT COMPONENTS CAN OCCUR SUCH THAT AN ADAPTER WILL BE BENT IN EITHER SINGLE OR DOUBLE CURVATURE.

SINGLE CURVATURE



DOUBLE CURVATURE

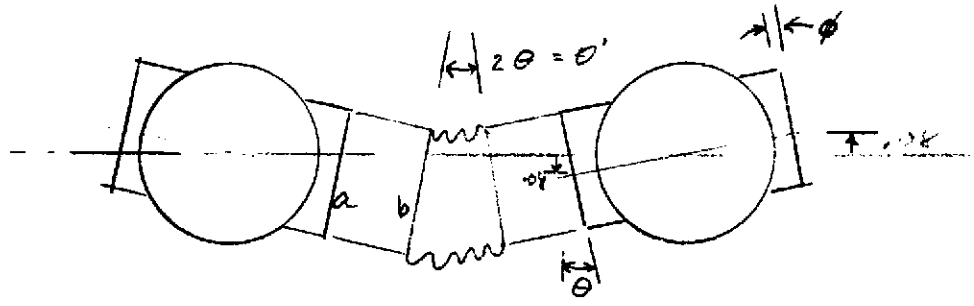


CLEARLY, DOUBLE CURVATURE IMPOSES GREATER STRAIN ON THE ADAPTER BELLOWS THAN SINGLE CURVATURE.

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

However, it should be possible to control installation alignment so that adapters between adjacent components are bent in single curvature. Each component can be set in its final position after the next component and bellows/adapter are installed for rough alignment, i.e. concrete anchors are not installed.

The maximum rotation at the bellows is a function of the angular misalignment of adjacent components at installation and the misalignment of flanges that are not parallel and not perpendicular to the optical ℄. Rotation for single curvature is independent of adapter length.



Assume that ends of adapter saddles, a & b are parallel

θ is likely to be maximum for the corner station BSCs. The distance from the BSC ℄ to the face of the 66 in flange is 113.75/2 = 56.9 in (DWG V049-4-001).

$$\theta = \frac{.08}{56.9} + \phi$$

$$= 1.407(10)^{-3} \text{ RAD} + \phi$$

ϕ IS THE ANGULAR MISALIGNMENT RESULTING FROM TOLERANCES ON PARALLELISM AND PERPENDICULARITY. THIS ANGLE IS MAXIMUM WHEN THE FLANGE FACE IS OUT OF PERPENDICULARITY.

$$\phi = \frac{.03}{r}$$ WHERE .03 IS TOLERANCE ON PERPENDICULARITY SEE DWG 4049-V-001

r = FLANGE MAX RADIUS

$$= \frac{68.25}{2}$$

$$= 34.125$$

$$\phi = \frac{.03}{34.125} =$$

$$= .879\,(10)^{-3} \text{ RAD}$$

$$\theta = (1.407 + .879)(10)^{-3}$$

$$= 2.286\,(10)^{-3} \text{ RAD}$$

THE MAX CHANGE IN ROTATION BETWEEN THE ENDS OF A BELLOWS IS $\theta' = 2\theta$

$$\theta' = 2\,(2.286)(10)^{-3}$$

$$= .0046 \text{ RAD}$$

SINCE ROTATION CAN OCCUR IN BOTH THE VERTICAL & HORIZONTAL PLANES

$$\theta_{MAX} = \left[2(\theta')^2\right]^{\frac{1}{2}}$$

$$= .0065$$

$$= 0.37^\circ \quad \text{SAY } 0.50^\circ$$

LONGITUDINAL COMPRESSION OR EXTENSION

ASSUME THAT COMPONENT INSTALLATION CAN BE WITHIN ± .25 IN IN AXIAL DIRECTION OF OPTICAL BEAM. HENCE, FOR 2 ADJACENT COMPONENTS, THE MAX BELLOWS ELONGATION OR COMPRESSION DURING INSTALLATION IS

$$\delta = \pm .50 \text{ IN}$$

IT IS REASONABLE TO ASSUME THAT THE ± 2" OF MOTION REQUIRED BY THE SPEC (¶ 4.2, VOYS-2-017) IS ENOUGH TO ALLOW FOR δ

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-079 PAGE 1 OF 7
REV.	DEO #	DATE	BY:	CHECK	TITLE: Analysis of BSC Support Leg to Cross Beam Connection	
0	0 131	4/19/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Analyze welded tube steel connection at junction of support leg and cross member to confirm structural integrity of the side of the support leg which is required to resist a high bending moment at the end of the cross member.

METHOD: A local finite element model of the connection was created to analyze the support leg stresses. The IMAGES program was used.

ASSUMPTIONS: See calculations attached.

INPUTS: Forces and moments at end of cross member from Doc. No. V049-1-024

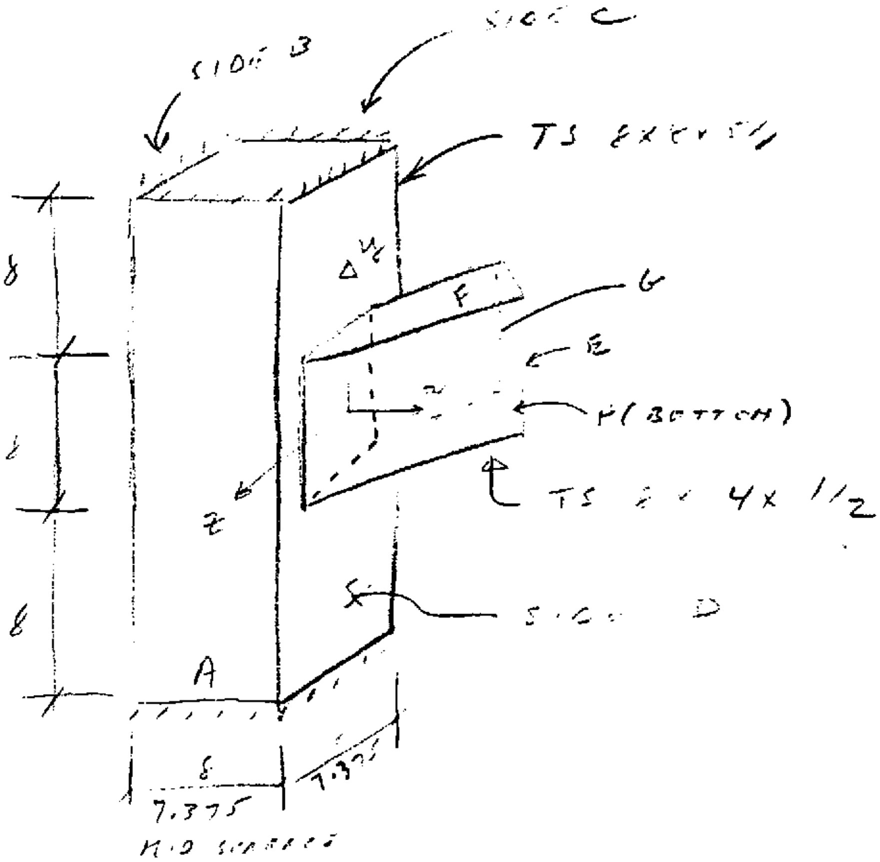
REFERENCES:
1. LIGO project drawings V049-4-001 and V049-4-023
2. Calculation V049-1-024, Design of Support Legs and Base Plates
3. IMAGES-3D, Version 3.0, R. L. Cloud and Associates
4. V049-1-026, LIGO Vacuum Equip. Struct. Design Criteria

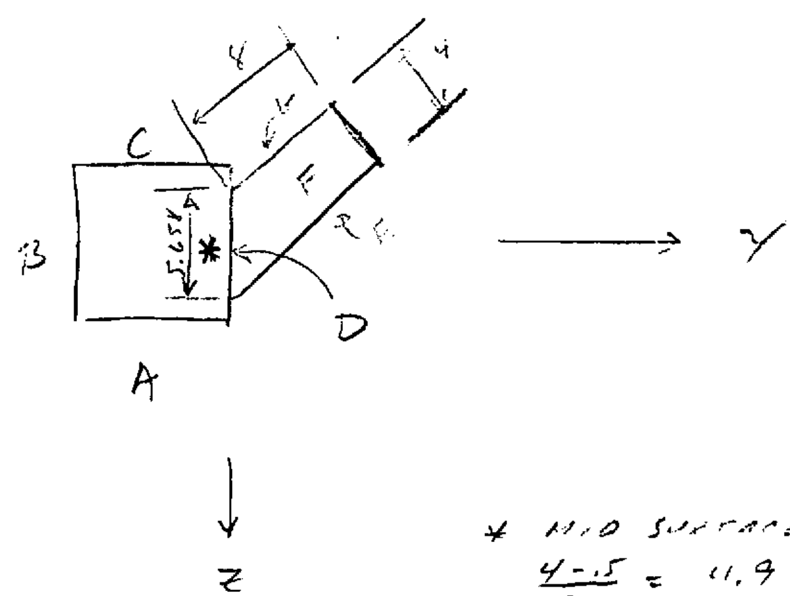
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The cross member was changed from a 7x4 tube steel member to an 8x4 in tube steel member to reduce the bending stress applied to the support leg. Stresses in the 8x8 tube steel leg member are within AISC code limits.

NOTES: Load case 1 includes the 3 forces, load case 2 includes the 3 moments and load case 3 is the combined forces and moments. The IMAGES file is SUPPCONN.*

FE MODEL



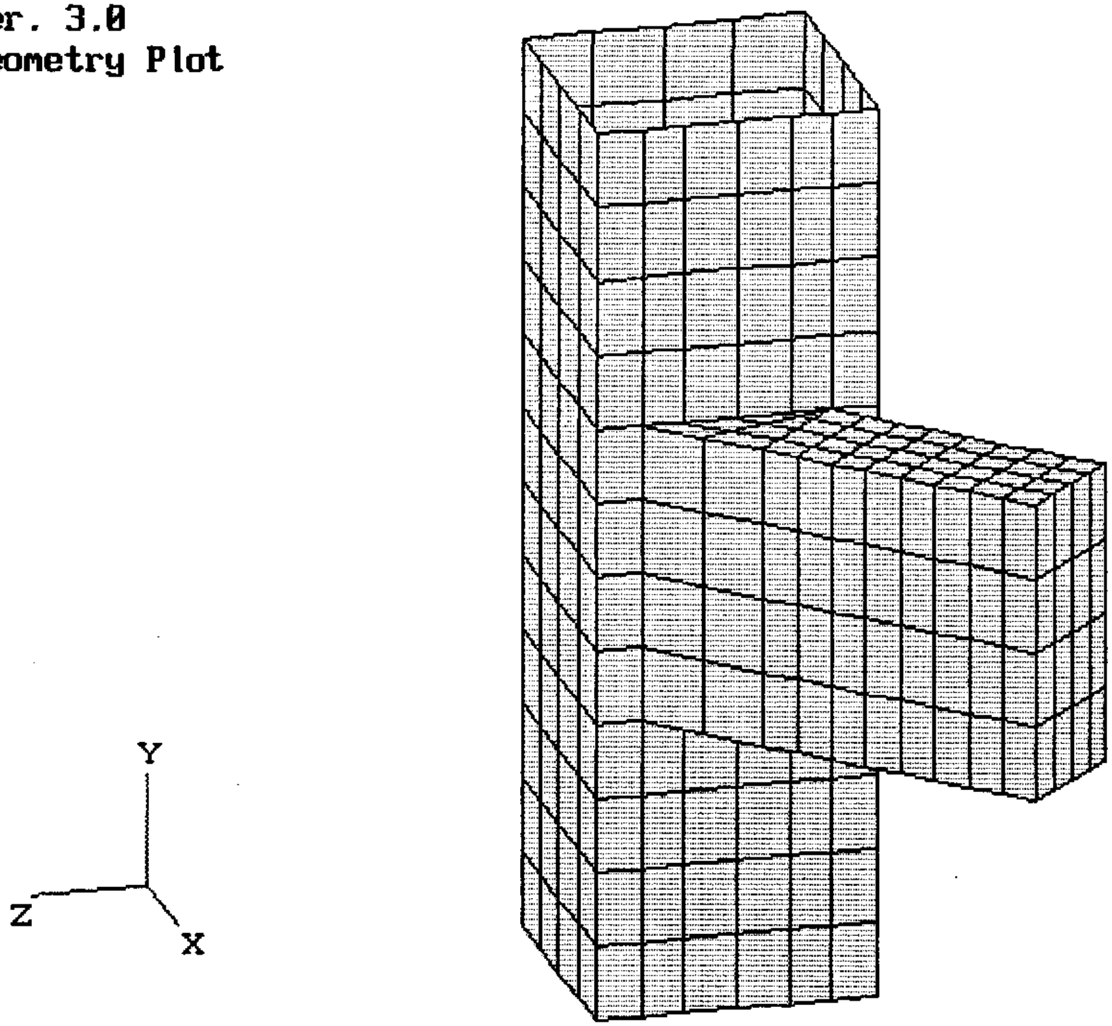


* MID SURFACE LENGTH

$\frac{4-.5}{.707} = 4.950$

Rev 0
Doc No VA49-1-079
P. 2 of 7

IMAGES-3D
Ver. 3.0
Geometry Plot

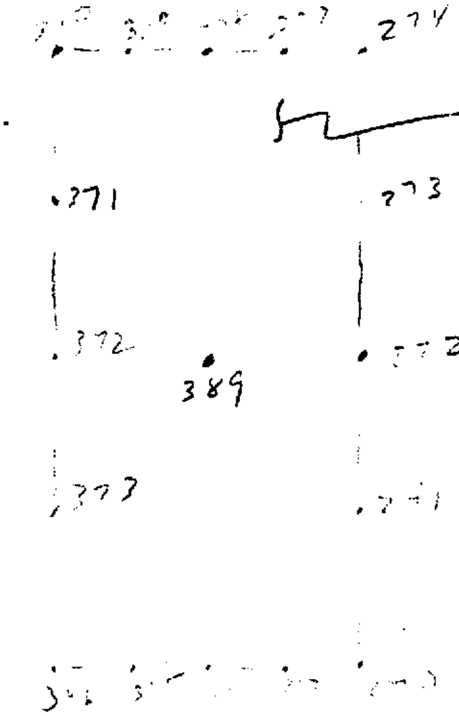


BSC Support Connection
Hidden Line Removal

4/ 1/96
12:42:54

Rev 0
Doc. No.
P. 3 of 7

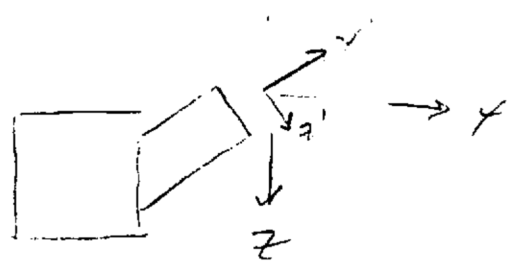
END VIEW AT [illegible]



STIFF PLATE ELEMENTS AT END OF MODEL TRANSFER FORCES & MOMENTS FROM NODE 389 TO PERIMETER NODES. SEE PLOT ON P. 3

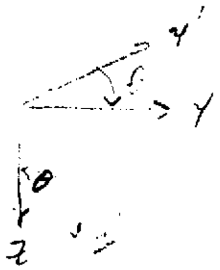
FORCES AT NODE 389

FROM CALC V[illegible]-1-024, THE [illegible] CROSS MEMBER SPECIFIES [illegible] B-9. THE GLOBAL LOADS FROM THE FRAME MODEL ARE AT 45° TO THE GLOBAL AXIS OF THE FE [illegible]. NODE 5 HAS THE LARGER LOADS. LET THE FRAME MODEL GLOBAL AXES BE THE PRIME AXES, x', y', z'.



$F_{x'}$ = [illegible]23[illegible]3
$F_{y'}$ = 9287
$F_{z'}$ = [illegible]
$M_{x'}$ = [illegible] IN LB
$M_{y'}$ = 71[illegible]
$M_{z'}$ = [illegible]1[illegible]00

REV 0
DOC. NO [illegible]-1-079
P. 4 OF 7



$F_Y = F_{Y'} \cos\theta + F_{Z'} \sin\theta$

$F_Z = -F_{Y'} \sin\theta + F_{Z'} \cos\theta$

$F_X = F_{X'}$

$F_Y = 8235(.707) + 0$

$= 5822$

$F_X = 2217$

$F_Z = -8235(.707) + 0$

$= -5822$

$M_Y = [illegible](.707) - [illegible](.707)$
$= [illegible]$

$M_X = M_{X'} = 713$

$M_Z = -4993(.707) + 404300(.707)$
$= 282310$

THESE FORCES ARE APPLIED TO NODE 369 WHICH IS AT THE CENTER OF A STIFF (E = 90 x 10[6] psi) , THICK (3 in) PLATE AT THE END OF THE 8 x 4 STUB IN THE MODEL.

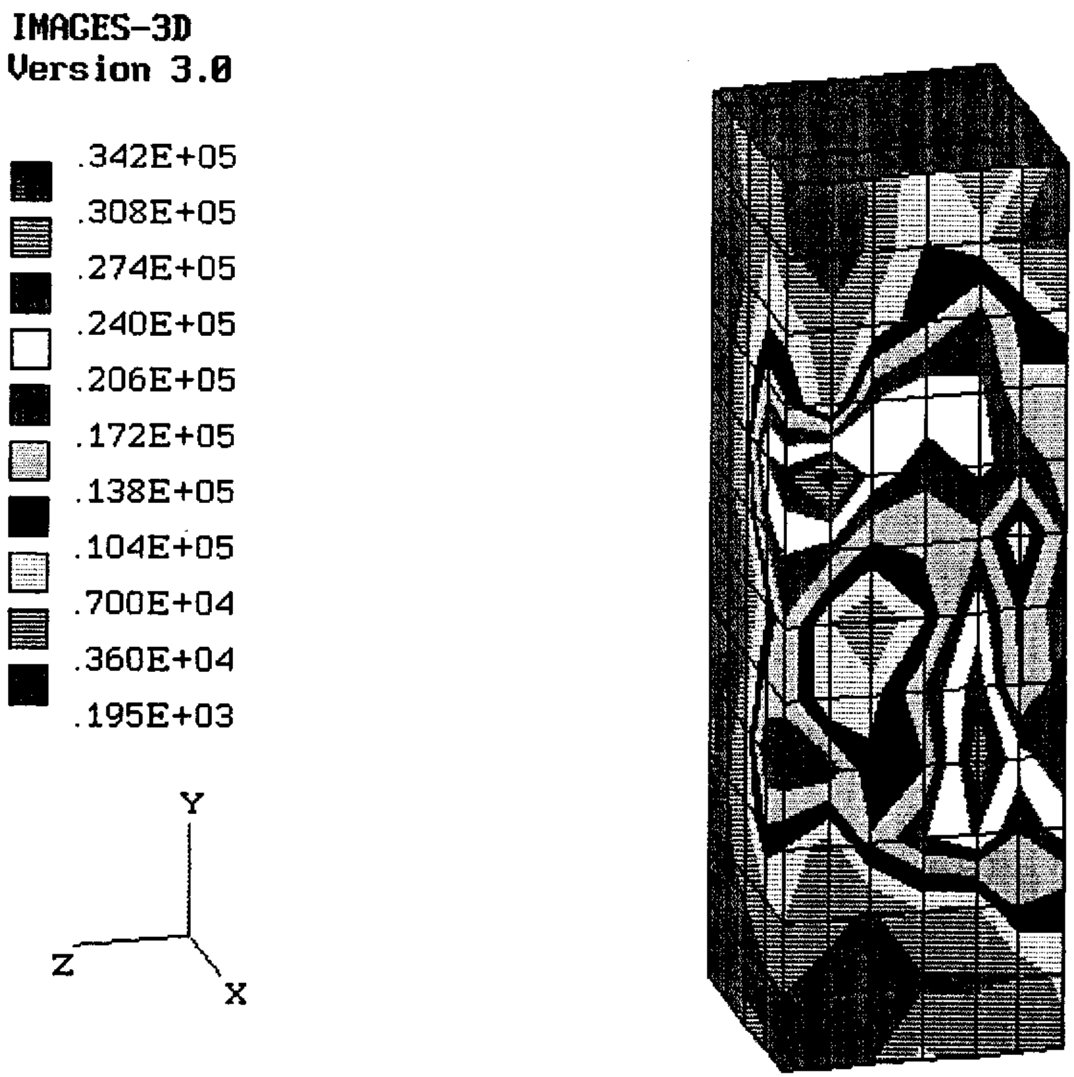
STRESS IN SIDE D OF 8x8x5/8 TS COLUMN

THE LOCAL STRESS INTENSITY IS SHOWN IN THE STRESS CONTOUR PLOT ON THE FOLLOWING SHEET. THE MAX SI IS LOCATED AT THE CORNER OF THE JUNCTION WITH THE 4x4x1/2 TS CROSS MEMBER.

$$SI = 34,200 \text{ psi}$$
$$< .75 F_y^{*}$$
$$= .75 (46)$$
$$= 34.5 \text{ ksi}$$

* F_y = 46 ksi for A500 Gr B

THE SI IS MUCH LESS (10 TO 24 ksi) FOR OTHER LOCATIONS AT THE WELDED CONNECTION WHICH WILL BE A FULL PEN. WELD.



Load Case 3 | Stress Contour Plot | 4/ 1/96

Surf: Top | Stress Intensity | 12:48:49

Rev 0
Doc. No. V0Y5-1-074
p. 7 of 7

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-080 PAGE 1 OF 10
REV.	DEO #	DATE	BY:	CHECK	TITLE: Analysis of Bolted Flange for Initial Out of Flatness	
0	C 191	4/27/93	RDC	AGR		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To determine if Viton O-rings in the bolted flanges will seal if flange flatness is at maximum tolerance considering the stiffening effects of the attached shell.

METHOD: A 3D IMAGES finite element model of a segment of the bolted flange was created. The flange out of flatness was analyzed using gap elements, with the gap equial to the flatness tolerance at the flange mating surface. A nonlinear analysis of this model was performed. Loads included the bolt preload, which is 10 kips, and the maximum tensile load in the shell.

ASSUMPTIONS: The maximum gap occurs at the bolt centerline. The amplitude of the gap is the same as the flatness tolerance for the 60 in flange.

INPUTS: Drawing V049-4-019 for the flatness tolerance
Calculation V049-1-016 for the initial 3D finite element model
Calculations V049-1-018 and -042 for Viton properties and shell forces, respectively.

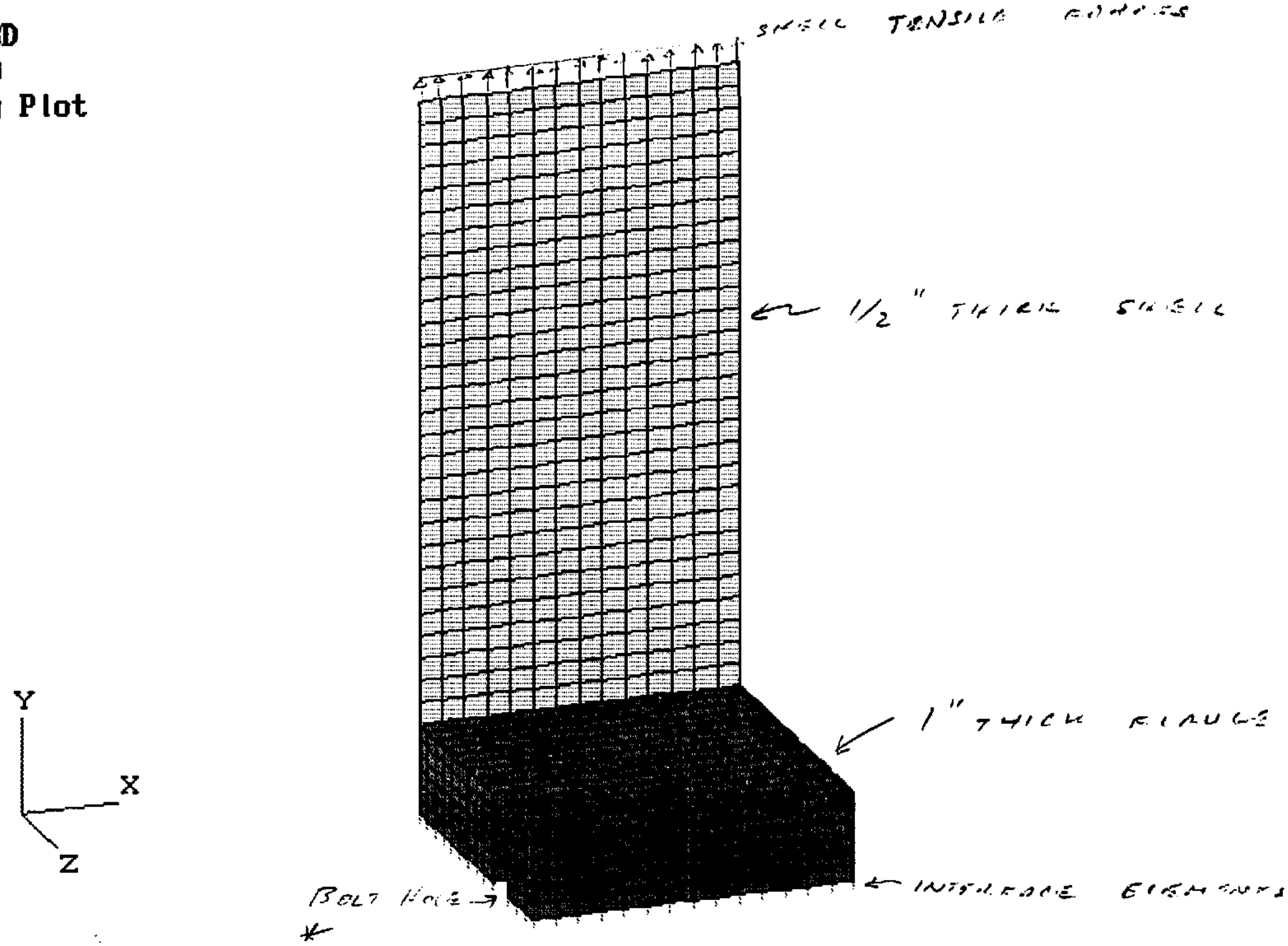
REFERENCES: See Inputs

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Even though the bolt clamping force must resist the shell stiffness, the bolt will bring the flanges together and the seal will be maintained. When the maximum gap occurs between bolts, the clamping force connot close the gap but the seal is maintained even with the maximum tolerance.

NOTES: The computer file is FLANGED.*

IMAGES-3D
Ver. 3.0
Geometry Plot



Bolted Flange - 48.25 in, 24 bolts 4/3/96
Hidden Line Removal 15:6:5

* BOLT FORCE NOT SHOWN

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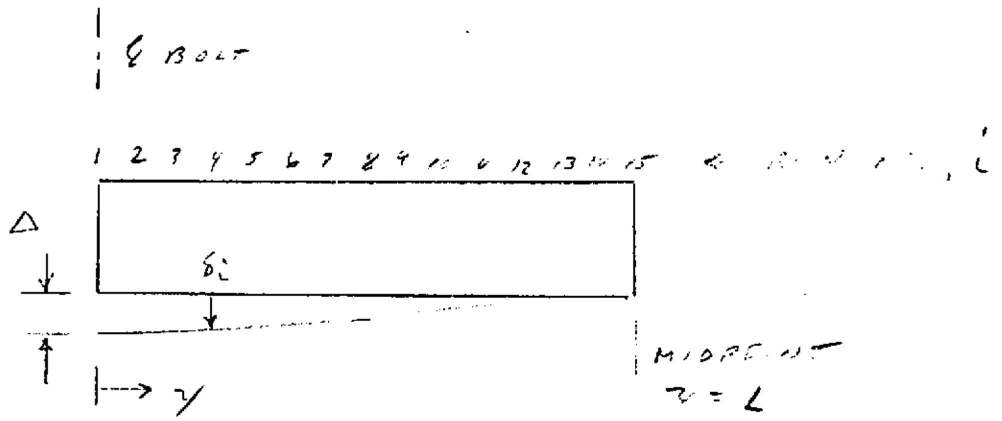
P. 2 of 10

THERE ARE 15 ROWS OF NONLINEAR FOUNDATION ELEMENTS. THE NONLINEAR SPRING CONSTANTS CAN BE VARIED FROM ROW TO ROW TO SIMULATE A GAP THAT CAN RESULT FROM THE FLATNESS TOLERANCE

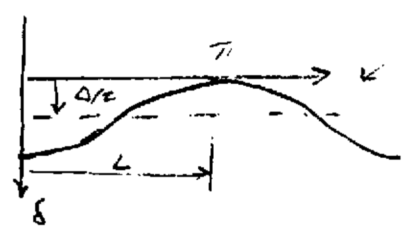
IT IS ASSUMED THAT FLANGE FACES ARE IN CONTACT AT THE MIDPOINT BETWEEN BOLTS AND THAT THE GAP IS MAXIMUM AT THE BOLTS. THEN BOLTUP CAN BE USED TO CLOSE THE GAP.



$\Delta = .010$ IN (FLATNESS TOLERANCE – DWG V0V9-4-019

ASSUME THAT GAP VARIES AS A SINE FUNCTION

$$\delta = \frac{\Delta}{2} + \frac{\Delta}{2} \cos \frac{x}{L}\pi$$



$$\delta_i = \frac{\Delta}{2} + \frac{\Delta}{2} \cos \frac{(i-1)\frac{L}{14}}{L}\pi$$

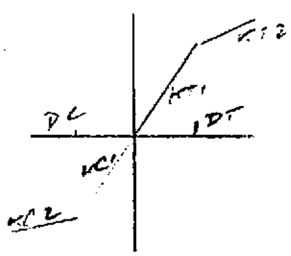
$$= \frac{\Delta}{2}\left(1 + \cos\left(\frac{i-1}{14}\right)\pi\right)$$

$$= .005\left(1 + \cos\left(\frac{i-1}{14}\right)\pi\right)$$

Row i	i-1	Theta (i-1)*Pi/15	A cos Theta	B A+1	delta .005*B
1	0	0	1	2	0.0100
2	1	0.2094393	0.978148	1.978148	0.0099
3	2	0.4188787	0.913546	1.913546	0.0096
4	3	0.628318	0.809017	1.809017	0.0090
5	4	0.8377573	0.669131	1.669131	0.0083
6	5	1.0471967	0.500001	1.500001	0.0075
7	6	1.256636	0.309018	1.309018	0.0065
8	7	1.4660753	0.10453	1.10453	0.0055
9	8	1.6755147	-0.10453	0.895473	0.0045
10	9	1.884954	-0.30902	0.690985	0.0035
11	10	2.0943933	-0.5	0.500002	0.0025
12	11	2.3038327	-0.66913	0.330871	0.0017
13	12	2.513272	-0.80902	0.190984	0.0010
14	13	2.7227113	-0.91354	0.086455	0.0004
15	14	2.9321507	-0.97815	0.021853	0.0001

42-142 100 SHEETS
42-144 200 SHEETS

IMAGES NONLINEAR SPRING CONSTANTS



KT1 = 0
KC1 = 0 ([illegible] ROW 15, KC1 = 1x10^8)
KT2 = 0
KC2 = 1x10^8
DT = 1
DC = δ FROM ABOVE FOR EA
ROW OF NON LIN SPRINGS

FOR ROWS 1 TO 14 SPRING CONSTANT
NUMBERS ARE 2 TO 15, RESPECTIVELY
FOR ROW 15, THE SPRING CONSTANT
NUMBER IS 1, FOR THAT ROW

KT1 = 0
KC1 = 1E+8
KT2 = 0
KC2 = 1E+8
DT = 1
DC = 1

REV 0
DOC. NO. V0??-1-02?
P. 4 OF 10

ADDED DUMMY/ELEMENT TO REPRESENT SHELL

USE MAX SHELL THICKNESS

$$t = .5 \text{ IN}$$

SHELL WILL BE IN X-Y PLANE ($Z = 0$)
ADD ENOUGH PLATE ELEMENTS TO GIVE A LONG SHELL LENGTH. FOR THE 30 IN DIA FLANGE,

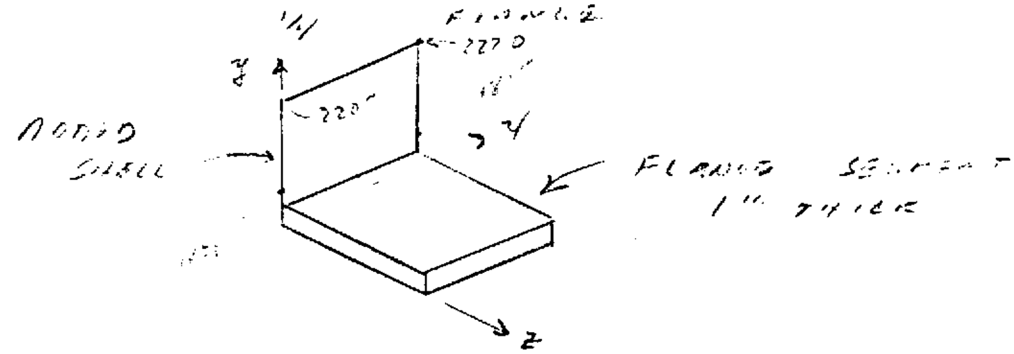
$$L = 2.5\sqrt{Rt}$$

$$= 2.5(15(.5))^{\frac{1}{2}}$$

$$= 6.8 \text{ IN} \quad \text{SAY } 7 \text{ IN}$$

FOR 1/4 IN WIDE ELEMENTS ADD

$$\frac{7}{1/4} = 28 \text{ ROWS TO THE OD FLANGE}$$



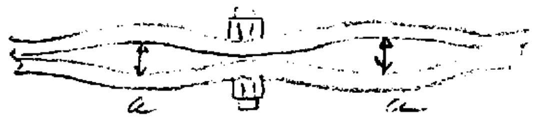
SEE CALC 018, P. 5 FOR SPRING STIFFNESS OF VITON O-RING

$$K_s = 709 \text{ LB/IN}$$

REV 0
DOC. NO: V047-1-080
P. 5 OF 10

Question!

What happens when the maximum out of flatness occurs at the midpoint between two flanges? Bolt tightening will not close the gap.



The opening increases due to tensile force in the shell. The max deflection at the inner El O-ring is

Δ = .00372   Calc V049-1-042 P. 25

Total defl for 2 flanges

$a = 2(.010 + .00372)$

$= .0274$

$< .058$

Ratio $\frac{.058}{.0274} = 2.1$

Rev 0
Doc. No. V049-1-010
P. 10 of 10

22-142 100 SHEETS
22-144 200 SHEETS

INNER VITON O-RING IS REPRESENTED BY THE LINEAR SPRINGS

FIRST: NODE 1576 TO NODE 1, INCR = 15

DOF = 1
SPRING CONST = 1

LAST: NODE 1786 TO NODE 211

OUTER O-RING IS REPRESENTED BY SIMILAR ELEMENTS SEE CALC 016, P. 18

MAXIMUM AXIAL FORCE IN STEEL (FY) OCCURS IN 30 ?? TUBE (SEE CALC 042)

F_{Y1} = 93.1 @ NODES 2207 TO 2219 (INCR = 1)

F_{Y1} = 116.6 @ NODE 2206 & 2220

REF PP 12 & 19 CALC V049-1-042

BOLT FORCE

EACH BOLT IS PRELOADED TO 10K, FOR THE HALF MODEL, THE NODAL FORCES FOR PRELOAD ARE GIVEN IN CALC 042, P. 20

REV 0
DOC. NO. V049-1-043

42-381 50 SHEETS 42-142 100 SHEETS 42-141 200 SHEETS

50 SHEETS
100 SHEETS
200 SHEETS

THE DISPLACEMENT CONTOUR PLOT ON THE FOLLOWING SHEET SHOWS THAT THE BOLT CLAMPING FORCE IS BRINGING THE TWO FLANGES TOGETHER WHEN THEY HAVE A HIGH SPOT THAT IS MIDWAY BETWEEN TWO BOLTS.

HOWEVER, THE MAXIMUM TENSILE FORCE IN THE SHELL TENDS TO OPEN THE GAP SLIGHTLY. THE MAXIMUM GAP OPENING IS AT THE INNER O-RING,

$$\Delta_y = .00136 \quad \text{REF p. 8}$$

THIS IS AT THE MID POINT BETWEEN FLANGES AND THE OUT OF FLATNESS DOES NOT ADD TO THE GAP. FOR 2 FLANGES

$$\Delta_y = 2(.00136) = .00272 \text{ IN}$$

<< .058 IN WHICH IS THE MIN O-RING COMPRESSION

AT THE BOLT ℄, THE MAXIMUM OPENING IS .000953 WHICH ADDS TO THE INITIAL GAP CAUSED BY OUT OF FLATNESS.

$$\Delta_y = .000953 + .010 = .0110 \text{ IN}$$

REF: p. 8

FOR 2 FLANGES

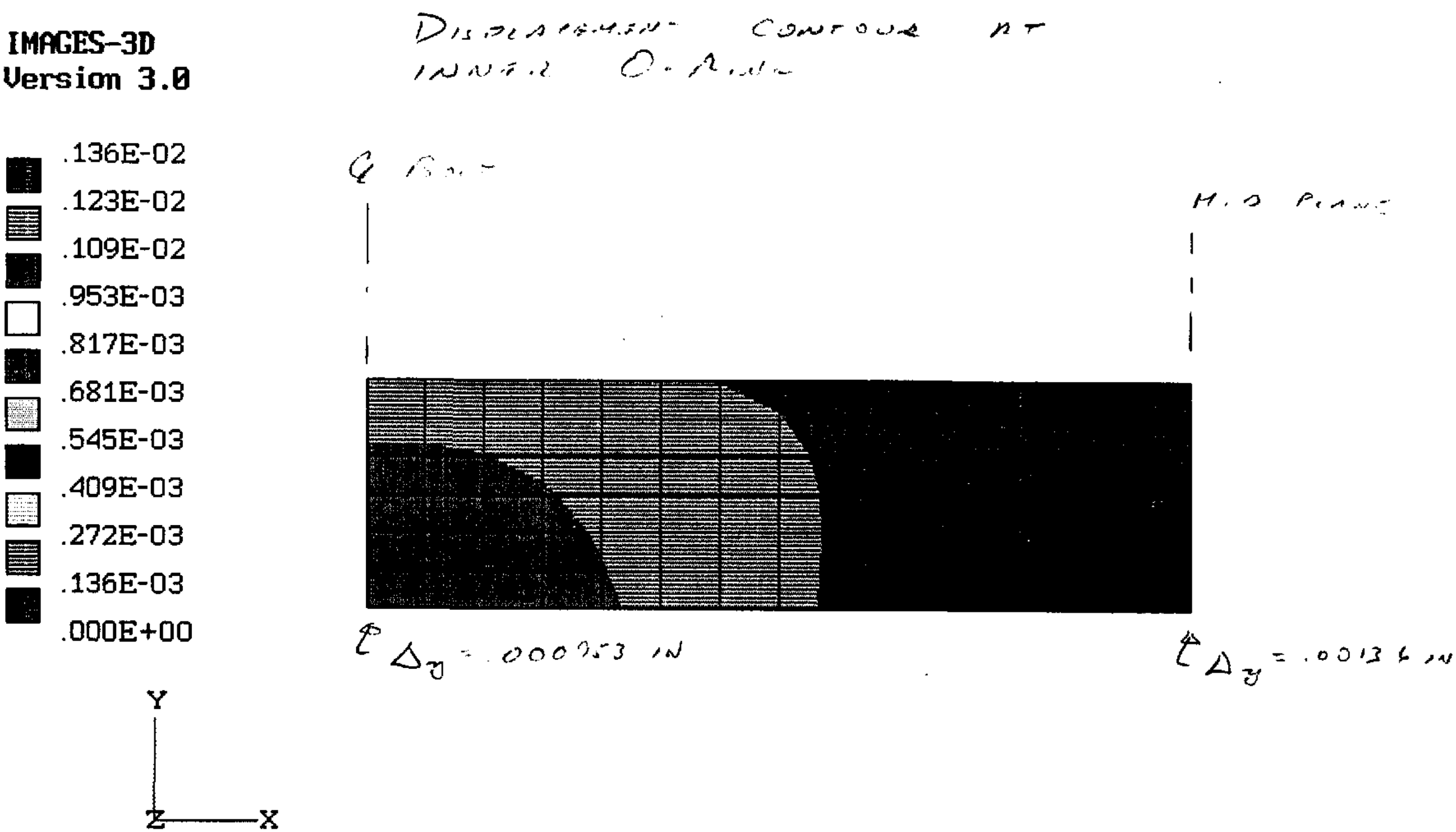
$$\Delta_y = 2(.0110) = .022$$

< .058 MIN O-RING COMPRESSION

OK

$$\text{RATIO} = \frac{.058}{.022} = 2.6$$

IMAGES-3D
Version 3.0

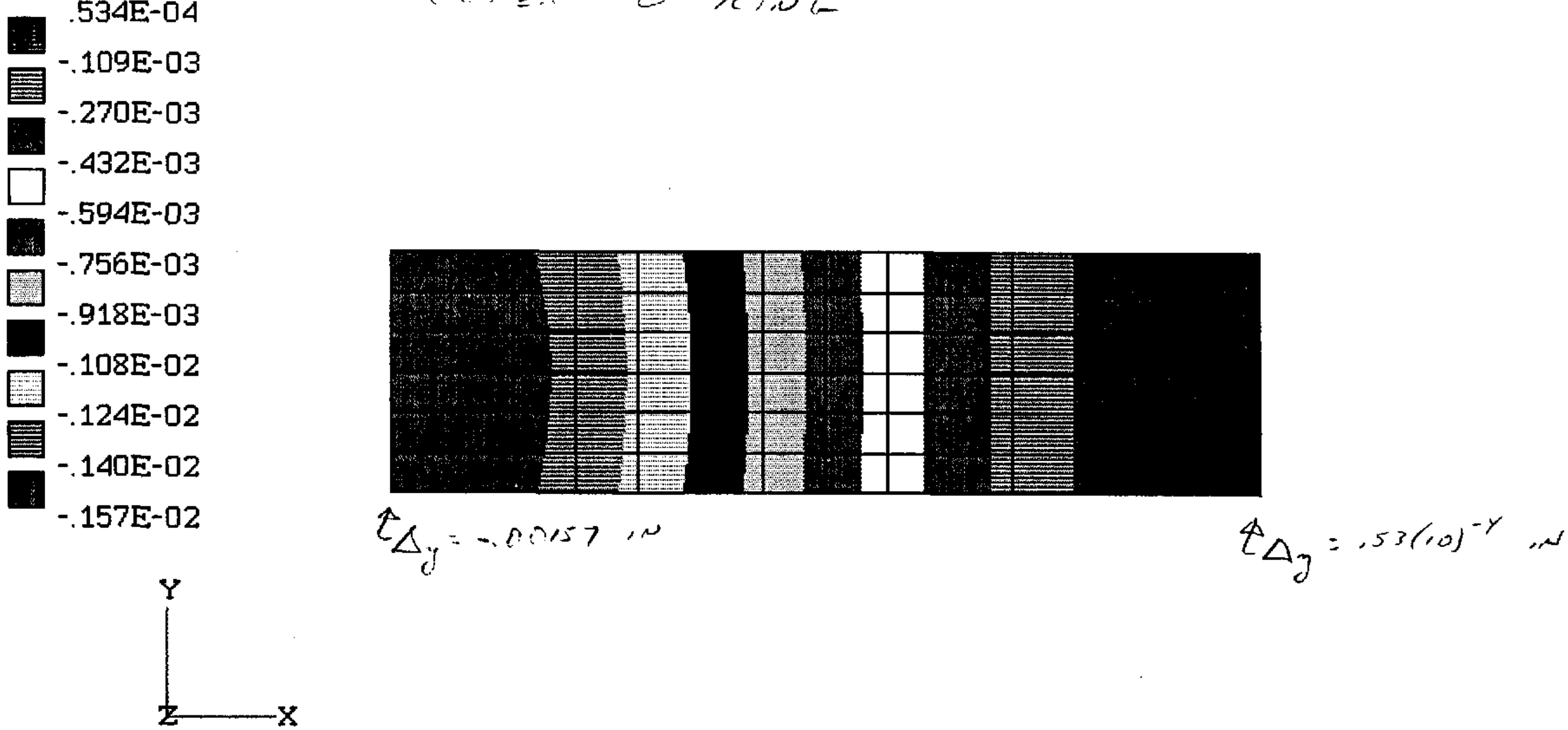


Rev 0

Load Case	Displacement Contour Plot	4/ 3/96
1	DY	14:22:37

IMAGES-3D
Version 3.0

Displacement contours at outer O-ring



Rev 0
Doc. No. V0r9-1-0?0
? of 10

Load Case	Displacement Contour Plot	4/ 3/96
1	DY	14:25:53

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-084
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 37
0	0029	4/12/96	AGR	RJC	TITLE: EXPANSION JOINT TIE ROD "LUG DESIGN"	
					By: ART ROUSSOPOULOS	DEPT.: 749
PROJECT: LIGO					PROJECT NO: V59049	

PURPOSE: PROVIDE A SINGLE LUG DESIGN FOR ALL EXPANSION JOINT/TUBE SIZES UP TO AND INCLUDING 72 1/4" I.D.

METHOD: · COMPRESS 5.53 COMPUTER PRESSURE VESSEL SOFTWARE

ASSUMPTIONS: SEE CALCS

INPUTS: "DESIGN LOADS" FROM DOC. NO. V049-1-048
"STRUCTURAL DESIGN CRITERIA" DOC. NO. V049-1-066

REFERENCES: DOC. NO. V049-1-048
COMPRESS 5.53
Doc. No. V049-1-066, LIGO VACUUM EQUIP., STRUCTURAL DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: A SINGLE LUG DESIGN, AS SHOWN IN DESIGN SKETCH, UTILIZING A MINIMUM OF 4 LUGS PER EXPANSION JOINT IS ADEQUATE FOR ALL SIZES UP TO AND INCLUDING 72 1/4" I.D.

NOTES: THIS LUG DESIGN REQUIRES A REINFORCING PLATE AS SHOWN IN THE DESIGN SKETCH

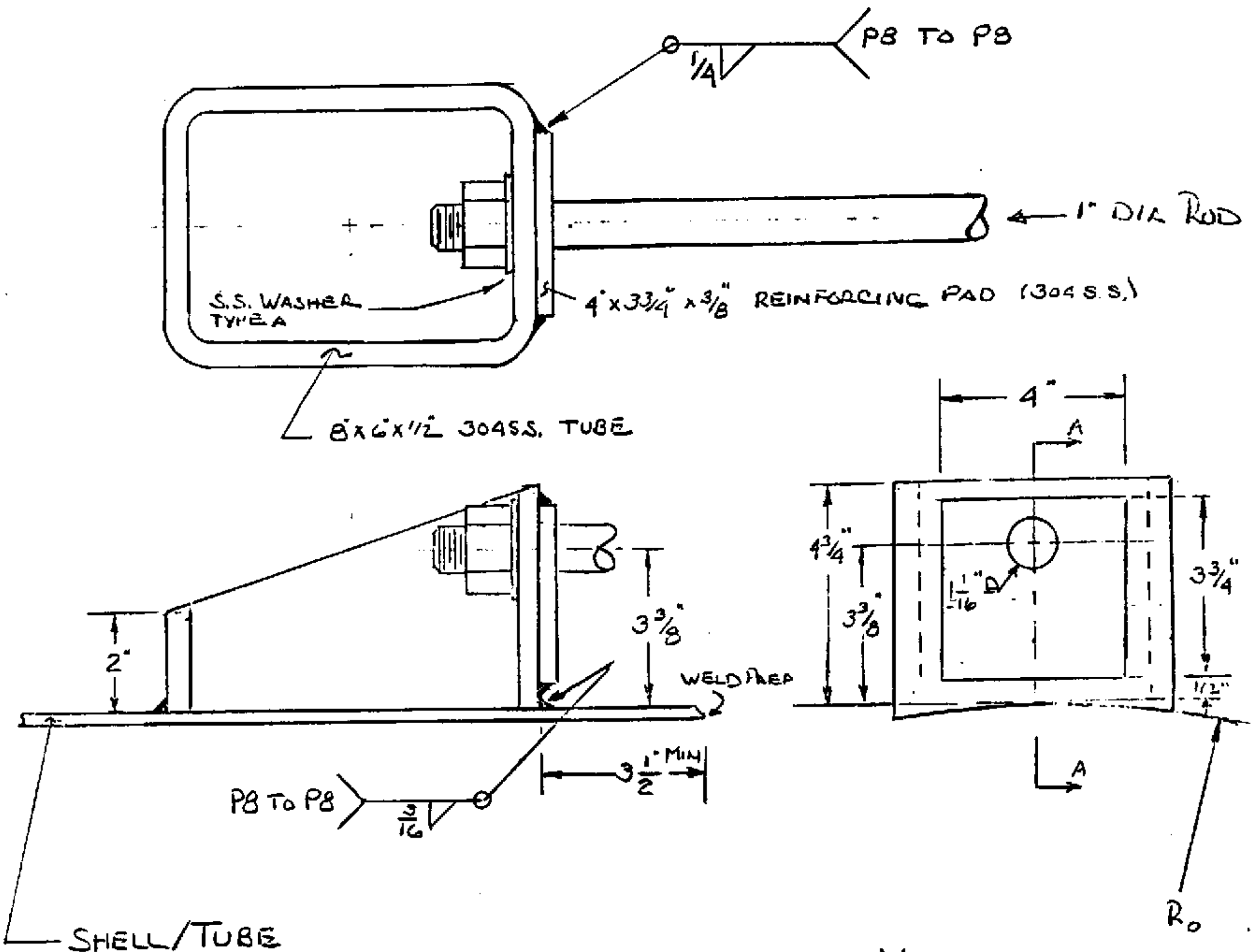
TABLE OF CONTENTS:

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

1.0 – DESIGN SKETCH   SHEET 1 OF 2

SK-V049-1-084 REV0

- LUG TO SHELL ATTACHMENT FOR EXPANSION JOINT TIE ROD CONNECTIONS UP TO AND INCLUDING 72 1/4" ID TUBE SIZE
FOR SPOOL BE-3 SEE SHEET 2 FOR MODIFIED DESIGN



WHERE:
Ro = OUTSIDE RADIUS OF TUBE
TYPICAL FRONT + REAR

NOTE:
THIS DESIGN IS BASED ON USING FOUR (4) LUGS SPACED AT 90°

REV 0
Doc. No. V049-1-084
P. 3 OF 37

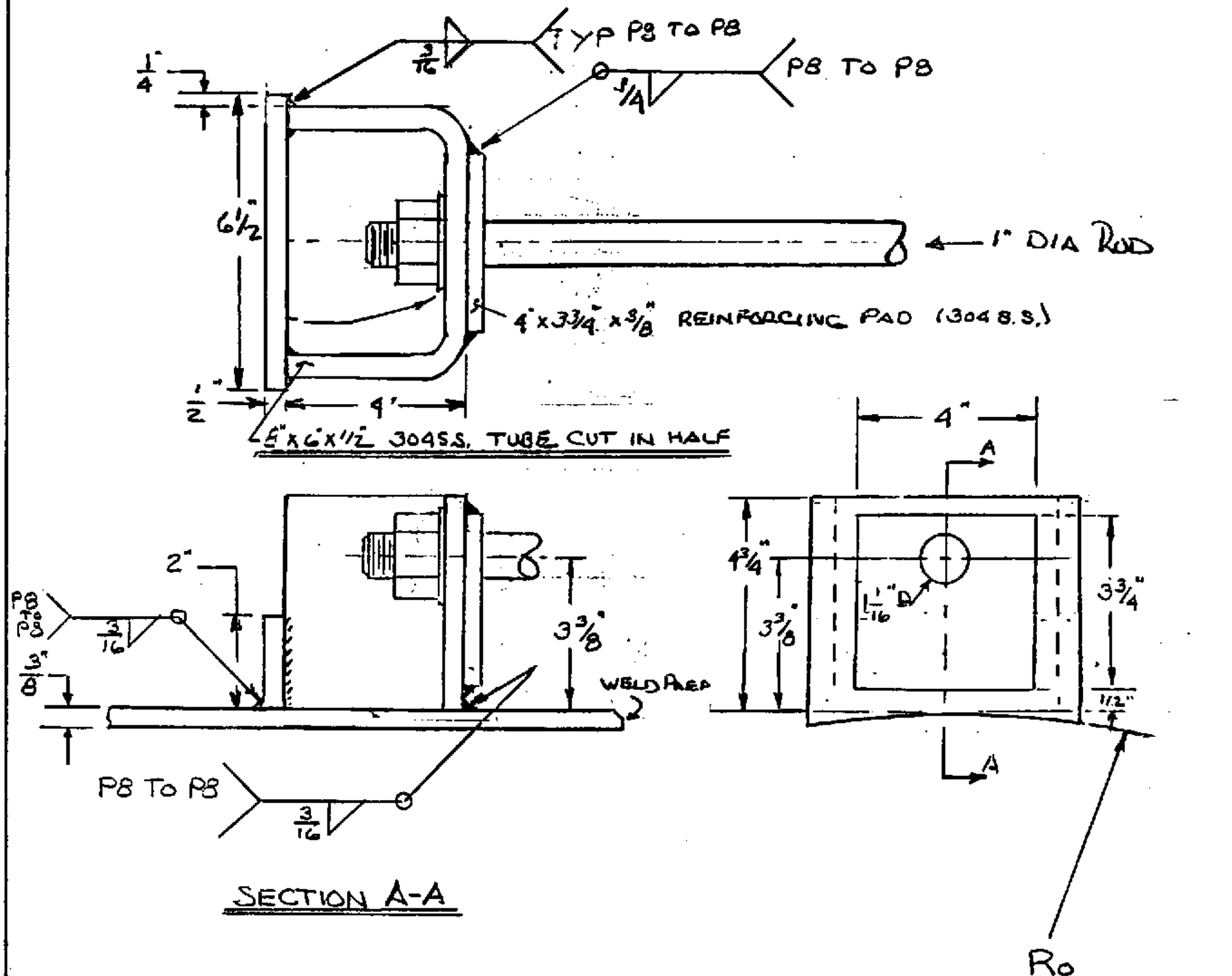
AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

DESIGN SKETCH

SHEET 2 OF 2

SK-V049-1-084 REVO

MODIFIED DESIGN FOR SPOOL BE-3 WITH 3/8" THK WALL



SECTION A-A

WHERE:
Ro = OUTSIDE RADIUS OF TUBE
TYPICAL FRONT + REAR

NOTE: THIS DESIGN IS BASED ON USING FOUR (4) LUGS SPACED AT 90°

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

2.0 – COMPRESS INPUT FOR SPOOL A-13 (TYPICAL)

- SHELL/TUBE
  - MATERIAL: SA 304L HIGH
  - EXTERNAL/INTERNAL PRESSURE = 0 PSI
  - TEMP =
  - ID = 60.5" (SPOOL A-13)
  - LENGTH = 23" (SPOOL A-13)
  - THK'S = 3/16"

- LUG
  - MATERIAL: SA 240 304
  - LUG ALLOWABLE STRESS = 16,200 PSI
  - WP = 2" - HEIGHT OF LUG-BACKSIDE
  - WB = 4.75" - HEIGHT OF LUG - TIE ROD SIDE
  - t = .5" - THK'S OF LUG - BACKSIDE
  - tB = .75" - THK'S OF LUG - TIE ROD SIDE (INCLUDES 1/4" THK PAD)
  - L = 6" - LUG WIDTH / CIRC. LENGTH
  - h = 8 - 2 x 1/2" THK = 7" - GUSSET HEIGHT / LUG SIDES
  - tg = .5" - GUSSET THKS / SIDE THK
  - NUMBER OF LUGS – 4
  - ANGULAR POSITION 1ST LUG = 0° (NOTE FOR DRAFT VESSEL LAYOUT INFO ONLY)
  - FILLET WELD SIZE - 3/16" - LUG TO VESSEL WELD
  - FORCE BEARING WIDTH = 2" - DIAMETER OF 1" ROD WASHER

- DESIGN LOAD INPUT FROM DOC. NO. V049-1-048 FOR SPOOL BE-3; ID = 60.5"

  LOAD PER ROD = 6,400#

  DISTANCE FROM SHELL TO ROD = 3 3/8"

  - d = 3.375" – DISTANCE TO LOAD
  - VL = 6400# - LONGITUDINAL SHEAR LOAD
  - ML = 1800 FT-# - LONGITUDINAL MOMENT LOAD

    WHERE: ML = 6400# X 3.38"/12"/FT = 1800 FT-#

  - DESIGN FACTOR = 3 ; STRESS CONCENTRATION = 0
  - NO PAD
  - MIN DISTANCE OF LUG TO WELD $= \sqrt{Dt} = \sqrt{(60.5)(.1875)} = 3.37"$

∴ TO DATUM: 4 + 3.37 = 7.37" MIN → 7 1/2"

REV 0
DOC. NO. V049-1-01

- DESIGN LOADS FOR OTHER TUBE SIZES

  - SHALL BE BASED ON A DESIGN AXIAL SPRING RATE OF 7500 #/IN FOR 2" TRAVEL REF: DOC. NO. V049-1-048 (EX. JT. FOR SPOOL BE-3)

  ∴ CIRCUMFERENTIAL LOADING IS:

  $$-\frac{7500}{\pi D}\frac{\#/IN}{IN} = \frac{7500}{\pi(60.5)} = \frac{39.5\ \#/IN}{IN}$$

  - FOR 2" TRAVEL:

    LOAD = 39.5 x 2 = 79 #/IN OF CIRCUMFERENCE

  - SPECIFY 100 #/IN OF CIRCUMFERENCE FOR DESIGN

  ∴ THE DESIGN ATTACHMENT INPUT LOADS, BASED ON LOADING ONLY 3 RODS, FOR THE FOLLOWING SIZE ARE:

- 72.25" I.D.:
  - $V_L = \pi(72.25)(100)/3 = 7,566\ \#$
  - $M_L = (7566)(3.375/12) = 2128$ FT-#
- 48.25" ID:
  - $V_L = \pi(48.25)(100)/3 = 5,053\ \#$
  - $M_L = (5053)(3.375/12) = 1,421$ FT-#
- 44.625" ID:
  - $V_L = \pi(44.625)(100)/3 = 4,673\ \#$
  - $M_L = (4673)(3.375/12) = 1,314$ FT-#
- 30.5" ID:
  - $V_L = \pi(30.5)(100)/3 = 3,194\ \#$
  - $M_L = (3194)(3.375/12) = 898\ \#$

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

3.0 – LUG TO SHELL STRESS SUMMARY

- 8" X 6" X 1/2" 304 S.S. TUBE ; SALLOWABLE AT 100°F = 18,900 PSI
- SHELL – SA 304L HIGH ; SALLOWABLE AT 100°F = 16,700 PSI
- PRIMARY MEMBRANE ALLOWABLE STRESS:

  1.5S = 1.5(16,700) = 25,050 PSI

- PRIMARY MEMBRANE PLUS SECONDARY ALLOWABLE STRESS.

  3S = 3(16,700) = 50,100 PSI

	SPOOL PIECE	ID	THK'S	LOADS VL [#]	ML [FT-#]	PRIMARY MEMBRANE	PRIMARY + SECONDARY
	B-9	72.25"	1/4"	7566	2128	-9,554	-29,944
	BE-3	60.5	3/8"	6400	1800	-6,062	-24,261
*	A-13	60.5	3/16"	6400	1800	-12,905	-37,235
*	A-2	48.25	3/16"	5053	1421	-9583	-26,071
*	A-1	44.625	3/16"	4673	1314	-8672	-22619
	B-2	30.5	1/4"	3194	898	-4966	-12257

* STRESS SUMMARY FOR 1/4 THK IN LIEU OF 3/16"

A-13	60.5	1/4"	6400	1800	-7903	-23871
A-2	48.25	1/4"	5053	1421	-6030	-16274
A-1	44.625	1/4"	4673	1314	-5482	-14739

NOTE: THE FINAL DESIGN FOR SPOOL PIECES A-1, A-2 + A-13 HAS INCORPORATED A 1/4" WALL THICKNESS

AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

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4.0 - COMPRESS 5.53 OUTPUT

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

* PWHT is performed

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

Estimated weight: new = 1040.3 corr = 1040.3 lb
capacity: new = 1118.134 corr = 1118.134 US ga

ID = 72.25 length Lc= 63 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 100 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

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.875 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 7 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness, Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(7566*3.375*6)/(18800*2^2*7)
   = 0.25 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(7/(0.289*0.5))^2 )
   = 15923.95 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 7566*(3*3.375 - 4.75)/(15923.95*4.75^2*SIN(68.552)^2)
   = 0.1307 in
```

Lug base plate required thickness

From Escoe table 4-8

```
fc = VL/(Fb*L) = 630.5 psi

Mx = Cx*fc*Gs^2
   = 0.0923*630.5*5^2 = 1454.879

My = Cy*fc*wb^2
   = -.126*630.5*4.75^2 =-1792.433

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*1792.433 / 18800)
   = 0.7563 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

Longitudinal moment	ML =	2128 lbf-ft
Longitudinal shear	VL =	7566 lbf
Internal pressure	P =	0 psi

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

Mean radius Rm = 36.25 in
Rm/t = 145

C1 = 3, C2 = 4.1875 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 =-29944 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-9554 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	12.214	0.116								
4C*	20.246	0.105								
1C	0.0830	0.093								
2C-1	0.0496	0.093								
3A*	5.6036	0.092								
1A	0.0799	0.096								
3B*	14.832	0.103	-9554	-9554	9554	9554				
1B-1	0.0289	0.096	-20390	20390	20390	-20390				
pressure stress*										
Total circ stress			-29944	10836	29944	-10836				
Primary membrane circ stress*			-9554	-9554	9554	9554				
3C*	13.347	0.105								
4C*	19.497	0.116								
1C-1	0.0733	0.107								
2C	0.0440	0.107								
4A*	10.110	0.092								
2A	0.0379	0.108								
4B*	5.6717	0.103	-4530	-4530	4530	4530				
2B-1	0.0357	0.107	-22615	22615	22615	-22615				
pressure stress*										
Total long stress			-27145	18085	27145	-18085				
Primary membrane long stress*			-4530	-4530	4530	4530				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-1807	-1807	1807	1[illegible]
Total Shear stress							-1807	-1807	1807	1[illegible]
Combined stress			-29944	18085	29944	-18085	3614	3614	3614	3[illegible]

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SPOOL BE-3

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

* PWHT is performed

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

Estimated weight:	new = 478.4	corr = 478.4	lb
capacity:	new = 286.231	corr = 286.231	US ga

ID = 60.5 length Lc= 23 t = 0.375 in (new)

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

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.375/(30.25 + 0.6*0.375) - 0
= 174.6719 psi

MAWP: (Corroded & at 100 deg F) UG-27(c)(1)

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.375/(30.25 + 0.6*0.375) - 0
= 174.6719 psi

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.75 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 3.25 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness, Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(6400*3.375*6)/(18800*2^2*3.25)
   = 0.3977 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(3.25/(0.289*0.5))^2 )
   = 17507.97 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 6400*(3*3.375 - 4.75)/(17507.97*4.75^2*SIN(49.764)^2)
   = 0.1494 in
```

Lug base plate required thickness

From Escoe table 4-8

```
fc = VL/(Fb*L) = 533.3333 psi

Mx = Cx*fc*Gs^2
   = 0.0923*533.3333*5^2 = 1230.667

My = Cy*fc*wb^2
   = -.126*533.3333*4.75^2 =-1516.2

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*1516.2 / 18800)
   = 0.6956 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

Longitudinal moment ML = 1800 lbf-ft
Longitudinal shear VL = 6400 lbf
Internal pressure P = 0 psi

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

Mean radius Rm = 30.4375 in
Rm/t = 81.16666

C1 = 3, C2 = 2.25 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 =-24621 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-6062 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	11.520	0.085								
4C*	13.244	0.092								
1C	0.1040	0.093								
2C-1	0.0696	0.093								
3A*	2.8538	0.09								
1A	0.0879	0.099								
3B*	8.6001	0.081	-6062	-6062	6062	6062				
1B-1	0.0421	0.083	-15275	15275	15275	-15275				
pressure stress*										
Total circ stress			-21337	9213	21337	-9213				
Primary membrane circ stress*			-6062	-6062	6062	6062				
3C*	10.947	0.092								
4C*	13.484	0.085								
1C-1	0.1104	0.087								
2C	0.0740	0.087								
4A*	4.4600	0.09								
2A	0.0475	0.095								
4B*	2.6643	0.081	-1663	-1663	1663	1663				
2B-1	0.0642	0.085	-22958	22958	22958	-22958				
pressure stress*										
Total long stress			-24621	21295	24621	-21295				
Primary membrane long stress*			-1663	-1663	1663	1663				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-1896	-1896	1896	18
Total Shear stress							-1896	-1896	1896	18
Combined stress			-24621	21295	24621	-21295	3792	3792	3792	3

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SPOOL A-13

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

* PWHT is 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 100 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

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.75 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 7 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness, Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(6400*3.375*6)/(18800*2^2*7)
   = 0.25 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(7/(0.289*0.5))^2 )
   = 15923.95 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 6400*(3*3.375 - 4.75)/(15923.95*4.75^2*SIN(68.552)^2)
   = 0.1105 in
```

Lug base plate required thickness

From Escoe table 4-8

```
fc = VL/(Fb*L) = 533.3333 psi

Mx = Cx*fc*Gs^2
   = 0.0923*533.3333*5^2 = 1230.667

My = Cy*fc*wb^2
   = -.126*533.3333*4.75^2 =-1516.2

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*1516.2 / 18800)
   = 0.6956 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

Longitudinal moment	ML =	1800 lbf-ft
Longitudinal shear	VL =	6400 lbf
Internal pressure	P =	0 psi

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

Mean radius Rm = 30.34375 in
Rm/t = 161.8333

C1 = 3, C2 = 4.125 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 =-37235 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-12905 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	10.354	0.136								
4C*	20.589	0.124								
1C	0.0707	0.111								
2C-1	0.0366	0.111								
3A*	6.3028	0.11								
1A	0.0729	0.114								
3B*	14.701	0.122	-12905	-12905	12905	12905				
1B-1	0.0226	0.113	-24330	24330	24330	-24330				
pressure stress*										
Total circ stress			-37235	11425	37235	-11425				
Primary membrane circ stress*			-12905	-12905	12905	12905				
3C*	11.749	0.124								
4C*	19.629	0.136								
1C-1	0.0613	0.126								
2C	0.0391	0.126								
4A*	12.653	0.11								
2A	0.0328	0.127								
4B*	5.9259	0.122	-6520	-6520	6520	6520				
2B-1	0.0273	0.125	-26506	26506	26506	-26506				
pressure stress*										
Total long stress			-33026	19986	33026	-19986				
Primary membrane long stress*			-6520	-6520	6520	6520				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-2069	-2069	2069	2[illegible]
Total Shear stress							-2069	-2069	2069	2[illegible]
Combined stress			-37235	19986	37235	-19986	4138	4138	4138	4[illegible]

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SPOOL A-2

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

* PWHT is 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 100 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

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.625 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 7 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness. Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(5053*3.375*6)/(18800*2^2*7)
   = 0.25 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(7/(0.289*0.5))^2 )
   = 15923.95 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 5053*(3*3.375 - 4.75)/(15923.95*4.75^2*SIN(68.552)^2)
   = 0.0873 in
```

Lug base plate required thickness

From Escoe table 4-8

```
fc = VL/(Fb*L) = 421.0833 psi

Mx = Cx*fc*Gs^2
   = 0.0923*421.0833*5^2 = 971.6498

My = Cy*fc*wb^2
   = -.126*421.0833*4.75^2 =-1197.087

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*1197.087 / 18800)
   = 0.6181 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

```
Longitudinal moment          ML =  1421 lbf-ft
Longitudinal shear           VL =  5053 lbf
Internal pressure             P =  0 psi
```

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

Mean radius Rm = 24.21875 in
Rm/t = 129.1667

C1 = 3, C2 = 4.0625 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 =-26071 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-9583 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	7.1556	0.168								
4C*	15.373	0.154								
1C	0.0648	0.138								
2C-1	0.0308	0.138								
3A*	4.9415	0.137								
1A	0.0672	0.143								
3B*	10.889	0.152	-9583	-9583	9583	9583				
1B-1	0.0195	0.142	-16488	16488	16488	-16488				
pressure stress*										
Total circ stress			-26071	6905	26071	-6905				
Primary membrane circ stress*			-9583	-9583	9583	9583				
3C*	7.9455	0.154								
4C*	14.630	0.168								
1C-1	0.0520	0.157								
2C	0.0357	0.157								
4A*	10.505	0.137								
2A	0.0289	0.16								
4B*	4.6023	0.152	-4863	-4863	4863	4863				
2B-1	0.0220	0.158	-16744	16744	16744	-16744				
pressure stress*										
Total long stress			-21607	11881	21607	-11881				
Primary membrane long stress*			-4863	-4863	4863	4863				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-1658	-1658	1658	16
Total Shear stress							-1658	-1658	1658	16
Combined stress			-26071	11881	26071	-11881	3316	3316	3316	3[illegible]

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SPOOL A-1

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

* PWHT is performed

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

Estimated weight:	new = 229.7	corr = 229.7	lb
capacity:	new = 203.121	corr = 203.121	US ga

ID = 44.625 length Lc= 30 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 100 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

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.625 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 7 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness, Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(4673*3.375*6)/(18800*2^2*7)
   = 0.25 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(7/(0.289*0.5))^2 )
   = 15923.95 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 4673*(3*3.375 - 4.75)/(15923.95*4.75^2*SIN(68.552)^2)
   = 0.0807 in
```

Lug base plate required thickness

From Escoe table 4-8

```
fc = VL/(Fb*L) = 389.4167 psi

Mx = Cx*fc*Gs^2
   = 0.0923*389.4167*5^2 = 898.5789

My = Cy*fc*wb^2
   = -.126*389.4167*4.75^2 =-1107.063

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*1107.063 / 18800)
   = 0.5944 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

Longitudinal moment	ML =	1314 lbf-ft
Longitudinal shear	VL =	4673 lbf
Internal pressure	P =	0 psi

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

Mean radius Rm = 22.40625 in
Rm/t = 119.5

C1 = 3, C2 = 4.0625 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 =-22614 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-8672 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	6.2968	0.182								
4C*	13.925	0.167								
1C	0.0603	0.149								
2C-1	0.0271	0.149								
3A*	4.6292	0.148								
1A	0.0651	0.155								
3B*	9.8548	0.164	-8672	-8672	8672	8672				
1B-1	0.0179	0.154	-13942	13942	13942	-13942				
pressure stress*										
Total circ stress			-22614	5270	22614	-5270				
Primary membrane circ stress*			-8672	-8672	8672	8672				
3C*	7.1198	0.167								
4C*	13.186	0.182								
1C-1	0.0491	0.169								
2C	0.0352	0.169								
4A*	10.031	0.148								
2A	0.0277	0.174								
4B*	4.2361	0.164	-4428	-4428	4428	4428				
2B-1	0.0209	0.172	-14636	14636	14636	-14636				
pressure stress*										
Total long stress			-19064	10208	19064	-10208				
Primary membrane long stress*			-4428	-4428	4428	4428				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-1534	-1534	1534	15
Total Shear stress							-1534	-1534	1534	15
Combined stress			-22614	10208	22614	-10208	3068	3068	3068	30

NOTE: LAST COLUMN IS "DL" WITH VALUES IDENTICAL TO "DU"

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SPOOL B-2

ASME Section VIII Division 1, 1992 Edition, A94 Addenda

Component:	Cylinder		
Material specification:	SA 240 304L HIGH		
Corrosion allowance:	Inner C = 0	Outer= 0	in

* PWHT is performed

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

Estimated weight:	new = 546.3	corr = 546.3	lb
capacity:	new = 246.702	corr = 246.702	US ga

ID = 30.5 length Lc= 78 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 100 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

8X6 LUG - WITH NO PAD

Lug material specification		= A 240 304
Lug allowable stress		= 18800 psi
Top plate width	wp	= 2 in
Base plate width	wb	= 4.75 in
Top plate thickness	t	= 0.5 in
Base plate thickness	tb	= 0.625 in
Lug length circ. direction	L	= 6 in
Gusset height	h	= 7 in
Gusset thickness	tg	= 0.5 in
Number of lugs		= 4
Angular position, first lug		= 0 degrees
Fillet weld size	tw	= 0.1875 in
Force bearing width	Fb	= 2 in
Distance to load	d	= 3.375 in

Lug top plate required thickness, Bednar pg 153

```
ta = 0.75*(VL*d*L)/(Sa*wp^2*h)
   = 0.75*(3200*3.375*6)/(18800*2^2*7)
   = 0.25 in
```

Lug gusset required thickness

```
Sc = 18000/(1 + (1/18000)*(h/(0.289*tg))^2 )
   = 18000/(1 + (1/18000)*(7/(0.289*0.5))^2 )
   = 15923.95 psi

tg = VL*(3*d - wb)/(Sc*wb^2*SIN(Alpha)^2)
   = 3200*(3*3.375 - 4.75)/(15923.95*4.75^2*SIN(68.552)^2)
   = 0.0553 in
```

Lug base plate required thickness

```
From Escoe table 4-8

fc = VL/(Fb*L) = 266.6667 psi

Mx = Cx*fc*Gs^2
   = 0.0923*266.6667*5^2 = 615.3333

My = Cy*fc*wb^2
   = -.126*266.6667*4.75^2 =-758.1

tb = Sqr(6*Mmax / Sa)
   = Sqr(6*758.1 / 18800)
   = 0.4919 in
```

Check lug attachment stresses

Radial load	Pr =	0 lbf
Circumferential moment	Mc =	0 lbf-ft
Circumferential shear	Vc =	0 lbf

8X6 LUG - WITH NO PAD

Longitudinal moment	ML =	900 lbf-ft
Longitudinal shear	VL =	3200 lbf
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 = 4.0625 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 =-8055 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-3214 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

8X6 LUG - WITH NO PAD

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	D
3C*	2.9982	0.265								
4C*	6.9678	0.243								
1C	0.0648	0.218								
2C-1	0.0231	0.218								
3A*	2.3063	0.216								
1A	0.0633	0.235								
3B*	4.8286	0.239	-3214	-3214	3214	3214				
1B-1	0.0164	0.231	-4792	4792	4792	-4792				
pressure stress*										
Total circ stress			-8006	1578	8006	-1578				
Primary membrane circ stress*			-3214	-3214	3214	3214				
3C*	3.3975	0.243								
4C*	6.5477	0.265								
1C-1	0.0403	0.247								
2C	0.0321	0.247								
4A*	5.4408	0.216								
2A	0.0254	0.263								
4B*	2.2933	0.239	-1831	-1831	1831	1831				
2B-1	0.0237	0.257	-6224	6224	6224	-6224				
pressure stress*										
Total long stress			-8055	4393	8055	-4393				
Primary membrane long stress*			-1831	-1831	1831	1831				
torsion moment Mt										
Circ shear from Vc										
Long shear from VL							-788	-788	788	8
Total Shear stress							-788	-788	788	8
Combined stress			-8055	4393	8055	-4393	1576	1576	1576	15

NOTE: LAST COLUMN IS "DL" WITH VALUES IDENTICAL TO "DU"