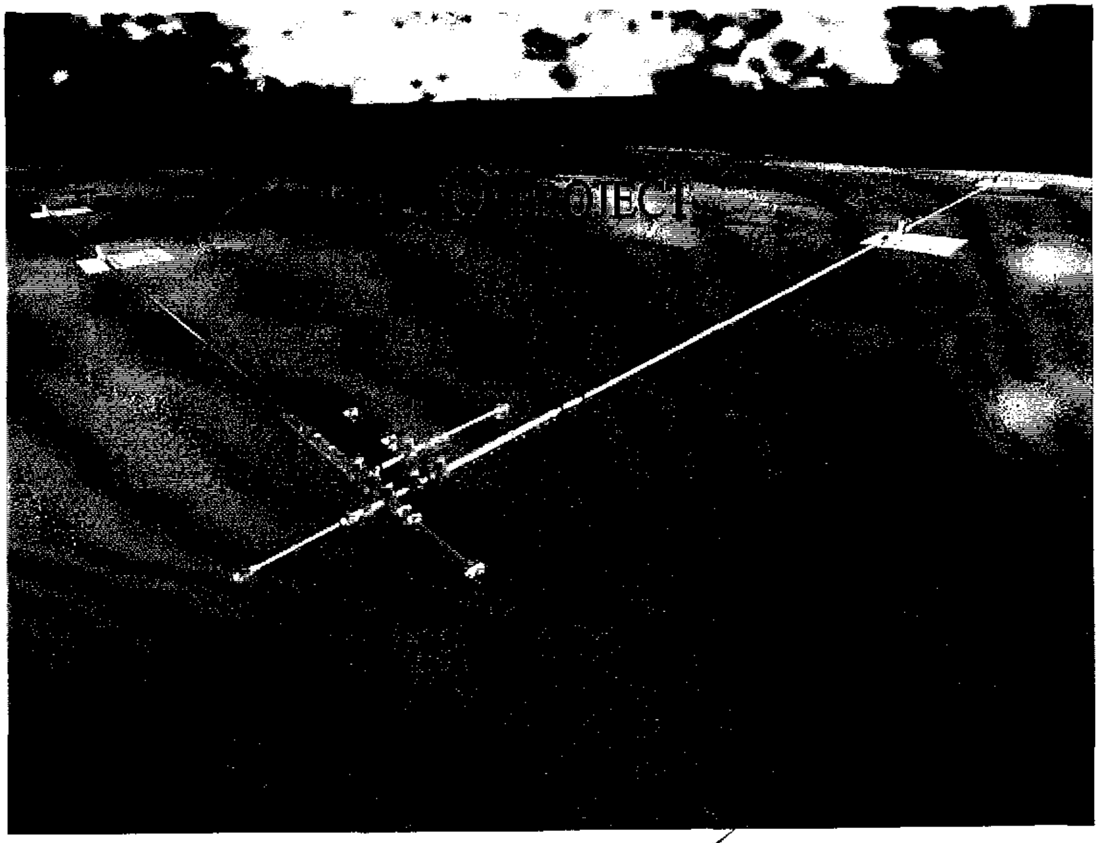
LIGO VACUUM EQUIPMENT
FINAL DESIGN REPORT

VOLUME II ATTACHMENT 1 - 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 1

1. STRUCTURAL CALCULATIONS

TITLE	DOCUMENT NO.	REV.
LIGO Vacuum Equipment Structural Design Criteria	V049-1-066	0
Beam Splitter Chamber		
Finite Element Analysis of Upper Section	V049-1-014	0
ASME Code Calculations for Upper Section	V049-1-015	0
FE Analysis of 1 in. Thick Flange for Bolt Preload	V049-1-016	0
FE Analysis of 1 in. Thick Flange for Bolt Preload & Pos. Pressure	V049-1-017	0
FE Analysis of 3/4 in Thick Flange	V049-1-018	0
Flange Design for Internal Pressure	V049-1-019	0
Design of Removable Work Floor	V049-1-020	0
Design of Flange Welds	V049-1-021	0
Finite Element Analysis of Lower Section	V049-1-022	0
Design of 60 in Access Covers	V049-1-023	0
Design of Support Legs & Base Plates	V049-1-024	0
Temporary Cover for 60 in Nozzle	V049-1-025	0
Nozzle to Shell Welds	V049-1-026	0
Lifting Lugs	V049-1-027	0
Shipping Loads	V049-1-028	0
BSC Deflections	V049-1-029	0
NASTRAN Buckling Analysis	V049-1-040	0
BSC Support Clevis	V049-1-069	0

TITLE	DOCUMENT NO.	REV.
Vacuum Equipment General Structural Calculations		
Vacuum Equipment Seismic Acceleration	V049-1-031	0
Component Interface Loads	V049-1-032	0
Bolted Flange Analysis for Tensile Forces	V049-1-042	0
Design of Pipe Bridge (Corner Station)	V049-1-071	0
Horizontal Access Module		
Ham Vessel Stress Analysis (Finite Element Analysis)	V049-1-039	0
Ham Vessel Buckling Analysis	V049-1-041	0
Design of 60 inch Cover	V049-1-073	0
Design of 84 inch Cover	V049-1-074	0
Design of Nozzle Jacking Bolt Assembly	V049-1-048	0

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-066

PAGE 1 OF 3

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/24/96	RDC	DMW

TITLE: LIGO Vacuum Equipment Structural Design Criteria

BY: R. D. Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Establish structural design criteria for LIGO vacuum vessels and supports.

METHOD: Review LIGO vacuum equipment specification and design codes to determine requirements for structural integrity.

ASSUMPTIONS: N/A

INPUTS: LIGO project drawings and sketches.
LIGO E940002-02-V, Vacuum Equipment Specification

REFERENCES: See INPUTS

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: These LIGO vacuum equipment structural design criteria conform to project and code requirements.

NOTES:

LIGO VACUUM EQUIPMENT STRUCTURAL DESIGN CRITERIA

Design Code for Vessels: ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1, 1992 Edition through 1994 Addenda

Alternate Design Code for Vessels: ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 2, 1992 Edition through 1994 Addenda

Internal Vacuum = -14.7 psig

Positive Internal Pressure = 2 psig for vacuum chambers. Special conditions for 80K cryopumps (see Doc. No. V049-I-056).

Mechanical Loads

- Unbalanced Vacuum Loads - These loads are imposed at end components, and at branches in the system.
- Component Interface Loads - Equipment shall be designed for loads from adjacent components that are imposed when gate valves are closed and portions of the system are vented. See Doc. No. V049-1-032.

Design Temperature = 400° F

Seismic Acceleration = .05625 G (ASCE 7-88) lateral only, single direction

Pressure Boundary Material = SA240, Type 304/304L stainless steel for shells and SA182, Grade F Type 304L for flange forging. Other specification numbers and product forms of Type 304/304L may be used for miscellaneous pressure parts. Flange Bolting Material = SA193, Gr B7.

Basic Stress Limits (Section VIII, Div. 1):

Type 304L
S = 14.7 ksi at 400° F for membrane stress
S = 1.5S = 22 ksi at 400° F for membrane + bending stress

Type 304
S = 16.2 ksi at 400° F for membrane stress
S = 1.5S = 24.3 ksi at 400° F for membrane + bending stress

Basic Stress Limits (Section VIII, Div. 2):

Type 304L

Sm = 15.8 ksi at 400° F for Primary Membrane Stress Intensity
1.5Sm = 23.7 ksi at 400° F for Primary Bending Stress Intensity
3Sm = 47.4 ksi at 400° F for Secondary Membrane + Bending

Type 304

Sm = 18.7 ksi at 400° F for Primary Membrane Stress Intensity
1.5Sm = 28.0 ksi at 400° F for Primary Bending Stress Intensity
3Sm = 56.1 ksi at 400° F for Secondary Membrane + Bending

O-Ring Seal Material = Viton (1/4 in)

Maximum Durometer = 90
Compression Range = .058 in to .080 in (21% to 29 %)
Maximum Compression Force = 160 lb/in

Shipping Acceleration

Vertical Accel = 1G
Horizontal Accel = .5G

Design Code for Supports: AISC Manual of Steel Construction, Allowable Stress Design, Ninth Edition.

Material for Supports: A36 shapes and plate, A500 Gr B tube steel. See AISC Code for allowable stresses.

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WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-066

PAGE 1 OF 3

REV.	DEO #	DATE	BY:	CHECK
0	0136	4/24/96	RDC	DMW

TITLE: LIGO Vacuum Equipment
Structural Design Criteria

BY: R. D. Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Establish structural design criteria for LIGO vacuum vessels and supports.

METHOD: Review LIGO vacuum equipment specification and design codes to determine requirements for structural integrity.

ASSUMPTIONS: N/A

INPUTS: LIGO project drawings and sketches.
LIGO E940002-02-V, Vacuum Equipment Specification

REFERENCES: See INPUTS

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: These LIGO vacuum equipment structural design criteria conform to project and code requirements.

NOTES:

LIGO VACUUM EQUIPMENT STRUCTURAL DESIGN CRITERIA

Design Code for Vessels: ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1, 1992 Edition through 1994 Addenda

Alternate Design Code for Vessels: ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 2, 1992 Edition through 1994 Addenda

Internal Vacuum = -14.7 psig

Positive Internal Pressure = 2 psig for vacuum chambers. Special conditions for 80K cryopumps (see Doc. No. V049-I-056).

Mechanical Loads

- Unbalanced Vacuum Loads - These loads are imposed at end components, and at branches in the system.
- Component Interface Loads - Equipment shall be designed for loads from adjacent components that are imposed when gate valves are closed and portions of the system are vented. See Doc. No. V049-1-032.

Design Temperature = 400° F

Seismic Acceleration = .05625 G (ASCE 7-88) lateral only, single direction

Pressure Boundary Material = SA240, Type 304/304L stainless steel for shells and SA182, Grade F Type 304L for flange forging. Other specification numbers and product forms of Type 304/304L may be used for miscellaneous pressure parts. Flange Bolting Material = SA193, Gr B7.

Basic Stress Limits (Section VIII, Div. 1):

Type 304L
S = 14.7 ksi at 400° F for membrane stress
S = 1.5S = 22 ksi at 400° F for membrane + bending stress

Type 304
S = 16.2 ksi at 400° F for membrane stress
S = 1.5S = 24.3 ksi at 400° F for membrane + bending stress

Basic Stress Limits (Section VIII, Div. 2):

Type 304L
Sm = 15.8 ksi at 400° F for Primary Membrane Stress Intensity
1.5Sm = 23.7 ksi at 400° F for Primary Bending Stress Intensity
3Sm = 47.4 ksi at 400° F for Secondary Membrane + Bending

Type 304
Sm = 18.7 ksi at 400° F for Primary Membrane Stress Intensity
1.5Sm = 28.0 ksi at 400° F for Primary Bending Stress Intensity
3Sm = 56.1 ksi at 400° F for Secondary Membrane + Bending

O-Ring Seal Material = Viton (1/4 in)

Maximum Durometer = 90
Compression Range = .058 in to .080 in (21% to 29 %)
Maximum Compression Force = 160 lb/in

Shipping Acceleration

Vertical Accel = 1G
Horizontal Accel = .5G

Design Code for Supports: AISC Manual of Steel Construction, Allowable Stress Design, Ninth Edition.

Material for Supports: A36 shapes and plate, A500 Gr B tube steel. See AISC Code for allowable stresses.

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ENGINEERING CALCULATIONS

NO: V049-1-014

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REV.	DEO #	DATE	BY:	CHECK
0	0024	12/6/95	RDC	WDB

TITLE: Beam Splitter Chamber - Finite Element Analysis of Upper Section

BY: R.D.Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To evaluate the upper section of the beam splitter chamber for vacuum pressure and lifting loads.

METHOD: Finite element analysis of vessel upper section including cylinder, head and lifting lugs. 563 nodes and 537 elements.

ASSUMPTIONS: Ring stiffener and nozzle omitted from analysis since area of interest is shell near lug.

INPUTS: LIGO project sketches and drawings. The thickness of the cylinder is .25 in and the thickness head is .375 in.

REFERENCES: 1. ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1.
2. Images - 3D, Version 3.0, R.L. Cloud & Associates.
3. Doc. No V049-1-066, LIGO Vacuum Equip., Struct. Design Criteria

CALCULATIONS: (See Attachment)

CONCLUSIONS: Stresses in head and shell in the area of the lifting lugs are within limits of ASME Code, Section VIII, Div. 1.
A spreader beam should be used when lifting vessel.

NOTES: See stress contour plots attached. See V049-1-015 for buckling analysis per the ASME Code.

Computer File: BSCUPPER

FINITE ELEMENT ANALYSIS OF BEAM SPLITTER CHAMBER UPPER SECTION

THE PURPOSE OF THIS ANALYSIS IS TO EVALUATE THE UPPER HEAD AND CYLINDER OF THE BEAM SPLITTER CHAMBER FOR THE EFFECTS OF VACUUM PRESSURE AND LIFTING LUG LOADS. IT IS NOTED THAT THE UPPER HEAD IS A FLANGED AND DISHED HEAD WITH A CROWN RADIUS OF 105 IN AND A THICKNESS OF 3/4 IN. THE THICKNESS OF THE STRAIGHT CYLINDER IS 1/4 IN.

TO TAKE ADVANTAGE OF SYMMETRY, THE MODEL EXTENDS 180° AROUND ITS CIRCUMFERENCE.

IMAGES WAS USED FOR THE MODEL WHICH IS FILED AS

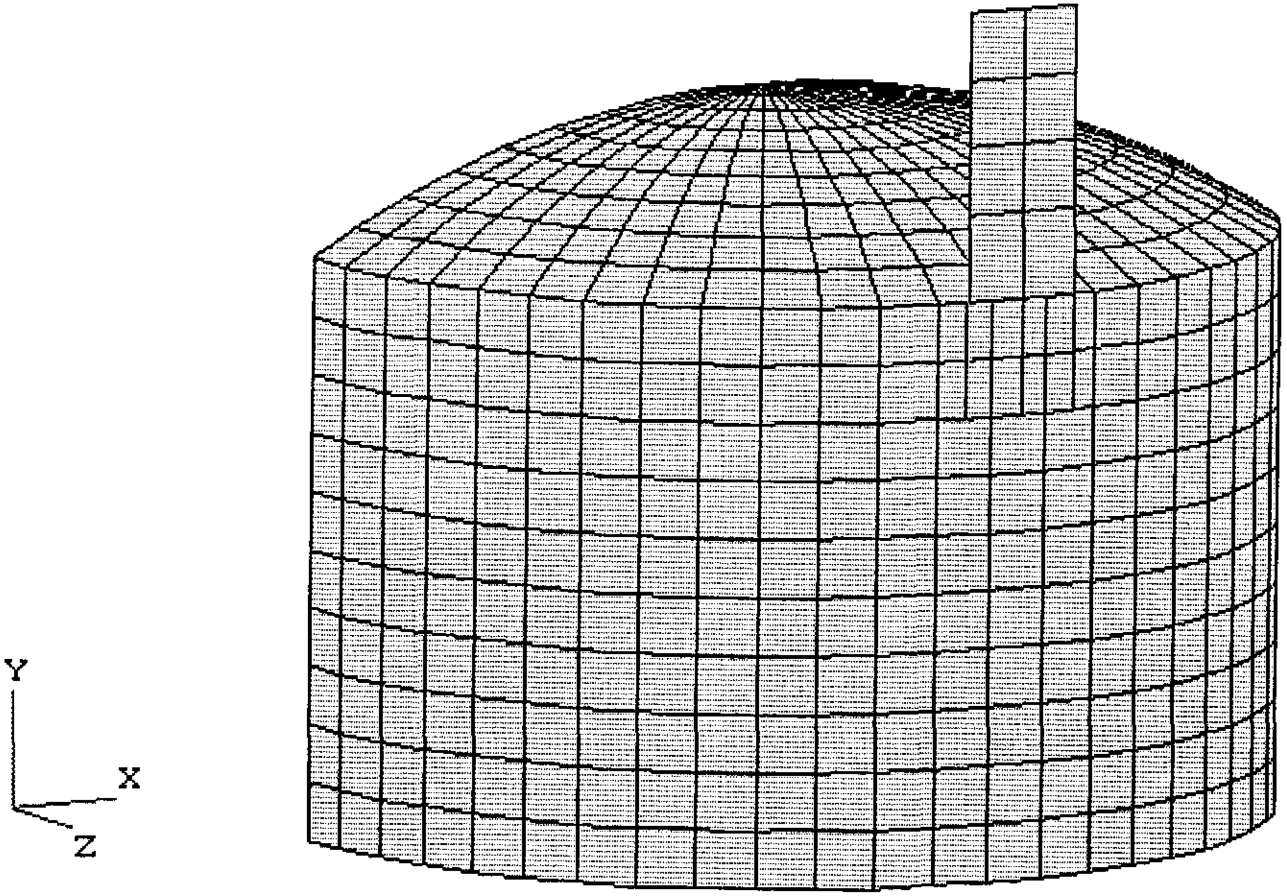
FILE NAME : BSCUPPER

THE STRESS INTENSITY PLOTS SHOWN IN THIS SECTION CONFIRM THAT STRESSES ARE LOW AND MEET THE REQUIREMENTS OF ASME SECT. VIII, DIV. 1, PAR UG-23(c).

PRIMARY MEMBRANE STRESS $< S_{ALL} = 14.7$ KSI
@ 400°F

PRIMARY MEMBRANE + BENDING STRESS $< 1.5\ S_{ALL}$
$= 22$ KSI
@ 400°F

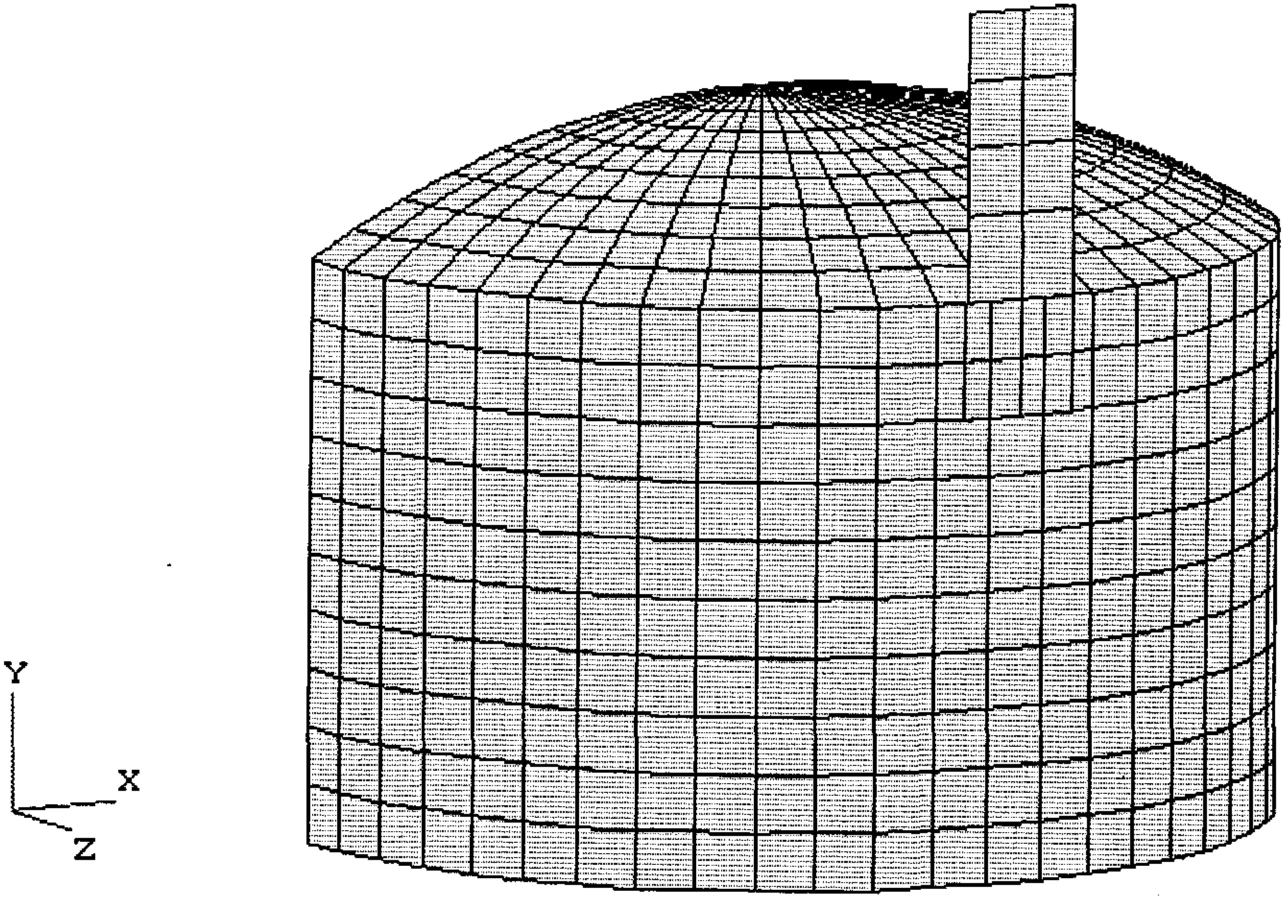
IMAGES-3D
Ver. 3.0
Geometry Plot



BEAM SPLITTER CHAMBER - UPPER SECTION CYLINDER & HEAD
Hidden Line Removal

10/25/95
13:53:32

IMAGES-3D
Ver. 3.0
Geometry Plot



BEAM SPLITTER CHAMBER - UPPER SECTION CYLINDER & HEAD
Hidden Line Removal

10/25/95
13:53:32

MATERIAL PROPERTIES OF SA240 TYPE 304L
AT 400 °F

MODULUS OF ELASTICITY

26.5×10^{6} PSI

POISSONS RATIO

$\nu = .3$

COEF. OF THERMAL EXPANSION

$\alpha = 1.15 \times 10^{-6}$

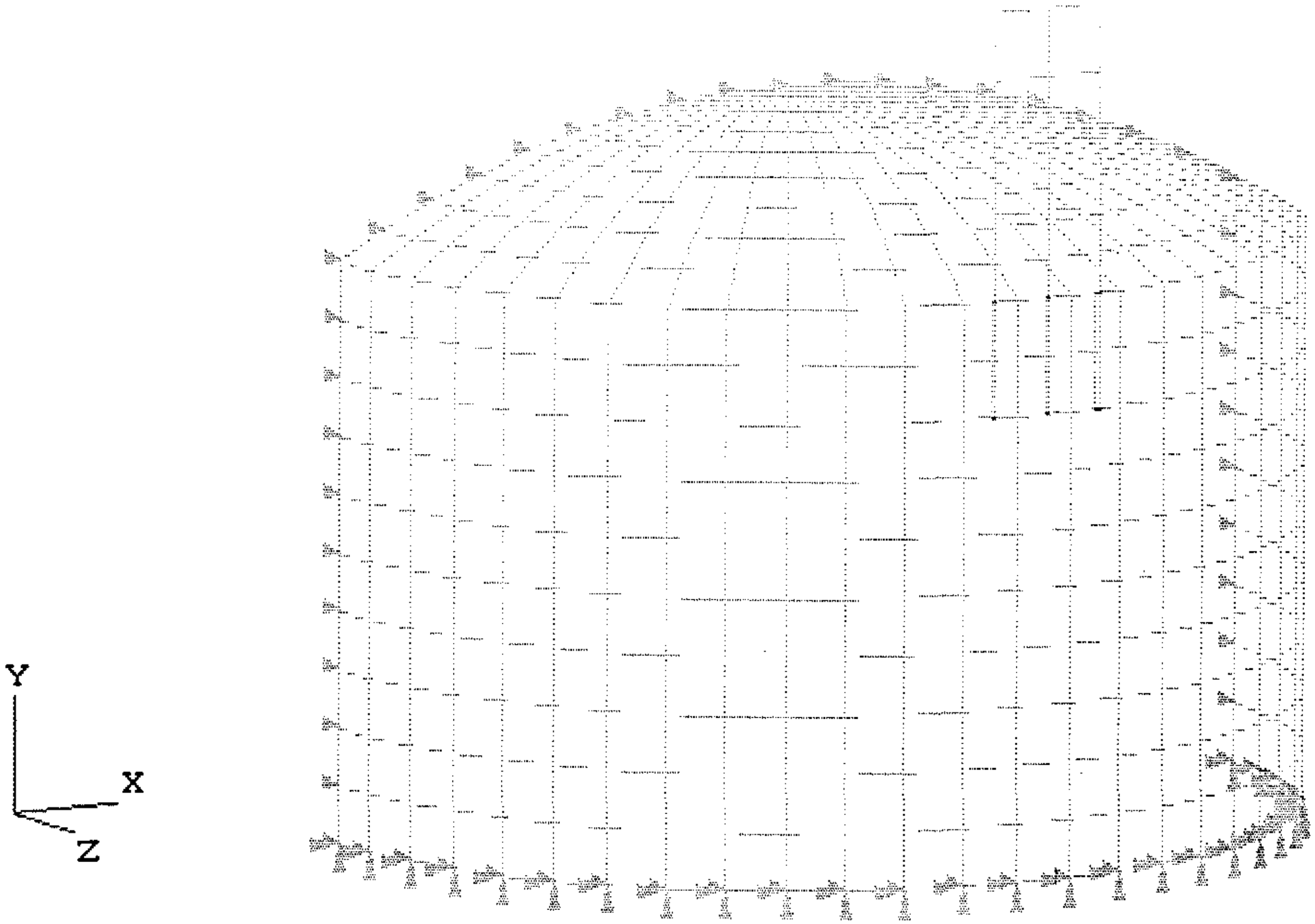
DENSITY

$\rho = .290$ LB/IN^3

THESE PROPERTIES ARE USED IN IMAGES MODELS FOR TYPE 304L SS.

Boundary Conditions Shown

IMAGES-3D
Ver. 3.0
Geometry Plot

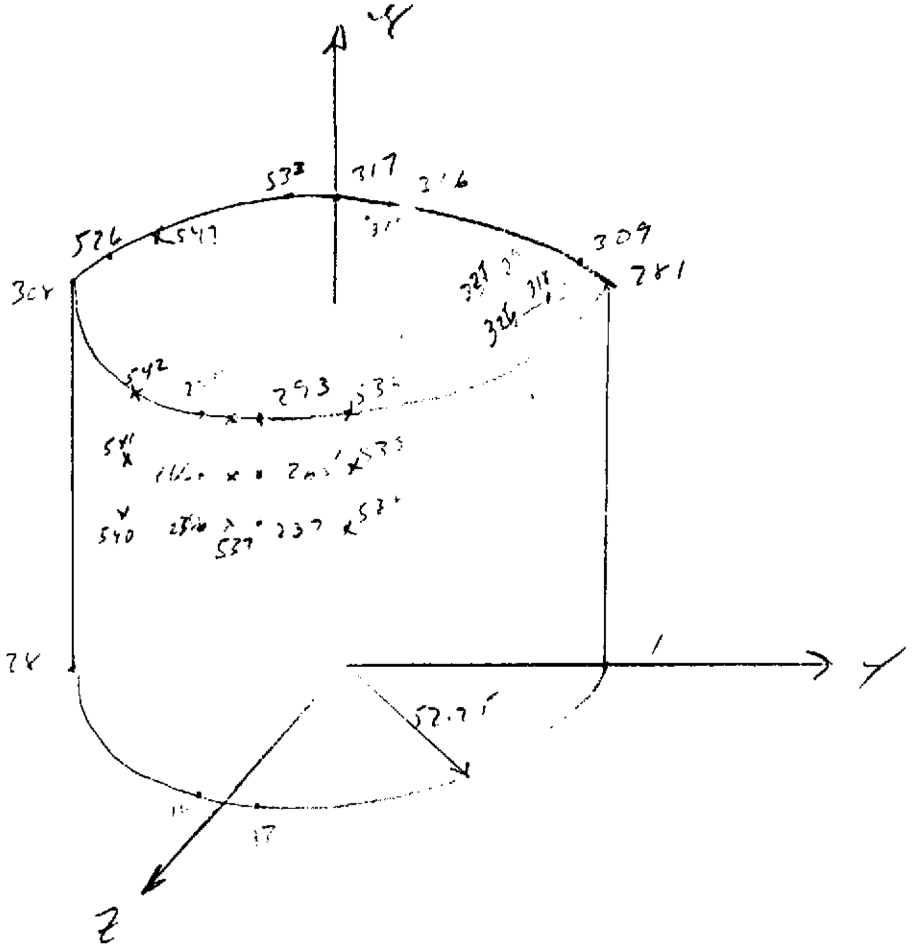


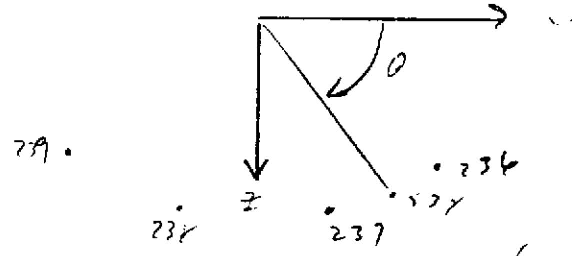
?

Auto	Blowup	Elem#	Exit	Full	Help	Local	Move
Node	Node#	Plot	Range	Rest	Rotate	Shrink	Slice

IMAGES FE MODEL

KEY NODE NUMBERS

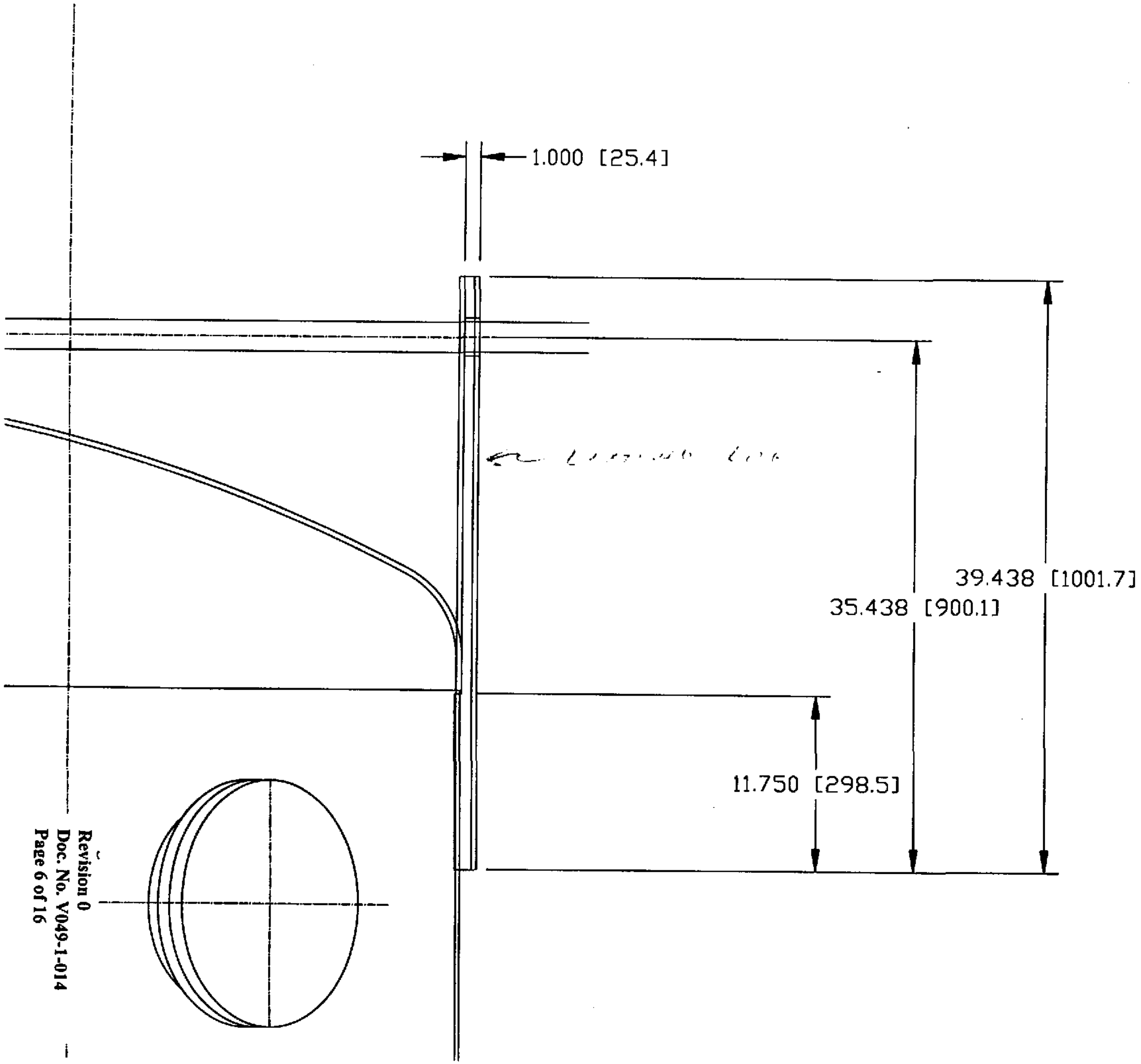




$\theta = 90 - \frac{180}{27}$

$= 83.3333°$

534 $\left\{ \begin{array}{l} X = 52.75 \cos 83.3333 \\ \quad = 6.0675 \\ Y = 48 \\ Z = 52.75 \sin 83.3333 \\ \quad = 51.4967 \end{array} \right.$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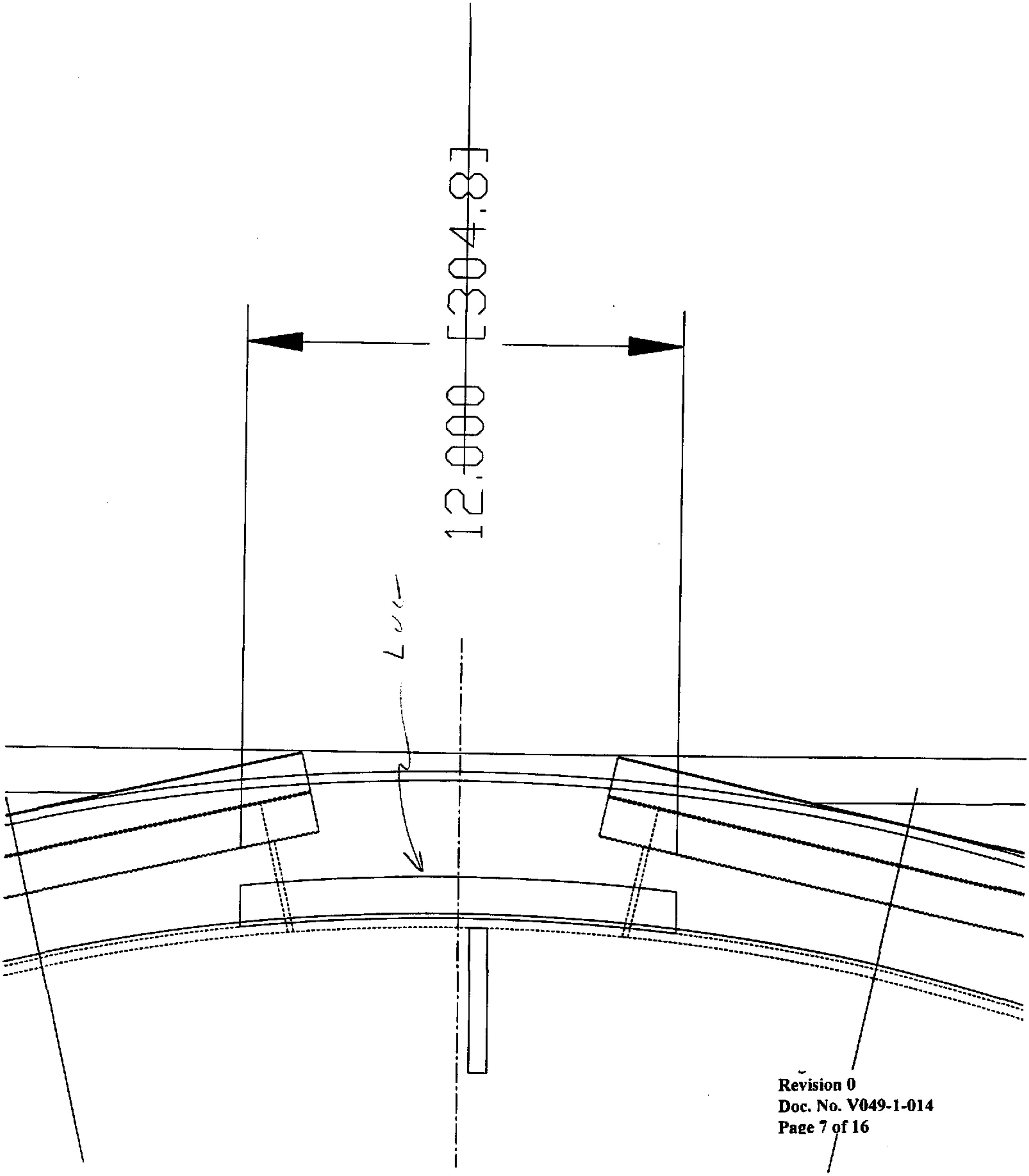
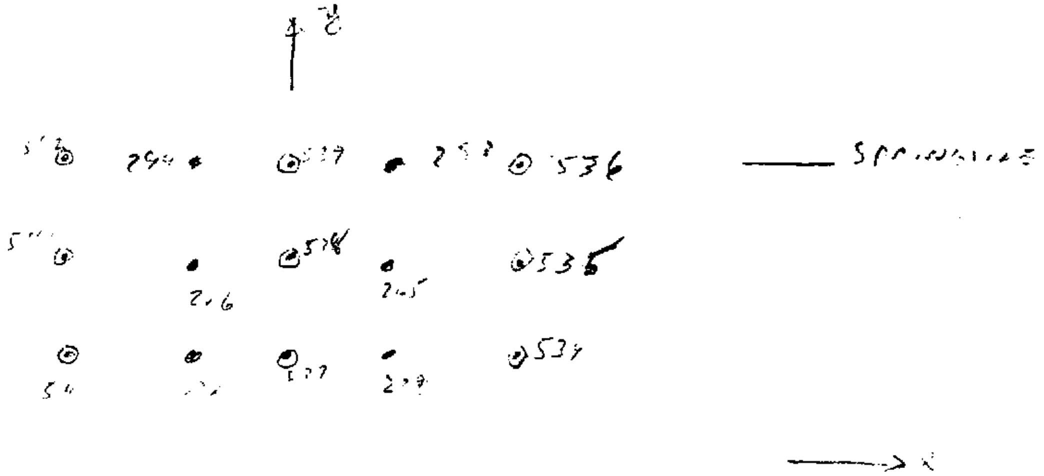
39.438 [1001.7]
35.438 [900.1]
11.750 [298.5]
[illegible] line

6



LUG

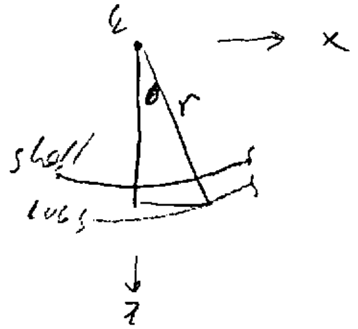
NODES 534 TO 541 ARE ADDED AT MIDSURFACE OF PLATE



ELEMENTS 225 TO 231, 254 TO 258 WERE DELETED AND REPLACED WITH ELEMENTS WITH ABOVE NODES

ADDITIONAL NODES WILL BE OFFSET FROM NODES 534 TO 541 WITH RIGID ELEMENTS. THESE NEW ELEMENTS WILL REPRESENT THE LIFTING LUG

ASSUME LUG IS 1 IN THICK, RADIUS TO MIDSURFACE IS



$r = 52.25 + .125 + .5 = 52.875$ in

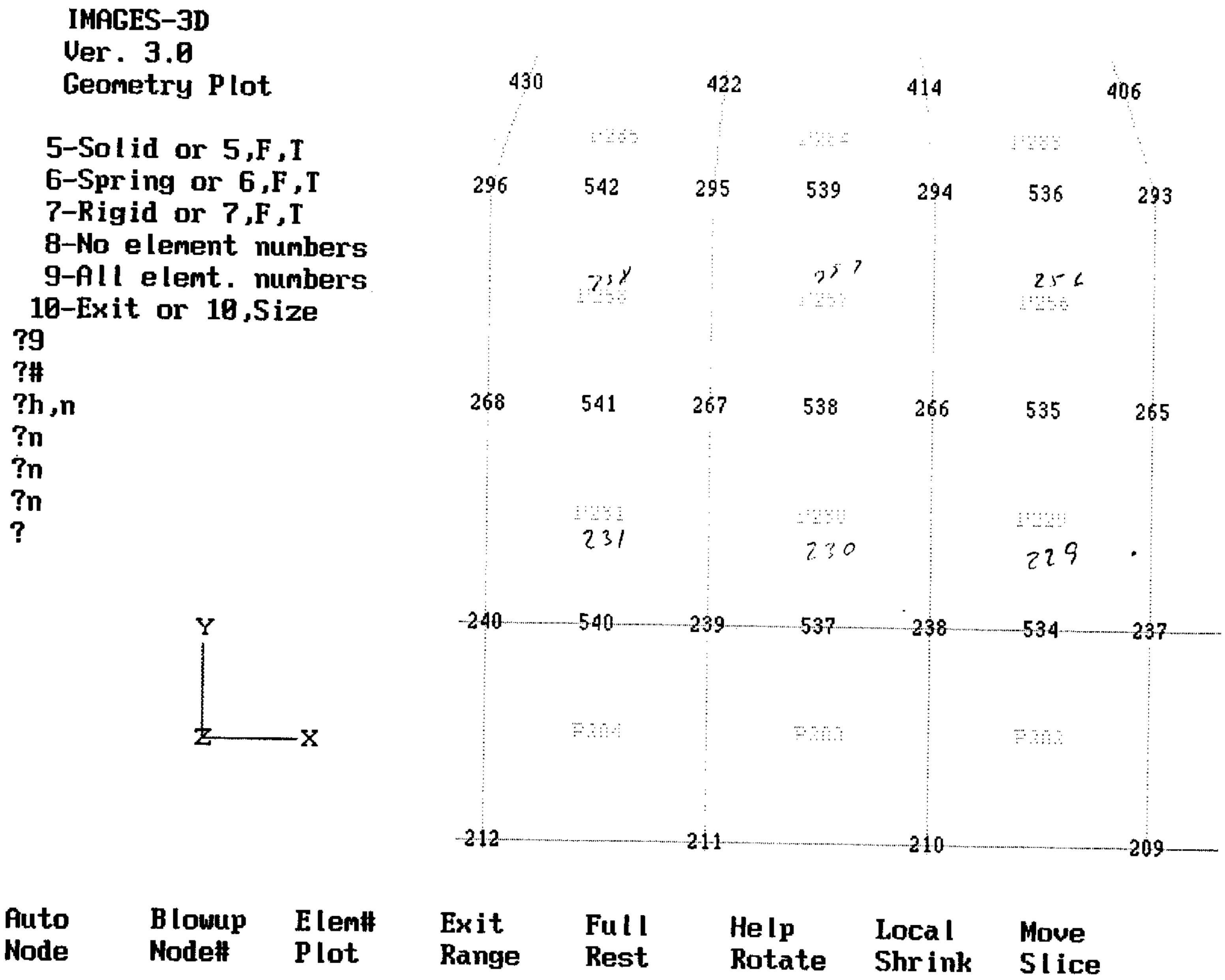
$\theta = \tan^{-1}\left(\frac{6.0619}{51.8969}\right) = 6.6627°$

$y = r \sin \theta$

$= 52.875 \sin 6.6627 = 6.1345$ in

$z = r \cos \theta$

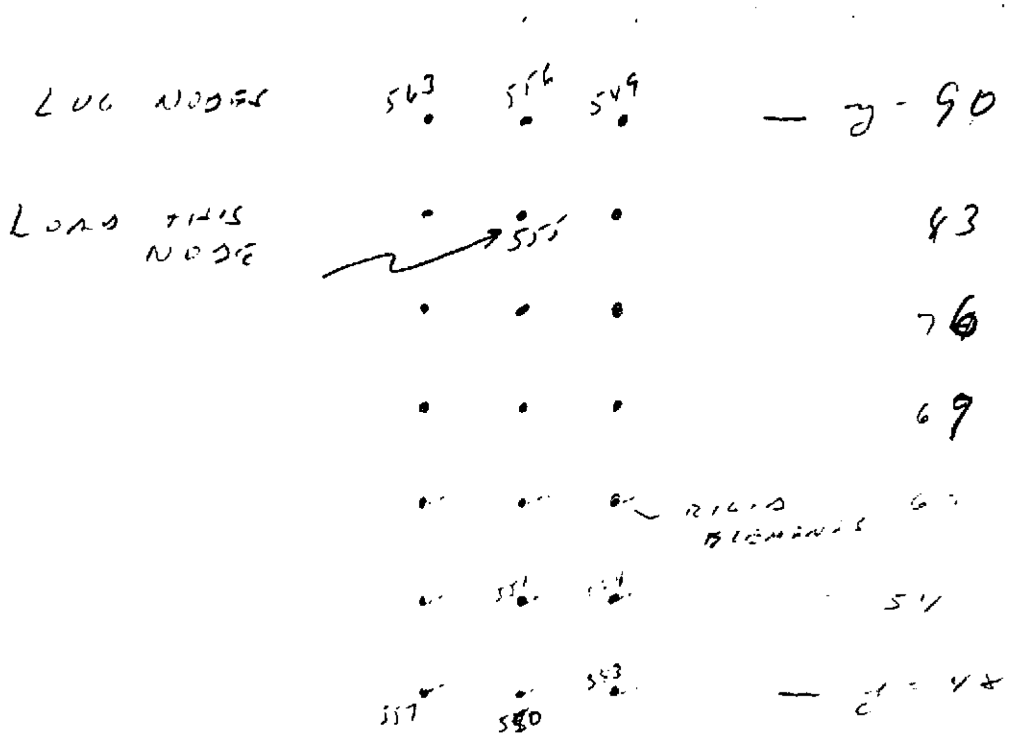
$= 52.5175$ in



```
IMAGES-3D
Ver. 3.0
Geometry Plot

  5-Solid or 5,F,T
  6-Spring or 6,F,T
  7-Rigid or 7,F,T
  8-No element numbers
  9-All elemt. numbers
 10-Exit or 10,Size
?9
?#
?h,n
?n
?n
?n
?
```

8



RIGID ELEMENTS

I	J	TYPE	RELEASE
534	543	1	0
535	544		
536	545		
537	550		
538	551		
539	552		
540	557		
541	558		
542	559		

PLATES 1 TO 25 HAVE EXT. MACHINING

LUG LOADS (NODE 555)

VERTICAL (LOAD CASE 2)

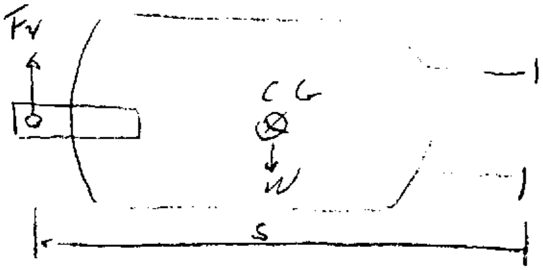
TOTAL ESTIMATED WEIGHT

$$W = 12500 \text{ LB}$$

$$F_{Y_{555}} = \frac{12500}{2}$$

$$= 6250 \text{ LB}$$

FOR LIFT TO VERTICAL POSITION FROM HORIZONTAL CONSTRUCTION, SHIPPING POSITION, LOAD IS IN X-DIRECTION. ASSUME VESSEL PIVOTS ABOUT BASE PLATE & CG IS MIDWAY BETWEEN BASE PLATE AND EYE OF LUG

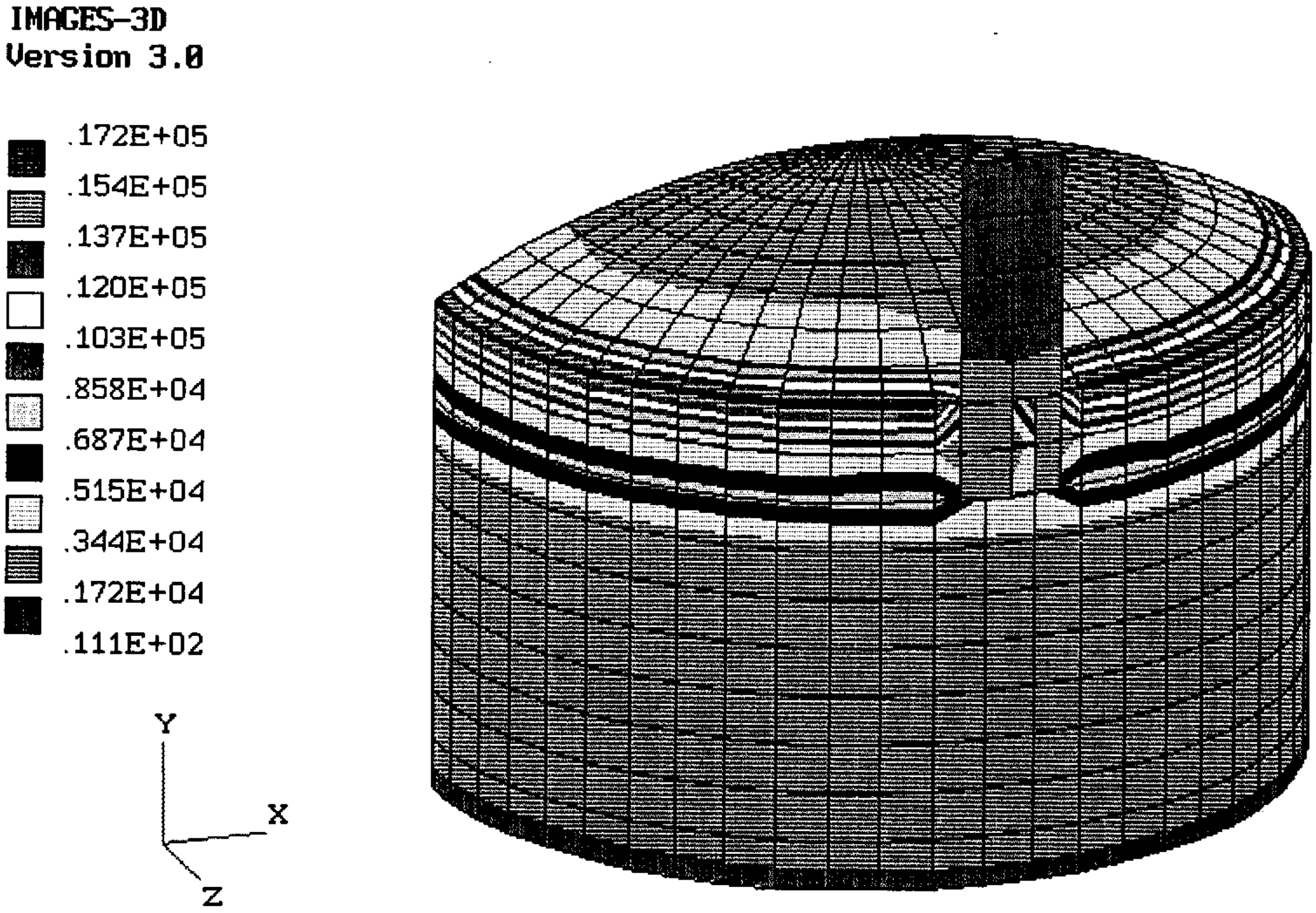


$$F_X = \frac{W}{2} \times \frac{S}{2} \div S = \frac{W}{4}$$

$$= \frac{12500}{4} = 3125 \text{ LB}$$

LOAD CASE 3

$$F_{Y_{555}} = 3125$$



Load Case
1

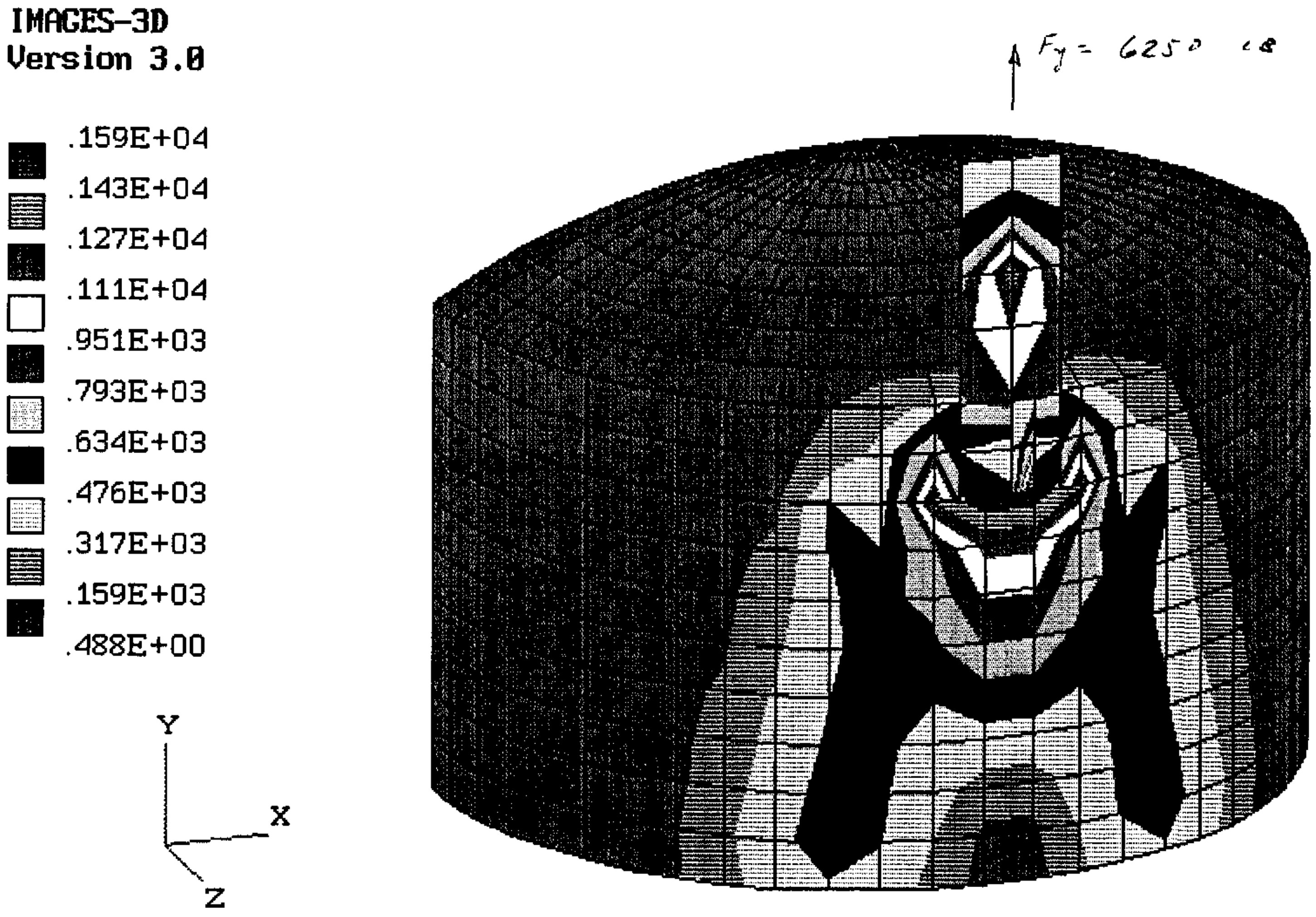
Stress Contour Plot

Surf: Bottom

Stress Intensity

10/25/95
10:46:21

Vacuum Pressure



Load Case
2

Stress Contour Plot

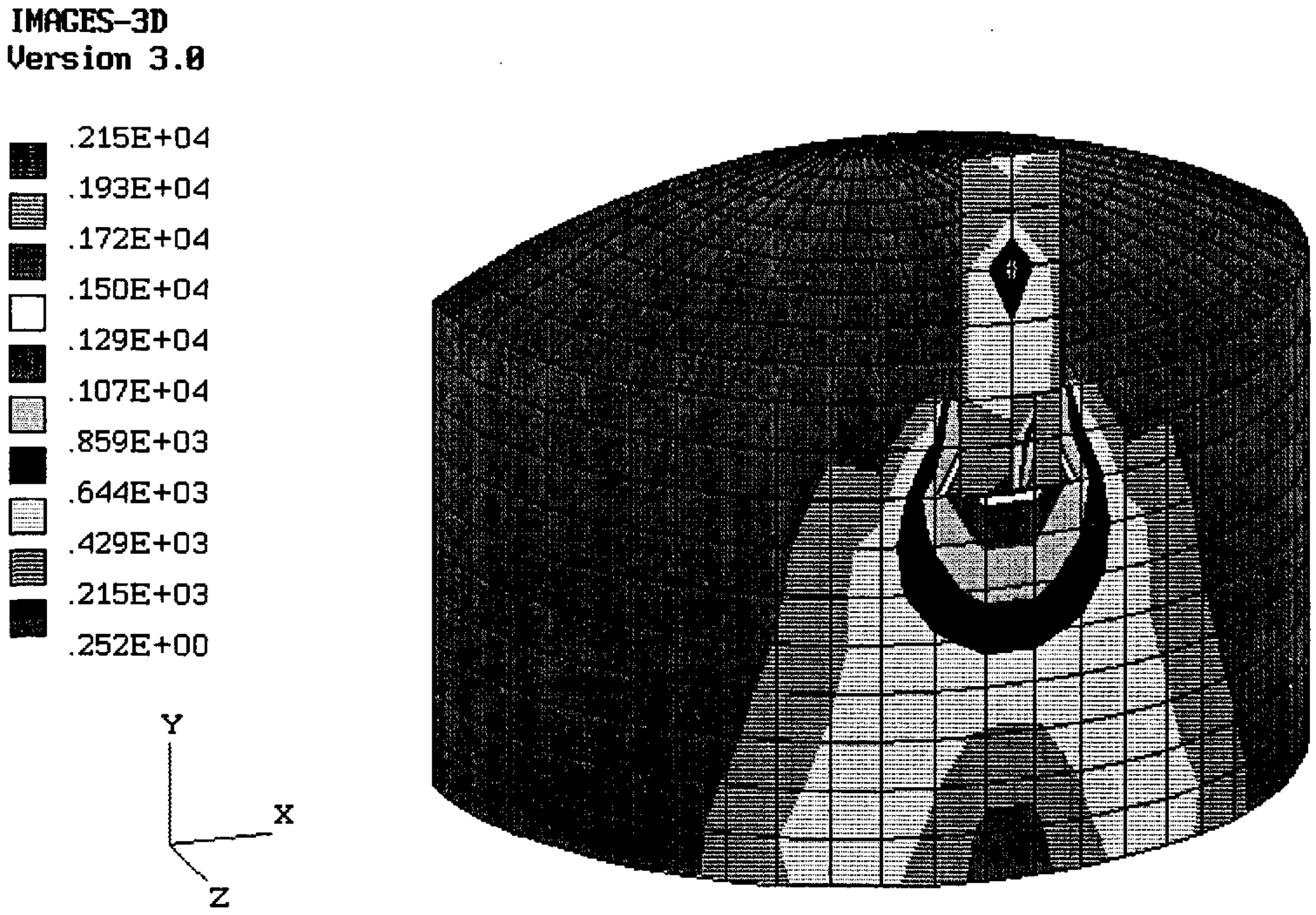
Surf: Top

Stress Intensity

10/25/95
10:48:56

VERTICAL LUG LOAD

2



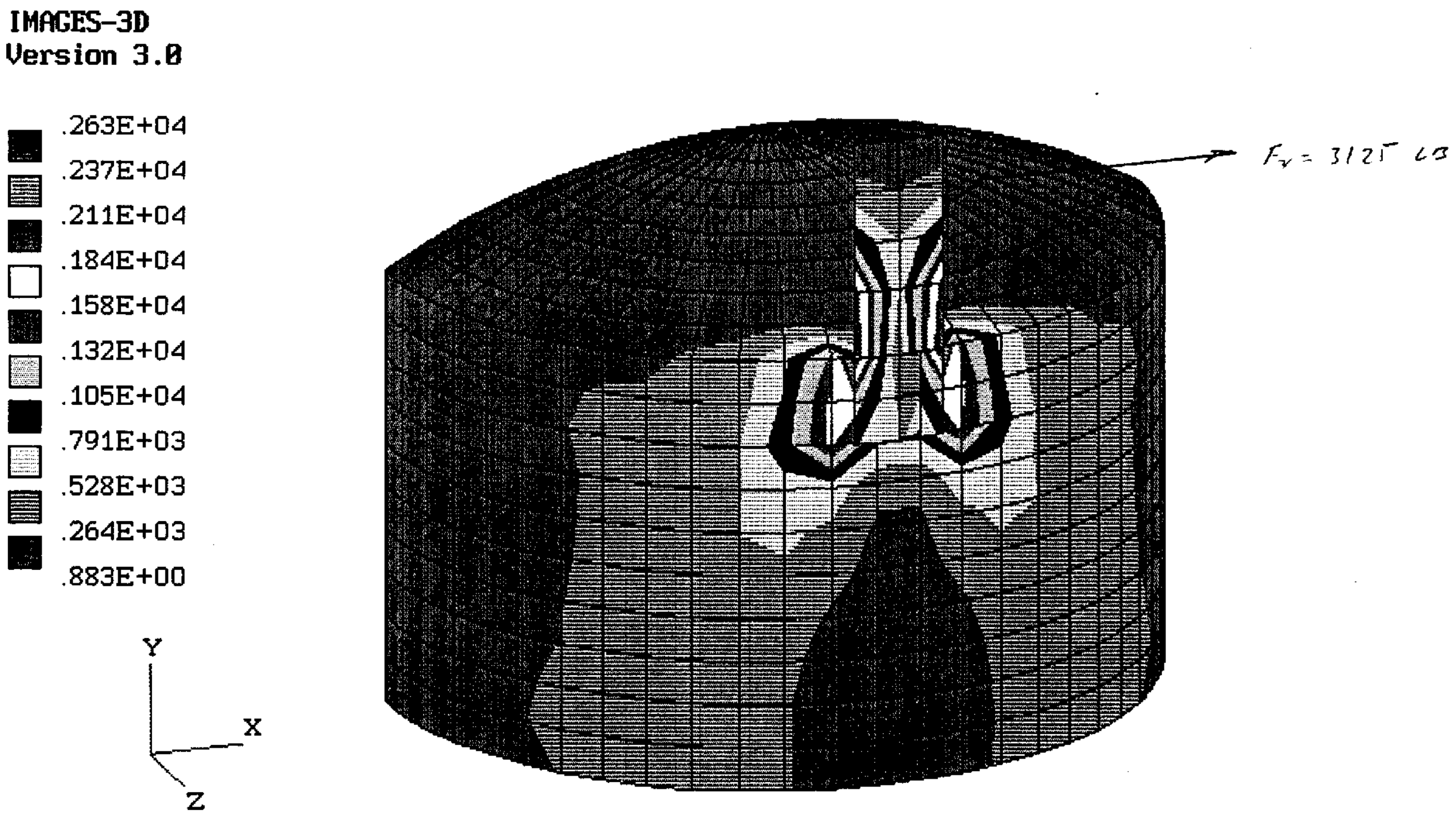
Load Case
2

Stress Contour Plot

Surf: Middle

Stress Intensity

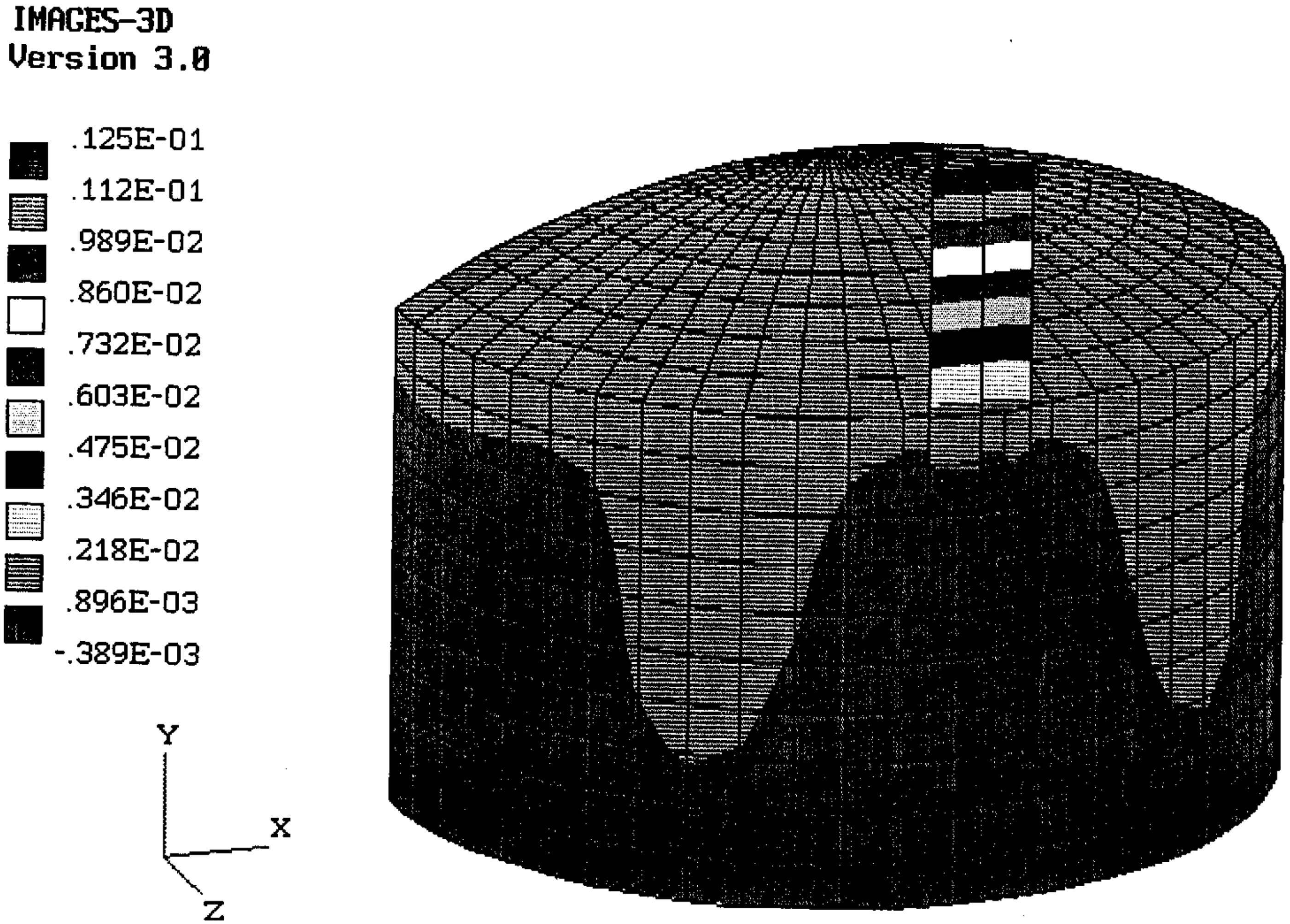
10/25/95
10:52:10



$F_v = 3125$ LB

Load Case **Stress Contour Plot** **10/25/95**
3 **Surf: Middle** **Stress Intensity** **10:54:34**

HORIZONTAL LUG LOAD



Load Case
3

Displacement Contour Plot
DX

10/25/95
11:21: 2

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-015 PAGE 1 OF 57
REV.	DEO #	DATE	BY:	CHECK	TITLE: Beam Splitter Chamber - ASME Code Calculations for Upper Section.	
0	002"	12/6/95	RDC	P.W.Y.		
					BY: R. D. Ciatto	DEPT.: 744
PROJECT: LIGO Vacuum Equipment					PROJECT NO: V59049	

PURPOSE: To determine if the upper section of the beam splitter chamber meets Section VIII, Div. 1 of the ASME Code for vacuum pressure.

METHOD: Equations for thickness requirements and pressure rating in the ASME Code, Section VIII, Div.1 are evaluated using the COMPRESS computer program, Version 5.31.

ASSUMPTIONS:

INPUTS: Vacuum pressure = 14.7 psi
Design temperature = 400^{0}F

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

CALCULATIONS: (See Attached)

CONCLUSIONS: Requirements of the ASME Code, Section VIII, Div. 1 are met for the BSC upper section head and cylinder.

NOTES: Nozzle G in lower section is included in this analysis. This nozzle penetrates the 1/2 in. shell. No reinforcing pad is required by code.

THE COMPRESS PROGRAM IS USED TO EVALUATE THE UPPER SECTION OF THE BSC. THIS INCLUDES:

TOP HEAD

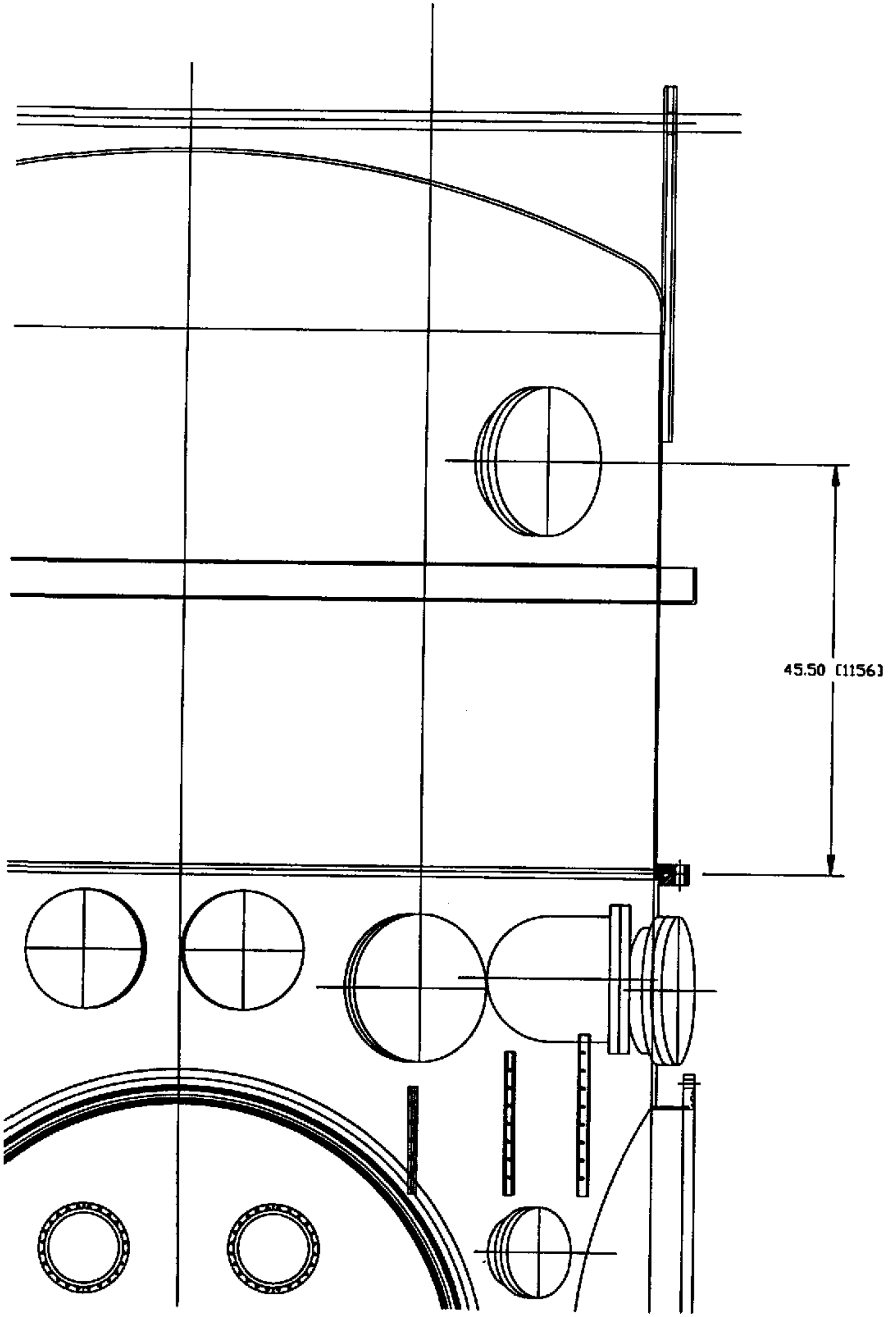
UPPER CYLINDRICAL SHELL (ABOVE FLANGE)

SHELL STIFFENER

MAIN CYLINDRICAL SHELL (BELOW FLANGES) DOES NOT INCLUDE NOZZLES

COMPRESS FILENAME: BSCUPPER.USL

NOTE: THE 1/2 IN LOWER SHELL INCLUDING NOZZLE 6 IS ALSO INCLUDED IN THE COMPRESS MODEL.


45.50 [1156]

NOZZLE E (LOCATED ON 1/4 IN SHELL)
RADIAL LOAD FROM VACUUM PAGE 13.

$F_R = \pi r^2 p$

$r \; \frac{13.75}{2} = 6.875$ in INSIDE RADIUS

$p = 14.7$ psi

$F_R = \pi (6.875)^2 (14.7)$

$= 2183$ LB

WRC 107 ANAL BY COMPRESS

MAX STRESS IS

f = 13222 psi ok
AT EDGE OF REIN. PAD

f = 4686 psi
AT NOZZLE O.D.

PAD REQ'D (COMPRESS) FOR NOZ E ON UPPER SECTION

OD = 20" × t = .75 in *

WELDS FROM COMPRESS*

INNER FILLET = .125

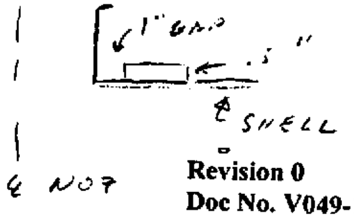
OUTER " = .25

UPPER GROOVE = 0

LOWER GROOVE = .25

PAD FOR VACUUM SERVICE

*.5 IN USED TO COMPENSATE FOR GAP



* WELDS WERE MODIFIED FOR VACUUM SERVICE
SEE V049-1-026

NOZZLE G (LOCATED ON 1/2 IN SHELL)

RADIAL LOAD FROM VACUUM PRESSURE

$$F_R = \pi r^2 P$$

$$r = \frac{7.75}{2} = 3.875$$

$$P = 14.7 \text{ psi}$$

$$F_R = \pi (3.875)^2 (14.7)$$

$$= 693.4 \text{ LB}$$

MAX STRESS FROM WRC 107

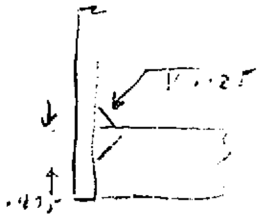
$$f = 2378 \text{ psi}$$

NO REINF PAD REQ'D FOR THIS NOZZLE SINCE IT IS ATTACHED TO 1/2" SHELL

REQUIRED WELDS FROM COMPRESS*

FILLET WELD = .125

GROOVE WELD = .1875



* WELDS WERE MODIFIED FOR VACUUM VESSEL SERVICE

Top Head - BSC

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: F&D head
Material specification: SA 240 304L HIGH

Internal design pressure: P = 2 psi @ 400 deg F
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
Head to shell seam - Spot UW-11(b) type 1

Estimated weight:	new = 1232.9	corr = 1232.9	lb
capacity:	new = 468.96	corr = 468.96	US ga

ID = 104.25 crown L = 105 knuckle r = 6.5 t = .375 in (min)

Straight flange = 2 forming allowance = 0 in

Design thickness: (At 400 deg F) Appendix 1-4(d) Eq 3

M = .25*(3 + (L/r)^.5)
= .25*(3 + (105/6.5)^.5)
= 1.7548

t = P*L*M/(2*S*E - 0.2*P) + Corrosion + fa
= 2*105*1.7548/(2*14700*0.85 - 0.2*2) + 0 + 0
= 0.0147 in

MAP: (New & at 0 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.375/(105*1.7548 + 0.2*0.375) - 0
= 57.75679 psi

MAWP: (Corroded & at 400 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*14700*0.85*0.375/(105*1.7548 + 0.2*0.375) - 0
= 50.83981 psi

External Pressure: (Corroded & at 400 deg F) UG-33(e)

A = .125/(Ro/t)
= .125/(105.375/0.32589)
= 0.000387

From table HA-3: B = 4755.5

Top Head - BSC

Pa= B/(Ro/t)
= 4755.5/(105.375/0.32589)
= 14.7072 psi

Check the external pressure per UG-33(a)(1)

t = 1.67*Pa*Lo*M/(2*S*E + 1.67*Pa*(M-0.2))
= 1.67*14.7072*105.375*1.7548/(2*14700*1 + 1.67*14.7072*(1.7548-0.2))
= 0.154277 in

Design thickness for external pressure Pa = 14.7072 psi:

= t + Corrosion + fa
= 0.32589 + 0 + 0
= 0.32589 in

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

A = .125/(Ro/t)
= .125/(105.375/0.375)
= 0.000445

From table HA-3: B = 4873.8

Pa= B/(Ro/t)
= 4873.8/(105.375/0.375)
= 17.3445 psi

Check the Maximum External Pressure: UG-33(a)(1) & App. 1-4(d)

Pc= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
= 2*14700*1*0.375/((1.7548*105.375 - 0.375*(1.7548-0.2))*1.67)
= 35.81529 psi

The maximum allowable external pressure is 17.3445 psi.

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Top Head - BSC

ANALYSIS FOR THICKNESS
REDUCED BY 1/32"

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

```
Component:                  F&D head
Material specification:     SA 240 304L HIGH

Internal design pressure:   P = 2        psi @  400      deg F
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
               Head to shell seam -  Spot UW-11(b) type 1

Estimated weight:        new = 1128.8     corr = 1128.8     lb
        capacity:        new = 468.96     corr = 468.96     US ga

ID = 104.25  crown L = 105     knuckle r = 6.5       t = .34375  in (min)
Straight flange = 2            forming allowance = 0         in
```

= 11/32

WARNING! F&D head geometry is not per UG-32(j).

CROWN RAD = 105 > OD = 104

Design thickness: (At 400 deg F) Appendix 1-4(d) Eq 3

```
M = .25*(3 + (L/r)^.5)
  = .25*(3 + (105/6.5)^.5)
  = 1.7548

t = P*L*M/(2*S*E - 0.2*P) + Corrosion + fa
  = 2*105*1.7548/(2*14700*0.85 - 0.2*2) + 0 + 0
  = 0.0147 in
```

MAP: (New & at 0 deg F) Appendix 1-4(d) Eq 3

```
P = 2*S*E*t/(L*M + 0.2*t) - Ps
  = 2*16700*0.85*0.34375/(105*1.7548 + 0.2*0.34375) -  0
  = 52.94551 psi
```

MAWP: (Corroded & at 400 deg F) Appendix 1-4(d) Eq 3

```
P = 2*S*E*t/(L*M + 0.2*t) - Ps
  = 2*14700*0.85*0.34375/(105*1.7548 + 0.2*0.34375) -  0
  = 46.60474 psi
```

External Pressure: (Corroded & at 400 deg F) UG-33(e)

```
A = .125/(Ro/t)
  = .125/(105.3438/0.32589)
```

Top Head - BSC

```
   = 0.000387

   From table HA-3:                         B = 4754.8

 Pa= B/(Ro/t)
   = 4754.8/(105.3438/0.32589)
   = 14.7094 psi

 Check the external pressure per UG-33(a)(1)

 t = 1.67*Pa*Lo*M/(2*S*E + 1.67*Pa*(M-0.2))
   = 1.67*14.7094*105.3438*1.7548/(2*14700*1 + 1.67*14.7094*(1.7548-0.2))
   = 0.154254 in
```

Design thickness for external pressure Pa = 14.7094 psi:

```
   = t + Corrosion + fa
   = 0.32589 + 0 + 0
   = 0.32589 in
```

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

```
 A = .125/(Ro/t)
   = .125/(105.3438/0.34375)
   = 0.000408

   From table HA-3:                         B = 4797.2

 Pa= B/(Ro/t)
   = 4797.2/(105.3438/0.34375)
   = 15.6539 psi

 Check the Maximum External Pressure:  UG-33(a)(1) & App. 1-4(d)

 Pe= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
   = 2*14700*1*0.34375/((1.7548*105.3438 - 0.34375*(1.7548-0.2))*1.67)
   = 32.83179 psi

 The maximum allowable external pressure is 15.6539 psi.
```

Upper Cylindrical Shell - BSC

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Internal design pressure: P = 2 psi @ 400 deg F
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 = 1428.1 corr = 1428.1 lb
capacity: new = 2217.078 corr = 2217.078 US ga

ID = 104.25 length Lc= 60 t = 0.25 in (new)

Design thickness: UG-27(c)(1) Circ. stress

t = P*R/(S*E - 0.6*P) + Corrosion
= 2*52.125/(14700*0.85 - 0.6*2) + 0
= 0.0083 in

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

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(52.125 + 0.6*0.25) - 0
= 67.88618 psi

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

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.25/(52.125 + 0.6*0.25) - 0
= 59.7561 psi

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

L/Do = 37.90131/104.75 =0.3618 Do/t = 104.75/0.23897 = 438.3395
From table G: A = 0.000425
From table HA-3: B = 4834.6

Pa= 4*B/(3*Do/t)
= 4*4834.6/(3*104.75/0.23897)
= 14.7058 psi

Design thickness for external pressure Pa = 14.7058 psi:

= t + Corrosion
= 0.23897 + 0

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Upper Cylindrical Shell - BSC

= 0.23897 in

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

L/Do = 37.90131/104.75 =0.3618   Do/t = 104.75/0.25 = 419
From table G: A = 0.000452
From table HA-3: B = 4887.2

Pa= 4*B/(3*Do/t)
= 4*4887.2/(3*104.75/0.25)
= 15.5519 psi

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Shell Stiffener

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Identifier: Shell Stiffener
Ring material specification: SA 240 304L HIGH
Number of rings in this group: 1
Distance first ring to datum line: 110 in
Ring spacing: 0 in

Ring description: 4x4x1/4 Equal Angle
Ring is rolled: leg out (easy way)
Ring cross sectional area: As = 1.94 in^2
Ring moment of inertia: Ir = 3.04 in^4

Calculations for ring 110 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.23897 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 104.75 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 33.95065 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*104.75/(0.23897 + 1.94/33.95065))
= 3900.111

From table HA-3 (ring) A = 2.949634E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (104.75^2*33.95065*(0.23897 + 1.94/33.95065)*2.949634E-04)/10.9
= 2.985063 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 5.62911

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(104.75*0.25)
= 5.62911 in

W = Ls = 33.95065 in

Shell area A1 = W*ts = 1.407277 in^2

Distance to the ring neutral axis

Shell Stiffener

```
Y2 = Ring NA + ts/2
   = 1.09 + 0.25/2
   = 1.215 in
```

Neutral axis of combined section

```
NA = As*Y2/(A1 + As)
   = 1.94*1.215/(1.407277 + 1.94)
   = .7041842 in
```

Inertia of the shell about the combined section NA

```
I1 = W*ts^3/12 + A1*NA^2
   = 5.62911*0.25^3/12 + 1.407277*0.7041842^2
   = .7051639 in^4
```

Inertia of the ring about the combined section NA

```
I2 = Ir + As*(NA - Y2)^2
   = 3.04 + 1.94*(0.7041842 - 1.215)^2
   = 3.54621 in^4
```

Total available I = I1 + I2 = 4.251373 in^4

The 4x4x1/4 Equal Angle vacuum stiffener is satisfactory.

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RING STIFFENER CONNECTION WELD PER ASME VIII-1, UG-30

USE INTERMITTENT WELD STAGGERED, 2 IN @ 4 IN

MAX CLEAR SPACING

$S = 2\text{ IN} = 8t$ FOR EXT. RING - ok

$t = .25$ IN SHELL THICKNESS

1) RADIAL PRESS LOAD

$$PL_s = 14.7(30) = 441\ \text{LB/IN}$$

2) RADIAL SHEAR LOAD

$$.01\ PL_s\ D_o = .01(441)(105)$$

$$= 463\ \text{LB}$$

FOR A 4 IN SPACING THE TOTAL RADIAL PRESS LOAD IS

$$F = 4\,PL_s = 4(441) = 1764\ \text{LB}$$

WELD AREA FOR $t = 3/16$ =

$$A_w = 2 \times 2 \times .707(3/16) = .53\ \text{IN}^2$$

WELD SHEAR STRESS

$$f_v = \frac{F}{A_w} = \frac{1764}{.53} = 3300\ \text{psi ok}$$

$< .55(14700) = 8085$ psi

MIN WELD SIZE IS 1/4" (UG 30 f)

∴ USE 1/4 IN 2 IN @ 4 IN STAGGERED

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Main Section Cylinder

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Internal design pressure: P = 2 psi @ 400 deg F
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 = 3817.3 corr = 3817.3 lb
capacity: new = 2956.104 corr = 2956.104 US ga

ID = 104.25 length Lc= 80 t = 0.5 in (new)

Design thickness: UG-27(c)(1) Circ. stress

t = P*R/(S*E - 0.6*P) + Corrosion
= 2*52.125/(14700*0.85 - 0.6*2) + 0
= 0.0083 in

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

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.5/(52.125 + 0.6*0.5) - 0
= 135.3839 psi

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

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.5/(52.125 + 0.6*0.5) - 0
= 119.1702 psi

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

L/Do = 80/105.25 =0.7601 Do/t = 105.25/0.30747 = 342.3098
From table G: A = 0.000288
From table HA-3: B = 3807.2

Pa= 4*B/(3*Do/t)
= 4*3807.2/(3*105.25/0.30747)
= 14.8295 psi

Design thickness for external pressure Pa = 14.8295 psi:

= t + Corrosion
= 0.30747 + 0

Main Section Cylinder

= 0.30747 in

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

L/Do = 80/105.25 =0.7601 Do/t = 105.25/0.5 = 210.5
From table G: A = 0.000587
From table HA-3: B = 5117.2

Pa= 4*B/(3*Do/t)
= 4*5117.2/(3*105.25/0.5)
= 32.413 psi

Nozzle E

Opening N-E Reinforcement Calculations Per UG-37

Located on:	Upper Cylindrical Shell - BSC
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	14 inch 75# SO A240304L
ANSI B16.47 flange rating MAP:	115 psi
ANSI B16.47 flange rating MAWP:	80 psi
Nozzle material specification:	SA 240 304L HIGH
Pad material specification:	SA 240 304L HIGH
Nozzle orientation:	45 degrees
End of nozzle to shell center:	55.875 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	3.5 in

```
       tn ->| |<-                                   corrosion allow = 0 in
dp->|         _          _  |<-    noz thick new tn= .12 in
    |        | |<- d ->| |twl |    nozzle id. new d= 13.75 in
->| |<tw2|  |         |>| |<-|     pad diameter dp = 20 in
__| |____/ |          | |\____     pad thickness te= .25 in
te|/|      |          | |     |\   fillet weld twl = .125 in
_________|_|_v        | |_________ fillet weld tw2 = .25 in
________/|_|_tw3      |_|\________ groove weld tw3 = .25 in
             ^
<---- L ---->|                      To datum L= 124 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .55 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 2*6.875/(14700*1 - 0.6*2)
= 0.0009 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 2*52.125/(14700*1 - 0.6*2)
= 0.0071 in

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Area required

Nozzle E

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)
= 13.75*0.0071*1 + 2*0.12*0.0071*1*(1 - 1)
= .0976 in^2

Area available

A1 = larger of the following = 3.34 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.75*(1*0.25-1*0.0071) - 2*0.12*(1*0.25-1*0.0071)*(1-1)
= 3.34 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.12)*(1*0.25-1*0.0071) - 2*0.12*(1*0.25-1*0.0071)*(1-1)
= .18 in^2

A2 = smaller of the following = 0.131 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.0009)*1*0.25
= .149 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.12 - 0.0009)*(2.5*0.12 + 0.25)*1
= .131 in^2

A41 = Leg^2*fr3
= 0.125^2*1 = .016 in^2

A42 = Leg^2*fr4
= 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (20 - 13.75 - 2*0.12)*0.25*1
= 1.5025 in^2

Area = A1 + A2 + A41 + A42 + A5
= 3.34 + 0.131 + 0.016 + 0.063 + 1.5025
= 5.0525 in^2

As Area > A the reinforcement is adequate for MAWP = 2 at 400 Deg F

Check the welds - From UW-16(c)(2)

Inner Fillet: tmin = lesser of 0.75 or tn or te, tmin = 0.12 in
tw(min) = 0.7*tmin = 0.084 in

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Nozzle E

tw(actual) = 0.7*Leg = 0.7*0.125 = 0.0875 in

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 = 0.0009 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.0071 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 = 0.12 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*13.99*0.125*7203 = 19776.11 lbf

(2) Outer fillet weld in shear
(Pi/2)*Pad O.D.*Leg*So = 1.57*20*0.25*7203 = 56543.55 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.87*0.12*10290 = 26888.88 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*13.99*0.25*10878 = 59731.91 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.0976 - (13.75 - 2*0.12)*(1*0.25 - 1*0.0071))*14700
=-46804.49 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.131 + 1.5025 + 0.016 + 0.063)*14700
= 25173.75 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv

Nozzle E

= (0.131 + 0 + 0.016 + 0 + 2*0.12*0.25*1)*14700
= 3042.9 lbf

W3-3 = (A2 + A3 + A5 + A41 + A42 + A43 + 2*tn*t*fr1)*Sv
= (0.131 + 0 + 1.5025 + 0.016 + 0.063 + 0 + 2*0.12*0.25*1)*14700
= 26055.75 lbf

Load for path 1-1 lesser of W or W1-1 =-46804.49 lbf
Path 1-1 Thru (2) & (3) = 56543.55 + 26888.88 = 83432.43 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 =-46804.49 lbf
Path 2-2 Thru (1), (4) = 19776.11 + 59731.91 = 79508.02 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 =-46804.49 lbf
Path 3-3 Thru (2), (4) = 56543.55 + 59731.91 = 116275.5 lbf
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Pad strength = A5*Sp = 22086.75 lbf
Outer fillet weld strength is adequate.

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .55 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

L/Do = 3.5/13.99 = .2502 Do/t = 13.99/0.03032 = 461.4116
From table G: A = 0.000587
From table HA-3: B = 5117.2

Pa= 4*B/(3*Do/t)
= 4*5117.2/(3*13.99/0.03032)
= 14.7871 psi

Nozzle required thickness trn = .03032 in

Required thickness tr from UG-37(d)(1) = .239 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

Nozzle E

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(13.75*0.239*1 + 2*0.12*0.239*1*(1 - 1))
= 1.6431 in^2

Area available

A1 = larger of the following = .151 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.75*(1*0.25-1*0.239) - 2*0.12*(1*0.25-1*0.239)*(1-1)
= .151 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.12)*(1*0.25-1*0.239) - 2*0.12*(1*0.25-1*0.239)*(1-1)
= .008 in^2

A2 = smaller of the following = 0.099 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.03032)*1*0.25
= .112 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.12 - 0.03032)*(2.5*0.12 + 0.25)*1
= .099 in^2

A41 = Leg^2*fr3
= 0.125^2*1 = .016 in^2

A42 = Leg^2*fr4
= 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (20 - 13.75 - 2*0.12)*0.25*1
= 1.5025 in^2

Area = A1 + A2 + A41 + A42 + A5
= 0.151 + 0.099 + 0.016 + 0.063 + 1.5025
= 1.8315 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 = 0.03032 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0522 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

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Nozzle E

Available nozzle wall thickness new, tn = 0.12 in

The nozzle neck thickness is adequate for Pe.

Nozzle E

Applied Loads

Radial load	Pr = 2183 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 = 2 psi

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

Mean radius Rm = 52.25 in
Rm/t = 104.5

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*(6.875/7.12)^2 + 3*(6.875/7.12)^4)
= 2.351

Local circ. pressure stress = I*P*Rm/t = 491 psi

Local long. pressure stress = P*Rm/2t = 104 psi

Maximum combined stress =-4686 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-1154 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle E

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	10.677	0.117					-892	-892	-892	-892
4C*	15.057	0.117	-1258	-1258	-1258	-1258				
1C	0.0765	0.117					-4008	4008	-4008	4008
2C-1	0.0440	0.117	-2305	2305	-2305	2305				
3A*	4.1315	0.117								
1A	0.0774	0.117								
3B*	11.036	0.117								
1B-1	0.0281	0.117								
pressure stress*			491	491	491	491	491	491	491	491
Total circ stress			-3072	1538	-3072	1538	-4409	3607	-4409	3607
Primary membrane circ stress*			-767	-767	-767	-767	-401	-401	-401	-401
3C*	10.677	0.117	-892	-892	-892	-892				
4C*	15.057	0.117					-1258	-1258	-1258	-1258
1C-1	0.0744	0.117	-3898	3898	-3898	3898				
2C	0.0467	0.117					-2447	2447	-2447	2447
4A*	7.5665	0.117								
2A	0.0389	0.117								
4B*	4.0872	0.117								
2B-1	0.0385	0.117								
pressure stress*			104	104	104	104	104	104	104	104
Total long stress			-4686	3110	-4686	3110	-3601	1293	-3601	1293
Primary membrane long stress*			-788	-788	-788	-788	-1154	-1154	-1154	-1154
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-4686	3110	-4686	3110	-4409	3607	-4409	3607

Nozzle E

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

Mean radius Rm = 52.25 in
Rm/t = 209

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*(6.875/10.25)^2 + 3*(6.875/10.25)^4)
 = 1.489

Local circ. pressure stress = I*P*Rm/t = 622 psi

Local long. pressure stress = P*Rm/2t = 209 psi

Maximum combined stress =-13222 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-3300 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

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Nozzle E

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	8.2255	0.167					-1375	-1375	-1375	-1375
4C*	20.996	0.167	-3509	-3509	-3509	-3509				
1C	0.0595	0.167					-12469	12469	-12469	12469
2C-1	0.0148	0.167	-3102	3102	-3102	3102				
3A*	6.4789	0.167								
1A	0.0553	0.167								
3B*	13.437	0.167								
1B-1	0.0104	0.167								
pressure stress*			622	622	622	622	622	622	622	622
Total circ stress			-5989	215	-5989	215	-13222	11716	-13222	11716
Primary membrane circ stress*			-2887	-2887	-2887	-2887	-753	-753	-753	-753
3C*	8.2255	0.167	-1375	-1375	-1375	-1375				
4C*	20.996	0.167					-3509	-3509	-3509	-3509
1C-1	0.0390	0.167	-8173	8173	-8173	8173				
2C	0.0353	0.167					-7398	7398	-7398	7398
4A*	17.794	0.167								
2A	0.0238	0.167								
4B*	5.7771	0.167								
2B-1	0.0144	0.167								
pressure stress*			209	209	209	209	209	209	209	209
Total long stress			-9339	7007	-9339	7007	-10698	4098	-10698	4098
Primary membrane long stress*			-1166	-1166	-1166	-1166	-3300	-3300	-3300	-3300
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-9339	7007	-9339	7007	-13222	11716	-13222	11716

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Nozzle G

Opening N-G Reinforcement Calculations Per UG-37

Located on:	Main Section Cylinder
Local vessel thickness:	.5 in
Liquid static head included:	0 psi
Flange description:	8 inch 75# WN A240304L
ANSI B16.47 flange rating MAP:	115 psi
ANSI B16.47 flange rating MAWP:	80 psi
Nozzle material specification:	SA 240 304L HIGH
Nozzle orientation:	90 degrees
End of nozzle to shell center:	55.625 in
Nozzle offset from center Lo:	0 in
Projection outside vessel Lpr:	3 in

```
  tn ->|  |<-
        _        _
       | |<- d ->| |
tw1->| |<|       | |
     |/| |  v    | |\
_____.-| |  -    | |-._____
_____\|_|_tw2    |_|/_____
            ^
<---- L ---->|

corrosion allow = 0 in
noz thick new tn= .12 in
nozzle id. new d= 7.75 in
fillet weld tw1 = .125 in
groove weld tw2 = .1875 in

To datum L= 40 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 2*3.875/(14700*1 - 0.6*2)
= 0.0005 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 2*52.125/(14700*1 - 0.6*2)
= 0.0071 in

Area required

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

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

Nozzle G

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

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
  = 7.75*0.0071*1 + 2*0.12*0.0071*1*(1 - 1)
  = .055 in^2
```

Area available

```
A1 = larger of the following          = 3.82 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.75*(1*0.5-1*0.0071) - 2*0.12*(1*0.5-1*0.0071)*(1-1)
  = 3.82 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.5+0.12)*(1*0.5-1*0.0071) - 2*0.12*(1*0.5-1*0.0071)*(1-1)
  = .611 in^2

A2 = smaller of the following          = 0.072 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.12 - 0.0005)*1*0.5
  = .299 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.12 - 0.0005)*1*0.12
  = .072 in^2

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

Area = A1 + A2 + A41
  = 3.82 + 0.072 + 0.016
  = 3.908 in^2

As Area > A the reinforcement is adequate for MAWP = 2 at 400 Deg F
```

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

```
tmin = lesser of 0.75 or tn or t, tmin = 0.12 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.084 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 = 0.0005 in (E = 1)
Wall thickness per UG-45(b)(1):       tr2 = 0.0071 in
Wall thickness per UG-16(b):          tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):        tr4 = 0.28175 in
```

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Nozzle G

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 = 0.12 in

The nozzle neck thickness is adequate for MAWP.

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

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

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*7.99*0.125*7203 = 11294.57 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.87*0.12*10290 = 15257.07 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*7.99*0.1875*10878 = 25585.67 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.055 - (7.75 - 2*0.12)*(1*0.5 - 1*0.0071))*14700
=-53606.18 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.072 + 0 + 0.016 + 0)*14700
= 1293.6 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.072 + 0 + 0.016 + 0 + 2*0.12*0.5*1)*14700
= 3057.6 lbf

Load for path 1-1 lesser of W or W1-1 =-53606.18 lbf
Path 1-1 Thru (1) & (3) = 11294.57 + 15257.07 = 26551.64 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 =-53606.18 lbf
Path 2-2 Thru (1), (4) = 11294.57 + 25585.67 = 36880.24 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 = 7.75 in

Nozzle G

Normal to the vessel wall outside 2.5*(tn-Cn) + tc = .3 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

L/Do = 3/7.99 = .3755 Do/t = 7.99/0.01833 = 435.8974
From table G: A = 0.000412
From table HA-3: B = 4808.2

Pa= 4*B/(3*Do/t)
= 4*4808.2/(3*7.99/0.01833)
= 14.7074 psi

Nozzle required thickness trn = .01833 in

Required thickness tr from UG-37(d)(1) = .3075 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*(7.75*0.3075*1 + 2*0.12*0.3075*1*(1 - 1))
= 1.1916 in^2

Area available

A1 = larger of the following = 1.492 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.75*(1*0.5-1*0.3075) - 2*0.12*(1*0.5-1*0.3075)*(1-1)
= 1.492 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.5+0.12)*(1*0.5-1*0.3075) - 2*0.12*(1*0.5-1*0.3075)*(1-1)
= .239 in^2

A2 = smaller of the following = 0.061 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.01833)*1*0.5
= .254 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.12 - 0.01833)*1*0.12
= .061 in^2

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

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Nozzle G

Area = A1 + A2 + A41
 = 1.492 + 0.061 + 0.016
 = 1.569 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 = 0.01833 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0522 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.28175 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 = 0.12 in

The nozzle neck thickness is adequate for Pe.

Nozzle G

Applied Loads

Radial load	Pr = 693.4 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 = 2 psi

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

Mean radius Rm = 52.375 in
Rm/t = 104.75

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*(3.875/4.12)^2 + 3*(3.875/4.12)^4)
= 2.25

Local circ. pressure stress = I*P*Rm/t = 471 psi

Local long. pressure stress = P*Rm/2t = 105 psi

Maximum combined stress = -2379 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress = -364 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle G

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	16.021	0.067					-424	-424	-424	-424
4C*	17.720	0.067	-469	-469	-469	-469				
1C	0.1209	0.067					-2012	2012	-2012	2012
2C-1	0.0837	0.067	-1393	1393	-1393	1393				
3A*	3.2919	0.067								
1A	0.0926	0.067								
3B*	10.724	0.067								
1B-1	0.0440	0.067								
pressure stress*			471	471	471	471	471	471	471	471
Total circ stress			-1391	1395	-1391	1395	-1965	2059	-1965	2059
Primary membrane circ stress*			2	2	2	2	47	47	47	47
3C*	16.021	0.067	-424	-424	-424	-424				
4C*	17.720	0.067					-469	-469	-469	-469
1C-1	0.1238	0.067	-2060	2060	-2060	2060				
2C	0.0837	0.067					-1393	1393	-1393	1393
4A*	4.8183	0.067								
2A	0.0535	0.067								
4B*	3.2756	0.067								
2B-1	0.0696	0.067								
pressure stress*			105	105	105	105	105	105	105	105
Total long stress			-2379	1741	-2379	1741	-1757	1029	-1757	1029
Primary membrane long stress*			-319	-319	-319	-319	-364	-364	-364	-364
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-2379	1741	-2379	1741	-1965	2059	-1965	2059

MAXIMUM ALLOWABLE COMPRESSIVE STRESS IN UPPER SECTION CYLINDRICAL SHELL

REF: UG-23(b)

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

$R_o = 52.375$ IN

$t = .25$ IN

$A = 597(10)^{-4}$

B = 5750 (FIG HA-1 FOR TP304
(ASME CODE SECT. II, P. 640)

LONGITUDINAL STRESS

$$\sigma_L = \frac{Pr}{2t}$$

$$= \frac{14.7(52.375)}{2(.25)}$$

$= 1540$ psi $< B$ ✓
$= 5750$ psi

REQUIREMENT OF UG-23(b) IS MET
CYLINDRICAL SHELL

105 IN ID SHELL *

HEAD FOR 105 ID SHELL

DIMENSIONS FROM SECT VIII, DIV 1, UG-32(e)

CROWN RADIUS (INSIDE)

ICR = OD OF SHELL

= 105 + 2t

t = .375

ICR = 105 + 2(.375) = 105.75

KNUCKLE RADIUS = 6% OF ICR

= .06 (105.75) = 6.345 IN

COMPRESS ANALYSIS OF BSC WITH AN INCREASED ID = 105 IN FOLLOWS

FILENAME: BSC105ID.VSL

RESULTS SHOW THAT CODE REQUIREMENTS ARE MET FOR THE INCREASED ID.

* FINAL ID IS 104.5 IN

Top Head - BSC

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

```
Component:                F&D head
Material specification:   SA 240 304L HIGH

Internal design pressure: P = 2       psi @  400     deg F
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
              Head to shell seam -   Spot UW-11(b) type 1

Estimated weight:         new = 1140.8     corr = 1140.8     lb
         capacity:        new = 474.64     corr = 474.64     US ga

ID = 105     crown L = 105.75  knuckle r = 6.345     t = .34375   in (min)

Straight flange = 2        forming allowance = 0       in
```

3/8 - 1/32 FOR
THINNING

WARNING! F&D head geometry is not per UG-32(j).

Design thickness: (At 400 deg F) Appendix 1-4(d) Eq 3

```
M = .25*(3 + (L/r)^.5)
  = .25*(3 + (105.75/6.345)^.5)
  = 1.7706

t = P*L*M/(2*S*E - 0.2*P) + Corrosion + fa
  = 2*105.75*1.7706/(2*14700*0.85 - 0.2*2) + 0 + 0
  = 0.015 in
```

MAP: (New & at 0 deg F) Appendix 1-4(d) Eq 3

```
P = 2*S*E*t/(L*M + 0.2*t) - Ps
  = 2*16700*0.85*0.34375/(105.75*1.7706 + 0.2*0.34375) - 0
  = 52.10122 psi
```

MAWP: (Corroded & at 400 deg F) Appendix 1-4(d) Eq 3

```
P = 2*S*E*t/(L*M + 0.2*t) - Ps
  = 2*14700*0.85*0.34375/(105.75*1.7706 + 0.2*0.34375) - 0
  = 45.86155 psi
```

External Pressure: (Corroded & at 400 deg F) UG-33(e)

```
A = .125/(Ro/t)
  = .125/(106.0938/0.32873)
  = 0.000387
```

Top Head - BSC

From table HA-3: B = 4755.5

Pa= B/(Ro/t)
= 4755.5/(106.0938/0.32873)
= 14.7348 psi

Check the external pressure per UG-33(a)(1)

t = 1.67*Pa*Lo*M/(2*S*E + 1.67*Pa*(M-0.2))
= 1.67*14.7348*106.0938*1.7706/(2*14700*1 + 1.67*14.7348*(1.7706-0.2))
= 0.15702 in

Design thickness for external pressure Pa = 14.7348 psi:

= t + Corrosion + fa
= 0.32873 + 0 + 0
= 0.32873 in

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

A = .125/(Ro/t)
= .125/(106.0938/0.34375)
= 0.000405

From table HA-3: B = 4793.7

Pa= B/(Ro/t)
= 4793.7/(106.0938/0.34375)
= 15.5319 psi

Check the Maximum External Pressure: UG-33(a)(1) & App. 1-4(d)

Pe= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
= 2*14700*1*0.34375/((1.7706*106.0938 - 0.34375*(1.7706-0.2))*1.67)
= 32.30824 psi

The maximum allowable external pressure is 15.5319 psi.

Upper Cylindrical Shell - BSC

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: Cylinder
Material specification: SA 240 304L HIGH

Internal design pressure: P = 2 psi @ 400 deg F
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 = 1438.3 corr = 1438.3 lb
capacity: new = 2249.093 corr = 2249.093 US ga

ID = 105 length Lc= 60 t = 0.25 in (new)

Design thickness: UG-27(c)(1) Circ. stress

t = P*R/(S*E - 0.6*P) + Corrosion
= 2*52.5/(14700*0.85 - 0.6*2) + 0
= 0.0084 in

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

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.25/(52.5 + 0.6*0.25) - 0
= 67.40266 psi

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

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.25/(52.5 + 0.6*0.25) - 0
= 59.33049 psi

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

L/Do = 37.90327/105.5 =0.3593 Do/t = 105.5/0.24092 = 437.9047
From table G: A = 0.000429
From table HA-3: B = 4842.5

Pa= 4*B/(3*Do/t)
= 4*4842.5/(3*105.5/0.24092)
= 14.7445 psi

Design thickness for external pressure Pa = 14.7445 psi:

= t + Corrosion
= 0.24092 + 0

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Upper Cylindrical Shell - BSC

= 0.24092 in

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

L/Do = 37.90327/105.5 =0.3593 Do/t = 105.5/0.25 = 422
From table G: A = 0.000452
From table HA-3: B = 4887.2

Pa= 4*B/(3*Do/t)
= 4*4887.2/(3*105.5/0.25)
= 15.4414 psi

Shell Stiffener

Stiffening Ring Calculations Per UG-29

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Identifier: Shell Stiffener
Ring material specification: SA 240 304L HIGH
Number of rings in this group: 1
Distance first ring to datum line: 110 in
Ring spacing: 0 in

Ring description: 4x4x1/4 Equal Angle
Ring is rolled: leg out (easy way)
Ring cross sectional area: As = 1.94 in^2
Ring moment of inertia: Ir = 3.04 in^4

Calculations for ring 110 in from datum

Shell material specification: SA 240 304L HIGH
Required shell thickness: t = 0.24092 in
Corroded shell thickness: ts = 0.25 in
Shell outer diameter: Do = 105.5 in
Design temperature: = 400 deg F
External design pressure: P = 14.7 psi
Stiffener supported length: Ls = 33.95164 in

B = .75*(P*Do/(t + As/Ls))
= .75*(14.7*105.5/(0.24092 + 1.94/33.95164))
= 3902.359

From table HA-3 (ring) A = 2.951318E-04

Required moment of inertia of the combined ring-shell section

Is= (Do^2*Ls*(t + As/Ls)*A)/10.9
= (105.5^2*33.95164*(0.24092 + 1.94/33.95164)*2.951318E-04)/10.9
= 3.049713 in^4

Available moment of inertia of the combined ring-shell section

Shell width contributing smaller of = 5.649226

W = 1.1*Sqr(Do*ts)
= 1.1*Sqr(105.5*0.25)
= 5.649226 in

W = Ls = 33.95164 in

Shell area A1 = W*ts = 1.412306 in^2

Distance to the ring neutral axis

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Shell Stiffener

Y2 = Ring NA + ts/2
 = 1.09 + 0.25/2
 = 1.215 in

Neutral axis of combined section

NA = As*Y2/(A1 + As)
 = 1.94*1.215/(1.412306 + 1.94)
 = .7031279 in

Inertia of the shell about the combined section NA

I1 = W*ts^3/12 + A1*NA^2
 = 5.649226*0.25^3/12 + 1.412306*0.7031279^2
 = .7055842 in^4

Inertia of the ring about the combined section NA

I2 = Ir + As*(NA - Y2)^2
 = 3.04 + 1.94*(0.7031279 - 1.215)^2
 = 3.548306 in^4

Total available I = I1 + I2 = 4.25389 in^4

The 4x4x1/4 Equal Angle vacuum stiffener is satisfactory.

Main Section Cylinder

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component:	Cylinder			
Material specification:	SA 240 304L HIGH			
Internal design pressure:	P = 2	psi @	400	deg F
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 = 3844.7	corr = 3844.7	lb
capacity:	new = 2998.79	corr = 2998.79	US ga

ID = 105 length Lc= 80 t = 0.5 in (new)

Design thickness: UG-27(c)(1) Circ. stress

t = P*R/(S*E - 0.6*P) + Corrosion
= 2*52.5/(14700*0.85 - 0.6*2) + 0
= 0.0084 in

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

P = S*E*t/(R + 0.6*t) - Ps
= 16700*0.85*0.5/(52.5 + 0.6*0.5) - 0
= 134.4223 psi

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

P = S*E*t/(R + 0.6*t) - Ps
= 14700*0.85*0.5/(52.5 + 0.6*0.5) - 0
= 118.3239 psi

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

L/Do = 80/106 =0.7547 Do/t = 106/0.30843 = 343.6761
From table G: A = 0.000288
From table HA-3: B = 3807.2

Pa= 4*B/(3*Do/t)
= 4*3807.2/(3*106/0.30843)
= 14.7705 psi

Design thickness for external pressure Pa = 14.7705 psi:

= t + Corrosion
= 0.30843 + 0

Main Section Cylinder

= 0.30843 in

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

L/Do = 80/106 =0.7547 Do/t = 106/0.5 = 212
From table G: A = 0.000586
From table HA-3: B = 5115.7

Pa= 4*B/(3*Do/t)
= 4*5115.7/(3*106/0.5)
= 32.1742 psi

Rev D

Nozzle E

Opening N-E Reinforcement Calculations Per UG-37

Located on: Upper Cylindrical Shell - BSC
Local vessel thickness: .25 in
Liquid static head included: 0 psi
Flange description: 14 inch 75# SO A240304L
ANSI B16.47 flange rating MAP: 115 psi
ANSI B16.47 flange rating MAWP: 80 psi

Nozzle material specification: SA 240 304L HIGH

Pad material specification: SA 240 304L HIGH

Nozzle orientation: 45 degrees
End of nozzle to shell center: 55.875 in
Nozzle offset from center Lo: 0 in
Projection outside vessel Lpr: 3.125 in

```
    tn ->| |<-                    corrosion allow = 0 in
dp->|     _         _     |<-     noz thick new tn= .12 in
    |    | |<- d ->| |twl |       nozzle id. new d= 13.75 in
->| |<tw2| |       |>| |<-|       pad diameter dp = 20 in
__| ____/| |       | |\_____      pad thickness te= .25 in
te|/|    | |       | |    |\      fillet weld twl = .125 in
_________|_|_v     | |_________   fillet weld tw2 = .25 in
________/|_|_tw3   |_|\________   groove weld tw3 = .25 in
             ^
<----- L ----->|                  To datum L= 124 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .55 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 2*6.875/(14700*1 - 0.6*2)
= 0.0009 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 2*52.5/(14700*1 - 0.6*2)
= 0.0071 in

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Area required

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Nozzle E

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)
= 13.75*0.0071*1 + 2*0.12*0.0071*1*(1 - 1)
= .0976 in^2

Area available

A1 = larger of the following = 3.34 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.75*(1*0.25-1*0.0071) - 2*0.12*(1*0.25-1*0.0071)*(1-1)
= 3.34 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.12)*(1*0.25-1*0.0071) - 2*0.12*(1*0.25-1*0.0071)*(1-1)
= .18 in^2

A2 = smaller of the following = 0.131 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.0009)*1*0.25
= .149 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.12 - 0.0009)*(2.5*0.12 + 0.25)*1
= .131 in^2

A41 = Leg^2*fr3
= 0.125^2*1 = .016 in^2

A42 = Leg^2*fr4
= 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (20 - 13.75 - 2*0.12)*0.25*1
= 1.5025 in^2

Area = A1 + A2 + A41 + A42 + A5
= 3.34 + 0.131 + 0.016 + 0.063 + 1.5025
= 5.0525 in^2

As Area > A the reinforcement is adequate for MAWP = 2 at 400 Deg F

Check the welds - From UW-16(c)(2)

Inner Fillet: tmin = lesser of 0.75 or tn or te, tmin = 0.12 in
tw(min) = 0.7*tmin = 0.084 in

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Nozzle E

tw(actual) = 0.7*Leg = 0.7*0.125 = 0.0875 in

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 = 0.0009 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0.0071 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 = 0.12 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*13.99*0.125*7203 = 19776.11 lbf

(2) Outer fillet weld in shear
(Pi/2)*Pad O.D.*Leg*So = 1.57*20*0.25*7203 = 56543.55 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*13.87*0.12*10290 = 26888.88 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*13.99*0.25*10878 = 59731.91 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.0976 - (13.75 - 2*0.12)*(1*0.25 - 1*0.0071))*14700
=-46804.49 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.131 + 1.5025 + 0.016 + 0.063)*14700
= 25173.75 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv

Nozzle E

= (0.131 + 0 + 0.016 + 0 + 2*0.12*0.25*1)*14700
= 3042.9 lbf

W3-3 = (A2 + A3 + A5 + A41 + A42 + A43 + 2*tn*t*fr1)*Sv
= (0.131 + 0 + 1.5025 + 0.016 + 0.063 + 0 + 2*0.12*0.25*1)*14700
= 26055.75 lbf

Load for path 1-1 lesser of W or W1-1 =-46804.49 lbf
Path 1-1 Thru (2) & (3) = 56543.55 + 26888.88 = 83432.43 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 =-46804.49 lbf
Path 2-2 Thru (1), (4) = 19776.11 + 59731.91 = 79508.02 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 =-46804.49 lbf
Path 3-3 Thru (2), (4) = 56543.55 + 59731.91 = 116275.5 lbf
Path 3-3 is stronger than W so it is acceptable per UG-41(b)(2).

Pad strength = A5*Sp = 22086.75 lbf
Outer fillet weld strength is adequate.

Reinforcement Calculations for External Pressure

Limits of reinforcement UG-40

Parallel to the vessel wall d = 13.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + tc = .55 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

L/Do = 3.125/13.99 = .2234 Do/t = 13.99/0.02972 = 470.7268
From table G: A = 0.000642
From table HA-3: B = 5198.5

Pa= 4*B/(3*Do/t)
= 4*5198.5/(3*13.99/0.02972)
= 14.7247 psi

Nozzle required thickness trn = .02972 in

Required thickness tr from UG-37(d)(1) = .2409 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

Nozzle E

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(13.75*0.2409*1 + 2*0.12*0.2409*1*(1 - 1))
= 1.6562 in^2

Area available

A1 = larger of the following = .125 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 13.75*(1*0.25-1*0.2409) - 2*0.12*(1*0.25-1*0.2409)*(1-1)
= .125 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.25+0.12)*(1*0.25-1*0.2409) - 2*0.12*(1*0.25-1*0.2409)*(1-1)
= .007 in^2

A2 = smaller of the following = 0.099 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.02972)*1*0.25
= .113 in^2

= 2*(tn - trn)*(2.5*tn + te)*fr2
= 2*(0.12 - 0.02972)*(2.5*0.12 + 0.25)*1
= .099 in^2

A41 = Leg^2*fr3
= 0.125^2*1 = .016 in^2

A42 = Leg^2*fr4
= 0.25^2*1 = .063 in^2

A5 = (Dp - d - 2*tn)*te*fr4
= (20 - 13.75 - 2*0.12)*0.25*1
= 1.5025 in^2

Area = A1 + A2 + A41 + A42 + A5
= 0.125 + 0.099 + 0.016 + 0.063 + 1.5025
= 1.8055 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 = 0.02972 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0525 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

Nozzle E

Available nozzle wall thickness new, tn = 0.12 in

The nozzle neck thickness is adequate for Pe.

Nozzle E

Applied Loads

Radial load	Pr = 2183 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 = 2 psi

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

Mean radius Rm = 52.625 in
Rm/t = 105.25

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*(6.875/7.12)^2 + 3*(6.875/7.12)^4)
= 2.351

Local circ. pressure stress = I*P*Rm/t = 495 psi

Local long. pressure stress = P*Rm/2t = 105 psi

Maximum combined stress =-4703 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-1154 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle E

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	10.776	0.116					-894	-894	-894	-894
4C*	15.180	0.116	-1259	-1259	-1259	-1259				
1C	0.0768	0.116					-4024	4024	-4024	4024
2C-1	0.0443	0.116	-2321	2321	-2321	2321				
3A*	4.1565	0.116								
1A	0.0776	0.116								
3B*	11.121	0.116								
1B-1	0.0282	0.116								
pressure stress*			495	495	495	495	495	495	495	495
Total circ stress			-3085	1557	-3085	1557	-4423	3625	-4423	3625
Primary membrane circ stress*			-764	-764	-764	-764	-399	-399	-399	-399
3C*	10.776	0.116	-894	-894	-894	-894				
4C*	15.180	0.116					-1259	-1259	-1259	-1259
1C-1	0.0747	0.116	-3914	3914	-3914	3914				
2C	0.0469	0.116					-2457	2457	-2457	2457
4A*	7.6047	0.116								
2A	0.0390	0.116								
4B*	4.1127	0.116								
2B-1	0.0387	0.116								
pressure stress*			105	105	105	105	105	105	105	105
Total long stress			-4703	3125	-4703	3125	-3611	1303	-3611	1303
Primary membrane long stress*			-789	-789	-789	-789	-1154	-1154	-1154	-1154
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-4703	3125	-4703	3125	-4423	3625	-4423	3625

Nozzle E

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

Mean radius Rm = 52.625 in
Rm/t = 210.5

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*(6.875/10.25)^2 + 3*(6.875/10.25)^4)
= 1.489

Local circ. pressure stress = I*P*Rm/t = 627 psi

Local long. pressure stress = P*Rm/2t = 210 psi

Maximum combined stress =-13225 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-3307 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle E

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	8.3321	0.166					-1383	-1383	-1383	-1383
4C*	21.196	0.166	-3517	-3517	-3517	-3517				
1C	0.0595	0.166					-12469	12469	-12469	12469
2C-1	0.0149	0.166	-3123	3123	-3123	3123				
3A*	6.5607	0.166								
1A	0.0553	0.166								
3B*	13.588	0.166								
1B-1	0.0104	0.166								
pressure stress*			627	627	627	627	627	627	627	627
Total circ stress			-6013	233	-6013	233	-13225	11713	-13225	11713
Primary membrane circ stress*			-2890	-2890	-2890	-2890	-756	-756	-756	-756
3C*	8.3321	0.166	-1383	-1383	-1383	-1383				
4C*	21.196	0.166					-3517	-3517	-3517	-3517
1C-1	0.0392	0.166	-8215	8215	-8215	8215				
2C	0.0353	0.166					-7398	7398	-7398	7398
4A*	17.922	0.166								
2A	0.0238	0.166								
4B*	5.8428	0.166								
2B-1	0.0144	0.166								
pressure stress*			210	210	210	210	210	210	210	210
Total long stress			-9388	7042	-9388	7042	-10705	4091	-10705	4091
Primary membrane long stress*			-1173	-1173	-1173	-1173	-3307	-3307	-3307	-3307
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-9388	7042	-9388	7042	-13225	11713	-13225	11713

Nozzle G

Opening N-G Reinforcement Calculations Per UG-37

Located on: Main Section Cylinder
Local vessel thickness: .5 in
Liquid static head included: 0 psi
Flange description: 8 inch 75# WN A240304L
ANSI B16.47 flange rating MAP: 115 psi
ANSI B16.47 flange rating MAWP: 80 psi

Nozzle material specification: SA 240 304L HIGH

Nozzle orientation: 90 degrees
End of nozzle to shell center: 55.625 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= .12 in
twl->|  |<                |  |              nozzle id. new d= 7.75 in
        |/|   v            |  |\             fillet weld twl = .125 in
______.-| |  --            |  |-.______      groove weld tw2 = .1875 in
______\|_|_tw2           |_|/______
              ^
<---- L ---->|                                To datum L= 40 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.75 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

trn = P*Rn/(Sn*E - 0.6*P)
= 2*3.875/(14700*1 - 0.6*2)
= 0.0005 in

Required thickness tr from UG-37(a)

tr= P*R/(S*E - 0.6*P)
= 2*52.5/(14700*1 - 0.6*2)
= 0.0071 in

Area required

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

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

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Nozzle G

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

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 7.75*0.0071*1 + 2*0.12*0.0071*1*(1 - 1)
= .055 in^2

Area available

A1 = larger of the following = 3.82 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.75*(1*0.5-1*0.0071) - 2*0.12*(1*0.5-1*0.0071)*(1-1)
= 3.82 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.5+0.12)*(1*0.5-1*0.0071) - 2*0.12*(1*0.5-1*0.0071)*(1-1)
= .611 in^2

A2 = smaller of the following = 0.072 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.0005)*1*0.5
= .299 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.12 - 0.0005)*1*0.12
= .072 in^2

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

Area = A1 + A2 + A41
= 3.82 + 0.072 + 0.016
= 3.908 in^2

As Area > A the reinforcement is adequate for MAWP = 2 at 400 Deg F

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

tmin = lesser of 0.75 or tn or t, tmin = 0.12 in
t1 or t2(min) = lesser of 0.25 or 0.7*tmin, t1(min) = 0.084 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 = 0.0005 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.0071 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 in

Nozzle G

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 = 0.12 in

The nozzle neck thickness is adequate for MAWP.

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

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

Strength of welded joints:

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*7.99*0.125*7203 = 11294.57 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.87*0.12*10290 = 15257.07 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*7.99*0.1875*10878 = 25585.67 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0.055 - (7.75 - 2*0.12)*(1*0.5 - 1*0.0071))*14700
=-53606.18 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.072 + 0 + 0.016 + 0)*14700
= 1293.6 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.072 + 0 + 0.016 + 0 + 2*0.12*0.5*1)*14700
= 3057.6 lbf

Load for path 1-1 lesser of W or W1-1 =-53606.18 lbf
Path 1-1 Thru (1) & (3) = 11294.57 + 15257.07 = 26551.64 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 =-53606.18 lbf
Path 2-2 Thru (1), (4) = 11294.57 + 25585.67 = 36880.24 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 = 7.75 in

Nozzle G

Normal to the vessel wall outside 2.5*(tn-Cn) + te = .3 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .3 in

Nozzle required thickness

L/Do = 2.625/7.99 = .3285 Do/t = 7.99/0.01796 = 444.8775
From table G: A = 0.000462
From table HA-3: B = 4906.1

Pa= 4*B/(3*Do/t)
= 4*4906.1/(3*7.99/0.01796)
= 14.704 psi

Nozzle required thickness trn = .01796 in

Required thickness tr from UG-37(d)(1) = .3084 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*(7.75*0.3084*1 + 2*0.12*0.3084*1*(1 - 1))
= 1.1951 in^2

Area available

A1 = larger of the following = 1.485 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.75*(1*0.5-1*0.3084) - 2*0.12*(1*0.5-1*0.3084)*(1-1)
= 1.485 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.5+0.12)*(1*0.5-1*0.3084) - 2*0.12*(1*0.5-1*0.3084)*(1-1)
= .238 in^2

A2 = smaller of the following = 0.061 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.12 - 0.01796)*1*0.5
= .255 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.12 - 0.01796)*1*0.12
= .061 in^2

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

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Nozzle G

Area = A1 + A2 + A41
= 1.485 + 0.061 + 0.016
= 1.562 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 = 0.01796 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0525 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.28175 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 = 0.12 in

The nozzle neck thickness is adequate for Pe.

Nozzle G

Applied Loads

Radial load	Pr = 693.4 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 = 2 psi

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

Mean radius Rm = 52.75 in
Rm/t = 105.5

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*(3.875/4.12)^2 + 3*(3.875/4.12)^4)
= 2.25

Local circ. pressure stress = I*P*Rm/t = 475 psi

Local long. pressure stress = P*Rm/2t = 106 psi

Maximum combined stress =-2389 psi
Allowable combined stress = +-3*S = +- 44100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-363 psi
Allowable primary membrane stress = +-1.5*S = +- 22050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle G

From Fig.	Value read	beta	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
3C*	16.149	0.066					-425	-425	-425	-425
4C*	17.850	0.066	-469	-469	-469	-469				
1C	0.1215	0.066					-2022	2022	-2022	2022
2C-1	0.0842	0.066	-1401	1401	-1401	1401				
3A*	3.3073	0.066								
1A	0.0927	0.066								
3B*	10.765	0.066								
1B-1	0.0441	0.066								
pressure stress*			475	475	475	475	475	475	475	475
Total circ stress			-1395	1407	-1395	1407	-1972	2072	-1972	2072
Primary membrane circ stress*			6	6	6	6	50	50	50	50
3C*	16.149	0.066	-425	-425	-425	-425				
4C*	17.850	0.066					-469	-469	-469	-469
1C-1	0.1244	0.066	-2070	2070	-2070	2070				
2C	0.0842	0.066					-1401	1401	-1401	1401
4A*	4.8372	0.066								
2A	0.0535	0.066								
4B*	3.2886	0.066								
2B-1	0.0699	0.066								
pressure stress*			106	106	106	106	106	106	106	106
Total long stress			-2389	1751	-2389	1751	-1764	1038	-1764	1038
Primary membrane long stress*			-319	-319	-319	-319	-363	-363	-363	-363
torsion moment Mt										
Circ shear from Vc										
Long shear from VL										
Total Shear stress										
Combined stress			-2389	1751	-2389	1751	-1972	2072	-1972	2072

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Doc. No. V049-1-015

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-016

PAGE 1 OF 33

REV.	DEO #	DATE	BY:	CHECK
0	5139	12/6/95	RDC	AGR

TITLE: Beam Splitter Chamber - Finite Element Analysis of 1 in. Thick Flanges for Bolt Preload.

BY: R.D. Cirarro

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To determine if bolt clamping force results in flange deformation that could allow leakage at Viton o-rings.

METHOD: A 3D finite element analysis of a section of the plane flange is performed. Brick elements (3D solids) are used in the IMAGES program. Both a coarse model and an enhanced finer model are analyzed. The enhanced model includes compression only springs at the flange interface to simulate gap opening (nonlinear).

ASSUMPTIONS: Symmetry is used to minimize the model by using appropriate boundary conditions. Curvature of the flange is ignored. O-ring glands and pumping channel are not included.

INPUTS: LIGO project design sketches and drawings. Durometer is 90 for Viton o-rings.

REFERENCES: 1. Parker O-Ring Handbook.
2. IMAGES 3D, Version 3.0, R.L. Cloud & Associates

CALCULATIONS: (See Attachment)

CONCLUSIONS: At a location that is midway between bolts, the gap between flanges opens a negligible amount that does not affect the seal.

NOTES: This analysis was performed for the 104 in diameter flange, but it applies to other diameter as well because of similar dimensions and bolt spacing. Computer file is FLANGE.

<u>104 1/4" I D FLANGES</u> - ANALYSIS FOR VACUUM LOAD

HOLE SPACING

No. OF BOLTS = 48

BOLT CIRCLE DIAM

$C = 110''$

CIRCUM =

$C' = \pi C = 345.6$ IN

SPACING

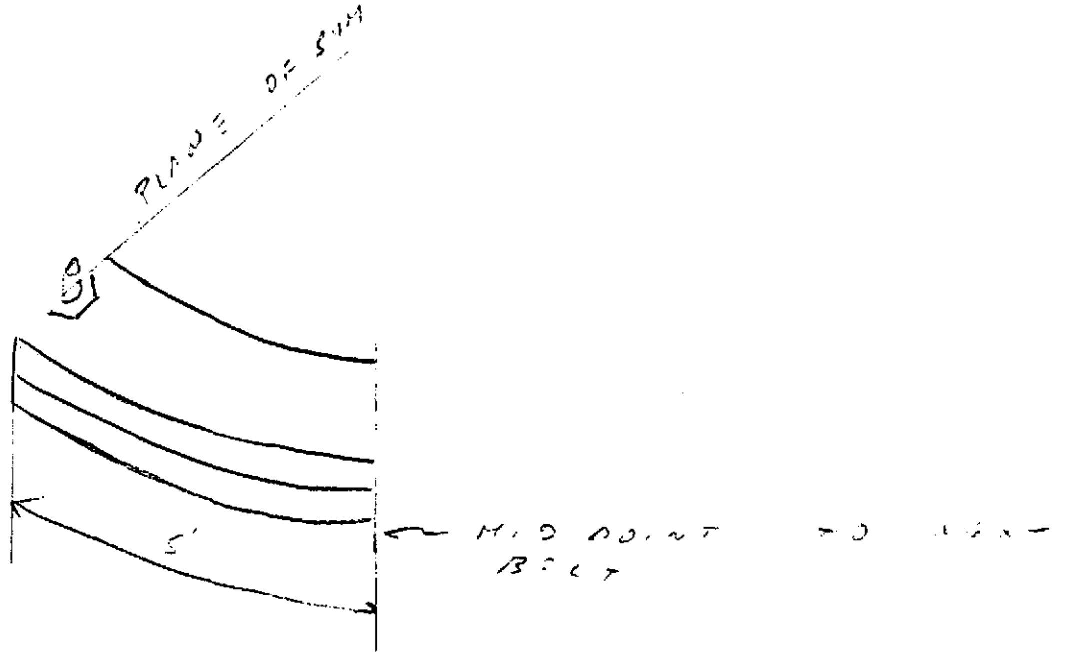
$$S = \frac{C'}{N} = \frac{345.6}{48}$$

$$= 7.20 \text{ IN}$$

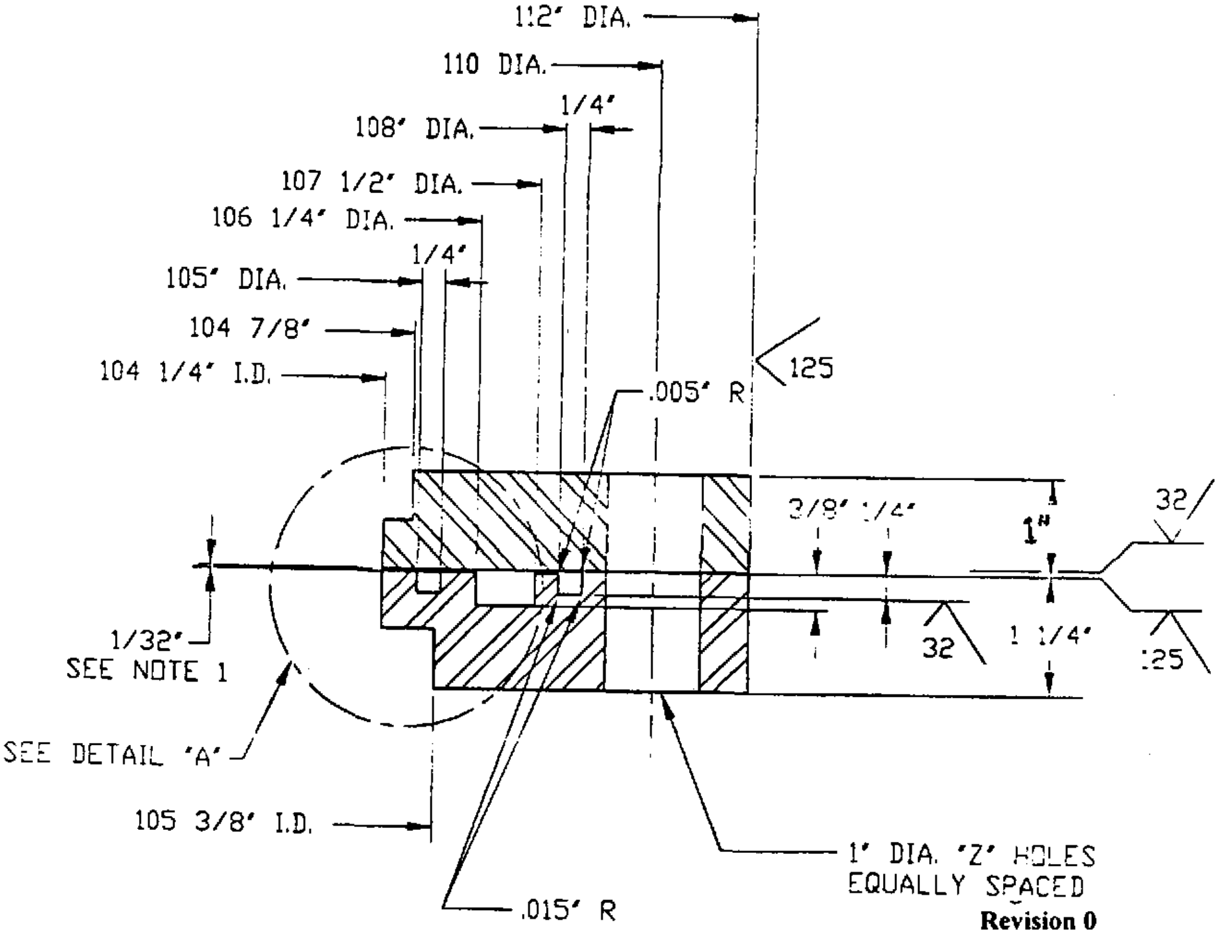
TRY 7/8" D BOLTS W/ 1" D HOLES

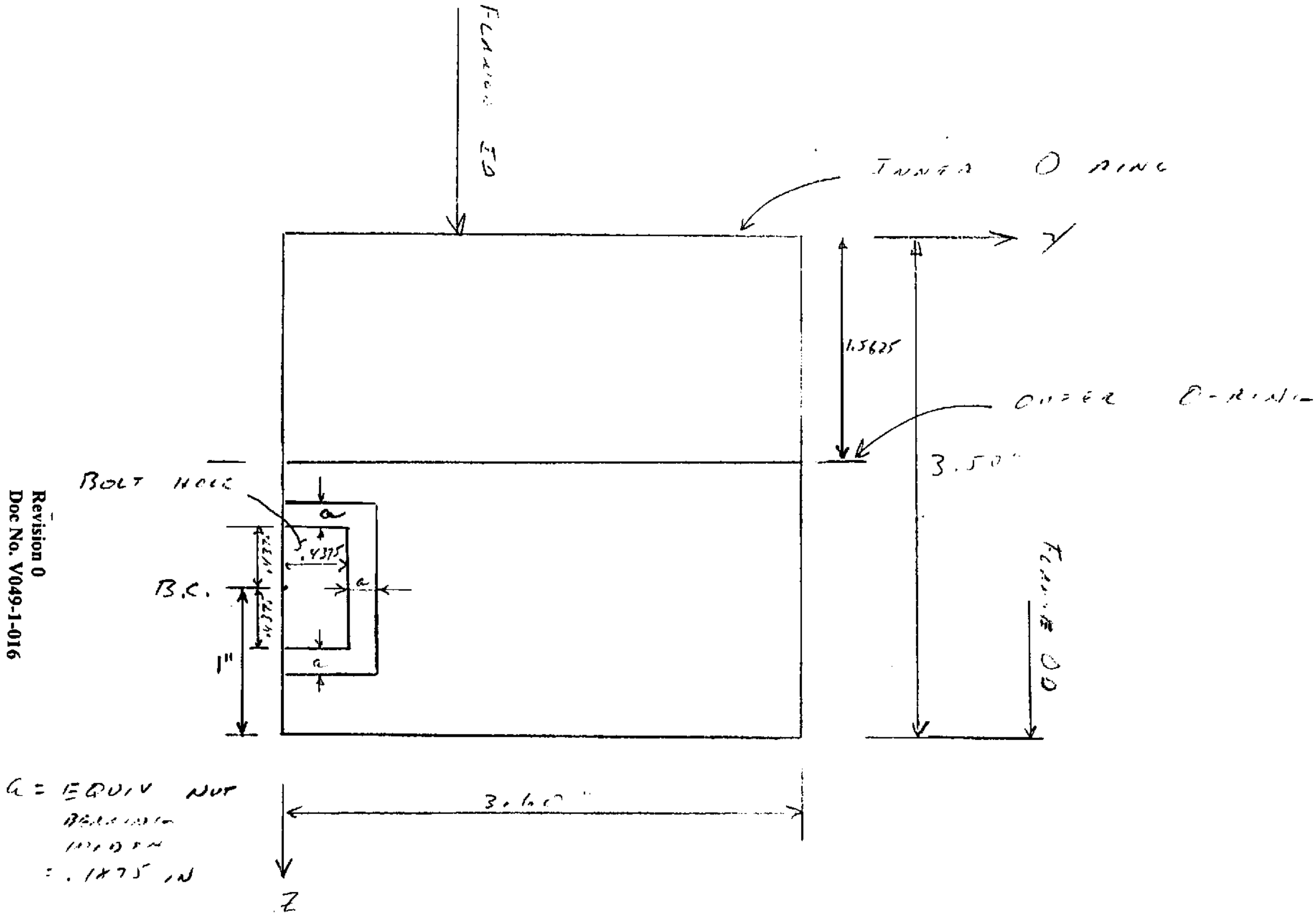
USE FE MODEL TO DETERMINE IF BOLT SPACING & FLANGE THICKNESS WILL BE SUFFICIENT TO PROVIDE CLAMPING FORCE BETWEEN THE BOLTS AT THE O-RING. 3-D BRICK ELEMENTS WILL BE USED. MODEL TOP FLANGE WHICH IS THINNER THAN BOTTOM FLANGE.

THE FE MODEL WILL NEGLECT CHAMFERS WHICH HAS NEGLIGIBLE EFFECT ON RESULTS.



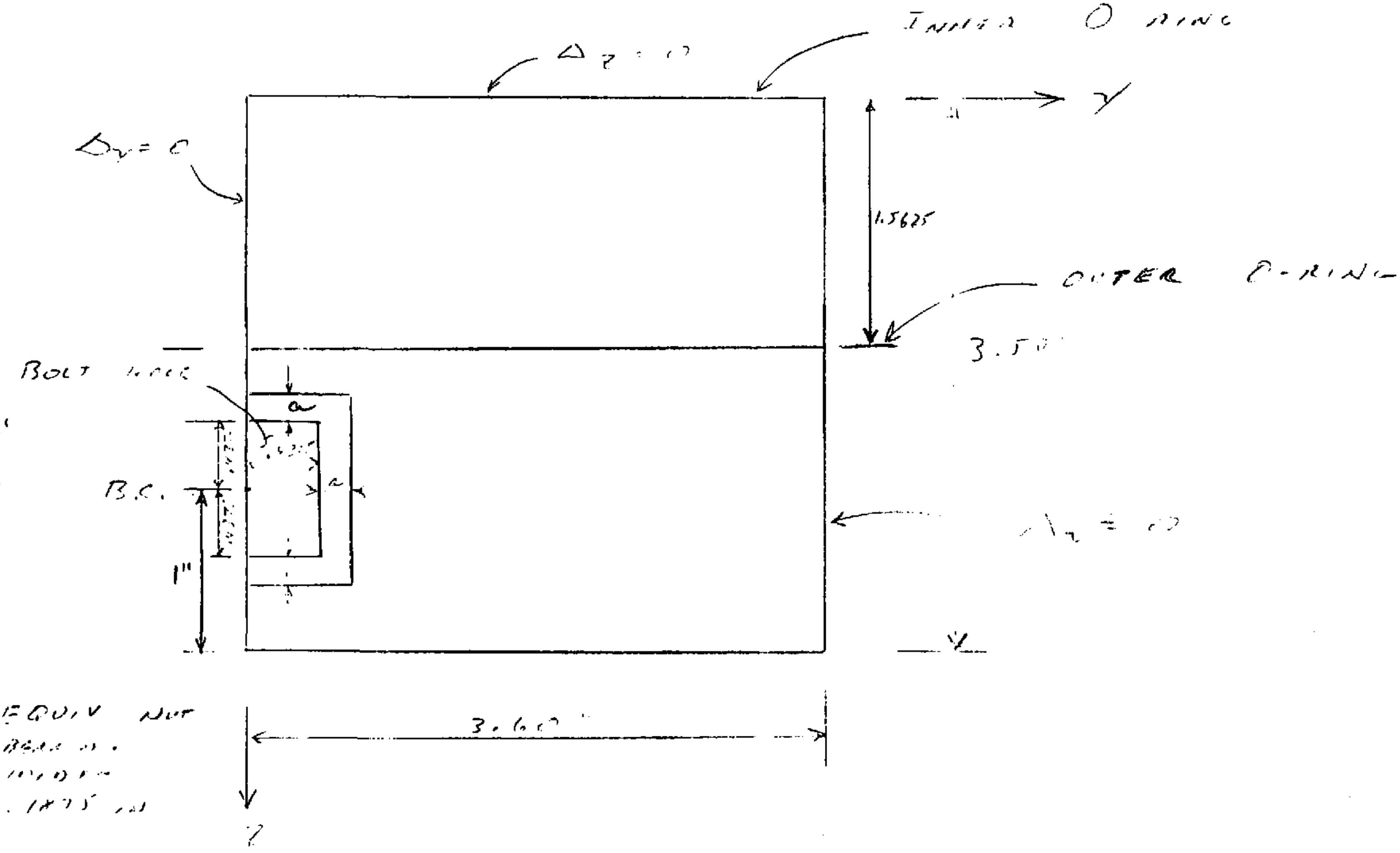
$S' = \frac{S}{2} = 3,60$ in



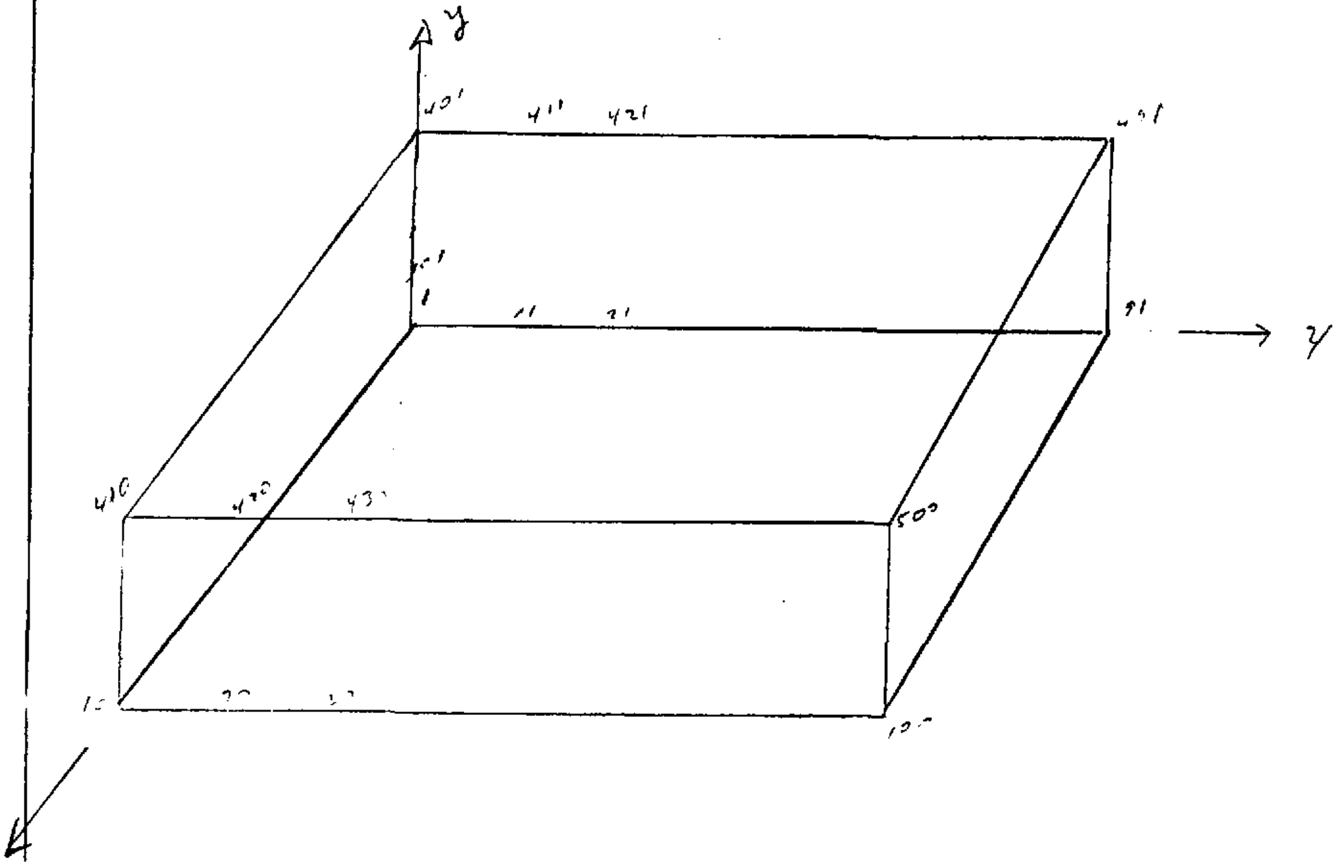


a = EQUIV NUT
BEARING
WIDTH
= .1875 IN

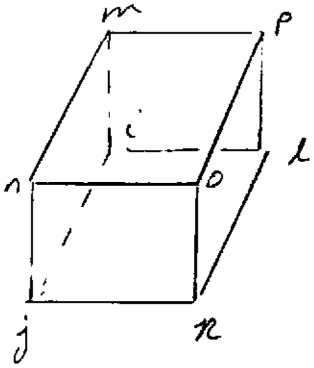
BOUNDARY CONDITIONS
@ y = 0, Δ[illegible]



a = EQUIV NUT
BEARING
WIDTH
.1875 in



TYPICAL ELEMENT NODE NUMBERING



1ST EL i j k l m n o p

1, 2, 12, 11, 101, 102, 112, 111

DELETE ELEMENTS AT BOLT HOLE
6, 7, 17, 18, 168, 169, 249 250

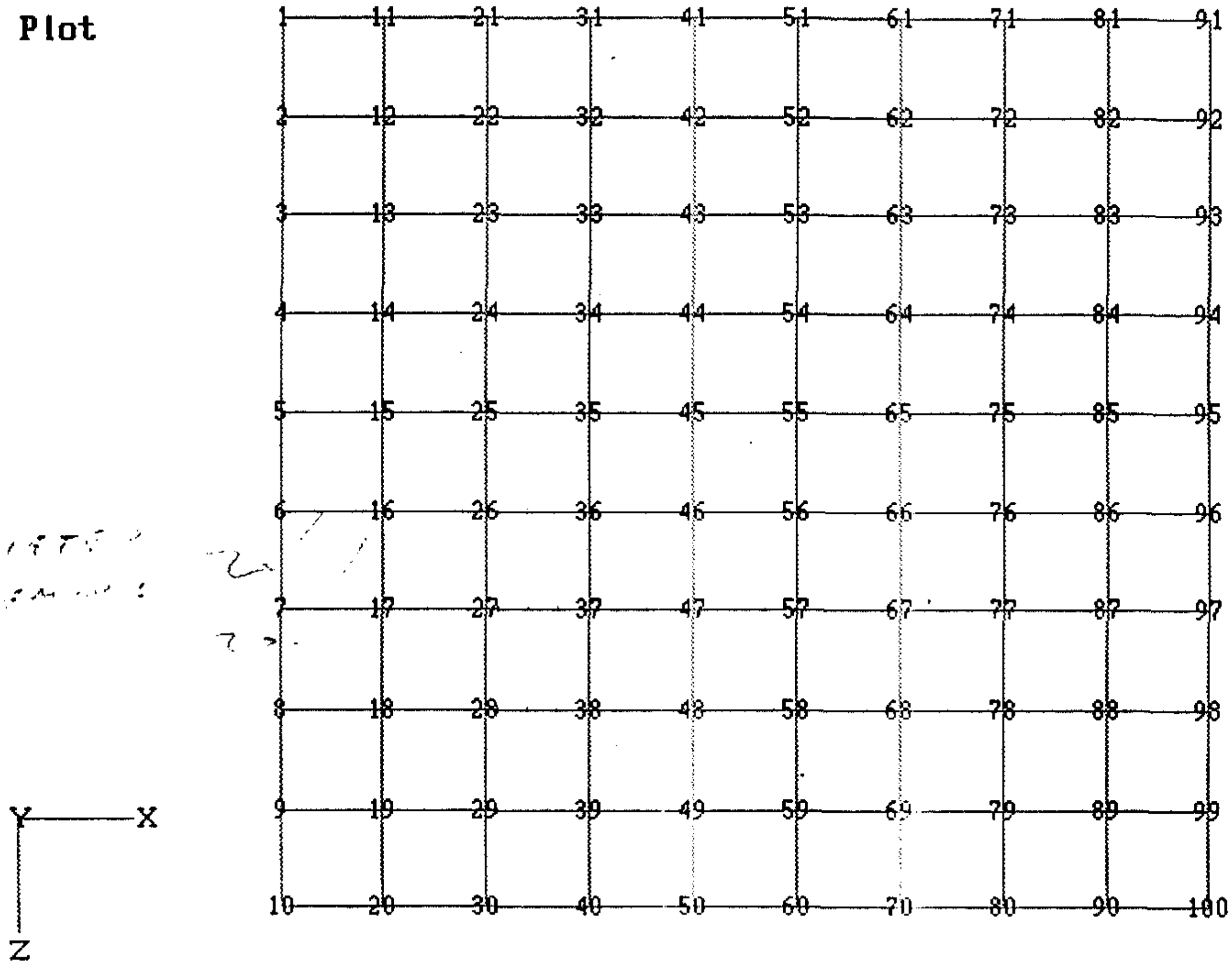
REACTIONS AT BOLT

NODE	F_x
6	14.3
8	-25.6
16	16.7
17	-29.7
18	-8.5

REACTIONS AT OUTER O-RING

NODE	F_x
5	49.3
15	65.2
25	50.6
35	43.4
45	41.0
55	27.6
65	46.7
75	57.5
85	-47.0

IMAGES-3D
Ver. 3.0
Geometry Plot



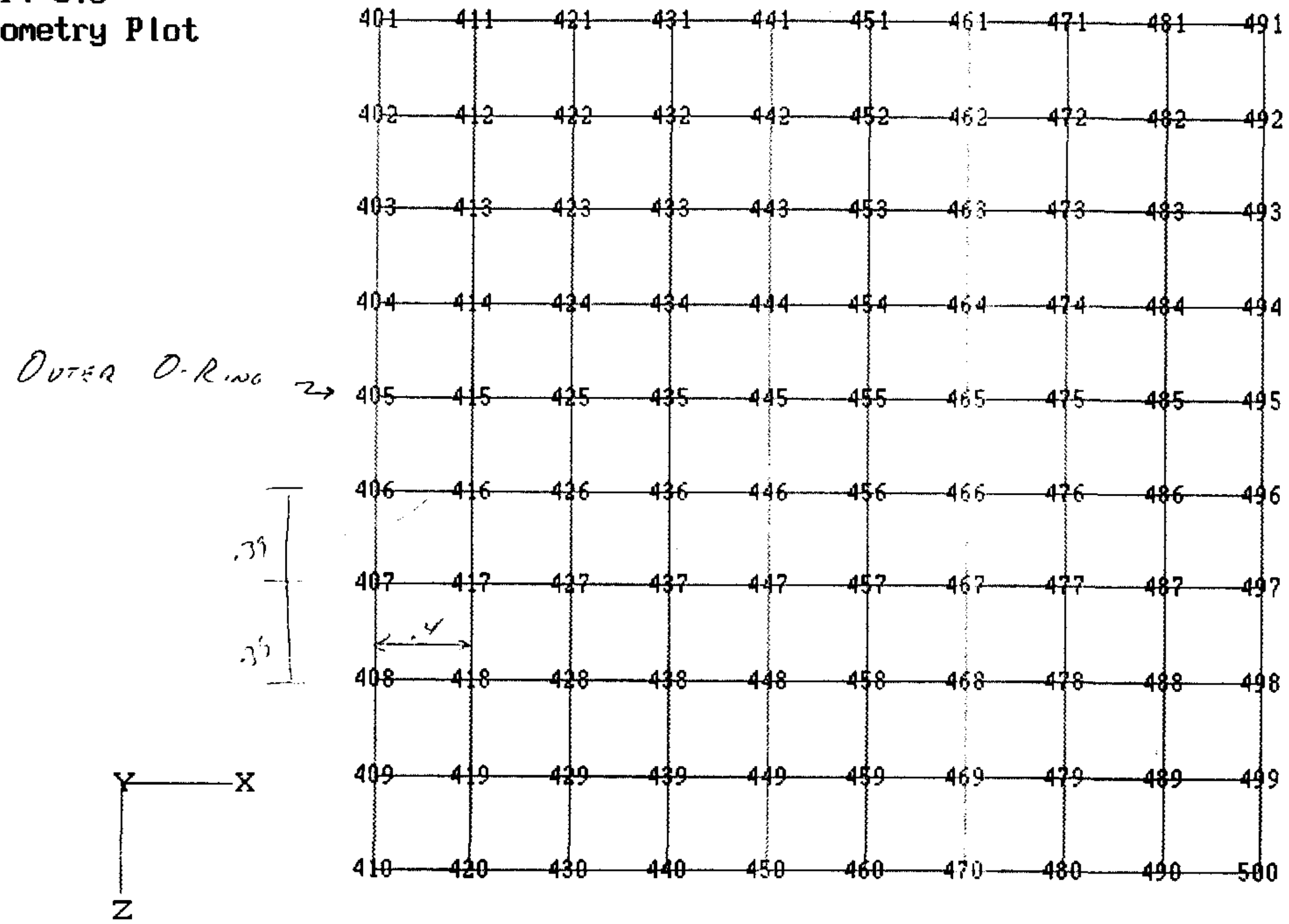
[illegible]

Flange - ID = 104, No. Bolts = 48
Wireframe Plot

9/29/95
15: 4:28

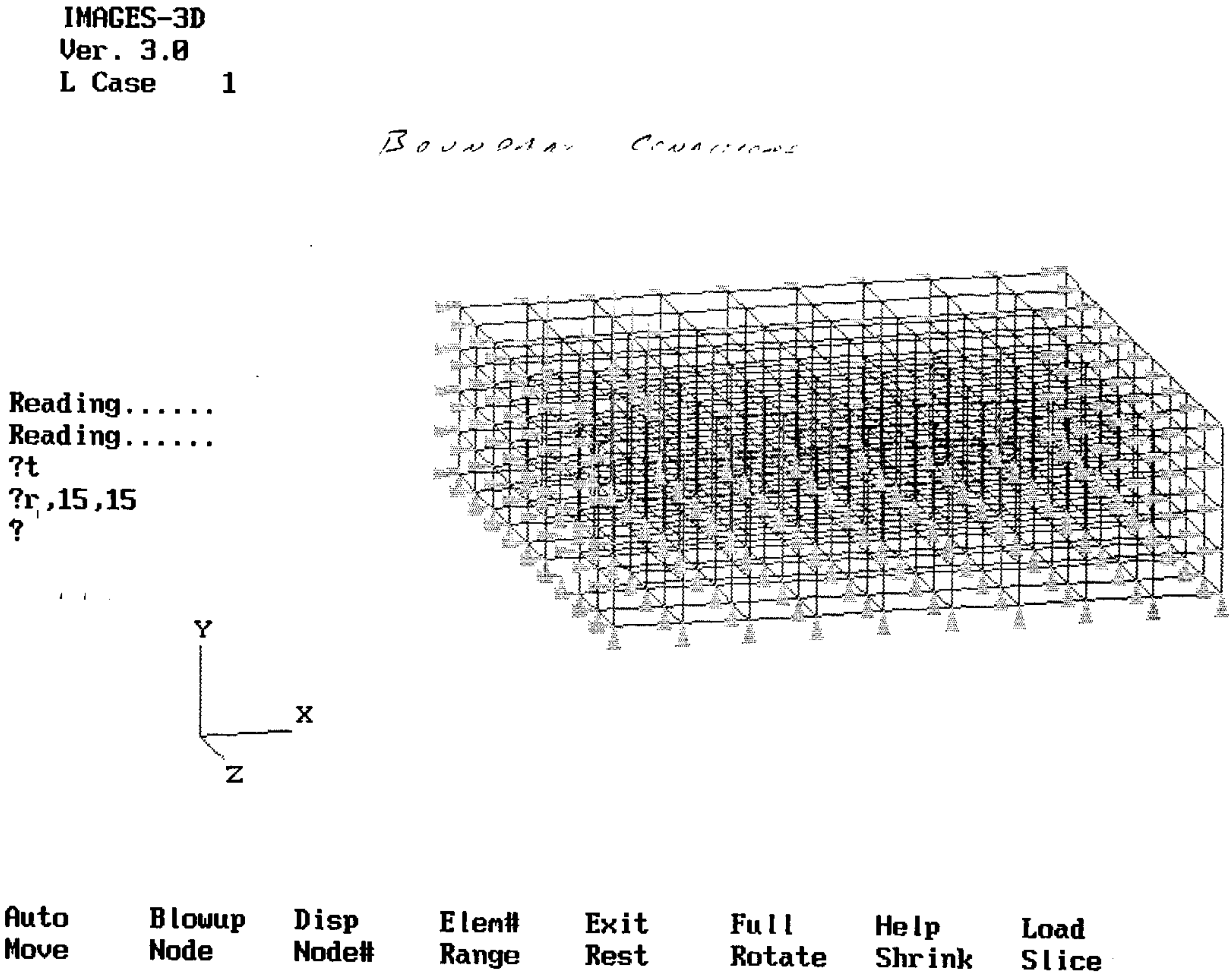
Top [illegible]

IMAGES-3D
Ver. 3.0
Geometry Plot



Flange - ID = 104, No. Bolts = 48
Wireframe Plot

9/29/95
14:55:49



```
IMAGES-3D
Ver. 3.0
L Case    1
```

Boundary Conditions

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Reading......
Reading......
?t
?r,15,15
?
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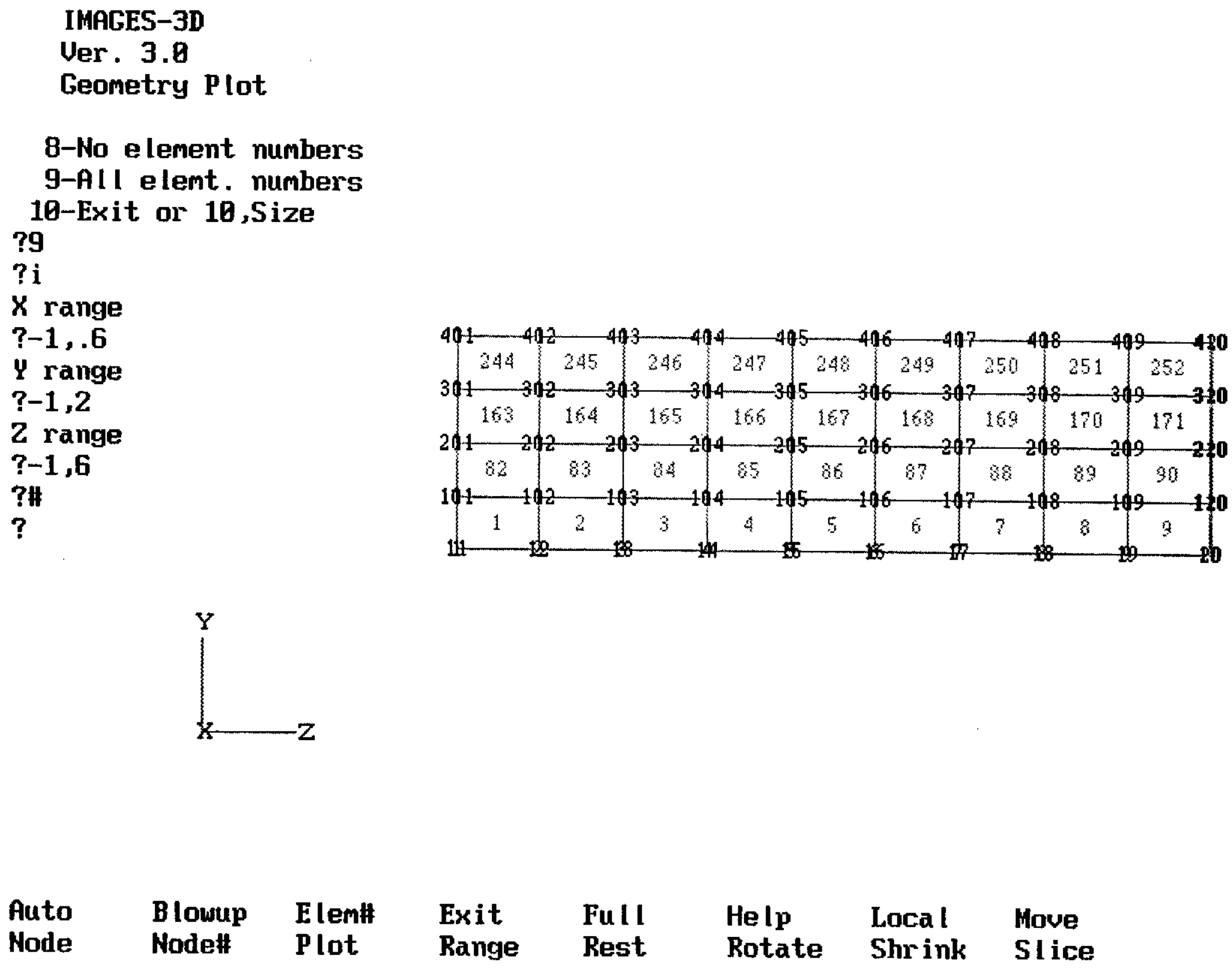

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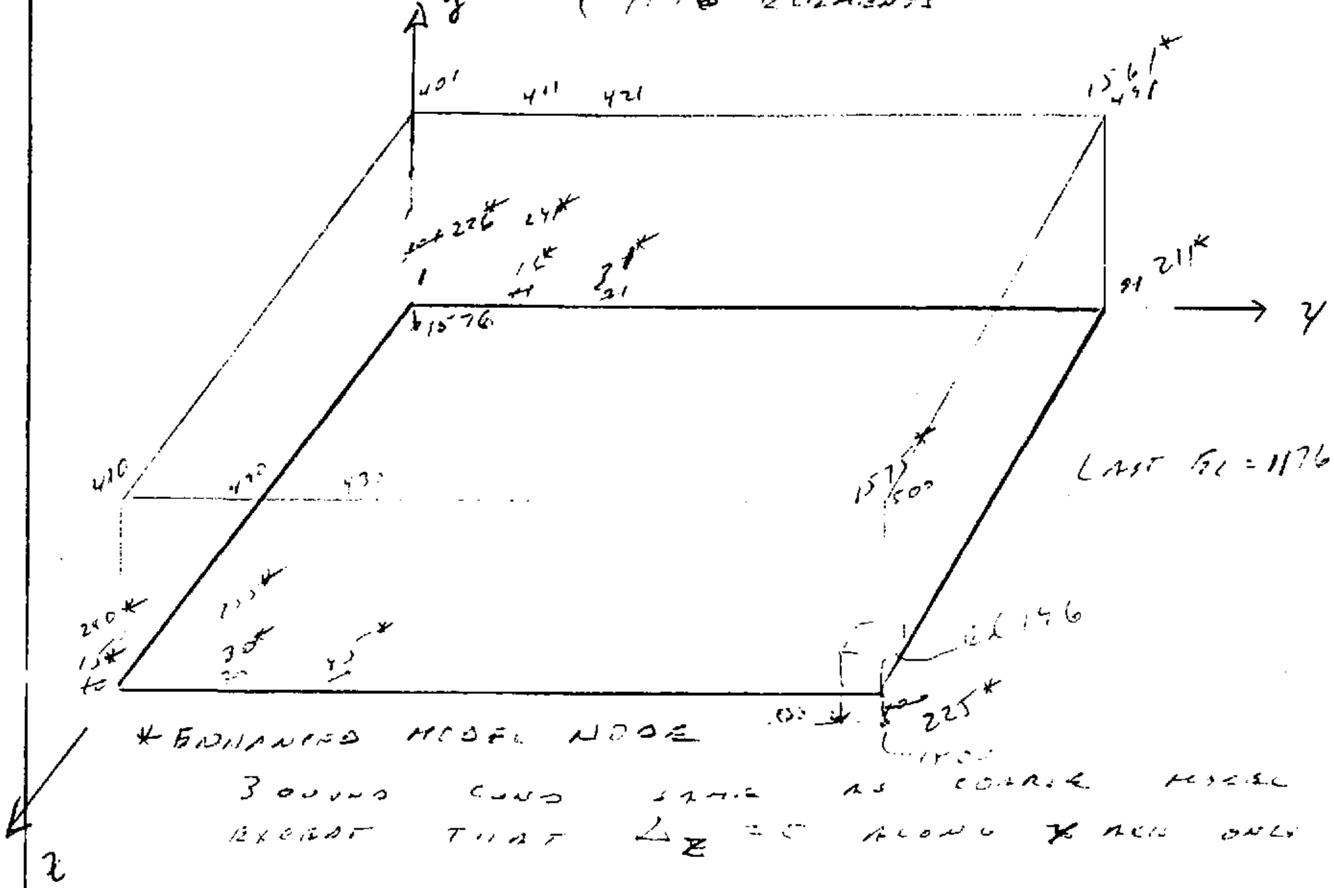
IMAGES-3D
Ver. 3.0
Geometry Plot

  8-No element numbers
  9-All elemt. numbers
 10-Exit or 10,Size
?9
?i
X range
?-1,.6
Y range
?-1,2
Z range
?-1,6
?#
?
```

ENHANCED FE MODEL

THE MODEL WILL BE ENHANCED BY
INCREASING THE NO. OF ELEMEN-
THROUGH THE FLANGE THICKNESS FROM
4 TO 6 AND BY INCREASING THE
NO OF ELEMENTS ALONG EACH SIDE
FROM 9 TO 14.

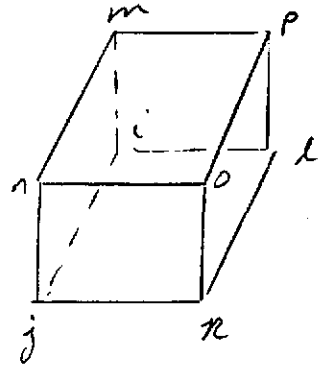
ENHANCED MODEL { 1575 NODES
1176 ELEMENTS



*ENHANCED MODEL NODE

BOUND COND SAME AS COARSE MODEL EXCEPT THAT $\angle_Z = 0$ ALONG X AXIS ONLY

TYPICAL ELEMENT NODE NUMBERING



1ST EL i j k l m n o p

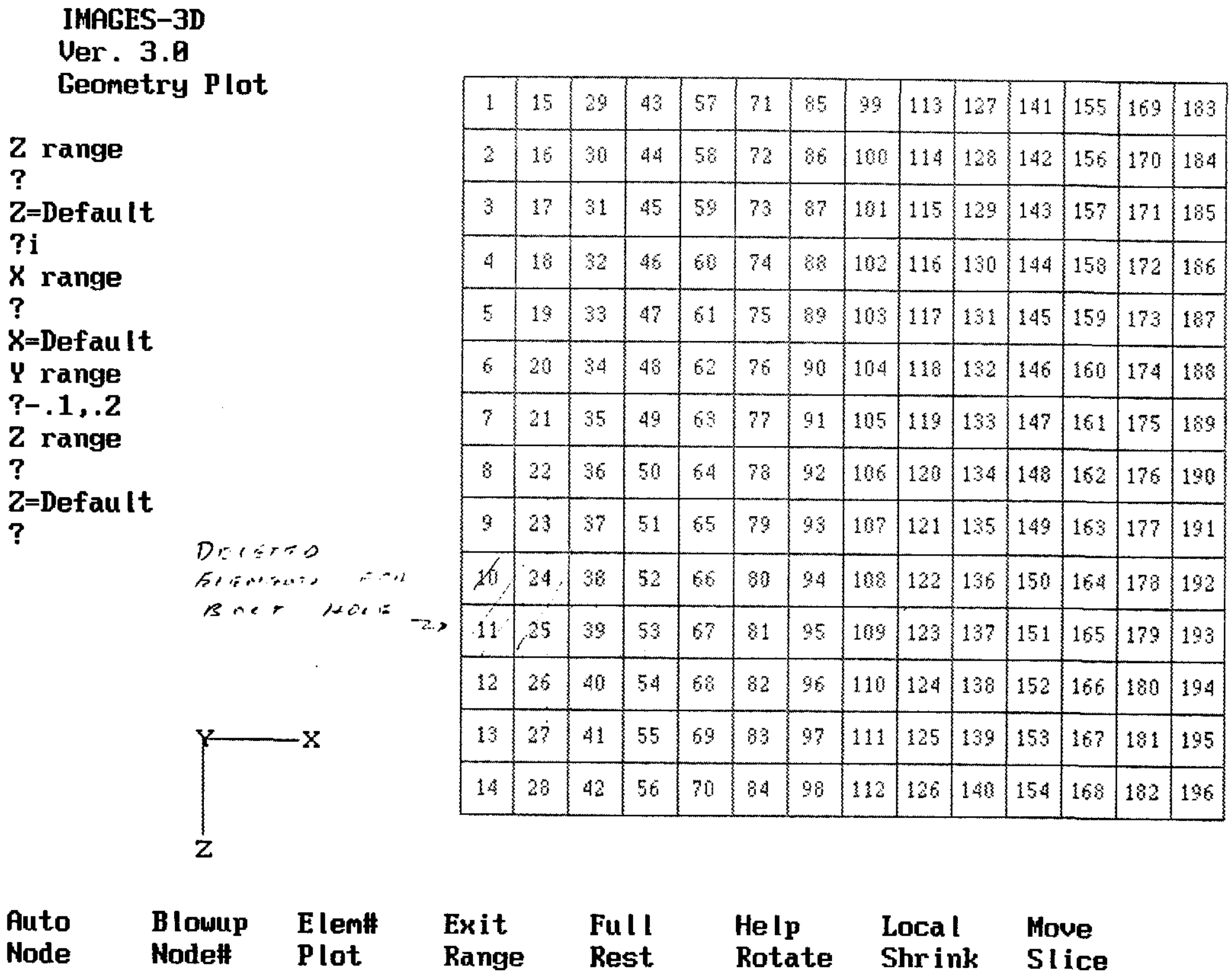
INITIAL MODEL → 1, 2, 12, 11, 101, 102, 112, 111

ENHANCED MODEL { 1, 2, 17, 16, 226, 227, 242, 241

MAT = 1 (STAINLESS)

REAL = 2 (3RD ORDER INTEGRATION)

Bottom Layer Elements



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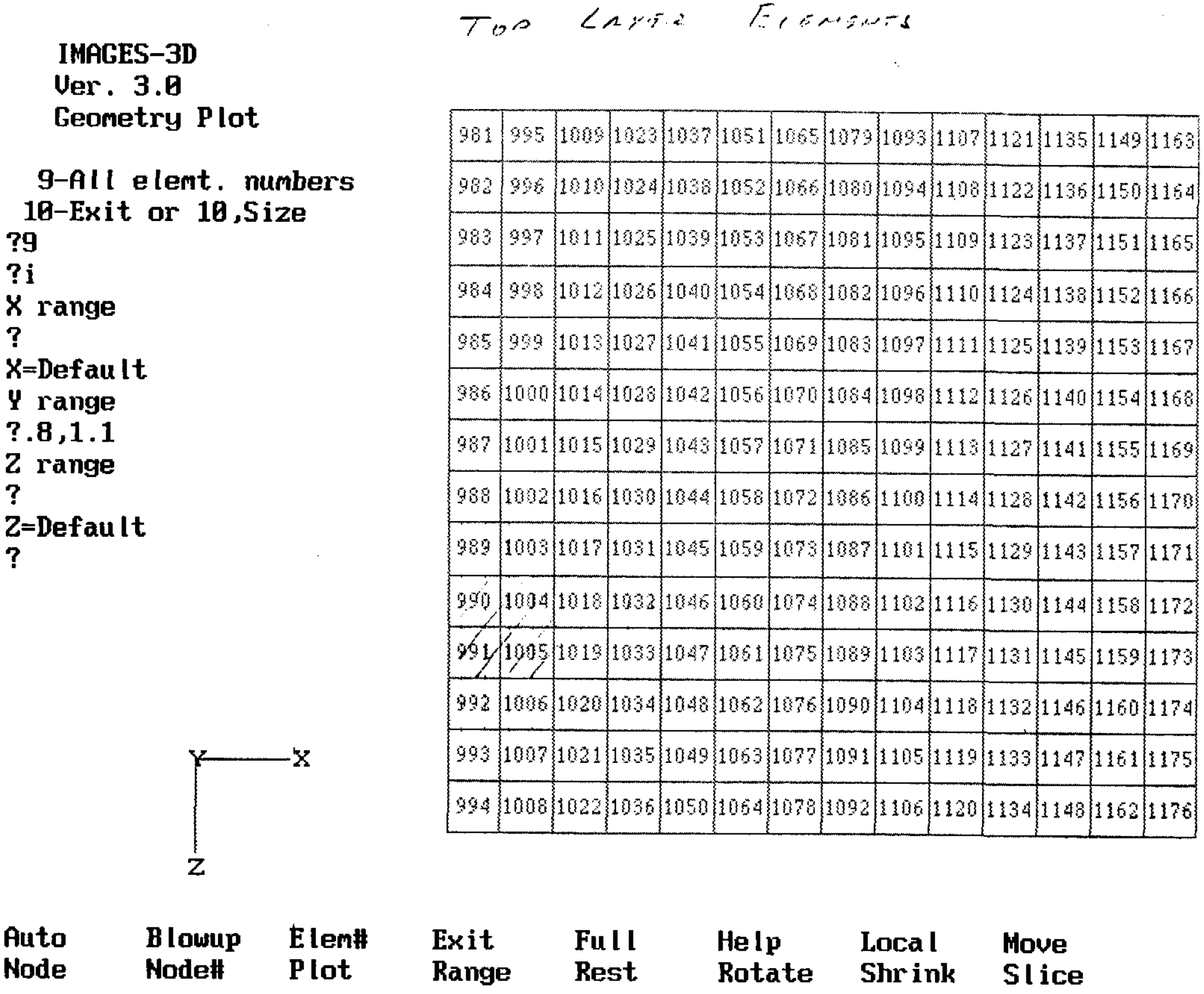
IMAGES-3D
Ver. 3.0
Geometry Plot

Z range
?
Z=Default
?i
X range
?
X=Default
Y range
?-.1,.2
Z range
?
Z=Default
?
```

1	15	29	43	57	71	85	99	113	127	141	155	169	183
2	16	30	44	58	72	86	100	114	128	142	156	170	184
3	17	31	45	59	73	87	101	115	129	143	157	171	185
4	18	32	46	60	74	88	102	116	130	144	158	172	186
5	19	33	47	61	75	89	103	117	131	145	159	173	187
6	20	34	48	62	76	90	104	118	132	146	160	174	188
7	21	35	49	63	77	91	105	119	133	147	161	175	189
8	22	36	50	64	78	92	106	120	134	148	162	176	190
9	23	37	51	65	79	93	107	121	135	149	163	177	191
10	24	38	52	66	80	94	108	122	136	150	164	178	192
11	25	39	53	67	81	95	109	123	137	151	165	179	193
12	26	40	54	68	82	96	110	124	138	152	166	180	194
13	27	41	55	69	83	97	111	125	139	153	167	181	195
14	28	42	56	70	84	98	112	126	140	154	168	182	196

Deleted Elements for Bolt Hole →



TOP LAYER ELEMENTS

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IMAGES-3D
Ver. 3.0
Geometry Plot

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10-Exit or 10,Size
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X range
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X=Default
Y range
?.8,1.1
Z range
?
Z=Default
?
```

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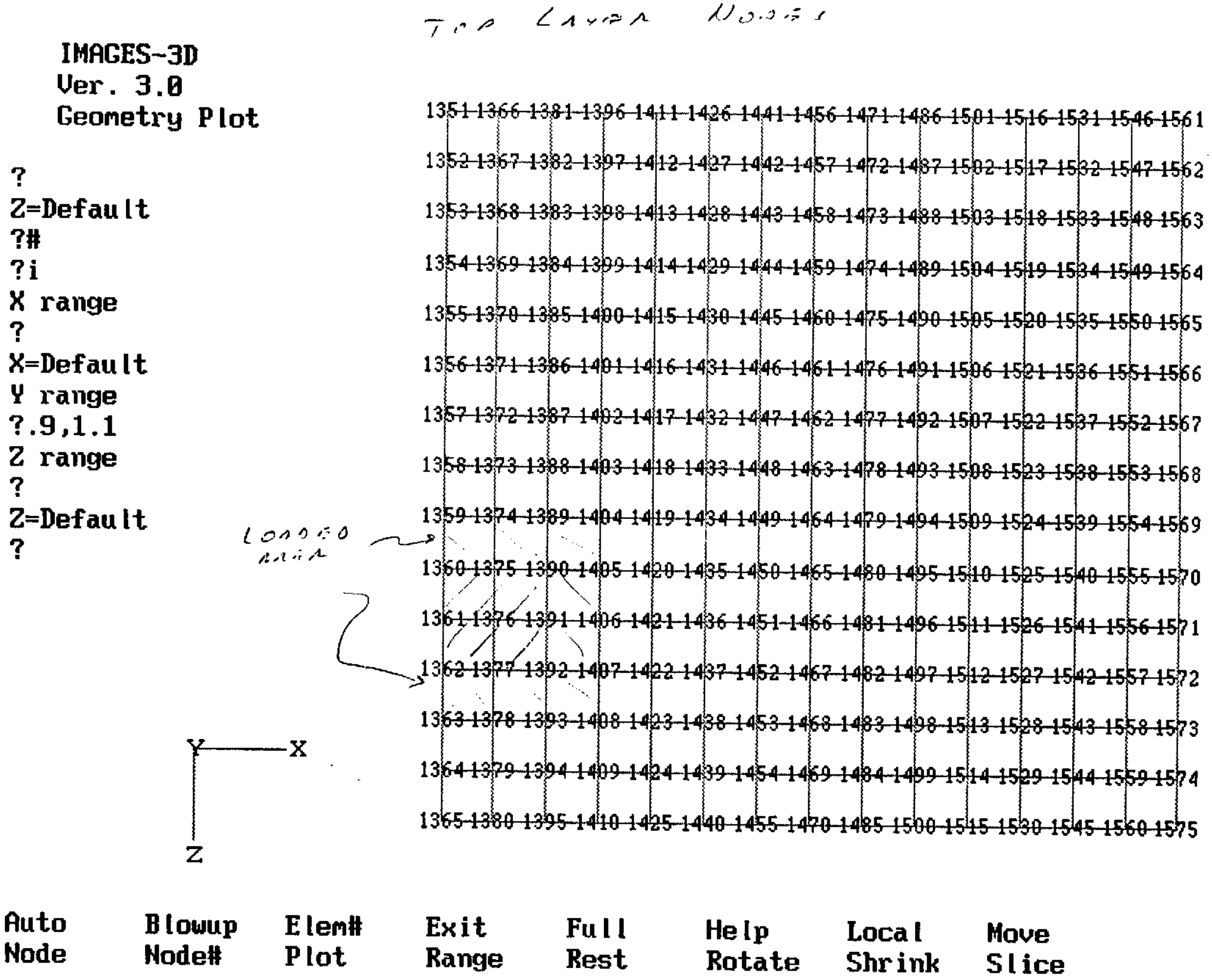
982	996	1010	1024	1038	1052	1066	1080	1094	1108	1122	1136	1150	1164
983	997	1011	1025	1039	1053	1067	1081	1095	1109	1123	1137	1151	1165
984	998	1012	1026	1040	1054	1068	1082	1096	1110	1124	1138	1152	1166
985	999	1013	1027	1041	1055	1069	1083	1097	1111	1125	1139	1153	1167
986	1000	1014	1028	1042	1056	1070	1084	1098	1112	1126	1140	1154	1168
987	1001	1015	1029	1043	1057	1071	1085	1099	1113	1127	1141	1155	1169
988	1002	1016	1030	1044	1058	1072	1086	1100	1114	1128	1142	1156	1170
989	1003	1017	1031	1045	1059	1073	1087	1101	1115	1129	1143	1157	1171
990	1004	1018	1032	1046	1060	1074	1088	1102	1116	1130	1144	1158	1172
991	1005	1019	1033	1047	1061	1075	1089	1103	1117	1131	1145	1159	1173
992	1006	1020	1034	1048	1062	1076	1090	1104	1118	1132	1146	1160	1174
993	1007	1021	1035	1049	1063	1077	1091	1105	1119	1133	1147	1161	1175
994	1008	1022	1036	1050	1064	1078	1092	1106	1120	1134	1148	1162	1176

Top Layer Nodes



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IMAGES-3D
Ver. 3.0
Geometry Plot

?
Z=Default
?#
?i
X range
?
X=Default
Y range
?.9,1.1
Z range
?
Z=Default
?
```

1351	1366	1381	1396	1411	1426	1441	1456	1471	1486	1501	1516	1531	1546	1561
1352	1367	1382	1397	1412	1427	1442	1457	1472	1487	1502	1517	1532	1547	1562
1353	1368	1383	1398	1413	1428	1443	1458	1473	1488	1503	1518	1533	1548	1563
1354	1369	1384	1399	1414	1429	1444	1459	1474	1489	1504	1519	1534	1549	1564
1355	1370	1385	1400	1415	1430	1445	1460	1475	1490	1505	1520	1535	1550	1565
1356	1371	1386	1401	1416	1431	1446	1461	1476	1491	1506	1521	1536	1551	1566
1357	1372	1387	1402	1417	1432	1447	1462	1477	1492	1507	1522	1537	1552	1567
1358	1373	1388	1403	1418	1433	1448	1463	1478	1493	1508	1523	1538	1553	1568
1359	1374	1389	1404	1419	1434	1449	1464	1479	1494	1509	1524	1539	1554	1569
1360	1375	1390	1405	1420	1435	1450	1465	1480	1495	1510	1525	1540	1555	1570
1361	1376	1391	1406	1421	1436	1451	1466	1481	1496	1511	1526	1541	1556	1571
1362	1377	1392	1407	1422	1437	1452	1467	1482	1497	1512	1527	1542	1557	1572
1363	1378	1393	1408	1423	1438	1453	1468	1483	1498	1513	1528	1543	1558	1573
1364	1379	1394	1409	1424	1439	1454	1469	1484	1499	1514	1529	1544	1559	1574
1365	1380	1395	1410	1425	1440	1455	1470	1485	1500	1515	1530	1545	1560	1575

DELETE ELEMENTS

10, 11, 24, 25 IN BOTTOM LAYER

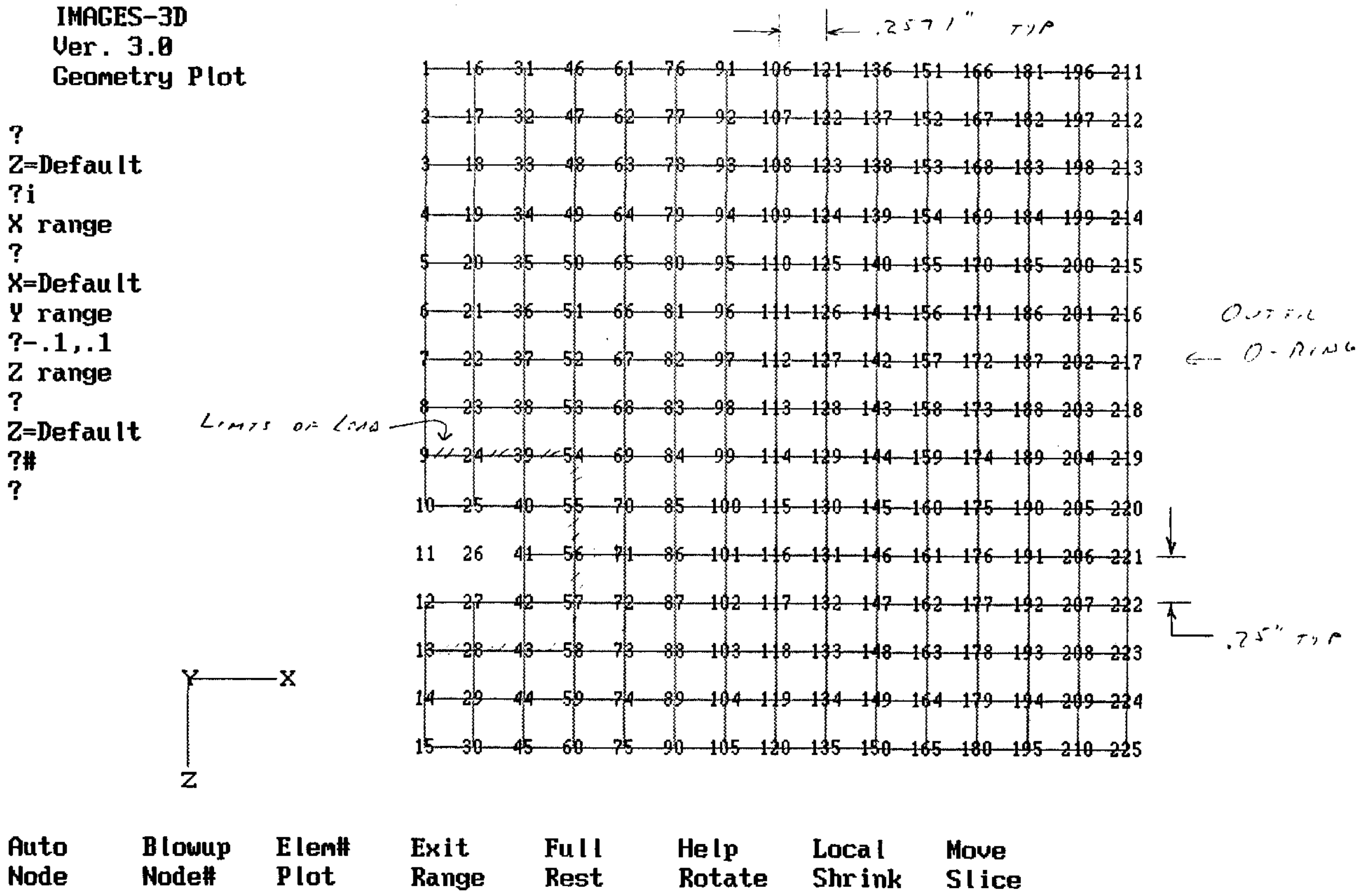
INCREMENT = 196

TO

990, 991, 1004, 1005 IN TOP LAYER

APPLY LOADS Fy = -1000* lb AT
TOP LAYER NODES 1355, 1360, 1362, 1363
1374, 1375, 1377, 137[illegible]
1385, TO 1393
1404 TO 1408

* UNIT LOAD SELECTED
TO DETERMINE REQUIRED
LOAD FROM OUTPUT



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IMAGES-3D
Ver. 3.0
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13	28	43	58	73	88	103	118	133	148	163	178	193	208	223
14	29	44	59	74	89	104	119	134	149	164	179	194	209	224
15	30	45	60	75	90	105	120	135	150	165	180	195	210	225

CLAMPING FORCE AT OUTER O-RING

ENHANCED MODEL

FORCE WILL BE NORMALIZED BY NODE SPACING AND TOTAL BOLT LOAD

NODE SPACING

$$S = \frac{3.6}{14} = .2571$$

TOTAL FORCE F_y = 18000 LB, SAY 18K

$$F_y = \frac{F_{iy}}{.2571(18)} = \frac{F_{iy}}{4.629}$$

WHERE .2571 = NODE SPACING

NODE	F_{iy}	F_y	$F_y/.25$ *
7	150.5	32.5	130
22	282.5	61.0	244
37	232.6	50.3	201
52	164.8	35.6	142.4
67	96.3	20.8	83.2
82	42.3	9.14	36.6
97	9.02	1.95	7.8
112	-6.58	-1.42	-5.68
127	-11.1	-2.40	-9.60
142	-10.3	-2.22	-8.88
157	-7.69	-1.66	-6.64
172	-5.14	-1.11	-4.44
187	-3.24	-.70	-2.8
202	-2.12	-.46	-1.84
217	-.88	-.19	-.76

WHERE F_{iy} = OUTPUT FORCE, FILE = FLANGE

$F_y/.25$ NORMALIZED BY NODE SPACING IN BOTH DIRECTIONS

CLAMPING FORCE AT OUTER O-RING

COARSE MODEL

$$S = \frac{3.6}{9} = .40$$

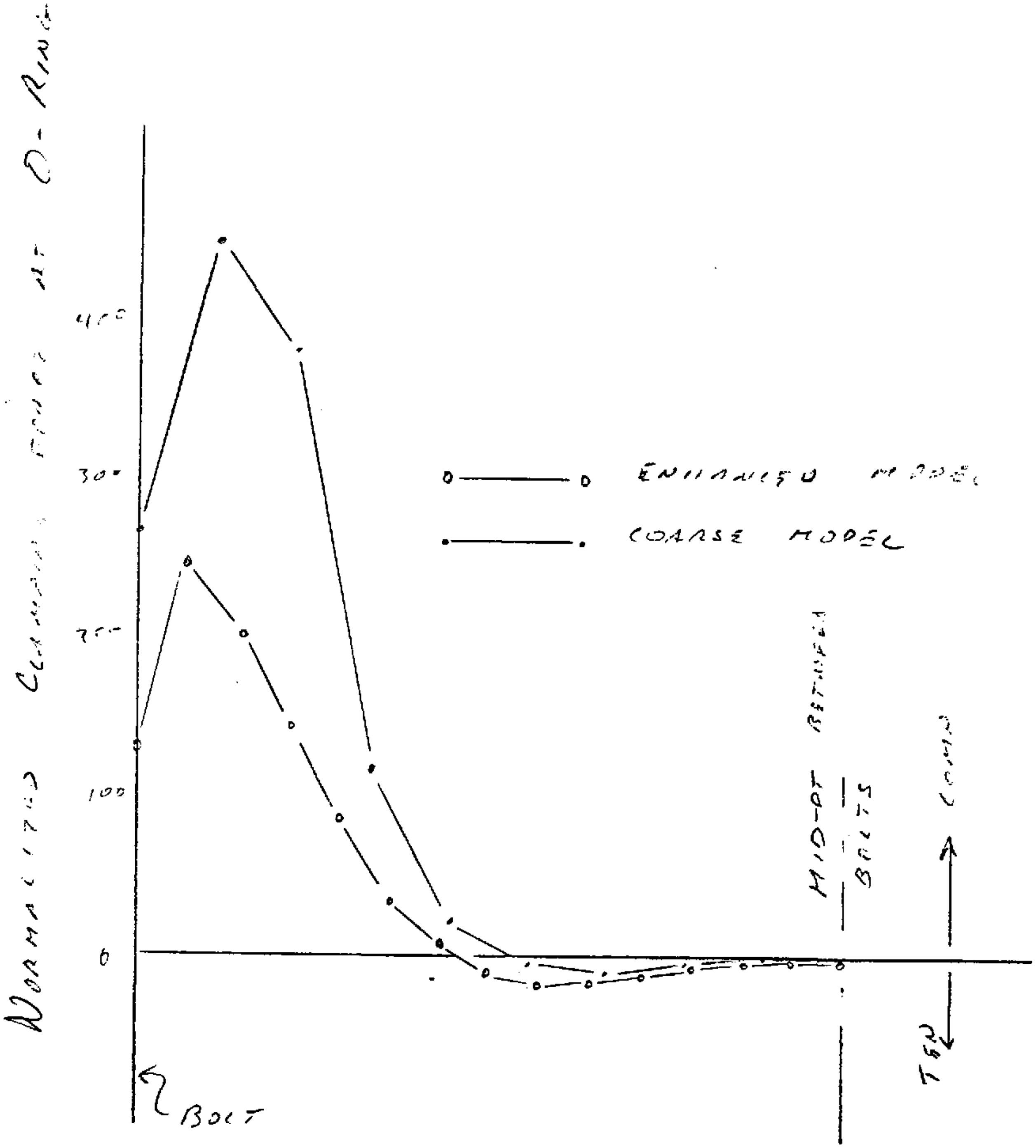
TOTAL FORCE = F_y = 14000 LB = 14K

$$F_y = \frac{F_{iy}}{.40(14)} = \frac{F_{iy}}{5.6}$$

WHERE .40 = NODE SPACING

NODE	F_{iy}	F_y	$F_{y\,1,349}$
5	577.4	103.1	265.1
15	984.6	175.8	452.1
25	612.8	109.4	281.3
35	260.7	46.6	119.8
45	54.3	9.69	24.9
55	-16.2	-2.89	-7.4
65	-21.8	-3.89	-10.0
75	-12.6	-2.25	-5.79
85	-5.46	-.975	-2.51
95	-1.64	-.293	-.753

F_{iy} = OUTPUT FORCE, FLLE = FLANGE



NOTE - HIGHER LOAD RESULTS FROM COARSE MODEL BECAUSE APPLIED BOLT FORCE IN MODEL IS CLOSER TO O-RING NODES THAN IT IS IN ENHANCED MODEL

FINALIZED MODEL W/ COMP. ONLY SPRINGS FOR FOUNDATION AND LINEAR SPRINGS FOR VITON

SPRING RATE OF VITON O RING

CROSS SECTION .275 IN

COMPRESSION 20%

= .20(.275)

= .055 IN

GROOVE DEPTH = .201 TO .211

∴ COMP = .275 - .211
= .064
= $\frac{.064}{.275}$ = 23 % MIN

= .275 - .201
= .074
= .074/.275 = 27% MAX

COMPRESSION LOAD

F ≈ 25 TO 100 LB PER IN OF LENGTH /FT DUROMETER 70

SEE p. A4-11 OF PARKER O-RING HANDBOOK

SAY F = 60 LB

SPRING RATE

$k = \frac{60}{.064}$ = 938 LB/IN MAX
PER IN OF CIRCUM

$k = \frac{60}{.074}$ = 810 LB/IN MIN
PER IN OF CIRCUM

USE

k = 900 LB/IN FOR 1 IN LENGTH
k = 900 (.2571) = 231 LB/IN
FOR MODEL

10/13/95

TRY DUROMETER = 90

SQUEEZE (COMPRESSION) VARIES FROM 21 TO 29 % (P. A5-13 OF PARKER SEALS HANDBOOK)
FROM P. A4-11 OF THE PARKER HANDBOOK, THE COMPRESSIVE FORCE PER INCH OF SEAL RANGES FROM

70 TO 160 LB/IN

FOR .080 IN COMPRESSION (CORRESPONDING TO MAX DEFLECTION) THE STIFFNESS PER IN OF SEAL IS

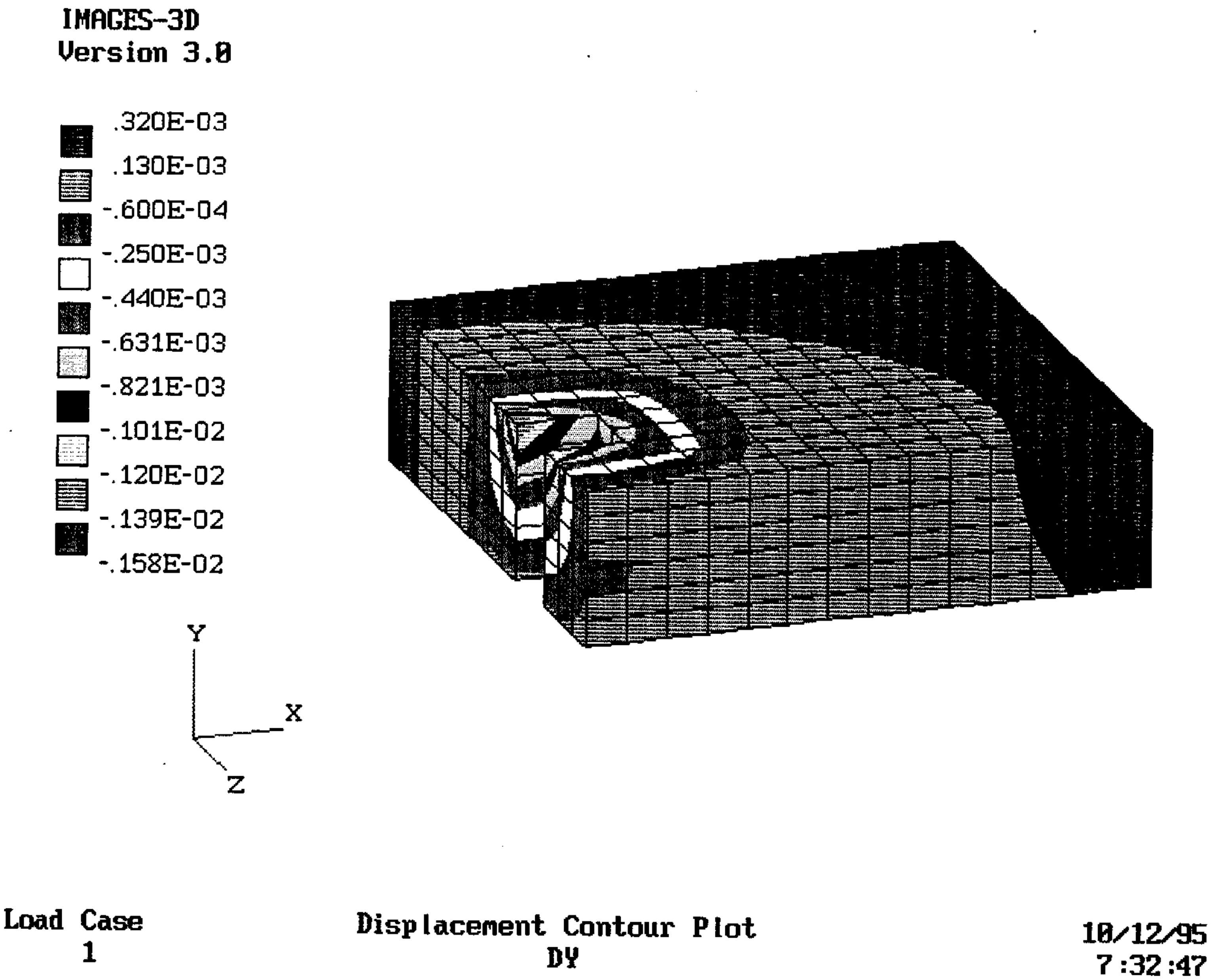
$$k = \frac{160}{.080} = 2000 \text{ LB/IN}$$
PER IN OF CIRCUM.

FOR DISCRETE SPRINGS SPACED .2571 IN APART IN MODEL

$$k = 2000(.2571)$$
WHERE .2571 = NODE SPACING
$$= 514 \text{ LB/IN} \quad *$$

ALTHOUGH THIS IS HIGHER THAN k 231 LB/IN USED IN FE ANALYSIS, IT IS ORDERS OF MAGNITUDE LESS STIFF THAN FOUNDATION SPRINGS USED TO REPRESENT THE STEEL – ∴ THE MODEL RESULTS WOULD NOT CHANGE SIGNIFICANTLY IF THE HIGHER VALUE OF k IS USED.

* SEE CALC 018, P. 5 FOR UPDATED VALUE OF k. RESULTS WILL NOT BE AFFECTED.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Version 3.0
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Y
X
Z
Load Case
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Displacement Contour Plot
DY
10/12/95
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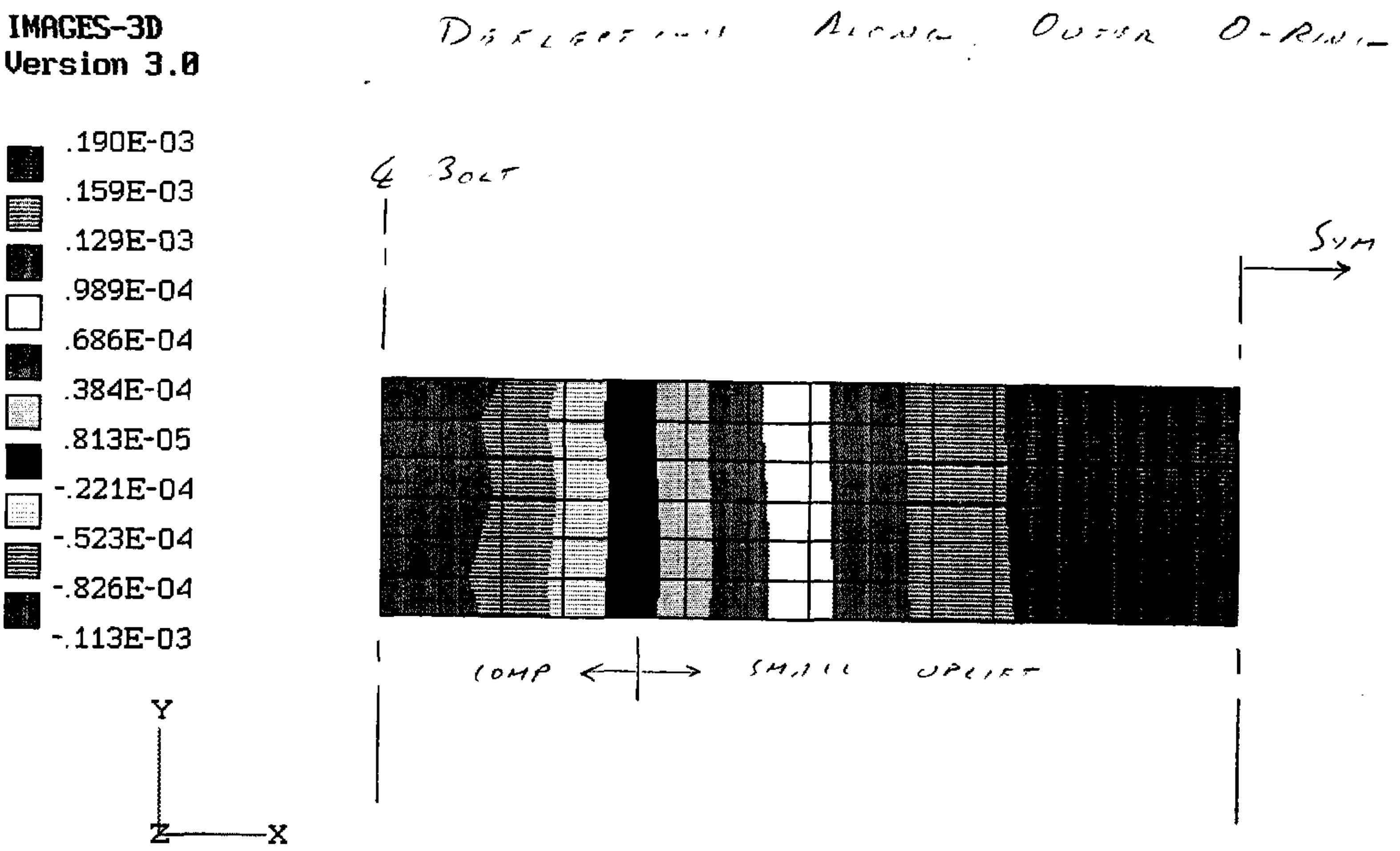

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Version 3.0
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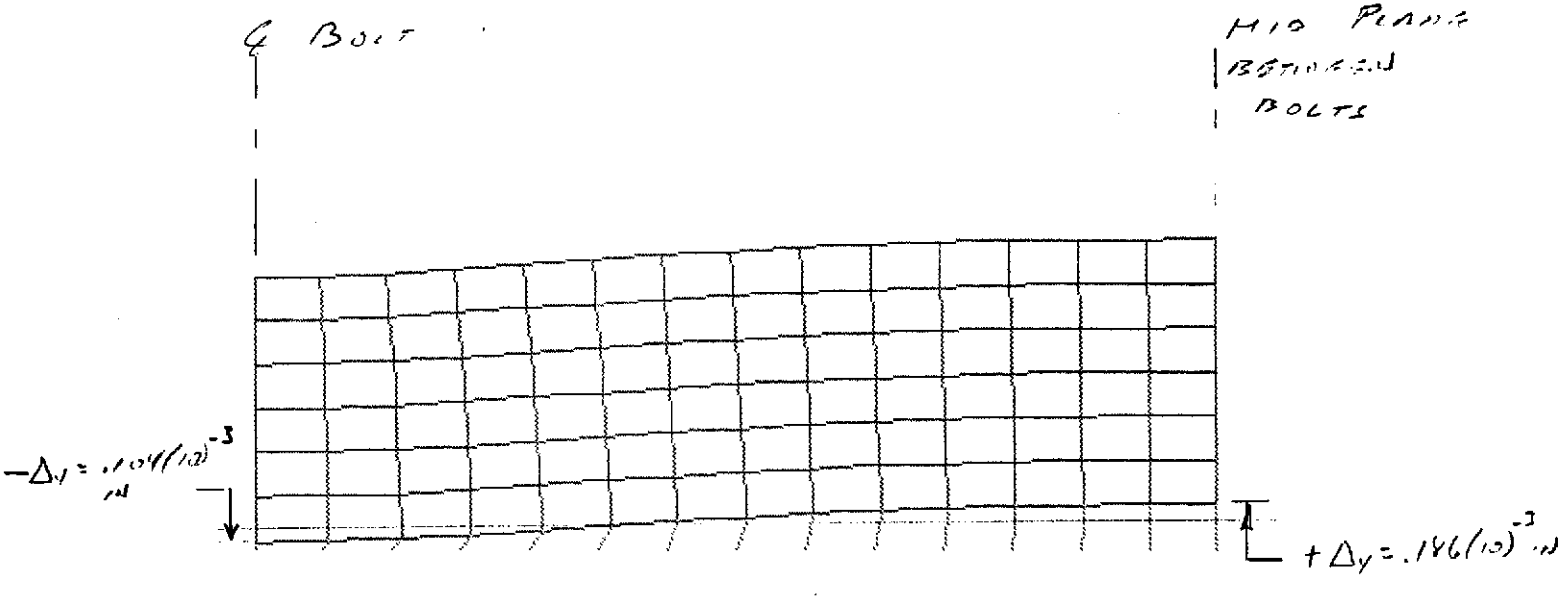
Deflection Along Outer O-Ring



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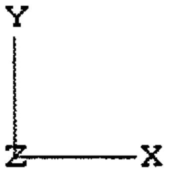

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Animate  Auto   Blowup  Elem#  Exit   Full    Help   Lcase
Move     Node#  Origin  Plot   Range  Rotate  Scale  Slice
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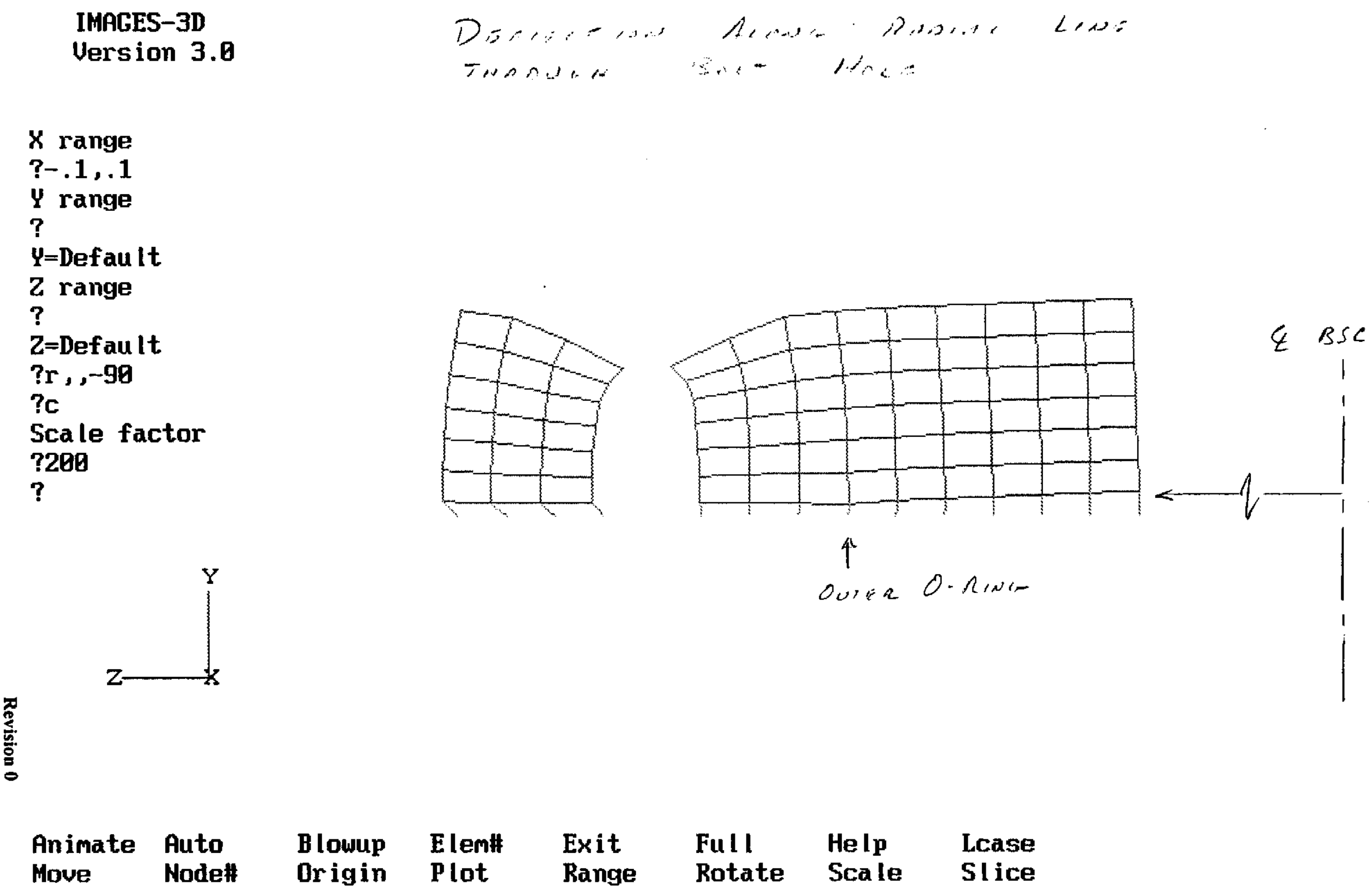
Deflection Along Radial Line
Through Bolt Hole



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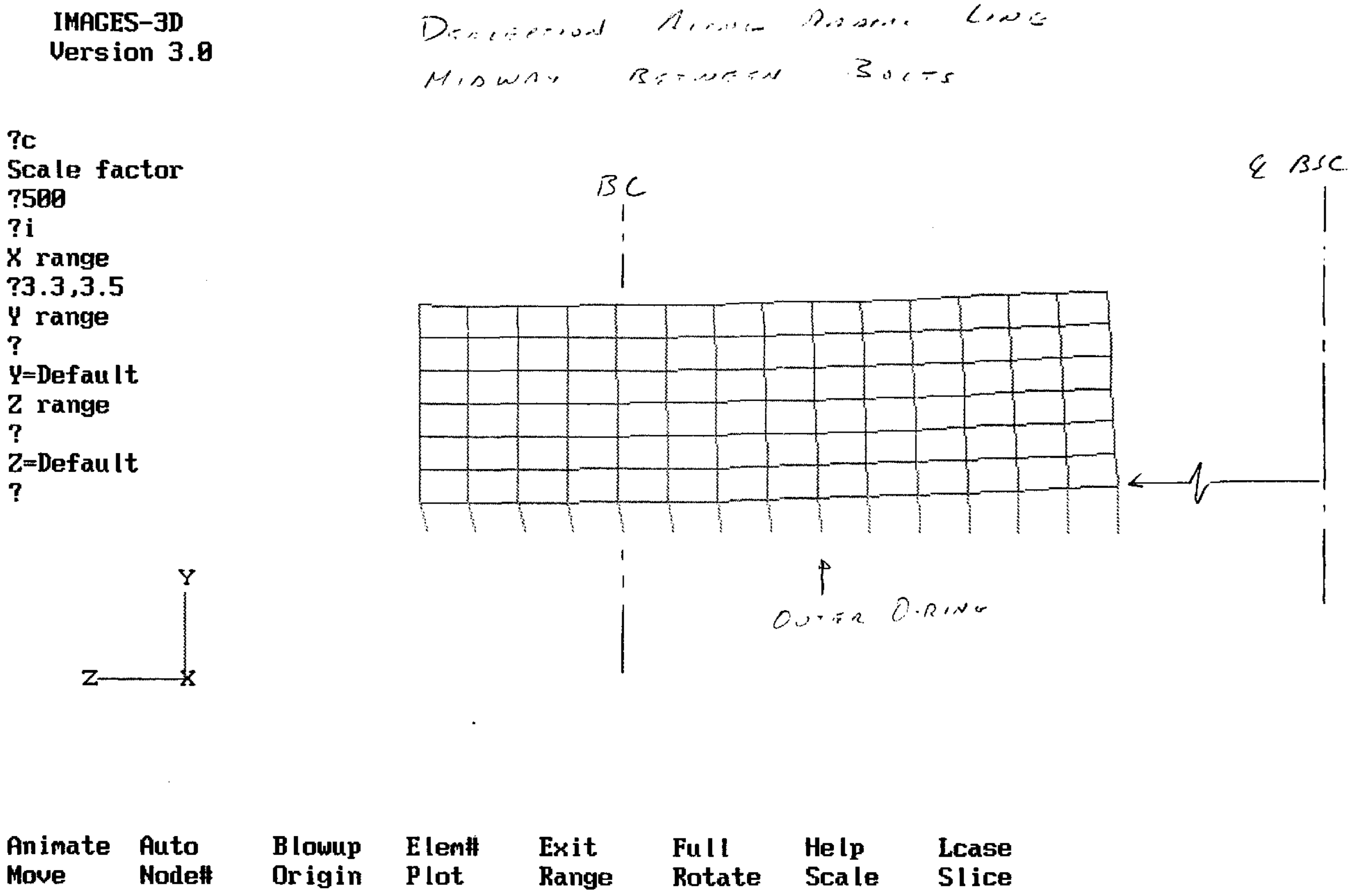
Deflection Along Radial Line
Midway Between Bolts



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Version 3.0

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Z range
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Z=Default
?
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ENHANCED MODEL

FOUNDATION STIFFNESS = 10×10^6 LB/IN

OUTER O-RING DEFLECTIONS

NODE	Δy	EXP (10^{EXP})
7	-.104	-3
22	-.917	-4
37	-.768	-4
52	-.470	-4
67	-.125	-4
82	.239	-4
97	.572	-4
112	.876	-4
127	.114	-3
142	.136	-3
157	.154	-3
172	.168	-3
187	.178	-3
202	.184	-3
217	.186	-3

FROM COMPUTER OUTPUT
FILE: FLANGE

DEFLECTIONS AT BOLT

BOTTOM LAYER NODES			TOP LAYER NODES			
NODE	Δ_Y BOT		NODE	Δ_Y TOP		Δ_{YT}/Δ_{YB}
9	-.540	-4	1359	-.799	-3	14.8
10	-.353	-4	1360	-.153	-2	43
12	-.382	-4	1362	-.158	-2	41
13	-.542	-4	1363	-.822	-3	15
24	-.851	-4	1374	-.576	-3	6.8 *
25	-.592	-4	1375	-.101	-2	17.1
27	-.633	-4	1377	-.105	-2	16.6
28	-.847	-4	1378	-.596	-3	7.0
35	-.702	-4	1389	-.500	-3	7.1
40	-.657	-4	1390	-.668	-3	10.2
41	-.464	-4	1391	-.890	-3	19.2
42	-.664	-4	1392	-.684	-3	10.3
43	-.683	-4	1393	-.514	-3	7.53
54	-.510	-4	1404	-.409	-3	8.0
55	-.622	-4	1405	-.468	-3	7.5
56	-.664	-4	1406	-.484	-3	7.3
57	-.618	-4	1407	-.474	-3	7.7
58	-.468	-4	1408	-.416	-3	8.9

MIN RATIO OF TOP TO BOTTOM DEFLECTION = 6.8
∴ FOUNDATION STIFFNESS, K = 10×10^6 LB/IN
IS REASONABLE

MAXIMUM LIFTOFF AT OUTER O-RING

IF THE DEFLECTION IN THE NEG DIRECTION IS ACTUALLY 0 AND THE RELATIVE Δy REMAINS CONSTANT, THE MAXIMUM SEPARATION BETWEEN THE FLANGES IS

$$\Delta_y = [.186 - (-.104)] \times 10^{-3}$$
$$= .290(10)^{-3}$$

THIS IS DOUBLED FOR 2 FLANGES

$$\Delta_y = 2(.290)(10)^{-3}$$
$$= .58(10)^{-3}$$
$$= .00058 \text{ IN}$$

THIS COMPARES TO THE MINIMUM O-RING COMPRESSION OF .064 IN *

THE COMPRESSION IS MORE THAN 100 TIMES THE FLANGE SEPARATION.

$$\frac{.064}{.00058} = 110$$

* CALCULATED VALUE FROM PARKER HANDBOOK, MAXIMUM COMPRESSION IS .080 IN FOR .25 IN O-RING.

FOR THE ANALYSIS, THE BOLT LOAD IS 18000 LB FOR THE HALF MODEL OR 36000 LB PER BOLT. THE TOTAL VACUUM THRUST ON THE FLANGE IS

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

$$r = \frac{108}{2} = 54$$

= RADIUS TO OUTER O-RING

$$F_V = \pi (54)^2 (14.7)$$

$$= 134,700 \text{ LB}$$

FOR 48 BOLTS THE FORCE PER BOLT IS

$$F_{BOLT} = \frac{134700}{48}$$

$$= 2800 \text{ LB} < 36000$$

∴ BOLT PRELOAD CAN BE REDUCED TO, SAY, 6000 LB, AND THE BOLTS WILL HAVE A NET TENSION UNDER THE VACUUM LOAD

$$F_T = 6000 - 2800 = 3200 \text{ LB}$$

FOR A PRELOAD OF 6000 LB THE UNIFORM LOAD ON THE INNER AND OUTER O-RINGS IS

$$\omega = \frac{48(6000)}{\pi(108) + \pi(105)} \quad \text{(ASSUME RIGID FLGS)}$$

$$= 430 \text{ LB/IN} >> 160 \text{ LB/IN}$$

MAX LOAD REQUIRED TO COMPRESS 1/4 VITON O-RING FOR DUROMETER 90

∴ VITON WILL BE COMPRESSED INTO GLAND

FOR FLANGES OF OTHER DIAMETERS,
MAINTAIN BOLT SPACING AT 7.2 IN

FLANGE ID	BC DIAM D_{BC}	BC CIRCUM $\pi D_{BC} = C_{BC}$	NO. OF BOLTS $n = C_{BC}/7.2$	USE $N =$
104 1/4	110	345.6"	48	48
84 1/4	90	282.7	39	40
72 1/4	78	245.0	34	36
60 1/4	66	207.3	29	30
48 1/4	54	169.6	24	24
44 1/4	50	157.1	22	24
30 1/4	36	113	16	16

BOLT DIAMETER = 7/8"
WITH 1" HOLE

TOP FLANGE = 1" THICK
BOTTOM " = 1 1/4" THICK

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CALCULATIONS

NO: V049-1-017
PAGE 1 OF 10

REV.	DEO #	DATE	BY:	CHECK
0	0135	12/6/95	RDC	AGR

TITLE: Beam Splitter Chamber Finite Element
Analysis of 1 in Thick Flange for Bolt Preload plus Positive Pressure

BY: R D. Ciarro

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To determine if bolt clamping force combined with a positive internal pressure of 2 psi results in flange deformation that could allow leakage at o-rings.

METHOD: The same method used for the preload - only analysis (V049-1-016) is used in this analysis. Pressure load is added to the finite elements model.

ASSUMPTIONS: Same as preload-only analysis (calc. V049-1-016). The fine model is used with compression-only springs at the surface between flanges.

INPUTS: LIGO project design sketches and drawings. Durometer of 90 for Viton o-rings.

REFERENCES: 1. Parker O-Ring Handbook.
2. IMAGES-3D, Version 3.0, R.L. Cloud and Associates

CALCULATIONS: (SEE ATTACHED)

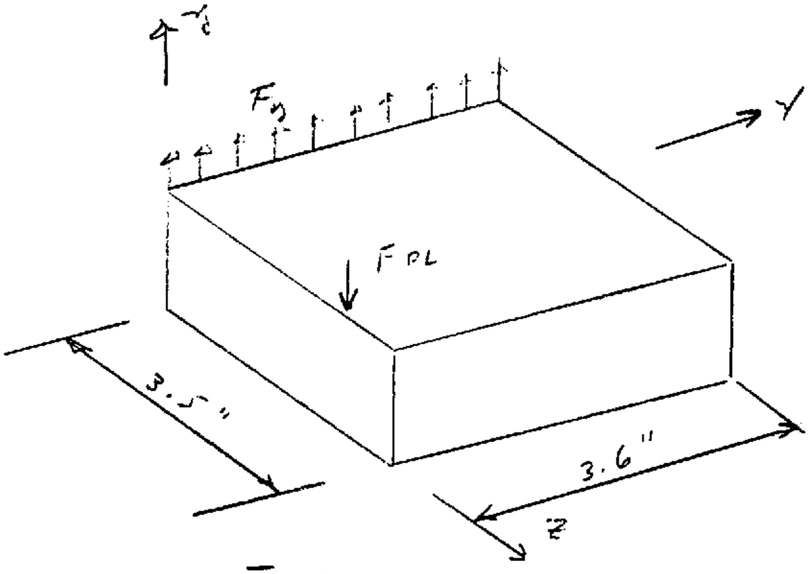
CONCLUSIONS: The gap opening between flanges is negligible and does not permit leakage of o-ring seals.

NOTES: Computer file is FLANGE A.

FLANGES - 3D FE ANALYSIS FOR BOLT PRELOAD PLUS POS PRESSURE

ANALYSIS FOR POSITIVE PRESSURE USING 3D FE MODEL - 104 ID FLANGE USED

PRESSURE LOAD FROM ATTACHED CYLINDER



$$F_y = \frac{pr}{2}$$

$$p = 2 \text{ psi}$$

$$r = \frac{104.25}{2}$$

$$F_y = \frac{2\left(\frac{104.25}{2}\right)}{2}$$

$$= 52.1 \text{ LB/IN}$$

NODE SPACING ALONG Y-AXIS IS .2571

$F_{yi} = 52.1(.2571)$
$= 13.4$ LB NODES 1366 TO 1546, INC 15

$= \frac{13.4}{2} = 6.7$ AT Y = 0, 3.6
END NODES 1351 & 1561

PRELOAD FORCE

$$F_{PL} = 6000^{*} \text{ LB} \quad \text{FOR } 7/8'' \varnothing \text{ BOLTS}$$

14 NODES ARE LOADED, 4 NODES ARE AT PLANE OF SYMMETRY (Y = 0)

$$F_{PL} = 14 F_{yi} + 4 \frac{F_{yi}}{2}$$

$$= 16 F_{yi} \qquad \text{℄}_{Y=0}$$

$$F_{yi} = \frac{6000}{16} = -375 \text{ LB}$$

NODES 1374, 1375, 1377, 1378
1385 TO 1393
1404 TO 1408

$$F_y = \frac{375}{2} = -188 \text{ LB}$$ NODES 1359, 1360
1362, 1363

THE TOTAL PRESSURE FORCE ON THE CYLINDER IS

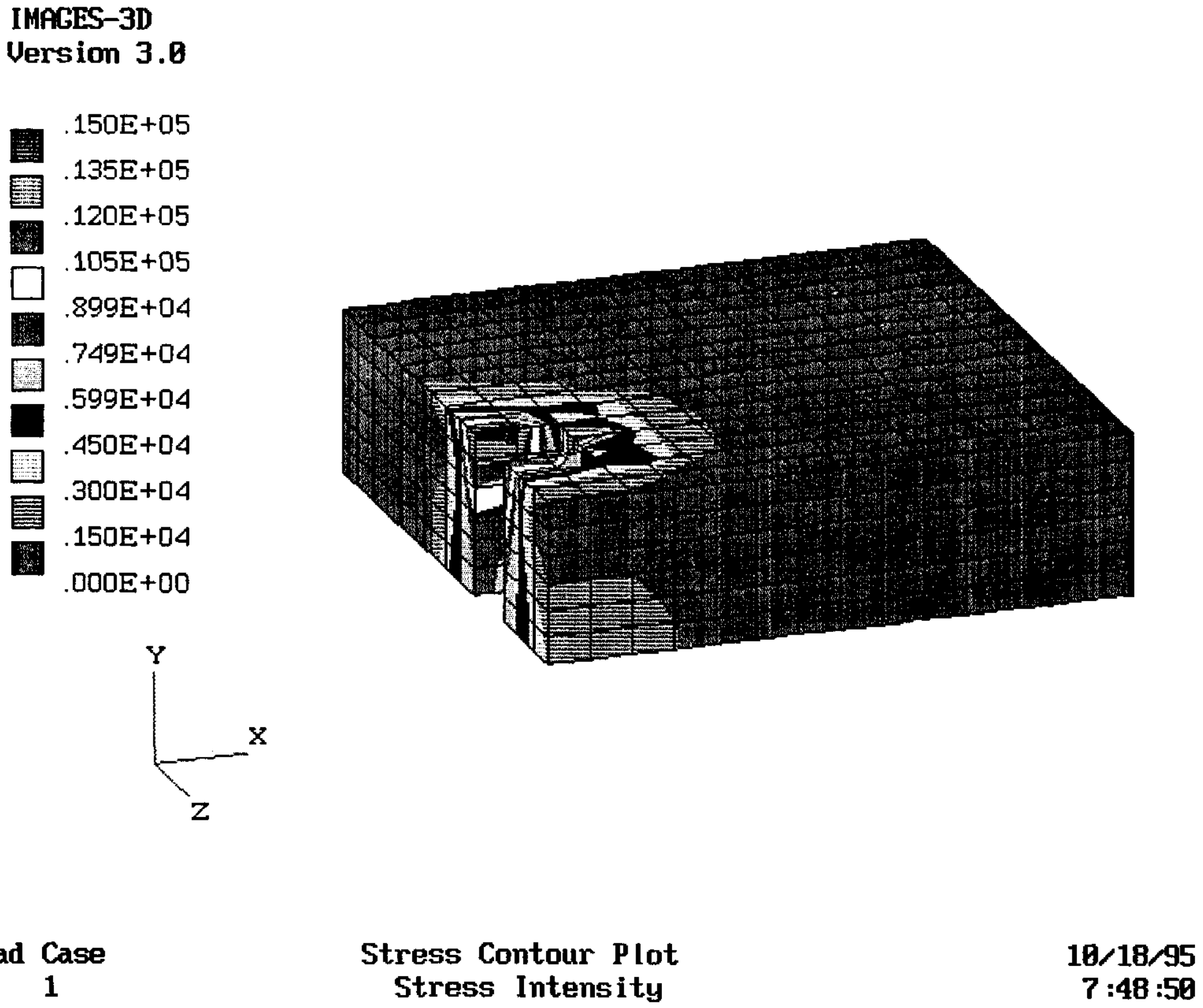
$$F_y = 52.1 \times 3.60 = 188 \text{ LB}$$

$$<< F_{PL} = 6000 \text{ LB}$$

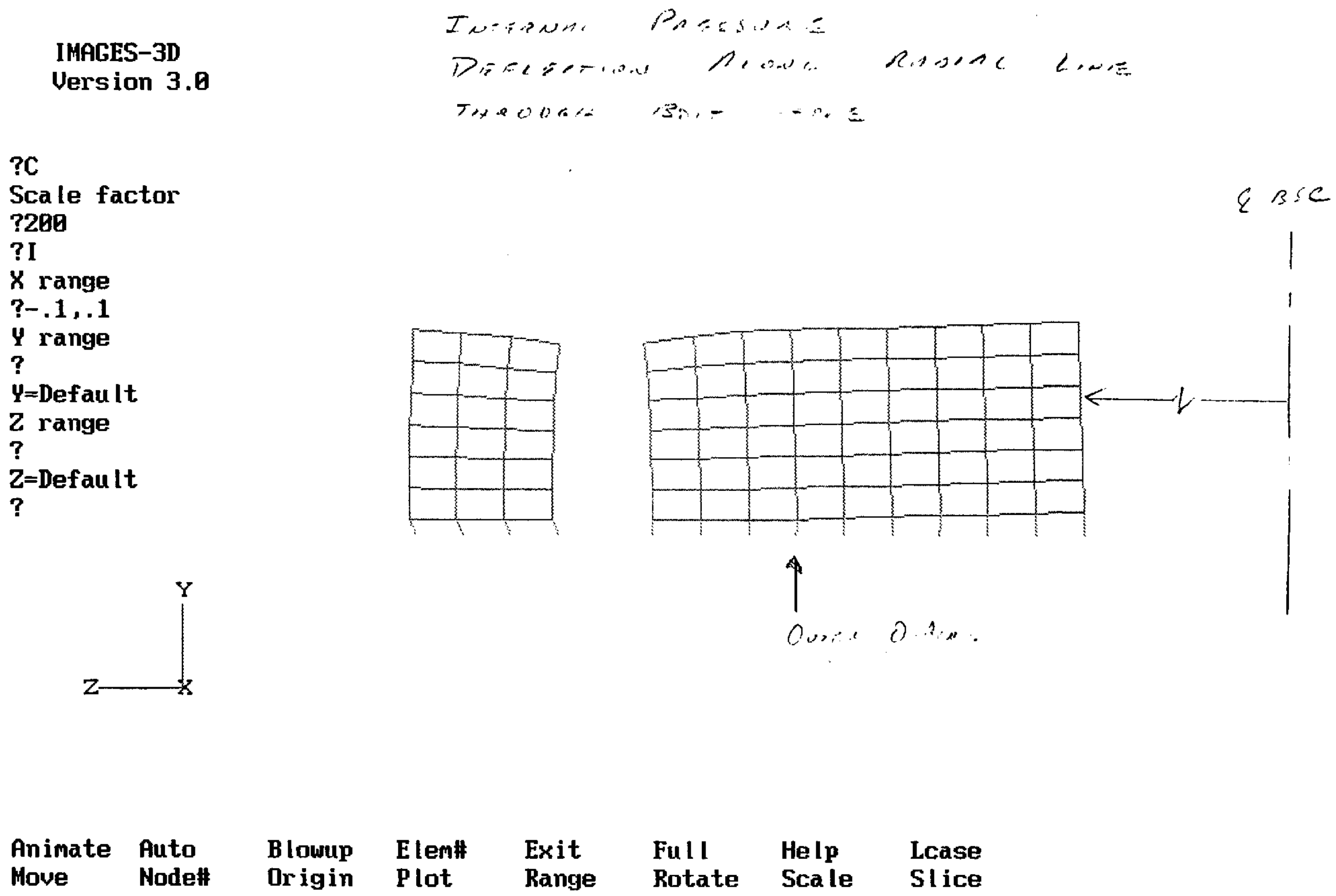
∴ IT WILL BE ASSUMED THAT PRESSURE DOES NOT CHANGE THE PRELOAD FORCE

* ACTUAL LOAD = 7000 LB FOR 1/2 BOLT
THIS ANALYSIS IS CONSERVATIVE FOR EVALUATION OF FLANGE SEPARATION.

Internal Pressure



INTERNAL PRESSURE
DEFLECTION ALONG RADIAL LINE
THROUGH BOLT HOLE



IMAGES-3D
Version 3.0

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Z range
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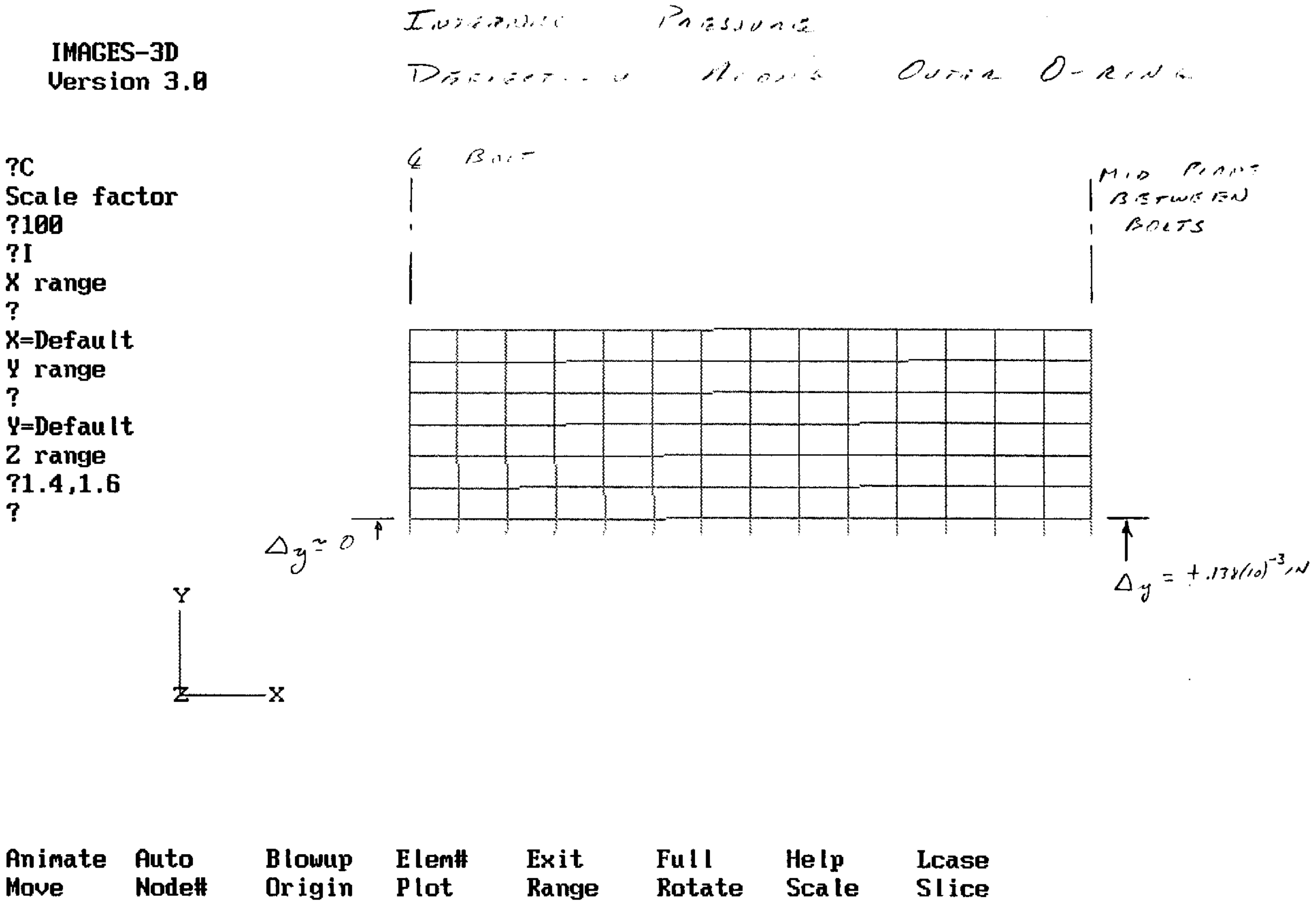
INTERNAL PRESSURE

DEFLECTION NEAR OUTER O-RING



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Z range
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?
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DEFLECTIONS AT OUTER O-RING

NODE	Δy
7	$.256 \times 10^{-5}$
217	$.138 \times 10^{-3}$

SPRING LOADS ALONG OUTER O-RING

NODE	F_y *	EXPONENT
7	.152	-2
22	.271	-2
37	.615	-2
52	.120	-1
67	.197	-1
82	.281	-1
97	.366	-1
112	.445	-1
127	.515	-1
142	.574	-1
157	.624	-1
172	.662	-1
187	.690	-1
202	.706	-1
217	.711	-1

* OUTPUT FROM FILE' FLANGEA

MAXIMUM SEPARATION OF FLANGES

AT NODE 217, WHICH IS MIDWAY BETWEEN 2 BOLTS ALONG THE OUTER O-RING, THE DEFLECTION IS

$$\Delta_y = .138(10)^{-3} \text{ IN}$$

WHICH INDICATES A VERY SLIGHT OPENING OF THE GAP UNDER INTERNAL PRESSURE OF 2 PSI. FOR THE 2 FLANGES, THIS IS DOUBLED

$$\Delta_y = 2(.138)(10)^{-3}$$
$$= .276(10)^{-3} \text{ IN}$$

THIS COMPARES TO THE MINIMUM COMPRESSION OF .058 IN FROM PARKER HANDBOOK (P. A5-13)

$$\frac{58(10)^{-3}}{.276(10)^{-3}} = 210$$

$\therefore$ OPENING OF GAP << INITIAL COMPRESSION OF O-RING AND O-RING REMAINS COMPRESSED DURING INTERNAL PRESS = 2 PSIG.

MAX TENSILE LOAD IS $T = \frac{.711(10)^{-1} \text{ LB}}{.257 \text{ IN}}$

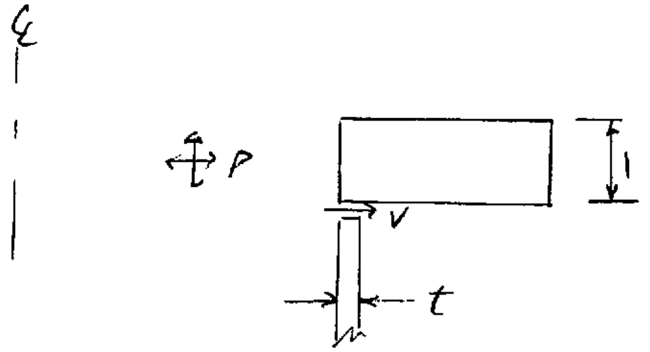
$$T = .280 \text{ LB/IN}$$

THIS COMPARES TO MIN SEALING LOAD OF 70 LB/IN FOR DUROMETER = 90 (PARKER HANDBOOK P A4-11)

$$C - T = 70 - .28 = 69.7 \text{ LB/IN}$$

HOOP STRESS IN FLANGE RING DUE TO INTERNAL PRESSURE

3D FE MODEL DOES NOT COMPUTE HOOP STRESS



$p \approx 2$ psi

$V = .660\, p \sqrt{rt}$

$r = \frac{ID}{2} + \frac{t}{2}$

ID = 104.75 (LARGEST)

t = .5 (MAX THICKNESS)

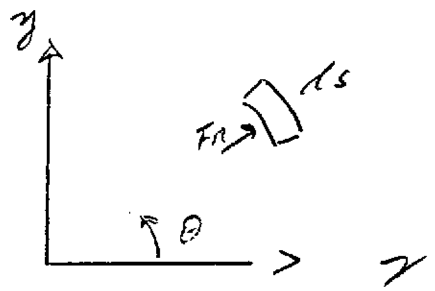
$r = \frac{104.75}{2} + \frac{.5}{2} = 52.4$

$V = .660\ (2)\ \sqrt{52.4(.5)}$

$= 6.8$ LB/IN

TOTAL RADIAL LOAD

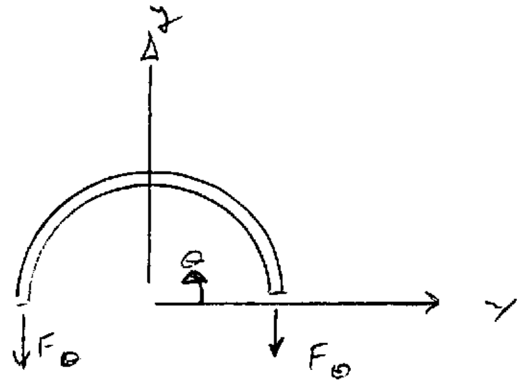
$F_R = p(1) + V = 2 + 6.8 = 8.8$ LB/IN



$dF_y = F_R\, ds \sin\theta$

$ds = r\, d\theta$

$dF_y = F_R\, r \sin\theta\, d\theta$



$$F_\theta = -\int_0^{\frac{\pi}{2}} d F_y =$$

$$= -\int_0^{\frac{\pi}{2}} F_R \, r \sin\theta \, d\theta$$

$$= -F_R \, r \int_0^{\frac{\pi}{2}} \sin\theta \, d\theta$$

$$= +F_R \, r \cos\theta \Big|_0^{\frac{\pi}{2}}$$

$$= +F_R \, r \, (1)$$

$$= +F_R \, r$$

$$= 8.8(52.4) = 461 \text{ LB}$$

FLANGE CROSS SECTION

$$A = 3.5(1) = 3.5 \text{ IN}^2$$

HOOP STRESS

$$f_\theta = \frac{461}{3.5} = 132 \text{ psi NEG}$$

THIS STRESS & STRESS INTENSITY PLOT CONFIRMS THAT STRESS IN FLANGE ARE LOW, EXCEPT AT LOCAL AREA UNDER BOLT

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NO: V049-1-018

PAGE 1 OF 18

REV.	DEO #	DATE	BY:	CHECK
0	139	12/6/95	RDC	AGR

TITLE: Beam Splitter Chamber - Finite Element Analysis of 3/4 in. Thick Flange

BY: R. D. Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To determine if thin flange (3/4 in) can withstand clamping force due to bolt preload plus 2 psi internal pressure without leakage at o-ring.

METHOD: The 3-D finite element model used for the 1 in. thick flange is modified to obtain a 3/4 thick flange model.

ASSUMPTIONS: Same as 1 in. thick flange analysis.

INPUTS: LIGO project design sketches and drawings.
Durometer of 90 for Viton o-rings.

REFERENCES: 1. Parker O-Ring Handbook.
2. IMAGES 3D, Version 3.0, R.L. Cloud & Associates.

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Although the gap opening between flanges is greater for the 3/4 in. thickness than it is for the 1 in. thickness, it still does not permit leakage. If a 1 in. or 1 1/4 in. flange is damaged by gouging, its thickness may be reduced by as much as 1/4 in by machining.

NOTES: If a flange requires machining, it location should be evaluated for tensile force.
Computer file is FLANGE B.

FLANGE ANALYSIS USING 3D MODEL
FOR THICKNESS = 3/4 IN

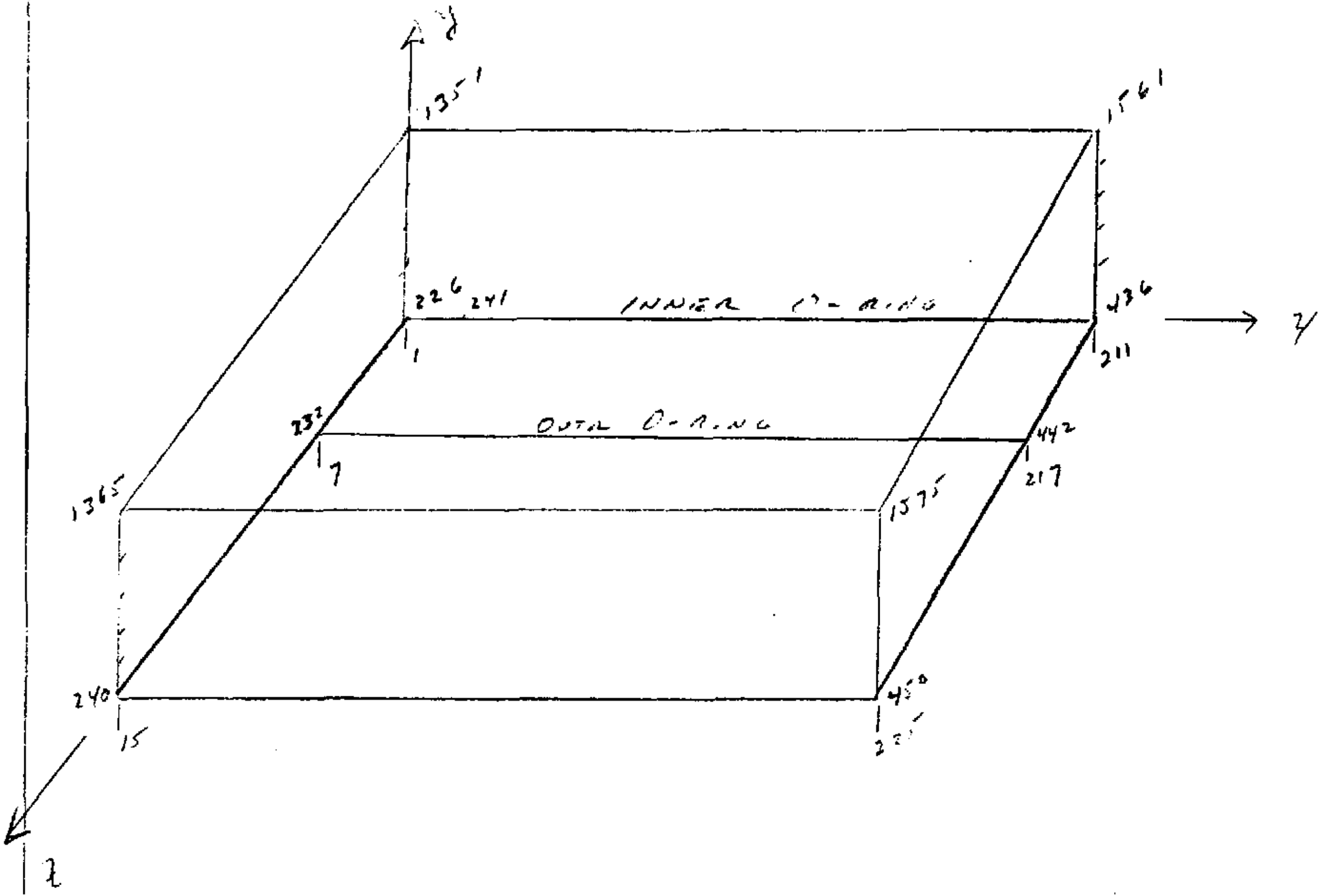
THE FOLLOWING ANALYSIS USES THE SAME MODEL AS THE ENHANCED MODEL BUT THERE ARE 5 ELEMENTS THROUGH THE THICKNESS RATHER THAN 6 BECAUSE THE THE FLANGE IS THINNER, 3/4" VS. 1".

LOADS INCLUDE THE 8500.0* LB AL-PRELOAD AND THE 2 PSI INTERNAL PRESSURE WHICH IS A WORST CASE FOR OPENING OF THE GAP BETWEEN THE FLANGES.

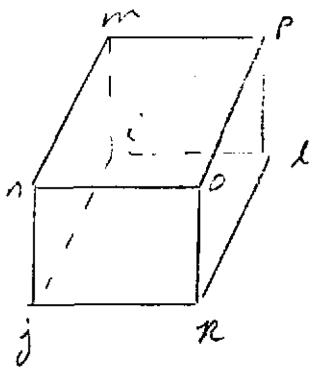
NONLINEAR GAP ELEMENTS ARE USED AT THE FOUNDATION OF THE MODEL TO SIMULATE THE OPENING OF THE GAP.

BOTH THE INNER AND OUTER O RINGS ARE INCLUDED. THESE ARE MODELED AS LINEAR SPRINGS USING THE MAX STIFFNESS POSSIBLE FOR THE 1/4 IN VITON MATERIAL.

* THE MAXIMUM PRELOAD WILL BE 10000 LB (REF CALC V049-1-042, P. 26). THIS WILL NOT AFFECT THE RESULTS OF THIS CALC SIGNIFICANTLY.



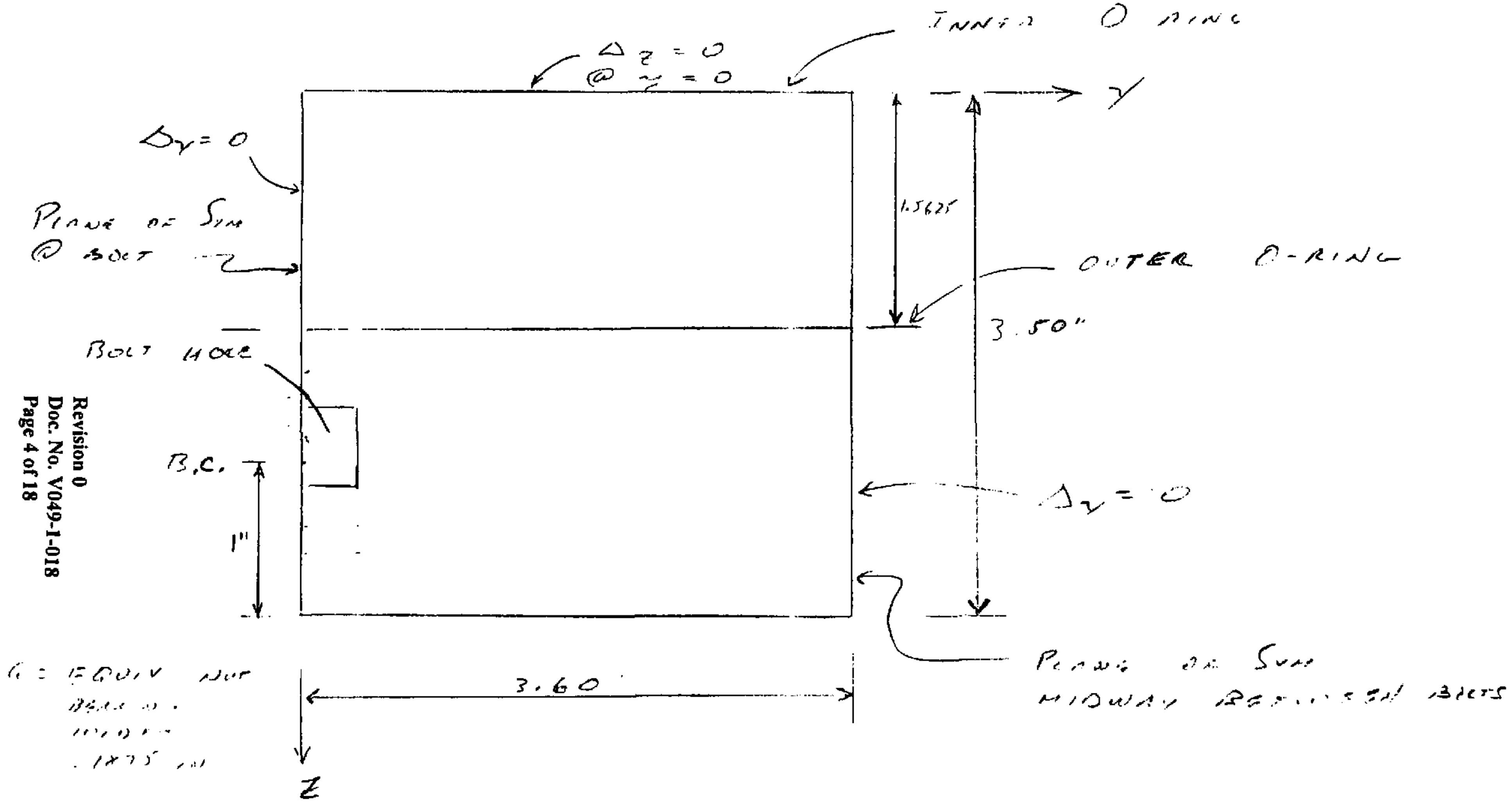
TYPICAL ELEMENT NODE NUMBERING



1ST EL i j k l m n o p

226, 227, 242, 241, 451, 452, 467, 466

BOUNDARY CONDITIONS
@ $z = 0$, $\Delta z = 0$



h

SPRING RATE FOR SPRINGS REPRESENTING
VITON O RING

DUROMETER = 90

OBTAIN MAX SPRING RATE

MAX COMP IS 25% (P A5-13 OF PARKER HANDBOOK). FROM P A4-11 THE MAX LINEAR FORCE IS

160 LB/IN

MIN DEFLECTION (SQUEEZE) IS .058 (P. A5-13)

$$R = \frac{160}{.058} = 2759 \text{ LB/IN}$$

PER IN OF CIRCUMFERENCE

FOR DISCRETE SPRINGS AT .2571* IN SPACING

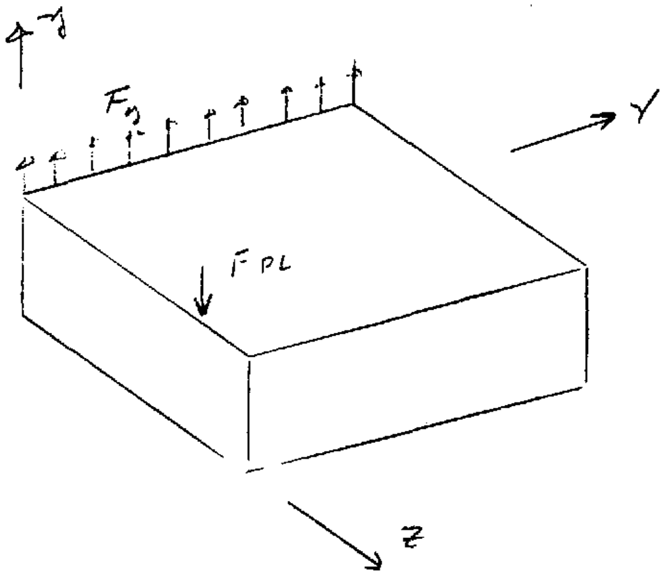
$$R_s = 2759 (.2571)$$
$$= 709 \text{ LB/IN}$$

* REF CALC V049-1-016, P. 18 FOR NODE SPACING

FLANGES - 3D FE ANALYSIS FOR BOLT PRELOAD PLUS POS PRESSURE

ANALYSIS FOR POSITIVE PRESSURE USING 3D FE MODEL - 104 ID FLANGE USED

PRESSURE LOAD FROM ATTACHED CYLINDER



$$F_y = \frac{p\,r}{2}$$

$$p = 2 \text{ psi}$$

$$r = \frac{104.25}{2}$$

$$F_y = \frac{2\left(\frac{104.25}{2}\right)}{2}$$

$$= 52.1 \text{ LB/IN}$$

NODE SPACING ALONG Y-AXIS IS .2571

$$F_{yi} = 52.1(.2571)$$
$$= 13.4 \text{ LB}$$

$$= \frac{13.4}{2} = 6.7 \text{ AT } Y = 0,\ 7.6$$

DELETE SPRINGS

151, 152

DELETE SOLIDS

10, 11, 24, 25

206, 207, 220, 221

402, 403, 416, 417

598, 599, 612, 613

794, 795, 808, 809

BOLT LOADS

F_{PL} = 8500 LB

FOR 1/2 BOLT

$F_{PL} = -4250$ LB

$\swarrow$ Y = 0

$F_{PL} = 14 F_{yi} + 4 \frac{F_{yi}}{2}$

$-4250 = 16 F_{yi}$

$F_{yi} = -266$ LB INTERIOR NODES

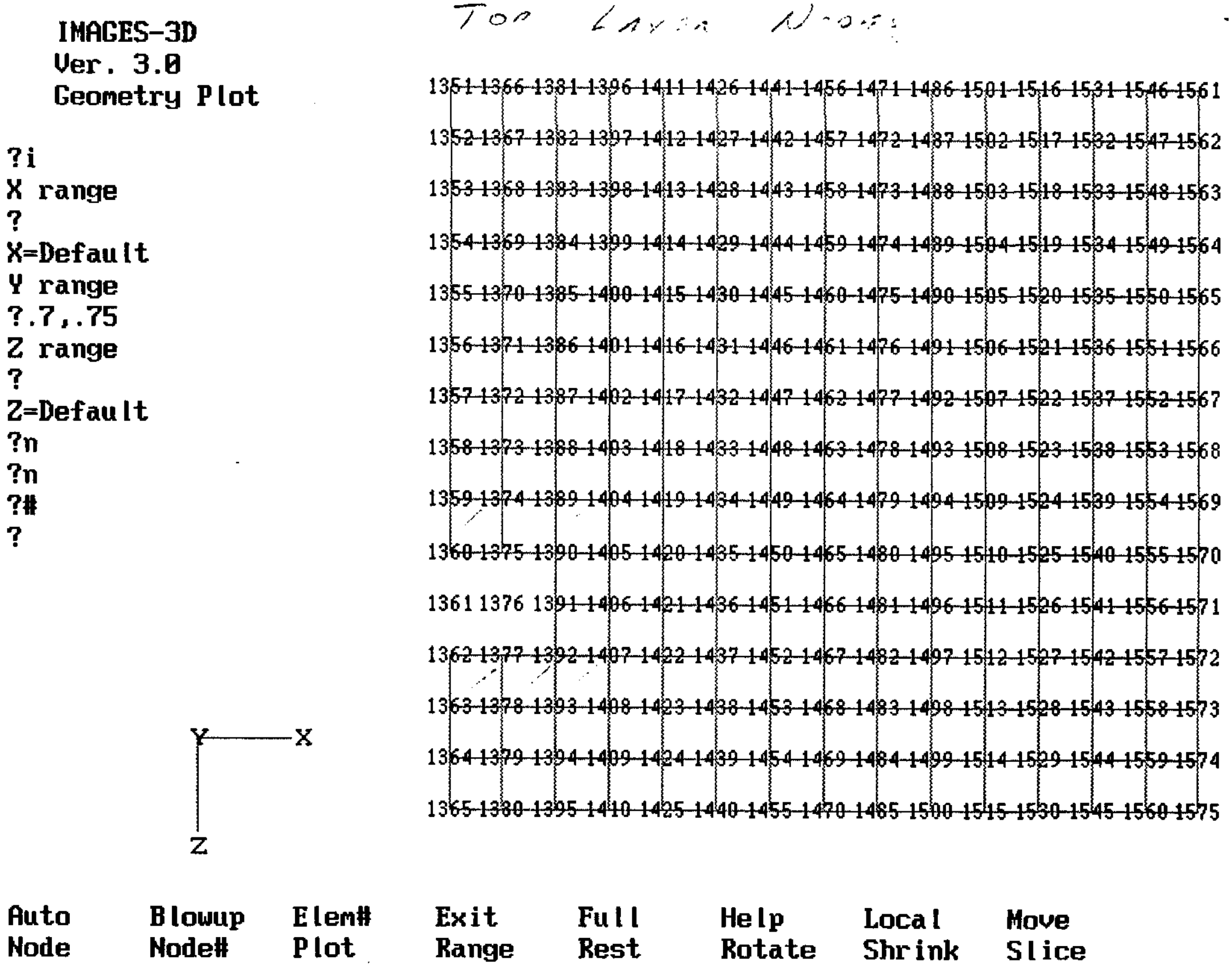
$F_{yi} = -\frac{266}{2} = -133$ LB @ X = 0 AT END NODES

PRESSURE LOAD

F_{yi} = +13.4 LB AT INTERIOR NODES @ Z=0

F_{yi} = +6.7 LB AT END NODES @ Z=0

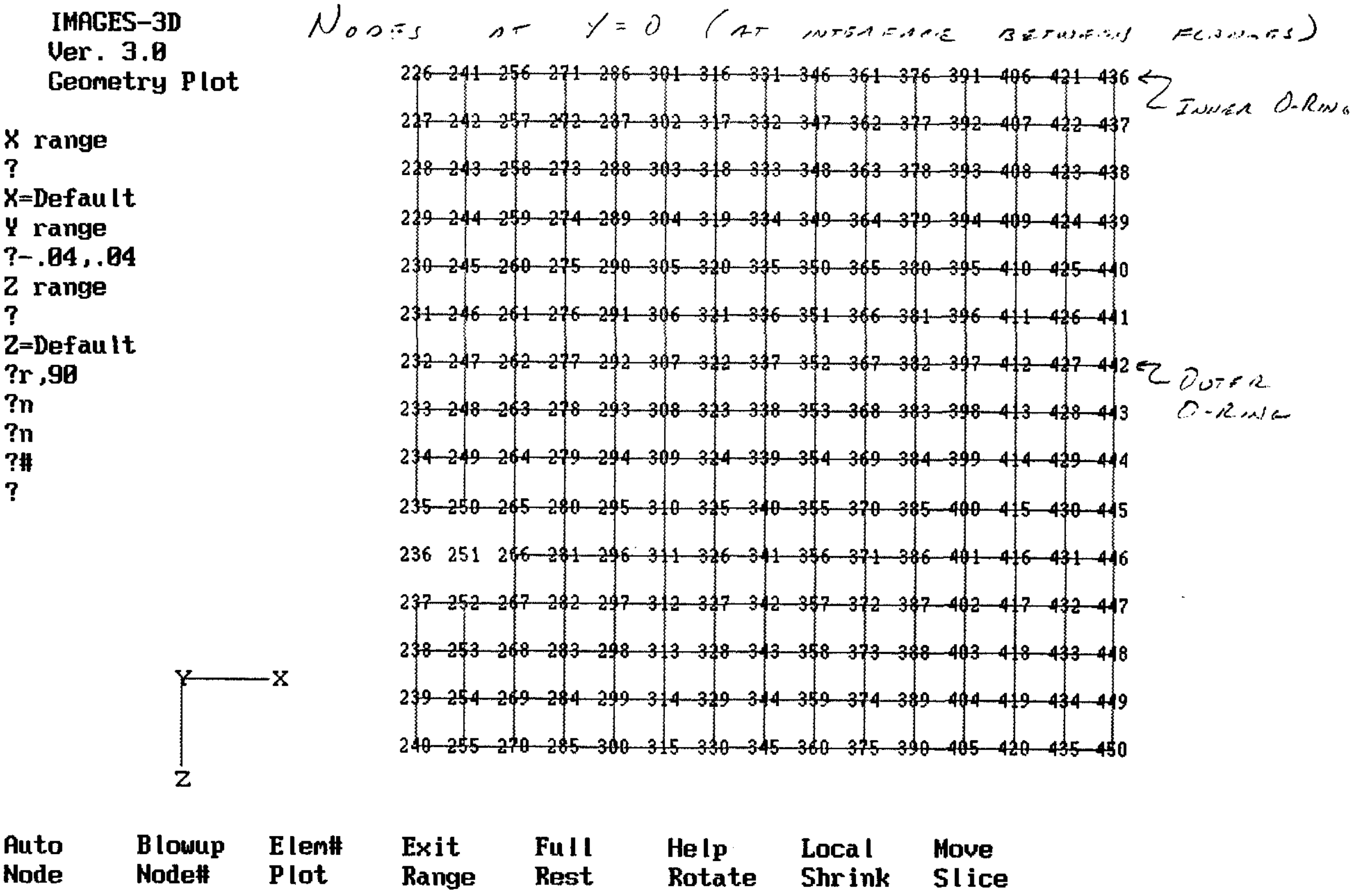
Top Layer Nodes



IMAGES-3D
Ver. 3.0
Geometry Plot

```
?i
X range
?
X=Default
Y range
?.7,.75
Z range
?
Z=Default
?n
?n
?#
?
```

1351	1366	1381	1396	1411	1426	1441	1456	1471	1486	1501	1516	1531	1546	1561
1352	1367	1382	1397	1412	1427	1442	1457	1472	1487	1502	1517	1532	1547	1562
1353	1368	1383	1398	1413	1428	1443	1458	1473	1488	1503	1518	1533	1548	1563
1354	1369	1384	1399	1414	1429	1444	1459	1474	1489	1504	1519	1534	1549	1564
1355	1370	1385	1400	1415	1430	1445	1460	1475	1490	1505	1520	1535	1550	1565
1356	1371	1386	1401	1416	1431	1446	1461	1476	1491	1506	1521	1536	1551	1566
1357	1372	1387	1402	1417	1432	1447	1462	1477	1492	1507	1522	1537	1552	1567
1358	1373	1388	1403	1418	1433	1448	1463	1478	1493	1508	1523	1538	1553	1568
1359	1374	1389	1404	1419	1434	1449	1464	1479	1494	1509	1524	1539	1554	1569
1360	1375	1390	1405	1420	1435	1450	1465	1480	1495	1510	1525	1540	1555	1570
1361	1376	1391	1406	1421	1436	1451	1466	1481	1496	1511	1526	1541	1556	1571
1362	1377	1392	1407	1422	1437	1452	1467	1482	1497	1512	1527	1542	1557	1572
1363	1378	1393	1408	1423	1438	1453	1468	1483	1498	1513	1528	1543	1558	1573
1364	1379	1394	1409	1424	1439	1454	1469	1484	1499	1514	1529	1544	1559	1574
1365	1380	1395	1410	1425	1440	1455	1470	1485	1500	1515	1530	1545	1560	1575



NODES AT Y=0 (AT INTERFACE BETWEEN FLANGES)

```
IMAGES-3D
Ver. 3.0
Geometry Plot

X range
?
X=Default
Y range
?-.04,.04
Z range
?
Z=Default
?r,90
?n
?n
?#
?
```

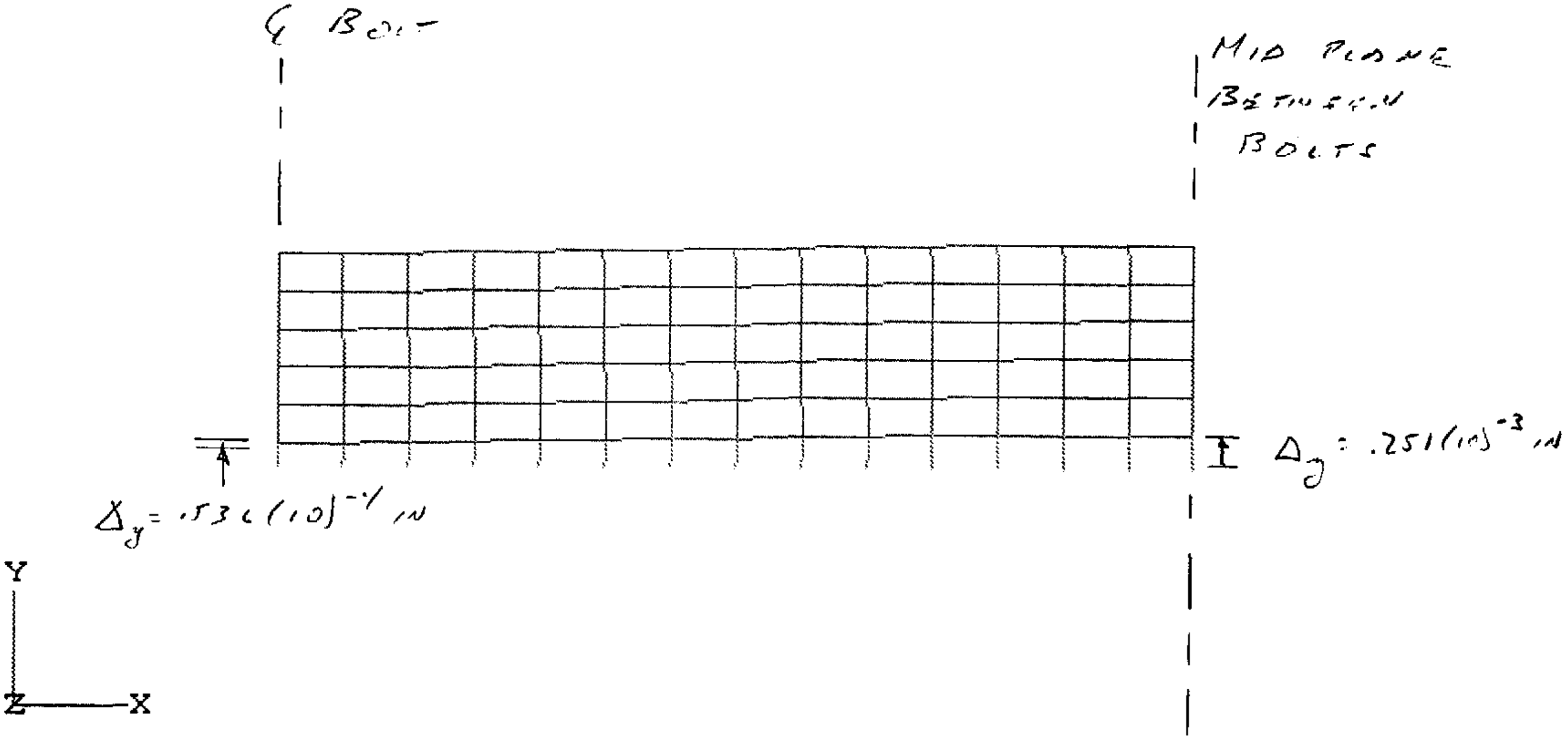
```
226 241 256 271 286 301 316 331 346 361 376 391 406 421 436
227 242 257 272 287 302 317 332 347 362 377 392 407 422 437
228 243 258 273 288 303 318 333 348 363 378 393 408 423 438
229 244 259 274 289 304 319 334 349 364 379 394 409 424 439
230 245 260 275 290 305 320 335 350 365 380 395 410 425 440
231 246 261 276 291 306 321 336 351 366 381 396 411 426 441
232 247 262 277 292 307 322 337 352 367 382 397 412 427 442
233 248 263 278 293 308 323 338 353 368 383 398 413 428 443
234 249 264 279 294 309 324 339 354 369 384 399 414 429 444
235 250 265 280 295 310 325 340 355 370 385 400 415 430 445
236 251 266 281 296 311 326 341 356 371 386 401 416 431 446
237 252 267 282 297 312 327 342 357 372 387 402 417 432 447
238 253 268 283 298 313 328 343 358 373 388 403 418 433 448
239 254 269 284 299 314 329 344 359 374 389 404 419 434 449
240 255 270 285 300 315 330 345 360 375 390 405 420 435 450
```

INNER O-RING

OUTER O-RING

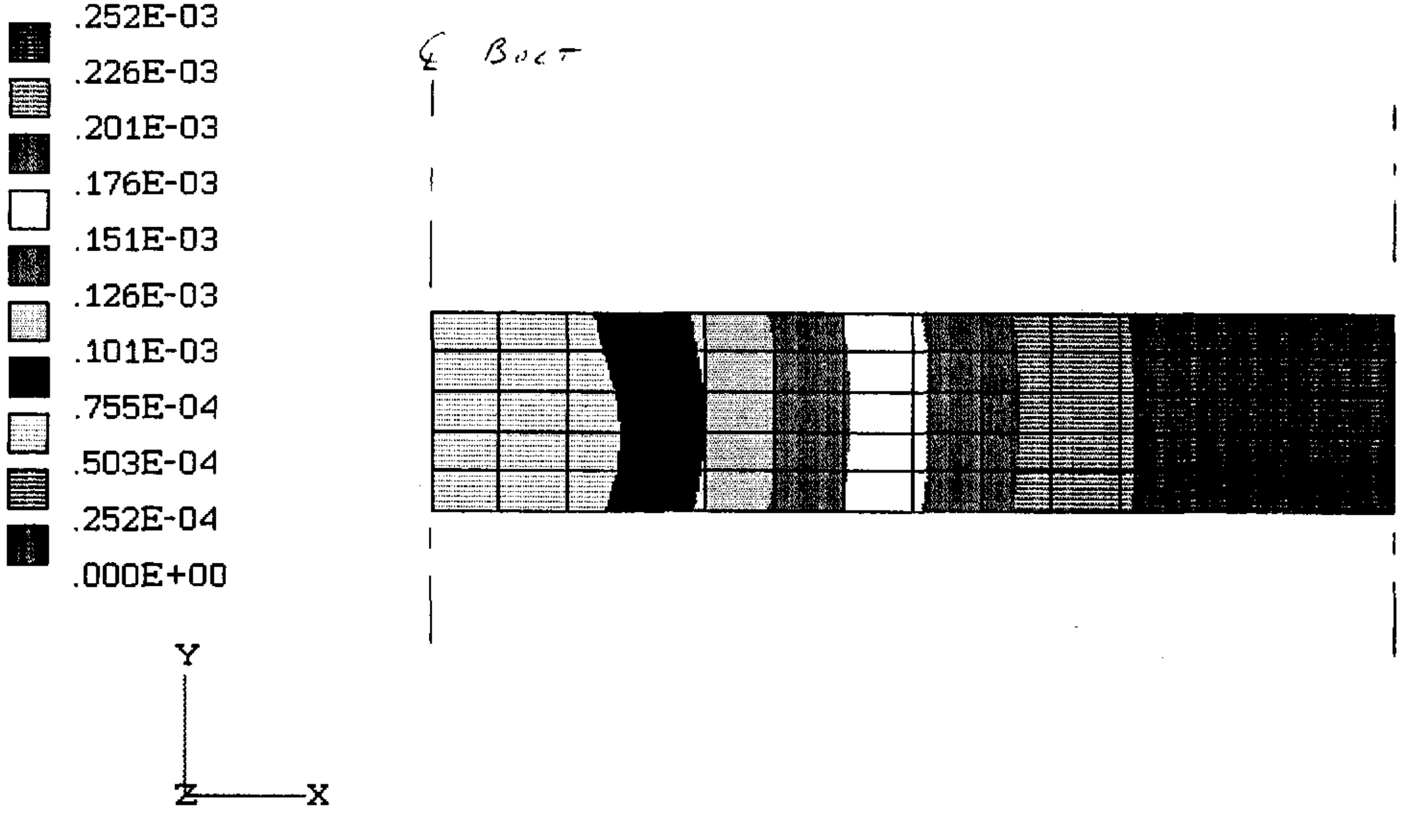
IMAGES-3D
Version 3.0

DEFLECTION ALONG OUTER O-RING



IMAGES-3D
Version 3.0

Y- Displacement along Outer O-Ring



℄ Bolt

Mid Plane
Between Bolts

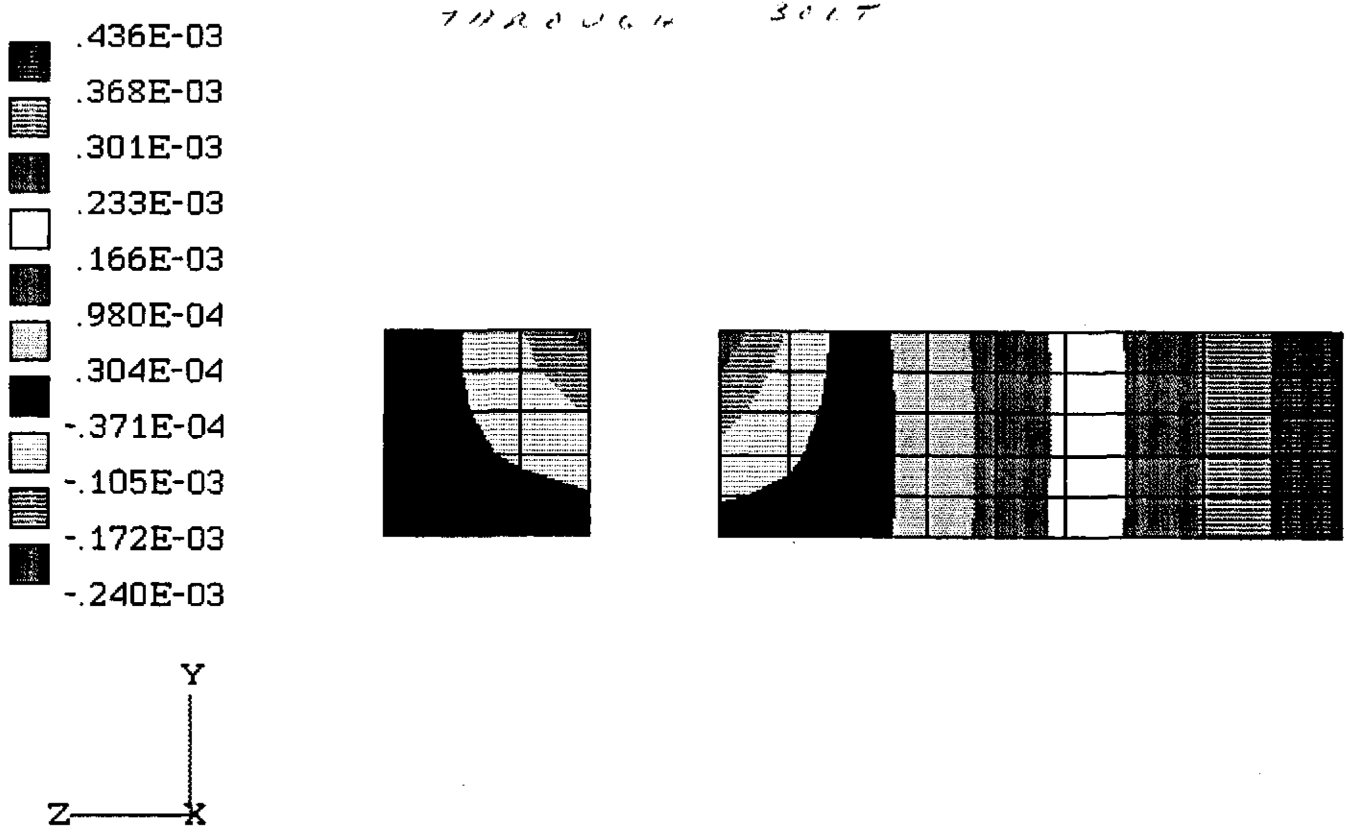
Load Case
1

Displacement Contour Plot
DY

10/20/95
6:53:23

IMAGES-3D
Version 3.0

Y - DISPLACEMENT ALONG RADIAL PLANE PASSING THROUGH BOLT



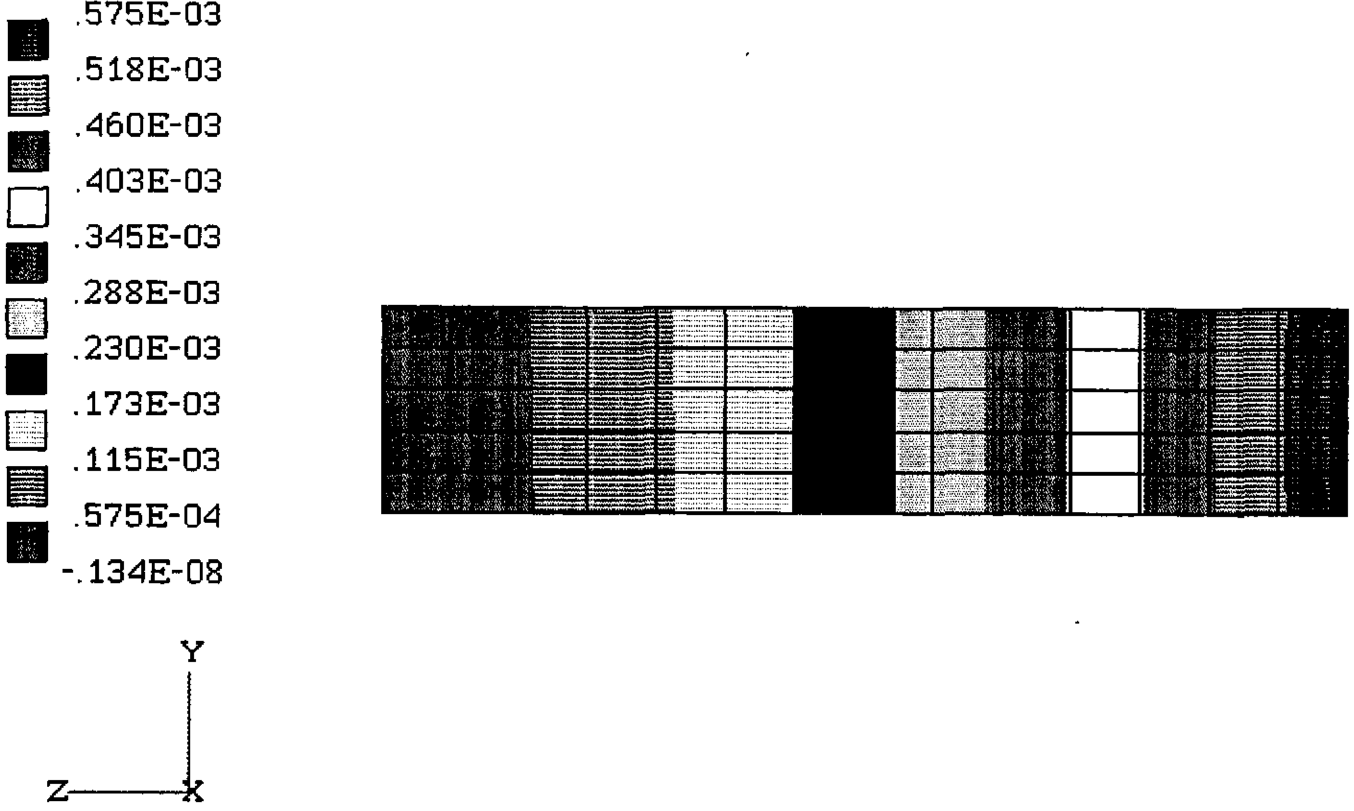
Load Case
1

Displacement Contour Plot
DY

10/20/95
6:57: 6

IMAGES-3D
Version 3.0

Y- DISPLACEMENT ALONG RADIAL PLANE
PASSING MIDWAY BETWEEN BOLTS

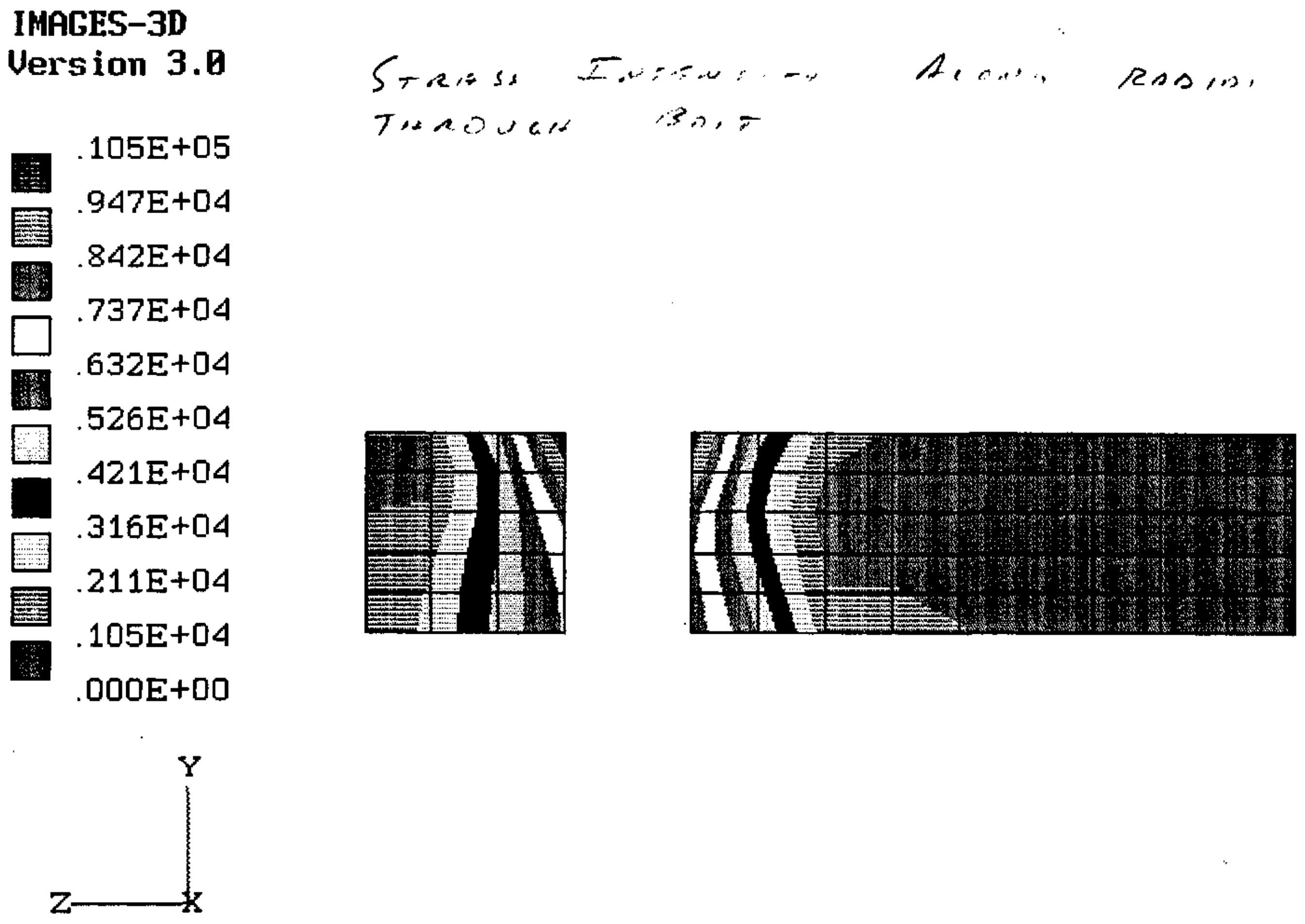


Load Case
1

Displacement Contour Plot
DY

10/20/95
7: 2:23

Stress Intensity Along Radial Plane Passing Through Bolt



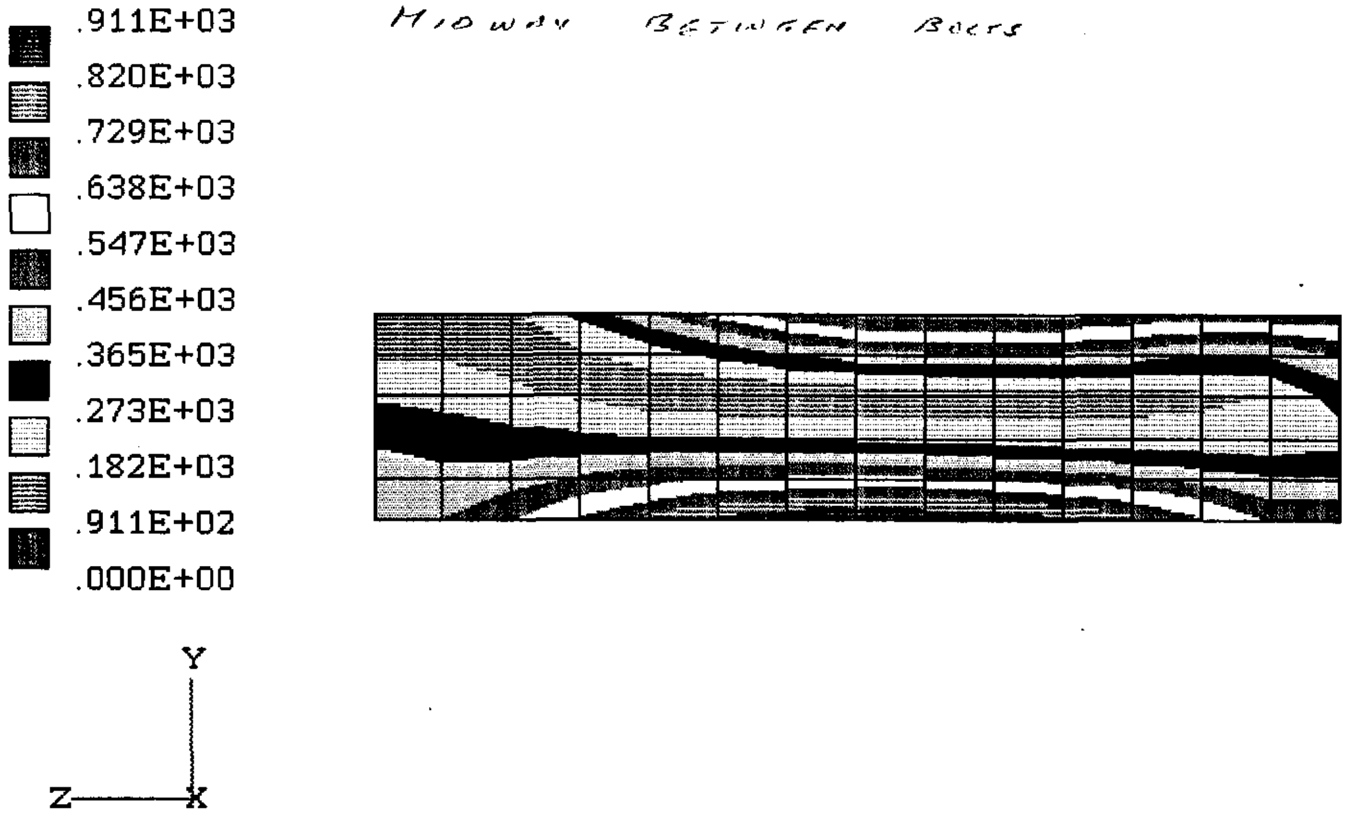
Load Case
1

Stress Contour Plot
Stress Intensity

10/20/95
7:17:13

IMAGES-3D
Version 3.0

Stress Intensity Along Radial Plane Passing Midway Between Bolts



Load Case	**Stress Contour Plot**	**10/20/95**
1	**Stress Intensity**	**7:22:44**

Y - DISPLACEMENTS

	NODE	Δ_Y	EXP	
INNER O-RING	226	.1127	-3	IN } FROM OUTPUT FILE: FLANGE3
	331	.501	-3	
	436	.568	-3	
OUTER O-RING	232	.536	-4	} SEE P. 10
	337	.172	-3	
	442	.251	-3	

RESIDUAL NORM $= .184\,(10)^{-10}$

$< 1\,(10)^{-5}$

∴ RUN CONVERGED BEFORE 10 ITERATIONS

FOUNDATION SPRING LOADS

	NODE	F_Y	
INNER O-RING	226	.303	LB
	331	.355	
	436	.403	
OUTER O-RING	232	$.380\,(10)^{-1}$	ok
	337	.122	
	442	.178	

CHECK Y-DIRECTION REACTION

BOLT + PRESS

$-4250 + 52.1 \ lb/in \times 3.6 \ in$

$= -4067 \ \#$

REACTION FROM OUTPUT =

ΣF_y 4068 ok

MAXIMUM SEPARATION OF FLANGES

MAX DEFLECTION IS AT NODE 436 (AT INNER O-RING MIDWAY BETWEEN BOLTS)

$$\Delta_y = .568 (10)^{-3}$$

FOR BOTH BOLT PRELOAD AND INTERNAL PRESSURE. DOUBLE THIS FOR 2 FLANGES

$$\Delta_y = 2(.568)(10)^{-3}$$
$$= 1.137 (10)^{-3} \ IN$$

COMPARE TO MINIMUM COMPRESSION OF .058 IN FROM PARKER HANDBOOK (P A5-13)

$$\frac{58(10)^{-3}}{1.137} = 51$$

∴ OPENING OF GAP << INITIAL COMPRESSION OF O-RING AND O-RING REMAINS COMPRESSED DURING INTERNAL PRESS = 2 PSIG.

MAXIMUM TENSILE LOAD AT VITON O-RING

T = .403 LB AT NODE 436

ALONG THE O-RING, THE LINEAR FORCE IS

$$T = \frac{.403}{.257} \leftarrow \text{NODE SPACING}$$

$$= 1.57 \text{ LB/IN}$$

THIS COMPARES TO MINIMUM SEALING LOAD OF 70 LB/IN (PARKER HANDBOOK, P. A4-11)

$$C - T = 70 - 1.57 = 68.4 \text{ LB/IN}$$

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-019 PAGE 1 OF 24
REV.	DEO #	DATE	BY:	CHECK	Flange Design for Internal Pressure	
0	0024	12/6/95	RDC	P.W.Y.		
					BY: R.D.Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To evaluate bolted flanges ranging in diameter from 30 in. to 104 in. for positive internal pressure in accordance with the ASME Code.

METHOD: The calculation method provided in Appendix Y of the ASME Code, Section VIII, Division 1, is used. This method applies to flat face flanges with metal-to-metal contact. It has been programmed on the Quatro-Pro spread sheet program.

ASSUMPTIONS:

INPUTS: LIGO project sketches and drawings.

REFERENCES: 1. ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Div. 1, Appendix Y.
2. Quattro-Pro Version 5.00
3. Doc. No. V049-1-066, LIGO Vacuum Equip., Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Using a nominal bolt spacing of 7.2 in. for 7/8 in. diameter bolts, the flanges meet App. Y of Section Viii, Div. 1 for 2 psi internal pressure. Computer file names are shown in the lower left corner of the output in this calculation.

NOTES: In this calculation, flange thickness varies from 3/4 in. for small diameter to 1 in. for large diameter flanges.

FLANGE DESIGN FOR INTERNAL PRESSURE

THE FLANGES ARE EVALUATED IN ACCORDANCE WITH SECT VIII, DIV 1 APP Y FOR FLAT FACE FLANGES. THE DESIGN INTERNAL PRESSURE IS 2.00 PSIG

THE NOMINAL FLANGE THICKNESS IS 2.00 IN

QUICKPAD PAC IS USED FOR THE FLANGE EVALUATION. IT SHOWS THAT 7/8" BOLTS SPACED AT APPROX 7.2 IN ARE ADEQUATE.

FOR THE MAXIMUM DUROMETER OF 50, THE MAXIMUM O-RING COMPRESSION LOAD IS 160 LB/IN SINCE THERE IS A DOUBLE O-RING, THE LOAD IS MULTIPLIED BY 2 FOR THE ANALYSIS.

$$H_g = 2(160) = 320 \text{ LB/IN}$$

THE ROOT DIAMETER OF THE 7/8" BOLT IS

$$d_b = .755 \text{ IN} \quad (\text{AISC P } 4\text{-}147)$$

WHICH IS USED TO COMPUTE THE TENSILE AREA

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............104 1/4 in Flange

C	PRES	B	A	g1	go	V
110.00	2.00	105.00	112.00	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
0.75	1.00	108.25	48	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.0525	0.0292	105.00	1.02	1.0571
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	17318.0	18406.7	1088.66	108824.8

hg	ht	I	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.755	140353.861	95221.7	0.00	7129.60
			operating moment	bolt up moment		operating slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
4837.01	2.807E+05	190443.3	407939.2	299268.1	21.49	0.818
bolt up slope	operating contact	bolt up contact	operating bolt load	bolt up bolt load		

AR	rB	nrB	K	Z
0.113550	0.000467	0.022424	1.066667	15.52

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
18983.24	13926.29	18844.7	13832.3	2749.0	1865.0
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
67.9	46.1
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............84 1/4 in Flange

C	PRES	B	A	g1	go	V
89.75	2.00	84.75	91.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	1.00	88.00	40	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.0650	0.0363	84.75	1.03	1.0708
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	11282.3	12164.2	881.90	88467.2

hg	ht	l	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.755	107102.913	77408.8	0.00	6759.70
			operating moment	bolt up moment		operating slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
4885.59	2.142E+05	154817.7	314837.3	243284.9	17.91	0.880
bolt up slope	operating contact	bolt up contact	operating bolt load	bolt up bolt load		

AR	rB	nrB	K	Z
0.124841	0.000685	0.027398	1.082596	12.63

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
17580.95	13585.37	17451.7	13491.9	2604.2	1882.2
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
79.8	57.6
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............72 1/4 in Flange

C	PRES	B	A	g1	go	V
77.75	2.00	72.75	79.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	1.00	76.00	36	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.0754	0.0422	72.75	1.03	1.0825
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	8313.5	9072.9	759.38	76403.5

hg	ht	I	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.755	88918.3929	66853.1	0.00	6516.01
			operating	bolt up		operating
			moment	moment		slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
4899.04	1.778E+05	133706.2	263313.2	210109.7	16.12	0.880
bolt up	operating	bolt up	operating	bolt up		
slope	contact	contact	bolt load	bolt load		

AR	rB	nrB	K	Z
0.129698	0.000825	0.029710	1.096220	10.92

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
16337.53	13036.47	16213.8	12943.5	2509.7	1886.9
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
89.6	67.3
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............60 1/4 in Flange Thickness = 7/8 in

C	PRES	B	A	g1	go	V
65.75	2.00	60.75	67.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	0.875	64.00	30	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.0896	0.0500	60.75	1.04	1.0988
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	5797.1	6434.0	636.86	64339.8

hg	ht	I	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.505	71864.8462	56297.3	0.00	9327.89
			operating moment	bolt up moment		operating slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
7307.26	1.437E+05	112594.7	214503.5	176934.5	13.43	0.880
bolt up slope	operating contact	bolt up contact	operating bolt load	bolt up bolt load		

AR	rB	nrB	K	Z
0.127808	0.000960	0.028798	1.115226	9.21

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
15970.90	13173.69	15777.3	13022.0	3126.0	2448.9
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
134.4	105.2
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES........... 48 1/4 in Flange Thickness = 7/8 in

C	PRES	B	A	g1	go	V
53.75	2.00	48.75	55.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	0.875	52.00	24	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.1103	0.0615	48.75	1.05	1.1231
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	3733.1	4247.4	514.34	52276.1

hg	ht	I	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.505	55942.2729	45741.6	0.00	8927.49
			operating moment	bolt up moment		operating slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
7299.62	1.119E+05	91483.2	168408.1	143759.3	10.74	0.880
bolt up slope	operating contact	bolt up contact	operating bolt load	bolt up bolt load		

AR	rB	nrB	K	Z
0.125074	0.001146	0.027507	1.143590	7.50

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
15673.57	13379.53	15489.8	13229.3	2967.4	2426.3
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
160.2	131.0
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
A=OD OF FLANGE
g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............44 1/4 in Flange   Thickness = 3/4 in

C	PRES	B	A	g1	go	V
49.75	2.00	44.75	51.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	0.750	48.00	24	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.1199	0.0670	44.75	1.06	1.1341
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	3145.6	3619.1	473.50	48254.9

hg	ht	l	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.255	50886.0759	42223.0	0.00	14046.64
			operating	bolt up		operating
			moment	moment		slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
11655.27	1.018E+05	84446.0	153646.1	132700.9	10.74	0.880
bolt up	operating	bolt up	operating	bolt up		
slope	contact	contact	bolt load	bolt load		

AR	rB	nrB	K	Z
0.135130	0.001351	0.032420	1.156425	6.93

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
14299.69	12350.34	13981.6	12086.4	4015.4	3331.8
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
235.4	195.3
14700.00	14700.00
ok	ok

THIS PROGRAM SOLVES APPENDIX Y (Y-6.1) FLAT FACE FLANGES FOR CLASS 1, CAT 3 (LOOSE TYPE) ASSEMBLIES WITH OR WITHOUT SELF ENERGIZING GASKETS FOR POSITIVE PRESSURE OR VACUUM PRESSURE.

ANALYZE CLASS 1 CATEGORY 3 LOOSE TYPE FLANGES ONLY.

ASSUMPTIONS:

1. g1=g0=thickness of vessel wall
2. B substituted for B1
3. conditions at bolt up and operating evaluated separately
4. F'=0 for loose type flanges implies Ms is zero

REQUIRED INPUT:

C = BOLT CIRCLE DIAM in.
PRES = Internal Pressure for this case
B=ID OF FLANGE
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g1=THICKNESS OF HUB AT LARGE END
g0=THICK @ SMALL END
rb=SEE FIG Y3.1
V=SEE FIG 2-7.3
F=SEE FIG 2-7.2
t=FLANGE THICKNESS ASSUMED VALUE
G=DIAM OF GASKET
n=NUMBER OF BOLTS
db=DIAM OF BOLTS
re=RATIO MOD E (flange)/ MOD E (bolts)
Z=SEE FIG 2-7.1

INPUT VALUES............30 1/4 in Flange Thickness = 3/4 in

C	PRES	B	A	g1	go	V
35.75	2.00	30.75	37.75	0.000	0.000	0.11
				g1 and g2=0 for loose type flanges		fig 2-7.3 required for integral only

F	t	G	n	db	rE	fhub
	0.750	34.00	16	0.755	0.96	1.00
fig 2-7.2 required for integral only						fig 2-7.6 fhub= 1 for loose type flanges

Sbb	Sfb	Snb	Sbo	Sfo	Sno	Hg(unit)
25000	14700	14700	25000	14700	14700	320
						unit gasket seating and sealing forces

RESULTS/OUTPUT:

Si = DESIGN PRESTRESS IN BOLTS
Sr@BC = RAD. FLANGE STRESS @ BOLT CIRCLE
Sr@ID = RAD FLG STRESS @ ID
St = TANGENTIAL FLANGE STRESS @ ID
Sh = LONGITUDINAL HUB STRESS (= 0 FOR CL1, CAT3 LOOSE TYPE FLANGES)

CALCULATED VALUES.............

R	hd	Js	Jp	B1	BETA	a
2.50	2.50	0.1694	0.0942	30.75	1.08	1.1951
	for loose type flgs					

hc	ho	F'	Hd	H	Ht	Hg
0.50	0.00	0.00	1485.3	1815.8	330.55	34180.5

hg	ht	I	Mpo	Mpb	Ms	E0bo
0.88	1.688	2.255	34178.988	29908.0	0.00	13266.80
			operating moment	bolt up moment		operating slope

E0bb	Hco	Hcb	Wm1o	Wm1b	Ab	D
11608.97	6.836E+04	59815.9	104354.3	93996.5	7.16	0.880
bolt up slope	operating contact	bolt up contact	operating bolt load	bolt up bolt load		

AR	rB	nrB	K	Z
0.125365	0.001728	0.027643	1.227642	4.94

SIGMAbo	SIGMAbb	Sio	Sib	Sr@BCo	Sr@BCb
14568.23	13122.23	14273.2	12864.0	3711.4	3247.6
25000.00	25000.00	25000.00	25000.00	14700.00	14700.00
ok	ok	ok	ok	ok	ok

St@IDo	St@IDb
323.6	283.1
14700.00	14700.00
ok	ok

BOLT PRELOAD

PER APP Y, THE DESIGN BOLT PRELOAD IS WM10 (CONSIDERS INTERNAL PRESSURE AT OPERATING CONDITION)

FLANGE SIZE	N	WM10 LB	FPL = WM10/N	USE
104	48	407939	8498	8500 LB
84	40	314837	7870	
72	36	263313	7314	
60	30	214504	7150	
48	24	168408	7017	
44	24	153646	6402	
30	16*	104354	6522	

NOTE: BOLT PRELOAD IS INCREASED TO 10K. BOLT STRESS IS STILL WITHIN LIM. REF CALC 042, P. 20.

* NO. OF BOLTS WAS INCREASED TO 24 FOR THE 30 IN FLANGE. REF CALC 042, P. 26

REVISION 0
DOC. NO V049-1-019
P 24 OF 24

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-020 PAGE 1 OF 13
REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber - Design of Removable Work Floor	
0	0024	4/12/96	RDC	AGR		
					BY: R.D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: To design removable floor and support members to be installed in lower section of BSC.

METHOD: Hand calculations using standard beam design method for support beams and removable floor sections.

ASSUMPTIONS:

INPUTS: See Doc. No. LIGO-C951078-00-4 which provides response to V049-NL-PL-9 (requesting clarifications of BSC internal floor requirements). Maximum load is 500 Kg during maintenance. This occurs at room temperature.

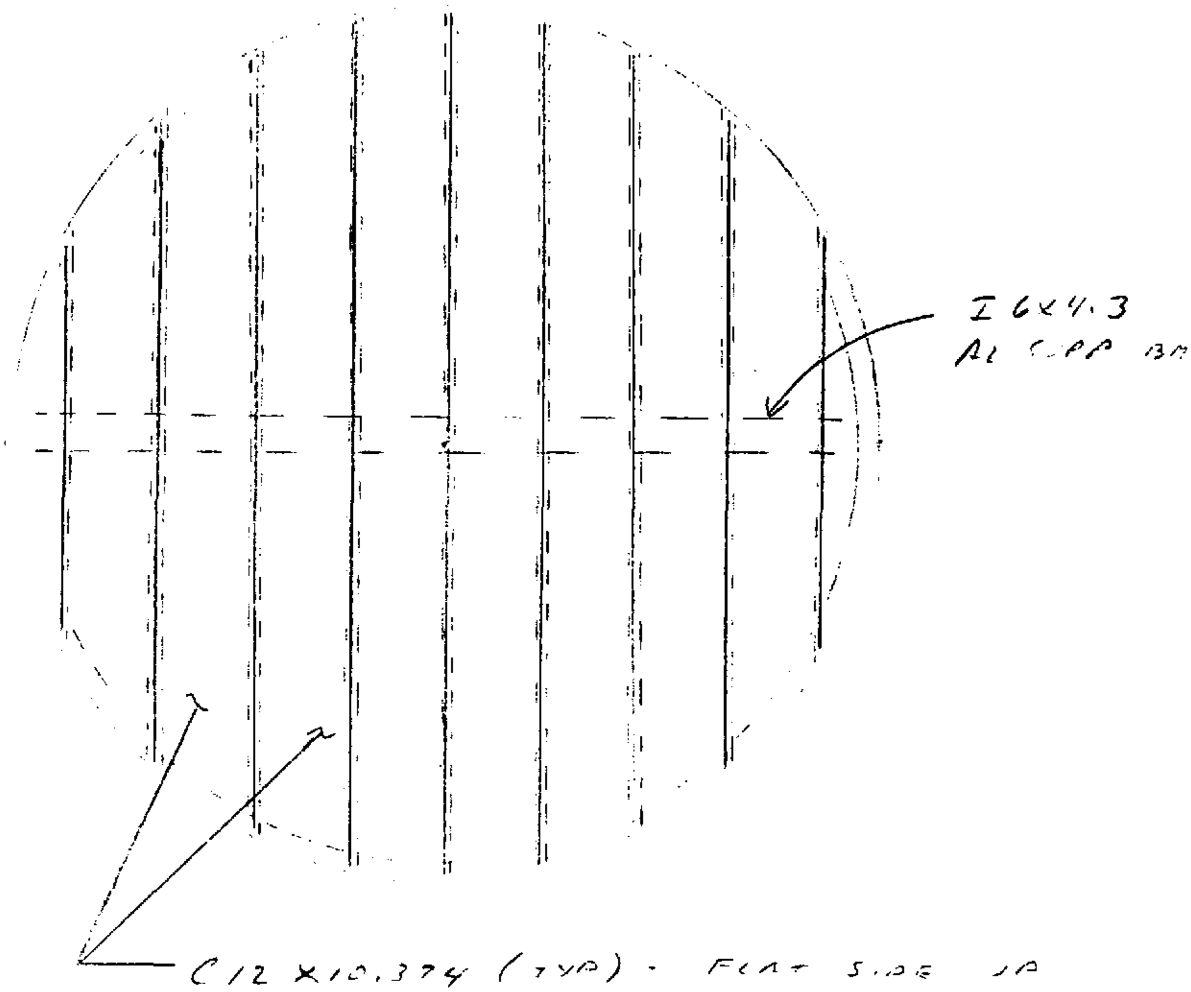
REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1.
2. Aluminum Association Hankbook
3. DOC. NO. V049-1-006, LIGO VAC. EQUIP., SEISMIC DESIGN REQ.

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The design of the aluminum floor meets LIGO requirements and the requirements of the applicable design codes.

NOTES:

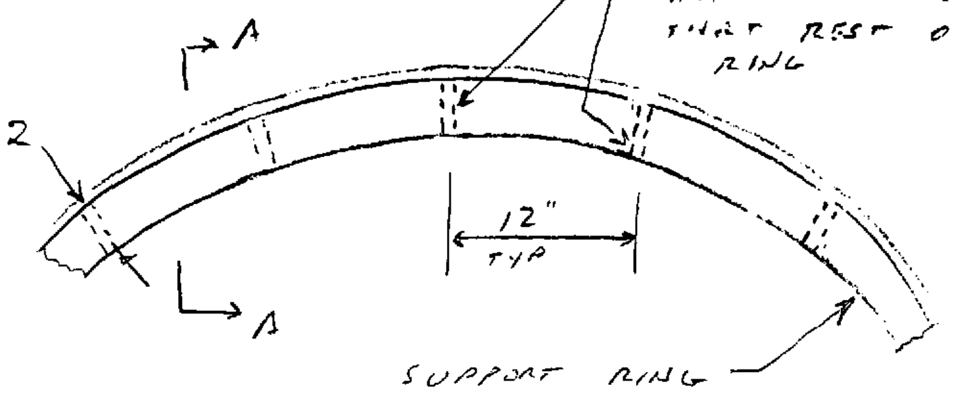
BSC FLOOR 2-23-96



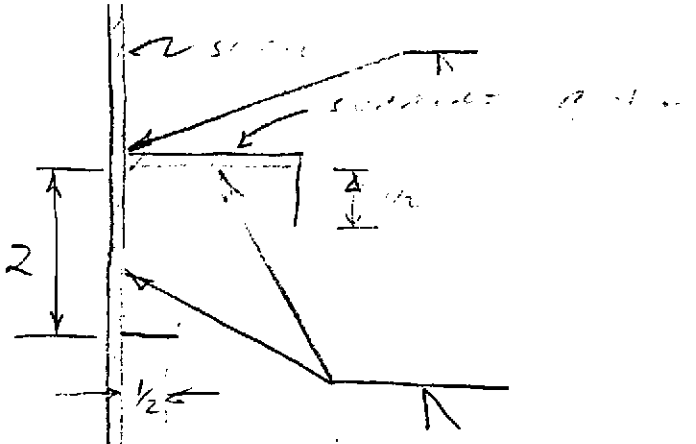
MATERIAL

SB 221 - 6061 - T6

2-23-96



GUSSETS SHALL BE ALIGNED WITH C12 FLANGES THAT REST ON SUPPORT RING



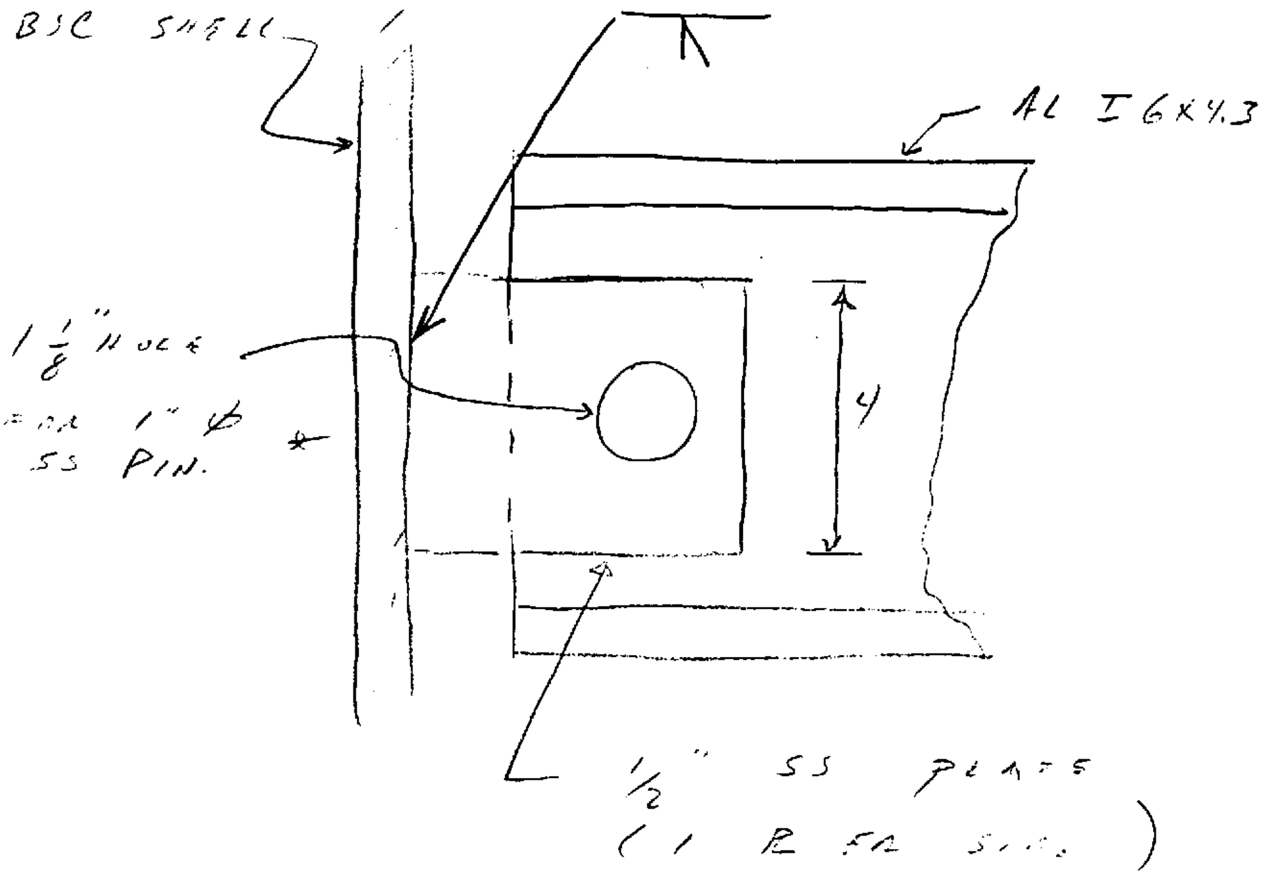
RING & GUSSETS ARE 304/304L

A - A

RING THICKNESS = 1/2"
GUSSET THICKNESS = 3/8"

2-23-96

FLOOR SUPPORT TO SHELL CONNECTION



REV 0
DOC. NO V047-1-020
P. 4 OF 12

FILLER MATERIAL

SB 221 ALLOY 6061
TEMPER T6

YIELD F_y = 35 KSI @ ROOM TEMP

ULTIMATE F_u = 38 KSI @ ROOM TEMP
REF ASME B&PV CODE SECT II, TABLE 13

ALLOWABLE BENDING STRESS

FOR WEAK AXIS BENDING USE AISC ALLOW

$F_b = .75\ F_y$

$= .75(35) = 26.25$ KSI

NOTE: THIS IS LESS THAN ALUMINUM ASSOC. ALLOWABLE USING FS = 1.5

FOR STRONG AXIS BENDING STRESS WILL BE KEPT REASONABLY LOW TO AVOID LOCAL & LATERAL TORSIONAL BUCKLING

REV 0
DOC. NO V0V9.1-070
P. 5 OF 13

STIFFNESS OF ALUM C12x 7.41 FOR LOAD AT CENTER BENT ABOUT WEAK AXIS

$$\Delta_y = \frac{PL^3}{48EI_y}$$

$L = 104$

$E = 10(10)^6$ psi

$I_y = 3.99$ in^4

$$\Delta_y = \frac{P(104)^3}{48(10)^7(3.99)}$$

$$= \frac{P}{1702.6}$$

$$R_1 \; 1702.6 = \frac{P}{\Delta_y} \; \text{LB/IN}$$

STIFFNESS OF ALUM I6x 4.3 FOR LOAD AT CENTER BENT ABOUT STRONG AXIS

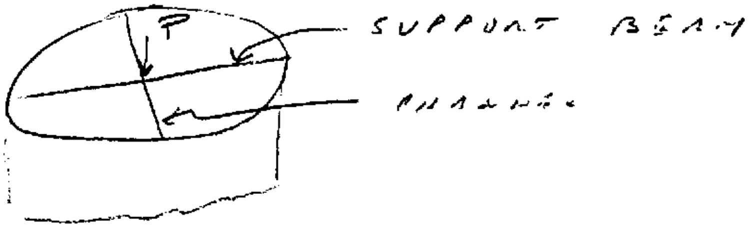
$I_x = 22.08$ in^4

$$R_2 = \frac{P}{\Delta_y} = \frac{48(10)^7(22.08)}{(104)^3}$$

$$= 9422 \text{ LB/IN}$$

REV 0
DOC. NO. V049-1-020
P. 6 OF 13

THE SUPPORT BEAM AND THE [illegible] — CHANNEL ACT AS SPRINGS IN PARALLEL FOR A LOAD AT THE CENTER OF THE VESSEL



$$K = k_1 + k_2$$

$$= 1703 + 5422 = 11125 \text{ LB/IN}$$

MAX DEFL AT CTR (LIVE LOAD)

$$K = \frac{P}{\Delta}$$

$$\Delta = \frac{P}{k} = \frac{1100}{11125} = .10 \text{ IN} \quad \text{ok}$$

STRESS IN INVERTED CHANNEL DUE TO LOAD AT CTR

$$\Delta = \frac{P_1}{k_1}$$

$$P_1 = \Delta k_1 = .10(1703) = 170 \text{ LB}$$

$$M = \frac{PL}{4} + \frac{wL^2}{8}$$

$$= \frac{170(104)}{4} + \frac{\frac{7.41}{12}(104)^2}{8}$$

$$= 4420 + 835$$

$$= 5255 \text{ IN-LB}$$

$S_y = 1.76$ FOR C12 × 7.41*

* CHANGED TO C12 × 10.374

$f_b = \frac{M}{S} = \frac{5235}{1.76} = 3000$ psi ok

STRESS IN INVERTED CHANNEL W/ LOAD AT 1/4 PT

$$M = \frac{1100(52)}{4} + \frac{\frac{7.41}{12}(52)^2}{8}$$

$$= 14300 + 209$$

$$= 14500 \text{ IN-LB}$$

$$f_b = \frac{M}{S} = \frac{14500}{1.76} = 8250 \text{ psi} \quad ok$$

STRESS IN SUPPORT BEAM DUE - DW

USE $w = 30 \overset{C12}{+} 4.3 = 34.3$ LB/FT

$$\cong 3 \text{ LB/IN}$$

$$M = \frac{wL^2}{8} = \frac{3(104)^2}{8}$$

$$= 4056$$

$$f_b = \frac{M}{S_x} = \frac{4056}{7.36} = 550 \text{ psi}$$

STRESS IN SUPPORT BEAM DUE TO
LIVE LOAD AT CENTER

$$\Delta = \frac{P_2}{K_2}$$

$$P_2 = K_2 \Delta$$

$$= 9422(.10) = 942 \text{ LB}$$

$$M = \frac{PL}{4} = \frac{942(104)}{4} = 24500$$

$$f_b = \frac{M}{S_x} = \frac{24500}{22.04}$$

$$= 1100 \text{ psi}$$

TOTAL STRESS IN SUPPORT BEAM DUE TO
DW & LL

$$f_b = 1100 + 550$$

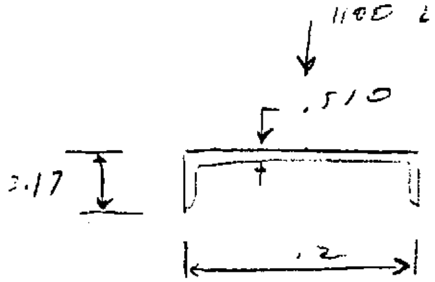
$$= 1660 \text{ psi} \quad \text{LOW}$$

REV. 0
DOC. NO. V045-1-070
P. 9 OF 13

BENDING STRESS IN WEB OF CHANNEL

TRAY C12 X 13.334 AMSC STD

WEB THICKNESS t = .510



ASSUME THAT LOAD IS 3 IN WIDE

$$M = \frac{PL}{4} = \frac{1100(12)}{4}$$

$$= 3300 \text{ IN}\cdot\#$$

$$f = \frac{6M}{bt^2} = \frac{6(3300)}{3(.510)^2}$$

$$= 25400 \text{ psi}.$$

$$< 26250 \text{ psi} \quad \text{OK}$$

FOR BENDING ABOUT WEAK AXIS

S_y = 2.06 REF AISC CODE
= SECT. MODULUS

ASSUME SINGLE SUPPORT BEAM AT CENTER OF BSC

$$L = 52$$

$$M = \frac{1100(52)}{4} = 14300 \text{ in-\#}$$

$$f_b = \frac{14300}{2.06} = 6940 \quad \text{OK}$$

REV 0
DOC NO V0119-1-027
P. 10 OF 13

SUPPORT RING

GUSSETS WILL BE PLACED UNDER SUPPORT-RING SO THAT THEY ARE ALIGNED WITH POINT OF CONTACT OF C12 FLANGE

THE MAX REACTION FROM THE C12 IS

$$R = 1100 + 52 \times 10.374$$
$$\approx 1640 \text{ LB}$$

SINCE THE GUSSET IS 3/8" THICK AND THE WELD BETWEEN THE SHELL & GUSSET IS A FULL PEN., THE WELD AREA IS

$$A_w = 2\left(3/8\right) = .75 \text{ IN}^2$$

WELD SHEAR STRESS

$$f_v = \frac{R}{A_w}$$
$$= \frac{1640}{.75} =$$
$$= 2200 \text{ psi} \quad \text{OK}$$

SUPPORT RING & GUSSETS ARE 304/304L

SUPPORT BEAM CONNECTION TO SHELL

THE WEB THICKNESS FOR THE I 6 × 4.3 IS

$$t_w = .23 \text{ IN}$$

FOR A SINGLE 3/4 IN PIN THE BEARING AREA IS

$$A_p = .75(.23)$$
$$= .1725$$

THE MAX REACTION IS

$$R = \frac{104}{2(12)} (2 \times 1[illegible] \text{ LB/FT}) + 1100$$

$$= 150 + 1100 = 1250 \text{ LB}$$

BEARING STRESS

$$f_p = \frac{R}{A_p}$$

$$= \frac{1250}{.1725} = 7250 \text{ psi} \quad \text{OK}$$

USE A 1 IN PIN TO REDUCE f_p

$$f_p = 7250 \times .75 = 5400 \text{ psi}$$

IN DOUBLE SHEAR

$$A_s = 2\pi(.5)^2$$

$$= 1.57 \text{ IN}^2$$

$$f_v = \frac{1250}{1.57} = 800 \text{ psi}$$ OK FOR SS PIN

DIFFERENTIAL EXPANSION BETWEEN
STEEL AND ALUM SUPPORT BEAM

$$\alpha_{AL} = 13.52\ (10)^{-6}\ \frac{IN}{IN\ {}^\circ F}$$

FOR 6061

$$\alpha_{CS} = 9.19\ (10)^{-6}$$

FOR TEMP RISE TO 400°F

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

$$\delta = (\alpha_{AL} - \alpha_{CS})\ L\ \Delta T$$

$$L = 104\ IN$$

$$\delta = (13.52 - 9.19)(10)^{-6}(104)(330)$$

$$= .15\ IN$$

USE AN OVERSIZE BOLT HOLE TO
TAKE δ. FROM B/C ℄

$$\delta = \frac{.15}{2} = .075$$

HOLE SIZE = $1\frac{1}{4}$ GIVES CLEARANCE

$$.125 > \delta = .075\ \ OK$$

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-021
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REV.	DEO #	DATE	BY:	CHECK
0	0136	12/6/95	RDC	WDB

Beam Splitter Chamber - Design of Flange Welds

BY: R. D. Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Design partial penetration seal weld and external stitch weld between vessel flange and shell.

METHOD: Hand calculation method programmed on the Quattro-Pro spreadsheet program.

ASSUMPTIONS: The maximum discontinuity moments and forces are used for design by assuming the welded joint behaves as a cylinder/rigid wall junction.

INPUTS: LIGO Project sketches and drawings.

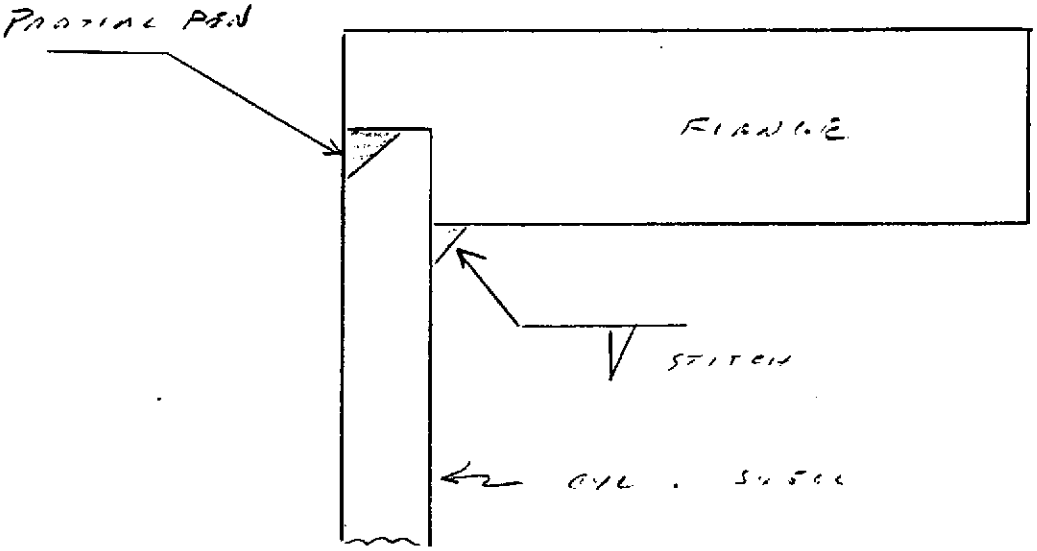
REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Div. 1.
2. Doc. No. V049-1-042, Bolted Flange Analysis for Tensile Forces.
3. Doc. No. V049-1-066, LIGO Vacuum Equip., Structural Design Criteria.

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: See attached spreadsheet for acceptable welds for various size flanges.

NOTES: Computer File: Flange.wb1

EACH FLANGE IS CONNECTED TO THE CYLINDRICAL SHELL WITH 2 WELDS AS SHOWN BELOW



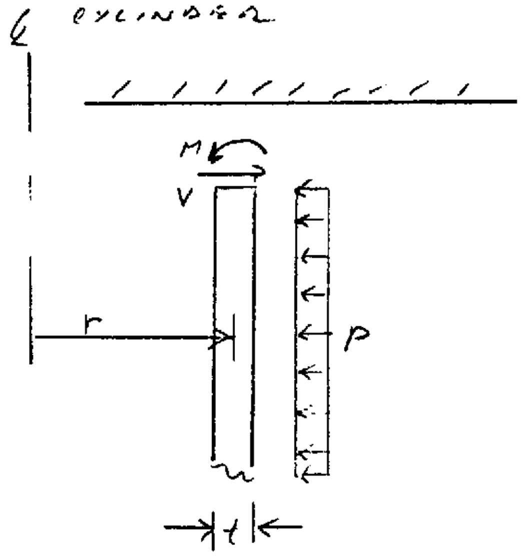
THESE WELDS RESIST DISCONTINUITY FORCES BETWEEN THE CYLINDER AND THE FLANGE.

FOR VACUUM PRESSURE, THE FILLET WELD (STITCH) IS ASSUMED TO RESIST THE DISCONTINUITY MOMENT. FOR POSITIVE PRESSURE, THIS MOMENT IS ASSUMED TO BE RESISTED BY THE PARTIAL PEN WELD

HOWEVER, FOR DESIGNING THE PARTIAL PENETRATION WELD, IT WILL BE ASSUMED THAT THIS WELD ALSO RESISTS THE DISCONTINUITY SHEAR FORCE DUE TO THE VACUUM AND THE POSITIVE PRESSURE.

PRESSURE DISCONTINUITY STRESSES FOR A CYLINDER AT A RIGID WALL.

(FLANGE IS ASSUMED TO ACT AS A RIGID WALL



FOR EXTERNAL PRESSURE, p

SHEAR $V = .660 p \sqrt{rt}$

MOMENT $M = .257 prt$

BSC - 104 1/4 ID FLANGE

$r = 52.125 + .25 = 52.375$ IN
$t = .5$

$p = 14.7$ FOR VACUUM

$V = .660\, p\sqrt{rt} = .660\,(14.7)\,(52.375 \times .5)^{\frac{1}{2}}$
$= 49.65$ LB/IN

$M = .257\, p\, r\, t = .257(14.7)(52.375)(.5)$
$= 98.93$ IN-LB/IN

PEN. WELD SHEAR STRESS (NO TENSILE BENDING IN WELD DUE TO EXTERNAL PRESSURE)

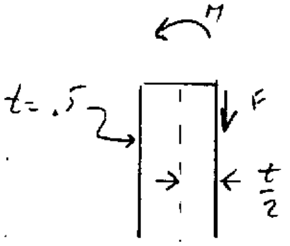
$$f_v = \frac{V}{t_{wp}}$$

$t_{wp} = .25$

$$f_v = \frac{49.65}{.25} = 199 \text{ psi}$$

(AGREES W/ SPREADSHEET)

STITCH WELD (1/4 LEG, 2 IN LONG @ 6 IN) RESISTS MOMENT



$$F \times \frac{t}{2} = M$$

$$F = \frac{2 \times 98.93}{.5} = 396 \text{ LB/IN}$$

FORCE IN 1 IN OF WELD

$$F = 396 \times \frac{6}{2} = 1188 \text{ LB/IN}$$

STITCH WELD SHEAR STRESS

$$f_v = \frac{F}{.707\, t_{ws}} = \frac{1188}{.707(.25)}$$

$= 6721$ psi
(AGREES W/ SPREAD SHEET)

CONT. FOR POS PRESSURE

LET $p = 10$ psi *

$V = 49.65 \times \frac{10}{14.7} = 33.79$

$M = 98.93 \times \frac{10}{14.7} = 67.30$

LONG STRESS IN PEN WELD

$t_{wp} = .25$

$f_a = \frac{pr}{2t_{wp}} = \frac{10(52.375)}{2(.25)}$

$= 1048$ psi

WELD BENDING STRESS

$f_b = \frac{6M}{t_{wp}^2} = \frac{6(67.30)}{.25^2}$ ↖ CONSERVATIVE

$= 6461$ psi

TOTAL AXIAL STRESS

$f_t = f_a + f_b = 7509$ psi

PAR. PEN WELD SHEAR STRESS

$f_v = \frac{V}{t_{wp}} = \frac{33.78}{.25} = 135$ psi

* FINAL POS PRESS = 2 psi

ALLOWABLE WELD STRESSES

FILLET WELDS - ALLOW SHEAR STRESS

$\tau_{all} = .55\ S_{all}$, SECT VIII(1), UW-13

$S_{all} = 14.7$ KSI *

$\tau_{all} = .55(14.7) = 8.1$ KSI

BUTT WELD IN SHEAR

$\tau_{all} = .70\ S_{all}$

$= .70\ (14.7)$

$= 10.3$ KSI

* CONSERVATIVE SINCE DUAL GRADE
MATERIAL 304/304L IS USED

R. D. Ciatto LIGO 16-Oct-95

FLANGE TO SHELL WELD

Flange I. D., (in) =	104.25	104.25	84.25	72.25	60.25	48.25	44.25	30.25
Shell Thickness, tsh, (in) =	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Shell Mean Radius, r (in) =	52.375	52.25	42.25	36.25	30.25	24.25	22.25	15.25
Partial Pen Weld Thickness, twp (in) =	0.25	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Stitch Weld Fillet Weld Thickness, tws (in) =	0.25	0.1875	0.125	0.125	0.125	0.125	0.125	0.125
Stitch Weld Spacing, s (in) =	6	4	4	4	6	6	6	6
Stitch Weld Length, l (in) =	2	2	2	2	2	2	2	2
Vacuum								
Pressure, p (psi) =	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Shear, V, (lb/in) = .660*p*(r*tsh)^.5	49.65	35.07	31.53	29.21	26.68	23.89	22.88	18.94
Moment, M (in-lb/in) = .257*p*r*tsh	98.93	49.35	39.90	34.24	28.57	22.90	21.01	14.40
Pen Weld Shear Stress, fv (psi) = V/twp	199	281	252	234	213	191	183	152
Stitch Weld Force per in from Moment, f = M/(tsh/2) =	396	395	319	274	229	183	168	115
Stitch Weld Shear Stress, fv (psi)= f*(s/(.707*l*tws)) =	6717	5956	7224	6199	7759	6220	5707	3911
Positive Pressure in Vessel								
Pressure, ppos (psi) =	3	3	3	3	3	3	3	3
Shear, Vp, (lb/in) = .660*ppos*(r*tsh)^.5	10	7	6	6	5	5	5	4
Moment, Mp (in-lb/in) = .257*ppos*r*tsh	20	10	8	7	6	5	4	3
Pen Weld Long. Pressure Stress, fl (psi) = ppos*r/(2*twp)	314	627	507	435	363	291	267	183
Pen Weld Bending Stress, fb (psi) = 6*Mp/twp^2	1938	3867	3127	2683	2239	1795	1647	1129
Pen Weld Total Axial stress, ft (psi) = fl+fb	2253	4494	3634	3118	2602	2086	1914	1312
Pen Weld Shear Stress, fv (psi) = Vp/twp	41	57	51	48	44	39	37	31

Flange.wb1

EFFECT OF FLANGE TENSION DUE TO COMPONENT INTERFACE LOAD

REF CALC V047-1-042 PP 26 & 77

THE MAXIMUM AXIAL STRESS DUE TO COMPONENT INTERFACE LOADS IS 2500 psi IN A 1/8 IN PAR PEN WELD (30 IN FL). THE MAXIMUM DESIGN POSITIVE PRESSURE IS NOW 2 psi. THE MAX DISCONTINUITY AXIAL STRESS IS IN THE 104 IN FLANGE (4517 FOR 3 psi). CONSERVATIVELY ADDING THESE WORST CASE AXIAL WELD STRESS GIVES

$$f_a = 2500 + \frac{2}{3}(4517)$$

$$= 2500 + 3011$$

$$= 5911 \text{ psi}$$

OK

REV 0
DOC. NO. V049-1-021
P. 7A OF 7

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-022

PAGE 1 OF 16

Beam Splitter Chamber, FE Analysis of Lower Section

REV.	DEO #	DATE	BY:	CHECK
0	0128	12/6/95	RDC	
		4/18/96		P.W.Y.

BY: R.D.Ciatto

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To evaluate the lower section of the beam splitter chamber for vacuum pressure.

METHOD: A finite element analysis of the lower section shell, head and nozzles is performed.

ASSUMPTIONS:

INPUTS: LIGO project sketches and drawings.
Shell thickness = .5 in.
60 in. nozzle thickness = .5 in.
Head thickness = .375 in.

REFERENCES: 1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1
2. IMAGES 3D, Version 3.0, R.L. Cloud & Associates
3. Doc. No. V049-1-066, LIGO Vacuum Equip. Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Stresses are within the limitsof the ASME Code, Section VIII. Div. 1.

NOTES: Computer files are BMSPLI10, BMSPLI11, and BMSPLI12.

<u>BSC</u>

END CAP LOADS ON 60 IN NOZZLES

THERE ARE 32 ELEMENTS AROUND THE 60 IN FLANGE, THE AREA FOR THE MODEL IS 1/2 OF THE CIRCLE

$$A = \frac{\pi r^2}{2}$$

$$r = 30 \text{ in}$$

$$A = 1414 \text{ in}^2$$

THE TOTAL VACUUM LOAD IS

$$F = pA$$

$$p = 14.7 \text{ psi}$$

$$F = 14.7(1414) = 20,782 \text{ LB}$$

FOR EACH FLANGE NODE AT THE NOZZLE INNER SURFACE, EXCEPT THE CORNER NODES THE FORCE IS

$$F_i = \frac{20782}{32} = 649.4 \text{ LB}$$

FOR CORNER NODES

$$F_i = \frac{649.4}{2} = 324.7 \text{ LB}$$

RDC 11/16/95

BSC FE ANALYSIS OF LOWER SHELL

FILENAME: BHSPLI12 - FINAL MODEL

LOAD CASES

1. VACUUM PRESS = 14.7 PSI
   END CAP LOAD ON BOTH 60 IN NOZZLES

2. SAME AS 1 BUT 60 IN NOZZLE ON Y AXIS HAS NO END CAP LOAD (SIMULATES BELLOWS)

3. SAME AS 1 BUT SUPPORT LEG REACTIONS ARE APPLIED TO SHELL AT 12 NODES AT WELD PAD

LOAD CASE 3

SUPPORT LEG REACTION ON SHELL

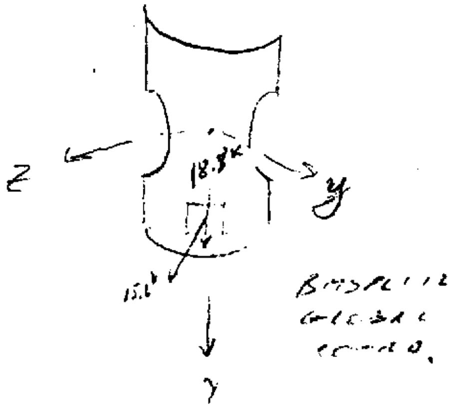
LOCAL MEMBER FORCES (FROM BSCSOPB FILE*)

MEMBER	NODE	F_x (VERT)	F_y (TANGENTIAL)	F_z (RADIAL)
2	3	-3019	-14900	442. LB
→ 4	6	-18760	125	-15620
6	9	-3281	14900	654
8	12	12460	-125	14440

THE BOUNDING LOADS ARE AT MEMBER 4 WHERE THE VERTICAL LOAD IS 14760 AND THE RADIAL LOAD IS 15620 LB, MOMENTS ARE NOT [illegible] SINCE THEY ARE [illegible] LIMITED.

* [illegible] PRINTED OUTPUT, [illegible] FROM [illegible]

FOR THE BMSPLIT MODEL, THE RADIAL LOAD WILL BE APPLIED OUTWARD AND THE VERTICAL LOAD WILL BE DOWNWARD. THE GLOBAL LOAD COMPONENTS IN THE BMSPLIT MODEL ARE



F_x = 18 760 LB

F_y = .707 (15620) = 11045 LB

F_z = F_y = 11045 LB

θ = 45° = ANGULAR LOCATION OF PAD FROM Z-AXIS

APPLY LOADS TO THE FOLLOWING NODES

131
134
178
179
273
275
278
279 ⇒ 12 NODES
281
1028
1031
1035
1174
1172

NODAL LOADS

$$F_{xi} = \frac{F_x}{12} = \frac{18760}{12} = 1563 \text{ LB}$$

$$F_{yi} = \frac{F_y}{12} = \frac{11045}{12} = 920.4 \text{ LB}$$

$$F_{zi} = \frac{F_z}{12} = 920.4 \text{ LB}$$

NOTE: THE FINAL SUPPORT LEG FORCES ARE GIVEN ON P. 32 OF CALC 024. THE RESULTANT FINAL LOAD IS F = 27.2 K. FOR THE FORCES ANALYZED IN THIS CALC THE RESULTANT IS SLIGHTLY LOWER

$$F = (18.76^2 + 11.0^2 + 11.0^2)^{\frac{1}{2}}$$

$$= 24.4 \text{ K}$$

SINCE THE SHELL STRESS PLOT ON P. 15 SHOWS THAT THE MAX STRESS INTENSITY IS ONLY ABOUT 8.5 KSI AT THE LEG ATTACHMENT, THE SHELL STRESSES MEET THE CRITERIA FOR THE FINAL LOADS.

LOAD CASE 1 RESULTS SUMMARY FOR 3 LAST-MODELS

BASELINE 10

- NO STIFFENERS AT 6-NOZZLES
- RING STIFFENER ABOVE PORTS
- ANGLE STIFFENER BELOW "

MAX SI = 15.5 KSI AT MIDDLE 6-NOZ

" " = 14 KSI AT UPPER NOZZLES
(VERY LOCAL AT RING STIFFENER

MAX SI = 23.8 KSI AT BOTTOM OF
60 IN PORTS

STRESS IN LOWER HEAD ≈ 2.7 KSI
MAX RADIAL DISP = .15" @ 6 NOZ

BASELINE 11

- SAME AS BASELINE 10 BUT NO STIFFENER
BELOW 60" PORT

MAX RADIAL DISP = .19 IN @ 6 NOZ

AT MIDDLE NOZ 6, MAX SI = 21 KSI

AT UPPER NOZZLES, MAX SI = 17.1 KSI
AT RING STIFFENER.

AT BOTTOM OF 60 IN PORTS, SI = 28.4 KSI

LOAD CASE 1 RESULTS CONT.

BMSPLI12 (FINAL MODEL)

- STIFFENERS BETWEEN 6 NOZ*
- RING STIFFENER ABOVE POSTS (4"x3/8")
- NO STIFFENER BELOW POSTS

AT 6 - NOZZ

MAX SI = 22.9 KSI AT STIFF. TOP W/ 60 IN PORT

MAX Δ = .14" (RADIAL)

AT UPPER NOZZLES

MAX SI = 14 KSI AT TOP OF 60' PORT

AT BOT [illegible]S

MAX SI = 27.9 KSI ([illegible])

NOTE, ALL SIs ARE AT SURFACES

*STIFFENER IS 3" x 3/4"

THE FOLLOWING PLOTS ARE FROM THE MODEL WITH

FILENAME: BMSPLI12

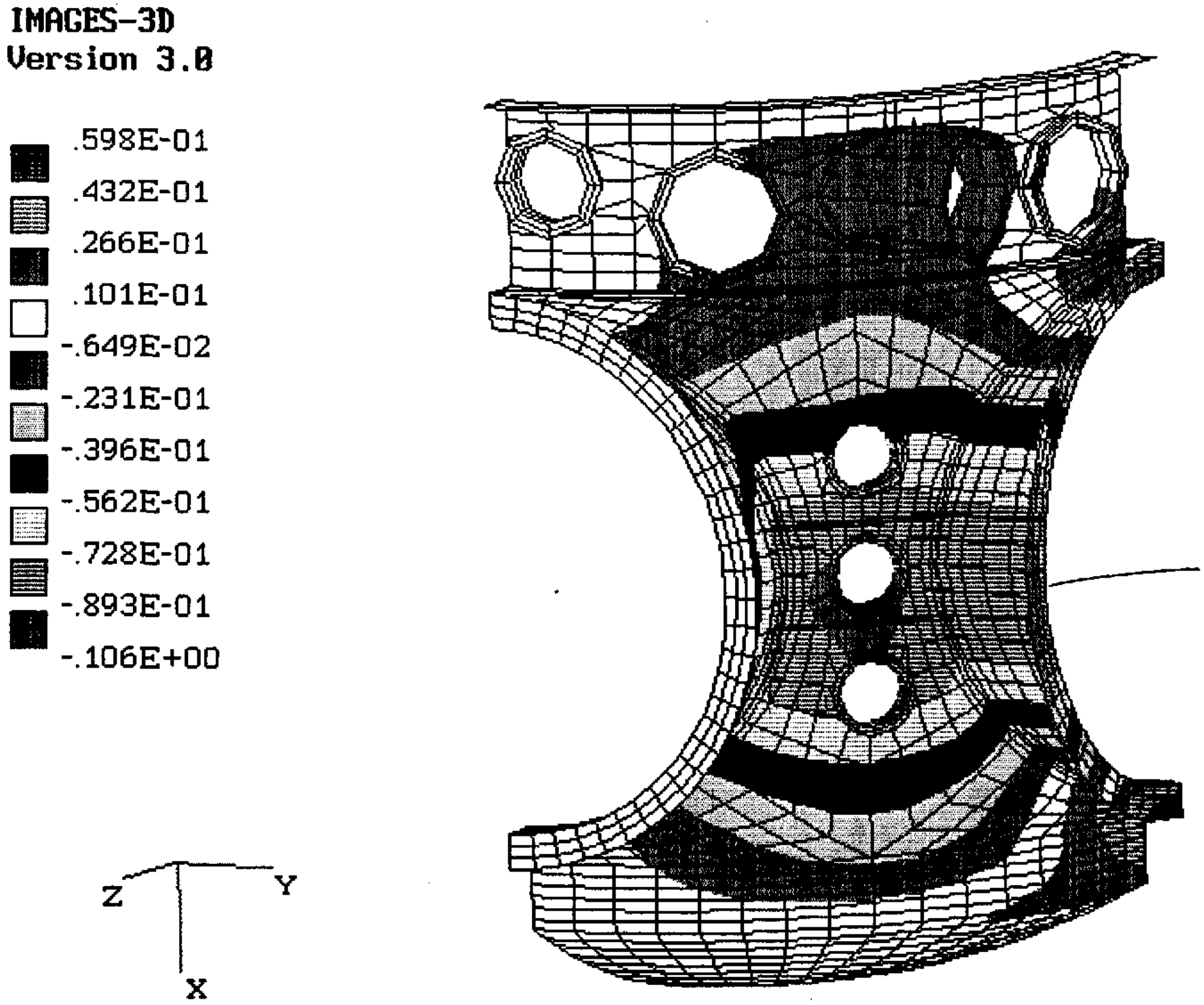
MAX STRESS INTENSITY

$SI_{MAX} = 23.5$ KSI AT BOTTOM OF 60 IN NOZZLES

$\leq 1.5\ S = 24.3$ KSI @ 400°F

FOR 304/304L DUAL CERTIFIED MATERIAL

THIS MAX STRESS IS VERY LOCAL



MAX DEFL A - MIDDLE NOZZLE G

$D_Y = D_Z = .106$"

RADIAL $\Delta = (.106^2 + .106^2)^{\frac{1}{2}}$

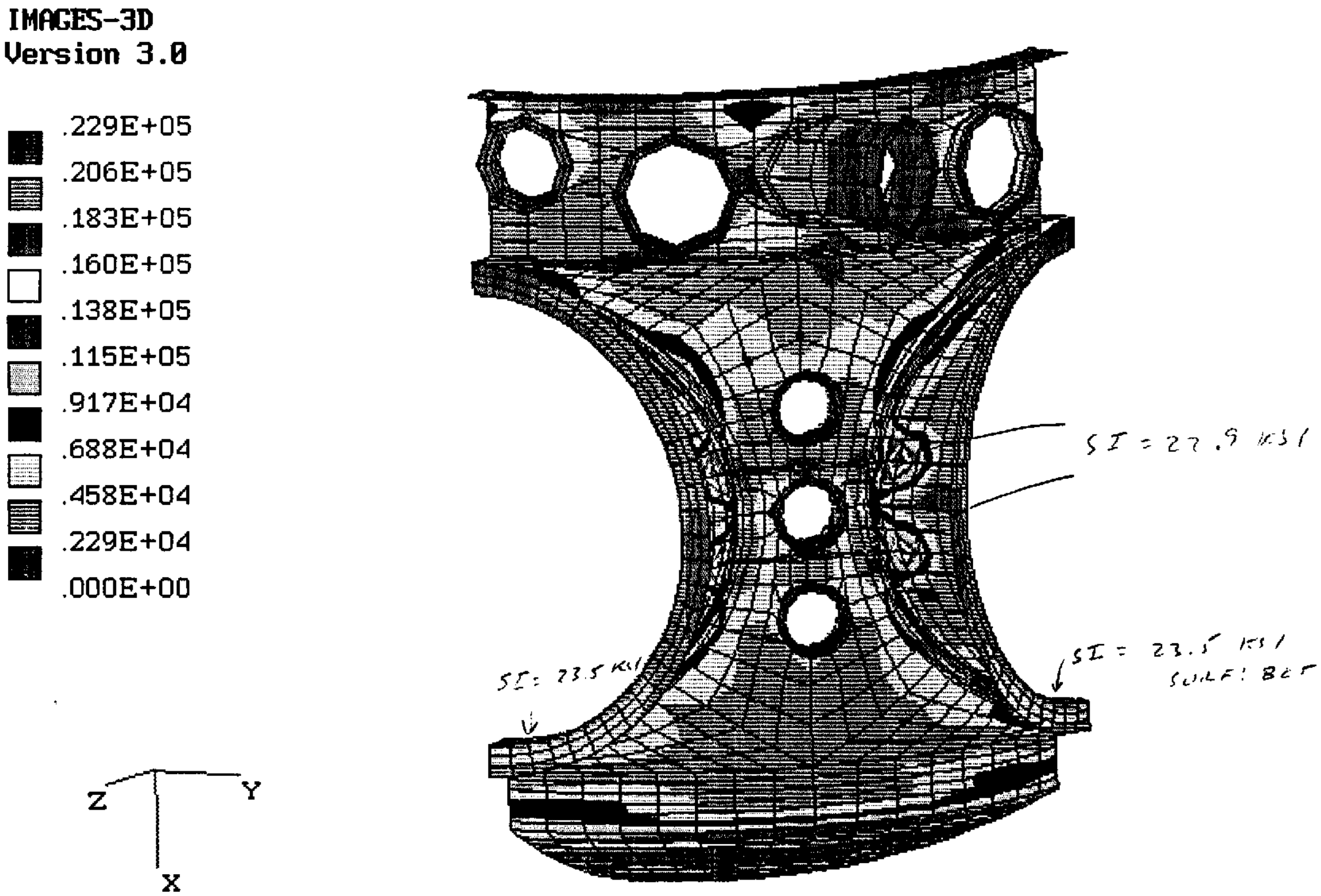
= .15 in

INWARD

Load Case 1

Displacement Contour Plot DY

11/16/95
11:53:45



SI = 27.9 KSI

SI = 23.5 KSI

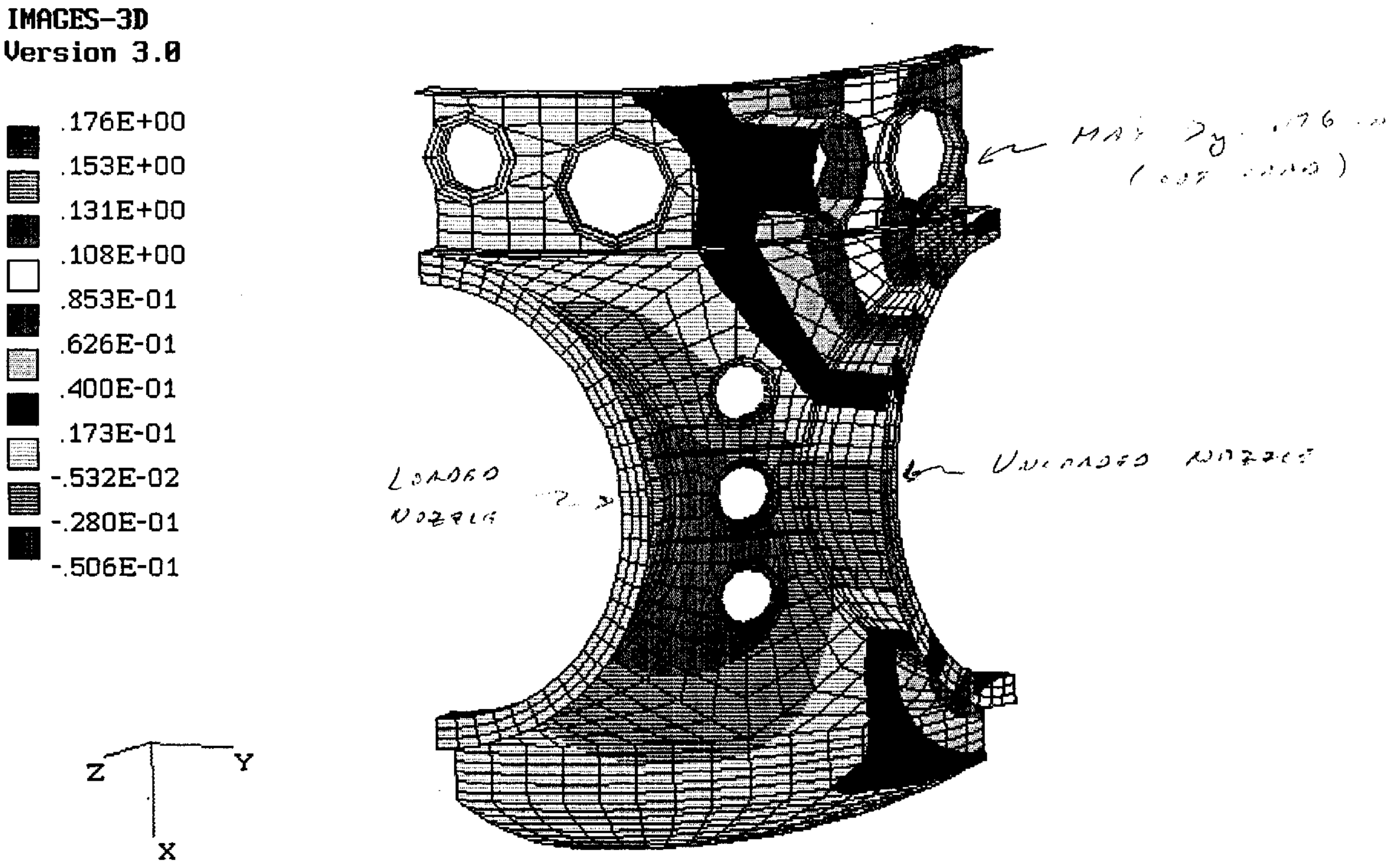
SI = 23.5 KSI
SURF: BOT

Load Case 1

Stress Contour Plot

Surf: Top **Stress Intensity**

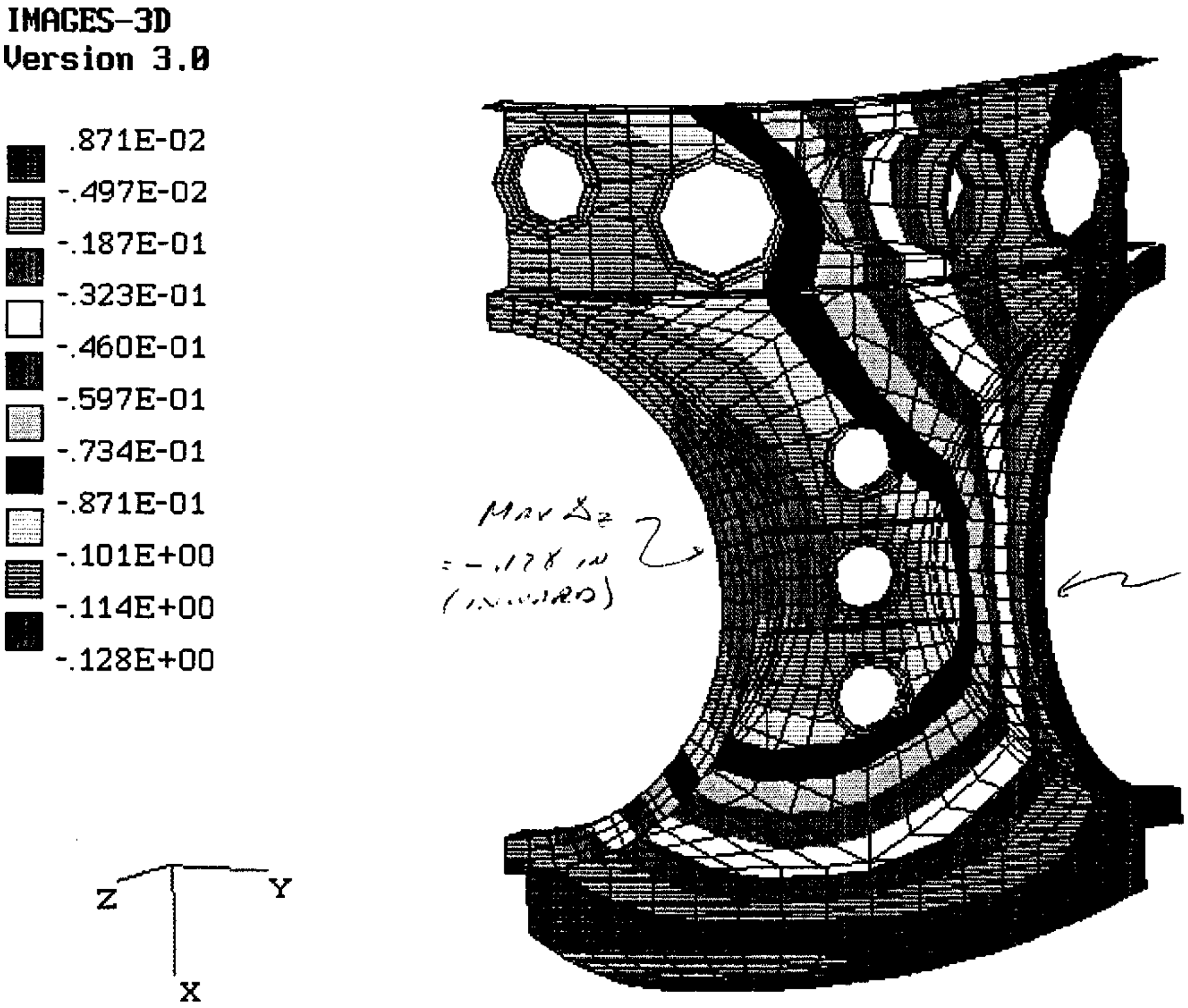
11/16/95
11:50:33



Load Case
2

Displacement Contour Plot
DY

11/16/95
12: 2: 0



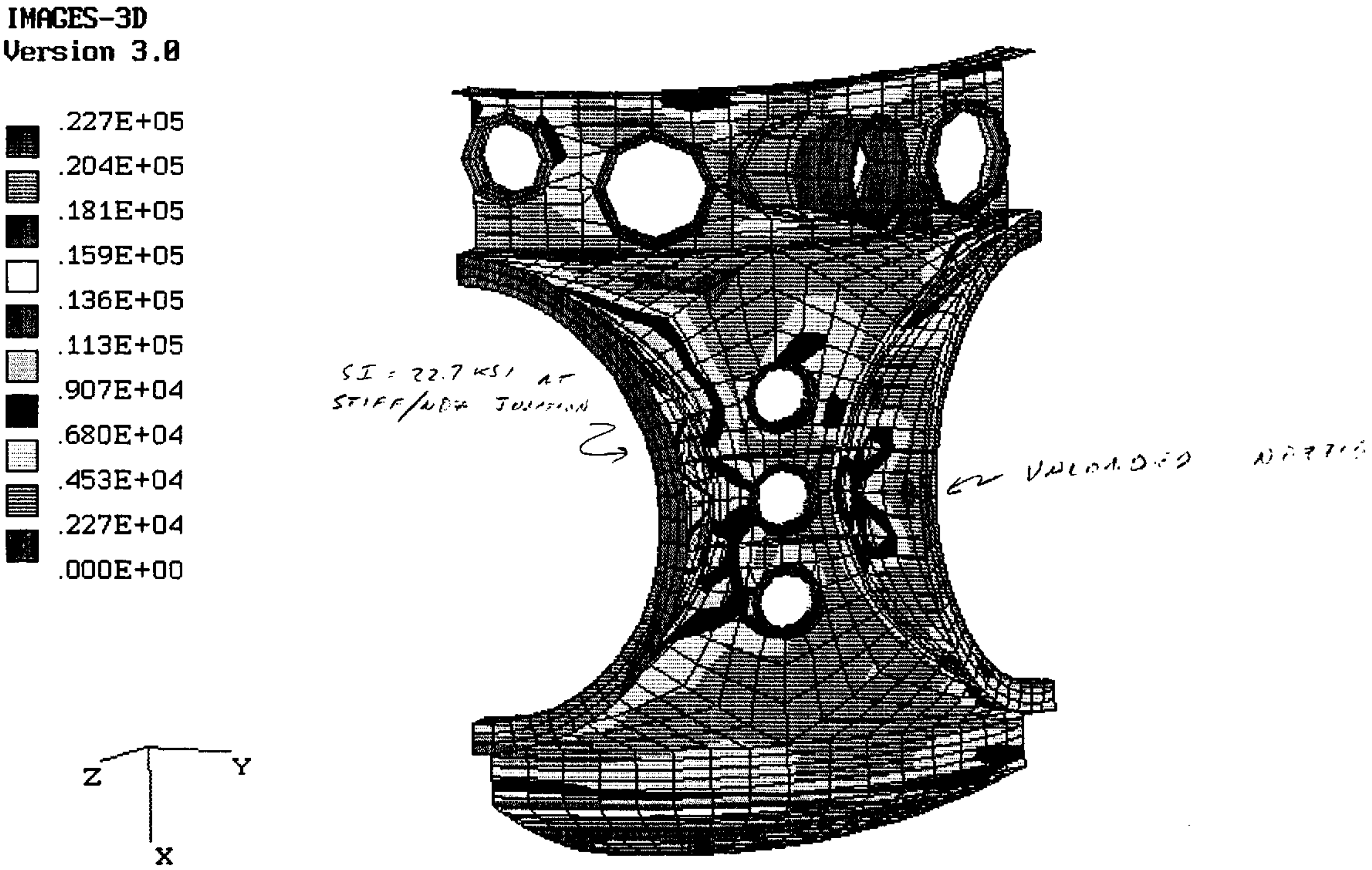
MAX Δz = -.128 IN (INWARD)

THIS NOZZLE NOT LOADED

Load Case
2

Displacement Contour Plot
DZ

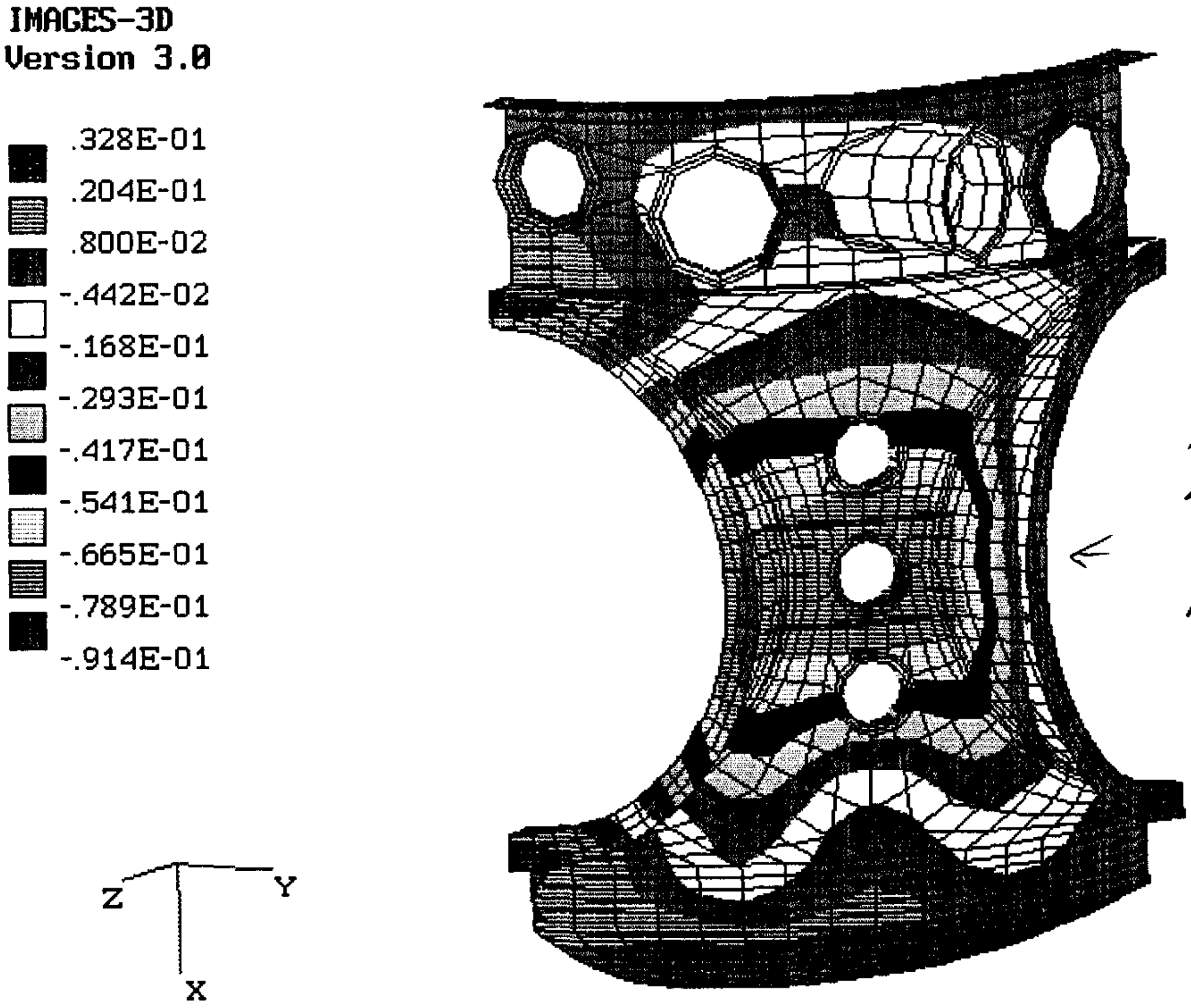
11/16/95
11:57:54



Load Case
2

Stress Contour Plot
Surf: Top
Stress Intensity

11/16/95
13: 1:10

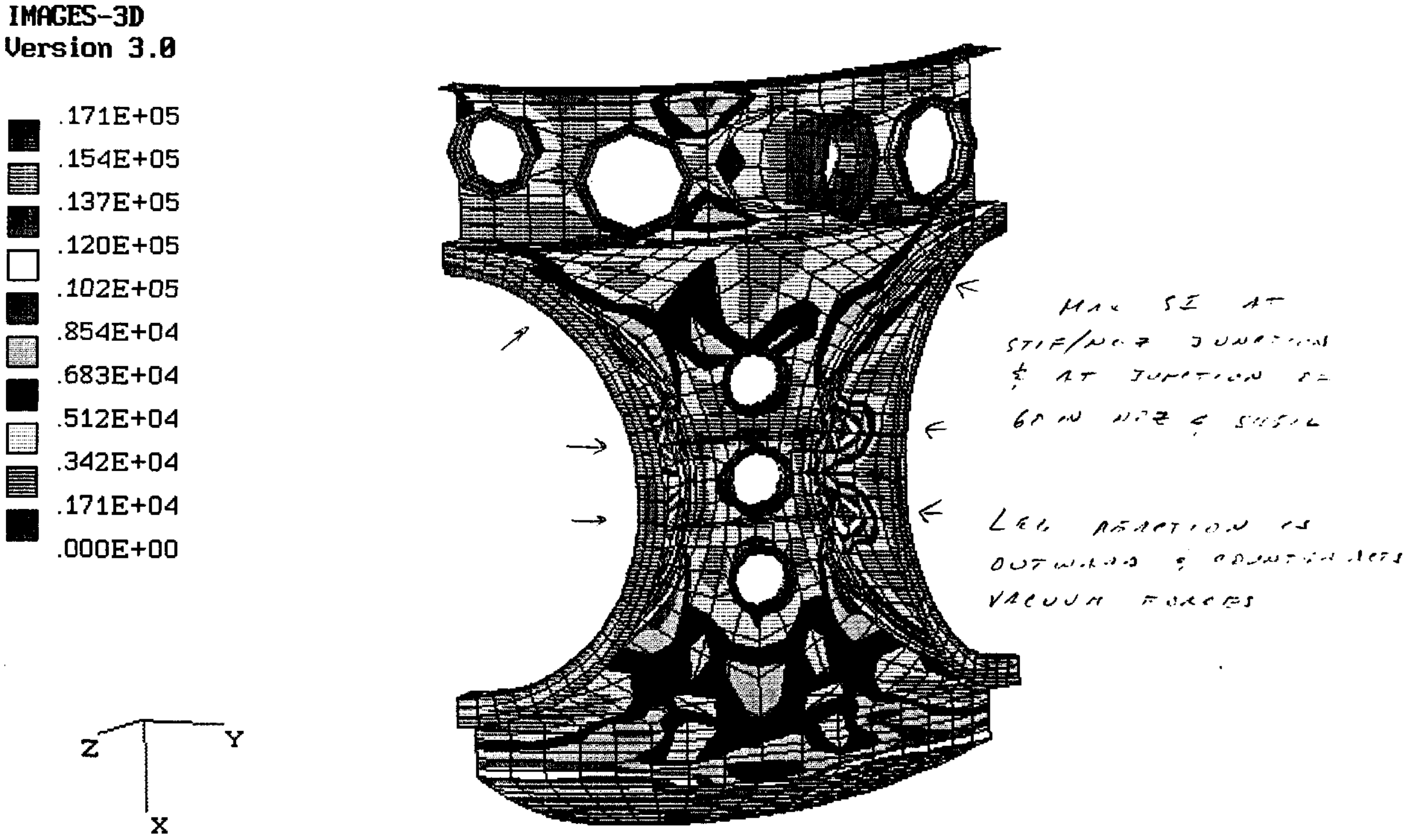


MAX INWARD DEFL
AT MIDDLE NOZ G
$D_Y = D_Z \approx .0914$ IN
RADIAL $\Delta = (.0914^2 + .0914^2)^{\frac{1}{2}}$
$= .129$ IN

Load Case 3

Displacement Contour Plot DZ

11/16/95
13: 7:39



MAX SI AT STIF/NOZ JUNCTION & AT JUNCTION OF GRN NOZ & SHELL

LEG REACTION IS OUTWARD & COUNTERACTS VACUUM FORCES

Load Case
3

Stress Contour Plot

Surf: Top

Stress Intensity

11/16/95
13:12:30

CONFIRMATION OF NOZZLE G

NOZ G WRC 107 ANALYSIS FOR RADIAL FORCE

$$F = 738.5 \text{ LB}$$

STRESS

$$\sigma = -2646 \text{ psi}$$

THE "COMPRESS" PRESSURE VESSEL PROGRAM SHOWS THAT NO REINFORCEMENT IS NEED.

SHELL THICKNESS = .5 IN

NOZZLE THICKNESS = .125 IN

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-023 PAGE 1 OF 19
REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber - Design of 60 in. Access Covers	
0	0024	12/6/95	RDC	R.W.Y.		
					BY: R.D. Clarke	DEPT.: 744
PROJECT: LIGO Vacuum Equipment					PROJECT NO:	

PURPOSE:. To design the cover and nozzles for the 60 in. port in accordance with Section VIII, Division 1 of the ASME Code.

METHOD: Equations for thickness and reinforcement requirements of the ASME Code, Section VIII, Division 1, are evaluated using the COMPRESS computer program, Version 5.31.

ASSUMPTIONS:

INPUTS: Vacuum pressure = 14.7 psi
Design temperature = 400^{0}F

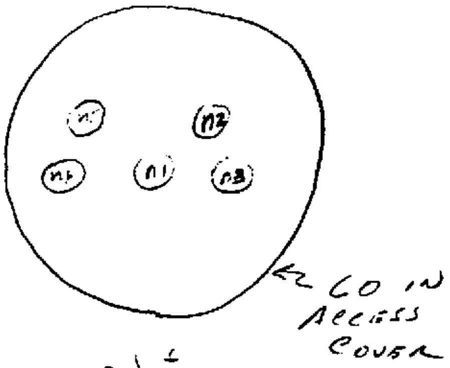
REFERENCES: 1. ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Division 1.
.2. COMPRESS 5.31, Computer Aided Pressure Vessel Design, Codeware Computer Systems, Inc.
3. Doc. No. V049-1-066, LIGO Vacuum Equip., Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code, Section VIII. Division 1, are met for the cover and nozzles for the 60 in. port.

NOTES:

NOZZLE LOCATIONS IN COMPRESS



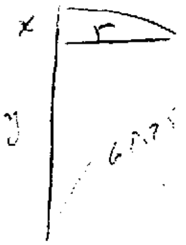
n1 @ CENTER

n2 $\theta = 47.90$

$r = (10.625^2 + 9.875^2)^{\frac{1}{2}}$

$= 14.51$

$L = 14.53 - y'$



$y = (60.75^2 - 14.51^2)^{\frac{1}{2}}$

$= 58.48$ IN

$y' = 60.75 - 58.48$

$= 1.77$

$L = 14.53 - 1.77$

$= 12.76$

n_3 $\theta = 90$

$r = 15.75$

$y = (60.75^2 - 15.75^2)^{\frac{1}{2}}$

$= 58.15$

$y' = 60.25 - 58.15 = 2.10$

$L = 14.53 - 2.10 = 12.43$

DUE TO OVERLAPPING REINFORCEMENT, NOZZLE LOCATIONS WERE MOVED AS SHOWN ON THE FOLLOWING SHEET

6-NOZZLES IN 60 IN PORT

ID = 7.5 IN

WALL THICKNESS = .25 IN

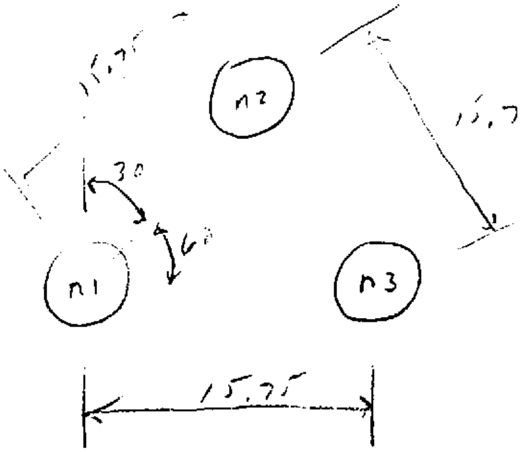
FILLET WELD = .25

PARTIAL PEN GROOVE WELD = .1875

REINF. REQ'D = .73 IN^2

" AVAIL = .83 IN^2 OK W/O PAD

LOCATE NOZZLES AS FOLLOWS



RADIAL PRESSURE LOAD FOR WRC 107 ANAL

$$F_R = \frac{\pi}{4}(7.5)^2(14.7)$$
$$= 649.4 \text{ LB}$$

MAX STRESS AT OD OF NOZZLE

f = 2802 psi FROM

WRC 107 ANAL

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: F&D head
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
Head to shell seam - Spot UW-11(b) type 1

Estimated weight: new = 272.9 corr = 272.9 lb
capacity: new = 88.89 corr = 88.89 US ga

ID = 60.25 crown L = 60.25 knuckle r = 3.75 t = .25 in (min)

Straight flange = 1 forming allowance = 0 in

MAP: (New & at 0 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.25/(60.25*1.7521 + 0.2*0.25) - 0
= 67.20225 psi

MAWP: (Corroded & at 0 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.25/(60.25*1.7521 + 0.2*0.25) - 0
= 67.20225 psi

External Pressure: (Corroded & at 400 deg F) UG-33(c)

A = .125/(Ro/t)
= .125/(60.5/0.18787)
= 0.000388

From table HA-3: B = 4757.7

Pa= B/(Ro/t)
= 4757.7/(60.5/0.18787)
= 14.774 psi

Check the external pressure per UG-33(a)(1)

t = 1.67*Pa*Lo*M/(2*S*E + 1.67*Pa*(M-0.2))
= 1.67*14.774*60.5*1.7521/(2*14700*1 + 1.67*14.774*(1.7521-0.2))
= 0.088842 in

Design thickness for external pressure Pa = 14.774 psi:

= t + Corrosion + fa
= 0.18787 + 0 + 0
= 0.18787 in

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

A = .125/(Ro/t)
= .125/(60.5/0.25)
= 0.000517

From table HA-3: B = 5004.1

Pa= B/(Ro/t)
= 5004.1/(60.5/0.25)
= 20.6781 psi

Check the Maximum External Pressure: UG-33(a)(1) & App. 1-4(d)

Pc= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
= 2*14700*1*0.25/((1.7521*60.5 - 0.25*(1.7521-0.2))*1.67)
= 41.67247 psi

The maximum allowable external pressure is 20.6781 psi.

Center Nozzle n1

Opening n1 Reinforcement Calculations Per UG-37

Located on:	BSC 60 in Port
Local vessel thickness:	.25 in
Liquid static head included:	0 psi
Flange description:	8 inch 75# SO A240304L
ANSI B16.47 flange rating MAP:	115 psi
ANSI B16.47 flange rating MAWP:	115 psi

Nozzle material specification: SA 240 304L HIGH

Nozzle orientation:	0 degrees
End of nozzle to datum line:	14.53 in
Nozzle calculated as hillside:	no
Projection outside vessel Lpr:	2.996 in

```
    tn ->|  |<-
          _              _
         | |<- d ->|   | |        corrosion allow = 0 in
twl->|   |<|       |   | |        noz thick new tn= .25 in
     |/  | |  v    |   | \        nozzle id. new d= 7.5 in
_____.-| | |--     |   |-.______  fillet weld twl = .25 in
______\|_|_tw2     |_|/________   groove weld tw2 = .1875 in
            ^
<----- R ----->|                  To head center R= 0 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.5 in
Normal to the vessel wall outside 2.5*(tn-Cn) + tc = .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*3.75/(16700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)(1)

tr= P*L*M/(2*S*E - 0.2*P)
= 0*60.25*1/(2*16700*1 - 0.2*0)
= 0 in

Area required

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

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

Center Nozzle n1

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

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 7.5*0*1 + 2*0.25*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 1.875 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= 1.875 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
= 1.875 + 0.313 + 0.063
= 2.251 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) = 0.1875 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 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 = 0.28175 in

Center Nozzle n1

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*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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0 - (7.5 - 2*0.25)*(1*0.25 - 1*0))*16700
=-29225 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 =-29225 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 =-29225 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.5 in

Center Nozzle n1

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

Nozzle required thickness

L/Do = 2.996/8 = .3745 Do/t = 8/0.0184 = 434.7826
From table G: A = 0.000415
From table HA-3: B = 4814.3

Pa= 4*B/(3*Do/t)
= 4*4814.3/(3*8/0.0184)
= 14.7639 psi

Nozzle required thickness trn = .0184 in

Required thickness tr from UG-37(d)(1) = .1879 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*(7.5*0.1879*1 + 2*0.25*0.1879*1*(1 - 1))
= .7046 in^2

Area available

A1 = larger of the following = .466 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.25-1*0.1879) - 2*0.25*(1*0.25-1*0.1879)*(1-1)
= .466 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*0.1879) - 2*0.25*(1*0.25-1*0.1879)*(1-1)
= .062 in^2

A2 = smaller of the following = 0.289 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.0184)*1*0.25
= .289 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.0184)*1*0.25
= .289 in^2

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

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Center Nozzle n1

Area = A1 + A2 + A41
= 0.466 + 0.289 + 0.063
= .818 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 = 0.0184 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0528 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 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.

Center Nozzle n1

Applied Loads

Radial load	Pr = 649.4 lbf
Circumferential moment	M1 = 0 lbf-ft
Circumferential shear	V2 = 0 lbf
Longitudinal moment	M2 = 0 lbf-ft
Longitudinal shear	V1 = 0 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

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

Mean dish radius Rm = 60.375 in
U = ro/Sqr(Rm*t) = 1.03

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

Pressure stress intensity factor, Farr equation 11.7

I = 1 + (r/x)^2
= 1 + (3.75/4.25)^2
= 1.779

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

Maximum combined stress =-2802 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-670 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

Center Nozzle n1

From Fig.	Value read	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
SR-2*	0.0645	-670	-670	-670	-670	-670	-670	-670	-670
SR-2	0.0342	-2132	2132	-2132	2132	-2132	2132	-2132	2132
SR-3*	0.0750								
SR-3	0.0711								
SR-3*	0.0750								
SR-3	0.0711								
pressure stress*									
Total Ox stress		-2802	1462	-2802	1462	-2802	1462	-2802	1462
Primary membrane Ox stress*		-670	-670	-670	-670	-670	-670	-670	-670
SR-2*	0.0200	-208	-208	-208	-208	-208	-208	-208	-208
SR-2	0.0103	-642	642	-642	642	-642	642	-642	642
SR-3*	0.0226								
SR-3	0.0214								
SR-3*	0.0226								
SR-3	0.0214								
pressure stress*									
Total Oy stress		-850	434	-850	434	-850	434	-850	434
Primary membrane Oy stress*		-208	-208	-208	-208	-208	-208	-208	-208
torsion moment Mt									
Shear from V1									
Shear from V2									
Total Shear stress									
Combined stress		-2802	1462	-2802	1462	-2802	1462	-2802	1462

Nozzle n5

Opening n5 Reinforcement Calculations Per UG-37

Located on: BSC 60 in Port
Local vessel thickness: .25 in
Liquid static head included: 0 psi
Flange description: 8 inch 75# WN A240304L
ANSI B16.47 flange rating MAP: 115 psi
ANSI B16.47 flange rating MAWP: 115 psi

Nozzle material specification: SA 240 304L HIGH

Nozzle orientation: 330 degrees
End of nozzle to datum line: 13.76 in
Nozzle calculated as hillside: no
Projection outside vessel Lpr: 4.173 in

```
  tn ->| |<-
                                corrosion allow = 0 in
        _         _
       | |<- d ->| |            noz thick new tn= .25 in
twl->| | |<      | |            nozzle id. new d= 7.5 in
     |/| |  v    | |\           fillet weld twl = .25 in
______.-| |--    | |-._____     groove weld tw2 = .1875 in
______\|_|_tw2   |_|/______
            ^
<---- R ---->|                  To head center R= 15.75 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.5 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*3.75/(16700*1 - 0.6*0)
= 0 in

Required thickness tr from UG-37(a)(1)

tr= P*L*M/(2*S*E - 0.2*P)
= 0*60.25*1/(2*16700*1 - 0.2*0)
= 0 in

Area required

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

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

Nozzle n5

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

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 7.5*0*1 + 2*0.25*0*1*(1 - 1)
= 0 in^2

Area available

A1 = larger of the following = 1.875 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.25-1*0) - 2*0.25*(1*0.25-1*0)*(1-1)
= 1.875 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
= 1.875 + 0.313 + 0.063
= 2.251 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) = 0.1875 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 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 = 0.28175 in

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Nozzle n5

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*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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (0 - (7.5 - 2*0.25)*(1*0.25 - 1*0))*16700
=-29225 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 =-29225 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 =-29225 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.5 in

Nozzle n5

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 = 4.173/8 = .5216 Do/t = 8/0.02022 = 395.6479
From table G: A = 0.000332
From table HA-3: B = 4394.8

Pa= 4*B/(3*Do/t)
= 4*4394.8/(3*8/0.02022)
= 14.8105 psi

Nozzle required thickness trn = .02022 in

Required thickness tr from UG-37(d)(1) = .1879 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*(7.5*0.1879*1 + 2*0.25*0.1879*1*(1 - 1))
= .7046 in^2

Area available

A1 = larger of the following = .466 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.25-1*0.1879) - 2*0.25*(1*0.25-1*0.1879)*(1-1)
= .466 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*0.1879) - 2*0.25*(1*0.25-1*0.1879)*(1-1)
= .062 in^2

A2 = smaller of the following = 0.287 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.02022)*1*0.25
= .287 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.02022)*1*0.25
= .287 in^2

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

Nozzle n5

Area = A1 + A2 + A41
= 0.466 + 0.287 + 0.063
= .816 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 = 0.02022 in (E = 1)
Wall thickness per UG-45(b)(2): tr2 = 0.0528 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.28175 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.

Nozzle n5

Applied Loads

Radial load	Pr = 649.4 lbf
Circumferential moment	M1 = 0 lbf-ft
Circumferential shear	V2 = 0 lbf
Longitudinal moment	M2 = 0 lbf-ft
Longitudinal shear	V1 = 0 lbf
Torsion moment	Mt = 0 lbf-ft
Internal pressure	P = 0 psi

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

Mean dish radius Rm = 60.375 in
U = ro/Sqr(Rm*t) = 1.03

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

Pressure stress intensity factor, Farr equation 11.7

I = 1 + (r/x)^2
= 1 + (3.75/4.25)^2
= 1.779

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

Maximum combined stress =-2802 psi
Allowable combined stress = +-3*S = +- 50100 psi

The maximum combined stress is within allowable limits.

Maximum primary membrane stress =-670 psi
Allowable primary membrane stress = +-1.5*S = +- 25050 psi

The maximum primary membrane stress is within allowable limits.

Nozzle n5

From Fig.	Value read	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
SR-2*	0.0645	-670	-670	-670	-670	-670	-670	-670	-670
SR-2	0.0342	-2132	2132	-2132	2132	-2132	2132	-2132	2132
SR-3*	0.0750								
SR-3	0.0711								
SR-3*	0.0750								
SR-3	0.0711								
pressure stress*									
Total Ox stress		-2802	1462	-2802	1462	-2802	1462	-2802	1462
Primary membrane Ox stress*		-670	-670	-670	-670	-670	-670	-670	-670
SR-2*	0.0200	-208	-208	-208	-208	-208	-208	-208	-208
SR-2	0.0103	-642	642	-642	642	-642	642	-642	642
SR-3*	0.0226								
SR-3	0.0214								
SR-3*	0.0226								
SR-3	0.0214								
pressure stress*									
Total Oy stress		-850	434	-850	434	-850	434	-850	434
Primary membrane Oy stress*		-208	-208	-208	-208	-208	-208	-208	-208
torsion moment Mt									
Shear from V1									
Shear from V2									
Total Shear stress									
Combined stress		-2802	1462	-2802	1462	-2802	1462	-2802	1462

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V0V9-1-023

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-024
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REV.	DEO #	DATE	BY:	CHECK
0	0128	12/29/97	RDC	AGL

Beam Splitter Chamber - Design of Support Legs and Base Plates

BY: R.D. C[illegible]

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To design BSC support structure to meet requirements of AISC Code for unbalanced vacuum loads.

METHOD: A stiffness analysis of the frame is performed using the IMAGES program.

ASSUMPTIONS:

INPUTS: 1. LIGO project design sketches & drawings.
2. Vacuum pressure = 14.7 psi.
3. Seismic acceleration = .05625 g.
4. Forces from V049-1-032

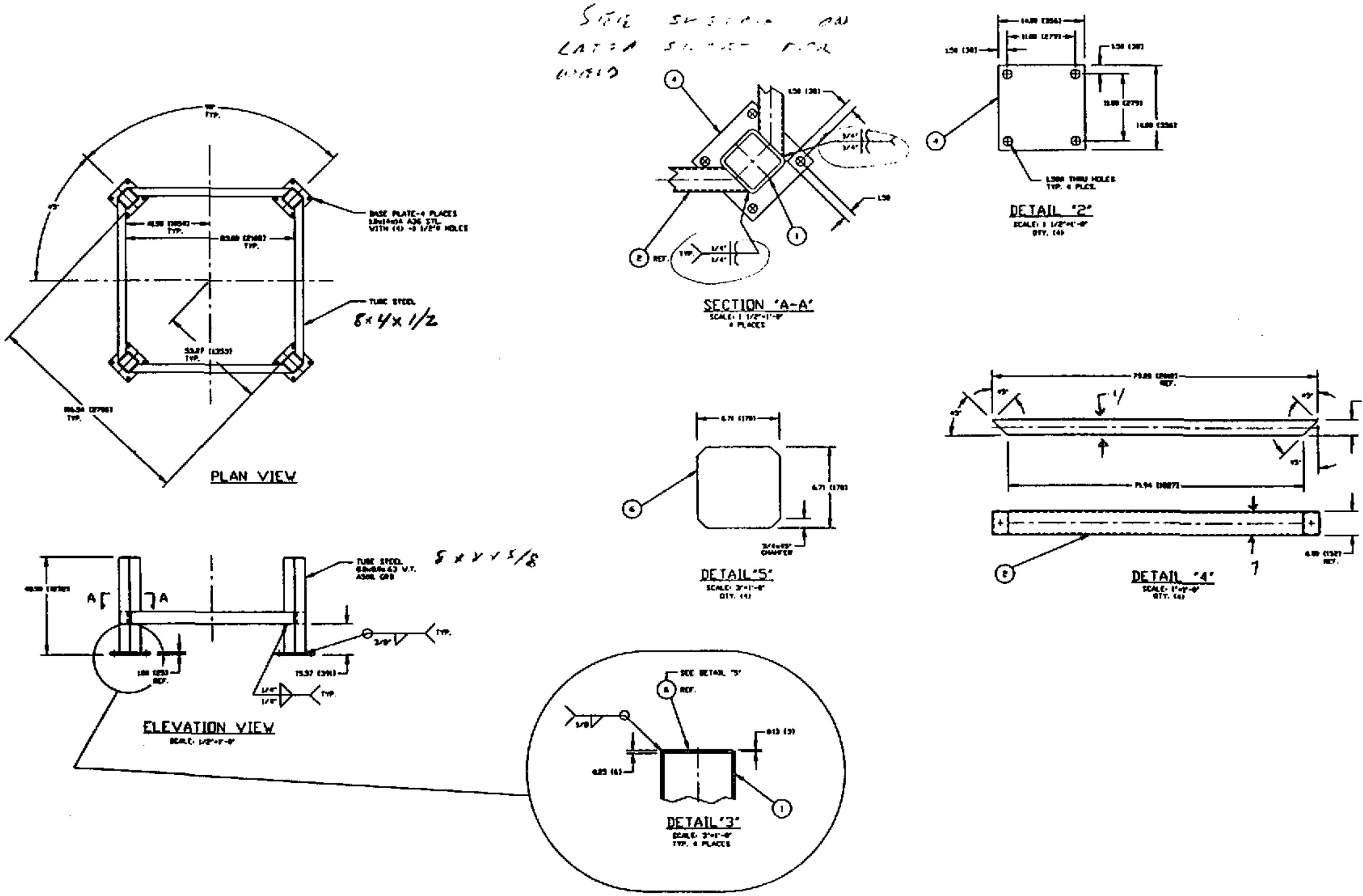
REFERENCES: 1. AISC Code, Ninth Edition, Allowable Stress Design.
2. ASCE 7-88, Minimum Design Loads
3. IMAGES 3D, Version 3.0, R.L. Cloud & Associates
4. Calc. No. V049-1-032 "Component Interface Loads"
5. V049-1-066, LIGO VAC. EQUIP STRUCT. DES CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Support legs and other frame members meet the AISC Code.

NOTES: Computer file is BSCSUPP. ✶

Site sketch on later sheet for weld



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PROCESS SYSTEMS INTERNATIONAL INC.

CHAMBER SUPPORT ASSEMBLY
BSC
LIGO VACUUM EQUIPMENT

SIZE	D
DWG NO.	B049-4-023
REV	P3
SCALE	1/2"=1'-0"
SHEET	1 OF 1

DO NOT SCALE THIS DRAWING
USED ON
NEXT ASS'Y

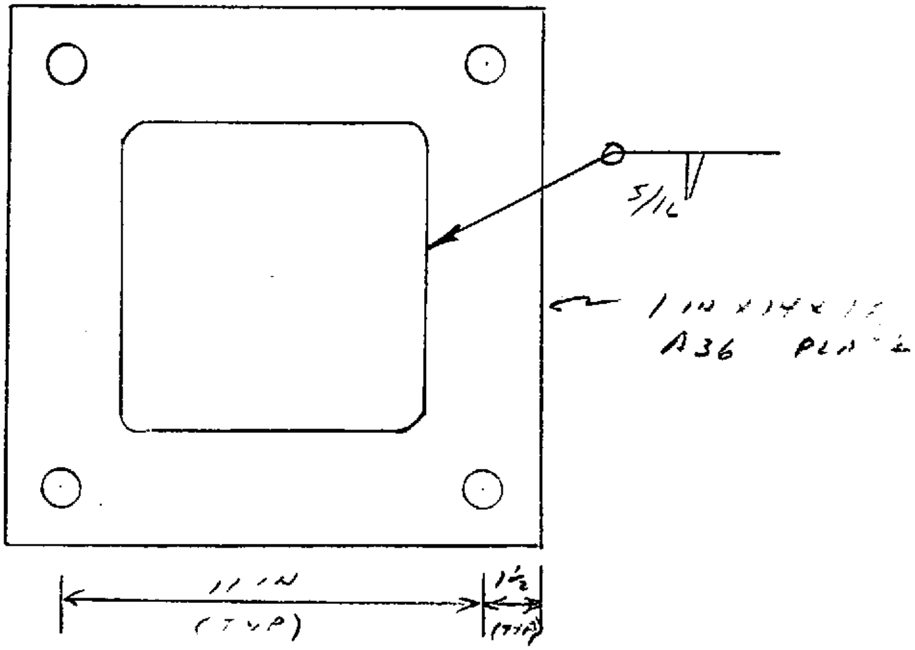
REV	DESCRIPTION	CHKD	DRWN	DATE	BLD#
P1	PRELIMINARY FOR QUOTES		PV	10/12/95	

ISSUE DESCRIPTION

DWG NO.	DESCRIPTION	DWG NO.	DESCRIPTION

REFERENCE DRAWINGS

BASE PLATE



HILTI HVA ADHESIVE ANCHORS

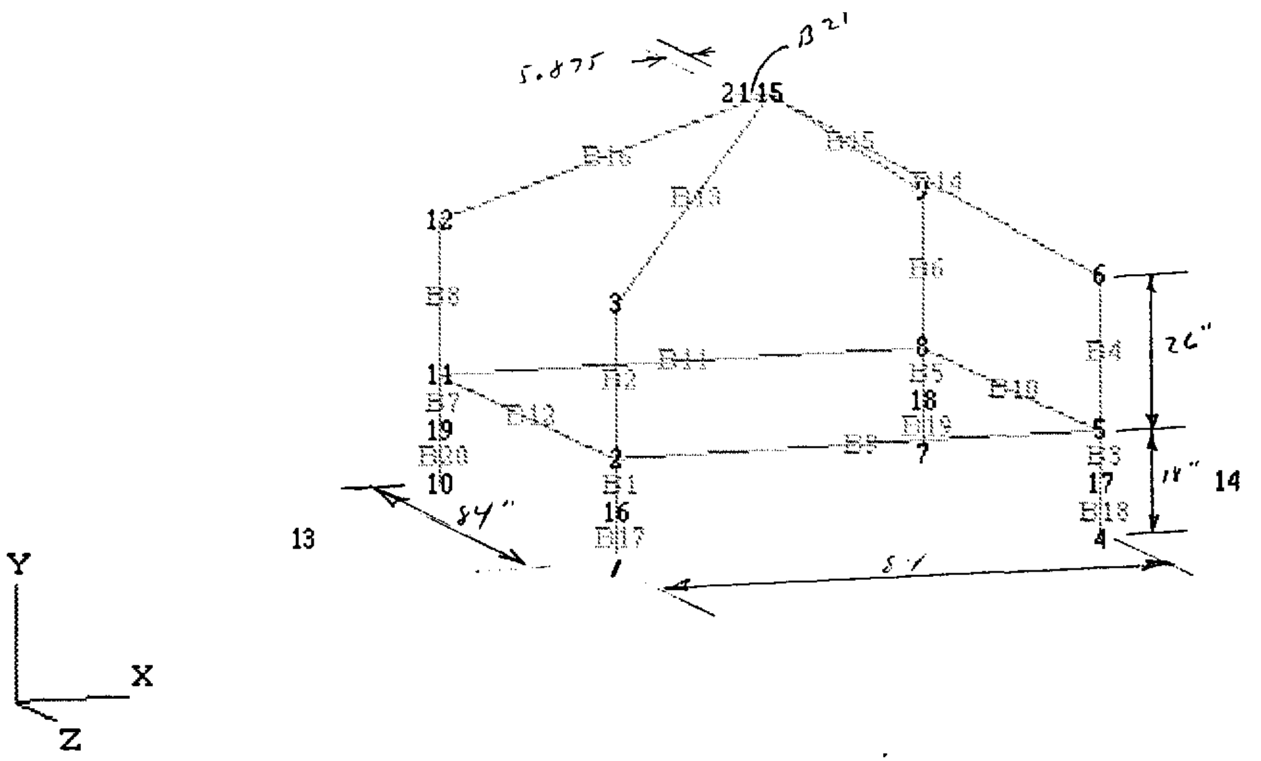
1" Φ , 8 1/4" EMBEDMENT

A307 (OR EQUIV) THREADED ROD

IMAGES-3D
Ver. 3.0
Geometry Plot

IMAGES 3D MODEL

BSC SUPPORT STRUCTURE



Beam Splitter Chamber Support Structure
Wireframe Plot

12/28/95
12:58:58

```
PROCESS ENGINEERING INC.  S/N:802506A                           03/21/96
PAGE   11                         Run ID=                         16:54:57
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          SOLVE BEAM LOADS/STRESSES        Version 3.0    12/31/93

Filename=BSCSUPP
Title    =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

                              BEAM LOADS AND/OR STRESSES

GLoads Node      Fx          Fy          Fz          Mx          My          Mz
LLoads Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
Stress Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
              Corner1     Corner2     Corner3     Corner4     Maximum     Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
                                  ***BEAM  NO.    1***
GLoads   16 -.1840E+05 -.3504E+04 -.1547E+05  .1393E+06  .4803E-11 -.1656E+06
GLoads    2  .1840E+05  .3504E+04  .1547E+05 -.2785E+06 -.4803E-11  .3313E+06
LLoads   16 -.3504E+04  .2395E+05  .2072E+04  .4803E-11  .1865E+05 -.2156E+06
LLoads    2  .3504E+04 -.2395E+05 -.2072E+04 -.4803E-11 -.3730E+05  .4312E+06
Stress   16  .2014E+03  .3201E+04  .2769E+03 -.7064E-13  .4876E+03  .5636E+04
            -.4947E+04  .6325E+04  .5350E+04 -.5923E+04  .6325E+04 -.5923E+04
Stress    2  .2014E+03  .3201E+04  .2769E+03 -.7064E-13  .9752E+03  .1127E+05
            -.1010E+05  .1245E+05  .1050E+05 -.1205E+05  .1245E+05 -.1205E+05
                                  ***BEAM  NO.    2***
GLoads    2 -.1016E+05 -.2198E+03 -.6706E+04  .4805E+05  .0000E+00  .4180E+05
GLoads    3  .1016E+05  .2198E+03  .6706E+04 -.2224E+06  .0000E+00  .2224E+06
LLoads    2 -.2198E+03  .1193E+05  .2444E+04  .0000E+00 -.6353E+05 -.4415E+04
LLoads    3  .2198E+03 -.1193E+05 -.2444E+04  .0000E+00  .0000E+00  .3145E+06
Stress    2  .1263E+02  .1594E+04  .3265E+03  .0000E+00 -.1661E+04  .1154E+03
            -.1764E+04 -.1533E+04  .1789E+04  .1558E+04  .1789E+04 -.1764E+04
Stress    3  .1263E+02  .1594E+04  .3265E+03  .0000E+00  .0000E+00  .8223E+04
            -.8211E+04  .8236E+04  .8236E+04 -.8211E+04  .8236E+04 -.8211E+04
                                  ***BEAM  NO.    3***
GLoads   17 -.5751E+04  .3504E+05  .2574E+04 -.2317E+05  .9770E-13 -.5176E+05
GLoads    5  .5751E+04 -.3504E+05 -.2574E+04  .4633E+05 -.9770E-13  .1035E+06
LLoads   17  .3504E+05 -.5886E+04  .2246E+04  .9770E-13  .2022E+05  .5298E+05
LLoads    5 -.3504E+05  .5886E+04 -.2246E+04 -.9770E-13 -.4043E+05 -.1060E+06
Stress   17 -.2014E+04 -.7866E+03  .3002E+03 -.1437E-14  .5285E+03 -.1385E+04
            -.1001E+03 -.2870E+04 -.3927E+04 -.1157E+04 -.1001E+03 -.3927E+04
Stress    5 -.2014E+04 -.7866E+03  .3002E+03 -.1437E-14  .1057E+04 -.2770E+04
             .1813E+04 -.3727E+04 -.5841E+04 -.3006E+03  .1813E+04 -.5841E+04
                                  ***BEAM  NO.    4***
GLoads    5 -.1399E+05  .2025E+05 -.9445E+04 -.3035E+06  .0000E+00  .3059E+06
GLoads    6  .1399E+05 -.2025E+05  .9445E+04  .5790E+05  .0000E+00  .5790E+05
LLoads    5  .2025E+05 -.3215E+04  .1657E+05  .0000E+00 -.4309E+06 -.1715E+04
LLoads    6 -.2025E+05  .3215E+04 -.1657E+05  .0000E+00  .0000E+00 -.8188E+05
Stress    5 -.1164E+04 -.4297E+03  .2215E+04  .0000E+00 -.1127E+05  .4484E+02
            -.1247E+05 -.1238E+05  .1015E+05  .1006E+05  .1015E+05 -.1247E+05
Stress    6 -.1164E+04 -.4297E+03  .2215E+04  .0000E+00  .0000E+00 -.2141E+04
             .9770E+03 -.3304E+04 -.3304E+04  .9770E+03  .9770E+03 -.3304E+04
```

LOADS

ESTIMATED WEIGHT

$W = 14000$ lb

SEISMIC FORCE

$F_{EQ} = aW$

$a = .05625\ g$ - REF CALC V049-1-031

$F_{EQ} = .05625(14000)$

$= 788$ lb

UNBALANCED VACUUM LOADS

FROM CALC V049-1-032, BSC 7 & 8 IN THE WALLS HAVE THE MAX UNBALANCED FORCES. LET $F_x = 45460$ lb

$F_z = 29440$ lb

COMBINE SEISMIC W/ F_x UNBALANCED LOAD

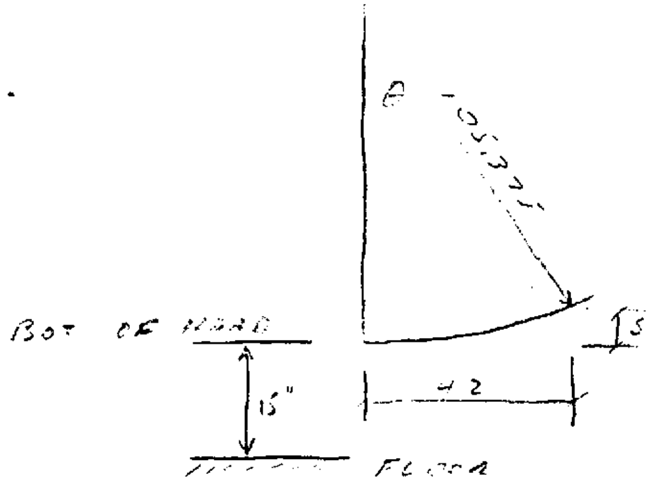
NODE 15: $F_x = 45460 + 788 = 46248$ lb

NODE 15: $F_y = -W = -14000$ lb

NODE 21: $F_z = 25440$ lb

DETERMINE IF CROSS MEMBER WILL CLEAR HEAD

LOWEST PT AT CENTER OF BOTTOM HEAD IS 15 IN ABOVE FLOOR. ℄ OF COLUMN IS 42 IN FROM BEAM TUBE AXIS. CROWN RADIUS OF LOWER HEAD IS 105.375



$$\sin\theta = \frac{42}{105.375}$$

$$\theta = 23.49^\circ$$

$$S = 105.375 - 105.375 \cos\theta$$

$$= 8.73 \text{ IN}$$

OR FOR 6 IN DEEP MEMBER

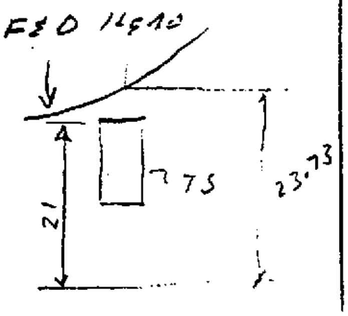
HEIGHT OF CROSS MEMBER ABOVE FLOOR

$$h = 15 + \frac{6}{2}$$

$= 18$ IN TO ℄ OF TS 6x4x1/4

USE TS 7x4x3/8

TOTAL CLEARANCE FROM FLOOR =
15 + 8.73 = 23.73 IN



MEMBERS

1 TO 8
17 TO 20 } TS 8x4x5/8

9 TO 12 TS 8x4x1/2

13 TO 16 DUMMY

PIN TYPE SUPPORTS AT NODES 1, 4, 7, [illegible]

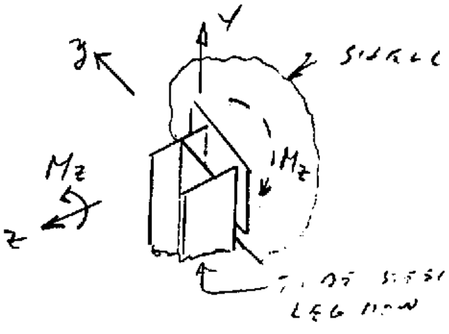
PIN RELEASE AT TOP OF 8x4x5/8 TUBE STL SUPPORT LEG

SINCE THE SHELL IS FLEXIBLE FOR LOCAL BENDING AT SUPPORT LEG ATTACHMENT, THE FOLLOWING LOCAL MOMENTS ARE RELEASED:

M_Y (PIN RELEASE 4 - TORSION IN W8x58)

M_y (" " 5 - WEAK AXIS BENDING IN W8x58)

M_Z IS RETAINED SINCE IT TRANSFERS MEMBRANE FORCES INTO SHELL



Y, y, Z ARE LOCAL AXES OF SUPPORT LEG

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Interactive Microcomputer Analysis & Graphics of Engineering Systems

IMAGES-3D             Version 3.0                12/31/93

Filename=BSCSUPP                              RUN ID=XX11111

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=     applicability of the results obtained from      =
=     IMAGES-3D.                                      =
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=     Any questions or comments concerning the use    =
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=                                                     =
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=                      Suite 1200                     =
=                     Berkeley, CA                    =
=                        94704                        =
=                                                     =
=                     510-843-0977                    =
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PAGE     1                          RUN ID=XX11111                   16:52:37
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         CHECK GEOMETRY                               Version 3.0  12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure


                       Acceleration of Gravity = 3.864E+02

         Force  Multiplier  Length Multiplier  Temp.  Multiplier
         -----------------  -----------------  -----------------
             1.0000E+00          1.0000E+00          1.0000E+00
                           (For database properties only)


                                MATERIAL PROPERTIES

                            Mat No.       N  a  m  e
                            -------  --------------------
                                1    STEEL
                                2    STEEL
                                3    STEEL

Mat       Ex         Ey         Ez         nxy        nyz        nzx       Density
 No       Gxy        Gyz        Gzx        axy        ayz        azx
----  ---------  ---------  ---------  ---------  ---------  ---------  ---------
   1 2.900E+07 2.900E+07 2.900E+07 3.000E-01 3.000E-01 3.000E-01 2.830E-01
     1.120E+07 1.120E+07 1.120E+07 6.500E-06 6.500E-06 6.500E-06
   2 2.900E+07 2.900E+07 2.900E+07 3.000E-01 3.000E-01 3.000E-01 2.830E-01
     1.120E+07 1.120E+07 1.120E+07 6.500E-06 6.500E-06 6.500E-06
   3 2.900E+07 2.900E+07 2.900E+07 3.000E-01 3.000E-01 3.000E-01 2.830E-01
     1.120E+07 1.120E+07 1.120E+07 6.500E-06 6.500E-06 6.500E-06


                           BEAM CROSS SECTION PROPERTIES


                           Prop No.       N  a  m  e
                           --------  --------------------
                              1      W8X58
                              2      TB4X4X4
                              4      TB8X4X8
                              5      TB8X8X10

Pr.  X-Section    Moment of Inertia     Torsional               Shear Shape Fact.
No.    Area        Iy     /     Iz      Const.- J     Iyz         SFy    /   SFz
---  ---------   ---------  ---------   ---------  ---------    --------  --------
  1  1.710E+01   7.510E+01  2.280E+02   3.340E+00  0.000E+00    3.83E+00  1.28E+00
  2  3.590E+00   8.220E+00  8.220E+00   1.350E+01  0.000E+00    1.79E+00  1.79E+00
  3  1.000E+02   1.000E+03  1.000E+03   2.000E+03  0.000E+00    0.00E+00  0.00E+00
  4  1.040E+01   2.460E+01  7.510E+01   6.410E+01  0.000E+00    1.30E+00  2.60E+00
  5  1.740E+01   1.530E+02  1.530E+02   2.580E+02  0.000E+00    1.74E+00  1.74E+00
```

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PROCESS ENGINEERING INC.  S/N:802506A                          03/21/96
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        CHECK GEOMETRY                       Version 3.0  12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

 Pr.    Bending Stress  Recovery Distances                    Shear Stress Fact.
 No.     Cy-     /    Cy+    /    Cz-    /    Cz+      Ctors       SSFy    /  SSFz
 ---  --------  --------  --------  --------  --------  --------  --------
   1  4.11E+00  4.11E+00  4.38E+00  4.38E+00  8.10E-01  4.36E+00  1.92E+00
   2  2.00E+00  2.00E+00  2.00E+00  2.00E+00  1.92E+00  2.31E+00  2.31E+00
   3  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
   4  2.00E+00  2.00E+00  4.00E+00  4.00E+00  2.44E+00  1.89E+00  3.43E+00
   5  4.00E+00  4.00E+00  4.00E+00  4.00E+00  3.79E+00  2.33E+00  2.33E+00


                            NODE COORDINATES

               Node    X-Coord.       Y-Coord.       Z-Coord.
               ----  ------------  ------------  ------------
                  1   0.00000E+00   0.00000E+00   0.00000E+00
                  2   0.00000E+00   1.80000E+01   0.00000E+00
                  3   0.00000E+00   4.40000E+01   0.00000E+00
                  4   8.40000E+01   0.00000E+00   0.00000E+00
                  5   8.40000E+01   1.80000E+01   0.00000E+00
                  6   8.40000E+01   4.40000E+01   0.00000E+00
                  7   8.40000E+01   0.00000E+00  -8.40000E+01
                  8   8.40000E+01   1.80000E+01  -8.40000E+01
                  9   8.40000E+01   4.40000E+01  -8.40000E+01
                 10   0.00000E+00   0.00000E+00  -8.40000E+01
                 11   0.00000E+00   1.80000E+01  -8.40000E+01
                 12   0.00000E+00   4.40000E+01  -8.40000E+01
                 13  -4.20000E+01   0.00000E+00  -4.20000E+01
                 14   1.26000E+02   0.00000E+00  -4.20000E+01
                 15   4.20000E+01   7.00000E+01  -4.20000E+01
                 16   0.00000E+00   9.00000E+00   0.00000E+00
                 17   8.40000E+01   9.00000E+00   0.00000E+00
                 18   8.40000E+01   9.00000E+00  -8.40000E+01
                 19   0.00000E+00   9.00000E+00  -8.40000E+01
                 20   0.00000E+00   0.00000E+00   0.00000E+00
                 21   3.61250E+01   7.00000E+01  -4.20000E+01

*** WARNING - *** Nodes   1  &  20  are <=0.0001 apart in all 3 dirs. ***

                           BEAM CONNECTIVITY

Beam   Nodes          Prop Mat    Pincodes     Rigid End Offset      Length    Beam
 No  From/ To / Ref   No    No    I  /   J        I    /     J                 Type
 --  -------------- ---- --- ------------- ----------------- ---------- -----
```

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          CHECK GEOMETRY                        Version 3.0  12/31/93

  Filename=BSCSUPP
  Title    =Beam Splitter Chamber Support Structure

Beam    Nodes         Prop Mat    Pincodes    Rigid End Offset     Length     Beam
 No  From/ To / Ref    No   No    I  /    J       I    /     J                 Type
---- -------------- ---- --- ------------- ----------------- ---------- -----
   1   16     2   13     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
   2    2     3   13     5   1            45 0.00E+00 0.00E+00 2.6000E+01 Beam
   3   17     5   14     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
   4    5     6   14     5   1            45 0.00E+00 0.00E+00 2.6000E+01 Beam
   5   18     8   14     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
   6    8     9   14     5   1            45 0.00E+00 0.00E+00 2.6000E+01 Beam
   7   19    11   13     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
   8   11    12   13     5   1            45 0.00E+00 0.00E+00 2.6000E+01 Beam
   9    2     5    1     4   2               0.00E+00 0.00E+00 8.4000E+01 Beam
  10    5     8    4     4   2               0.00E+00 0.00E+00 8.4000E+01 Beam
  11    8    11    7     4   2               0.00E+00 0.00E+00 8.4000E+01 Beam
  12   11     2   10     4   2               0.00E+00 0.00E+00 8.4000E+01 Beam
  13    3    15    0     3   3               0.00E+00 0.00E+00 6.4838E+01 Beam
  14    6    15    0     3   3               0.00E+00 0.00E+00 6.4838E+01 Beam
  15    9    15    0     3   3               0.00E+00 0.00E+00 6.4838E+01 Beam
  16   12    15    0     3   3               0.00E+00 0.00E+00 6.4838E+01 Beam
  17    1    16   13     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
  18    4    17   14     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
  19    7    18   14     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
  20   10    19   13     5   1               0.00E+00 0.00E+00 9.0000E+00 Beam
  21   15    21    0     3   3               0.00E+00 0.00E+00 5.8750E+00 Beam


                                 RESTRAINTS

                     Node                         Restraint
                      No     Global/Local        Directions
                     ----    ------------      ---------------
                        1        GLOBAL          X Y Z -   -   -
                        4        GLOBAL          X Y Z -   -   -
                        7        GLOBAL          X Y Z -   -   -
                       10        GLOBAL          X Y Z -   -   -

                             NODAL CONNECTIVITY

*** WARNING - Node  13  not connected to any element ***
```

```
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         CHECK GEOMETRY                           Version 3.0  12/31/93

Filename=BSCSUPP
Title    =Beam Splitter Chamber Support Structure

*** WARNING - Node  14  not connected to any element ***
*** WARNING - Node  20  not connected to any element ***
```

EXTRA NODE
(NOT RQ'S)

```
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          RENUMBER NODES                    Version 3.0  12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

                        NODE RENUMBERING CROSS REFERENCE LIST

     Was    Is        Was    Is        Was    Is        Was    Is        Was    Is
    ----   ----      ----   ----      ----   ----      ----   ----      ----   ----
       1     18         2     16         3     15         4      4         5     14
       6     11         7      1         8      7         9      5        10      3
      11     13        12     10        13     19        14     20        15     12
      16     17        17      9        18      2        19      8        20     21
      21      6
```

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             ASSEMBLE STIFFNESS MATRIX  Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

                        STIFFNESS ASSEMBLY SUMMARY

               Number of Node Points.................    21
               Number of Truss and Beam Elements.....    21
               Number of Plate Elements..............     0
               Number of Spring Elements.............     0
               Number of Solid Elements..............     0
               Number of Axisymmetric Elements.......     0
               Number of Nodes with Restraints.......     4
               Number of Equations to be Solved......    96
               Number of Blocks in the Matrix........     1

                     B L O C K   I N F O R M A T I O N

      BLCK   SIZE        BLCK   SIZE        BLCK   SIZE        BLCK   SIZE
       NO   (Byte)        NO   (Byte)        NO   (Byte)        NO   (Byte)
      ----  ------       ----  ------       ----  ------       ----  ------
         1   14208
```

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PROCESS ENGINEERING INC.  S/N:802506A                            03/21/96
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             ASSEMBLE STIFFNESS MATRIX  Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure


                  E Q U A T I O N   N U M B E R   L I S T


                  NODE        TRANSLATION        ROTATION
                WAS   IS     X     Y     Z     X     Y     Z
                ----  ----  ----  ----  ----  ----  ----  ----
                   1    18     0     0     0    94    95    96
                   2    16    82    83    84    85    86    87
                   3    15    76    77    78    79    80    81
                   4     4     0     0     0    13    14    15
                   5    14    70    71    72    73    74    75
                   6    11    52    53    54    55    56    57
                   7     1     0     0     0     1     2     3
                   8     7    28    29    30    31    32    33
                   9     5    16    17    18    19    20    21
                  10     3     0     0     0    10    11    12
                  11    13    64    65    66    67    68    69
                  12    10    46    47    48    49    50    51
                  13    19     0     0     0     0     0     0
                  14    20     0     0     0     0     0     0
                  15    12    58    59    60    61    62    63
                  16    17    88    89    90    91    92    93
                  17     9    40    41    42    43    44    45
                  18     2     4     5     6     7     8     9
                  19     8    34    35    36    37    38    39
                  20    21     0     0     0     0     0     0
                  21     6    22    23    24    25    26    27


                      STIFFNESS SUMMARY IN  1 BLOCKS

                 Minimum Diagonal Stiffness.....  .1541D+08
                 Eq No of Minimum Diagonal......     28
                 Maximum Diagonal Stiffness.....  .2597D+11
                 Eq No of Maximum Diagonal......     62
```

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          SOLVE DISPLACEMENTS                Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

                                L O A D   C A S E   1
       MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

                                   GRAVITY  LOADING

                             X            Y             Z
                         ----------   ----------   ----------
                          .0000E+00    .0000E+00    .0000E+00


                                   CONCENTRATED LOADS

   Node      Fx          Fy          Fz          Mx          My          Mz
   ----  ----------  ----------  ----------  ----------  ----------  ----------
     15   .4625E+05 -.1400E+05   .0000E+00   .0000E+00   .0000E+00   .0000E+00
     21   .0000E+00  .0000E+00   .2944E+05   .0000E+00   .0000E+00   .0000E+00

                            REFERENCE TEMPERATURE = .0000E+00
```

```
          ================= I M A G E S - 3 D =================
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          SOLVE DISPLACEMENTS                Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

                                L O A D   C A S E   1
       MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)
                                 APPLIED LOAD VECTOR

   Node       Fx         Fy         Fz         Mx         My         Mz
   ----  ---------- ---------- ---------- ---------- ---------- ----------
     15  .4625E+05 -.1400E+05  .0000E+00  .0000E+00  .0000E+00  .0000E+00
     21  .0000E+00  .0000E+00  .2944E+05  .0000E+00  .0000E+00  .0000E+00
```

```
          ================= I M A G E S - 3 D =================
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          SOLVE DISPLACEMENTS                Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

                                L O A D   C A S E   1
       MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

                                    DISPLACEMENTS

            T r a n s l a t i o n s     /         R o t a t i o n s
Node        X           Y           Z       /      X           Y           Z
----   ----------- ----------- ----------- / ----------- ----------- -----------
   1   .0000E+00   .0000E+00   .0000E+00 /  .1942E-02  -.4443E-05  -.3025E-02
   2   .5339E-01   .1250E-03   .3407E-01 /  .1377E-02  -.4443E-05  -.2353E-02
   3   .1134E+00   .1363E-03   .6336E-01 /  .1090E-02  -.5882E-03  -.1319E-02
   4   .0000E+00   .0000E+00   .0000E+00 /  .1870E-02   .2820E-04  -.3112E-02
   5   .5569E-01  -.1250E-02   .3381E-01 /  .1964E-02   .2820E-04  -.2902E-02
   6   .1485E+00  -.2293E-02   .1040E+00 / -.5761E-03  -.6703E-04  -.2981E-04
   7   .0000E+00   .0000E+00   .0000E+00 /  .1745E-02   .7949E-04  -.2866E-02
   8   .5069E-01  -.3747E-03   .3047E-01 /  .1151E-02   .7949E-04  -.2298E-02
   9   .1116E+00  -.7467E-03   .5170E-01 /  .1286E-02   .7517E-03  -.9411E-03
  10   .0000E+00   .0000E+00   .0000E+00 /  .2029E-02   .4685E-04  -.2914E-02
  11   .5208E-01   .1000E-02   .3651E-01 /  .2019E-02   .4685E-04  -.2676E-02
  12   .1368E+00   .1683E-02   .1058E+00 / -.1979E-03   .2306E-03  -.2257E-03
  13   .0000E+00   .0000E+00   .0000E+00 /  .0000E+00   .0000E+00   .0000E+00
  14   .0000E+00   .0000E+00   .0000E+00 /  .0000E+00   .0000E+00   .0000E+00
  15   .1524E+00  -.8364E-02   .9703E-01 /  .2621E-03   .1263E-03  -.4118E-03
  16   .2821E-01   .6250E-04   .1831E-01 /  .1801E-02  -.4443E-05  -.2857E-02
  17   .2832E-01  -.6249E-03   .1669E-01 /  .1894E-02   .2820E-04  -.3060E-02
  18   .2662E-01  -.1874E-03   .1657E-01 /  .1596E-02   .7949E-04  -.2724E-02
  19   .2658E-01   .5001E-03   .1828E-01 /  .2027E-02   .4685E-04  -.2855E-02
  20   .0000E+00   .0000E+00   .0000E+00 /  .0000E+00   .0000E+00   .0000E+00
  21   .1524E+00  -.5944E-02   .9785E-01 /  .2621E-03   .1438E-03  -.4118E-03
```

```
          ================= I M A G E S - 3 D =================
          = Copyright (c) 1984-1993.   RLCA/Celestial Software =
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          SOLVE BEAM LOADS/STRESSES        Version 3.0    12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads Node     Fx         Fy         Fz         Mx         My         Mz
LLoads Node    Axial     Y-Shear    Z-Shear    Torsion   Y-Bending  Z-Bending
Stress Node    Axial     Y-Shear    Z-Shear    Torsion   Y-Bending  Z-Bending
              Corner1    Corner2    Corner3    Corner4    Maximum    Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
                              ***BEAM  NO.     5***
GLoads   18 -.1555E+05  .1050E+05 -.1626E+05  .1464E+06 -.1348E-11 -.1400E+06
GLoads    8  .1555E+05 -.1050E+05  .1626E+05 -.2928E+06  .1348E-11  .2800E+06
LLoads   18  .1050E+05 -.2250E+05  .5027E+03 -.1348E-11  .4524E+04  .2025E+06
LLoads    8 -.1050E+05  .2250E+05 -.5027E+03  .1348E-11 -.9049E+04 -.4050E+06
Stress   18 -.6037E+03 -.3007E+04  .6718E+02  .1983E-13  .1183E+03 -.5294E+04
             .4808E+04 -.5779E+04 -.6016E+04  .4572E+04  .4808E+04 -.6016E+04
Stress    8 -.6037E+03 -.3007E+04  .6718E+02  .1983E-13  .2366E+03 -.1059E+05
             .1022E+05 -.1095E+05 -.1143E+05  .9747E+04  .1022E+05 -.1143E+05
                              ***BEAM  NO.     6***
GLoads    8 -.1056E+05  .7220E+04 -.4245E+04  .9017E+05  .0000E+00  .7412E+05
GLoads    9  .1056E+05 -.7220E+04  .4245E+04 -.2005E+06  .0000E+00  .2005E+06
LLoads    8  .7220E+04 -.1047E+05 -.4468E+04  .0000E+00  .1162E+06  .1135E+05
LLoads    9 -.7220E+04  .1047E+05  .4468E+04  .0000E+00  .0000E+00 -.2836E+06
Stress    8 -.4149E+03 -.1399E+04 -.5971E+03  .0000E+00  .3037E+04 -.2966E+03
             .2919E+04  .2326E+04 -.3749E+04 -.3156E+04  .2919E+04 -.3749E+04
Stress    9 -.4149E+03 -.1399E+04 -.5971E+03  .0000E+00  .0000E+00 -.7415E+04
             .7000E+04 -.7830E+04 -.7830E+04  .7000E+04  .7000E+04 -.7830E+04
                              ***BEAM  NO.     7***
GLoads   19 -.6542E+04 -.2804E+05 -.2763E+03  .2486E+04  .9042E-12 -.5888E+05
GLoads   11  .6542E+04  .2804E+05  .2763E+03 -.4973E+04 -.9042E-12  .1178E+06
LLoads   19 -.2804E+05  .4430E+04 -.4821E+04  .9042E-12 -.4339E+05 -.3987E+05
LLoads   11  .2804E+05 -.4430E+04  .4821E+04 -.9042E-12  .8678E+05  .7975E+05
Stress   19  .1611E+04  .5920E+03 -.6442E+03 -.1330E-13 -.1134E+04  .1042E+04
            -.5655E+03  .1519E+04  .3788E+04  .1703E+04  .3788E+04 -.5655E+03
Stress   11  .1611E+04  .5920E+03 -.6442E+03 -.1330E-13 -.2269E+04  .2085E+04
            -.2742E+04  .1427E+04  .5965E+04  .1795E+04  .5965E+04 -.2742E+04
                              ***BEAM  NO.     8***
GLoads   11 -.1153E+05 -.1325E+05 -.9043E+04 -.2712E+06  .0000E+00  .2638E+06
GLoads   12  .1153E+05  .1325E+05  .9043E+04  .3603E+05  .0000E+00  .3603E+05
LLoads   11 -.1325E+05  .1759E+04 -.1455E+05  .0000E+00  .3783E+06 -.5216E+04
LLoads   12  .1325E+05 -.1759E+04  .1455E+05  .0000E+00  .0000E+00  .5096E+05
Stress   11  .7614E+03  .2351E+03 -.1944E+04  .0000E+00  .9889E+04  .1364E+03
             .1051E+05  .1079E+05 -.8991E+04 -.9264E+04  .1079E+05 -.9264E+04
Stress   12  .7614E+03  .2351E+03 -.1944E+04  .0000E+00  .0000E+00  .1332E+04
            -.5708E+03  .2094E+04  .2094E+04 -.5708E+03  .2094E+04 -.5708E+03
                              ***BEAM  NO.     9***
GLoads    2 -.8235E+04 -.9287E+04 -.1037E+02 -.4993E+04  .1583E+03 -.3758E+06
```

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PROCESS ENGINEERING INC.  S/N:802506A                          03/21/96
PAGE   13                          Run ID=                     16:54:57
          ================= I M A G E S - 3 D =================
          = Copyright (c) 1984-1993.  RLCA/Celestial Software =
          =====================================================

          SOLVE BEAM LOADS/STRESSES        Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads Node     Fx          Fy          Fz          Mx          My          Mz
LLoads Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
Stress Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
              Corner1     Corner2     Corner3     Corner4     Maximum     Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
GLoads    5  .8235E+04  .9287E+04  .1037E+02  .4993E+04  .7129E+03 -.4043E+06
LLoads    2 -.8235E+04  .9287E+04  .1037E+02 -.4993E+04 -.1583E+03  .3758E+06
LLoads    5  .8235E+04 -.9287E+04 -.1037E+02  .4993E+04 -.7129E+03  .4043E+06
Stress    2  .7919E+03  .1685E+04✓ .3425E+01✓ .1902E+03 -.1287E+02 -.2002E+05
             .2080E+05 -.1924E+05 -.1921E+05  .2082E+05  .2082E+05 -.1924E+05
Stress    5  .7919E+03  .1685E+04  .3425E+01  .1902E+03  .5796E+02  .2153E+05
            -.2068E+05  .2238E+05  .2227E+05 -.2080E+05  .2238E+05 -.2080E+05
                              ***BEAM  NO.   10***
GLoads    5  .6602E+01  .5502E+04  .1201E+05  .2522E+06 -.7129E+03 -.5140E+04
GLoads    8 -.6602E+01 -.5502E+04 -.1201E+05  .2100E+06  .1583E+03  .5140E+04
LLoads    5 -.1201E+05 -.5502E+04 -.6602E+01  .5140E+04  .7129E+03 -.2522E+06
LLoads    8  .1201E+05  .5502E+04  .6602E+01 -.5140E+04 -.1583E+03 -.2100E+06
Stress    5  .1155E+04 -.9981E+03 -.2180E+01 -.1958E+03  .5796E+02  .1343E+05
            -.1222E+05  .1464E+05  .1453E+05 -.1233E+05  .1464E+05 -.1233E+05
Stress    8  .1155E+04 -.9981E+03 -.2180E+01 -.1958E+03  .1287E+02 -.1118E+05
             .1235E+05 -.1002E+05 -.1004E+05  .1233E+05  .1235E+05 -.1004E+05
                              ***BEAM  NO.   11***
GLoads    8 -.4983E+04  .8786E+04 -.1037E+02 -.7390E+04 -.1583E+03 -.3592E+06
GLoads   11  .4983E+04 -.8786E+04  .1037E+02  .7390E+04 -.7129E+03 -.3788E+06
LLoads    8  .4983E+04 -.8786E+04 -.1037E+02  .7390E+04  .1583E+03 -.3592E+06
LLoads   11 -.4983E+04  .8786E+04  .1037E+02 -.7390E+04  .7129E+03 -.3788E+06
Stress    8 -.4791E+03 -.1594E+04 -.3425E+01 -.2815E+03  .1287E+02  .1913E+05
            -.1960E+05  .1867E+05  .1864E+05 -.1963E+05  .1867E+05 -.1963E+05
Stress   11 -.4791E+03 -.1594E+04 -.3425E+01 -.2815E+03 -.5796E+02 -.2018E+05
             .1964E+05 -.2071E+05 -.2060E+05  .1975E+05  .1975E+05 -.2071E+05
                              ***BEAM  NO.   12***
GLoads   11  .6602E+01 -.6002E+04  .8756E+04  .2687E+06  .7129E+03 -.2743E+04
GLoads    2 -.6602E+01  .6002E+04 -.8756E+04  .2355E+06 -.1583E+03  .2743E+04
LLoads   11  .8756E+04  .6002E+04  .6602E+01 -.2743E+04 -.7129E+03  .2687E+06
LLoads    2 -.8756E+04 -.6002E+04 -.6602E+01  .2743E+04  .1583E+03  .2355E+06
Stress   11 -.8420E+03  .1089E+04  .2180E+01  .1045E+03 -.5796E+02 -.1431E+05
             .1341E+05 -.1521E+05 -.1510E+05  .1353E+05  .1353E+05 -.1521E+05
Stress    2 -.8420E+03  .1089E+04  .2180E+01  .1045E+03 -.1287E+02  .1254E+05
            -.1340E+05  .1169E+05  .1171E+05 -.1337E+05  .1171E+05 -.1340E+05
                              ***BEAM  NO.   13***
GLoads    3 -.1016E+05 -.2198E+03 -.6706E+04  .2224E+06 -.1574E-09 -.2224E+06
GLoads   15  .1016E+05  .2198E+03  .6706E+04 -.4060E+06  .7085E+06  .4774E+06
LLoads    3 -.2327E+04  .7785E+03 -.1193E+05  .2881E+06 -.1261E+06  .8643E-09
```

```
PROCESS ENGINEERING INC.  S/N:802506A                          03/21/96
PAGE    14                       Run ID=                       16:54:57
          ================ I M A G E S - 3 D =================
          = Copyright (c) 1984-1993.  RLCA/Celestial Software =
          =====================================================

          SOLVE BEAM LOADS/STRESSES        Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads Node     Fx         Fy         Fz         Mx         My         Mz
LLoads Node    Axial     Y-Shear    Z-Shear    Torsion   Y-Bending  Z-Bending
Stress Node    Axial     Y-Shear    Z-Shear    Torsion   Y-Bending  Z-Bending
              Corner1    Corner2    Corner3    Corner4    Maximum    Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
LLoads   15  .2327E+04 -.7785E+03  .1193E+05 -.2881E+06  .8995E+06  .5048E+05
Stress    3  .2327E+02  .7785E+01 -.1193E+03 -.1441E+03 -.1261E+03 -.8643E-12
            -.1029E+03 -.1029E+03  .1494E+03  .1494E+03  .1494E+03 -.1029E+03
Stress   15  .2327E+02  .7785E+01 -.1193E+03 -.1441E+03 -.8995E+03  .5048E+02
            -.9267E+03 -.8258E+03  .9732E+03  .8723E+03  .9732E+03 -.9267E+03
                              ***BEAM  NO.    14***
GLoads    6 -.1399E+05  .2025E+05 -.9445E+04 -.5790E+05  .6670E-09 -.5790E+05
GLoads   15  .1399E+05 -.2025E+05  .9445E+04  .6628E+06  .1910E+06 -.4288E+06
LLoads    6  .2330E+05  .1190E+05 -.3215E+04  .7501E+05 -.3284E+05 -.2778E-09
LLoads   15 -.2330E+05 -.1190E+05  .3215E+04 -.7501E+05  .2413E+06  .7718E+06
Stress    6 -.2330E+03  .1190E+03 -.3215E+02 -.3751E+02 -.3284E+02  .2778E-12
            -.2659E+03 -.2659E+03 -.2002E+03 -.2002E+03 -.2002E+03 -.2659E+03
Stress   15 -.2330E+03  .1190E+03 -.3215E+02 -.3751E+02 -.2413E+03  .7718E+03
            -.1246E+04  .2975E+03  .7801E+03 -.7635E+03  .7801E+03 -.1246E+04
                              ***BEAM  NO.    15***
GLoads    9 -.1056E+05  .7220E+04 -.4245E+04  .2005E+06 -.4327E-09 -.2005E+06
GLoads   15  .1056E+05 -.7220E+04  .4245E+04 -.6142E+06 -.6220E+06  .1720E+06
LLoads    9  .6988E+04  .4822E+04  .1047E+05 -.2598E+06  .1137E+06  .4116E-09
LLoads   15 -.6988E+04 -.4822E+04 -.1047E+05  .2598E+06 -.7927E+06  .3127E+06
Stress    9 -.6988E+02  .4822E+02  .1047E+03  .1299E+03  .1137E+03 -.4116E-12
             .4384E+02  .4384E+02 -.1836E+03 -.1836E+03  .4384E+02 -.1836E+03
Stress   15 -.6988E+02  .4822E+02  .1047E+03  .1299E+03  .7927E+03  .3127E+03
             .4102E+03  .1035E+04 -.5499E+03 -.1175E+04  .1035E+04 -.1175E+04
                              ***BEAM  NO.    16***
GLoads   12 -.1153E+05 -.1325E+05 -.9043E+04 -.3603E+05 -.1841E-08 -.3603E+05
GLoads   15  .1153E+05  .1325E+05  .9043E+04  .3574E+06 -.1045E+06 -.2206E+06
LLoads   12 -.1864E+05 -.6303E+04  .1759E+04 -.4668E+05  .2043E+05  .4527E-09
LLoads   15  .1864E+05  .6303E+04 -.1759E+04  .4668E+05 -.1345E+06 -.4087E+06
Stress   12  .1864E+03 -.6303E+02  .1759E+02  .2334E+02  .2043E+02 -.4527E-12
             .2068E+03  .2068E+03  .1660E+03  .1660E+03  .2068E+03  .1660E+03
Stress   15  .1864E+03 -.6303E+02  .1759E+02  .2334E+02  .1345E+03 -.4087E+03
             .7296E+03 -.8779E+02 -.3568E+03  .4606E+03  .7296E+03 -.3568E+03
                              ***BEAM  NO.    17***
GLoads    1 -.1840E+05 -.3504E+04 -.1547E+05 -.3289E-09 -.9815E-12 -.3440E-10
GLoads   16  .1840E+05  .3504E+04  .1547E+05 -.1393E+06  .9815E-12  .1656E+06
LLoads    1 -.3504E+04  .2395E+05  .2072E+04 -.9815E-12  .2569E-09  .2082E-09
LLoads   16  .3504E+04 -.2395E+05 -.2072E+04  .9815E-12 -.1865E+05  .2156E+06
Stress    1  .2014E+03  .3201E+04  .2769E+03  .1444E-13  .6715E-11 -.5444E-11
             .2014E+03  .2014E+03  .2014E+03  .2014E+03  .2014E+03  .2014E+03
```

```
          ================= I M A G E S - 3 D ==================
          = Copyright (c) 1984-1993.   RLCA/Celestial Software =
          ======================================================

          SOLVE BEAM LOADS/STRESSES        Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads Node      Fx          Fy          Fz          Mx          My          Mz
LLoads Node     Axial     Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
Stress Node     Axial     Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
               Corner1     Corner2     Corner3     Corner4     Maximum     Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
Stress   16  .2014E+03  .3201E+04  .2769E+03  .1444E-13  .4876E+03  .5636E+04
            -.4947E+04  .6325E+04  .5350E+04 -.5923E+04  .6325E+04 -.5923E+04
                               ***BEAM  NO.   18***
GLoads    4 -.5751E+04  .3504E+05  .2574E+04  .1465E-10  .9770E-13  .1489E-10
GLoads   17  .5751E+04 -.3504E+05 -.2574E+04  .2317E+05 -.9770E-13  .5176E+05
LLoads    4  .3504E+05 -.5886E+04  .2246E+04  .9770E-13 -.1705E-12 -.2089E-10
LLoads   17 -.3504E+05  .5886E+04 -.2246E+04 -.9770E-13 -.2022E+05 -.5298E+05
Stress    4 -.2014E+04 -.7866E+03  .3002E+03 -.1437E-14 -.4458E-14  .5461E-12
            -.2014E+04 -.2014E+04 -.2014E+04 -.2014E+04 -.2014E+04 -.2014E+04
Stress   17 -.2014E+04 -.7866E+03  .3002E+03 -.1437E-14  .5285E+03 -.1385E+04
            -.1001E+03 -.2870E+04 -.3927E+04 -.1157E+04 -.1001E+03 -.3927E+04
                               ***BEAM  NO.   19***
GLoads    7 -.1555E+05  .1050E+05 -.1626E+05 -.8290E-10 -.1348E-11  .4106E-10
GLoads   18  .1555E+05 -.1050E+05  .1626E+05 -.1464E+06  .1348E-11  .1400E+06
LLoads    7  .1050E+05 -.2250E+05  .5027E+03 -.1348E-11 -.2959E-10 -.8765E-10
LLoads   18 -.1050E+05  .2250E+05 -.5027E+03  .1348E-11 -.4524E+04 -.2025E+06
Stress    7 -.6037E+03 -.3007E+04  .6718E+02  .1983E-13 -.7735E-12  .2292E-11
            -.6037E+03 -.6037E+03 -.6037E+03 -.6037E+03 -.6037E+03 -.6037E+03
Stress   18 -.6037E+03 -.3007E+04  .6718E+02  .1983E-13  .1183E+03 -.5294E+04
             .4808E+04 -.5779E+04 -.6016E+04  .4572E+04  .4808E+04 -.6016E+04
                               ***BEAM  NO.   20***
GLoads   10 -.6542E+04 -.2804E+05 -.2763E+03 -.2741E-10  .9042E-12  .3778E-11
GLoads   19  .6542E+04  .2804E+05  .2763E+03 -.2486E+04 -.9042E-12  .5888E+05
LLoads   10 -.2804E+05  .4430E+04 -.4821E+04  .9042E-12  .2206E-10 -.1671E-10
LLoads   19  .2804E+05 -.4430E+04  .4821E+04 -.9042E-12  .4339E+05  .3987E+05
Stress   10  .1611E+04  .5920E+03 -.6442E+03 -.1330E-13  .5766E-12  .4369E-12
             .1611E+04  .1611E+04  .1611E+04  .1611E+04  .1611E+04  .1611E+04
Stress   19  .1611E+04  .5920E+03 -.6442E+03 -.1330E-13 -.1134E+04  .1042E+04
            -.5655E+03  .1519E+04  .3788E+04  .1703E+04  .3788E+04 -.5655E+03
                               ***BEAM  NO.   21***
GLoads   15 -.5457E-08 -.1210E-08 -.2944E+05 -.3399E-10 -.1730E+06 -.6029E-08
GLoads   21  .5457E-08  .1210E-08  .2944E+05  .3399E-10 -.6762E-08  .4820E-10
LLoads   15  .5457E-08 -.1210E-08  .2944E+05  .3399E-10 -.1730E+06  .6029E-08
LLoads   21 -.5457E-08  .1210E-08 -.2944E+05 -.3399E-10 -.6762E-08 -.4820E-10
Stress   15 -.5457E-10 -.1210E-10  .2944E+03 -.1700E-13 -.1730E+03 -.6029E-11
            -.1730E+03 -.1730E+03  .1730E+03  .1730E+03  .1730E+03 -.1730E+03
Stress   21 -.5457E-10 -.1210E-10  .2944E+03 -.1700E-13  .6762E-11 -.4820E-13
            -.4776E-10 -.4786E-10 -.6138E-10 -.6128E-10 -.4776E-10 -.6138E-10
```

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PROCESS ENGINEERING INC.  S/N:802506A                          03/21/96
PAGE   16                      Run ID=                          16:54:57
          ================ I M A G E S - 3 D =================
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          =====================================================

          SOLVE BEAM LOADS/STRESSES        Version 3.0   12/31/93

Filename=BSCSUPP
Title   =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads Node     Fx          Fy          Fz          Mx          My          Mz
LLoads Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
Stress Node    Axial      Y-Shear     Z-Shear     Torsion    Y-Bending   Z-Bending
              Corner1     Corner2     Corner3     Corner4     Maximum     Minimum
------ ---- ---------- ---------- ---------- ---------- ---------- ----------
```

```
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         ====================================================

         SOLVE BEAM LOADS/STRESSES        Version 3.0   12/31/93

Filename=BSCSUPP
Title    =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)


                 MAXIMUM STRESS SUMMARY FOR BEAMS/TRUSSES
                    WITHIN SPECIFIED RANGE     1-    21


             Element    Type      Stress Type         Value
             -------    -----   -----------------   ----------

                   7    BEAM    Axial Tension         .1611E+04
                   3    BEAM    Axial Compression    -.2014E+04
                   1    BEAM    Transv. Shear         .3201E+04
                  15    BEAM    Torsion Shear         .1299E+03
                   9    BEAM    Bending Stress        .2153E+05
                   9    BEAM    Max. Comb. Normal     .2238E+05
                   9    BEAM    Min. Comb. Normal    -.2080E+05
```

```
          ================= I M A G E S - 3 D ==================
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          ======================================================

          SOLVE REACTIONS                  Version 3.0   12/31/93

Filename=BSCSUPP
Title    =Beam Splitter Chamber Support Structure

Load Case  1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

                                      REACTIONS

   Node       Fx          Fy          Fz          Mx          My          Mz
   ----   ----------  ----------  ----------  ----------  ----------  ----------
      1   -.1840E+05  -.3504E+04  -.1547E+05   .0000E+00   .0000E+00   .0000E+00
      4   -.5751E+04   .3504E+05   .2574E+04   .0000E+00   .0000E+00   .0000E+00
      7   -.1555E+05   .1050E+05  -.1626E+05   .0000E+00   .0000E+00   .0000E+00
     10   -.6542E+04  -.2804E+05  -.2763E+03   .0000E+00   .0000E+00   .0000E+00

  Total   -.4625E+05   .1400E+05  -.2944E+05   .0000E+00   .0000E+00   .0000E+00
```

MEMBER STRESS EVALUATION

FROM THE IMAGES OUTPUT, LC 9, THE 8x4x1/2 TUBE STEEL MEMBER, HAS THE HIGHEST STRESS. THIS IS DUE TO BENDING AT THE COLUMN (8x8x5/8 TS SUPPORT LEG)

THIS MEMBER WILL BE A500 GR B WITH A MIN YIELD STRESS OF 46 KSI

FROM AISC-F3, THE ALLOWABLE UNBRACED LENGTH IS

$$L_c = \left(1950 + 1200\frac{M_1}{M_2}\right)\frac{b}{F_y}$$

$b = 4$ IN

$M_1 = 375$ IN-K (NODE 2)
$M_2 = 404$ IN-K (NODE 5)

F_y 46

$$L_c = \left(1950 + 1200 \times \frac{375}{404}\right)\frac{4}{46} = 266 \text{ IN}$$

$>> L = 84$ IN OK

$$\frac{b}{t} = \frac{4}{.50} = 8 < \frac{190}{\sqrt{F_y}} = 28 \quad \text{OK}$$

∴ SECTION IS COMPACT - AISC TABLE B5.1

$$\Rightarrow F_b = .66\,F_y = .66(46) = 30.4 \text{ KSI}$$

FROM THE IMAGES OUTPUT —

$$f_b = 22.4 \text{ KSI} < F_b = 30.4 \text{ KSI} \quad \text{OK}$$

MAX DEFLECTION (NODE 15)

$\Delta_y = .152$

$\Delta_z = .097$

$\Delta = (\Delta_y^2 + \Delta_z^2)^{\frac{1}{2}}$

$= .180$ IN

BASE PLATE / ANCHOR REACTIONS

NODE	1	4	7	10	
F_y	18.4	5.8	15.6	6.5	
F_x	-3.5	35.0	10.5	-28.0	+ = COMP - = TEN
F_z	15.5	2.6	11.3	.3	
$TEN = 1.25 F_y$	4.4	—	—	35	PRYING
$V = (F_y^2 + F_z^2)^{\frac{1}{2}}$	24.0	6.4	22.6	6.5	
$T = TEN/4$	1.1	—	—	8.75	← MAX BOLT TENSION
T_{ALL}	10.96		—	10.96	*
T/T_{ALL}	.10	—	-	.80	
$V/4$	6.0	1.6	5.7	1.6	
V_{ALL}	7.63	7.63	7.63	7.63	*
V/V_{ALL}	.79	.21	.75	.21	
$T/T_{ALL} + V/V_{ALL}$	.89	.21	.75	1.01	≃ 1.0 ok

* SEE FOLLOWING SHEET

BEARING FOR COMPRESSIVE FORCES

A - MODE 4 $F_y = 35.0^K$

FOR 14 x 14 BASE PLATE

$$f_p = \frac{35}{14 \times 14} = .18 \text{ ksi} \quad ok$$

$$<< f'_c = 3000 \text{ psi}$$
FOR CONCRETE

HILTI HVA ADHESIVE ANCHORS WILL BE USED - 4 PER BASE PLATE

USE 1 IN ANCHORS w/ 8 1/4" EMBEDMENT

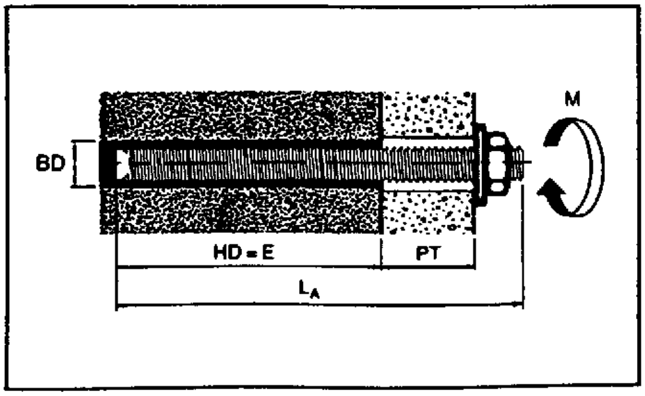
$T_{ALL} = 10.56^K$ (BOND IN 3000 psi CONC.)

$T_{ALL} = 12.12^K$ (A307 STEEL ROD)

$V_{ALL} = 7.63$

ALLOWABLES ARE FROM HILTI CATALOG

(HAS-Anchor Rod)



$PT_{MAX} = 2\frac{1}{2}$ IN FOR STANDARD ROD

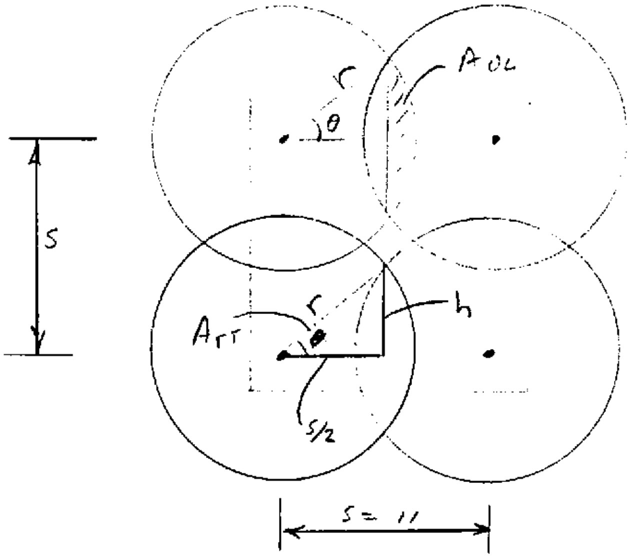
∴ USE CUSTOM ROD FOR LARGE GROUT PAD

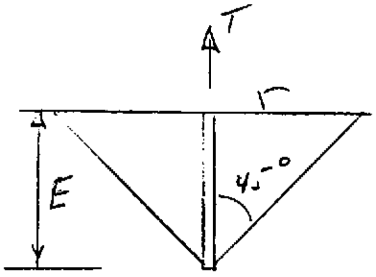
TENSILE CAPACITY OF 4-BOLT CLUSTER DUE TO CONCRETE CONE FAILURE. CONSIDER OVERLAPPING CONES

ANCHOR SPACING

$$S = 11 \text{ IN} > AS = 8\,{}^{1}\!/\!{}_{4} \text{ PER HILTI CATALOG}$$

SURFACE AREA OF INTERSECTING CONES





E = EMBEDMENT
= 8.25 IN

r = E

2 r = 16.5 > S = 11

$$\theta = \cos^{-1}\left(\frac{s/2}{r}\right) = \cos^{-1}\left(\frac{5.5}{8.25}\right) = .841 \text{ RAD}$$

$$= 48.2°$$

$$h = r \sin\theta = 8.25 \sin(.841 \text{ RAD}) = 6.15 \text{ IN}$$

$$A_{rT} = s/2\,(h/2) = \frac{11}{2}\left(\frac{6.15}{2}\right) = 16.91 \text{ IN}^2$$

$$A_{2\theta} = \pi r^2\left(\frac{2\theta}{2\pi}\right) = r^2\theta = (8.25)^2(.841) = 57.25 \text{ in}^2$$

$$A_{OL} = A_{2\theta} - 2A_{rT} = 57.25 - 2(16.91) = 23.43 \text{ in}^2$$

FOR EA CONE: $A_{CONE} = \pi r^2 - 2A_{OL} = \pi(8.25)^2 - 2(23.43) = 167 \text{ in}^2$

TOTAL CONE AREA

$A_T = 4\,A_{CONE} = 4(167) = 668 \text{ in}$

CONCRETE STRENGTH FOR THE 4 BOLT ANCHORAGE

$T_u = 4 \phi_c \sqrt{f'_c} \; A_T$

$f'_c = 3000$ psi

$\phi_c = .65$

$T_u = 4(.65)(3000)^{\frac{1}{2}}(668)$

$= 95113$ LB

MAXIMUM TENSILE FORCE IN ROD

$F_y = 28.0^K$

PER ACI CODE, CHAP 9, LOAD FACTOR = 1.7

$1.7 F_y = 47.6 < T_u = 95.1$ K OK

ALLOWABLE LOAD PER ANCHOR BASED ON
CONCRETE CONE FAILURE

$T_{ALL} = \frac{T_u}{4(1.7)} = \frac{95.1}{4(1.7)}$

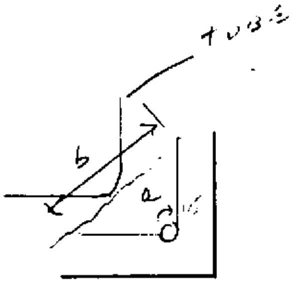
$= 14.0$ K

$> 10.96^K$ (BOND IN 3000 psi CONC)

$> 12.12^K$ (A307 STEEL ROD CAPACITY)

∴ BOND GOVERNS ANCHOR FOR 8 1/4" EMBEDMENT.

BASE PLATE BENDING DUE TO ANCHOR TENSION



$b = 2a$

$a = \left(\left(\frac{11-8}{2}\right)^2 \times 2\right)^{\frac{1}{2}}$

$a = 2.12$

$b = 2(2.12) = 4.24$

MOMENT $M = Ta = 8.75(2.12)$
$= 18.6$ IN-K

STRESS $f_s = \frac{6M}{bt^2}$

$= \frac{6(18.6)}{4(1)^2}$

$= 27.8$ KSI $\simeq .75 F_y = .75(36)$
$= 27$ KSI

SAY OK

TUBESTEEL TO BASE PLATE WELD

$T = 28.0^{k} = F_y$ MAX TENSION

TRY 5/16 FILLET,

$\ell = 4(8) = 32$

$A_w = .707\left(5/16\right)(32)$

$= 7.07 \text{ IN}^2$

WELD STRESS DUE TO SHEAR LOADS

$V = 24.0^{k}$ MAX SHEAR
ON ANOTHER
BASE PLATE

$$f_v = \frac{T}{A_w} + \frac{V}{A_w} =$$

$$= \frac{28.0}{7.07} + \frac{24.0}{7.07}$$

$$= 4.0 + 3.4 =$$

$$= 7.4 \text{ KSI}$$ OK

LEG TO VESSEL CONNECTION

PAD WELD - DESIGN FOR RESULTANT FORCE AND NO BENDING MOMENT AT TOP OF SUPPORT LEG

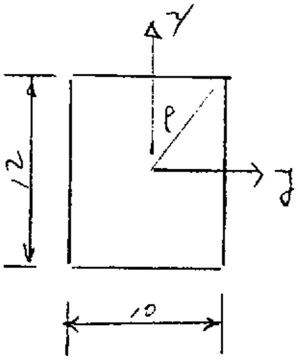
$$F = \left(F_Y^2 + F_y^2 + F_z^2\right)^{\frac{1}{2}}$$

$$= \left(20.3^2 + 3.2^2 + 16.6^2\right)^{\frac{1}{2}} \quad \text{(BEAM 4, NODE 6)}$$

$$= 26.4^k \quad \text{MAX FORCE}$$

M_z = 315 IN-K, MAX AT BEAM 2, NODE 3
($M_Y = M_y = 0$ DUE TO PIN RELEASES)

ASSUME [illegible] 3/8 IN FILLET ALL AROUND ON 10 x 12 PAD



$$A = 3/8\,(.707)(10+12)(2) = 11.67\ \text{IN}^2$$

$$I_y = \frac{3}{8}\left(2 \times \frac{12^3}{12} + 2 \times 10 \times 6^2\right)$$

$$= 3/8\,(1008) = 378\ \text{IN}^4$$

$$I_Y = \frac{3}{8}\left(2 \times \frac{10^3}{12} - 2 \times 12 \times 5^2\right)$$

$$= 3/8\,(767) = 288\ \text{IN}^4$$

$$J = I_Y + I_y = 666\ \text{IN}^4$$

$$\rho = \left(6^2 + 5^2\right)^{\frac{1}{2}} = 7.81\ \text{IN}$$

WELD SHEAR STRESS

$$f_v = \frac{F}{A_w} + \frac{M_z\,\rho}{J}$$

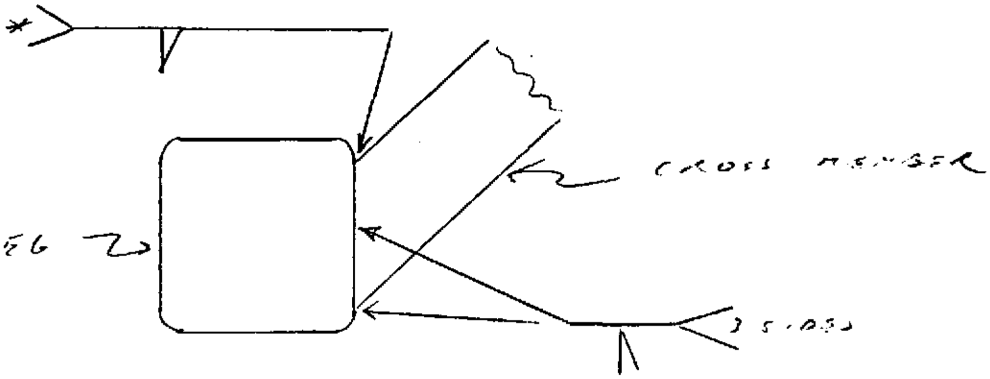
$$= \frac{26.4}{11.67} + \frac{315\ (7.81)}{666}$$

$$= 2.26 + 3.69 = 5.96\ \text{KSI} \quad \text{OK}$$

ACTUAL STRESS < 5.96 KSI SINCE MAX MOMENT & MAX FORCE OCCUR AT DIFFERENT JOINTS

WELDED CONNECTION BETWEEN SUPPORT LEG (8 x 8 x 5/8 TS) AND CROSS MEMBER (7 x 4 x 3/8 TS)

SINCE THE BENDING STRESS IN THE CROSS MEMBER IS HIGH AT THE SUPPORT LEG, THIS CONNECTION WILL BE A FP BUTT WELD



* FULL THROAT REQUIRED FOR 3/8" THICK MEMBER

NOTE: SEE CALCULATION V049-1-069 FOR DESIGN OF CLEVIS CONNECTION BETWEEN SUPPORT LEG AND WELD PAD AT SHELL.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-025
PAGE 1 OF 5

REV.	DEO #	DATE	BY:	CHECK
0	0128	4/17/96	RDC	WDB

TITLE: Design of Temporary Covers

BY: R. D. Ciatto
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. Design temporary shipping and test covers for 60.5 in nozzles in accordance with the requirements of ASME Section VIII, Div. 1.

METHOD: Hand calculation to determine membrane and shear stresses.

ASSUMPTIONS:

INPUTS:

1. Atmospheric pressure = 14.7 psi.
2. Temperature = 70°F (SHIPPING).
3. TEMP = 400°F DURING BAKEOUT

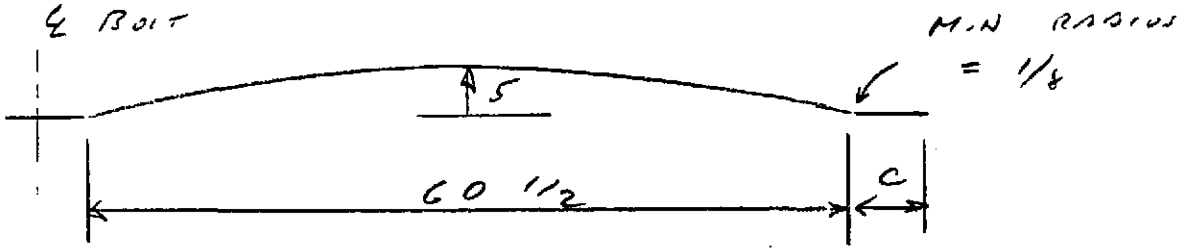
REFERENCES: 1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels
2 DOC. NO. V049-1-066, LIGO VACUUM EQUIP., STRUCT. DESIGN CRITERIA,

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The requirements of the ASME Code are met.

NOTES:

TEMPORARY 60.5 IN COVER



C = FLANGE WIDTH FOR 60.5 IN FLANGE

THICKNESS = 1/16 IN

MATERIAL SA 240 304L (CMTR REQD)

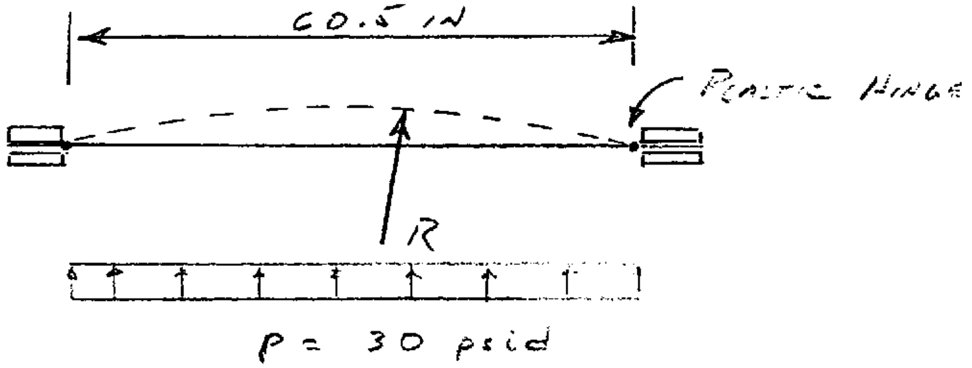
BOLT PATTERN & SIZE IS SAME AS FLANGE BOLT PATTERN & SIZE

Rev 0
Doc. No V049-1-025
P. 2 of 5

TEMPORARY COVER FOR 60 IN [illegible]

COVER WILL BE 1/16 IN SHEET 304L.
COLD FORM COVER USING 30 PSID APPROX.
PLATE

TO FORM THE COVER, THE SHEET WILL
BE CLAMPED BETWEEN 2 CIRCULAR PLATES.
PRESSURE WILL BE APPLIED ON ONE
SIDE. A PLASTIC HINGE WILL FORM
AT THE EDGE OF THE SHEET



MEMBRANE STRESS IN SPHERE

$$\sigma = \frac{pR}{2t}$$

YIELD STRESS AT ROOM TEMP

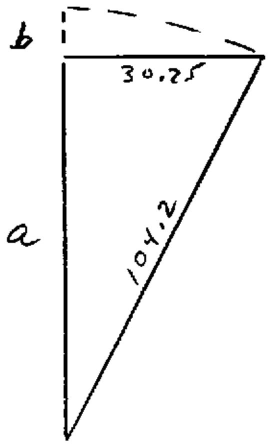
$$\sigma = S_y = 25 \text{ KSI FOR 304L}$$

$$p = 30$$

$$t = 1/16 = .0625$$

$$25{,}000 = \frac{30\ R}{2(.0625)}$$

$$R = 104.2 \text{ IN}$$



$$a = (104.2^2 - 30.25^2)^{\frac{1}{2}}$$

$$= 99.7$$

$$b = 104.2 - a$$

$$= 104.2 - 99.7$$

$$= 5.0 \text{ IN}$$

USING YIELD STRESS FROM CMTR
DETERMINE PRESSURE REQUIRED
TO OBTAIN $b = 5$ IN

$$P = \frac{2 S_y t}{R}$$

$$= \frac{2(.0625)}{104.2} S_y$$

$$= 1.20 (10)^{-3} S_y$$

P, S_y IN PSI, S_y @ ROOM TEMP

REQUIRED THICKNESS FROM ASME $\underline{\text{VIII}}$, (1), APP 1-1.

$$t = \frac{P R_o}{2SE + .8P}$$ FOR SPHERICAL SHELL

$$P = 14.7$$

$$R_o = 104.2 + .06$$

$$= 104.3$$

VESSELS WILL BE BAKED @ 400°F WHILE TEMP COVERS ARE IN PLACE

$S = 14.7$ @ 70°F ASME II TABLE 1A FOR SA 240 304L

E = JOINT EFFICIENCY

$= 1.0$ (NO WELD)

$$t = \frac{14.7(104.3)}{2(14{,}700)(1)+.8(14.7)}$$

$$= .052 < .0625 = 1/16$$

OK

SHEAR STRESS AT EDGE

$$\tau = \frac{\pi\left(\frac{66.5}{2}\right)^2(14.7)}{\pi(66.5)(.0625)}$$

$= 3600$ psi OK

REV 0

Doc. No. V079-1-025

p. 5 OF 5

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CALCULATIONS

NO: V049-1-026
PAGE 1 OF 3

REV.	DEO #	DATE	BY:	CHECK
0	0024	12/6/95	RDC	AGR

Beam Splitter Chamber - Evaluation of Nozzle to Shell Welds

BY: R.D. Ciarro

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To evaluate nozzle to shell fillet welds.

METHOD: Hand calculation using standard principles of mechaincs.

ASSUMPTIONS:

INPUTS: LIGO project sketches and drawings.

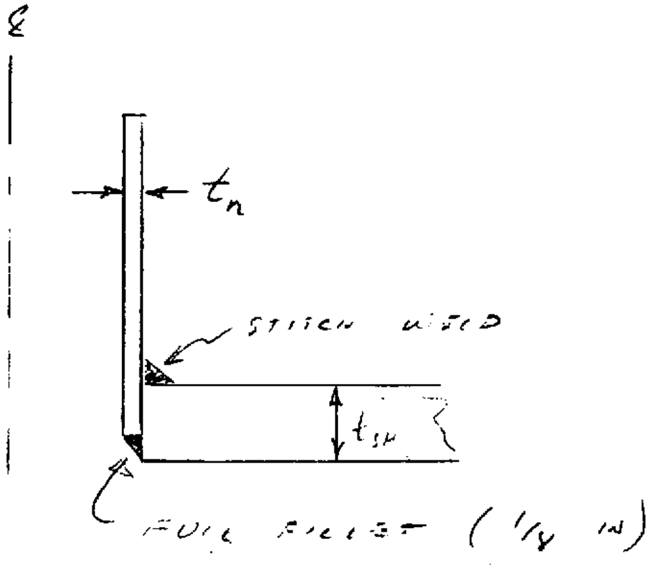
REFERENCES: ASME Boiler & Pressure Vessel Code, Section VIII, Division 1.
Doc. No. V049-1-066, LIGO Vacuum Equip. Structural Design Criteria.

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Nozzle welds are acceptable.

NOTES:

NOZZLE TO SHELL WELDS



MAX NOZZLE DIAMETER THAT USES THIS WELD IS 14" O.D. THE THICKNESS OF THE NOZZLES THAT RANGE FROM 8" TO 14" O.D. IS .125 IN. THE WELD FOR THE 14" NOZZLE HAS THE MAX STRESS.

EVALUATE FULL FILLET FOR END CAP LOAD ONLY. DISCONTINUITY BENDING & SHEAR WILL BE NEGLECTED SINCE THEY ARE SECONDARY, BUT THE STRENGTH ADDED BY THE STITCH WELD WILL BE IGNORED.

END CAP FORCE DUE TO VACUUM

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

$$= \pi \left(\frac{14}{2}\right)^2 (14.7) = 2263 \text{ LB}$$

14" NOZZLE HAS MAX END CAP LOAD

WELD THROAT AREA

$$A_w = \pi\, 14 \times .707(.125")$$

$$= 3.89 \text{ IN}^2$$

WELD SHEAR STRESS

$$f_v = \frac{F}{A_w}$$

$$= \frac{2263}{3.89}$$

$$= 582 \text{ psi}$$

ok

THE 60 IN NOZZLES ARE WELDED TO THE SHELL WITH FULL PENETRATION WELDS, NO FURTHER ANALYSIS OF THESE WELDS IS REQUIRED.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA	ENGINEERING CALCULATIONS	NO: V049-1-027 PAGE 1 OF 6

REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber - Vessel Lifting Devices
0	0024	12/6/95	RDC	WDB	
					BY: R D. CIATTO DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To design lifting lugs and evaluate leg stresses when BSC is lifted and rotated to & from a horizontal position.

METHOD: Hand calculation using standard stress analysis method.

ASSUMPTIONS:

INPUTS:
1. LIGO project skteches and drawings.
2. Vertical shock acceleration = 1g.
3. DOC. NO. V049-1-066, LIGO VACUUM EQUIP., STRUCTURAL DESIGN CRITERIA,

REFERENCES:

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Lug & weld stresses are acceptable. Stresses in support legs and shell are acceptable.

NOTES: A spreader beam should be used for the lift.

LIFTING LUGS

MAXIMUM ESTIMATED WEIGHT OF BSC

W = 15,000 LB

INCLUDES SUPPORTS & REMOVABLE FLOOR.

SHIPPING ACCELERATION LOADS FOR AIR-RIDE TRUCK.

VERT $a_V = 1.0$ g

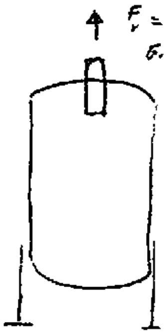
HORIZ. $a_H = .5$ g

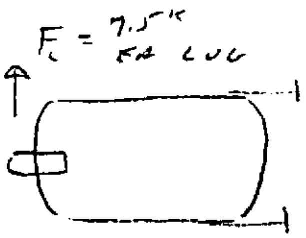
ASSUME THAT THESE ACCELERATIONS ALSO APPLY TO LIFTING IN SHOP

∴ VERTICAL LOAD = DL + SHIPPING LOAD

$$= F_V = W + W = 2W$$
$$= 30,000 \text{ LB}$$

SINCE THERE WILL BE 2 LIFTING LUGS THE LIFTING LOAD IN EA LUG (FOR DESIGN PURPOSES) IS 15000 LB. WHEN VESSEL IS IN HORIZ POSITION AND BEING RAISED TO VERTICAL WITH THE LUGS THE LATERAL LOAD IS $F_V/2$ = 7500 LB ON LUG





THE FE ANAL. OF THE BSC UPPER SECTION SHOWED THAT THE MAX SHELL STRESS FOR THE VERTICAL LIFT IS 1590 PSI FOR A LUG LOAD OF 6250 LB ∴ THE MAX STRESS FOR THIS CASE IS

$$SI = \frac{15000}{6250} \times 1590$$

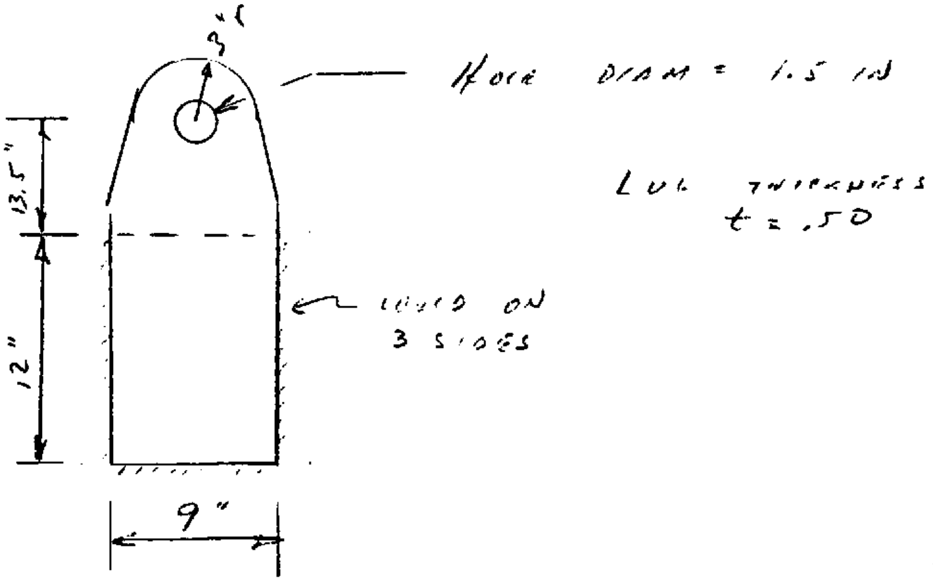
$$= 3800 \text{ psi} \quad OK$$

FOR THE HORIZ CASE THE MAX SHELL STRESS FROM THE FE ANALYSIS IS 2630 PSI FOR A LOAD OF 3125 LB. ∴ THE MAX STRESS INTENSITY FOR THIS CASE IS

$$SI = \frac{7500}{3125} \times 2630$$

$$= 6300 \text{ psi} \quad OK$$

LUG GEOMETRY



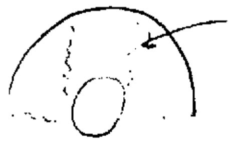
TENSILE STRESS AT PIN HOLE

$A_{NET} = (6 - 1.5)(.5) = 2.25 \text{ IN}^2$

$f_t = \frac{15}{2.25} = 6.67 \text{ KSI}$ ok

FOR $t = .5$

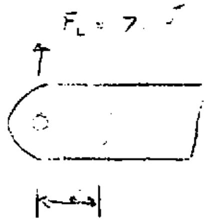
SHEAR STRESS



$A_V = 2\left(\frac{6}{2} - 1.5\right)(.5) = 4.5 \text{ IN}^2$

$f_V = \frac{15}{4.5} = 3.33 \text{ KSI}$

BENDING STRESS



$M = 13.5(7.5) = 101.25 \text{ IN-K}$

$f_b = \frac{6M}{t\,b^2} = \frac{6(101.25)}{1(9)^2} = 15.0 \text{ KSI}$ ok

WELD - TRY 1/4 IN FILLET WELD

$A_W = .707(.25)(12 + 12 + 9)$
$= 5.8 \text{ IN}^2$

NOTE: DWG V049-4-001 SH 5 SHOWS A WELD PAD BETWEEN LUG & VESSEL W/ 3/16 WELD ALL AROUND TO VESSEL

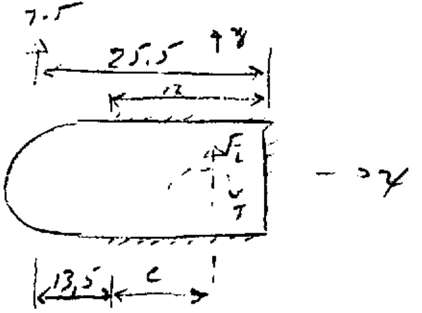
$A_W = 3/16(.707)(2 \times 12 + 2 \times 13.5)$

$= 6.8 \text{ IN}^2 > 5.8$ ok

FOR VERTICAL LOAD, WELD STRESS =

$$f_v = \frac{15}{A_w} = \frac{15}{5.8} = 2.6 \text{ KSI} \quad \text{ok}$$

TORSIONAL SHEAR STRESS DUE TO LIFT FROM HORIZONTAL POSITION



$$c = \frac{12\times9 + 2\times12\times6}{2\times12+9}$$

$$= 7.64 \text{ in}$$

$$F_L = 7.5^K$$

$$T = 7.5(13.5+7.64) = 158.6 \text{ in-K}$$

$$I_x = \left[\frac{9^3}{12} + 2(12)(4.5)^2\right](.75)(.707)$$

$$= 386.6(.75) = 96.6 \text{ in}^4$$

$$I_y = \left[9(12-7.64)^2 + 2\times\frac{12^3}{12} + 2\times12\times1.64^2\right](.707)(.75)$$

$$= 370.2(.75) = 92.6 \text{ in}^4$$

$$J = I_x + I_y = 96.6 + 92.6 = 189.2 \text{ in}^4$$

$$\rho_{MAX} = (7.64^2 + 4.5^2)^{\frac{1}{2}} = 8.90 \text{ in}$$

WELD SHEAR STRESS

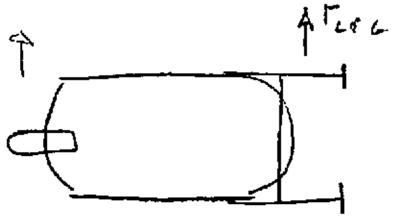
$$\tau = \frac{F_L}{A_w} + \frac{T\rho_{MAX}}{J}$$

$$= \frac{7.5}{5.8} + \frac{158.6(8.90)}{189.2}$$

$$= 1.3 + 7.43 = 8.7 \text{ KSI}$$

ok

LIFTING FORCE ON LEGS WHEN BSC IS IN HORIZONTAL POSITION



$F_{LEG} \cong 7.5^K$ EA. LEG

THIS FORCE IS BOUNDED BY THE MAX SHEAR FORCE IN THE BASE PLATE IMPOSED BY THE UNBALANCED VACUUM LOAD. FROM SUPPORT CALC

$V = 14.5^K$

∴ STRESSES IN SUPPORT STRUCTURE AND BSC SHELL DUE TO LIFT ARE ACCEPTABLE

STRESS IN OUTER WELD FOR PAD TO
SHELL ATTACHMENT (3/16 FILLET ALL AROUND)

FOR VERT LOAD

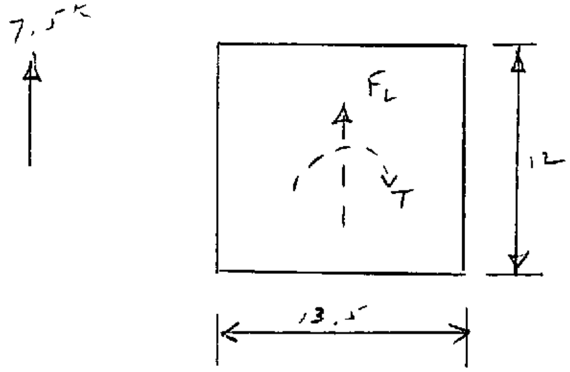
$$T = 15^{K}$$

$$A_w = .707 \times \tfrac{3}{16}\,(2 \times 12 + 2 \times 13.5)$$

$$= 6.76\ IN^2$$

$$f_L = \frac{15}{6.76} = 2.21\ KSI \quad OK$$

FOR HORIZ CASE



$$T = 7.5\left(25.5 - 1.5 - \frac{13.5}{2}\right)$$

$$= 151.9$$

$$I_x = \tfrac{3}{16}(.707)\left[2 \times \frac{12^3}{12} + 2 \times 13.5 \times 6^2\right]$$

$$= \tfrac{3}{16}(891) = 167\ IN^4$$

$$I_y = \tfrac{3}{16}(.707)\left[2 \times \frac{13.5^3}{12} + 2 \times 12 \times \left(\frac{13.5}{2}\right)^2\right]$$

$$= \tfrac{3}{16}(1063) = 199$$

$$J = I_x + I_y = 366\ IN^4$$

$$\rho = \left[6^2 + \left(\frac{13.5}{2}\right)^2\right]^{\frac{1}{2}} = 9.03\ IN$$

WELD SHEAR STRESS

$$\tau = \frac{7.5}{6.76} + \frac{151.9(9.03)}{366}$$

$$= 1.1 + 3.74$$

$$= 4.8\ KSI \quad OK$$

REV 0
DOC NO V049-1-077
P. 6a OF 6

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-028 PAGE 1 OF 8
REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber - Shipping Loads	
0	0136	6/20/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To evaluate the BSC shell for loads imposed during shipping.

METHOD: The IMAGES finite element computer program is used to analyze shell stresses.

ASSUMPTIONS: It is assumed that the BSC will be shipped with its long axis in a horizontal position. Also, it is assumed that the vessel will be supported by 2 wood saddles during shipping.

INPUTS: Vert shock accel = 1g
Horizontal shock accel. = .5g
Internal Vacuum Pressure = -14.7 psi

REFERENCES: 1. IMAGES 3D, Version 3.0, R.L. Cloud & Associates
2. Doc. No. V049-1-066, LIGO Vacuum Equipment, Structural Design Criteria

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Shell stresses that result from shipping loads are low. The vessel can withstand a shock of 5Gs or more without damage to the shell.

NOTES: The computer file name is BSC-SHIP.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-028
PAGE 1 OF 7

REV.	DEO #	DATE	BY:	CHECK
0	0128	12/6/95	RDC	[illegible]

Beam Splitter Chamber - Shipping Loads

BY: R.D.C

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To evaluate the BSC shell for loads imposed during shipping.

METHOD: The IMAGES finite element computer program is used to analyze shell stresses.

ASSUMPTIONS: It is assumed that the BSC will be shipped with its long axis in a horizontal position. Also, it is assumed that the vessel will be supported by 2 wood saddles during shipping.

INPUTS: Vert shock accel = 1g
Horizontal shock accel. = .5g

REFERENCES: IMAGES 3D, Version 3.0, R.L. Cloud & Associates

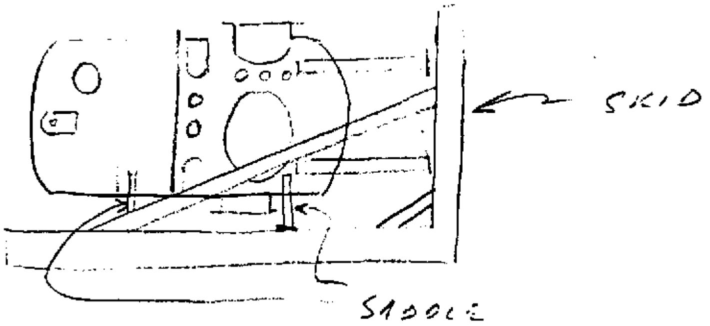
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Shell stresses that result from shipping loads are low. THE VESSEL COULD SUSTAIN A SHOCK ACCELERATION OF SEVERAL Gs.

NOTES: The computer file name is BSC-SHIP. *

BSC SHIPPING LOADS

IT IS EXPECTED THAT THE BSC WILL BE SHIPPED IN A HORIZONTAL POSITION WHILE SUPPORTED BY 2 WOOD SADDLES AND STAPPED TO A WOOD SKID



CRITICAL LOCATIONS ARE IN THE SHELL AT THE SADDLES. SINCE THE THINNEST SHELL IS THE 1/4 IN UPPER SECTION, IT IS EVALUATED.

BECAUSE THE VERTICAL ACCEL (1G) WHEN COMBINED WITH GRAVITY (1G) IS HIGHER THAN THE HORIZONTAL ACCEL (.5G), ONLY THE VERTICAL LOAD WILL BE ANALYZED. THESE ACCELERATIONS ARE THE MAXIMUM FOR AN AIR-RIDE TRUCK,

MAX EST WT

$$W = 15000 \text{ LB}$$

DL + SHOCK LOAD (VERTICAL)

$$F_V = W + W = 2W$$
$$= 30000 \text{ LB}$$

SADDLE LOAD

$$F_S = \frac{F_V}{2} = 15000 \text{ LB.}$$

THE HALF MODEL USED FOR THE UPPER SECTION ANALYSIS (BSCUPPER) IS USED TO EVALUATE THE SHELL. THE FILE WAS COPIED TO

FILE: BSC-SHIP

AND A SADDLE WAS ADDED. SINCE THIS IS A HALF MODEL, A 7500 LB LOAD IS APPLIED TO THE SADDLE IN THE X DIRECTION. NODAL LOADS ARE

$$F_{Y\,564} = F_{Y\,569} = 750 \text{ LB}$$

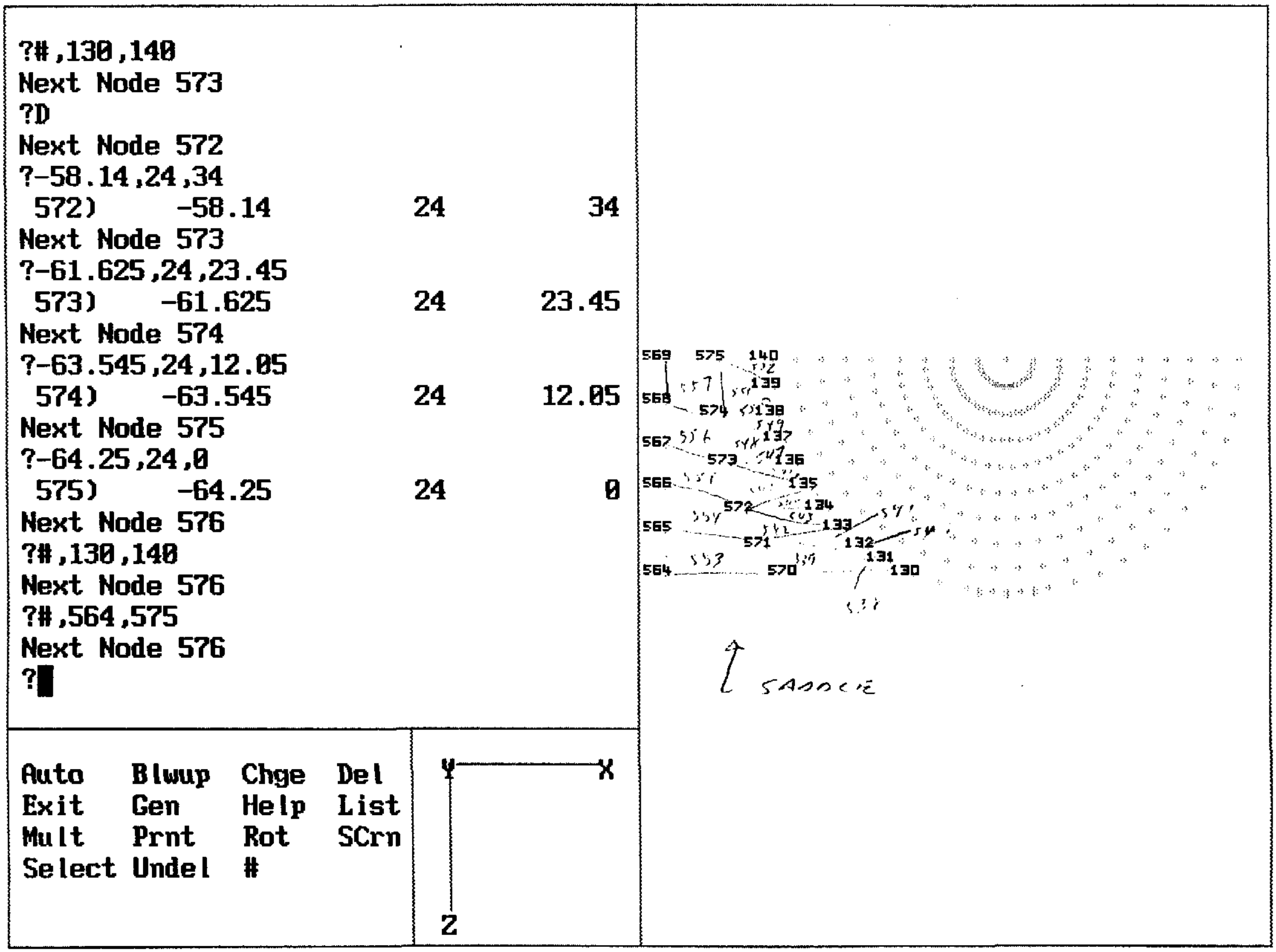
$$F_{Y\,565 \ldots 568} = 1500 \text{ LB}$$

THE WOOD SADDLE IS 1 IN THICK. IT IS INPUT IN MATL 4 AND PLATE LAYER NO. 6.

PLOTS ON THE FOLLOWING SHEETS SHOW THAT THE MAX STRESS INTENSITY IN THE 1/4 IN SHELL IS ONLY 2070 PSI AND THE MAX DEFLECTION IS .01 IN

WHEN COMBINED WITH VACUUM (LOAD CASE 3) THE SHIPPING LOAD STRESS IN THE SHELL IS ONLY 2600 PSI (SEE PLOT ON P. 7. THIS SHOWS THAT THE VERTICAL SHOCK COULD BE 5 GS OR MORE WITHOUT DAMAGING THE 1/4 IN SHELL

(LOAD CASE 2 IS VACUUM ALONE.)



```
?#,130,140
Next Node 573
?D
Next Node 572
?-58.14,24,34
 572)      -58.14          24          34
Next Node 573
?-61.625,24,23.45
 573)    -61.625          24       23.45
Next Node 574
?-63.545,24,12.05
 574)    -63.545          24       12.05
Next Node 575
?-64.25,24,0
 575)      -64.25          24           0
Next Node 576
?#,130,140
Next Node 576
?#,564,575
Next Node 576
?█
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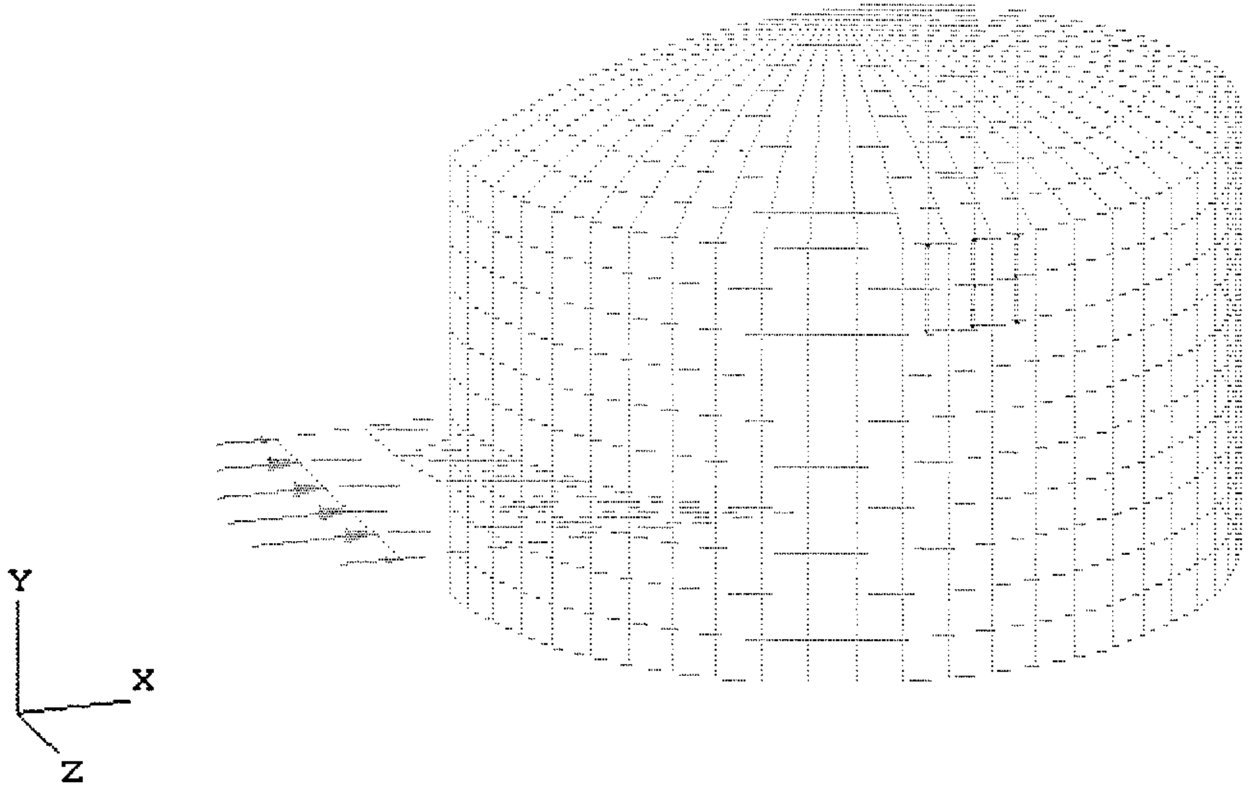
IMAGES-3D
Ver. 3.0

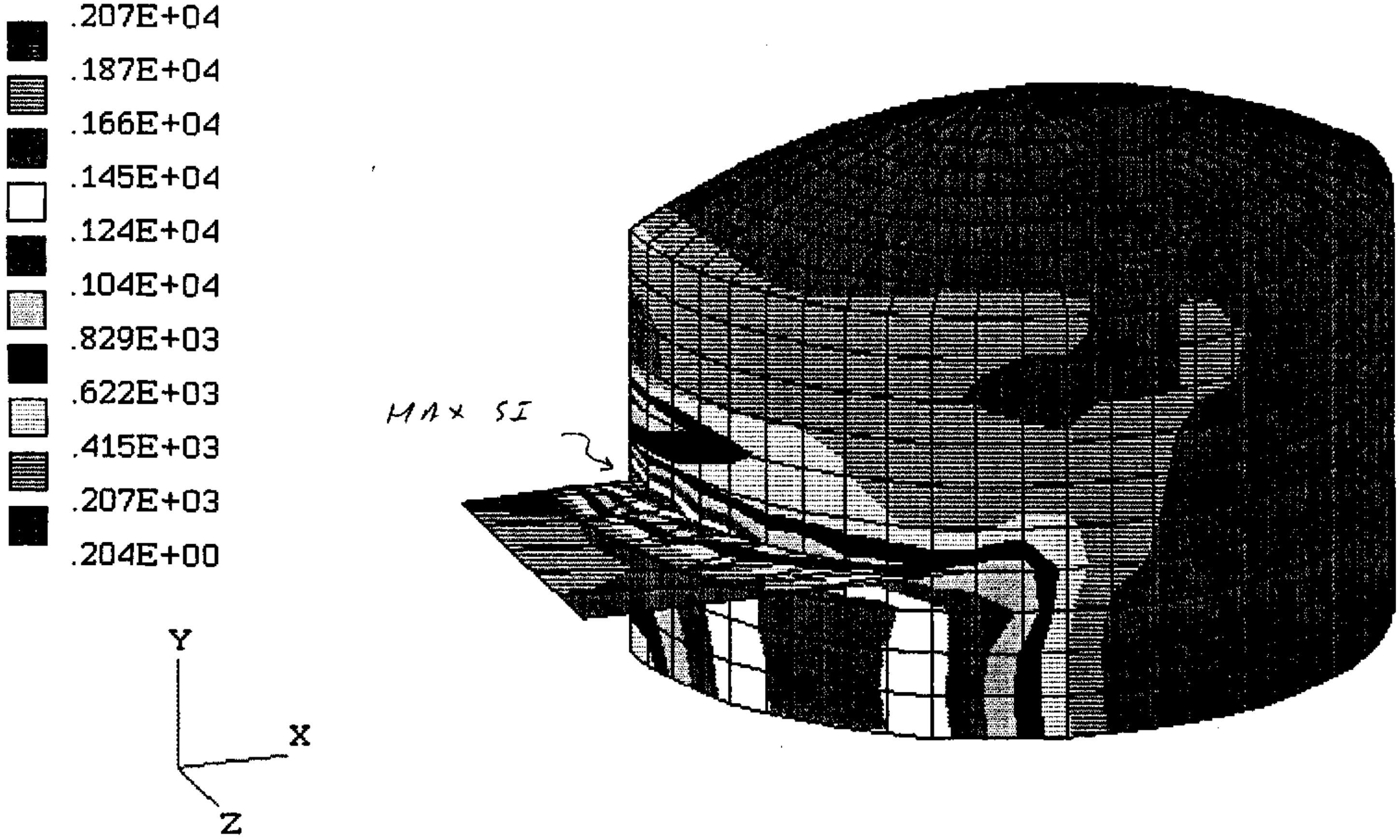


Load Case
1

Wireframe Plot

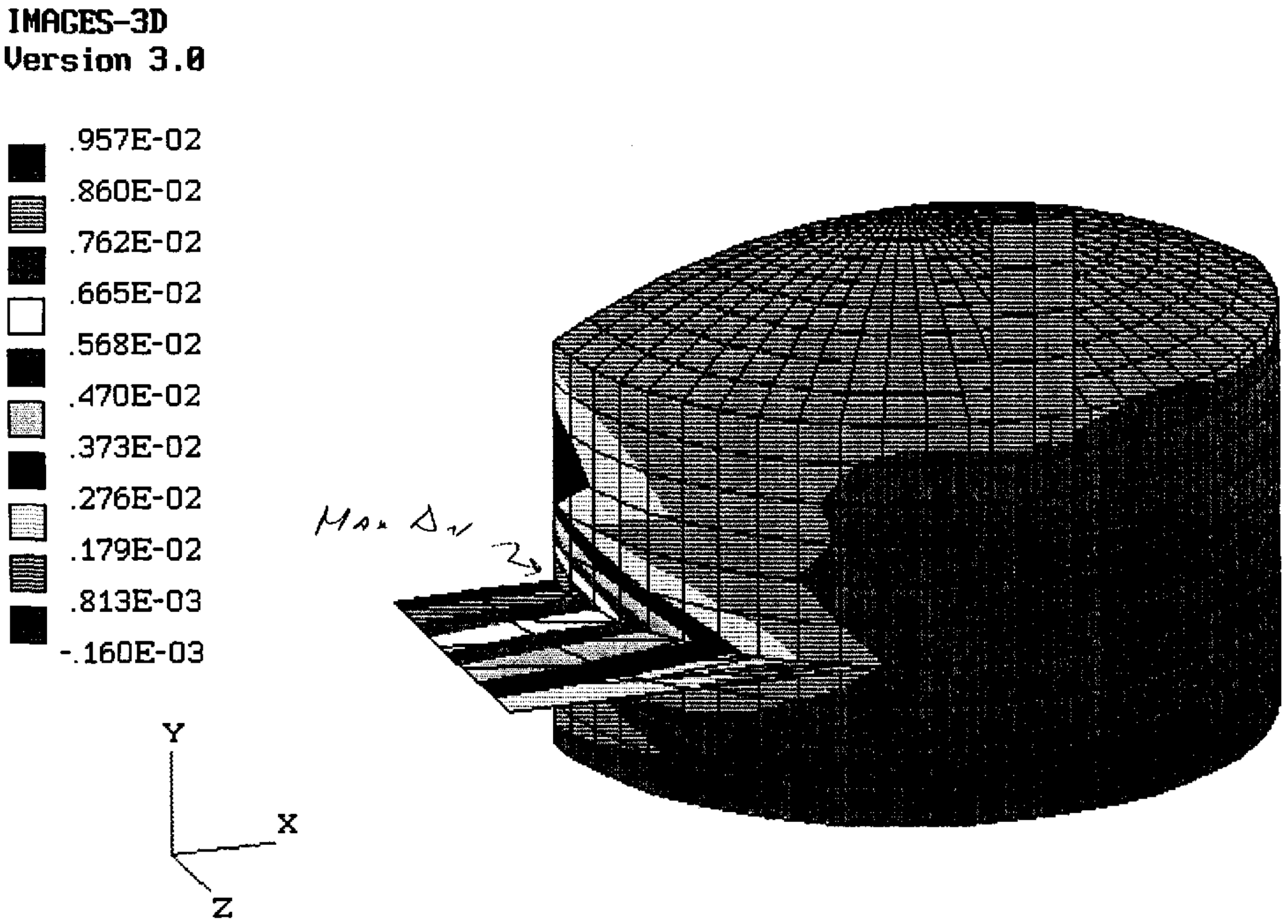
11/30/95
11:29: 2

IMAGES-3D
Version 3.0



MAX SI

Load Case **Stress Contour Plot** **11/30/95**
1 **Surf: Bottom** **Stress Intensity** **11:25: 6**

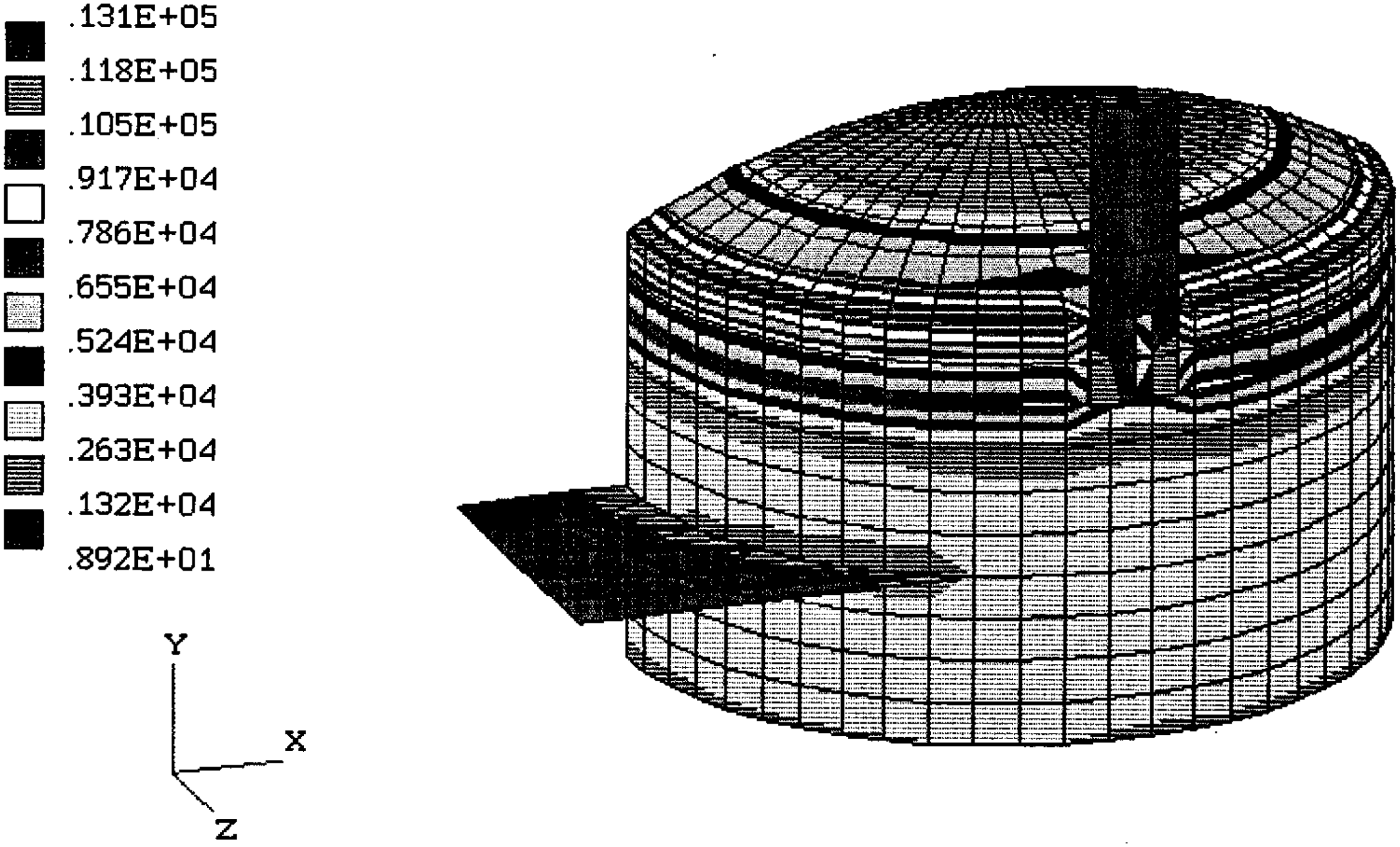


Load Case
1

Displacement Contour Plot
DX

11/30/95
11:27:37

IMAGES-3D
Version 3.0



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Load Case 3

Stress Contour Plot

Surf: Top

Stress Intensity

4/20/96
9:21:40

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-029 PAGE 1 OF 5
REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber Deflections	
0	0024	12/6/95	RDC			
					BY: R.D.Ciarro	DEPT.: 744
PROJECT: LIGO Vacuum Equipment					PROJECT NO: V59049	

PURPOSE:. Compute estimated deflections at Beam Splitter 60 in. nozzles.

METHOD: Combine shell deflections with support deflections to obtain maximum estimated deflections at ports.

ASSUMPTIONS: Bellows deflects with negligible force.

INPUTS: Deflections from shell FE analysis. Deflections from support frame analysis. PSI layout DWG. showing bellows location.

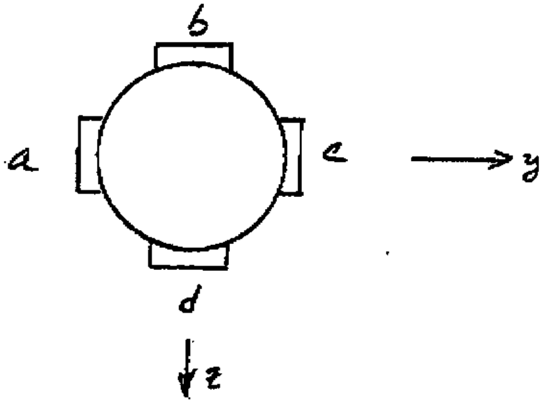
REFERENCES:

CALCULATIONS: (SEE ATTACHED)

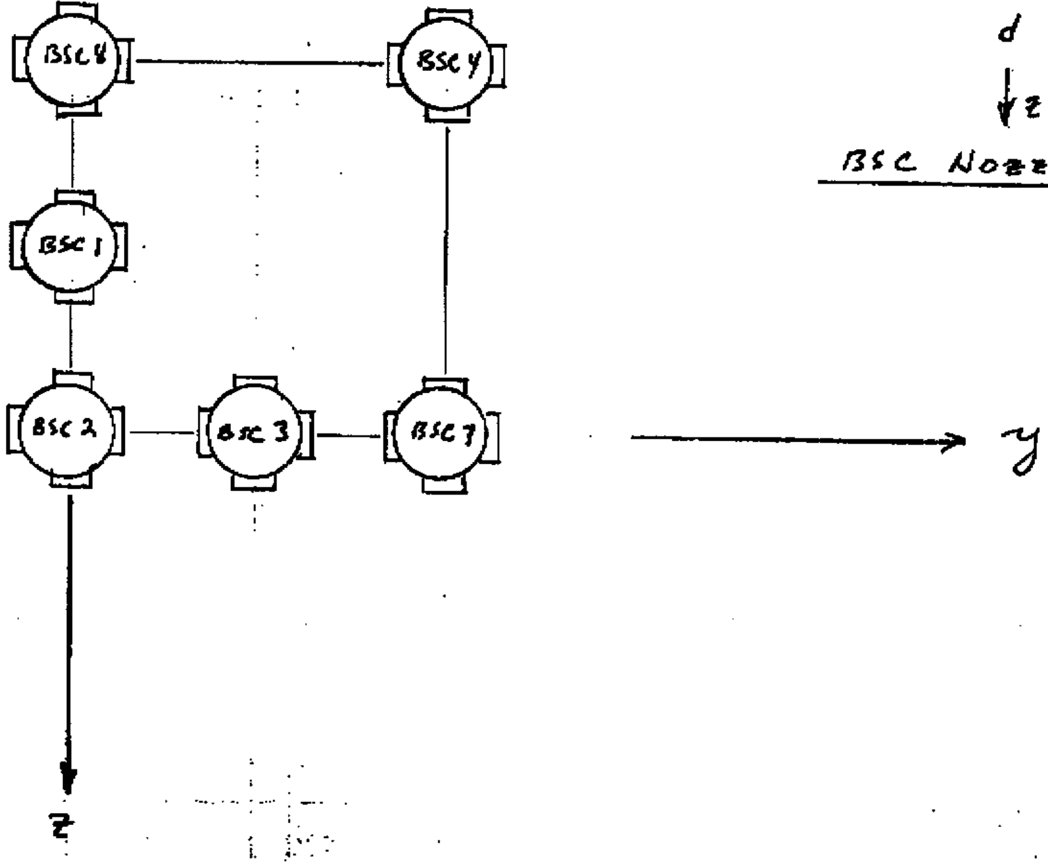
CONCLUSIONS:

NOTES: The basis for these deflections is the support structure presented in the PDR.

FILED\F:\TEMPLATE\ENGFORMS\ENGCALC



BSC NOZZLE ORIENTATION



CORNER STATION KEY PLAN

OPERATING CONDITIONS

1. ALL VACUUM

2. VERTEX SECTION VENTED

3. DIAGONAL SECTION VENTED

DEFLECTIONS RESULT FROM

- SHELL DISPLACEMENT
- SUPPORT DISPLACEMENT

DEFLECTIONS ARE IN INCHES

BSC No.	OP. COND. NO.	Port a		Port b		Port c		Port d	
		Δy	Δz	Δy	Δz	Δy	Δz	Δy	Δz
1	1	.125			.125	-.125			-.125
	2								
	3	.125			.125	-.125			-.125
2	1	.125			.125	-.125			-.125
	2								
	3	.125			.125	-.125			-.125
3	1	.125			.125	-.125			-.125
	2								
	3	.125			.125	-.125			-.125
4	1	.125			.125	-.125			-.125
	2	.125			.125	-.125			-.125
	3	-.25		-.25		-.25		-.25	

BSC No.	OP. COND. No.	PORT a		PORT b		PORT c		PORT d	
		Δy	Δz	Δy	Δz	Δy	Δz	Δy	Δz
7	1	.125	-.25		-.125	-.125	-.25		-.375
	2	.375	-.25	.25	-.125	.125	-.25	.25	-.375
	3	.125	-.25		-.125	-.125	-.25		-.375
8	1	.375		.25	.125	.125		.25	-.125
	2	.375	-.25	.25	-.125	.125	-.25	.25	-.375
	3	.375		.25	.125	.125		.25	-.125

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REV.	DEO #	DATE	BY:	CHECK
0	0128	1/24/96	KM	RDC

TITLE: Buckling Analysis of Beam Splitter Chamber

BY: Kyle Martini

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. Evaluate the beam splitter chamber (BSC) for buckling modes.

METHOD: Finite element method and hand calculation.

ASSUMPTIONS: See attached.

INPUTS: LIGO project drawings and sketches.

REFERENCES: NASTRAN Finite Element Program
DOC. NO. V049-1-066, LIGO VACUUM EQUIP STRUCT. DES. CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The minimum factor of safety against elastic buckling for vacuum loading is 5.9.

NOTES:

COMPUTER FILE: BMSP1*.INP

1.0 Hand Analysis

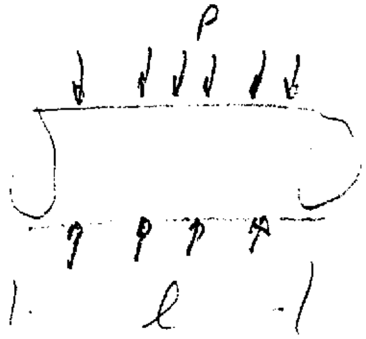
Assumption - (1) Extra material at nozzles replaces stiffness of vessel material removed

(2) pressure uniform over cylinder

(3) stiffners are ignore

(4) cylinder length is from bottom head to connection between lower & upper beamsplitter $\ell = 91''$.

From Roark 5th ed Table 35 Case 19 b



Short tube of length "ℓ" ends held circular but otherwise not constrained, no end loads

$$P_{cr} = .807 \frac{Et^2}{\ell r} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 \frac{t^2}{r^2}}$$

$t = 0.5''$ $\ell = 91''$ $\nu = 0.3$

$r = 52.75''$ $E = 29(10^6)$ psi

$$P_{cr} = 127.4 \text{ psi}$$

$$F.S = \frac{P_{cr}}{14.7} = \underline{8.67}$$

2.0 COMPUTER ANALYSIS.

a. The same length shell is analyzed using NASTRAN'S buckling program.

b. The shell is ½" thick with the openings or holes for the 60" diameter tubes.

c. The smaller nozzles are not modeled. It is assume the stiffness of the nozzle replaces the stiffness removed by the hole.

d. The stiffness of the tube nozzles are model as beams. Assuming the nozzles extend 3" and are ½" thick.

e. The vessel junction with the bottom head and the junction with the top portion of the vessel are model as reinforcement beams 3" x 1½".

f. An external pressure of 14.7 psi is applied to all plate elements.

g. An (vertical) axial ring load is applied to the bottom of the vessel and the top equal to −PA where A is inside Area of vessel and P = 14.7 PSI

h. The vessel is restrained at its connection with the support legs

i. Four configuration are analyzed, a four bellows model where no load is applied to the tube nozzle, a three bellows model where one nozzle is load, a two bellows model where two opposite nozzles are loaded, and two adjacent bellows loaded

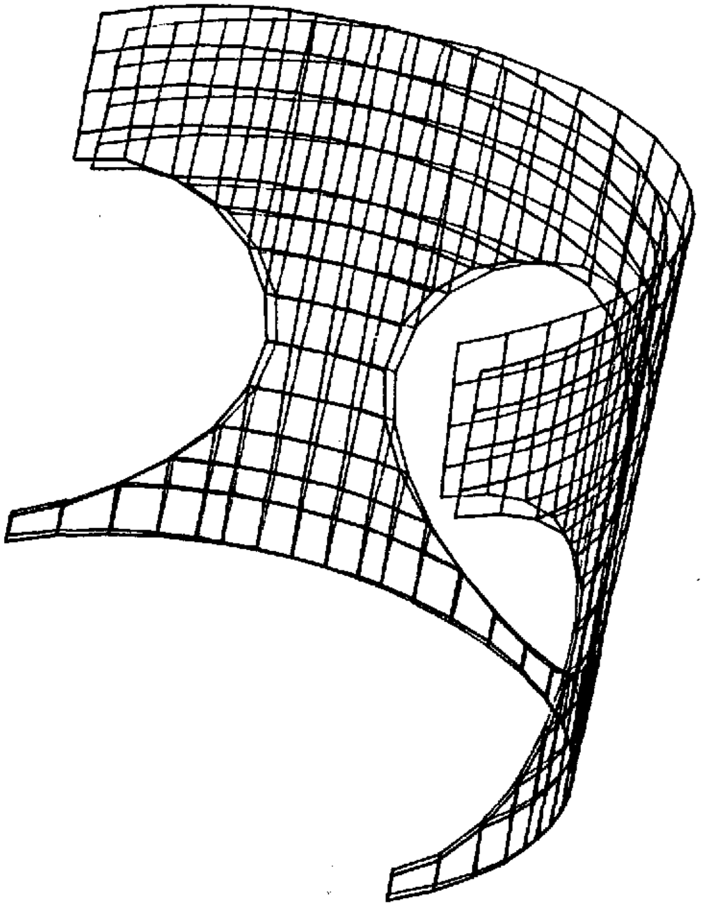
j. Except as describe above all other stiffeners are ignore

k. The model is a 180°

3.0 Computer Results

Model	Factor of Safety
4 - bellows (Fig 1)	7.0
3 - bellows (Fig 2)	6.5
2 - opp bellows (Fig3)	6.1
2 - adjacent bellow	5.9

5 1/29/96 MAX-DEF. = 1.00000000 5



HAM 1/1 SYMM MODEL

BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2 MODE 5 EIGENV. 7.043044 MASS MODEL

Fig 1 4 Bellows Buckling Shape

5/7

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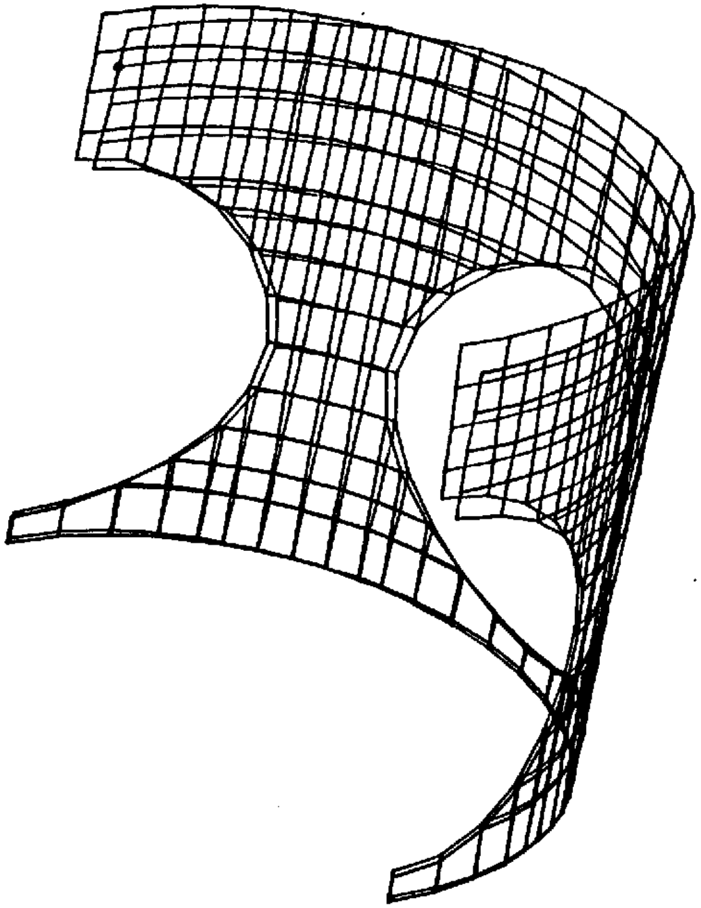
p. _ of 7

1/29/96 MAX-DEF. = 1.00000000



HAM 1/1 SYMM MODEL

BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2 MODE 6 EIGENV. 6.478190 MASS MODEL

Fig 2 3 Bellows B[illegible] [illegible]

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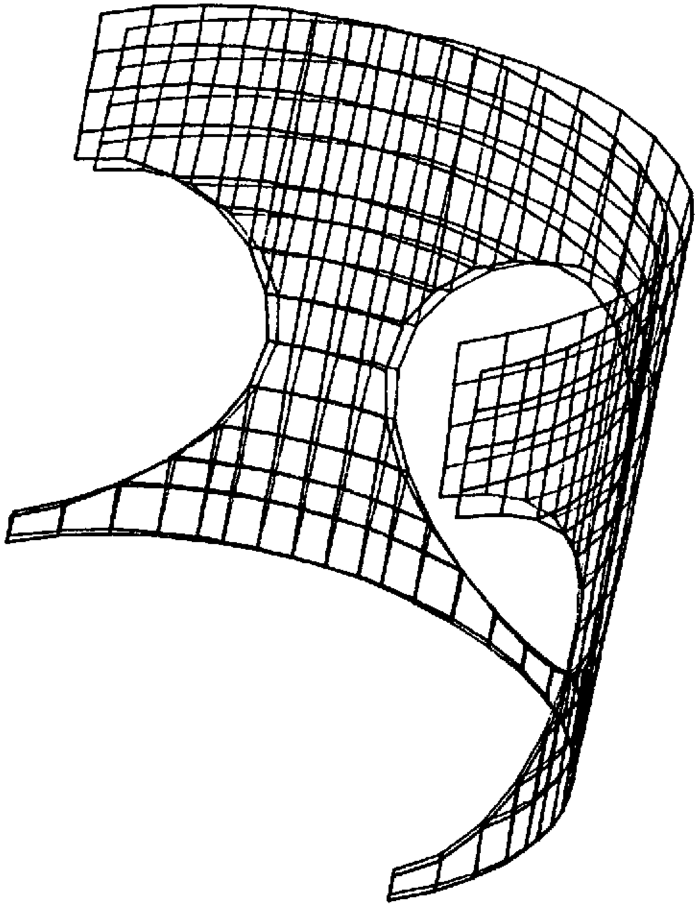
6   1/29/96   MAX-DEF. = 1.00000000   6



HAM 1/1 SYMM MODEL

BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2   MODE 6   EIGENV. 6.126621 MASS MODEL

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Fig 3 2 Bellows Per [illegible]

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WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-069

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REV.	DEO #	DATE	BY:	CHECK
0	0131	3-8-96	AGR	RDC

TITLE:
BEAM SPLITTER SUPPORT CLEVIS

By: ART ROUSSOPOULOS **DEPT.:** 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: DETERMINE THE STRUCTURAL INTEGRITY OF THE BSC CLEVIS SUPPORT ASSEMBLY

METHOD: • CLASSICAL STRESS ANALYSIS - MAX SHEAR STRESS THEORY

SUMPTIONS: SEE CALCS

INPUTS: V049-1-024

REFERENCES: DWGS: V049-4-023 + V049-4-001 DOC.NO.
ASME VIII, DIV 2, 1989 ED
AISC, SCM - 9TH. ED.
V049-1-066, LIGO VAC. EQUIP. STRUCT DESIGN CRITERIA

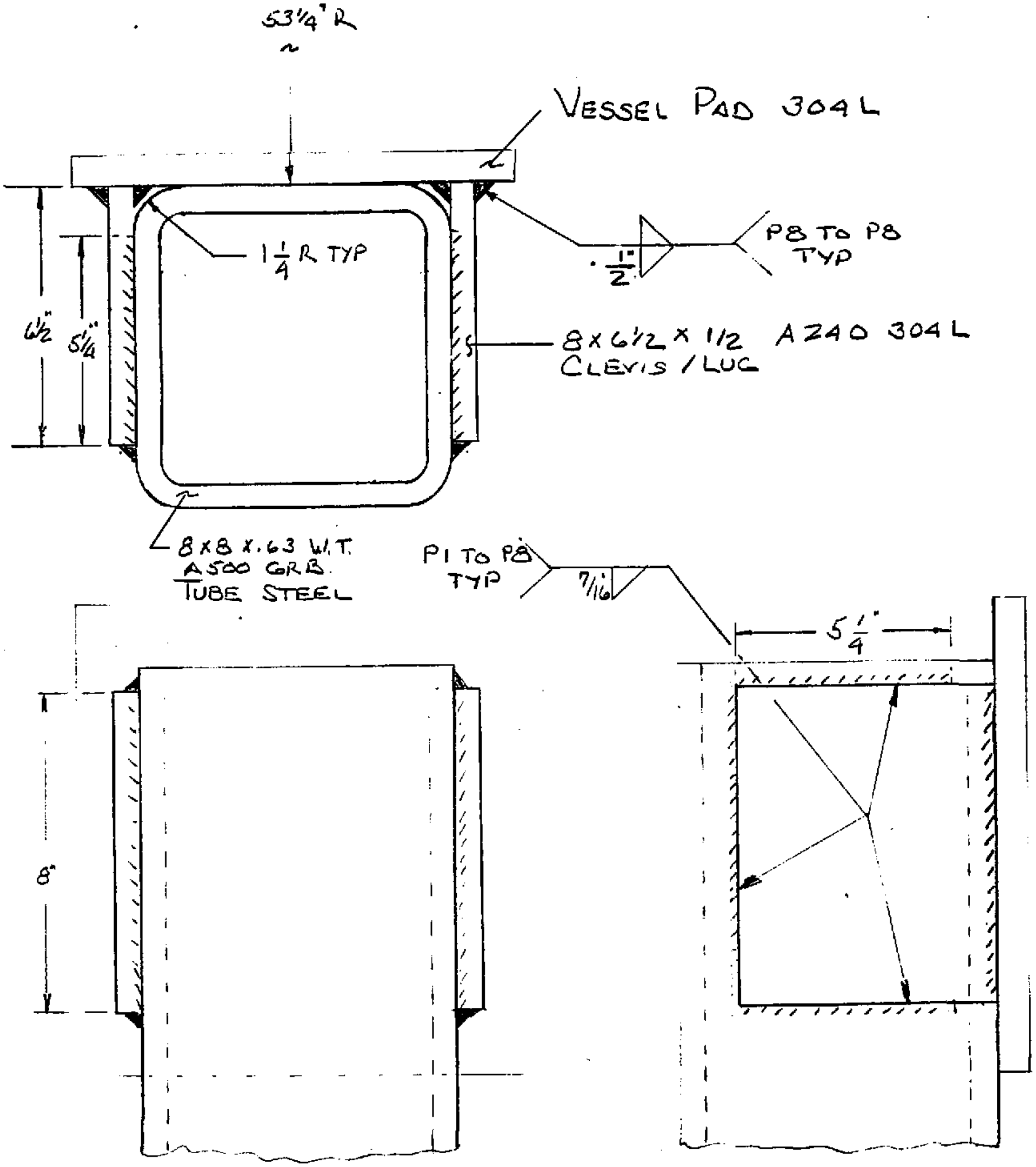
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: STRUCTURAL SUPPORT OF CLEVIS ATTACHMENT + WELDS ARE DESIGNED TO ASME VIII REQUIREMENTS

NOTES:

TABLE OF CONTENTS

1.0 BSC SUPPORT DESIGN SKETCH



2.- ALLOWABLE WELD STRESSES

- ALLOWABLE WELD STRESS FOR BASE MATERIAL EVALUATIONS SHALL BE BASED ON SA 240 TYPE 304 AND IS ACCEPTABLE DUE TO DUAL CERTIFICATION OF 304/304L MATERIAL, I.E. 304L SHALL, VIA CMTR'S, MEET THE MINIMUM YIELD AND TENSILE STRESS AND ALL OTHER SA MATERIAL REQUIREMENTS FOR 304.

- ALLOWABLE WELD STRESS IS BASED ON THE REQUIREMENTS OF ASME VIII, DIV 2, SECTION AD-920 "STRESS VALUES FOR WELD MATERIAL"

- DESIGN STRESS INTENSITY, Sm, FOR SA 240 TYPE 304 FROM PART AM, TABLE AMA-1:

$S_m = 18,700$ PSI AT 400°F

- STRESS INTENSITY REDUCTION FACTOR PER AD-920: = .5 FOR FILLET WELDS ≤ 1/2"

2.1 - ALLOWABLE WELD STRESS INTENSITY:

$$S_{m_{ALLOW}} = .5\,(18,700) = 9,350 \text{ PSI}$$

2.2 - ALLOWABLE SHEAR STRESS:

- SHALL BE THE LESSER OF THE FOLLOWING:

- PER AD-132.2 "PERIPHERY OF SECTION IN TORSION"

$$\tau \leq .8 S_{m_{ALLOW}} = .8\,(.5 S_m) = .4\,S_m$$

$$\therefore\ \tau \leq .4 S_m = .4\,(18,700) = 7,480 \text{ PSI}$$

OR

$$\tau \leq .6\,S_{m_{ALLOW}} = .6\,(.5 S_m) = .3\,S_m$$

$$\tau \leq .3 S_m = .3\,(18\ 700) = 5,610 \text{ PSI}$$ FOR PURE SHEAR

- PER AISC, TABLE J2.5, P. 5-70:

$\tau \le$ .30 X NOMINAL TENSILE STRENGTH OF WELD METAL. THIS VALUE WILL BE MULTIPLIED BY THE RATIO OF TENSILE STRESS OF THE BASE MATERIAL AT DESIGN TEMP TO THE TENSILE OF THE BASE MATERIAL AT ROOM TEMP FOR REPRESENTATIVE DESIGN CONDITIONS.

$$\therefore \ \tau \le .30 \times 75000 \left(\frac{S_{t\,HOT}}{S_{t\,COLD}}\right)$$

$$\tau \le .30 \times 75000 \left(\frac{63450}{82800}\right) = 17,242 \text{ PSI}$$

- CONCLUSION:

  - $\tau_{TORSION} \le .8 S_m = 7,480$ PSI
  - $\tau_{PURE} \le .6 S_m = 5,610$ PSI

2.3 - SUMMARY:

- TORSIONAL SHEAR: $\tau \le 7,480$ PSI $= .8 S_{m\,(ALLOWED)}$
- PURE SHEAR: $\tau \le 5,610$ PSI $= .6 S_{m\,(ALLOWED)}$
- LOCAL PRIMARY MEMBRANE STRESS: $P_L \le 1.5 S_m$ (REF: AD 140 (c))

  $P_L \le 1.5(.5 S_m) = 1.5(.5)(18,700) = 14,025$ PSI

- PRIMARY BENDING STRESS: $P_b \le 1.5 S_m$ (REF: AD 140 (d.))

  $P_b \le 14,025$ PSI

- $P_L + P_b \le 1.5 S_m = 14,025$ PSI

3 - SUPPORT WELD ANALYSIS

REF: BSC SUPPORT DESIGN SKETCH
PSI DWG. V049-4-043
" " V049-4-001

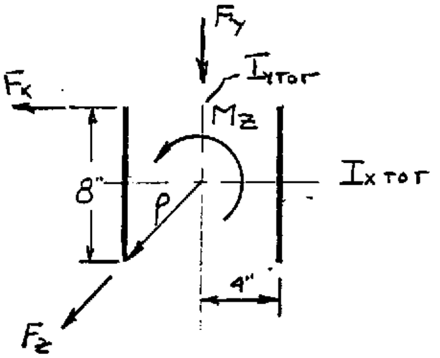
- THE FOLLOWING ARE THE WORSE CASE LOADS FOR BEAM #2, NODE 3 AS CALCULATED IN REF. DOC. NO. V049-1-024, P.19

$F_x = 220^{\#}$; $F_y = 11{,}930^{\#}$; $F_z = 2444^{\#}$

$M_z = 314{,}500$ IN-#

3.1 - CLEVIS / LUG TO VESSEL WELD

MODEL:



$\rho = [8^2+8^2]^{1/2} = 5.65''$

$I_{XTOT} = \dfrac{4bh^3}{12} = \dfrac{4(.707)(.5)(8)^3}{12} = 60,3$ IN⁴

$I_{YTOT} = 2\left\{\dfrac{8[2(.707)(.5)]^3}{12} + (2)(.707)(.5)(8)(4)^2\right\} = 181.5$ IN4

$J = I_{XTOT} + I_{YTOT} = 60.3 + 181.5 = 241.8$ IN⁴

- TORSION: $T = M_z = 314{,}500$ IN-#

$\tau = \dfrac{T\rho}{J} = \dfrac{314{,}500(5.65)}{241.8} = 7{,}349$ PSI $< .8S_m = 7{,}480$ PSI $\therefore$ OK

- SHEAR: $A_s = 4 \times (8)(.707)(.5) = 11.31$ IN²

$\sigma_{sx} = F_x/A_s = (220)/11.31 = 20$ PSI $< .6S_m = 5610$ PSI $\therefore$ OK

$\sigma_{sy} = F_y/A_s = (11{,}930)/11.31 = 1055$ PSI $< .6S_m = 5610$ PSI $\therefore$ OK

- TOTAL COMBINED SHEAR STRESS:

$\sigma_{STOT} = \sqrt{(\tau+\sigma_{sx})^2 + \sigma_{sy}^2}$

$\sigma_{STOT} = \sqrt{(7349+20)^2 + (1055)^2} = 7444$ PSI

$< .8\,S_m = 7{,}480$ PSI $\therefore$ OK

3.1 CON'T

- TENSILE / COMPRESSIVE NORMAL STRESS:

$$\sigma_{T/C} = \frac{F_Z}{A_s} = \frac{2444}{11.31} = 216 \text{ PSI}$$

- COMBINED STRESS:

$$\sigma = \sqrt{216^2 + 7444^2} = 7447 \text{ PSI} < .8 S_M = 7480 \text{ PSI}$$

$\therefore$ OK

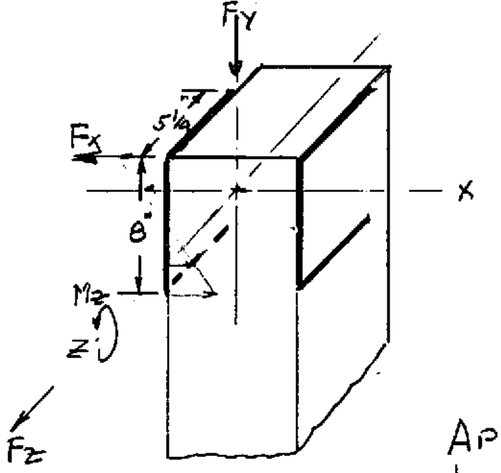
3.2. - 8X8 STEEL TUBE LEG TO CLEVIS/LUG

- SHEAR: $F_S = \sqrt{F_Y^2+F_Z^2} = \sqrt{(11930)^2+(2449)^2} = 12,178\#$

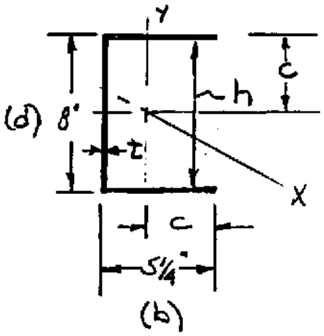
$$\sigma_S = \frac{F_S}{A_S} = \frac{12,178}{2[.707(4375)(8+2\times 5.25)]} = 1,064\text{ PSI}$$

$< .6\,S_m = 5,610$ PSI ∴ OK

- BENDING:



WELD LINE:



APPLIED MOMENT M PER WELD LINE $M_Z/2 = (314,500/2) = 157,250$ IN-#

$$\sigma_B = \frac{M_Z}{I/c} = \frac{M\,c}{I} = \frac{157,250(4)}{58.5} = 10,746\text{ PSI}$$

$< 1.5\,S_M = 14,025$ PSI ∴ OK

WHERE:

$I = \frac{bd^3 - h^3(b-t)}{12}$ REF: MACHINERY HDBK; 17ED; P.364

$I = [(5.25)(8)^3 - (7.38)^3(5.25 - .31\ )]/12 = 58.5$ IN4

$b = 5.25"$; $d = 8"$; $t = .707(.4375) = .31"$

$h = 8 - 2\times(.707)(.4375) = 7.38"$

$c = 4"$

- TENSILE / COMPRESSIVE

$$\sigma_{T/C} = \frac{F_X}{A_S} = \frac{220}{11.44} = 19\text{ PSI}$$

- <u>COMBINED STRESS</u>:

$$\sigma = \frac{(10,746+19)}{2} \pm \sqrt{\left(\frac{10746+19}{2}\right)^2 + (1064)^2}$$

$$\sigma_{1,2} = 5383 \pm 5487$$

$\sigma_1 = 10,870$ PSI ; $\sigma_2 = -104$ PSI ; $\sigma_3 = 0$

- <u>MAX STRESS INTENSITY</u>:

$S_{MAX} = 10,780 - (-104) = 10,884$ PSI

$< 1.5 S_m = 14,025$ PSI $\therefore$ OK

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-031

PAGE 1 OF 2

REV.	DEO #	DATE	BY:	CHECK
0	0128	12/6/95	RDC	WDB

Vacuum Equipment Seismic Acceleration

BY: R.D. CHATTE

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. To determine maximum seismic acceleration factors for design of LIGO vacuum equipment.

METHOD: Hand calculation using applicable construction code.

ASSUMPTIONS:

INPUTS: LIGO - E940002-02-4, Vacuum Equipment Specification, Rev. 2, September 6, 1995

REFERENCES: 1. LIGO Specification (above)
2. ASCE7-88, American Society of Cival Engineers - Minimum Design Loads for Buildings and Other Structures
3. DOC. NO. V049-1-066, LIGO VACUUM EQUIP'T STRUCT. DESIGN CRITERIA.

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The maximum seismic acceleration factor is .05625G. This factor will be applied to equipment weight in static analyses.

NOTES: The maximum seismic zone for LIGO equipment is Zone 1.

SEISMIC ACCEL CRITERIA PER ASCE 7-88

ZONE = 1, SECTION 9.10 APPLIES

$F_p = Z I C_p W_p$ EQ 16, ASCE 7-88

$Z = 3/16$ TABLE 21

$I = 1.0$ TABLE 22

$C_p = .3$ FOR EQUIPMENT TABLE 25

W_p = EQUIPMENT WEIGHT

$$F_p = 3/16\,(1.0)(.3)\,W_p$$
$$= .05625\ W_p$$

∴ SEISMIC ACCEL = .05625 G (LATERAL)

FORCES IN PRINCIPAL ORTHOGONAL DIRECTIONS ARE NON CONCURRENT (ASCE 7-88, 9.4.1)

Rev. 0

PROCESS SYSTEMS INTERNATIONAL, INC.
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ENGINEERING CALCULATIONS

NO: V049-1-032
PAGE 1 OF 23

REV.	DEO #	DATE	BY:	CHECK
0	139	12/29/95	RDC	AGR

TITLE: Component Interface Loads

BY: R. D. C[illegible]
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Determine vacuum forces on component flanges due to the venting of certain sections of the system while other sections remain under vacuum.

METHOD: Hand calculation methods of statics are used to determine unbalanced vacuum loads on:

- Beam Splitter Chambers
- Horizontal Access Modules
- Gate Valves
- 80K Pumps

ASSUMPTIONS: Bellows impose negligible axial forces on components. Adapters and valves have no axial restraint.

INPUTS: PSI Equipment Arrangement Plans and spool piece dwgs. Atmospheric pressure = 14.7 psi.

REFERENCES: Senior Flexonics, Inc. - Prelim. Design Calculations of LIGO Vacuum Equipment - Bellows (attached).

CALCULATIONS: (See Attachment)

CONCLUSIONS: See summary on following sheet.

NOTES: This calculation may be used to determine vacuum forces on adapters, spool pieces and tubes.

SUMMARY

THE MAXIMUM UNBALANCED FORCES ON THE BEAM SPLITTER CHAMBERS (BSCs) ARE ON BSC 7 & BSC 8 OF THE WASHINGTON CORNER STATION - SEE PAGES 7 & 8. THE MAX FLANGE TENSION IS 29.5^{K} ON THE 63.5 IN FLANGE

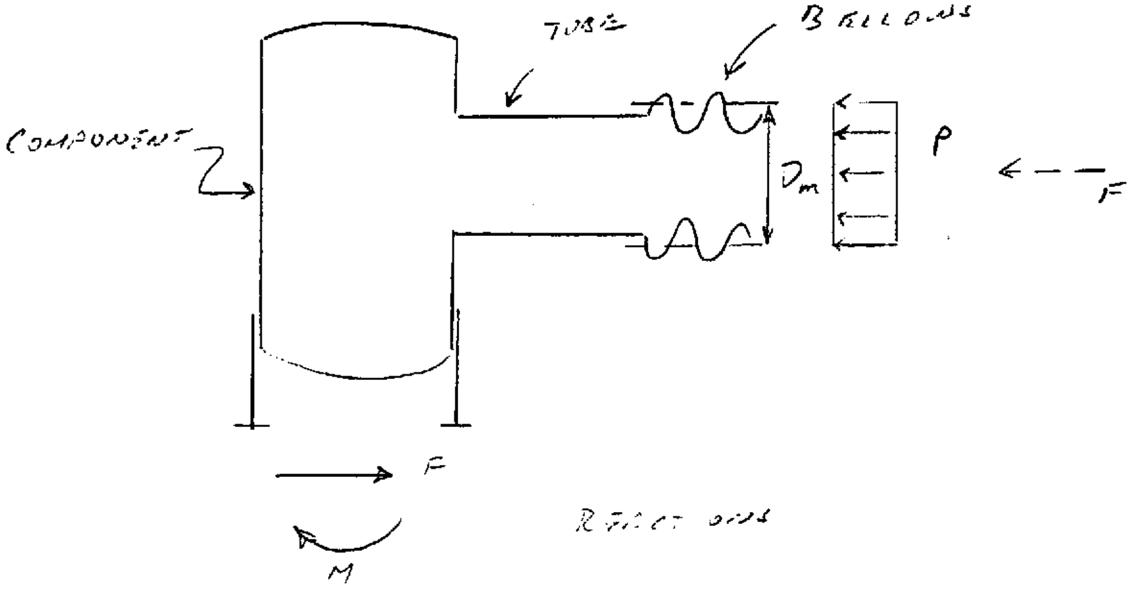
THE MAXIMUM UNBALANCED FORCE ON THE HORIZ. ACCESS MODULES (HAMs) ARE ON HAMS AT THE ENDS OF THE VACUUM SYSTEM. $F = 45.5^{K}$, NO TENSION ON FLANGE

FOR GATE VALVES, BOLTED FLANGES CAN HAVE TENSILE LOAD FROM FULL VACUUM, THE SAME IS TRUE FOR WELDED FLANGES,

$F = 29.5^{K}$ FOR 48.25" VALVE
$F = 25.4^{K}$ " 44.63" VALVE

FOR THE 80^{K} PUMPS THE MAXIMUM FLANGE FORCE IS 25.4^{K} IN TENSION OR COMPRESSION.

UNBALANCED FORCES RESULTING FROM BELLOWS



$F = P \; EA$

$P = -14.7$ psi

EA = PRESSURE AREA OF BELLOWS CORRESPONDING TO MEAN DIAM. OF BELLOWS, D_m (SEE ATTACHMENT)

48 IN TUBE (48 IN ID)

$EA = 1983 \text{ IN}^2$

$F = -14.7(1983) = -29,150 \text{ LB} = -29.2^K$

60 IN TUBE (60 IN ID)

$EA = 3043$

$F = -14.7(3043) = -44,730 \text{ LB} = -44.7^K$

72 IN TUBE (72 IN ID)

$EA = 4330$

$F = -14.7(4330) = -63,650 \text{ LB} = -63.7^K$

FROM THE PRESSURE AREA, EA, IT WAS DETERMINED THAT THE MEAN DIAM. D_M IS ABOUT 2.25 IN LARGER THAN THE TUBE I.D., EX. FOR 48 IN

$$r^2 = \frac{EA}{\pi} = \frac{1983}{\pi}$$

$$r = \left(\frac{1983}{\pi}\right)^{\frac{1}{2}} = 25.12$$

$$D_M = 2r = 50.25 > 48 \text{ IN}$$

FORCES FOR REVISED TUBE DIAMETERS ARE:

44.63 IN TUBE

$$D_M = 44.63 + 2.25 = 46.88 \text{ IN}$$

$$F = P \; \pi \frac{D_M^2}{4}$$

$$= -14.7 \frac{\pi}{4} (46.88)^2$$

$$= 25,37[illegible] \text{ LB} = 25.4 \text{ K}$$

NEGATIVE [illegible] SIGN FOR FORCE, THE LOAD PULLS FROM SUPPORTED COMPONENT TOWARDS BELLOWS WHERE THERE IS A CLOSED VALVE OR IT PUSHES ON BACK SIDE OF VALVE TOWARDS BELLOWS.

48.25 IN TUBE

$$D_M = 48.25 + 2.25 = 50.5 \text{ IN}$$

$$F = 14.7 \frac{\pi}{4} (50.5)^2 = 29\,4[illegible] \text{ LB} = 25.4 \text{ K}$$

60.5 IN TUBE

$$D_M = 60.5 + 2.25 = 62.75$$

$$F = 14.7 \frac{\pi}{4} (62.75)^2 = 45,460 \text{ LB} = 45.46 \text{ K}$$

72.25 IN TUBE

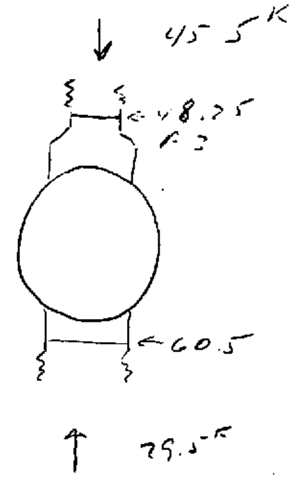
$$D_M = 72.25 + 2.25 = 74.5 \text{ IN}$$

$$F = 14.7\,\pi\,\frac{(74.5)^2}{4} = 64080 \text{ lb} = 64.1 \text{ K}$$

WASHINGTON CORNER STATION
REF. DWG V049-5-001 FOR LAYOUT OF [illegible]
& BELLOWS

BEAM SPLITTER CHAMBERS

BSC 1

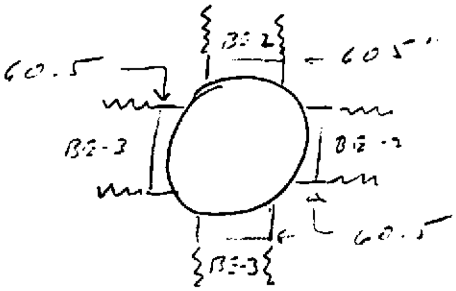


NET FORCE

$$F = 45.5 - 29.5$$
$$= 16^K$$

NO TENSION ON FLANGES

BSC 2



OFFSET
DOWN
3.94"*

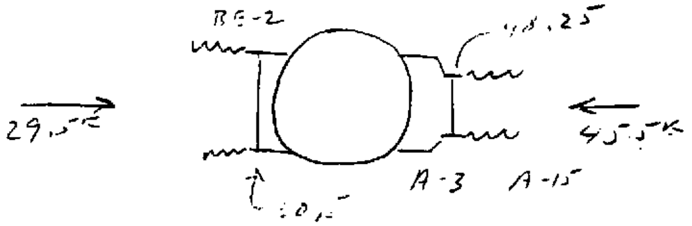
OFFSET
DOWN 3.94"*

No UNBALANCED
LOADS EXCEPT FOR
OFFSETS

No TENSION ON
FLANGES

* No EFFECT - BELLOWS ELEVATION SAME
AS BSC PORT

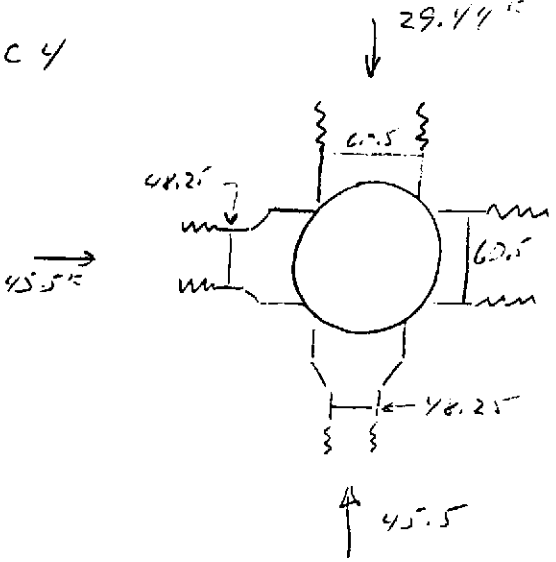
BSC 3



NET FORCE = 16K

No TENSION ON
FLANGES

BSC 4

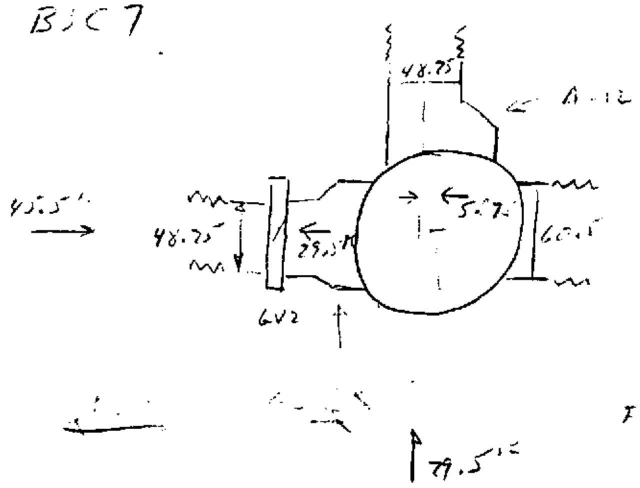


← 29.44K
OFFSET ON
3.94" (NO EFFECT)

UNBALANCED FORCES
F = 45.5 - 29.5 = 16K
[illegible] DIRECTION

N- TEN. ON FLANGES

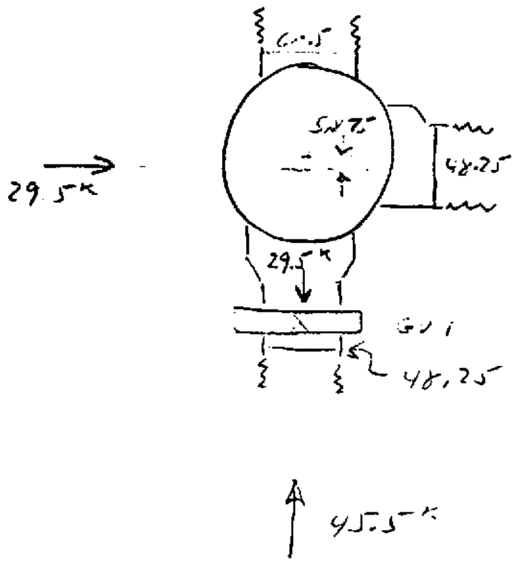
BSC 7



29.5K TEN ON LEFT FLANGE WHEN BSC IS VENTED

WHEN LEFT SIDE OF GV2 IS VENTED, UNBALANCED FORCE TO [illegible] AS [illegible]

BSC 8



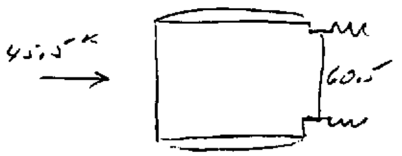
29.5K TEN ON LOWER FLANGE WHEN BSC IS VENTED

WHEN AREA BELOW GV1 IS VENTED, UNBALANCED LOAD IS 45.5K TOWARD TOP OF DIAGRAM.

Washington Corner Station cont.,

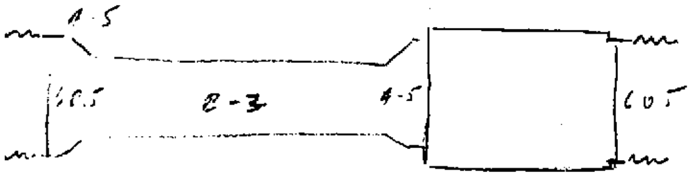
Horizontal Access Modules

HAM1



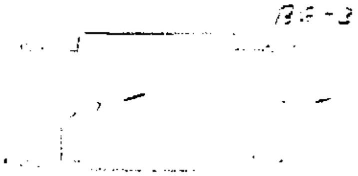
NO TENSION ON FLANGES

HAM 2



NO UNBALANCED FORCE

HAM 3



*OFFSET UP 3.9v

NO UNBALANCED FORCE*

HAM 4 SAME AS HAM 3 NO UNBALANCED FORCE*

HAM 5 - SAME AS HAM 2 - NO UNBALANCED FORCE

HAM 6 - SAME AS HAM 1 - UNBALANCED FORCE = 45 LB

HAM 7 - " " " " " "

HAM 8 - " " HAM 2 - NO UNBALANCED FORCE

HAM 9 - SAME AS HAM 3 - " " " *

HAM 10 - " " " " " " *

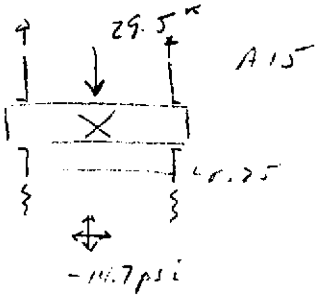
HAM 11 - SAME AS HAM 2 " " "

HAM 12 - SAME AS HAM 1 - UNBALANCED FORCE = 45 LB

WASHINGTON CORNER STATION CONT.

GATE VALVES

GV1

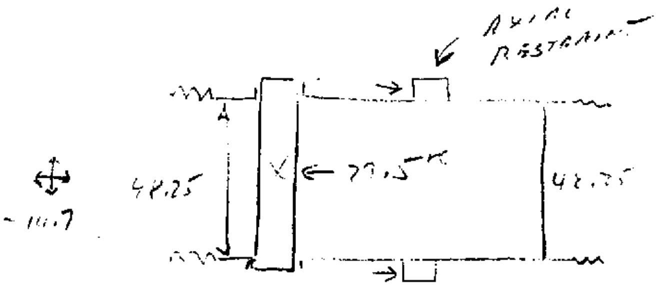


TENSILE FORCE ON VALVE BOLTED FLANGE IS 29.5K

OR COMPRESSIVE LOAD ON FLANGE IS 29.5K WHEN OTHER SIDE IS VENTED

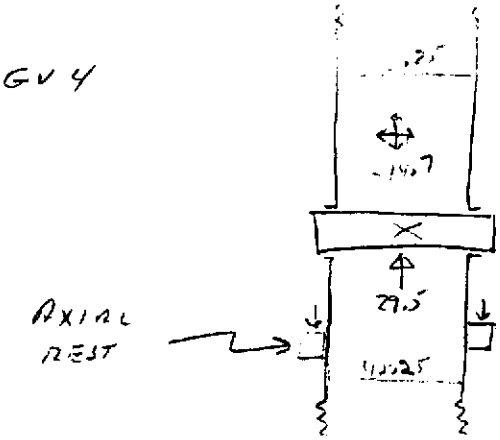
GV2. SAME AS GV1

GV3



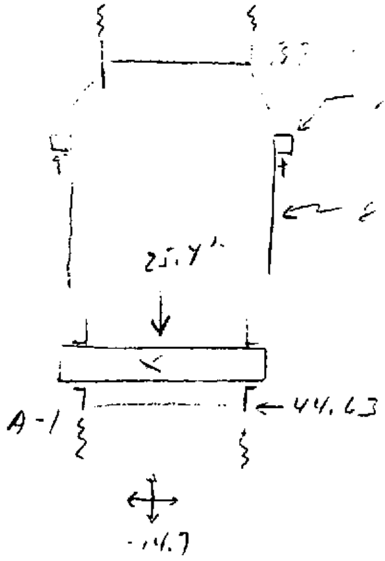
FORCES ON BOLTED FLANGES ARE SAME AS GV1

GV 4



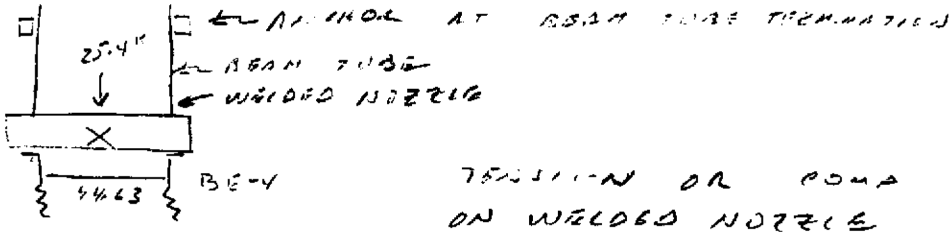
FORCES ON BOLTED FLANGES ARE SAME AS GV1

GV 5



FLANGES IN TENSION FOR CASE SHOWN

GV 6



TENSION OR COMP ON WELDED NOZZLE CONNECTION. NO LOAD ON BOLTED FLANGE.

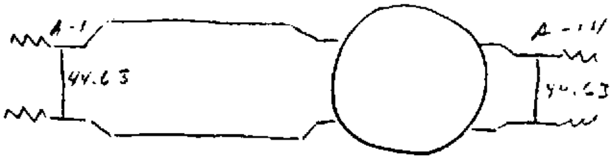
GV 7 SAME AS GV 5

GV 8 SAME AS GV 6

80K LONG PUMPS. SEE SKETCH FOR GV5. MAX FLANGE TENSION FOR 44.63 IN FLANGE IS 25.4 K. COMPRESSIVE FORCE ON FLANGE HAS SAME MAGNITUDE

WASHINTON MID STATION
REF. DWG V049-5-004

BSC

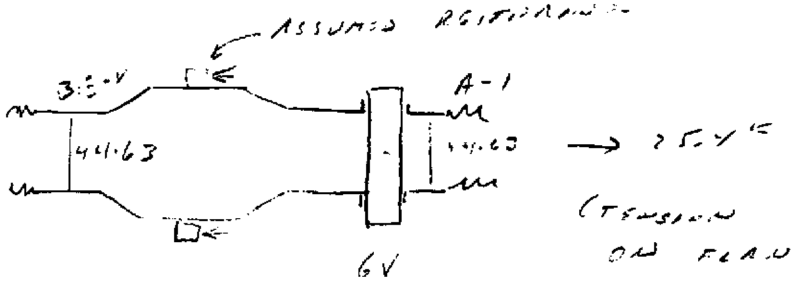


NO UNBALANCED LOAD

GATE VALVES. ALL GVs AT WA MID STA ARE 44 W/ BOLTED FLANGE CONNECTIONS. MAX TEN ON FLANGE IS SAME AS GV6 ABOVE, 25.4K.

WA MID STA (CONT.)

80K SHORT PUMPS



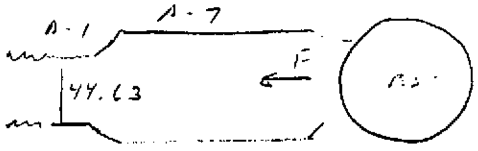
→ 25.4K

(TENSION OR COMP ON FLANGE)

VALVE AT BEAM TUBE ANNULAR WELDED ON ONE SIDE. SEE GV6 ON PREVIOUS SHEET

Washington/Louisiana End Stations
Ref Dwg V049-5-005

BSC



F = 25.4K
[illegible] ON BSC FLANGE

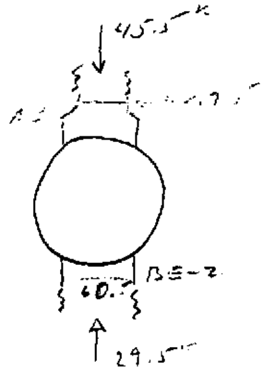
GATE VALVES. ALL VALVES HAVE 44.63 IN ID FLANGES. TENSION LOAD = 25.4K. VALVE AT BEAM TUBE ANNULAR WELDED ON ONE SIDE. SEE GV6 FOR WARS

80K SHORT PUMP. SAME AS ABOVE, MAX FLANGE LOAD = 25.4K TEN OR COMP.

LOUISIANNA CORNER STATION
REF DWG V049-5-003

BEAM SPLITTER CHAMBERS

BSC 1



UNBALANCED FORCE
$= 45.5^K - 29.5^K = 16^K$

NO TEN ON FLANGES

BSC 2 - SAME AS WASH BSC 2 - NO UNBALANCED LOADS

BSC 3 - SAME AS BSC 1, ABOVE, 16^K UNBAL FORCE, NO TENSION ON FLANGES.

HORIZ. ACCESS MODULES

HAM 1 - SAME AS WASH HAM 1. 45.5^K UNBAL. LOAD.

HAM 2 - " " " HAM 2. NO UNBAL. FORCE

HAM 3 - " " " " 3, " " " *

HAM 4 " " " " 4, " " " *

HAM 5 - " " " " 5, " " "

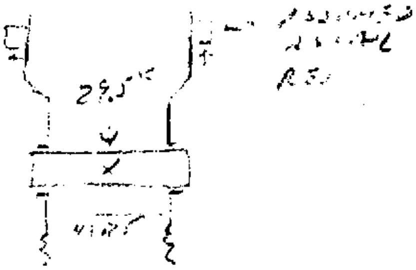
HAM 6 " " " " 6, 45.5^K UNBAL LOAD

* OFFSET = 3.94" ON BSC SIDE

LA FLANGE CALC CONT.

GATE VALVES

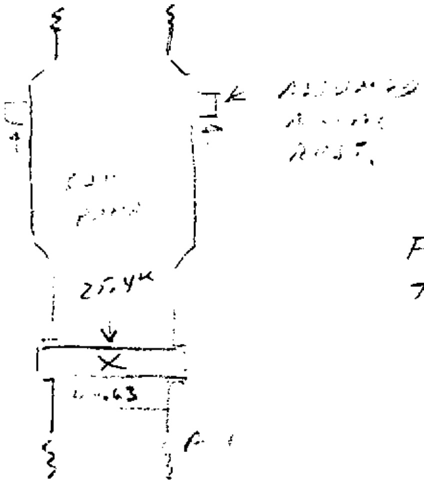
GV1



FORCE ON FLANGE = 29.5^K
TEN OR COMP

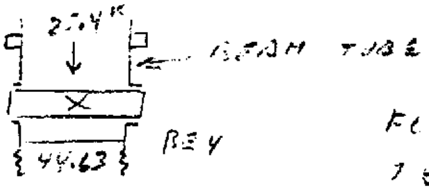
GV2 - SAME AS GV1

GV3



FORCE ON FLANGE IS 25.4^K
TEN OR COMP.

GV4



FLANGE FORCE = 25.4^K
TEN OR COMP

GV5 - SAME AS GV3 , 25.4^K FORCE TEN OR COMP

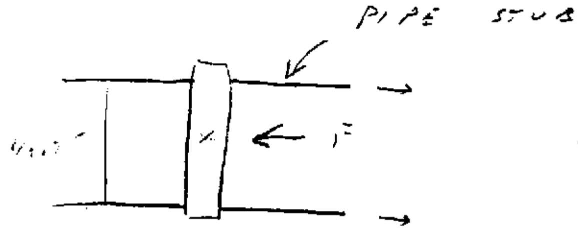
GV6 - " " GV4 " " " " "

LA CORNER STA CONT

80K LONG PUMP. SEE SKETCH FOR GV3 MAX FLANGE FORCE IS 25.4K TEN OR COMP.

LA MID POINT

THE ONLY COMPONENT AT THE LOCATION IS A BUTT WELDED 48" VALVE

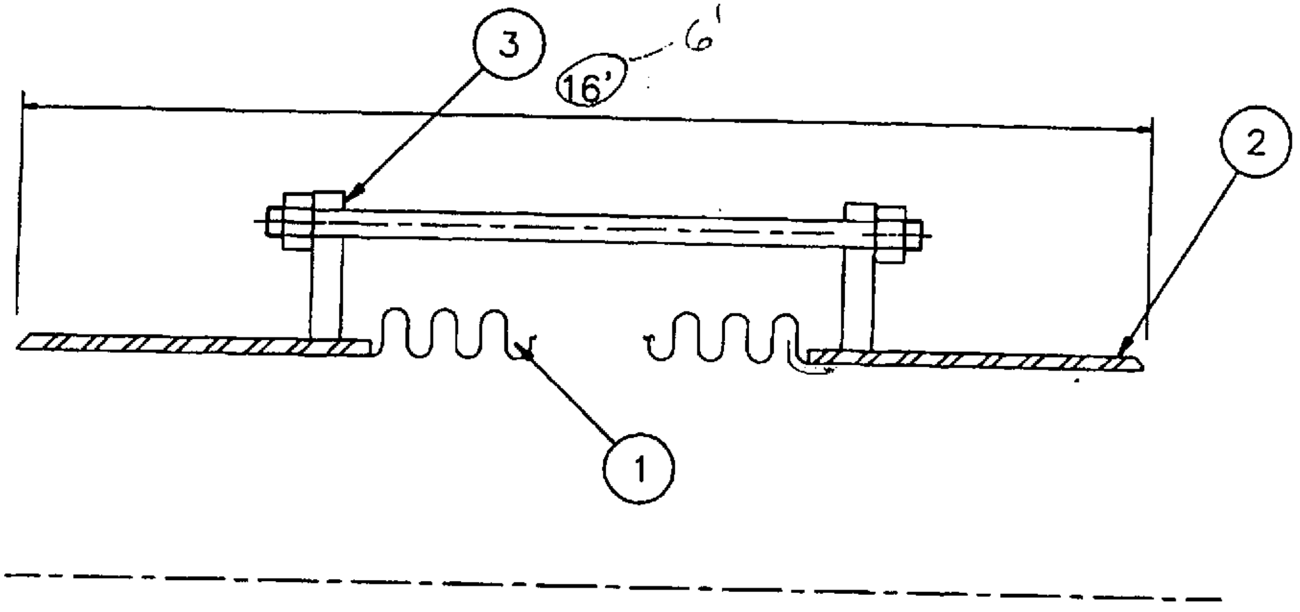


F = 29.5K
(ASSUMES [illegible])

ATTACHMENT

THE FOLLOWING SHEETS ARE PRELIMINARY SKETCHES AND DESIGN CALCULATIONS FOR BELLOWS BY SENIOR FLEXONICS, INC.

THE PRESSURE AREA, EA, IS GIVEN FOR EACH SIZE BELLOWS.



NOTES:
1) BUILT TO EJMA STANDARD
2) VISUAL INSPECTION FOR BELLOWS
3) VACUUM TEST IS NOT INCLUDED ON BID
–
–

P/N	QTY.	DESCRIPTION	MATERIAL
9			
8			
7			
6	—	—	—
5	—	—	—
4	—	—	—
3	4	BELLOWS ADJUSTMENT RODS 3/4"ø	A479–304L
2	2	WELD ENDS 48"ø 1/4" THK	A240–304L
1	1	BELLOWS 48"ø 1–PLY 20Ga	A240–304L

No. Req'd. 18

GENERAL SPECIFICATIONS	
DESIGN PRESS.	15 PSIG/FV
DESIGN TEMP.	347F
SERVICE	–
EFF. AREA	1983 in. sq
EXPANSION	–
COMPRESSION	1 3/4"
LATERAL OFFSET	–
ANGULAR ROT.	–
TEST PRESSURE	SOAP & AIR
WEIGHT	182 LBS.

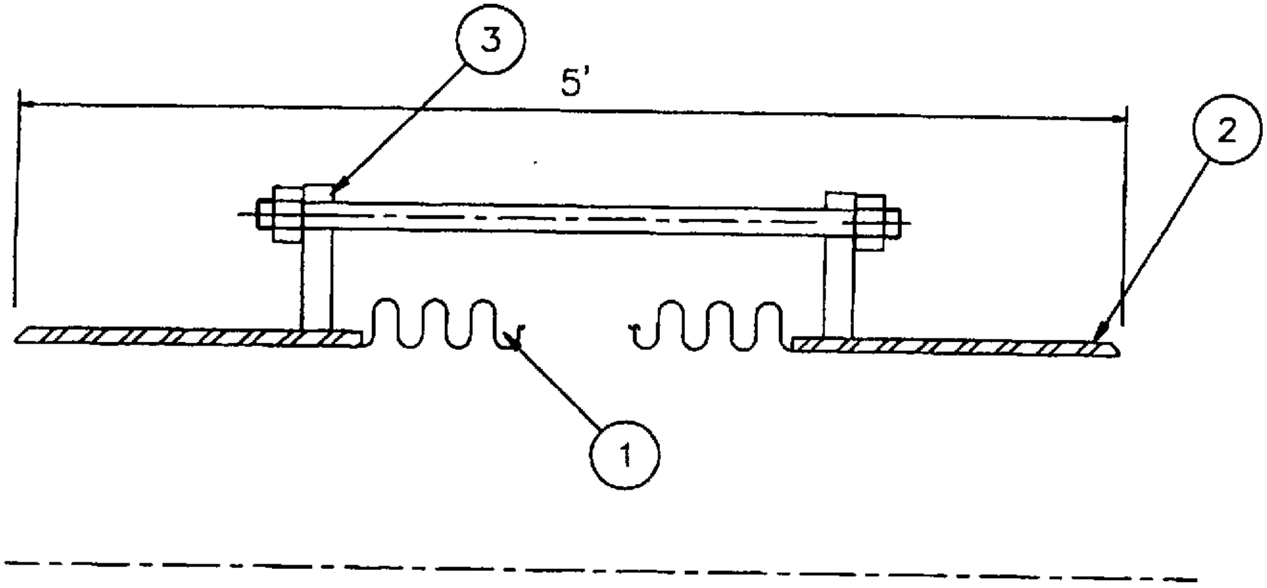
THIS DESIGN IS THE PROPERTY OF FLEXONICS THE REPRODUCTION, MANUFACTURE OR USE OF ANY ASSEMBLY, SUB-ASSEMBLY OR PART IS PERMITTED ONLY IF AUTHORIZED BY FLEXONICS.

SENIOR FLEXONICS INC.
EXPANSION JOINT DIVISION
New Braunfels, TX

CUSTOMER
PROCESS SYSTEMS

TITLE 48in BELLOWS
–

DRAWN BY:	QUOTE NO.:	REV.
LDC	5/26/LC	
DATE: 5/26/95	SK. NO.: C	0



NOTES:
1) BUILT TO EJMA STANDARD
2) VISUAL INSPECTION FOR BELLOWS
3) VACUUM TEST IS NOT INCLUDED ON BID
–
–

No. Req'd. 26

P/N	QTY.	DESCRIPTION	MATERIAL
9			
8			
7			
6	–	–	–
5	–	–	–
4	–	–	–
3	4	BELLOWS ADJUSTMENT RODS 3/4"ø	A479–304L
2	2	WELD ENDS 60"ø 1/4" THK	A240–304L
1	1	BELLOWS 60"ø 1-PLY 20Ga	A240–304L

GENERAL SPECIFICATIONS	
DESIGN PRESS.	15 PSIG/FV
DESIGN TEMP.	347°F
SERVICE	–
EFF. AREA	3043 in sq
EXPANSION	–
COMPRESSION	1 3/4"
LATERAL OFFSET	–
ANGULAR ROT.	–
TEST PRESSURE	SOAP & AIR
WEIGHT	225 LBS.

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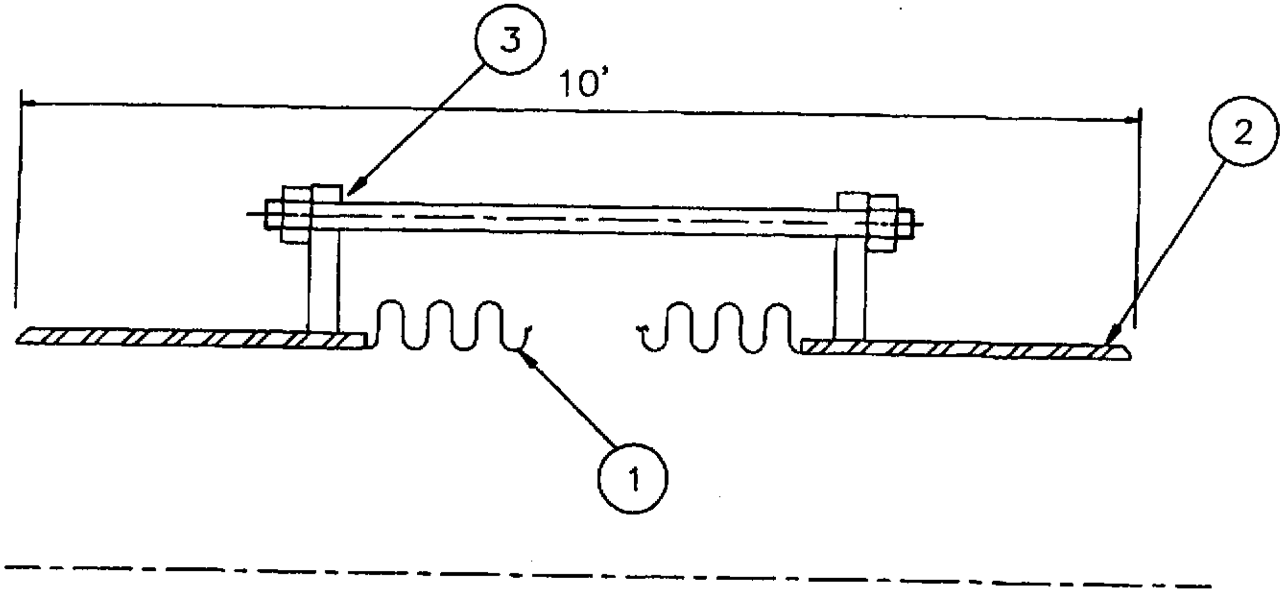
SENIOR FLEXONICS INC.
EXPANSION JOINT DIVISION
New Braunfels, TX

CUSTOMER
PROCESS SYSTEMS

TITLE 60in BELLOWS
–

DRAWN BY:	QUOTE NO.:	REV.
LDC	5/26/LC	
DATE: 5/26/95	SK. NO.: 8	0



NOTES:
1) BUILT TO EJMA STANDARD
2) VISUAL INSPECTION FOR BELLOWS
3) VACUUM TEST IS NOT INCLUDED ON BID
–
–

No. Req'd. 18

P/N	QTY.	DESCRIPTION	MATERIAL
9			
8			
7			
6	–	–	–
5	–	–	–
4	–	–	–
3	4	BELLOWS ADJUSTMENT RODS 3/4"ø	A479–304L
2	2	WELD ENDS 72"ø 1/4" THK	A240–304L
1	1	BELLOWS 72"ø 1–PLY 20Ga	A240–304L

GENERAL SPECIFICATIONS	
DESIGN PRESS.	15 PSIG/FV
DESIGN TEMP.	347F
SERVICE	–
EFF. AREA	230 in. sq
EXPANSION	–
COMPRESSION	1 3/4"
LATERAL OFFSET	–
ANGULAR ROT.	–
TEST PRESSURE	SOAP & AIR
WEIGHT	250 LBS.

THIS DESIGN IS THE PROPERTY OF FLEXONICS THE REPRODUCTION, MANUFACTURE OR USE OF ANY ASSEMBLY, SUB–ASSEMBLY OR PART IS PERMITTED ONLY IF AUTHORIZED BY FLEXONICS.

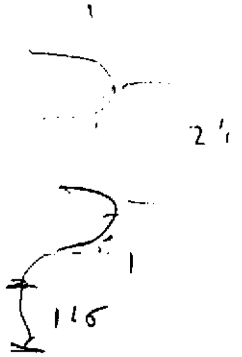
SENIOR FLEXONICS INC.
EXPANSION JOINT DIVISION
New Braunfels, TX

CUSTOMER
PROCESS SYSTEMS

TITLE 72in BELLOWS
–

DRAWN BY:	QUOTE NO.:	REV.
LDC	5/26/LC	
DATE: 5/26/95	SK. NO.: A	0

```
                    SENIOR FLEXONICS
                    CIRCULAR  BELLOWS
                  (UNREINFORCED SINGLE)
BD
CUSTOMER:  PROCESS SYSTEMS
JOB #:
DATE :      5/25/95                       20ga.       48in E.J.
                                                      RUN BY: LDC
INPUTED DATA
 1) Db = I.D. OF BELLOWS       = 48         in        MATERIAL INFORMATION
 2) n  = NUMBER OF PLIES       = 1                    BELLOWS MATERIAL SECT. VIII
 3) t  = NOM. THK. OF 1 PLY    = .0359      in        SA240-304
 4) q  = CONVOLUTION PITCH     = 2.         in        C-Mod. of E.= 2.83E+07
 5) w  = CONV HEIGHT (or OD)   = 2.25       in        H-Mod. of E.= 2.6865E+07
 6) N  = NO. OF CONVOLUTIONS   = 2.                   Sa= 16412 psi
 7) P  = PRESSURE              = 15         psig
 8) T  = TEMPERATURE           = 347        deg F
 9) Lt = LENGTH TANGENT        = 1.5        in
10) tc = THICKNESS OF COLLAR   = 0          in
11) Lc = LENGTH COLLAR         = 0          in
12) Ee = AXIAL EXTENSION       = 0          in
13) Ec = AXIAL COMPRESSION     = 1.5        in
14) Y+ = +'ve LATERAL OFFSET   = 0          in
15) Y- = -'ve LATERAL OFFSET   = 0          in
16) AN = ANGULAR ROTATION      = 0          deg
```



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                             RESULTS

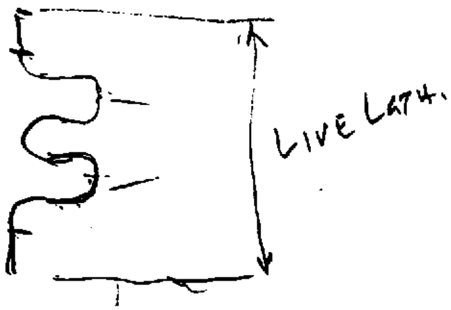
SPRING RATES                                           STRESSES  EJMA
THEORETICAL SPRING RATE =  2,979.37  lbf/in            S1   = 7644        psi
WORKING SPRING RATE     =  1,604.44  lbf/in            S1'  = N/A
LATERAL SPRING RATE     = 6.077E+05  lbf/in            S2   = 3804        psi
LATERAL MOMENT RATE     = 1.215E+06  in-lbs/in         S2'  =N/A
ANGULAR MOMENT RATE     =  8,838.58  in-lbs/deg        S2''=N/A
TORSION MOMENT RATE     = 3.955E+07  in-lbs/deg        S3   = 480.5       psi
                                                       S4(.35)= 7007      psi
MOVEMENTS                              in/conv.        S5   = 784.7       psi
CONVOLUTION GAP                     =  0.96410         S6   = 140900      psi
COMPRESION DUE TO AXIAL MOVEMENT    =  0.75000         ST   = 156000      psi
EXTENSION DUE TO AXIAL MOVEMENT     =  0.00000
AXIAL DISP. DUE TO LATERAL OFFSET   =  0.00000         EJMA FACTORS
AXIAL DISP. DUE TO ANG. ROTATION    =  0.00000         Cp = .6501
MAX. EQUIVALENT AXIAL COMPRESSION   =  0.75000         Cf = 1.463
MAX. EQUIVALENT AXIAL EXTENSION     =  0.00000         Cd = 1.74
MAX. EQUIVALENT AXIAL MOVEMENT      =  0.75000         Cr = N/A
OTHER DATA                                             Ct = 1  0
CYCLE LIFE                       =  19,316   cycles    EA =  1983         in^2
SQUIRM PRESSURE COLD /2.25 = 838             psig      Wt.= 17.34         lbs.
SQUIRM PRESSURE HOT / 2.25 = 795.5           psig      LCW= N/A
EQUIV. PIPE WALL THICKNESS = .8706           in
```

```
                SENIOR FLEXONICS
                CIRCULAR  BELLOWS
               (UNREINFORCED SINGLE)

BD
CUSTOMER:  PROCESS SYSTEMS
JOB #:
DATE :      5/25/95
                                                60in E.J.
                                                RUN BY: LDC

INPUTED DATA
 1) Db = I.D. OF BELLOWS        = 60       in
 2) n  = NUMBER OF PLIES        = 1
 3) t  = NOM. THK. OF 1 PLY     = .0359    in
 4) q  = CONVOLUTION PITCH      = 2        in
 5) w  = CONV HEIGHT (or OD)    = 2.25     in
 6) N  = NO. OF CONVOLUTIONS    = 2
 7) P  = PRESSURE               = 15       psig
 8) T  = TEMPERATURE            = 347      deg F
 9) Lt = LENGTH TANGENT         = 1.5      in
10) tc = THICKNESS OF COLLAR    = 0        in
11) Lc = LENGTH COLLAR          = 0        in
12) Ee = AXIAL EXTENSION        = 0        in
13) Ec = AXIAL COMPRESSION      = 1.5      in
14) Y+ = +'ve LATERAL OFFSET    = 0        in
15) Y- = -'ve LATERAL OFFSET    = 0        in
16) AN = ANGULAR ROTATION       = 0        deg
```

```
MATERIAL INFORMATION
BELLOWS MATERIAL SECT. VIII
SA240-304
C-Mod. of E.= 2.83E+07
H-Mod. of E.= 2.6865E+07
Sa= 16412 psi
```



```
                          RESULTS

SPRING RATES
THEORETICAL SPRING RATE =   3,633.83   lbf/in
WORKING SPRING RATE     =   1,945.34   lbf/in
LATERAL SPRING RATE     = 1.131E+06    lbf/in
LATERAL MOMENT RATE     = 2.261E+06    in-lbs/in
ANGULAR MOMENT RATE     = 16,446.06    in-lbs/deg
TORSION MOMENT RATE     = 7.717E+07    in-lbs/deg
```

EFL

WEIGHT.

```
MOVEMENTS                                  in/conv.
CONVOLUTION GAP                          =  0.96410
COMPRESION DUE TO AXIAL MOVEMENT         =  0.75000
EXTENSION DUE TO AXIAL MOVEMENT          =  0.00000
AXIAL DISP. DUE TO LATERAL OFFSET        =  0.00000
AXIAL DISP. DUE TO ANG. ROTATION         =  0.00000
MAX. EQUIVALENT AXIAL COMPRESSION        =  0.75000
MAX. EQUIVALENT AXIAL EXTENSION          =  0.00000
MAX. EQUIVALENT AXIAL MOVEMENT           =  0.75000
OTHER DATA
CYCLE LIFE                     =  16,408     cycles
SQUIRM PRESSURE COLD /2.25 = 1022            psig
SQUIRM PRESSURE HOT / 2.25 = 970.3           psig
EQUIV. PIPE WALL THICKNESS = .8706           in
```

SAME "I" as EQUAL LGTH. OF PIPE.

```
STRESSES  EJMA
S1    = 8545        psi
S1'   = N/A
S2    = 4692        psi
S2'  =N/A
S2''=N/A
S3    = 478.5       psi
S4(.35)= 7160       psi
S5    = 769.2       psi
S6    = 145600      psi
ST    = 161100      psi

EJMA FACTORS
Cp = .6701
Cf = 1.506
Cd = 1.691
Cr = N/A
Ct = 1  0
EA =  3043          in^2
Wt.= 21.67          lbs.
LCW= N/A
```

```
                          SENIOR FLEXONICS
                          CIRCULAR  BELLOWS
                        (UNREINFORCED SINGLE)

BD
CUSTOMER:  PROCESS SYSTEMS
JOB #:
DATE :      5/25/95                                    72in E.J.
                                                       RUN BY: LDC

INPUTED DATA                                           MATERIAL INFORMATION
 1) Db = I.D. OF BELLOWS        = 72      in           BELLOWS MATERIAL SECT. VIII
 2) n  = NUMBER OF PLIES        = 1                    SA240-304
 3) t  = NOM. THK. OF 1 PLY     = .0359   in           C-Mod. of E.= 2.83E+07
 4) q  = CONVOLUTION PITCH      = 2       in           H-Mod. of E.= 2.6865E+07
 5) w  = CONV HEIGHT (or OD)    = 2.25    in           Sa= 16412 psi
 6) N  = NO. OF CONVOLUTIONS    = 2
 7) P  = PRESSURE               = 15      psig
 8) T  = TEMPERATURE            = 347     deg F
 9) Lt = LENGTH TANGENT         = 1.5     in
10) tc = THICKNESS OF COLLAR    = 0       in
11) Lc = LENGTH COLLAR          = 0       in
12) Ee = AXIAL EXTENSION        = 0       in
13) Ec = AXIAL COMPRESSION      = 1.5     in
14) Y+ = +'ve LATERAL OFFSET    = 0       in
15) Y- = -'ve LATERAL OFFSET    = 0       in
16) AN = ANGULAR ROTATION       = 0       deg


                              RESULTS

SPRING RATES                                                STRESSES  EJMA
THEORETICAL SPRING RATE =   4,290.03   lbf/in               S1   = 9360       psi
WORKING SPRING RATE     =   2,289.71   lbf/in               S1'  = N/A
LATERAL SPRING RATE     = 1.893E+06    lbf/in               S2   = 5581       psi
LATERAL MOMENT RATE     = 3.787E+06    in-lbs/in            S2'  =N/A
ANGULAR MOMENT RATE     = 27,539.77    in-lbs/deg           S2''=N/A
TORSION MOMENT RATE     = 1.333E+08    in-lbs/deg           S3   = 477.1      psi
                                                            S4(.35)= 7215     psi
MOVEMENTS                                 in/conv.          S5   = 759.1      psi
CONVOLUTION GAP                        =  0.96410           S6   = 147900     psi
COMPRESION DUE TO AXIAL MOVEMENT       =  0.75000           ST   = 163400     psi
EXTENSION DUE TO AXIAL MOVEMENT        =  0.00000
AXIAL DISP. DUE TO LATERAL OFFSET      =  0.00000           EJMA FACTORS
AXIAL DISP. DUE TO ANG. ROTATION       =  0.00000           Cp = .6792
MAX. EQUIVALENT AXIAL COMPRESSION      =  0.75000           Cf = 1.535
MAX. EQUIVALENT AXIAL EXTENSION        =  0.00000           Cd = 1.67
MAX. EQUIVALENT AXIAL MOVEMENT         =  0.75000           Cr = N/A
OTHER DATA                                                  Ct = 1  0
CYCLE LIFE                     =  15,230   cycles           EA =  4330        in^2
SQUIRM PRESSURE COLD /2.25 = 1206          psig             Wt.= 26           lbs.
SQUIRM PRESSURE HOT / 2.25 = 1145          psig             LCW= N/A
EQUIV. PIPE WALL THICKNESS = .8706         in
```

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-042
PAGE 1 OF 37

REV.	DEO #	DATE	BY:	CHECK
0	[illegible]	4/25/96	RDC	AGA

Bolted Flange Analysis For Tensile Forces

BY:
DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. Analyze and evaluate flanges and bolts for large tensile forces resulting from normal operation from venting of parts of systems when gate valves are closed.

METHOD: Hand calculations for forces using statics analysis.
Finite element analysis of bolted flange using IMAGES program.

ASSUMPTIONS:

INPUTS: 1. Positive purge pressure = 2 psig.
2. Atmospheric pressure = 14.7 psig.
3. Component interface loads.

REFERENCES: 1. IMAGES - 3D, Version 3.0, R.L. Cloud and Associates.
2. Calc V049-1-032, Component Interface Loads

CALCULATIONS: (SEE ATTACHED)
Appendix A: Confirmatory Hand Calculations
Appendix B: Analysis of Bolt Prying
Appendix C: Test Pressure to Observe Flange Behavior Under Tension

CONCLUSIONS: The 30 1/4 in. flange has the maximum bolt force. The number of bolts is increased to 24 for this flange and the bolt preload is increased to 10,000 lb for all flanges.

NOTES: Computer file: FLANGEC.*

SINCE ALL FLANGES HAVE THE SAME THICKNESS AND CROSS-SECTION, EACH DIAMETER FLANGE WILL BE REVISITED TO FIND THE MAXIMUM BOLT TENSILE FORCE.

REF: CALC V049-1-032 FOR COMPONENT INTERFACE LOADS

104 IN FLANGES (IN. BSCs)

THESE ARE NOT AFFECTED BY VALVE OPERATION, THE ONLY TENSILE FORCE OCCURS FROM 2 PSI PURGE PRESSURE ANALYZED IN CALC 19.

54 IN FLANGES (HAM COVERS)

SAME AS 104 IN FLANGE NOT AFFECTED BY VALVE OPERATION

72 1/4 IN FLANGE

THESE ARE LOCATED IN THE BEAM TUBE MANIFOLDS AND IN OTHER ADAPTERS. VALVE AT END OF BEAM TUBE MANIFOLD WILL CAUSE LARGE TENSILE LOAD IN FLANGE WHEN THE BEAM TUBE MANIFOLD IS VENTED. A 2 PSI INTERNAL PURGE PRESSURE WILL ADD TO THE TENSILE FORCE

72 1/4 IN CONT.

DWG V049-5-003 SHOWS SPOOL A2 w/ UNBALANCED VALVE FORCE WHEN SYSTEM IS VENTED ON 1 SIDE OF VALVE.*

$G = 76''$ CALC-019, P.10

$$F = 23.44 + \pi \frac{76^2}{4} \left(\frac{2}{1000}\right) = 32.76^K$$

↑ 2 PSI PURGE

PER BOLT

$$N = 36$$

$$F_b = \frac{32.76}{36} = .91^K$$

BOLT CIRCLE DIAM

$$D_b = 77.75''$$ REF p.8 OF CALC -019

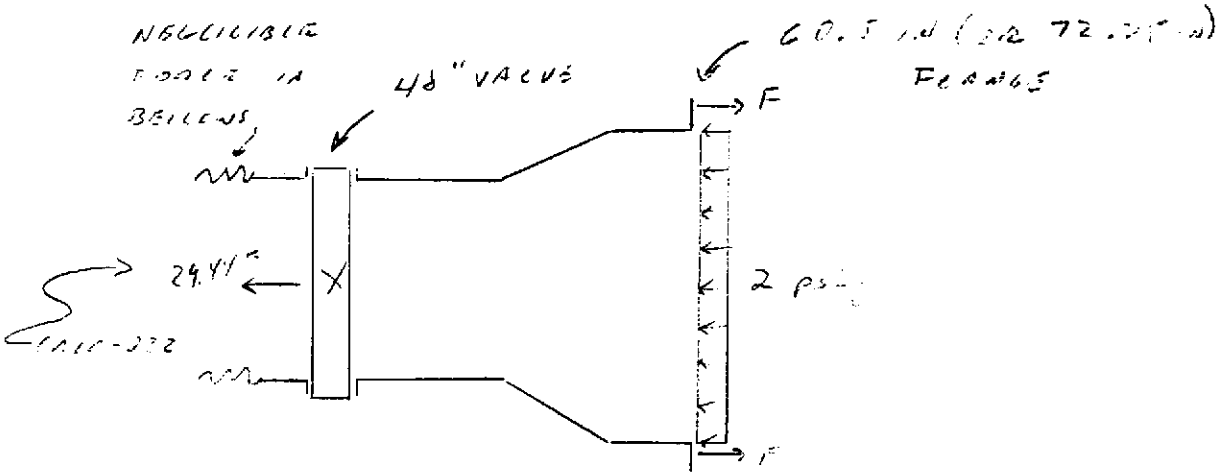
SPACING $$s = \frac{\pi D_b}{36} = 6.78 \text{ IN}$$

FORCE PER IN $$f = \frac{.91}{6.78} = 135 \text{ LB/IN}$$

*SEE SKETCH ON FOLLOWING SHEET FOR 60 1/2 IN FLANGE. FORCE DIAGRAM IS SIMILAR.

60 1/2 IN FLANGES

THE ONLY FLANGES OF THIS SIZE THAT ARE SUBJECTED TO TENSILE FORCES ARE THOSE IN PORTS OF BSCs 7 AND 8 OF THE WASHINGTON CORNER STATION (SEE CALC V049-1-032). IN ADDITION TO THE 29.44K VACUUM FORCE, WHICH OCCURS WHEN THE VALVE IS CLOSED AND THE BSC IS VENTED, A 2 PSIG PURGE PRESSURE WILL INCREASE THE FLANGE FORCE



GASKET DIAM FOR 60.5 IN FLANGE IS 64 IN

$$F = 29.44 + \pi \frac{64^2}{4}(2)\left(\frac{1}{1000}\right) = 35.9^K$$

THIS FLANGE HAS 30 BOLTS, FORCE PER BOLT IS

$$F_B = \frac{35.9}{30} = 1.20^K$$

SPACING

$$s = \frac{\pi D_b}{30}$$

D_b = BOLT CIRCLE DIAM

= 65.75 REF P.12 CALC
V049-1-019

$$S = \frac{\pi (65.75)}{30}$$

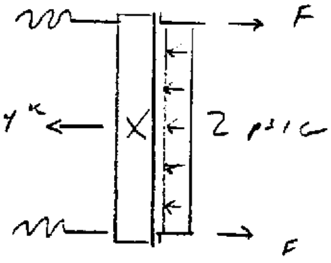
$$= 6.89 \text{ IN}$$

FORCE PER IN OF CIRCUMFERENCE

$$f = \frac{1.20}{6.89} = 174 \text{ lb/in}$$

48 1/4 IN FLANGE

THE MAXIMUM FLANGE FORCE DUE TO [illegible]
IS 29.44 K (CALC 032)



$$F = 29.44 + \pi \frac{\overset{\text{GASKET DIAM. *}}{52^2}}{4} \frac{2}{1000} = 33.7 \text{ K}$$

FOR 24 BOLTS

$$F_B = \frac{33.7}{24} = 1.40 \text{ K PER BOLT}$$

* REF P.16 CALC V049-1-019

SPACING

$$S = \frac{\pi C}{24}$$

$C = 53.75$ CALC 019, P. 15

$$S = \frac{\pi (53.75)}{24}$$

$= 7.04$ IN

FORCE PER IN

$$f = \frac{1.40}{7.04} = .199 K = 199 \text{ LB/IN}$$

44.63 IN FLANGE

℄ FROM CALC 019, P. 19

$$F = 25.37 + \pi \frac{44^2}{4} \left(\frac{2}{1000} \right)$$

$= 29.0 K$

$$F_B = \frac{29}{24} = 1.21 K$$

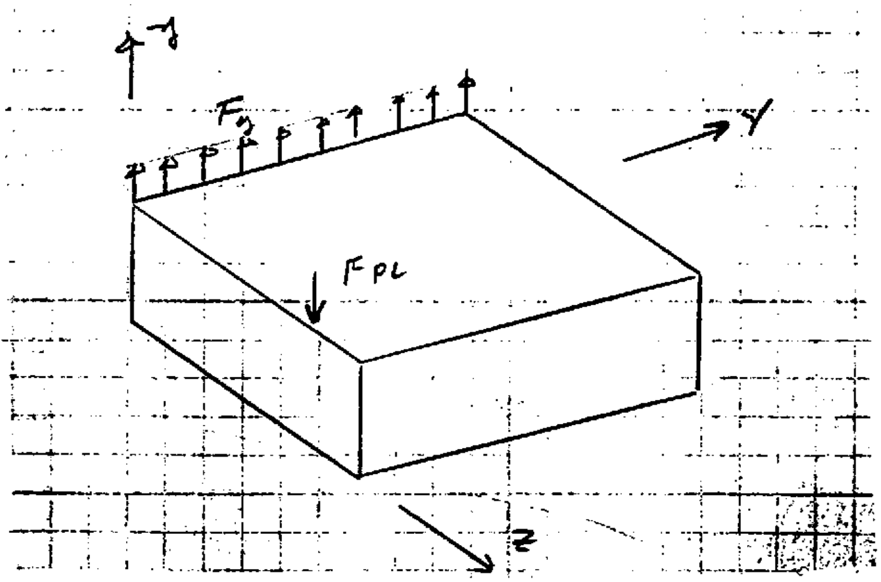
$$S = \frac{\pi (49.75)}{24} = 6.51$$

$$f = \frac{1.21}{6.51} = .186 = 186 \text{ LB/IN}$$

THE 48 1/4 IN FLANGE HAS THE MAX BOLT FORCE (1.40 K)* AND THE MAX FORCE PER IN OF CIRCUMFERENCE (159 LB/IN).

THIS FLANGE WILL BE ANALYZED USING THE MODEL GENERATED IN CALC V049.1-017. FILE FLANGEA.* OF CALC 017 WAS COPIED TO FLANGEC.* FOR THIS ANALYSIS.

NODAL FORCE AT SHELL



FROM CALC 017, P.2

$$F_y = 52.1 \text{ LB/IN} \quad \& \quad F_{yi} = 13.4 \text{ LB}$$

AT INTERIOR NODES

$$F_{yi} = 13.4 \left(\frac{159}{52.1}\right) = 51.2 \text{ LB}$$

@ NODES 1366 TO 1546, INC = 15

* SEE LATER SHEETS FOR ANALYSIS OF 30 1/4 IN FLANGE

$$F_y = 6.7\left(\frac{199}{52.1}\right) = 25.6 \text{ LB}$$

NODES 1351 & 1561

IN FLANGEL FILE

PRELOAD

F_{PL} = 8500 LB PER BOLT

OR F_{PL} = 8500/2 = 4250 FOR 1/2 BOLT

$$F_{yi} = -375 \times \frac{4250}{6000} \leftarrow \text{CALC 17, P. 3}$$

$$= -266 \text{ LB}$$

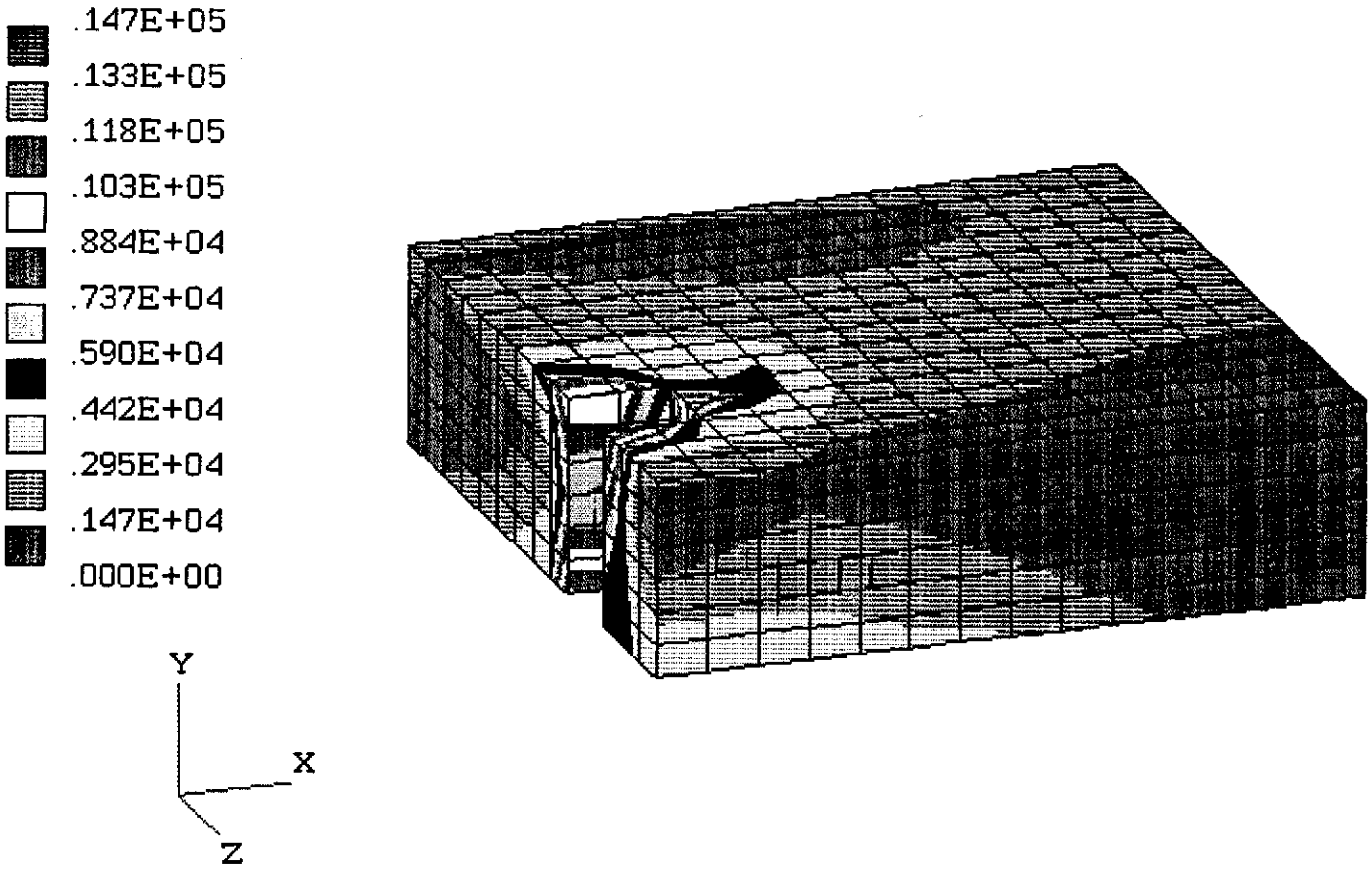
@ NODES 1374, 1375, 1377, 1378,
1389 TO 1393
1414 TO 1408

$$F_y = \frac{-266}{2} = -133 \text{ LB}$$

@ NODES 1358, 1360, 1362, 1313

IMAGES-3D
Version 3.0

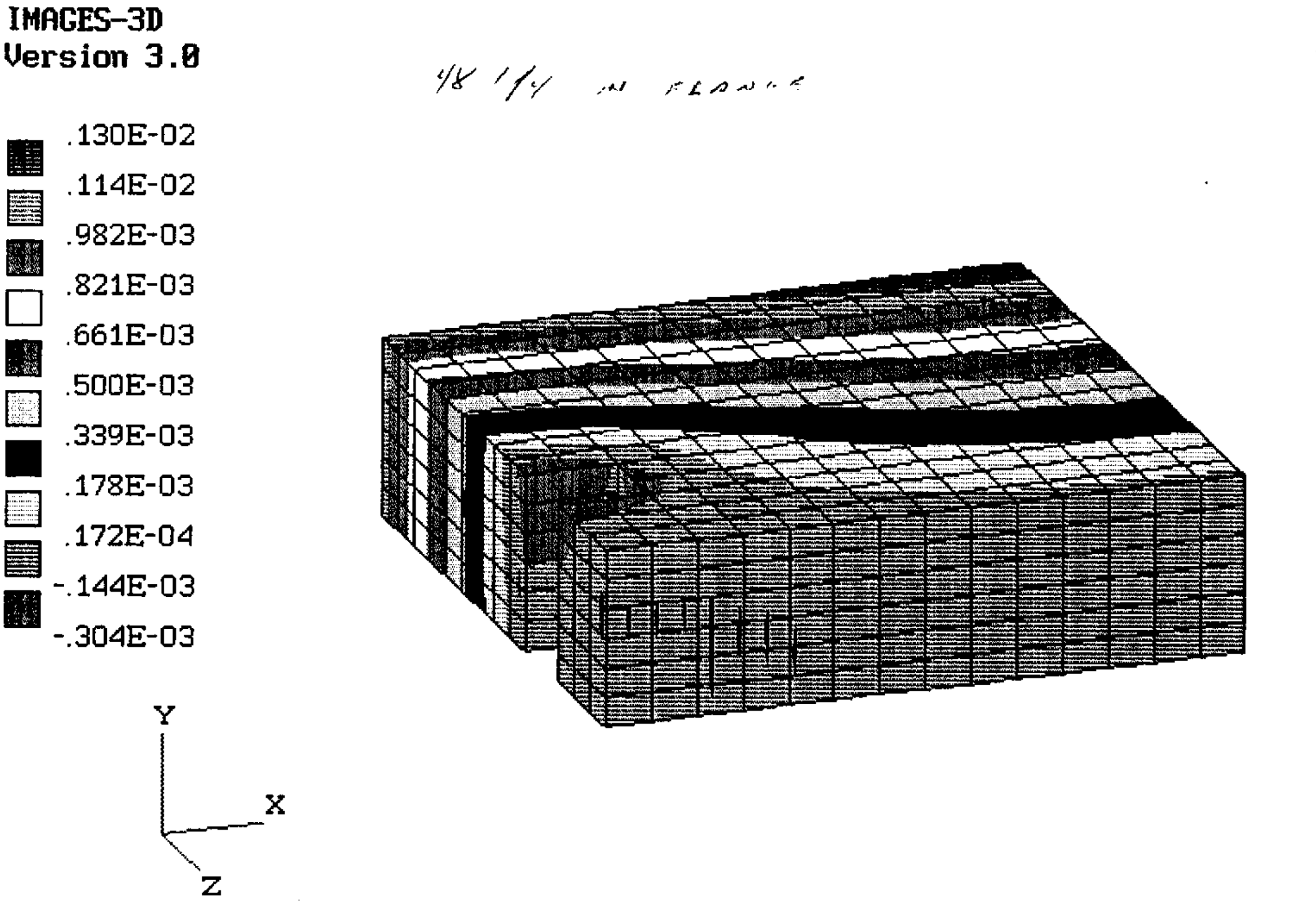
48 1/4 IN FLANGE



Load Case
1

Stress Contour Plot
Stress Intensity

1/ 5/96
7:51: 9



48 1/4 in flange

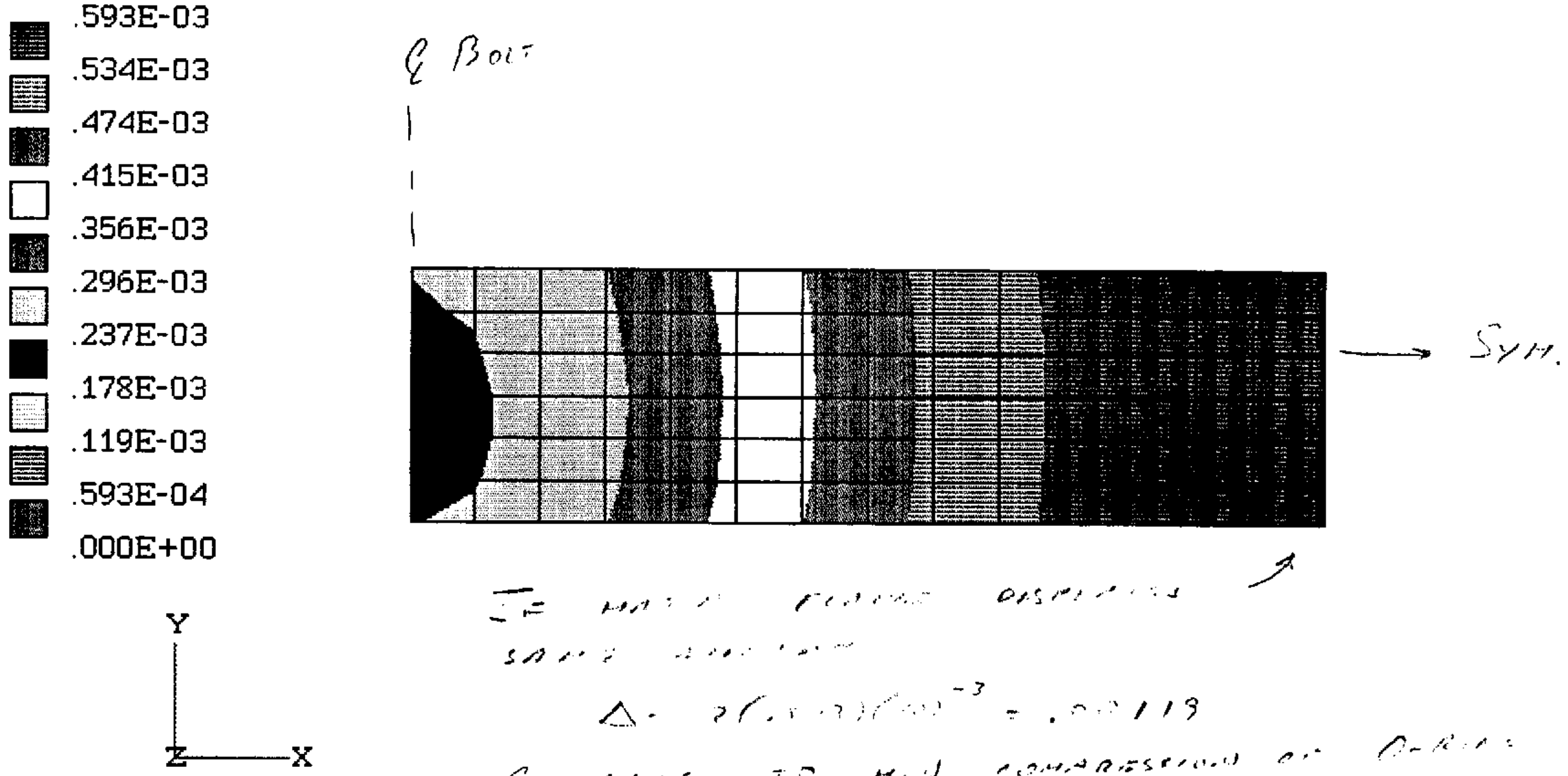
Load Case
1

Displacement Contour Plot
DY

1/ 5/96
7:29:53

IMAGES-3D
Version 3.0

DISPLACEMENT AT INNER O-RING
48 IN ID FLANGE



IF MATING FLANGE DISPLACES SAME AMOUNT

$\Delta = 2(.593)(10)^{-3} = .00119$

COMPARE TO MIN COMPRESSION OF O-RING FROM PARKER HANDBOOK (.058 IN)

RATIO = $\frac{.058}{.00119} = 49$

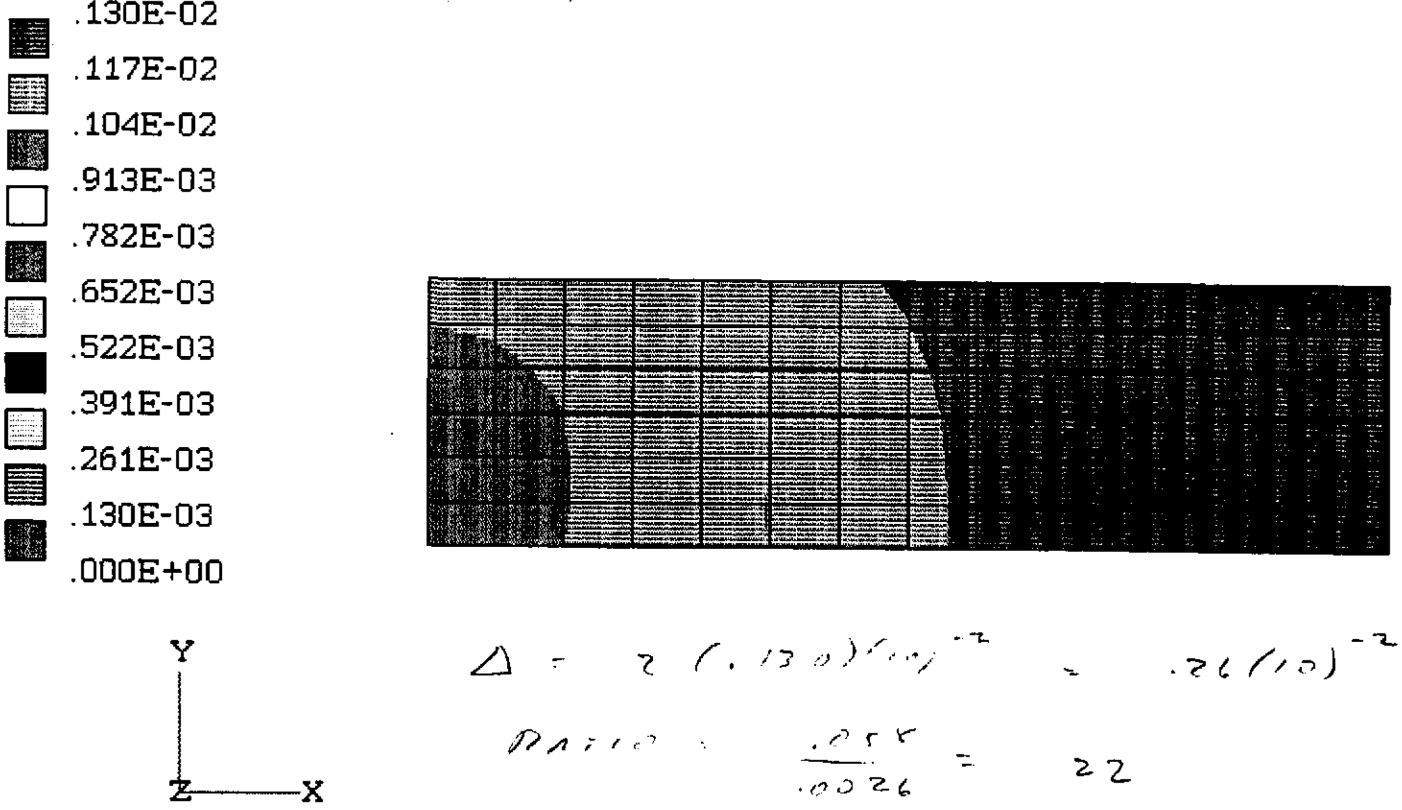
Load Case
1

Displacement Contour Plot
DY

1/ 5/96
7:34:52

IMAGES-3D
Version 3.0

Displacements at Inner O-Ring
4K lbf in clamp =



$\Delta = 2(.130)(10)^{-2} = .26(10)^{-2}$

$\text{Ratio} = \frac{.058}{.0026} = 22$

Load Case
1

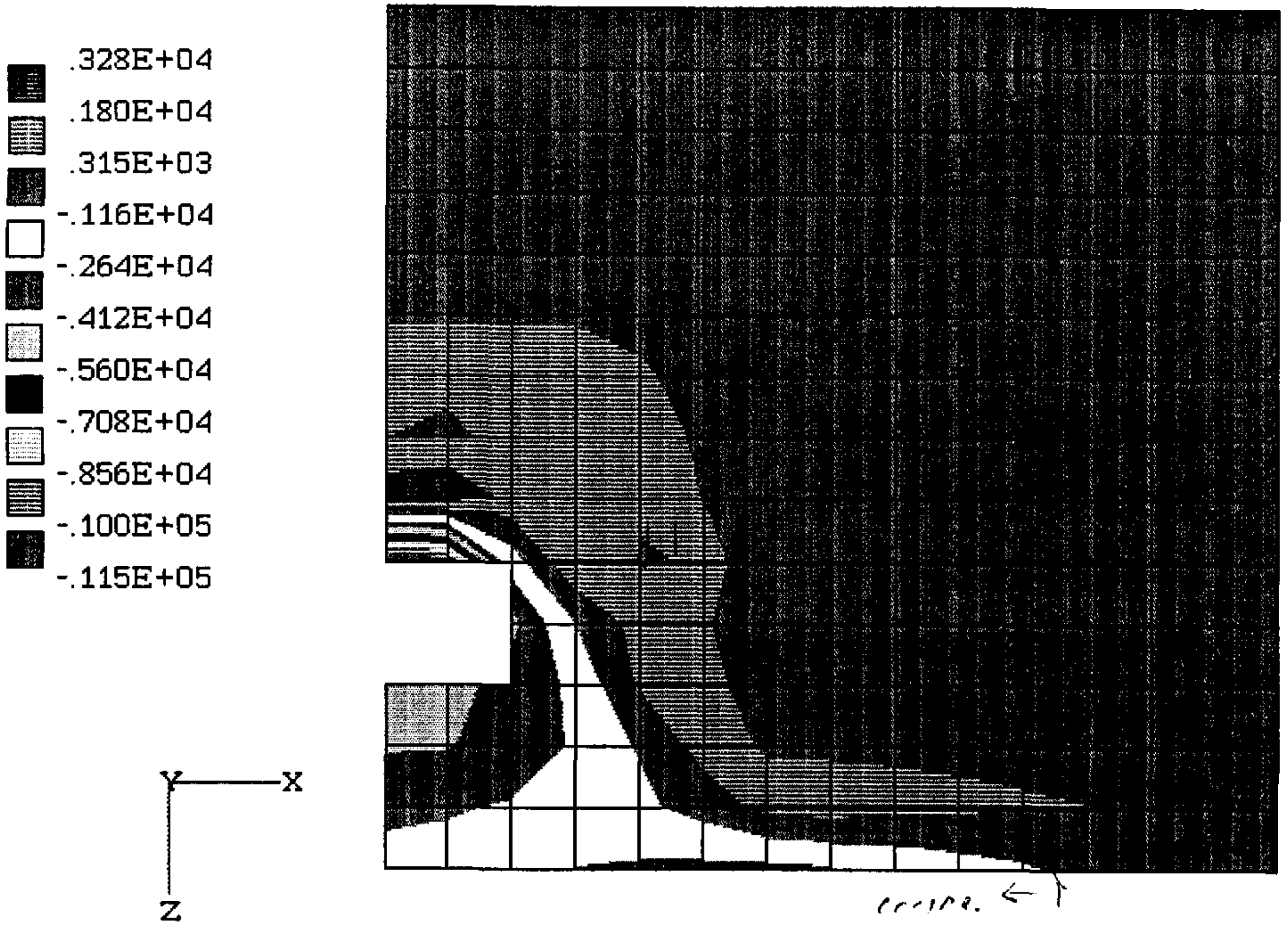
Displacement Contour Plot
DY

1/ 5/96
7:44:12

σ_y @ MATING SURFACE (Y=0)

48 1/4 IN FLANGE

IMAGES-3D
Version 3.0



COMPR. ←

Load Case
1

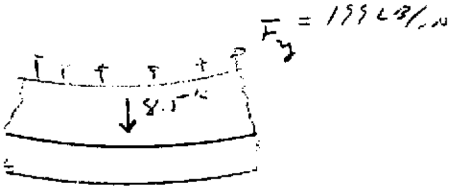
Stress Contour Plot
Gl St: S22

1/ 5/96
7:54:49

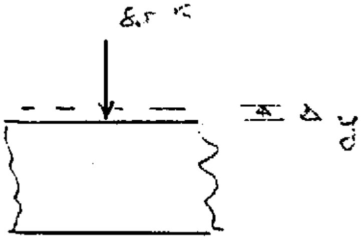
48 1/4 IN FLANGE CONT.

BOLT FORCE RESULTING FROM FLANGE DEFORMATION UNDER TENSILE LOAD

THE BOLT WILL BE PRELOADED TO 8500 LB WHICH WAS INPUT TO THE FLANGEC.+ IMAGES FILE. WHEN THE FLANGE IS LOADED IN TENSION FROM PRESSURE OR COMPONENT LOADS, THE FLANGE DEFORMS SLIGHTLY AND THE BOLT FORCE CHANGES. THE CHANGE CAN BE ESTIMATED CONSERVATIVELY BY ADDING THE AXIAL BOLT STRAIN FROM THE FLANGEC.+ OUTPUT TO THE PRELOAD STRAIN (STRESS).



FLANGE



DETAIL

Δ_y = DEFLECTION AT NUT FOR PRELOAD PLUS F_y, FROM DISPLACEMENT CONTOUR PLOT

$$\Delta_y = .172(10)^{-4} \text{ IN MAX}$$

FOR 1 IN FLANGE THICKNESS, STRAIN IS

$$\epsilon = \frac{\Delta_y}{1} = .172(10)^{-4}$$

BOLT STRESS

$$f_a = E\epsilon = 29(10)^6 \times .172(10)^{-4}$$

$$= 500 \text{ psi}$$

48 1/4 IN FLANGE AMT.

THE TENSILE STRESS AREA FOR THE BOLT IS .462 IN^2* FOR THE 7/8 IN BOLT, FINALLY IS

* REF AISC, P. 4-147

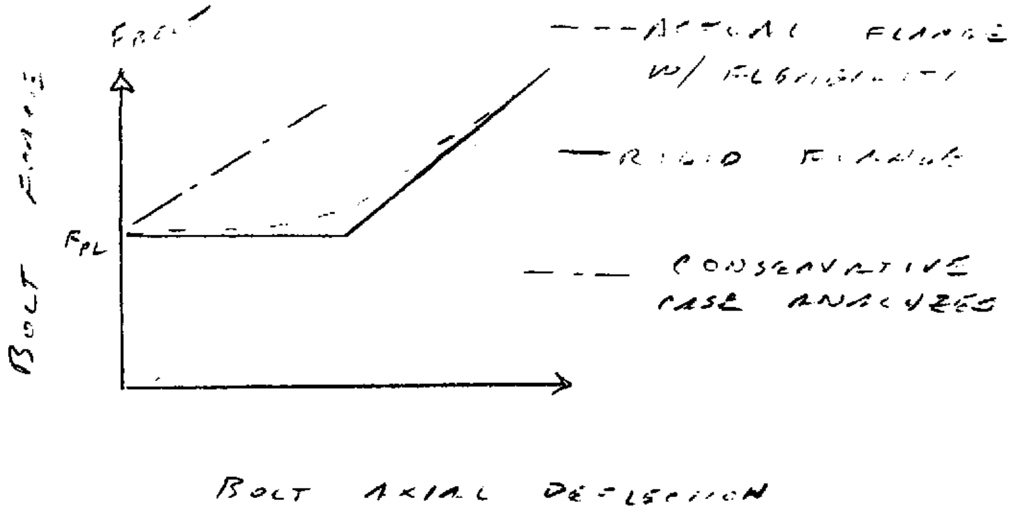
$$F = .462(500) = 230 \text{ LB}$$

TO OBTAIN A CONSERVATIVE BOLT STRESS, THE NOMINAL BOLT FORCE FROM THE TENSION, F_B, ON THE 48 1/4 IN FLANGE WILL BE ADDED TO THE PRELOAD

$$F_{TOTAL} = F_B + F_{PL}$$
$$= 1.72 + 8.50^K$$
$$= 10.22^K$$

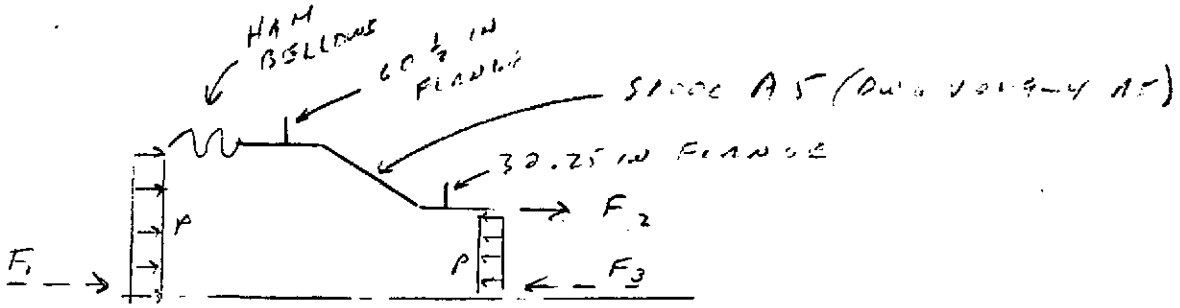
STRESS

$$f_t = \frac{10.22}{.462} = 22.1 \text{ KSI} < S = 25 \text{ KSI}$$
@ [illegible]°F
OK



30.25 IN FLANGES

FOR THE MODE CLEANER TUBES (SPOOL B-3, DWG V049-4-B3) THE 30.25 IN FLANGE IS UNDER TENSION DURING NORMAL OPERATION



$p = -14.7$ psi

F_1 = FORCE AT 60.5 IN TUBE

$= -45.46^K$ CALC -032, P. 4

F_2 = FLANGE FORCE (TBD)

$F_3 = pA$

$A = \pi r_o^2$

$r = \frac{G}{2} = \frac{34}{2} = 17$ G = GASKET DIA REF P. 22 OF CALC V049-1-019

$F_3 = -14.7 \pi (17)^2 = -13.35$ K

$F_1 + F_2 - F_3 = 0$

$F_2 = F_3 - F_1 = -13.35 - (-45.46)$

$= 32.11^K$

FOR F_3 USE INNER O-RING DIAMETER IN CASE OUTER O-RING LEAKS. THIS GIVES MAX. FLANGE FORCE F_2

$$F_3 = -14.7\pi\left(\frac{31}{2}\right)^2$$ ← DWG V049-4-016

$$= -11.10\ K$$

$$F_2 = -11.10 - (-45.46) = 34.36^K$$

FOR N = 20 BOLTS

$$F_B = \frac{34.36}{20} = 1.72^K \text{ PER BOLT}$$

SPACING

$$s = \frac{\pi C}{20}$$

$C = 36$* BOLT CIRCLE DIA - DWG V049-4-016

$S = 5.65$ IN

*ACTUAL CHANGES TO 35.75 - DOES NOT AFFECT FINAL RESULT

FORCE PER IN

$$f = \frac{F_B}{s}$$

$$= \frac{1.72}{5.65} = 304 \text{ LB/IN}$$

FORCE PER IN AT SHELL

$$d = 30.25$$

$$f = \frac{F_2}{\pi d}$$

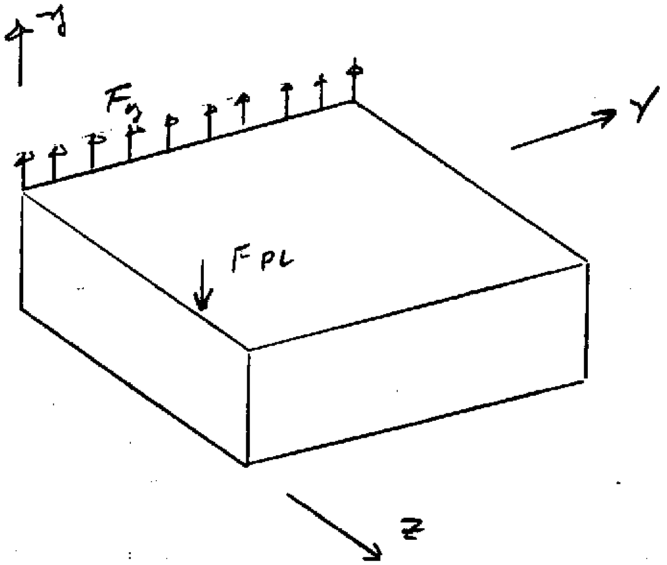
$$= 362 \text{ LB/IN}$$

30 1/4 IN FLANGE CALC

THE 30 1/4 IN FLANGE HAS THE MAX BOLT FORCE (1.72 K) AND THE MAX FORCE PER IN OF CIRCUMFERENCE (362 LB/IN) IN THE SHELL.

THIS FLANGE WILL BE ANALYZED USING THE FLANGE C,K MODEL

NODAL FORCE AT SHELL



FROM CALC 017, P.2

$$F_y = 52.1 \text{ LB/IN} \quad \& \quad F_{yi} = 13.4 \text{ LB}$$

AT INTERIOR NODES

$$F_{yi} = 13.4 \left(\frac{362}{52.1}\right) = 93.1 \text{ LB}$$

@ NODES 1366 TO 1546, INC = 15

30 1/4 IN FLANGE CONT

$$F_y = 6.7\left(\frac{362}{52.1}\right) = 46.6 \text{ LB}$$

NODES 1351 & 1561

IN FLANGE FILE

A PRELIMINARY RUN OF FLANGE SHOWED THAT IT IS NECESSARY TO INCREASE THE PAYLOAD TO 10000 LB FOR THE 30 1/4 IN FLANGE

CHANGE BOLT PRELOAD FROM 8500 TO 10000 LB FOR THE 30 IN FLANGE

$\frac{10}{8.5} = 1.176$ = FACTOR ON STUDS BOLT LOADS

REF. P. 8 THIS CALC

NODE	FORCE* FOR 8500 LB F_Y	FORCE FOR 10000 LB F_Y
1359	-133	-156
1360	-133	↓
1362	-133	
1363	-133	
1374	-266	-313
1375	-266	↓
1377	-266	
1378	-266	
1389	-266	
1390	-266	
1391	-266	
1392	-266	
1393	-266	
1404	-266	
1405	-266	
1406	-266	
1407	-266	
1408	-266	

* REF P. 6 OF THIS CALC

IMAGES-3D
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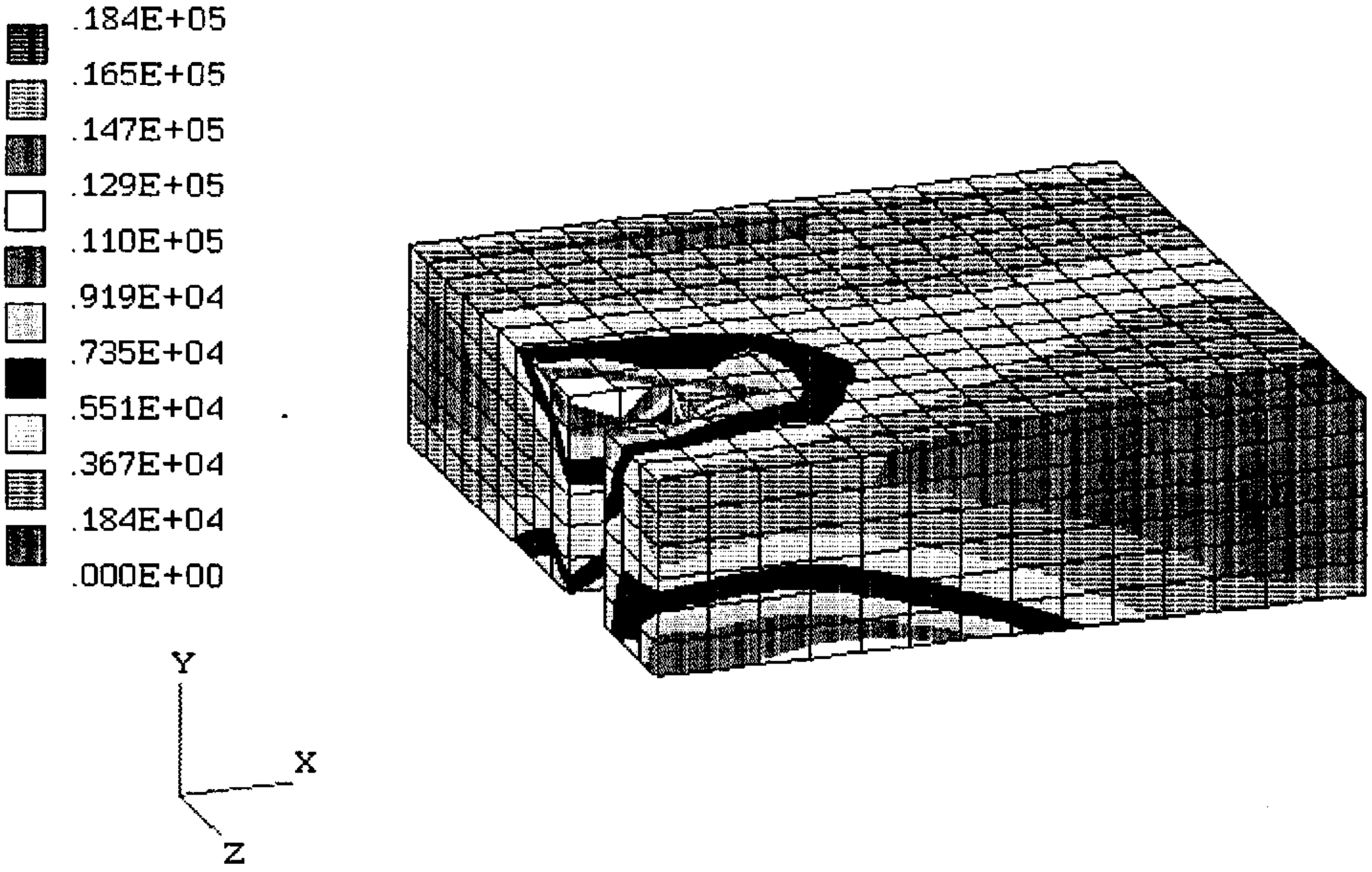
30 1/4 IN FLANGE



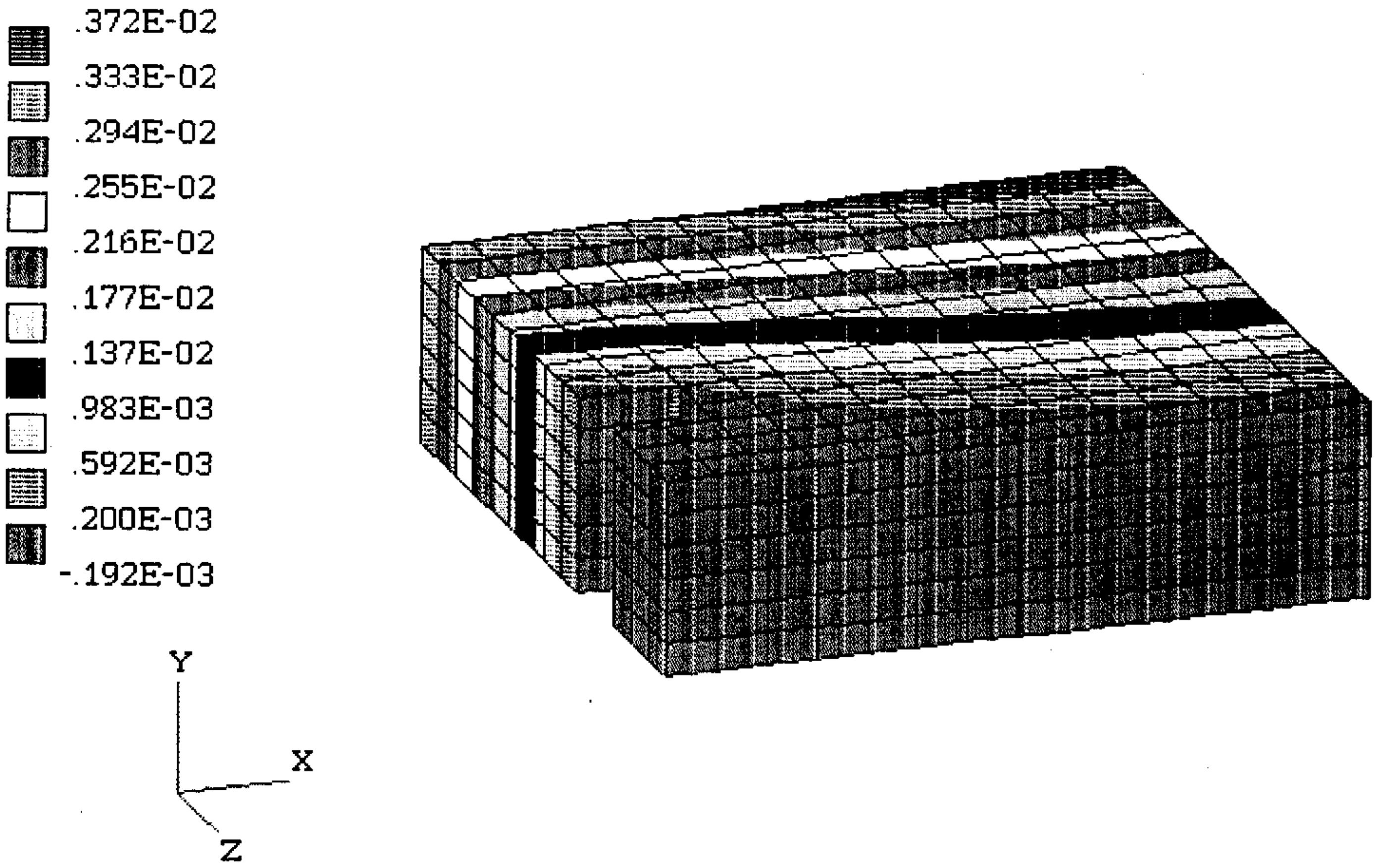
Load Case
1

Stress Contour Plot
Stress Intensity

2/ 2/96
9:13:50

IMAGES-3D
Version 3.0

30 1/4 in FLANGE



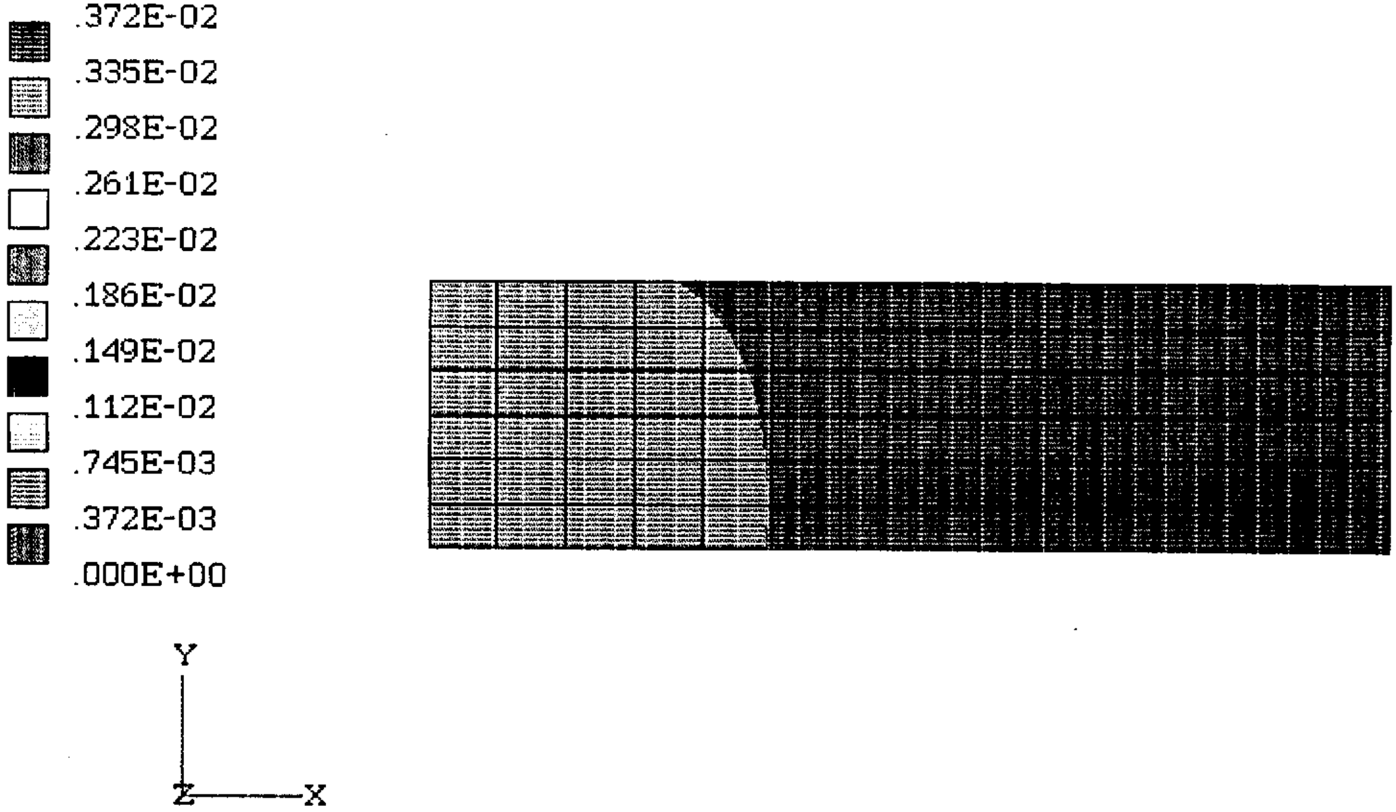
Load Case
1

Displacement Contour Plot
DY

2/ 2/96
9:17:45

IMAGES-3D
Version 3.0

30 1/4 IN FLANGE
DISPLACEMENT AT INNER O-RING

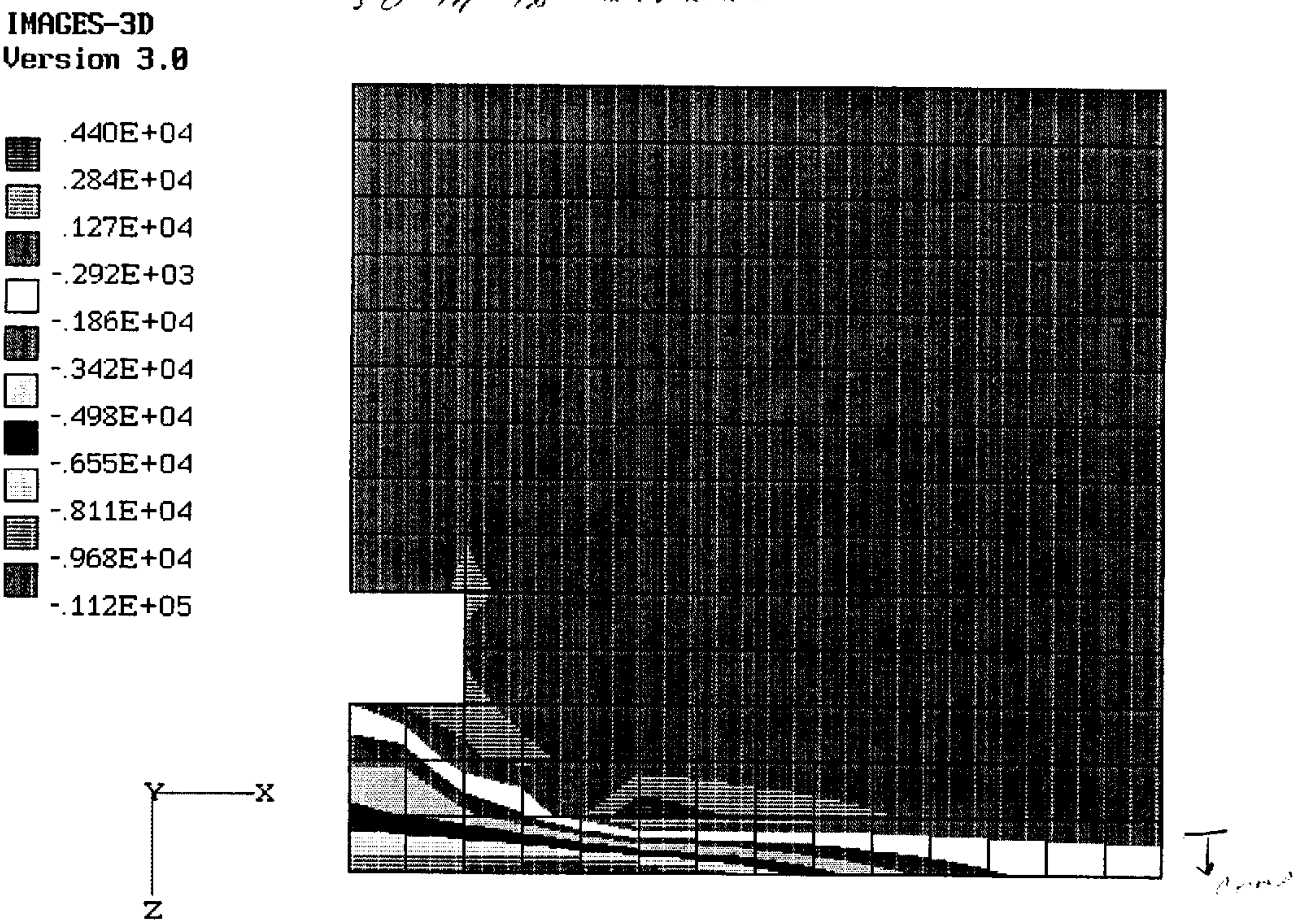


Load Case
1

Displacement Contour Plot
DY

2/ 2/96
9:21: 9

30 1/4 in [illegible]



Load Case
1

Stress Contour Plot
Gl St: S22

2/ 2/96
9:24: 0

30 1/4 IN FLANGE CONT

MAX STRESS INTENSITY

$$SI_{MAX} = 18.4 \text{ KSI}$$

VERY LOCAL, UNDER NUT

MAX FLANGE DISPLACEMENT OCCURS AT INNER O-RING IN Y-DIRECTION

$$\Delta = .00377 \text{ IN}$$

SEE IMAGES OUTPUT P. 23

FOR 2 FLANGES, THE GAP OPENING IS $2 \times \Delta = .0074$ IN. THIS COMPARES TO THE MIN O-RING COMPRESSION, .058 IN.

$$\text{RATIO} = \frac{.058}{.0074} = 7.8$$

NOTE: THE MODEL IS CONSERVATIVE FOR THIS CASE BECAUSE THE BOLT SPACING FOR THE 30 1/4 IN FLANGE WITH 20 BOLTS IS 5.65 IN BUT THE MODEL BOLT SPACING IS 7.2 IN.

$$\Delta_y \cong .00015 \text{ AT NUT}$$

BOLT STRAIN $\epsilon = \frac{.00015}{1} = .00015$

INCREASED STRESS

$$f_a = .00015(29)10^3$$

$$= 4.4 \text{ KSI}$$

FOR THE 10^K PRELOAD, THE STRESS IS

$$f_a = \frac{10}{.462} = 21.6 \text{ KSI}$$

REF: AISC P. 1-147 FOR
TENSILE AREA = .462 IN^2

TOTAL STRESS IS

$$f_a = 21.6 + 4.4 = 26 \text{ KSI} \quad \text{SAY OK}$$
$$\simeq 25$$

OR WHEN THE BOLT APPLIED LOAD
IS ADDED TO PRELOAD

$$f_a = \frac{10 + 1.72}{.462}$$

$$= 25.4 \text{ KSI} \cong 25 \text{ OK}$$

CHANGE NO. OF BOLTS TO 24

$$F_B = \frac{34.36}{24} = 1.43$$

$$f_a = \frac{10 + 1.43}{.462} = 24.7 < 25$$

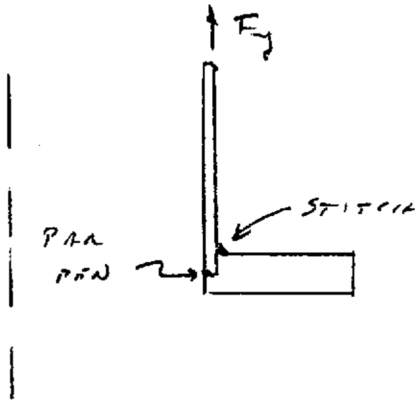
BOLT SPACING IS

$$S = \frac{\pi C}{24} = \frac{\pi(36)}{24}$$

$$= 4.71 \text{ IN} \quad \text{OK}$$

FORCE PER IN AT SHELL IS STILL 362 LB/IN

STRESS IN FLANGE TO SHELL WELD



THE PARTIAL PENETRATION WELD IS 1/8 IN THICK. NEGLECT STITCH WELD AND ASSUME THAT ALL LOAD IS TRANSMITTED THROUGH PARTIAL PEN WELD.

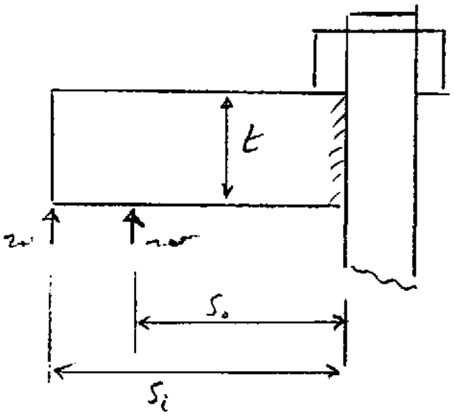
$$f_a = \frac{F_y}{.125}$$

$$= \frac{362}{.125} = 2900 \text{ OR psi}$$

REF p.17 OF THIS CALC FOR F_y = 362 LB/IN

CONFIRMATORY HAND CALC TO VERIFY IDEAS RESULTS FOR FLANGE TENSION.

DEFLECTION & STRESS IN A 1 IN STRIP FLANGE FOR O-RING FORCE



FOR A 1-IN STRIP

$$I = \frac{(1)t^3}{12}$$

W = MAX FORCE PER IN TO COMPRESS O-RING. THE NOMINAL DIAMETER IS 1/4"*. FROM THE PARKER HANDBOOK, P A 5-13 THE MAX "SQUEEZE" IS 23%. FROM P A4-11 THE MAX FORCE PER IN FOR DUROMETER 90 IS

$$w = 170 \text{ LB/IN}$$

FROM DWG V049-4-016 ← OUTER O-RING DIA

$$S_0 = \frac{36}{2} - .5 - \left(\frac{34}{2} + \frac{.34}{2}\right)$$

$$= .37 \text{ IN}$$

$$S_i = \frac{36}{2} - .5 - \left(\frac{31}{2} + \frac{.34}{2}\right)$$

$$= 1.83 \text{ IN}$$

* .275' CROSS SECTION

SINCE S_o IS SMALL, IGNORE INNER O-RING FORCE.

DEFLECTION

$$\Delta = \Delta_b + \Delta_s$$

Δ_b = BENDING DEFL

$$= \frac{w S_i^3}{3EI}$$

$$= \frac{170(1.83)^3}{3(28.8\times10^6)\left(\frac{t^3}{12}\right)}$$

$$= \frac{1.45(10)^{-4}}{t^2}$$

Δ_s = SHEAR DEFLECTION

$$= \frac{w S_i}{AG}$$

$$A = t(1) = t$$

$$G = \frac{28.8(10)^6}{2(1+\nu)} = 11.1(10)^6 \text{ psi}$$

$$\Delta_s = \frac{170(1.83)}{t(11.1\times10)^6} = \frac{.28(10)^{-4}}{t}$$

$$\Delta = \frac{1.45(10)^{-4}}{t^3} + \frac{.28(10)^{-4}}{t}$$

FOR $t = 1$

$$\Delta = (1.45 + .28)(10)^{-4} =$$
$$= 1.73(10)^{-4}$$

FOR $t = 7/8 = .875$

$$\Delta = \frac{1.45(10)^{-4}}{(.875)^3} + \frac{.28(10)^{-4}}{.875}$$
$$= 2.48(10)^{-4}$$

FOR $t = 3/4 = .75$

$$\Delta = \frac{1.45(10)^{-4}}{(.75)^3} + \frac{.28(10)^{-4}}{.75}$$
$$= 3.42(10)^{-4}$$

MIN COMP OF O-RING IS .058 IN (PARKER HANDBOOK, P A5-13). FOR MISSION FAILURE, ASSUME THAT Δ DOUBLES.

$t = 1$

$$\Delta = (2)1.73(10)^{-4} = 3.46(10)^{-4}$$

RATIO $\frac{.058}{3.46(10)^{-4}} = 168$

$t = 7/8$

$$\Delta = 2(2.48)(10)^{-4} = 4.96(10)^{-4}$$

RATIO = $\frac{.058}{4.96(10)^{-4}} = 117$

$t = 3/4$

$$\Delta = (2)3.42(10)^{-4} = 6.84(10)^{-4}$$

$$\text{RATIO} = \frac{.058}{6.84(10)^{-4}} = 85$$

ADD MAXIMUM TENSILE FORCE TO O-RING LOAD, THIS IS 362 LB/IN FOR THE 30 1/4 IN FLANGE

$$w = 170 + 362 = 532$$

RATIOS ARE

IMPULSE GIVES MORE [illegible] [illegible] RESULTS

$t = 1$ in $\quad R = 168\left(\frac{170}{532}\right) = 54$

$t = 7/8 \quad R = 117\left(\frac{170}{532}\right) = 37$

$t = 3/4 \quad R = 85\left(\frac{170}{532}\right) = 27$

MAX BENDING STRESS

$$M = w\,S_l =$$
$$= 532(1.83) = 974$$

$t = 1$

$$S_b = \frac{974(.5)}{1^3/12} =$$
$$= 5844 \text{ psi}$$

$t = 7/8$

$$f_b = \frac{974\left(\frac{.875}{2}\right)}{\frac{(.875)^3}{12}}$$

$= 7630$ psi

$t = 3/4$

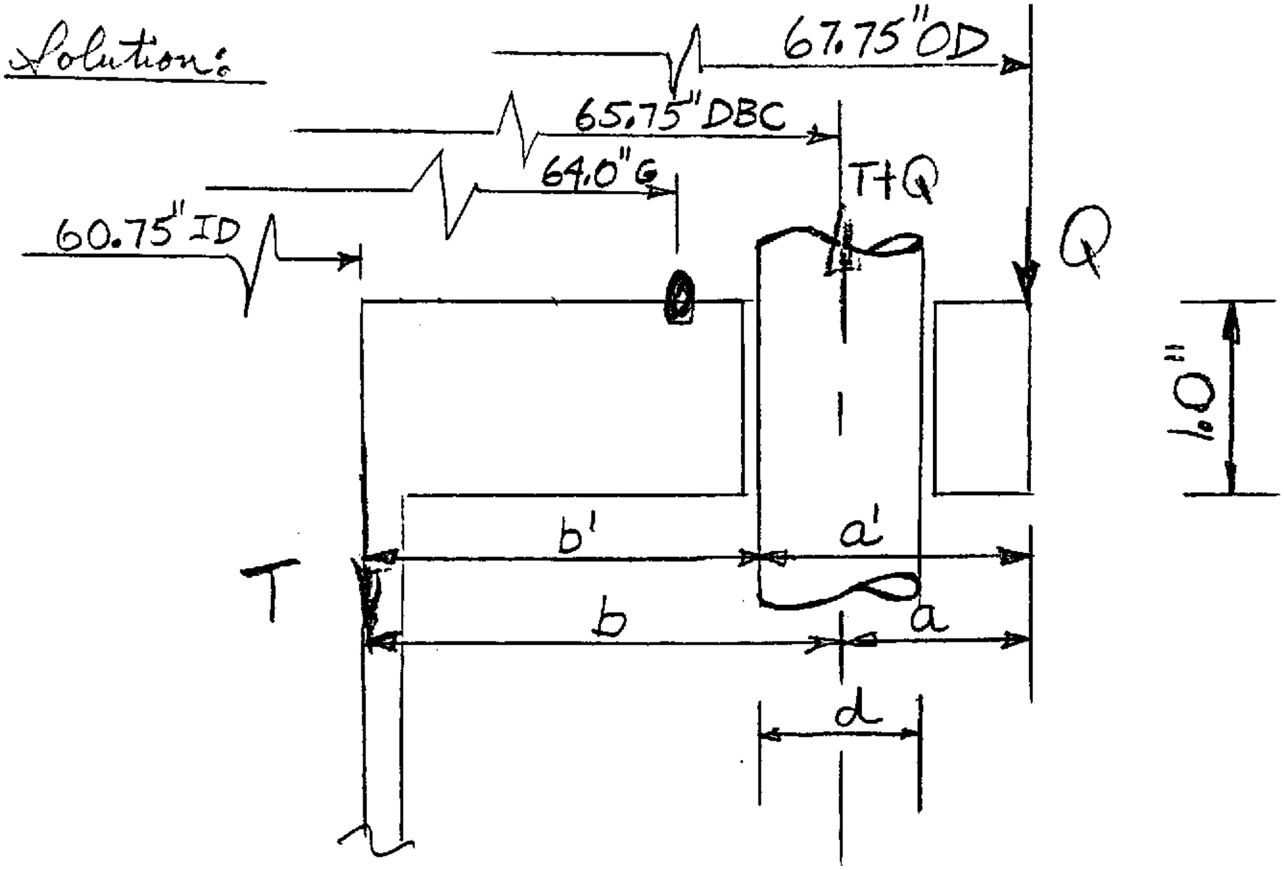
$$f_b = \frac{974\left(\frac{.75}{2}\right)}{\frac{.75^3}{12}}$$

$= 10400$ psi

Given: LIGO flanges of various sizes

Req'd: look @ a typical flange say a 60¼" flange and determine if there are any significant prying forces when the flange is put into tension. Reference previous analysis by Ray Ciatto 1/3/96
Reference AISC 9th edition pages 4-90, 4-91.

Solution:



$a = 1.0"$ $\quad a' = 1.0 + .875/2 = 1.4375"$

$b = 2.5"$ $\quad b' = 2.5 - .875/2 = 2.0625"$

T+Q is total bolt tension force including prying where Q is the prying force.

Appendix B

now calculate some constants

$$P = \frac{\pi(65.75)}{30} = 6.89''$$ trib width per bolt.

$$d' = 1.0'' \text{ ; } \delta = 1 - \frac{d'}{P} = 1 - \frac{1}{6.89} = .855$$

$$d = .875$$ bolt diameter

$$\rho = b'/a' = \frac{2.0625}{1.4375} = 1.4348$$

now since $\sigma_{\substack{allow\\bolts}} = 25\,ksi$

then
$$B = 25\overset{\text{root diameter of bolt (7/8" OD)}}{(.755)^2}/4\ \pi = 11.192K$$

$$T = 35.9/30 = 1.2K$$ force/bolt in 30 bolts

and
$$\beta = \frac{1}{\rho}\left(\frac{B}{T} - 1\right)$$

$$= \frac{1}{1.4348}\left[\frac{11.192}{1.2} - 1\right] = 5.803 > 1.0$$

$$\Rightarrow \alpha' = 1.0$$

then
$$t_{\substack{flg\\req'd}} = \sqrt{\frac{8(\overset{T}{1.2})(2.0625)}{6.89(36)(1+.855(1.0))}}$$

for the actual force T

$$= .2075'' < 1.0''$$ actual flg thickness

APPENDIX C

TEST PRESSURE TO OBSERVE FLANGE BEHAVIOR UNDER TENSION
10" TEST CHAMBER - REF DWG V049-4-030

HYDROPRESSURE REQUIRED TO GIVE
3^K PER BOLT

NOTE: MAX BOLT LOAD = 1.72^K FOR 30¼" FLANGE SAY 2^K. INCREASE BY 50% FOR HYDROTEST

$$1.5 \times 2^K = 3^K$$

$$pA = 3N$$

$$N = 6 \text{ BOLTS}$$

$$A = \pi r^2$$

$$r = 5$$

$$p\,\pi(5)^2 = 3(6) = 18^K$$

$$p = .229 \ K/IN^2$$

$$= 230 \text{ psi}$$

HOOP STRESS IN CYL

$$\sigma_\theta = \frac{pr}{t} =$$

$$t = 3/16$$

$$\sigma_\theta = \frac{230(5)}{3/16} = 6133 \text{ psi ok}$$

FOR 1/8 IN FILLET CONNECTING FLANGE TO CYL

$$A_w = \pi(10)(.125)(.707) = 2.8 \ IN^2$$

WELD STRESS

$$f_v = \frac{18}{2.8} = 6.5 \text{ ksi} \quad \text{ok}$$

MAXIMUM BENDING STRESS IN 10" FLAT PLATE:

$$\sigma_M = 1.24 \frac{P r^2}{t^2}$$

$$= 1.24 \frac{(230)(5)^2}{(.5)^2}$$

$$= 28500 \text{ psi}$$

OK FOR HYDRO

now

Calculate req'd thickness of flange to develop the full allowable flange force B

$$t_c = \sqrt{\frac{8Bb'}{PF_y}}$$

$$= \sqrt{\frac{8(11.192)(2.0625)}{6.89\,(36)}}$$

$$= .863''$$

again actual thickness is $t_{actual} = 1.0''$

now $$\alpha = \frac{1}{\delta}\left[\frac{T/B}{(t/t_c)^2} - 1\right]$$

$$= \frac{1}{.855}\left[\frac{1.2/11.192}{(1/.863)^2} - 1\right]$$

$$= -1.076$$

since this is neg, set $\alpha = 0$

$$\therefore \quad Q = B\delta\overset{0}{\cancel{\alpha}}\rho\left(\frac{t}{t_c}\right)^2 \equiv 0$$

or there is no prying force of any significance.

now

Calculate req'd thickness of flange to develop the full allowable flange force B

$$t_c = \sqrt{\frac{8Bb'}{PF_Y}}$$

$$= \sqrt{\frac{8(11.192)(2.0625)}{6.89\,(36)}}$$

$$= .863''$$

again actual thickness is $t_{actual} = 1.0''$

now

$$\alpha = \frac{1}{\delta}\left[\frac{T/B}{(t/t_c)^2} - 1\right]$$

$$= \frac{1}{.855}\left[\frac{1.2/11.192}{(1/.863)^2} - 1\right]$$

$$= -1.076$$

since this is neg, set $\alpha = 0$

$$\therefore \; Q = B\,\delta\,\overset{0}{\cancel{\alpha}}\,\rho\left(\frac{t}{t_c}\right)^2 \equiv 0$$

or there is no prying force of any significance.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

REV.	DEO #	DATE	BY:	CHECK
-	0128	3-18-96	AGR	RDC

ENGINEERING CALCULATIONS

NO: V049-1-071

PAGE 1 OF 19

TITLE: PIPE BRIDGE CORNER STATION

By: ART ROUSSOPOULOS **DEPT.:** 744

PROJECT: LIGO

PROJECT NO: V57049

PURPOSE: ANALYZE PROPOSED PIPE BRIDGE FOR AISC COMPLIANCE.

METHOD: • STAAD 3 STRUCTURAL COMPUTER SOFTWARE

ASSUMPTIONS: SEE CALCS

INPUTS: "STRUCTURAL DESIGN CRITERIA" REF: DOC. NO. V049-1-066
"DESIGN OF SUPPORT BASE PLATES" DOC. NO. V049-1-024
LIGO PIPE BRIDGE SKETCH SHT 2+3 - REF: V049-4-043 SHT 1 OF 3

DOC. NO. V049-1-066, LIGO VAC. EQUIP. STRUCT. DESIGN CRITERIA

REFERENCES: • DWG V049-4-043 • AISC - 9TH. ED., 3RD. IMP. 1/90
• STAAD3
• HILTI-TECH GUIDE - "ANCHOR + POWDER ACTUATED FASTENING
PUBLICATION # H-427 2/87

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: SUBJECT PIPE BRIDGE WITH REVISED 6x4x1/4 MEMBERS IS ACCEPTABLE
• ONLY TWO (2) ANCHOR BOLTS ARE REQUIRED PER PLATE
• ALL WELDS SHALL BE 3/16" FILLET EXCEPT WHEN NOTED.

NOTES: STAAD 3 FILE NAME ARTROU.STD FILED IN DIRECTORY \41896\

TABLE OF CONTENTS

1. - STAAD 3 INPUT:

- DENSITY = .283 #/IN^3
- MODULUS OF ELASTICITY E = 28X10^6 PSI
- POISSON ν = .3
- SEISMIC = .05625 g
- PIPE LOADS - (REF: 460 PIPE BRIDGE SKETCH SHT 3 OF 3)

F_1, F_3 = (1100/2) = 550# F_2 = 1100#
F_4 = 40#
F_5 = 40#
F_6 = 40#
F_7 = 90#
F_8 = 90#
F_9 = 150#
F_{10} = 90#
F_{11} = 150#

- SEISMIC LOADS F_x, F_z

- PIPING:

F_1, F_3 = 550(.05625) = 31# F_2 = 1100(.05625) = 62#
F_4 = 40(.05625) = 2.25#
F_5 = 40(.05625) = 2.25#
F_6 = 40(.05625) = 2.25#
F_7 = 90(.05625) = 5.063#
F_8 = 90(.05625) = 5.063#
F_9 = 150(.05625) = 8.44#
F_{10} = 90(.05625) = 5.063#

- PIPE BRIDGE STEEL TUBE (SEE MODEL P.3+4)

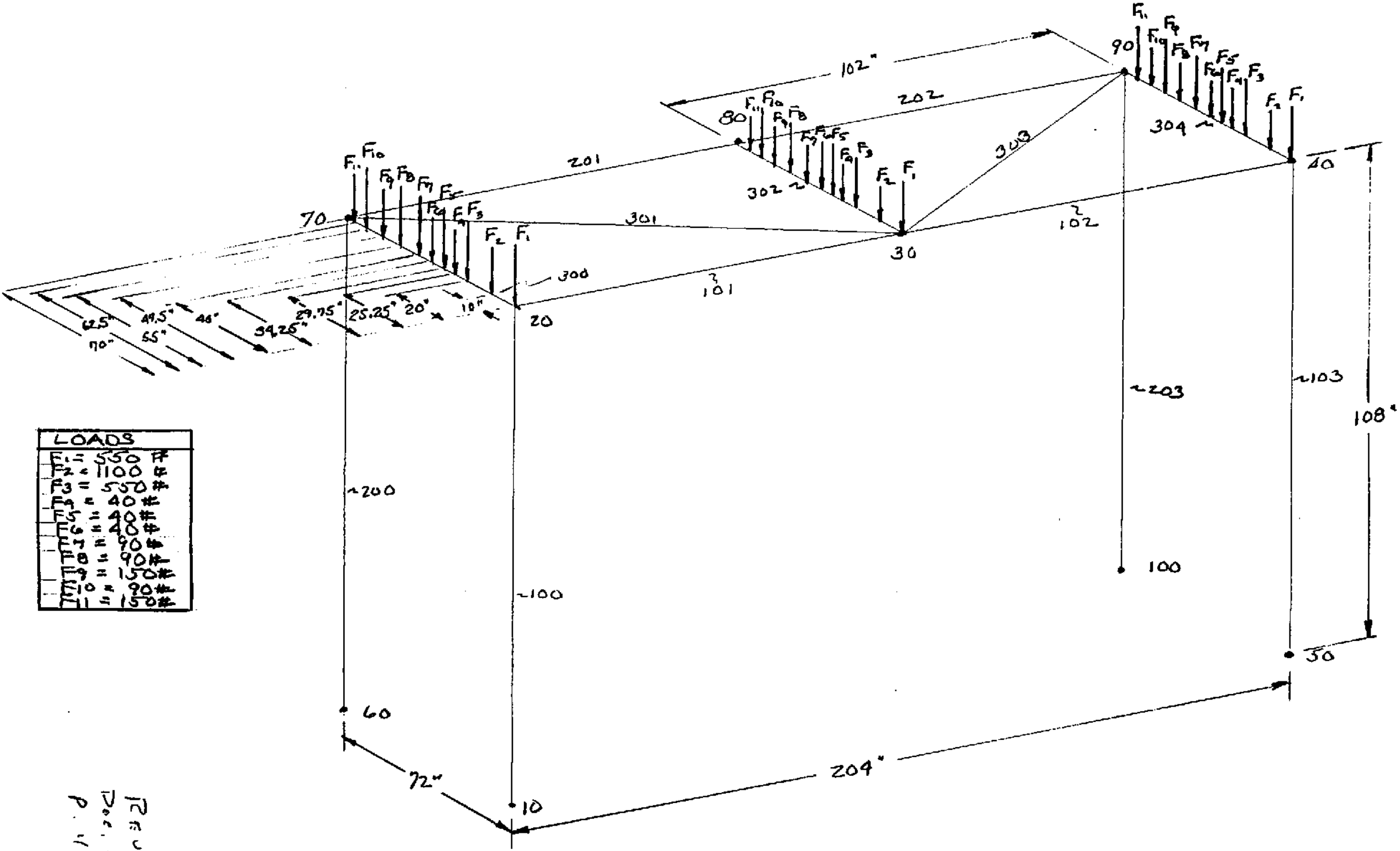
ELEMENT DEADWEIGHT:

- 100, 200, 103 + 203: 8X6X1/4 X 108" LONG EACH
  WT = [(22.42#/FT)/12] X 108 = 201.8# EACH
- 300, 302 + 304: 8X6X1/4 X 72" LONG EACH
  WT = (22.42/12) X 72 = 134.5# EACH
- 101, 102, 201 + 202: 8X6X1/4 X 102" LONG EACH
  WT = (22.42/12) X 102 = 190.6# EACH
- 301 + 303 4X3X1/4 X 124.85" LONG EACH
  WT = (10.51/12) X 124.85 = 109.3# EACH

SEISMIC LOADS:

- 100, 200, 103 + 203: F_x, F_z = 201.8(.06) = 12.1#
- 300, 302 + 304: F_x, F_z = 134.5(.06) = 8.07#
- 101, 102, 201 + 202: F_x, F_z = 190.6(.06) = 11.1#
- 301, 303: F_x, F_7 = 109.3(.06) = 6.6#

STAAD - MODEL FOR PIPEBRIDGE, REF. DWG. VO(4-043
PIPING LOADS:



LOADS
F1 = 550 #
F2 = 1100 #
F3 = 550 #
F4 = 40 #
F5 = 40 #
F6 = 40 #
F7 = 90 #
F8 = 90 #
F9 = 150 #
F10 = 90 #
F11 = 150 #

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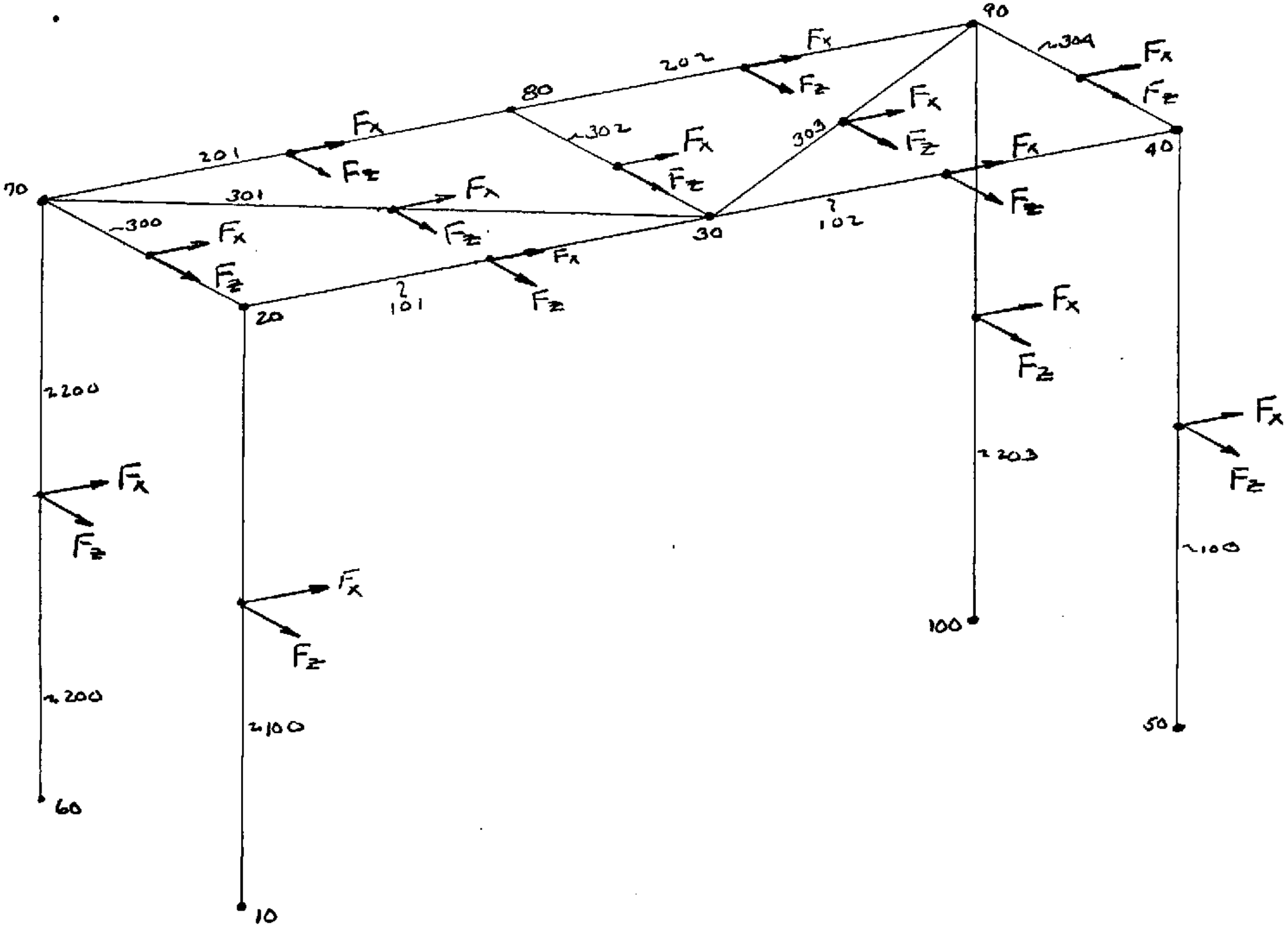
STAAD - MODEL FOR PIPEBRIDGE
SEIS LOADS



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1. - CON'T

STAAD3 - RESULTS: (SEE OUTPUT P. 8-17)

- MAXIMUM WELD SIZE OF 2/16" < 3/16 MINIMUM ∴ OK
- ALL STEEL TUBE ELEMENT MEMBERS PASS AISC ACCEPTANCE CRITERIA ∴ THE PIPE BRIDGE WITH REVISED FROM 8X6 X1/4 TO 6X4X1/4 MEMBERS IS ACCEPTABLE
- A MAXIMUM JOINT DISPLACEMENT OF .27606" OCCURS AT JOINT 30 (SEE P. 12)
  .27606" IS DEEMED ACCEPTABLE

2. - ANCHOR / PLATES: - LOCATED AT NODES 10, 50, 60 + 100

- DESIGN OF ANCHOR / SUPPORT BASE PLATES SHALL BE BASED ON THE DESIGN METHODOLOGY FOUND IN DOC. NO. V049-1-024
- REACTION LOADS FROM STAAD3 OUTPUT P.

```
JOINT  LOAD   FORCE-X    FORCE-Y    FORCE-Z     MOM-X      MOM-Y      MOM Z

  10     1      50.70     390.45      -3.30      0.00       0.00       0.00
         2     144.50    3454.01    -215.09      0.00       0.00       0.00
         3     195.20    3844.46    -218.39      0.00       0.00       0.00
  50     1     -50.70     390.45      -3.30      0.00       0.00       0.00
         2    -464.87    3698.52    -182.35      0.00       0.00       0.00
         3    -515.56    4088.97    -185.65      0.00       0.00       0.00
  60     1      49.03     390.45       3.30      0.00       0.00       0.00
         2      42.51     566.27    -128.68      0.00       0.00       0.00
         3      91.54     956.72    -125.38      0.00       0.00       0.00
 100     1     -49.03     390.45       3.30      0.00       0.00       0.00
         2    -340.81     951.20     -92.55      0.00       0.00       0.00
         3    -389.84    1341.64     -89.25      0.00       0.00       0.00
```

- SUMMARY OF BASE PLATE/ANCHOR REACTIONS

	NODES			
LOAD	10	50	60	100
F_x (#)	195	-516	92	-390
F_y (#)	3845	4089	957	1342
F_z (#)	-218	-186	-125	-89

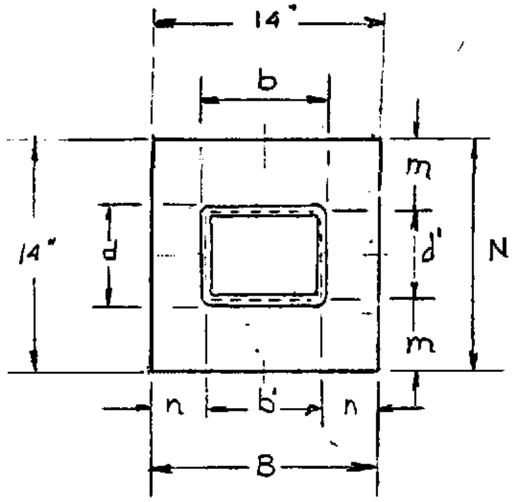
- VERTICAL LOADS ARE ALL COMPRESSIVE ∴ ONLY HORIZONTAL SHEAR LOADS ARE IMPOSED ONTO ANCHOR BOLTING.
- ANALYZE NODE 50 FOR WORSE CASE LOADING
  - MAXIMUM SHEAR LOAD:

$$F_{S\ MAX} = [F_x^2+F_z^2]^{1/2} = [(-516)^2+(-186)^2]^{1/2} = 549\ \text{\#}\ (\text{TOTAL})$$

2.- CON'T

- <u>ALLOWABLE LOAD</u> (REF: HILTI - SPEC TABLE FOR 3/4" HAS ANCHOR ROD)

- THE ALLOWABLE SHEAR LOAD FOR A 3/4" DIA. HAS STD. (SAE1018) ANCHOR ROD IS: 4,800# WHICH IS GREATER THAN THE MAXIMUM APPLIED SHEAR LOAD OF 549# ∴ TWO (2) 3/4" DIAMETER ANCHOR BOLTS PER BASE PLATE IS ADEQUATE.



$d' = 4 - .25 = 3.75"$
$m = (N - d')/2$
$m = \frac{14 - 3.75}{2} = 5.125"$

$b' = 6 - .25 = 5.75"$
$n = (B - b')/2$
$n = \frac{14 - 5.75}{2} = 4.125"$

3.- <u>BASE PLATE QUALIFICATION</u> REF: AISC P. 3-106

- <u>REQUIRED PLATE THICKNESS:</u>

$$t_p = 2(m \text{ or } n)\left[f_p/F_y\right]^{1/2} = 2(5.125)\left[(21)/(36000)\right]^{1/2} = .25"$$

WHERE: $m = 4.3125"$ (MAX OF M OR N)

$F_y = 36{,}000$ PSI FOR PLATE MIN YIELD STRESS

f_p = ACTUAL BEARING PRESSURE

$f_p = P/(B \times N) = 4{,}089./(14 \times 14) = 21.$ PSI

WHERE: P = 4089# (MAX COMPRESSIVE LOAD)

$f_p = 21$ PSI $< .35 f'_c = .35(3000) = 1{,}050$ PSI ∴ OK

$t_p = .25" < 1"$ ∴ OK

CONCLUSIONS

- PIPE BRIDGE WITH REVISED 6X4 X 1/4 MEMBERS IS ACCEPTABLE.
  - ONLY TWO(2) 3/4" DIA ANCHOR BOLTS PER BASE PLATE ARE REQUIRED
  - ALL WELDS SHALL BE 3/16" FILLET

4.-

```
     ****************************************************
     *                                                  *
     *          S T A A D - III                         *
     *          Revision 21.0                           *
     *          Proprietary Program of                  *
     *          Research Engineers, Inc.                *
     *          Date=    MAR 23, 1996                   *
     *          Time=    12:32:33                       *
     *                                                  *
     *     USER ID: Process Systems International       *
     ****************************************************


  1. STAAD SPACE PIPE BRIDGE
  2. INPUT WIDTH 72
  3. *FILE NAME:ARTROU
  4. *PIPE BRIDGE
  5. UNIT INCHES POUND
  6. JOINT COORDINATES
  7. 10 0. 0. 0.; 20 0. 108. 0.; 30 102. 108. 0.; 40 204. 108. 0.
  8. 50 204. 0. 0.; 60 0. 0. -72.; 70 0. 108. -72.; 80 102. 108. -72.
  9. 90 204. 108. -72.; 100 204. 0. -72.
 10. MEMBER INCIDENCES
 11. 100 10 20; 101 20 30; 102 30 40; 103 40 50; 200 60 70; 201 70 80
 12. 202 80 90; 203 90 100; 300 20 70; 301 30 70; 302 30 80; 303 30 90
 13. 304 40 90
 14. MEMBER PROPERTY AMER
 15. 100 TO 103 200 TO 203 300 302 304 TABLE ST TUBE TH 0.25 WT 4. DT 6.
 16. 301 303 TABLE ST TUBE TH 0.25 WT 4. DT 3.
 17. SUPPORTS
 18. 10 50 60 100 FIXED BUT MX MY MZ
 19. CONSTANTS
 20. E 27999998. ALL
 21. DENSITY 0.283 ALL
 22. POISSON 0.3 ALL
 23. BETA 0. ALL
 24. E STEEL ALL
 25. POISSON STEEL ALL
 26. LOAD 1 TRUSS SELFWEIGHT (D1)
 27. SELFWEIGHT Y -1.
 28. LOAD 2 PIPE LOADS (D2)
 29. JOINT LOAD
 30. 20 FX 31. FY -550. FZ 31.
 31. 30 FX 31. FY -550. FZ 31.
 32. 40 FX 31. FY -550. FZ 31.
 33. MEMBER LOAD
 34. 100 CON GX 12.1 54. 0.
 35. 100 CON GZ 12.1 54. 0.
 36. 200 CON GX 12.1 54. 0.
 37. 200 CON GZ 12.1 54. 0.
 38. 103 CON GX 12.1 54. 0.
 39. 103 CON GZ 12.1 54. 0.
 40. 203 CON GX 12.1 54. 0.
 41. 203 CON GZ 12.1 54. 0.
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```
42. 300 CON GX 8.07 36. 0.
43. 300 CON GZ 8.07 36. 0.
44. 302 CON GX 8.07 36. 0.
45. 302 CON GZ 8.07 36. 0.
46. 304 CON GX 8.07 36. 0.
47. 304 CON GZ 8.07 36. 0.
48. 101 CON GX 11.1 51. 0.
49. 101 CON GZ 11.1 51. 0.
50. 102 CON GX 11.1 51. 0.
51. 102 CON GZ 11.1 51. 0.
52. 201 CON GX 11.1 51. 0.
53. 201 CON GZ 11.1 51. 0.
54. 202 CON GX 11.1 51. 0.
55. 202 CON GZ 11.1 51. 0.
56. 301 CON GX 6.6 62.43 0.
57. 301 CON GZ 6.6 62.43 0.
58. 303 CON GX 6.6 62.43 0.
59. 303 CON GZ 6.6 62.43 0.
60. 300 CON GX 62. 10. 0.
61. 300 CON GY -1100. 10. 0.
62. 300 CON GZ 62. 10. 0.
63. 300 CON GX 31. 20. 0.
64. 300 CON GY -550. 20. 0.
65. 300 CON GZ 31. 20. 0.
66. 300 CON GX 2.25 25.25 0.
67. 300 CON GY -40. 25.25 0.
68. 300 CON GZ 2.25 25.25 0.
69. 300 CON GX 2.25 29.75 0.
70. 300 CON GY -40. 29.75 0.
71. 300 CON GZ 2.25 29.75 0.
72. 300 CON GX 2.25 34.25 0.
73. 300 CON GY -40. 34.25 0.
74. 300 CON GZ 2.25 34.25 0.
75. 300 CON GX 5.063 40. 0.
76. 300 CON GY -90. 40. 0.
77. 300 CON GZ 5.063 40. 0.
78. 300 CON GX 5.063 47.5 0.
79. 300 CON GY -90. 47.5 0.
80. 300 CON GZ 5.063 47.5 0.
81. 300 CON GX 8.44 55. 0.
82. 300 CON GY -150. 55. 0.
83. 300 CON GZ 8.44 55. 0.
84. 300 CON GX 5.063 62.5 0.
85. 300 CON GY -90. 62.5 0.
86. 300 CON GZ 5.063 62.5 0.
87. 300 CON GX 8.44 70. 0.
88. 300 CON GY -150. 70. 0.
89. 300 CON GZ 8.44 70. 0.
90. 302 CON GX 62. 10. 0.
91. 302 CON GY -1100. 10. 0.
92. 302 CON GZ 62. 10. 0.
93. 302 CON GX 31. 20. 0.
94. 302 CON GY -550. 20. 0.
95. 302 CON GZ 31. 20. 0.
96. 302 CON GX 2.25 25.25 0.
97. 302 CON GY -40. 25.25 0.
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 98. 302 CON GZ 2.25 25.25 0.
 99. 302 CON GX 2.25 29.75 0.
100. 302 CON GY -40. 29.75 0.
101. 302 CON GZ 2.25 29.75 0.
102. 302 CON GX 2.25 34.25 0.
103. 302 CON GY -40. 34.25 0.
104. 302 CON GZ 2.25 34.25 0.
105. 302 CON GX 5.063 40. 0.
106. 302 CON GY -90. 40. 0.
107. 302 CON GZ 5.063 40. 0.
108. 302 CON GX 5.063 47.5 0.
109. 302 CON GY -90. 47.5 0.
110. 302 CON GZ 5.063 47.5 0.
111. 302 CON GX 8.44 55. 0.
112. 302 CON GY -150. 55. 0.
113. 302 CON GZ 8.44 55. 0.
114. 302 CON GX 5.063 62.5 0.
115. 302 CON GY -90. 62.5 0.
116. 302 CON GZ 5.063 62.5 0.
117. 302 CON GX 8.44 70. 0.
118. 302 CON GY -150. 70. 0.
119. 302 CON GZ 8.44 70. 0.
120. 304 CON GX 62. 10. 0.
121. 304 CON GY -1100. 10. 0.
122. 304 CON GZ 62. 10. 0.
123. 304 CON GX 31. 20. 0.
124. 304 CON GY -550. 20. 0.
125. 304 CON GZ 31. 20. 0.
126. 304 CON GX 2.25 25.25 0.
127. 304 CON GY -40. 25.25 0.
128. 304 CON GZ 2.25 25.25 0.
129. 304 CON GX 2.25 29.75 0.
130. 304 CON GY -40. 29.75 0.
131. 304 CON GZ 2.25 29.75 0.
132. 304 CON GX 2.25 34.25 0.
133. 304 CON GY -40. 34.25 0.
134. 304 CON GZ 2.25 34.25 0.
135. 304 CON GX 5.063 40. 0.
136. 304 CON GY -90. 40. 0.
137. 304 CON GZ 5.063 40. 0.
138. 304 CON GX 5.063 47.5 0.
139. 304 CON GY -90. 47.5 0.
140. 304 CON GZ 5.063 47.5 0.
141. 304 CON GX 8.44 55. 0.
142. 304 CON GY -150. 55. 0.
143. 304 CON GZ 8.44 55. 0.
144. 304 CON GX 5.063 62.5 0.
145. 304 CON GY -90. 62.5 0.
146. 304 CON GZ 5.063 62.5 0.
147. 304 CON GX 8.44 70. 0.
148. 304 CON GY -150. 70. 0.
149. 304 CON GZ 8.44 70. 0.
150. LOAD COMB 3
151. 1 1. 2 1.
152. 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 =    10/    13/     4
   ORIGINAL/FINAL BAND-WIDTH =     6/     3
   TOTAL PRIMARY LOAD CASES  =     2, TOTAL DEGREES OF FREEDOM =     48
   SIZE OF STIFFNESS MATRIX =    1152 DOUBLE PREC. WORDS
   REQRD/AVAIL. DISK SPACE =  12.03/  378.2 MB,  EXMEM =  6.69 MB

++ PROCESSING ELEMENT STIFFNESS MATRIX.                    12:32:36
++ PROCESSING GLOBAL STIFFNESS MATRIX.                     12:32:37
++ PROCESSING TRIANGULAR FACTORIZATION.                    12:32:37
++ CALCULATING JOINT DISPLACEMENTS.                        12:32:37
++ CALCULATING MEMBER  FORCES.                             12:32:38


 153. *PRINT MATERIAL PROPERTIES ALL
 154. *PRINT JOINT COORDINATES ALL
 155. *PRINT SUPPORT INFORMATION ALL
 156. *PRINT MEMBER INFORMATION ALL
 157. *PRINT MEMBER PROPERTIES ALL
 158. PRINT JOINT DISPLACEMENTS ALL
```

```
 JOINT DISPLACEMENT (INCH RADIANS)    STRUCTURE TYPE = SPACE
 -----------------

  INT  LOAD    X-TRANS    Y-TRANS    Z-TRANS    X-ROTAN    Y-ROTAN    Z-ROTAN

   10    1     0.00000    0.00000    0.00000    0.00003    0.00000    0.00016
         2     0.00000    0.00000    0.00000    0.00384    0.00022   -0.00145
         3     0.00000    0.00000    0.00000    0.00387    0.00022   -0.00129
   20    1     0.00004   -0.00027    0.00141   -0.00003    0.00000   -0.00033
         2     0.20601   -0.00286    0.27114   -0.00015    0.00022   -0.00286
         3     0.20604   -0.00313    0.27255   -0.00018    0.00022   -0.00318
   30    1     0.00000   -0.03539    0.00146    0.00002    0.00000    0.00000
         2     0.20579   -0.24067    0.24518    0.00084    0.00025    0.00042
         3     0.20579   -0.27606    0.24665    0.00086    0.00025    0.00042
   40    1    -0.00004   -0.00027    0.00141   -0.00003    0.00000    0.00033
         2     0.20554   -0.00306    0.21760   -0.00023    0.00023    0.00105
         3     0.20550   -0.00333    0.21901   -0.00026    0.00023    0.00138
   50    1     0.00000    0.00000    0.00000    0.00003    0.00000   -0.00016
         2     0.00000    0.00000    0.00000    0.00314    0.00023   -0.00337
         3     0.00000    0.00000    0.00000    0.00317    0.00023   -0.00353
   60    1     0.00000    0.00000    0.00000   -0.00001    0.00000    0.00015
         2     0.00000    0.00000    0.00000    0.00330    0.00028   -0.00159
         3     0.00000    0.00000    0.00000    0.00330    0.00028   -0.00144
   70    1     0.00004   -0.00027    0.00141    0.00005    0.00000   -0.00031
         2     0.18703   -0.00047    0.27119    0.00094    0.00028   -0.00203
         3     0.18707   -0.00074    0.27260    0.00099    0.00028   -0.00234
   80    1     0.00000   -0.03030    0.00146    0.00010    0.00000    0.00000
         2     0.18679   -0.12860    0.24522    0.00199    0.00027    0.00039
         3     0.18679   -0.15890    0.24668    0.00209    0.00027    0.00039
   90    1    -0.00004   -0.00027    0.00141    0.00005    0.00000    0.00031
         2     0.18651   -0.00079    0.21762    0.00090    0.00030    0.00044
         3     0.18647   -0.00105    0.21903    0.00095    0.00030    0.00075
  100    1     0.00000    0.00000    0.00000   -0.00001    0.00000   -0.00015
         2     0.00000    0.00000    0.00000    0.00258    0.00030   -0.00280
         3     0.00000    0.00000    0.00000    0.00257    0.00030   -0.00295

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

 159. *PRINT MEMBER FORCES ALL
 160. *PRINT MEMBER STRESSES ALL
 161. PRINT SUPPORT REACTIONS
```

```
SUPPORT REACTIONS -UNIT POUN INCH    STRUCTURE TYPE = SPACE
-----------------

 INT  LOAD   FORCE-X    FORCE-Y    FORCE-Z     MOM-X      MOM-Y      MOM Z

 10     1      50.70     390.45      -3.30      0.00       0.00       0.00
        2     144.50    3454.01    -215.09      0.00       0.00       0.00
        3     195.20    3844.46    -218.39      0.00       0.00       0.00
 50     1     -50.70     390.45      -3.30      0.00       0.00       0.00
        2    -464.87    3698.52    -182.35      0.00       0.00       0.00
        3    -515.56    4088.97    -185.65      0.00       0.00       0.00
 60     1      49.03     390.45       3.30      0.00       0.00       0.00
        2      42.51     566.27    -128.68      0.00       0.00       0.00
        3      91.54     956.72    -125.38      0.00       0.00       0.00
100     1     -49.03     390.45       3.30      0.00       0.00       0.00
        2    -340.81     951.20     -92.55      0.00       0.00       0.00
        3    -389.84    1341.64     -89.25      0.00       0.00       0.00

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

162. PARAMETER
163. CODE AISC
164. MAIN 0. ALL
165. WELD 1. ALL
166. CHECK CODE ALL
```

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

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER     TABLE        RESULT/   CRITICAL COND/     RATIO/     LOADING/
                          FX            MY             MZ       LOCATION
=======================================================================

   100   ST   TUB E        PASS     AISC- H1-3        0.393        3
                       3706.97 C   22932.28      -21734.79    108.00
   101   ST   TUB E        PASS     AISC- H1-3        0.444        3
                        335.58 C    -464.13       65820.25    102.00
   102   ST   TUB E        PASS     AISC- H1-3        0.449        3
                        362.87 C    -398.99      -66632.07      0.00
   103   ST   TUB E        PASS     AISC- H1-3        0.585        3
                       3951.48 C  -19396.53       55027.61      0.00
   200   ST   TUB E        PASS     AISC- H1-3        0.192        3
                        819.23 C   12887.65      -10539.33    108.00
   201   ST   TUB E        PASS     AISC- H1-3        0.241        3
                        361.06 C     227.05       35356.93    102.00
   202   ST   TUB E        PASS     AISC- H1-3        0.241        3
                        407.22 C     337.93      -35233.39      0.00
   203   ST   TUB E        PASS     AISC- H1-3        0.368        3
                       1204.16 C   -8985.98       41448.94      0.00
   300   ST   TUB E        PASS     AISC- H1-3        0.175        3
                        177.87 C     359.43       25713.20      0.00
   301   ST   TUB E        PASS     AISC- H2-1        0.110        2
                        228.27 T     -23.11       -5896.90      0.00
   302   ST   TUB E        PASS     AISC- H1-3        0.045        3
                          9.01 C    -564.98       -5998.97     72.00
   303   ST   TUB E        PASS     AISC- H2-1        0.133        3
                        103.18 T     -28.97       -7279.46    124.85
   304   ST   TUB E        PASS     AISC- H1-3        0.156        3
                        125.55 C     771.02       22401.43      0.00
  167. SELECT WELD ALL
```

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```
                         STAAD-III WELD DESIGN
                         *********************

ALL UNITS ARE - INCH POUN

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

  100       STA              1               1/16              3084.49
             3             174.71              156.16           3075.57

  100       END              1               2/16             12567.55
             3              82.51               82.92          12567.00

  101       STA              1               1/16             11632.56
             3             802.92             1297.58          11532.04

  101       END              1               3/16              9936.68
             3             270.60              397.90           9925.02

  102       STA              1               3/16             10057.32
             3             290.05              499.31          10040.73

  102       END              1               2/16             13151.09
             3             439.51              800.91          13119.32

  103       STA              1               3/16             12733.40
             3              46.28              134.26          12732.61

  103       END              1               1/16              3300.42
             3             148.52              412.45           3271.18

  200       STA              1               1/16               775.38
             3             100.30               73.23            765.37

  200       END              1               1/16             12369.77
             3              90.62               82.91          12369.16

  201       STA              1               1/16              3032.48
             3             858.48              932.89           2754.75

  201       END              1               2/16              8085.26
             3             424.80              414.50           8063.44

  202       STA              1               2/16              8114.59
             3             444.35              535.50           8084.70

  202       END              1               2/16              7635.14
             3             439.91              587.44           7599.78

  203       STA              1               2/16             12144.24
             3              30.86              151.09          12143.26

  203       END              1               1/16              1119.99
             3              71.40              311.87           1073.32
```

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```
                     STAAD-III WELD DESIGN
                     *********************

ALL UNITS ARE - INCH POUN

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

  300       STA           1              1/16           12044.01
             3            986.83          2373.86       11766.44

  300       END           1              1/16            8890.62
             3            960.86           795.31        8802.69

  301       STA           1              1/16            6614.24
             2            410.22           620.97        6572.24

  301       END           1              1/16            4511.28
             3            458.68           758.17        4423.39

  302       STA           1              1/16            1405.35
             2            110.58          1194.18         732.61

  302       END           1              1/16            3080.75
             3             72.49           771.92        2981.59

  303       STA           1              1/16            6359.39
             2             17.50           120.31        6358.23

  303       END           1              1/16            7912.75
             3             39.66           226.60        7909.41

  304       STA           1              1/16           10724.02
             3            767.11          2155.18       10477.19

  304       END           1              1/16            7439.25
             3            721.40           707.88        7370.27

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

168. STEEL TAKE OFF
```

REV O
DOC. NO. V049-1-071
P 17 OF 19

```
STEEL TAKE-OFF
--------------

PROFILE                    LENGTH(INCH)      WEIGHT(POUN)

ST   TUB E                    1056.00           1344.293
ST   TUB E                     249.70            217.493
                                             ----------------
                                  TOTAL =        1561.79

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


169. LOAD LIST ALL
170. LOAD LIST 2 3
171. FINISH

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

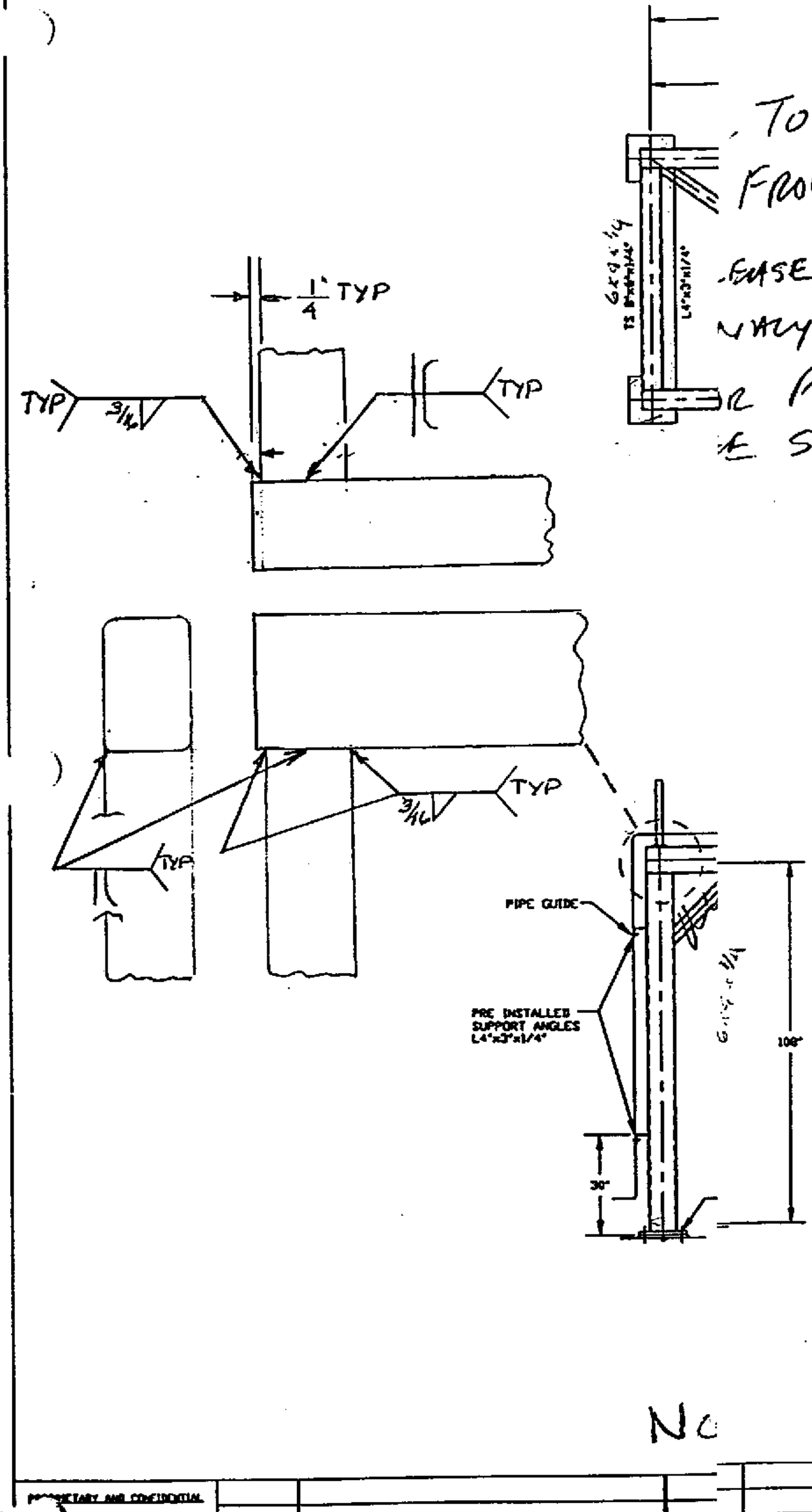
            **** DATE= MAR 23,1996   TIME= 12:32:39 ****

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

REV 0
DOC. NO. V049-1-071
P. 18 OF 19

5 MAR 96

To: R. CIATTO
FROM: D. CURTIS
.EASE REVIEW & PROVIDE
NALYSIS,
R PIPE & ELECT. LOADINGS
E SHTS. 2 & 3 OF 3



NOTES:
1.) FRAME TO BE SELF SUPPORTING BY FLOOR.
2.) ONE REQ'D. @ WASH. CORNER STATION.
ONE REQ'D. @ LA. CORNER STATION.

SHT. 1 OF 3

DWG. NO. | DESCRIPTION | DWG.
REFERENCE DRAWIN
DATE | DCD#

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

PROPOSED PIPE BRIDGE
CORNER STATION
LIGO VACUUM EQUIPMENT

CAD FILE V0494043
SIZE D
DWG. NO. V049-4-043
REV. P1
SCALE 1/2"=1'-0"
SHEET 1 OF 1

Mar 05 1996 - 142201

REV 0
DOC. NO. V049-1-071

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-039
PAGE 1 OF 19

REV.	DEO #	DATE	BY:	CHECK
0	0128	11/29.95	KM	RDC

TITLE: HAM Finite Element Analysis

BY: Kyle Martini

DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. Evaluate the horizontal access module (HAM)

METHOD: Finite element method and hand calculations.

ASSUMPTIONS: See attached.

INPUTS: LIGO project drawings and sketches.
Shell thickness = 0.5 in, 60 in nozzle thickness = .5 in, head thickness = 0.375 in
Thickness of other nozzles = 0.125 in, saddle wear plate thickness = 0.75 in,
Thickness of saddle and stiffeners = 0.5 in, baseplate thickness = 1.0 in

DOC. NO V049-1-066, LIGO VE STRUCT. DESIGN CRITERIA

REFERENCES: 1. ASME Boiler & Pressure Vessel Code, Section VIII, Pressure Vessels, Div. 1 and Div. 2.
2. IMAGES 3D, Version 3.0, R. L. Cloud & Associates
3. Hilti Concrete Fastener Catolog

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Stress are within the limits of the ASME Code, Section VIII, Div. 2.

NOTES: Computer files are HAM6.*

SUMMARY

Load case	Max Stress Intensity	ASME SEC VIII DIV 2 Allowable Stress
1. One Bellow Design	P_L+P_B+Q = 28.6 KSI	3 S_m = 56.1 KSI
	PL = 26.5 KSI	1.5 S_m = 28.0 KSI
	Bolt Force = 8683 lb	10,960 lb
2. Two Bellow Design		
	P_L+P_B+Q = 16.5 KSI	3 S_m = 56.1 KSI
	PL = 15.8 KSI	1.5 SM = 28.0 KSI
3. Seismic	X — 0.15 KSI	
	y - 0.05 KSI	
	z - 0.11 KSI	
4. Lifting	2.7 KSI	

1.0 MODEL (ref Dwg. V049-4-002)

The HAM finite element model was created using Images. A computer plot of the model is shown in Figure 1. Additional Information including a listing, diagrams identifying nodes and elements, loads and plots can be found in Appendix A.

The model is 1/2 symmetrical using B.C to represent the second half. The total weight of the model is 6300#.

2.0 ANALYSIS

2.1 One Bellows External Pressure Analysis

The HAM can be configured with one or two opposing bellows. In the analysis it is assumed that the bellows does not transmit any loads or add any stiffness. With one bellows an external pressure unbalance occurs and there are external reaction. A pressure load of -14.7 PSI is applied everywhere. At nozzle which are conservatively modeled w/o caps the load is applied as a line load equal to P_{nozzle}

The unbalance loading is shown on the deform plot of Figure 2. The effect of the overturning moment can be vividly seen. On the bellow side (opposite the unbalance loaded side) the compressive forces due to the overturning moment combine with the compressive forces from the external pressure. This produces greater deformation and higher stresses. On the loaded side the forces due to the overturning moment subtract from the external pressure forces.

Figure 3 is a contour plot of the resultant displacements $ds = \sqrt{dx^2 + dy^2 + dz^2}$. The maximum displacements occurs at the locations farthest from the center of rotation of the overturning moment. This occurs at the top of nozzle "B" the tube region. The maximum and minimum displacements in each directions are

direction	max	min
x	+.11"	-.04"
y	+.14"	-.30"
z	+.05"	-.34"

Stress Intensity contour plots of the model at the top surface, bottom surface, and averaged across the thickness (membrane) are shown in Figures 4-6. The highest stresses occur at local discontinuities such as nozzle-vessel junction and saddle support locations on the vessel. The maximum stress Intensities are

Top Surface - 26.9 KSI
Bottom Surface 28.6 KSI
Membrane 26.5 KSI

Using ASME SEC VIII DIV 2 rules.
The basic allowable stress Intensity is

S_m = 18.7 KSI @ 400°F for TP 304

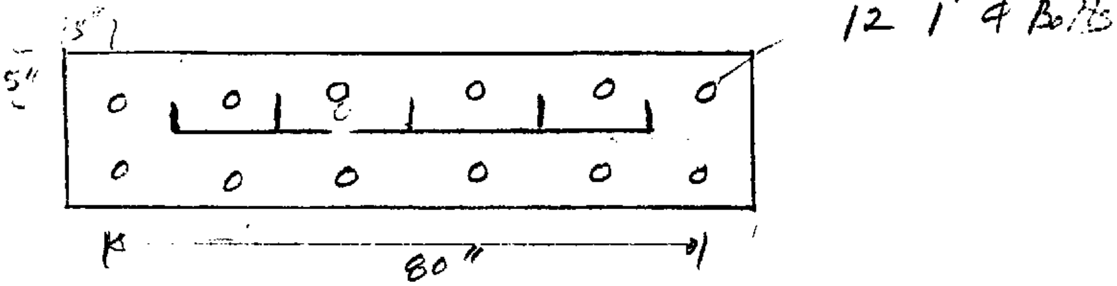
These stresses are discontinuity stresses and the maximinum allowable stress for combined bending and membrane are

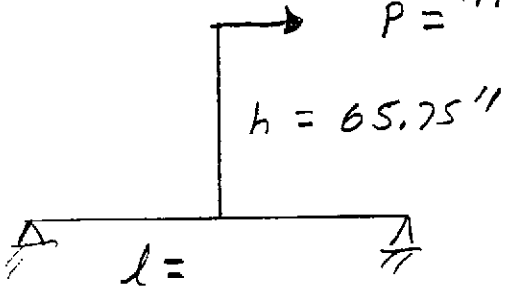
$P_L + P_b + Q = 28.6 \angle 3 S_m = 56.1$ KSI ok

For membrane alone

$P_L = 26.5$ KSI $\angle 1.5 S_m = 27.8$ KSI ok

The maximum anchor load due to the off balance load is calculated as follows





$$P = \frac{(14.7)(60.5)^2 \pi}{(4)(2\ sides)} = 21{,}129^{\#}$$

Assume only outer bolts take load

$$F_{bolt} = \frac{Ph}{l(2\ bolts)} = \frac{(21129^{\#})(65.75'')}{(80'')(2\ bolt)}$$

$$F_{bolt} = 8683^{\#}$$

For 3000 psi concrete, and a 1" Hilti adhesive anchor embedded 8 1/4" $F_{allow} = 10\,960^{\#}$

$$F.S = \frac{10960}{8683} = 1.26 \quad OK$$

2.2 Two Bellow External Pressure Analysis

In This configuration There is no Unbalance loading and no external reaction. The contour plot of the deflection is Shown in Figure 7. The maximum deflections for each direction are

Direction	Max	Min
X	+.05	-.04
Y	+.06	-.16
Z	+.05	-.05

Figures 8, 9, and 10 plot the Stress Intensities for this configuration. The max values are

Top Surface	15.3 KSI	< 56.1 KSI
Bottom Surface	16.5 KSI	< 56.1 KSI
Membrane	15.8 KSI	< 27.8 KSI

There are no external reaction

2.3 SEISMIC

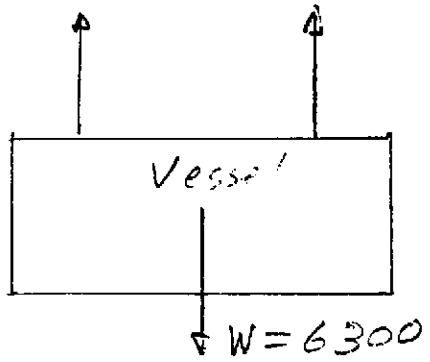
The seismic acceleration from (ASCE 7-95) are 0.05625 G in each direction. The weight of the HAM model is 6269#

$$F_{seismic} = (.05625)(6269) = 352^{\#}$$

This is a small force compared to the unbalance force due to the external pressure which is 42,259#. The corresponding stresses are also small. From the computer model The maximum stresses are

Direction	Stress
X	150 PSI
Y	54 PSI
Z	108 PSI

2.4 LIFTING LUGS



For the lifting lug analysis, the vessel was supported at four points on the stiffener for the lifting lug. The maximum stress for a 2 "g" load (DLF = 2.0) is **2.7 KSI**

The maximum [illegible] force on lug 1575#

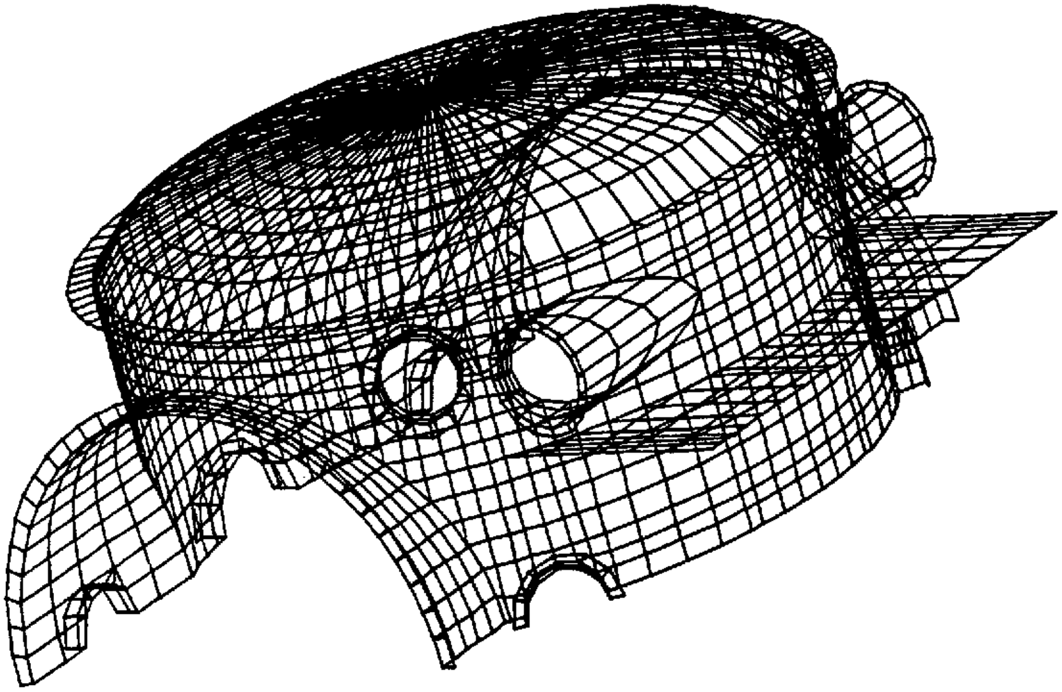


Fig 1 - FE Model

IMAGES-3D
Version 3.0
L Case 1
S= .300E+02

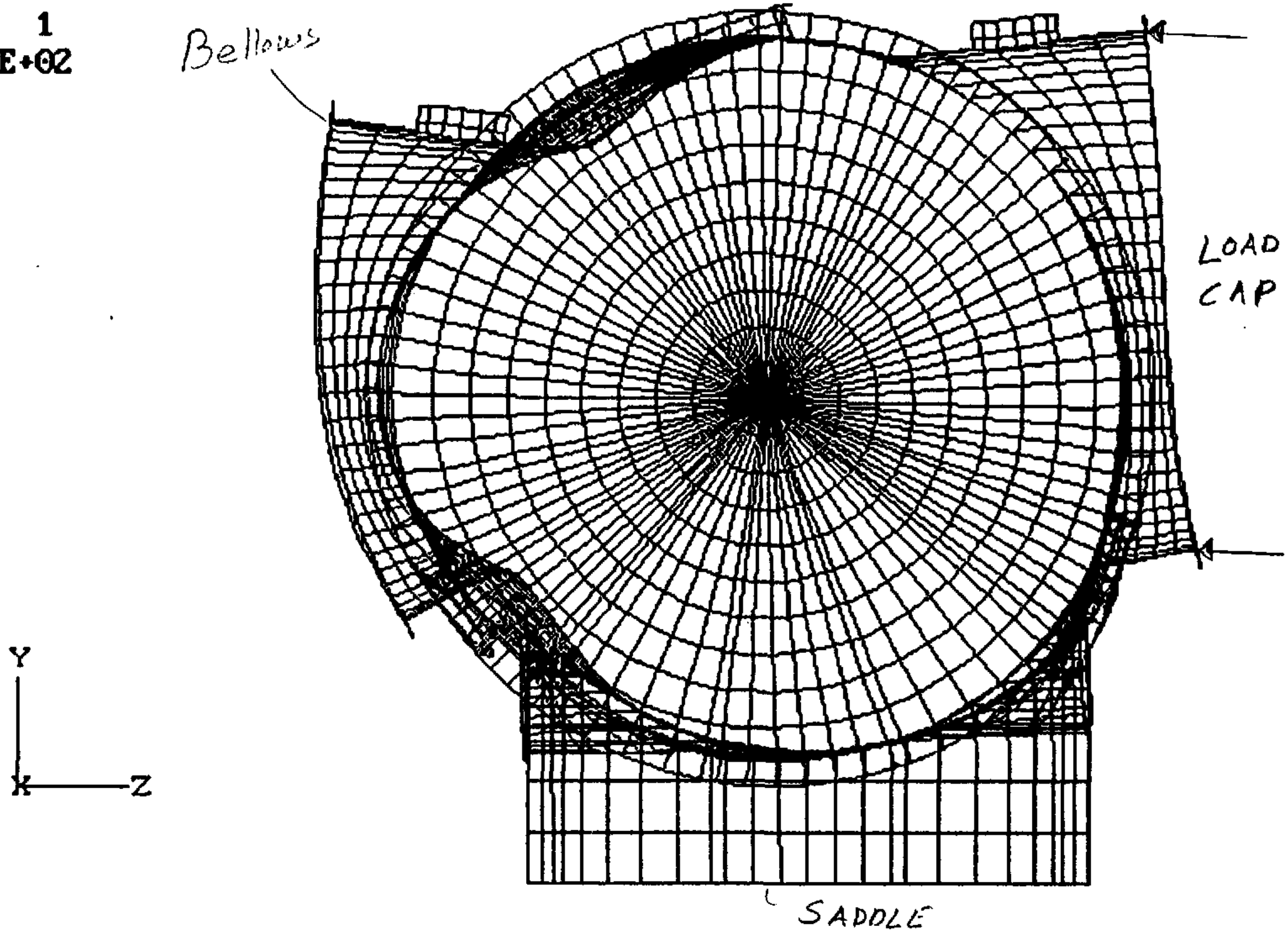
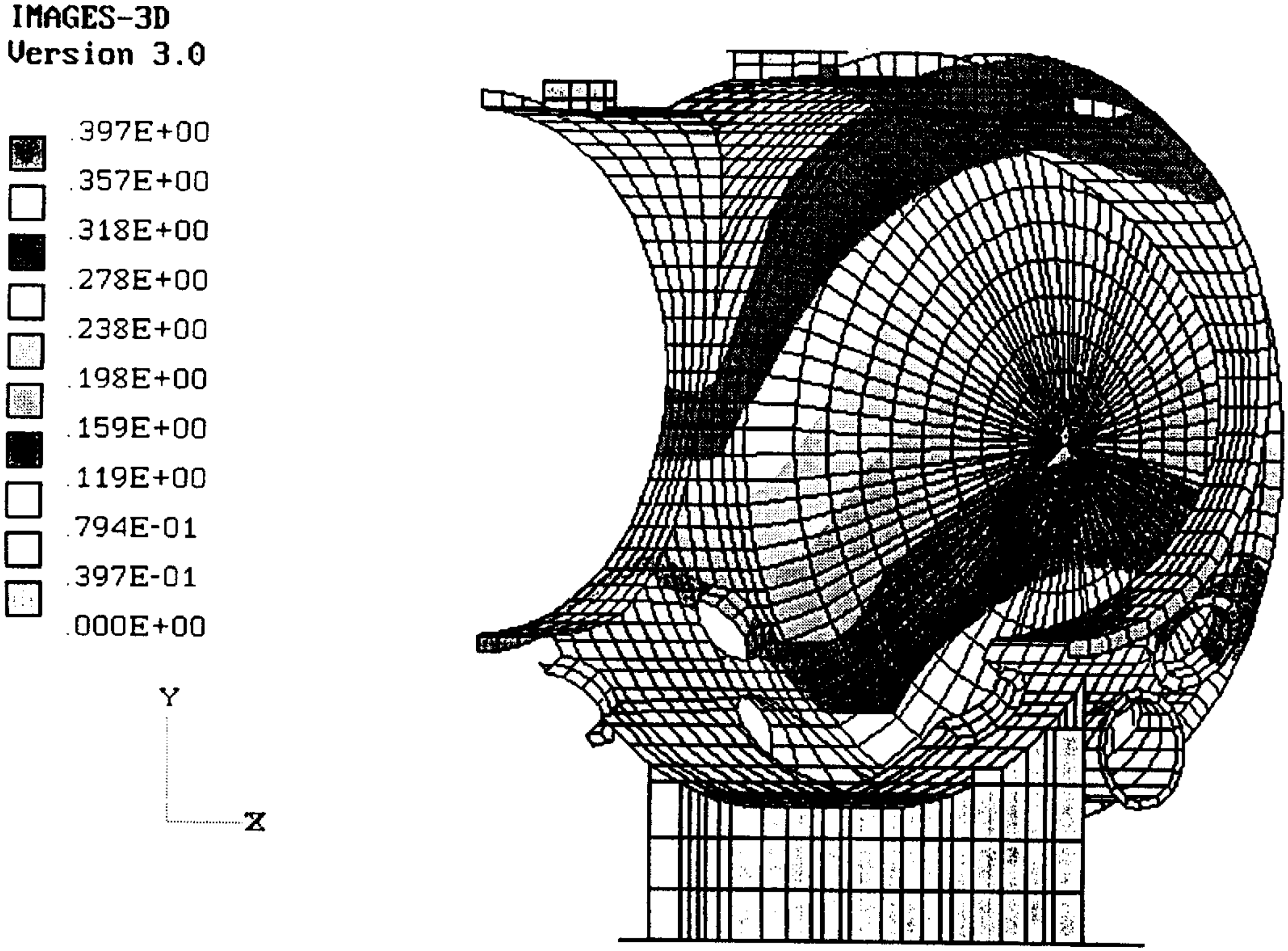


Fig 2 **Deflected Shape - Wireframe Plot**

12/20/95
9: 8:53



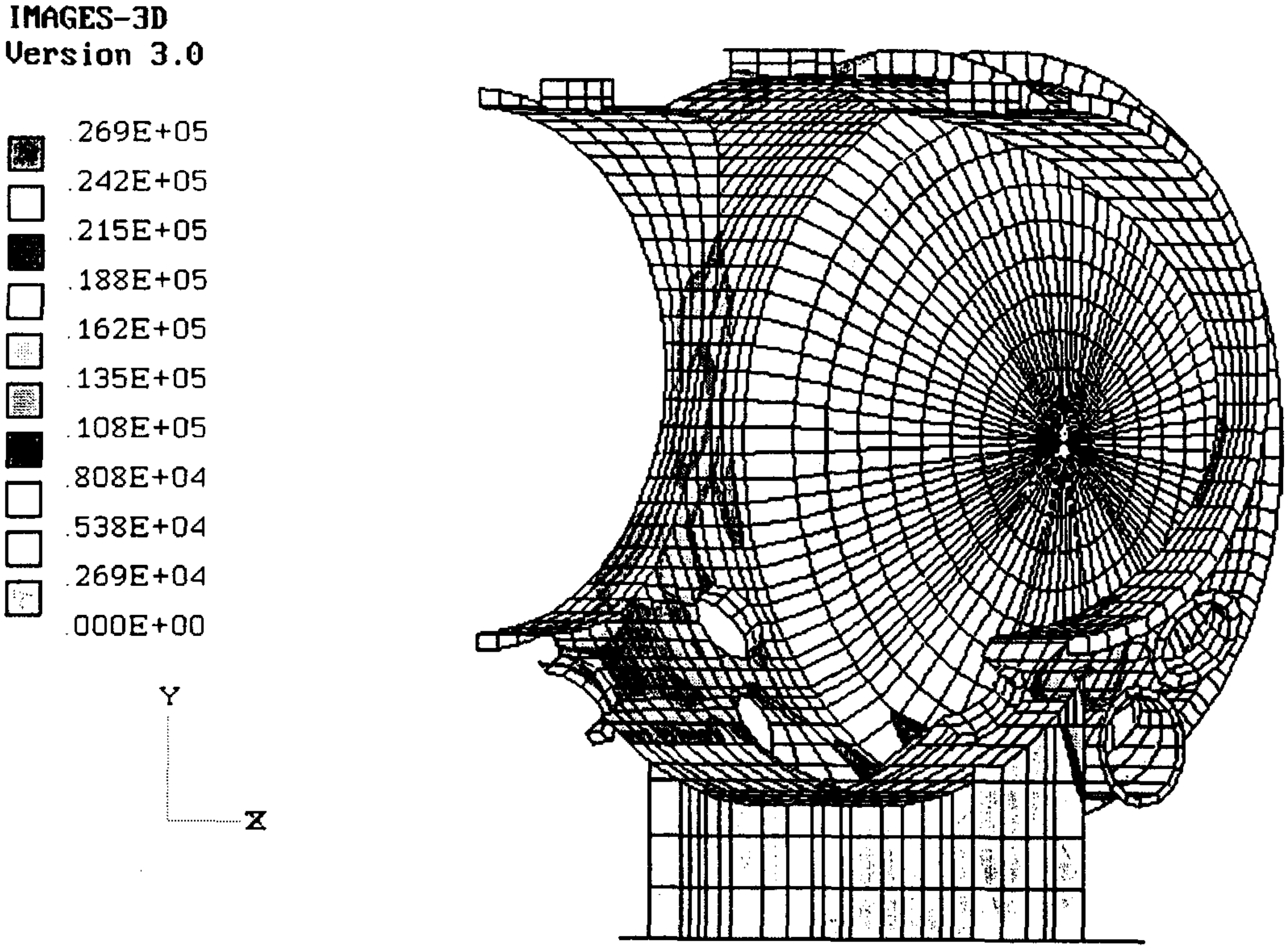
Load Case
1

Fig 3

Displacement Contour Plot
DS

1- Bellows Model

1/20/96
17:26:51



Load Case
1

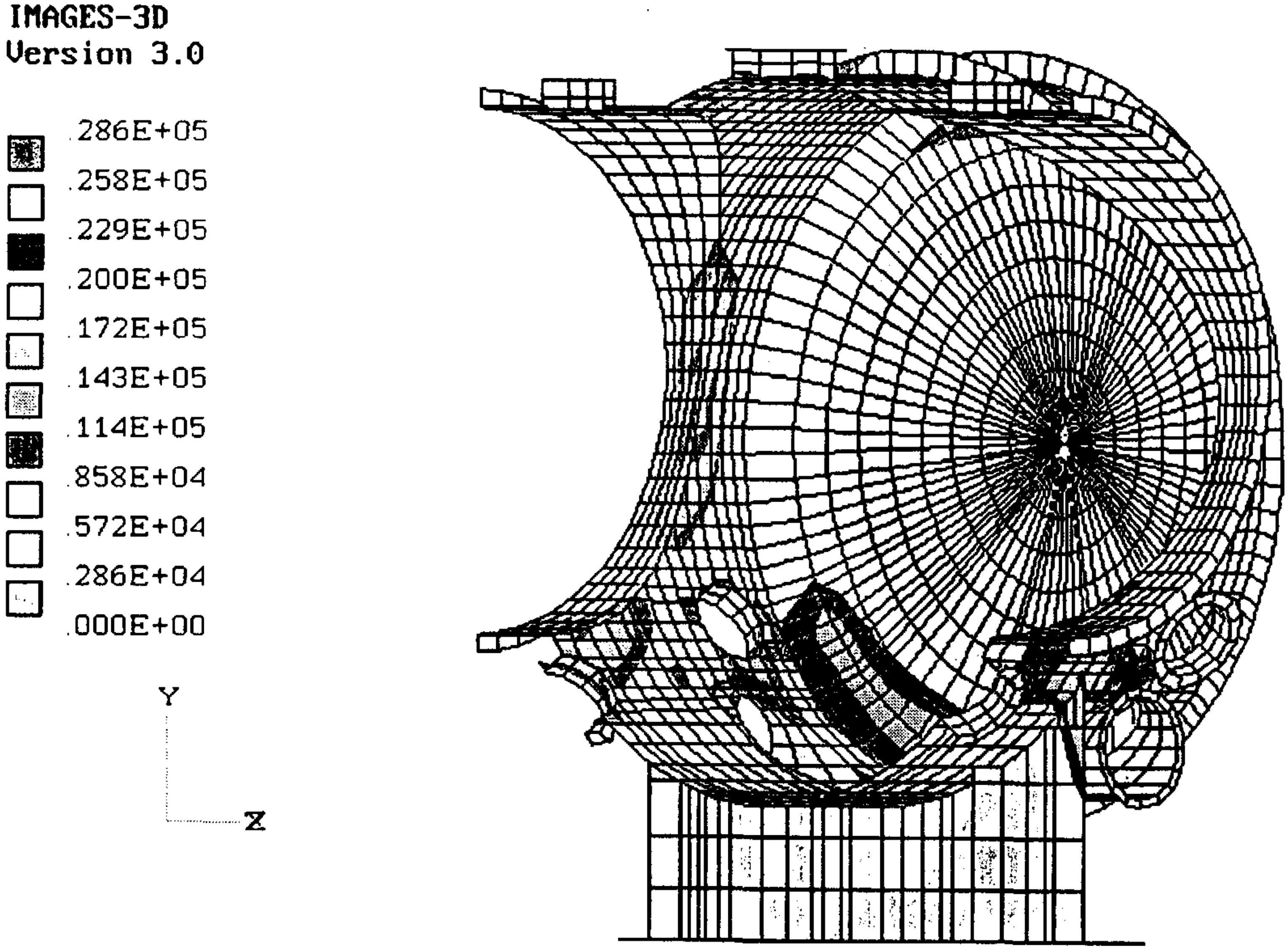
Stress Contour Plot

Surf: Top

Stress Intensity

1/16/96
11:50:53

Fig 4 Arc Bellows Head

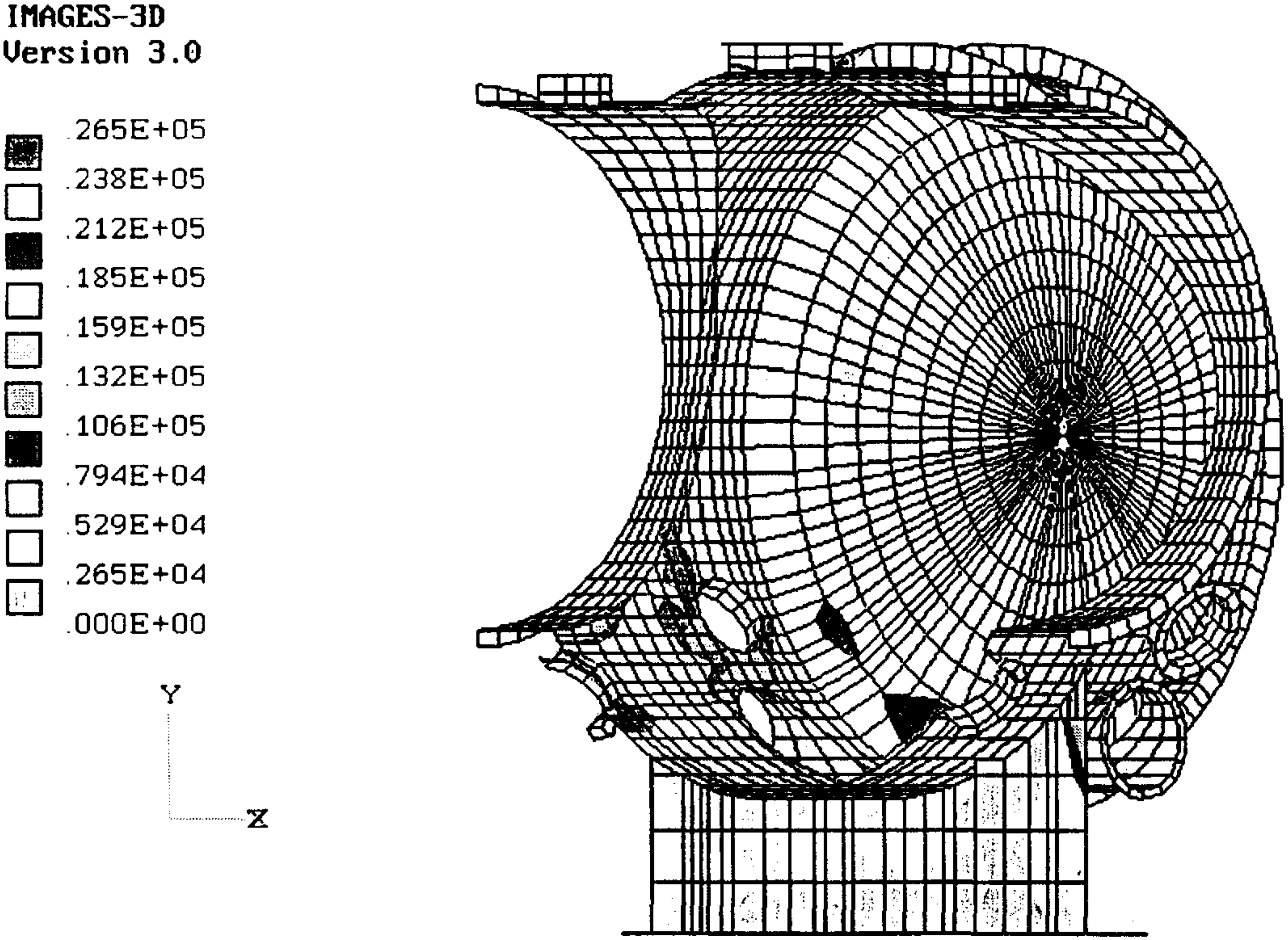


Load Case
1

Stress Contour Plot
Surf: Bottom **Stress Intensity**

1/16/96
12:15: 4

Fig 5 [illegible] Bottom [illegible]

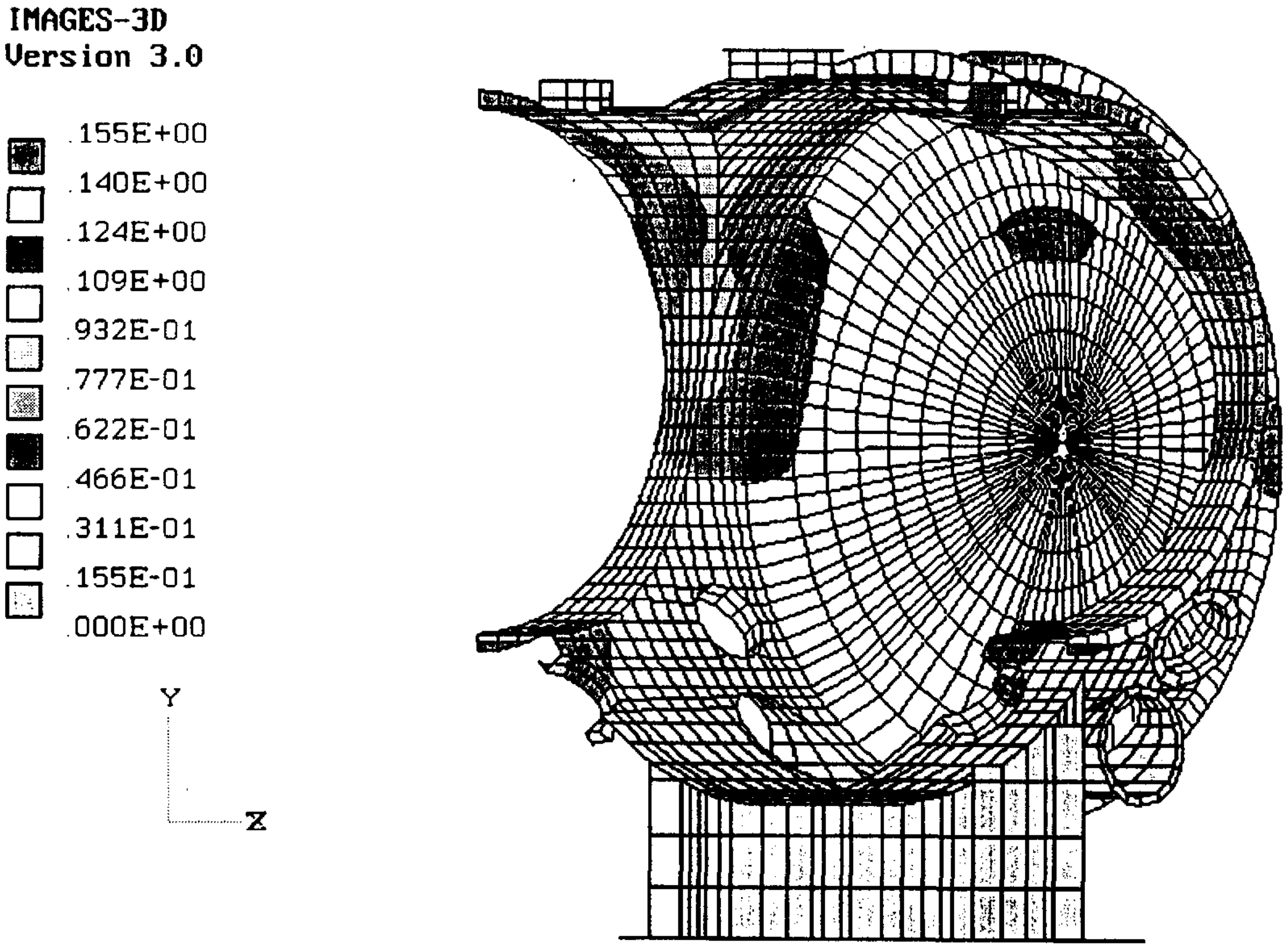


Load Case **Stress Contour Plot** **1/16/96**

1 **Membrane** **Stress Intensity** **12: 5:39**

Fig 6 [illegible] Bellows Model

15 of 19

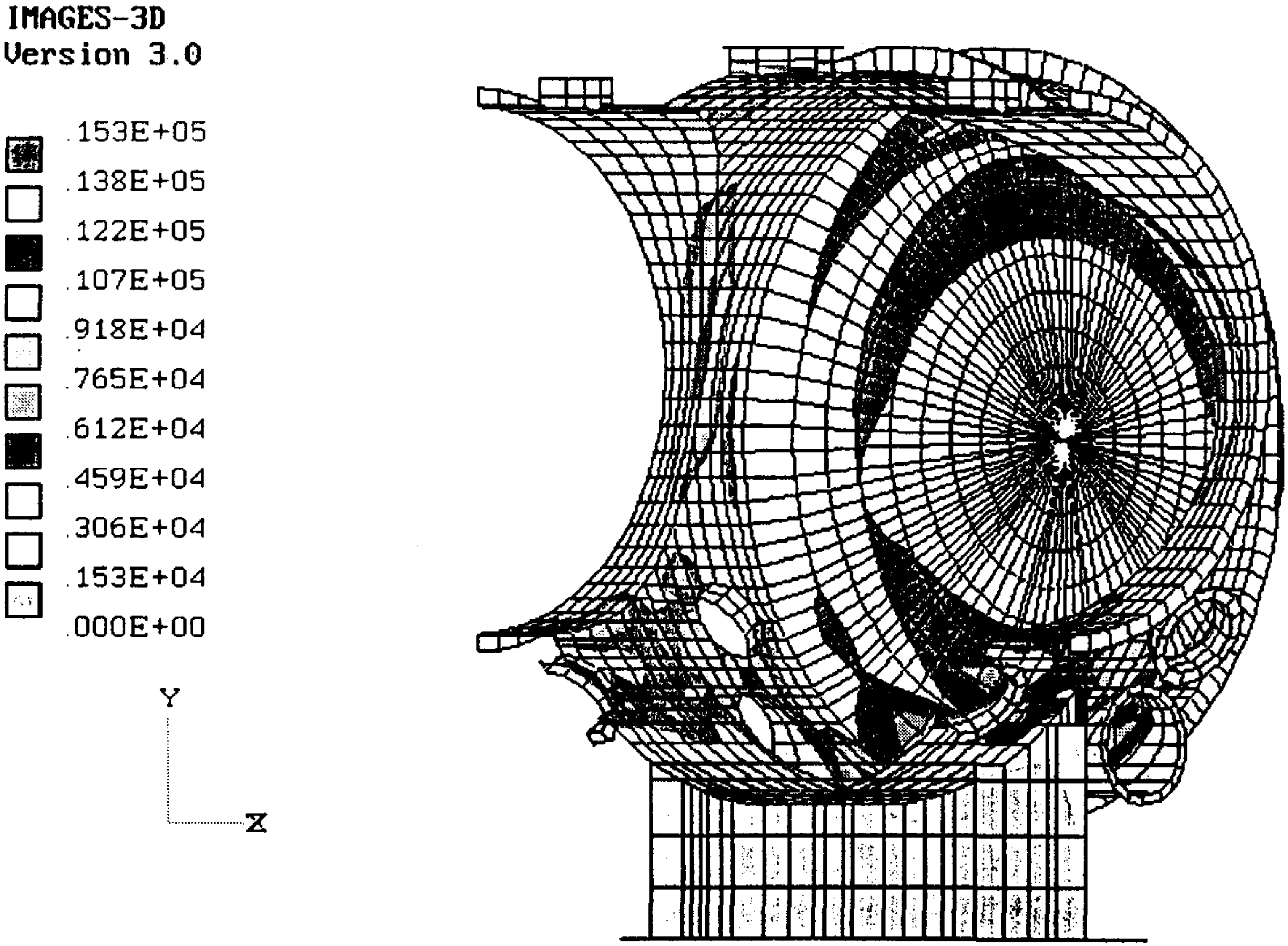


Load Case
2

Displacement Contour Plot
DS

1/20/96
17:34:46

Fig 2 Two Bellows Model



Load Case
2

Stress Contour Plot

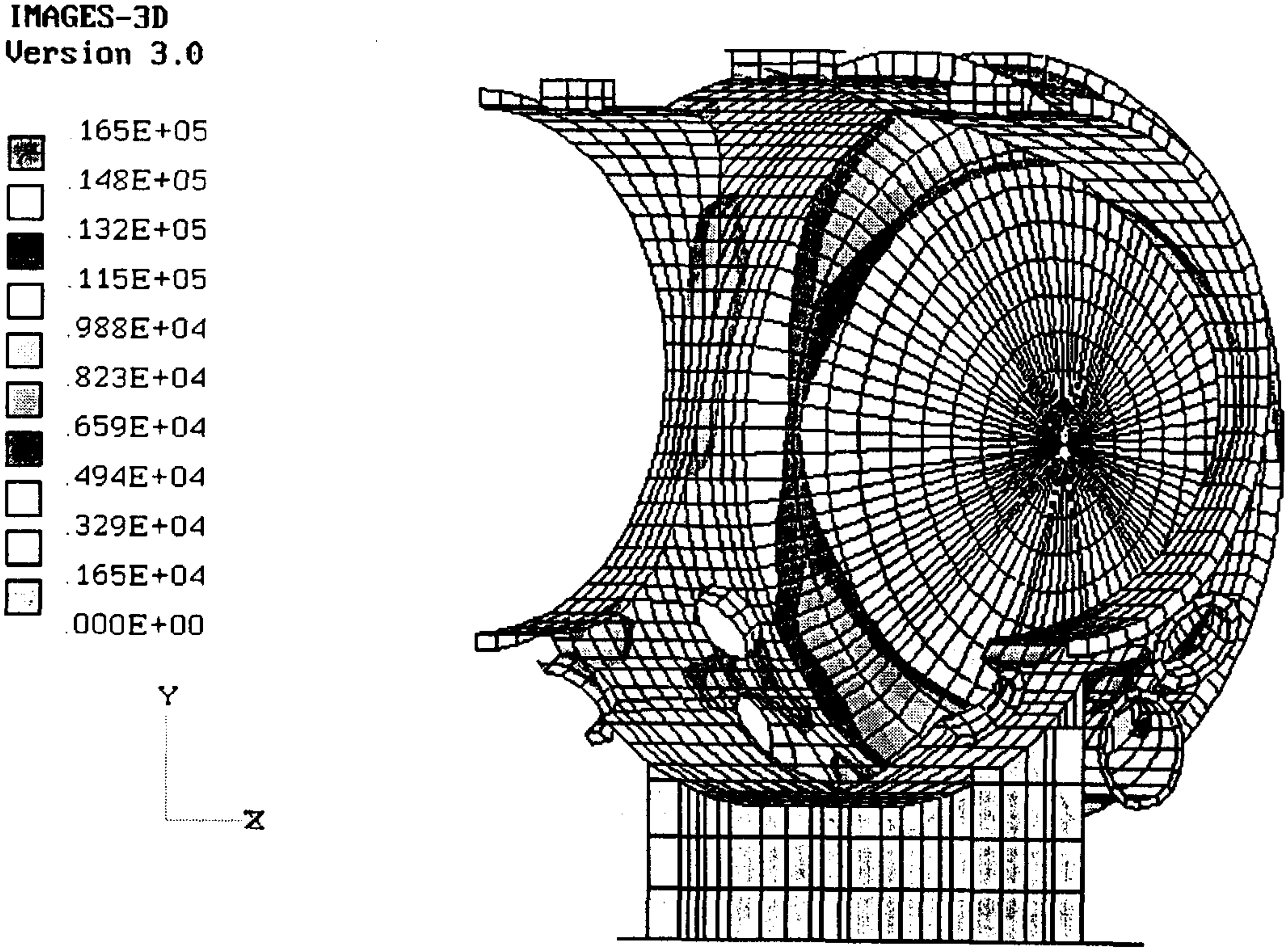
Surf: Top

Stress Intensity

1/16/96
12:53:58

Fig 8 [illegible] [illegible] [illegible]

17 of 19



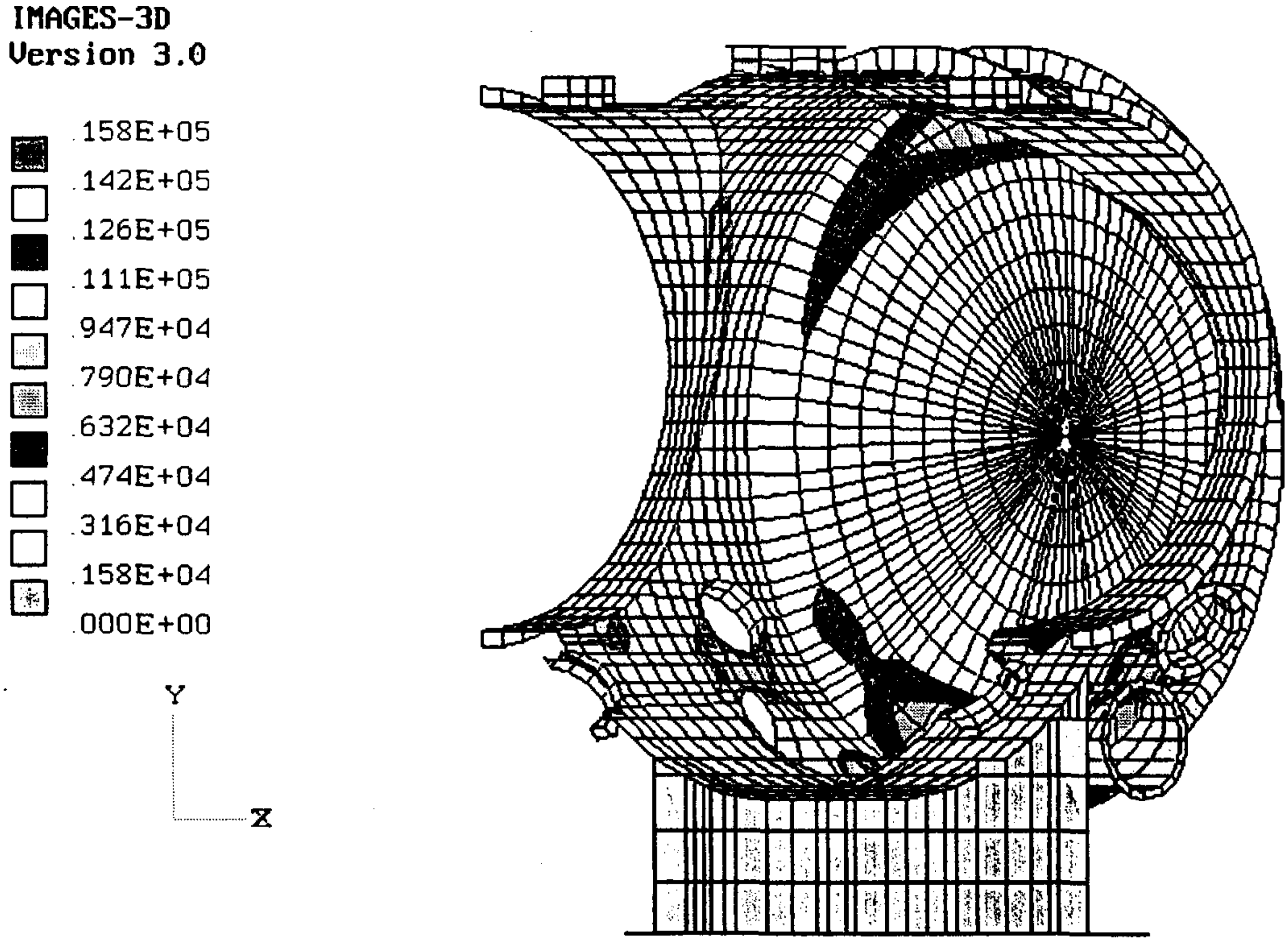
Load Case
2

Stress Contour Plot

Surf: Bottom **Stress Intensity**

1/16/96
13:19:28

Fig 7 Two Bellows Mod



Load Case
2

Stress Contour Plot

Membrane Stress Intensity

1/20/96
17:50:52

Fig 10 Two Bellows Model

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-041 PAGE 1 OF 6
REV.	DEO #	DATE	BY:	CHECK	TITLE: HAM Buckling Analysis	
0	0128	1/29/96	KM	RDC		
					BY: Kyle Martini	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE:. Evaluate the horizontal access module (HAM) for buckling modes.

METHOD: Finite element method and hand calculation.

ASSUMPTIONS: See attached.

INPUTS: LIGO project drawings and sketches.
Shell thickness = 0.5 in, 60 in nozzle thickness = 0.5 in, head thickness = 0.375 in
Thickness of other nozzles = 0.125 in, saddle wear plate thickness = 0.75 in,
Thickness of saddle and stiffeners = 0.5 in, baseplate thickness = 1.0 in

REFERENCES: NASTRAN Finite Element Program
DOC NO. V049-1-066, LIGO VAC. EQUIP. STRUCT. DES. CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The minimum factor of safety against elastic buckling for vacuum loading is 3.58.

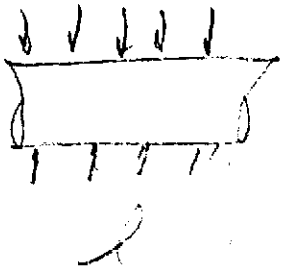
NOTES:

COMPUTER FILE. HAMLD.INP

FILED \F \TEMPLATE\ENGFORMS\ENGCALC

1.0 Hand Analysis

Assumptions; (1) Extra material of nozzle replaces stiffness of vessel material removed
(2) pressure uniform
(3) Cylinder length 74.8"



Ref. Roark 5th ed Table 35 case 19b
Short cylinder of length l, ends held circular but otherwise not constrained, no end loads

$$P_{cr} = .807 \frac{Et^2}{lr} \sqrt[4]{\frac{1}{1-\nu^2} \frac{t^2}{r^2}}$$

$t = .5"$ $l = 74.8$ $\nu = 0.3$

$r = 42.25"$ $E = 29(10^6)$ PSI

$$P_{cr} = 216.1 \text{ PSI}$$

$$F.S = \frac{P_{cr}}{14.7} = \underline{\underline{14.7}}$$

2.0 Computer Analysis

a. The same length shell is analyzed using NASTRAN buckling program

b. The shell is ½" thick with the opening for the 60" diameter tubes.

c. The small nozzles are not modeled. It is assumed the stiffness of the nozzle replaces the stiffness removed by the hole.

d. The stiffness of the tube nozzles are modeled as beams. Assuming the nozzles extend 3" and are ½" thick.

e. The vessel junction with the side heads are modeled as reinforcing rings 3"x1½"

f. An external pressure of 14.7 psi is applied to all plate elements.

g. An axial ring load is applied to the ends of the vessel equal to −pA

h. The vessel is restrained at its supports

i. Two configurations are model. A two bellows config and a one bellows

2.1 Results

Model	Factor of Safety
2 - bellows	11.8
1 - bellow (see fig)	11.9

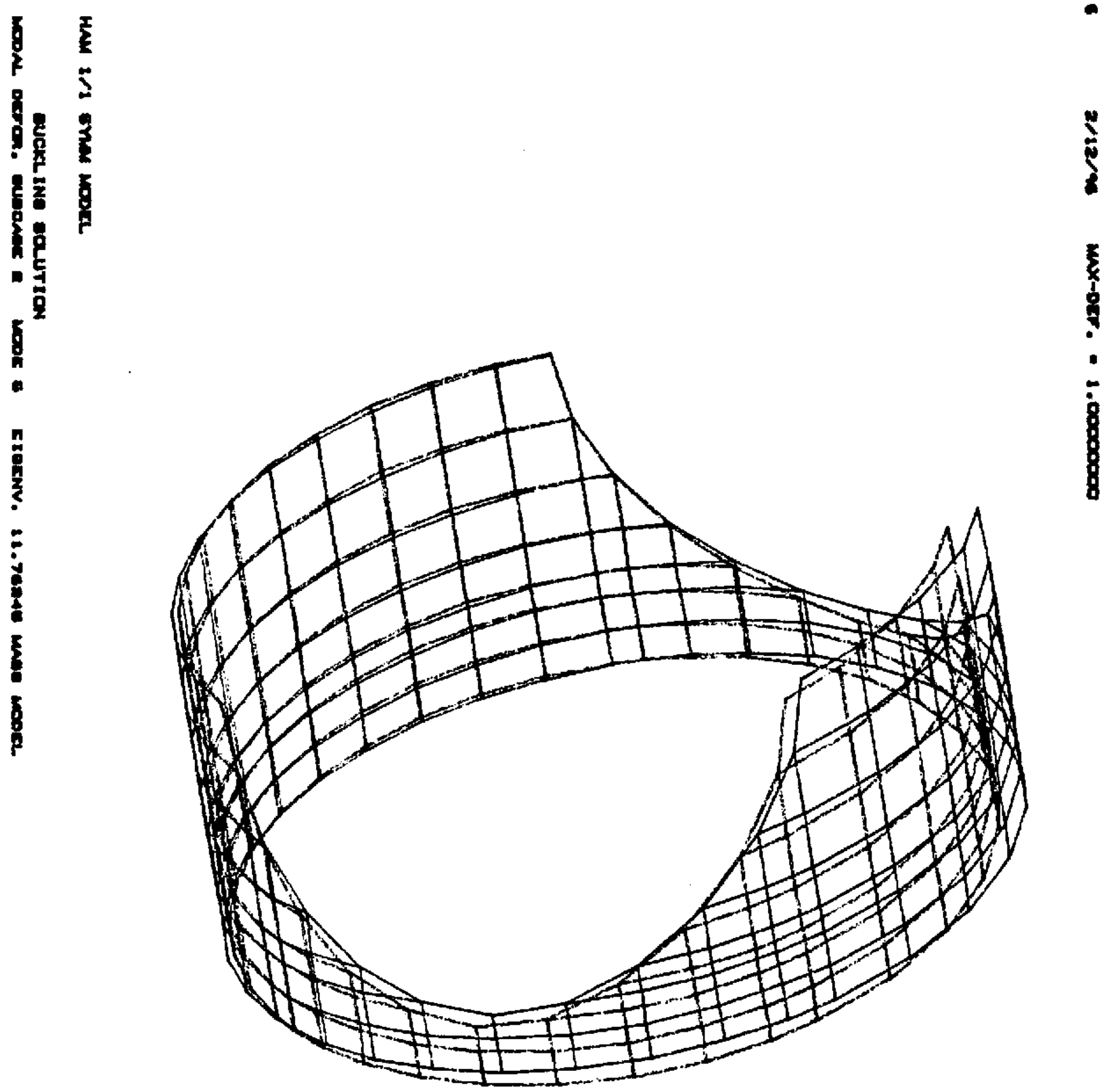
3.01 Alternative Model

Analysis on Static stress model (See fig 3)
reference Calc. V049-1-037

Model	Factor of Safety	
1. bellows	3.58	> 3.0
2. bellows	3.89	> 3.0

These values are believed to be conservative. The buckling modes extracted by NASTRAN are spurious due to the complicated model. The real modes are higher.

Fig 5 of 5



Fail - one bellows buckling shape

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6 of 6

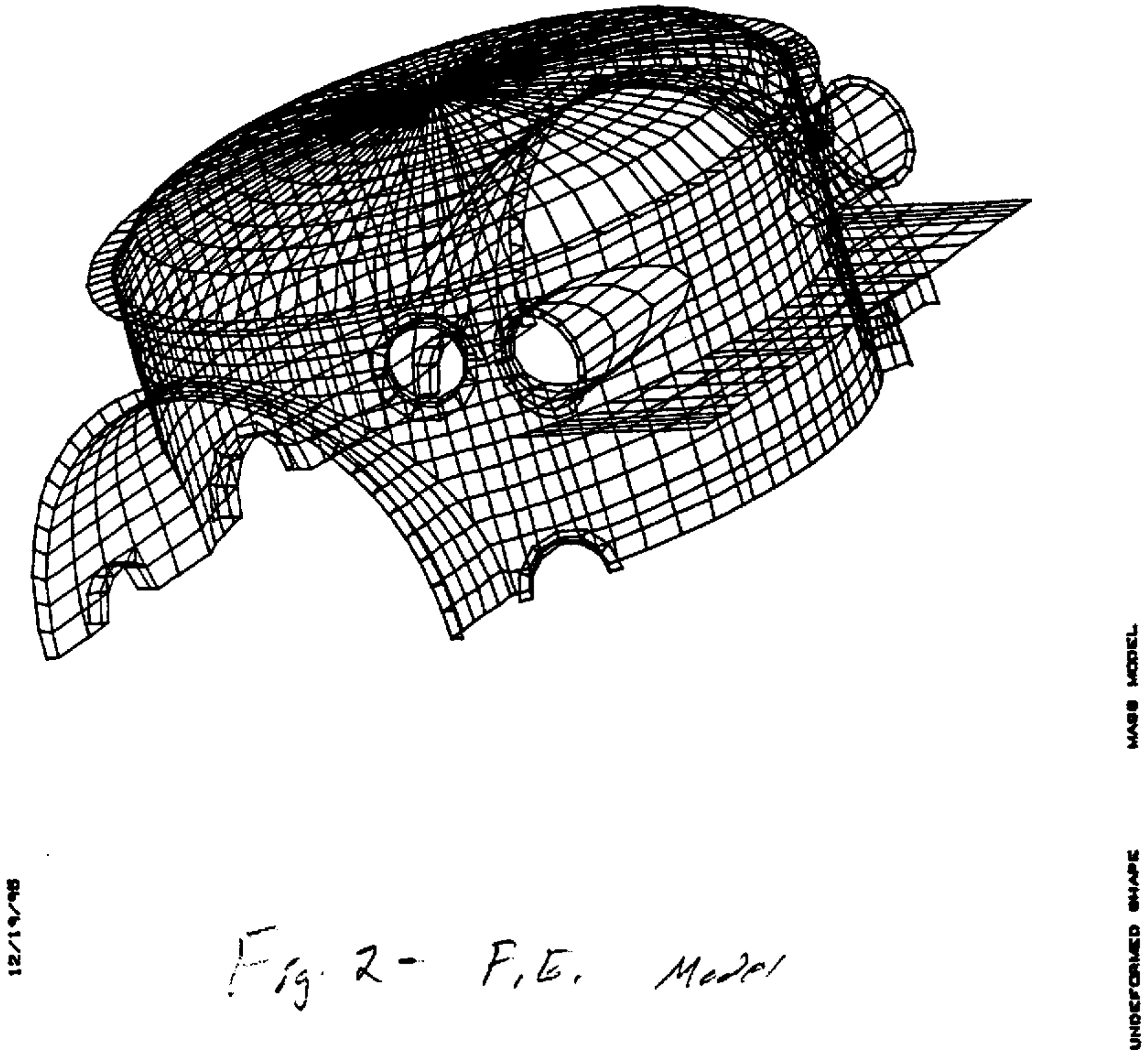

Fig. 2 - F.E. Model

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PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

REV.	DEO #	DATE	BY:	CHECK
0	0024	4-1-96	AGR	ROC

ENGINEERING CALCULATIONS

NO: V049-1-073

PAGE 1 OF 29

TITLE: 60" F+D HEAD/NOZZLE DESIGN FOR HAM

By: ART ROUSSOPOULOS **DEPT.:** 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: QUALIFY THE DESIGN OF THE 60" HAM COVER TO ASME VIII REQUIREMENTS

METHOD: • COMPRESS 5.53 COMPUTER PRESSURE VESSEL SOFTWARE

ASSUMPTIONS: SEE CALCS

INPUTS: "STRUCTURAL DESIGN CRITERIA" REF DOC. NO. V049-PL-73

REFERENCES: DOC. NO. V049-PL-73
DOC. NO. V049-1-066, LIGO VACUUM EQUIP. STRUCT. DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: COVER/NOZZLE DESIGN IS IN CONFORMANCE WITH ASME VIII REQUIREMENTS

NOTES: INSIDE DIAM ANALYZED = 60.25". ACTUAL ID = 60.5'
RESULTS ARE NOT AFFECTED

TABLE OF CONTENTS

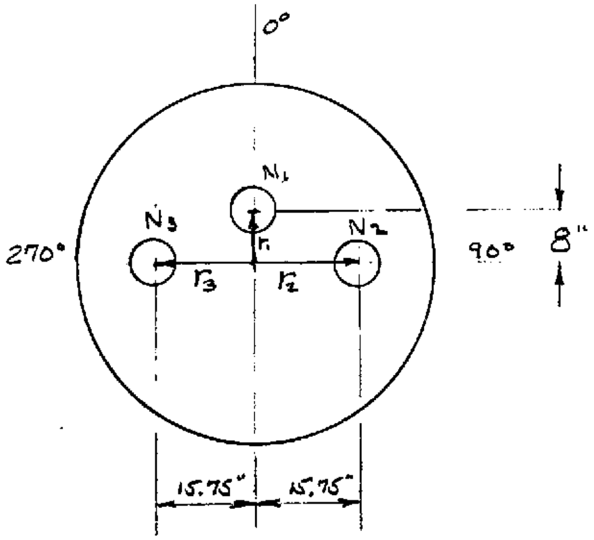
1.- SCOPE:

QUALIFY THE 60" HAM COVER TO ASME VIII REQUIREMENTS FOR THE NOZZLE LAYOUT AS PSI PROPOSED AND CUSTOMER MODIFIED PER DOC. NO. V049-PL-73

2.- DESIGN CRITERIA:

$P_{EXT.} = 14.7$ PSI
$T = 400$°F

3.- MODEL:



- NOZZLE LOCATION DATA:

- N1 $r_1 = 8"$
  $\theta_1 = 0°$
- N2 $r_2 = 15.75"$
  $\theta_2 = 90°$
- N3 $r_3 = 15.75"$
  $\theta_3 = 270°$

4.- COMPRESS 5.53 INPUT DATA:

- MATERIAL:
  - F+D HEAD: SA 240 304L HIGH
  - NOZZES (ALL): SA 240 304L HIGH
- EXTERNAL PRESSURE = 14.7 PSI
- DESIGN TEMP = 400°F

FOR F+D HEAD:

- LONG SEAM X-RAY
  - SEAMLESS ∴ NO X-RAY
- HEAD/SHELL SEAM X-RAY
  - SPOT PER UW-11(b) TYPE I
- ID = 60.25"
- CROWN INTERNAL RADIUS = 60.25"
- KNUCKLE INTERNAL RADIUS = 3.75"
- FORMING ALLOWANCE = 0"
- STRAIGHT FLANGE = 1"
- THICKNESS = .250"

FOR NOZZLES:

- ID = 7.5" (ALL)
- THICKNESS = .25" (ALL)
-

ANGLE Θ	DISTANCE r
N1: $\Theta_1 = 0°$	$r_1 = 8"$
N2: $\Theta_2 = 90°$	$r_2 = 15.75"$
N3: $\Theta_3 = 270°$	$r_3 = 15.75"$

5. - COMPRESS 5.53 - OUTPUT

OUTPUT FOR 60" F+D HEAD INCLUDING NOZZLES 1 + 2 ARE ATTACHED TO VERIFY COMPLIANCE TO ASME VIII, 1992 EDITION INCLUDING A93 ADDENDA

NOTE: ANALYSIS / RESULTS FOR NOZZLE # 3 IS SYMMETRICALLY IDENTICAL TO NOZZLE # 2.

TABLE OF CONTENTS

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	Nozzle Status (UG-45)	T design (deg F)	MAWP (psi)	MAP (psi)	Pe external (psi)	UG-99 Ratio	UCS-66		Corrosion Allowance (in)
							MDMT (deg F)	Exemption or Stress Reduction	
60" F&D HAM HEAD		0.0	67.2	67.2	20.6	1.000		Not applicable	0.000
n1 N1-CENTER	ok	0.0	79.0	79.0	15.5	1.000		Not applicable	0.000
n2 N2-RIGHT	ok	0.0	79.0	79.0	15.3	1.000		Not applicable	0.000
n3 N3-LEFT	ok	0.0	79.0	79.0	15.3	1.000		Not applicable	0.000

Vessel MAWP hot & corroded is 67.2 psi @ 0 degrees F.

Vessel MAP new & cold is 67.2 psi @ 70 degrees F.

Vessel allowable external pressure is 15.31 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1 = 100.8 psi

Vessel hydrotest pressure is 100.8 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
60" f&d ham hea	273	273	0	0	0	0	0	0	0	0	741	24
	273	273	0	0	0	0	0	0	0	0	741	24

Vessel operating weight, corroded: 297 lbs
Vessel empty weight, corroded: 297 lbs
Vessel empty weight, new: 297 lbs
Vessel test weight, new: 1,038 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new: 297 lbs
Center of gravity to seam: 7.6 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 (%)
n1	8.00	0.2500	0.1427	y	y	0.2500	0.1973	0.2500	0.0000	100.5
n2	8.00	0.2500	0.1427	y	y	0.2500	0.1937	0.2500	0.0000	104.3
n3	8.00	0.2500	0.1427	y	y	0.2500	0.1937	0.2500	0.0000	104.3

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

Thickness Summary

```
-----------------------------------------------------------------------------------------------
Component               ID      Length    Nom t    Req t   Joint         Governing          Deflect
Identifier             (in)      (in)     (in)     (in)      E     Load    Status    Stress   (in)
-----------------------------------------------------------------------------------------------
60" f&d ham head       60.25              0.2500   0.2500  0.85
-----------------------------------------------------------------------------------------------
```

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

60" F&D HAM HEAD

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: F&D head
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Seamless NO X-Ray
Head to shell seam - Spot UW-11(b) type 1

Estimated weight: new = 272.9 corr = 272.9 lb
capacity: new = 88.89 corr = 88.89 US ga

ID = 60.25 crown L = 60.25 knuckle r = 3.75 t = .25 in (min)

Straight flange = 1 forming allowance = 0 in

MAP: (New & at 70 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.25/(60.25*1.7521 + 0.2*0.25) - 0
= 67.20225 psi

MAWP: (Corroded & at 0 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.25/(60.25*1.7521 + 0.2*0.25) - 0
= 67.20225 psi

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

A = .125/(Ro/t)
= .125/(60.5/0.25)
= 0.000517

From table HA-3: B = 5004.1

Pa= B/(Ro/t)
= 5004.1/(60.5/0.25)
= 20.6781 psi

Check the Maximum External Pressure: UG-33(a)(1) & App. 1-4(d)

Pe= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
= 2*14700*1*0.25/((1.7521*60.5 - 0.25*(1.7521-0.2))*1.67)
= 41.67247 psi

The maximum allowable external pressure is 20.6781 psi.

N1-CENTER

Opening n1 Reinforcement Calculations Per UG-37

```
Located on:                       60" F&D HAM HEAD
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 datum line:      14.53 in
Nozzle calculated as hillside:    yes
Projection outside vessel Lpr:    3.527 in
```

```
  tn ->| |<-
        _         _            corrosion allow = 0 in
       | |<- d ->| |           noz thick new tn= .25 in
tw1->| | <        | |          nozzle id. new d= 7.5 in
     |/| |  v     | |\         fillet weld tw1 = .25 in
_____.-| |  -     | |-.____    groove weld tw2 = .1875 in
_____\|_|_tw2     |_|/_____
          ^
<---- R ---->|                 To head center R= 8 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.567 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((8 + 3.75)/60.32135)
       = 78.76797

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((8 - 3.75)/60.32135)
       = 85.96029

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*60.32135*Sin((85.96029 - 78.76797)/2)
  = 7.567 in
```

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 79.06141*3.75/(16700*1 - 0.6*79.06141)
    = 0.0178 in
```

N1-CENTER

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 79.06141*60.25*1/(2*16700*1 - 0.2*79.06141)
  = 0.1427 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)
  = 7.567*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
  = 1.0798 in^2
```

Area available

```
A1 = larger of the following                    = .812 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.567*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .812 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .107 in^2

A2 = smaller of the following                    = 0.29 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0178)*1*0.25
  = .29 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0178)*1*0.25
  = .29 in^2

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

Area = A1 + A2 + A41
  = 0.812 + 0.29 + 0.063
  = 1.165 in^2

As Area > A the reinforcement is adequate for MAWP = 79.06141 at 0 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
```

= 7.5*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
= 1.07025 in^2

Area available

A1 = larger of the following = .805 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
= .805 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
= .107 in^2

Area = A1 + A2 + A41
= 0.805 + 0.29 + 0.063
= 1.158 in^2

As Area > A the reinforcement is adequate for MAWP = 79.06141 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 = 0.0178 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.1427 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 in
The greater of tr2 or tr3:	tr5 = 0.1427 in
The lesser of tr4 or tr5:	tr6 = 0.1427 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1427 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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.0798 - (7.567 - 2*0.25)*(1*0.25 - 1*0.1427))*16700
= 5369.232 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.29 + 0 + 0.063 + 0)*16700
= 5895.1 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.29 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7982.6 lbf

Load for path 1-1 lesser of W or W1-1 = 5369.232 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 5369.232 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.567 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((8 + 3.75)/60.32135)
= 78.76797

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((8 - 3.75)/60.32135)
= 85.96029

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*60.32135*Sin((85.96029 - 78.76797)/2)
= 7.567 in

N1-CENTER

Nozzle required thickness

```
 trn = P*Rn/(Sn*E - 0.6*P)
     = 79.06141*3.75/(16700*1 - 0.6*79.06141)
     = 0.0178 in
```

Required thickness tr from UG-37(a)(1)

```
 tr= P*L*M/(2*S*E - 0.2*P)
   = 79.06141*60.25*1/(2*16700*1 - 0.2*79.06141)
   = 0.1427 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)
   = 7.567*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
   = 1.0798 in^2
```

Area available

```
 A1 = larger of the following                 = .812 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.567*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .812 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .107 in^2

 A2 = smaller of the following                = 0.29 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

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

 Area = A1 + A2 + A41
   = 0.812 + 0.29 + 0.063
   = 1.165 in^2

 As Area > A the reinforcement is adequate for MAP = 79.06141 at 70 Deg F
```

N1-CENTER

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
  = 7.5*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
  = 1.07025 in^2
```

Area available

```
A1 = larger of the following                  = .805 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .805 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .107 in^2

Area = A1 + A2 + A41
  = 0.805 + 0.29 + 0.063
  = 1.158 in^2
```

As Area > A the reinforcement is adequate for MAP = 79.06141 at 70 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 = 0.0178 in (E = 1)
Wall thickness per UG-45(b)(1):      tr2 = 0.1427 in
Wall thickness per UG-16(b):         tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):       tr4 = 0.28175 in
The greater of tr2 or tr3:           tr5 = 0.1427 in
The lesser of tr4 or tr5:            tr6 = 0.1427 in
```

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1427 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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
  = (1.0798 - (7.567 - 2*0.25)*(1*0.25 - 1*0.1427))*16700
  = 5369.232 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
  = (0.29 + 0 + 0.063 + 0)*16700
  = 5895.1 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
  = (0.29 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
  = 7982.6 lbf

Load for path 1-1 lesser of W or W1-1 = 5369.232 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 5369.232 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.567 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
  = ArcCos((8 + 3.75)/60.34865)
  = 78.77312

Theta2 = ArcCos((Lo - Rn)/Rm)
  = ArcCos((8 - 3.75)/60.34865)

N1-CENTER

```
      = 85.96212

 d = 2*Rm*Sin((Theta2 - Theta1)/2)
   = 2*60.34865*Sin((85.96212 - 78.77312)/2)
   = 7.567 in
```

Nozzle required thickness

```
   L/Do = 3.527/8 = .4409            Do/t = 8/0.01981 = 403.8364
   From table G:                        A = 0.000383
   From table HA-3:                     B = 4746.9

 Pa= 4*B/(3*Do/t)
   = 4*4746.9/(3*8/0.01981)
   = 15.6727 psi

 Nozzle required thickness trn = .01981 in
```

Required thickness tr from UG-37(d)(1) = .1973 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*(7.567*0.1973*1 + 2*0.25*0.1973*1*(1 - 1))
   = .7465 in^2
```

Area available

```
 A1 = larger of the following              = .399 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.567*(1*0.25-1*0.1973) - 2*0.25*(1*0.25-1*0.1973)*(1-1)
   = .399 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*0.1973) - 2*0.25*(1*0.25-1*0.1973)*(1-1)
   = .053 in^2

 A2 = smaller of the following              = 0.288 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.01981)*1*0.25
   = .288 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.01981)*1*0.25
   = .288 in^2
```

N1-CENTER

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

Area = A1 + A2 + A41
  = 0.399 + 0.288 + 0.063
  = .75 in^2

As Area > A the reinforcement is adequate for Pe = 15.58935 at 400 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
  = 0.5*(7.5*0.1973*1 + 2*0.25*0.1973*1*(1 - 1))
  = .739875 in^2
```

Area available

```
A1 = larger of the following                = .395 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.25-1*0.1973) - 2*0.25*(1*0.25-1*0.1973)*(1-1)
  = .395 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*0.1973) - 2*0.25*(1*0.25-1*0.1973)*(1-1)
  = .053 in^2

Area = A1 + A2 + A41
  = 0.395 + 0.288 + 0.063
  = .746 in^2

As Area > A the reinforcement is adequate for Pe = 15.58935 at 400 Deg F
```

UG-45 Nozzle Neck Thickness Check

```
Wall thickness per UG-45(a):        tr1 = 0.01981 in (E = 1)
Wall thickness per UG-45(b)(2):     tr2 = 0.032 in
Wall thickness per UG-16(b):        tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):      tr4 = 0.28175 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.
```

N2-RIGHT

Opening n2 Reinforcement Calculations Per UG-37

```
Located on:                       60" F&D HAM HEAD
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 datum line:      14.53 in
Nozzle calculated as hillside:    yes
Projection outside vessel Lpr:    5.082 in
```

```
   tn ->|  |<-
         _             _           corrosion allow = 0 in
        |  |<- d ->|  |            noz thick new tn= .25 in
tw1->|  |< |       |  |            nozzle id. new d= 7.5 in
     |/ |  |   v   |  |\           fillet weld tw1 = .25 in
_____.- |  |   --  |  |-.______    groove weld tw2 = .1875 in
______\|_|_tw2     |_|/______
               ^
<---- R ---->|                     To head center R= 15.75 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.771 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((15.75 + 3.75)/60.32135)
       = 71.13968

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((15.75 - 3.75)/60.32135)
       = 78.52576

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*60.32135*Sin((78.52576 - 71.13968)/2)
  = 7.771 in
```

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 79.06141*3.75/(16700*1 - 0.6*79.06141)
    = 0.0178 in
```

N2-RIGHT

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 79.06141*60.25*1/(2*16700*1 - 0.2*79.06141)
  = 0.1427 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)
  = 7.771*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
  = 1.1089 in^2
```

Area available

```
A1 = larger of the following                    = .834 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.771*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .834 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .107 in^2

A2 = smaller of the following                   = 0.29 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

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

Area = A1 + A2 + A41
   = 0.834 + 0.29 + 0.063
   = 1.187 in^2

As Area > A the reinforcement is adequate for MAWP = 79.06141 at 0 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
```

```
   = 7.5*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
   = 1.07025 in^2
```

Area available

```
 A1 = larger of the following                  = .805 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.5*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .805 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .107 in^2

 Area = A1 + A2 + A41
   = 0.805 + 0.29 + 0.063
   = 1.158 in^2
```

As Area > A the reinforcement is adequate for MAWP = 79.06141 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 = 0.0178 in (E = 1)
 Wall thickness per UG-45(b)(1):       tr2 = 0.1427 in
 Wall thickness per UG-16(b):          tr3 = 0.0625 in
 Std pipe wall per UG-45(b)(4):        tr4 = 0.28175 in
 The greater of tr2 or tr3:            tr5 = 0.1427 in
 The lesser of tr4 or tr5:             tr6 = 0.1427 in
```

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1427 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:

N2-RIGHT

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.1089 - (7.771 - 2*0.25)*(1*0.25 - 1*0.1427))*16700
= 5489.652 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.29 + 0 + 0.063 + 0)*16700
= 5895.1 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.29 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7982.6 lbf

Load for path 1-1 lesser of W or W1-1 = 5489.652 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 5489.652 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.771 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((15.75 + 3.75)/60.32135)
= 71.13968

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((15.75 - 3.75)/60.32135)
= 78.52576

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*60.32135*Sin((78.52576 - 71.13968)/2)
= 7.771 in

N2-RIGHT

Nozzle required thickness

```
 trn = P*Rn/(Sn*E - 0.6*P)
     = 79.06141*3.75/(16700*1 - 0.6*79.06141)
     = 0.0178 in
```

Required thickness tr from UG-37(a)(1)

```
 tr= P*L*M/(2*S*E - 0.2*P)
   = 79.06141*60.25*1/(2*16700*1 - 0.2*79.06141)
   = 0.1427 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)
   = 7.771*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
   = 1.1089 in^2
```

Area available

```
 A1 = larger of the following                 = .834 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.771*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .834 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
   = .107 in^2

 A2 = smaller of the following                 = 0.29 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.0178)*1*0.25
   = .29 in^2

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

 Area = A1 + A2 + A41
   = 0.834 + 0.29 + 0.063
   = 1.187 in^2

 As Area > A the reinforcement is adequate for MAP = 79.06141 at 70 Deg F
```

N2-RIGHT

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
  = 7.5*0.1427*1 + 2*0.25*0.1427*1*(1 - 1)
  = 1.07025 in^2
```

Area available

```
A1 = larger of the following                = .805 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.25-1*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .805 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*0.1427) - 2*0.25*(1*0.25-1*0.1427)*(1-1)
  = .107 in^2

Area = A1 + A2 + A41
  = 0.805 + 0.29 + 0.063
  = 1.158 in^2
```

As Area > A the reinforcement is adequate for MAP = 79.06141 at 70 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 = 0.0178 in (E = 1)
Wall thickness per UG-45(b)(1):      tr2 = 0.1427 in
Wall thickness per UG-16(b):         tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):       tr4 = 0.28175 in
The greater of tr2 or tr3:           tr5 = 0.1427 in
The lesser of tr4 or tr5:            tr6 = 0.1427 in
```

Req'd per UG-45 is the larger of tr1 or tr6 = 0.1427 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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.1089 - (7.771 - 2*0.25)*(1*0.25 - 1*0.1427))*16700
= 5489.652 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.29 + 0 + 0.063 + 0)*16700
= 5895.1 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.29 + 0 + 0.063 + 0 + 2*0.25*0.25*1)*16700
= 7982.6 lbf

Load for path 1-1 lesser of W or W1-1 = 5489.652 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 5489.652 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.77 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((15.75 + 3.75)/60.34685)
= 71.14795

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((15.75 - 3.75)/60.34685)

N2-RIGHT

```
        = 78.53069

  d = 2*Rm*Sin((Theta2 - Theta1)/2)
    = 2*60.34685*Sin((78.53069 - 71.14795)/2)
    = 7.77 in
```

Nozzle required thickness

```
   L/Do = 5.082/8 = .6352             Do/t = 8/0.02205 = 362.8118
   From table G:                         A = 0.000317
   From table HA-3:                      B = 4194.4

  Pa= 4*B/(3*Do/t)
    = 4*4194.4/(3*8/0.02205)
    = 15.4144 psi

  Nozzle required thickness trn = .02205 in
```

Required thickness tr from UG-37(d)(1) = .1937 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*(7.77*0.1937*1 + 2*0.25*0.1937*1*(1 - 1))
    = .7525 in^2
```

Area available

```
  A1 = larger of the following                    = .437 in^2

    = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
    = 7.77*(1*0.25-1*0.1937) - 2*0.25*(1*0.25-1*0.1937)*(1-1)
    = .437 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*0.1937) - 2*0.25*(1*0.25-1*0.1937)*(1-1)
    = .056 in^2

  A2 = smaller of the following                    = 0.285 in^2

    = 5*(tn - trn)*fr2*t
    = 5*(0.25 - 0.02205)*1*0.25
    = .285 in^2

    = 5*(tn - trn)*fr2*tn
    = 5*(0.25 - 0.02205)*1*0.25
    = .285 in^2
```

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

Area = A1 + A2 + A41
   = 0.437 + 0.285 + 0.063
   = .785 in^2
```

As Area > A the reinforcement is adequate for Pe = 15.31362 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
  = 0.5*(7.5*0.1937*1 + 2*0.25*0.1937*1*(1 - 1))
  = .726375 in^2
```

Area available

```
A1 = larger of the following                    = .422 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.5*(1*0.25-1*0.1937) - 2*0.25*(1*0.25-1*0.1937)*(1-1)
   = .422 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*0.1937) - 2*0.25*(1*0.25-1*0.1937)*(1-1)
   = .056 in^2

Area = A1 + A2 + A41
   = 0.422 + 0.285 + 0.063
   = .77 in^2
```

As Area > A the reinforcement is adequate for Pe = 15.31362 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

```
Wall thickness per UG-45(a):          tr1 = 0.02205 in (E = 1)
Wall thickness per UG-45(b)(2):       tr2 = 0.0314 in
Wall thickness per UG-16(b):          tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):        tr4 = 0.28175 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.

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

REV.	DEO #	DATE	BY:	CHECK
0	0029	3-30-96	AGR	RDG

ENGINEERING CALCULATIONS

NO: V049-1-074

PAGE 1 OF 38

TITLE: 84" F+D HEAD/NOZZLE DESIGN FOR HAM

By: ART KOUSSOPOULOS **DEPT.:** 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: QUALIFY THE DESIGN OF THE 84" HAM COVER TO ASME VIII REQUIREMENTS

METHOD: •COMPRESS 5.53 COMPUTER PRESSURE VESSEL SOFTWARE

ASSUMPTIONS: SEE CALCS

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

REFERENCES: DOC. NO, V049-PL-73
DWG. NO, V049-A-040
Doc. No, V049-1-066, LIGO VACUUM EQUIP., STRUCTURAL DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: COVER/NOZZLE DESIGN IS IN CONFORMANCE WITH ASME VIII, REQUIREMENTS

NOTES:

TABLE OF CONTENTS

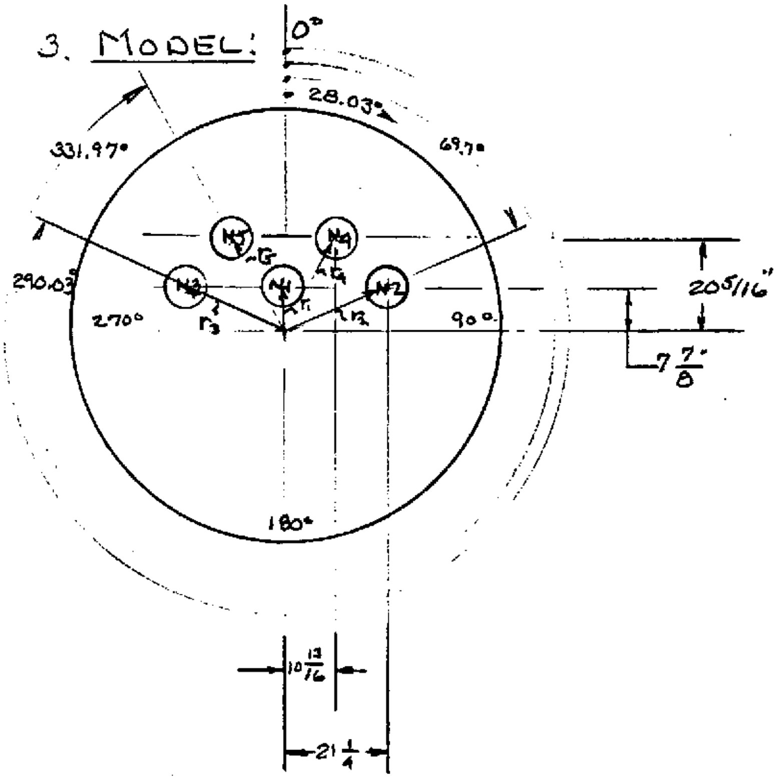
1.- SCOPE:

- QUALIFY THE 84" HAM COVER TO ASME VIII REQUIREMENTS FOR THE NOZZLE LAYOUT AS PSI PROPOSED AND CUSTOMER ACCEPTANCE PER DOC. NO. V049-PL-73

2. DESIGN CRITERIA:

$P_{EXT.} = 14.7$ PSI
$T = 400°F$

3. MODEL:



- NOZZLE LOCATION DATA:

- N1 $r_1 = 7.875"$; $\theta_1 = 0°$
- N2 $r_2 = \sqrt{21.25^2 + 7.875^2} = 22.66"$; $\theta_2 = \tan^{-1}\frac{21.25}{7.875} = 69.7°$
- N3 $r_3 = r_2 = 22.66"$; $\theta_3 = (90-69.7)+270 = 290.3°$
- N4 $r_4 = \sqrt{10.8125^2 + 20.3125^2} = 23.01"$; $\theta_4 = \tan^{-1}\frac{10.8125}{20.3125} = 28.03°$
- N5 $r_5 = r_4 = 23.01"$; $\theta = (90-28.03)+270 = 331.97°$

4 - COMPRESS 5.53 - INPUT DATA:

- MATERIAL:
  - F+D HEAD: SA 240 304L HIGH
  - NOZZLES (ALL) SA 240 304L HIGH
- EXTERNAL PRESSURE = 14.7 PSI
- DESIGN TEMP. = 400°F

FOR F+D HEAD:

- LONG. SEAM X-RAY
  - SEAMLESS ∴ NO XRAY
- HEAD/SHELL SEAM X-RAY
  - SPOT PER UW-11(b) TYPE 1
- ID = 84.25"
- CROWN INTERNAL RADIUS = 85"
- KNUCKLE INTERNAL RADIUS = 5.25"
- FORMING ALLOWANCE = 0"
- STRAIGHT FLANGE = 2"
- THICKNESS = .375"

FOR NOZZLES:

- ID = 7.75" (ALL)
- THICKNESS = .1875" (ALL)
- ANGLE θ / DISTANCE r

	ANGLE θ	DISTANCE r
N1:	$\theta_1 = 0°$	$r_1 = 7.875"$
N2:	$\theta_2 = 69.7°$	$r_2 = 22.66"$
N3:	$\theta_3 = 290.7°$	$r_3 = 22.66"$
N_4:	$\theta_4 = 28.03°$	$r_4 = 23.01"$
N_5:	$\theta_5 = 331.97°$	$r_5 = 23.01"$

5. COMPRESS 5.53 - OUTPUT

OUTPUT FOR 84" F+D HEAD, NOZZLES 1, 2 AND 4 ARE ATTACHED TO VERIFY COMPLIANCE TO ASME VIII . . . . . EDITION, INCLUDING A9 ADDENDA.

NOTE: THAT ANALYSIS/RESULTS FOR NOZZLE #3 IS SYMMETRICALLY IDENTICAL TO TO NOZZLE #2 AND NOZZLE #5 IS IDENTICAL TO #4

TABLE OF CONTENTS

3.12.1996

Pressure Summary

Pressure summary for pressure chamber 1

Identifier	Nozzle Status (UG-45)	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)
84" F&D HAM HEAD		0.0	72.1	72.1	22.4	1.000		Not applicable	0.000
N1 N1-1ST ROW-CENTE	ok	0.0	83.5	83.5	15.7	1.000		Not applicable	0.000
N2 N2-1ST ROW-RIGHT	ok	0.0	83.2	83.0	15.8	1.000		Not applicable	0.000
N3 N3-1ST ROW-LEFT	ok	0.0	83.2	83.0	15.8	1.000		Not applicable	0.000
N4 N4-2ND ROW-RIGHT	ok	0.0	83.2	83.0	15.8	1.000		Not applicable	0.000
N5 N5-2ND ROW-LEFT	ok	0.0	83.2	83.0	15.8	1.000		Not applicable	0.000

Vessel MAWP hot & corroded is 72.11 psi @ 0 degrees F.

Vessel MAP new & cold is 72.11 psi @ 70 degrees F.

Vessel allowable external pressure is 15.76 psi @ 400 degrees F.

Hydrotest pressure calculation based on MAWP

= 1.5*(MAWP + Operating Liquid Head)*1 = 108.2 psi

Vessel hydrotest pressure is 108.2 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
84" f&d ham hea	822	822	0	0	0	0	0	0	0	0	2149	28
	822	822	0	0	0	0	0	0	0	0	2149	28

Vessel operating weight, corroded:	850 lbs
Vessel empty weight, corroded:	850 lbs
Vessel empty weight, new:	850 lbs
Vessel test weight, new:	2,999 lbs

Vessel center of gravity location (from right weld seam)

Vessel lift weight, new:	848 lbs
Center of gravity to seam:	10.6 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 (%)
N1	8.00	0.2500	0.2108	y	y	0.3750	0.2777	0.3750	0.0000	100.1
N2	8.00	0.2500	0.2101	y	y	0.3750	0.2789	0.3750	0.0000	100.0
N3	8.00	0.2500	0.2101	y	y	0.3750	0.2788	0.3750	0.0000	100.0
N4	8.00	0.2500	0.2101	y	y	0.3750	0.2787	0.3750	0.0000	100.0
N5	8.00	0.2500	0.2101	y	y	0.3750	0.2790	0.3750	0.0000	100.0

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.

Thickness Summary

Component	ID	Length	Nom t	Req t	Joint		Governing		Deflect
Identifier	(in)	(in)	(in)	(in)	E	Load	Status	Stress	(in)
84" f&d ham head	84.25		0.3750	0.3750	0.85				

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

84" F&D HAM HEAD

ASME Section VIII Division 1, 1992 Edition, A93 Addenda

Component: F&D head
Material specification: SA 240 304L HIGH

Corrosion allowance: Inner C = 0 Outer= 0 in

PWHT is not performed

Radiography: Category A joints - Seamless NO X-Ray
Head to shell seam - Spot UW-11(b) type 1

Estimated weight: new = 821.5 corr = 821.5 lb
capacity: new = 257.65 corr = 257.65 US ga

ID = 84.25 crown L = 84.25 knuckle r = 5.25 t = .375 in (min)

Straight flange = 2 forming allowance = 0 in

MAP: (New & at 70 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.375/(84.25*1.7515 + 0.2*0.375) - 0
= 72.11008 psi

MAWP: (Corroded & at 0 deg F) Appendix 1-4(d) Eq 3

P = 2*S*E*t/(L*M + 0.2*t) - Ps
= 2*16700*0.85*0.375/(84.25*1.7515 + 0.2*0.375) - 0
= 72.11008 psi

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

A = .125/(Ro/t)
= .125/(84.625/0.375)
= 0.000554

From table HA-3: B = 5065.4

Pa= B/(Ro/t)
= 5065.4/(84.625/0.375)
= 22.4464 psi

Check the Maximum External Pressure: UG-33(a)(1) & App. 1-4(d)

Pe= 2*S*E*t/((M*Lo - t*(M-0.2))*1.67)
= 2*14700*1*0.375/((1.7515*84.625 - 0.375*(1.7515-0.2))*1.67)
= 44.71584 psi

The maximum allowable external pressure is 22.4464 psi.

N1-1ST ROW-CENTER

Opening N1 Reinforcement Calculations Per UG-37

```
Located on:                      84" F&D HAM HEAD
User input vessel thickness:     .375 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 datum line:     19.782 in
Nozzle calculated as hillside:   yes
Projection outside vessel Lpr:   3.39 in
```

```
  tn ->| |<-
        _          _           corrosion allow = 0 in
       | |<- d ->| |           noz thick new tn= .25 in
tw1->| | <|        | |         nozzle id. new d= 7.5 in
     |/ |   v      | | \       fillet weld tw1 = .25 in
______.-| |__      | | -.______ groove weld tw2 = .1875 in
______\|_|_tw2     |_| /______
             ^
<---- R ---->|                 To head center R= 7.875 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.533 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((7.875 + 3.75)/84.3554)
       = 82.07932

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((7.875 - 3.75)/84.3554)
       = 87.19758

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*84.3554*Sin((87.19758 - 82.07932)/2)
  = 7.533 in
```

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 83.53057*3.75/(16700*1 - 0.6*83.53057)
    = 0.0188 in
```

N1-1ST ROW-CENTER

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.53057*84.25*1/(2*16700*1 - 0.2*83.53057)
  = 0.2108 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)
  = 7.533*0.2108*1 + 2*0.25*0.2108*1*(1 - 1)
  = 1.588 in^2
```

Area available

```
A1 = larger of the following                  = 1.237 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.533*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
   = 1.237 in^2

   = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 2*(0.375+0.25)*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
   = .205 in^2

A2 = smaller of the following                  = 0.289 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.0188)*1*0.375
   = .433 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.0188)*1*0.25
   = .289 in^2

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

Area = A1 + A2 + A41
   = 1.237 + 0.289 + 0.063
   = 1.589 in^2

As Area > A the reinforcement is adequate for MAWP = 83.53057 at 0 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
```

N1-1ST ROW-CENTER

= 7.5*0.2108*1 + 2*0.25*0.2108*1*(1 - 1)
= 1.581 in^2

Area available

A1 = larger of the following = 1.231 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
= 1.231 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
= .205 in^2

Area = A1 + A2 + A41
= 1.231 + 0.289 + 0.063
= 1.583 in^2

As Area > A the reinforcement is adequate for MAWP = 83.53057 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 = 0.0188 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0.2108 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.28175 in
The greater of tr2 or tr3: tr5 = 0.2108 in
The lesser of tr4 or tr5: tr6 = 0.2108 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2108 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:

N1-1ST ROW-CENTER

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.588 - (7.533 - 2*0.25)*(1*0.375 - 1*0.2108))*16700
= 7234.131 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.289 + 0 + 0.063 + 0)*16700
= 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
= 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7234.131 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.533 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((7.875 + 3.75)/84.3554)
= 82.07932

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((7.875 - 3.75)/84.3554)
= 87.19758

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*84.3554*Sin((87.19758 - 82.07932)/2)
= 7.533 in

N1-1ST ROW-CENTER

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 83.54077*3.75/(16700*1 - 0.6*83.54077)
    = 0.0188 in
```

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.54077*84.25*1/(2*16700*1 - 0.2*83.54077)
  = 0.2108 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)
  = 7.533*0.2108*1 + 2*0.25*0.2108*1*(1 - 1)
  = 1.588 in^2
```

Area available

```
A1 = larger of the following               = 1.237 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.533*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
  = 1.237 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
  = .205 in^2

A2 = smaller of the following               = 0.289 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0188)*1*0.375
  = .433 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0188)*1*0.25
  = .289 in^2

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

Area = A1 + A2 + A41
  = 1.237 + 0.289 + 0.063
  = 1.589 in^2

As Area > A the reinforcement is adequate for MAP = 83.54077 at 70 Deg F
```

N1-1ST ROW-CENTER

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
  = 7.5*0.2108*1 + 2*0.25*0.2108*1*(1 - 1)
  = 1.581 in^2
```

Area available

```
A1 = larger of the following              = 1.231 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
  = 1.231 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2108) - 2*0.25*(1*0.375-1*0.2108)*(1-1)
  = .205 in^2

Area = A1 + A2 + A41
  = 1.231 + 0.289 + 0.063
  = 1.583 in^2

As Area > A the reinforcement is adequate for MAP = 83.54077 at 70 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 = 0.0188 in (E = 1)
Wall thickness per UG-45(b)(1):      tr2 = 0.2108 in
Wall thickness per UG-16(b):         tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):       tr4 = 0.28175 in
The greater of tr2 or tr3:           tr5 = 0.2108 in
The lesser of tr4 or tr5:            tr6 = 0.2108 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2108 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)

N1-1ST ROW-CENTER

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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.588 - (7.533 - 2*0.25)*(1*0.375 - 1*0.2108))*16700
= 7234.131 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.289 + 0 + 0.063 + 0)*16700
= 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
= 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7234.131 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.533 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((7.875 + 3.75)/84.38885)
= 82.08248

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((7.875 - 3.75)/84.38885)

N1-1ST ROW-CENTER

= 87.19869

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*84.38885*Sin((87.19869 - 82.08248)/2)
= 7.533 in

Nozzle required thickness

L/Do = 3.39/8 = .4238
From table G:
From table HA-3:

Do/t = 8/0.01987 = 402.617
A = 0.000401
B = 4785.4

Pa= 4*B/(3*Do/t)
= 4*4785.4/(3*8/0.01987)
= 15.8476 psi

Nozzle required thickness trn = .01987 in

Required thickness tr from UG-37(d)(1) = .2777 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*(7.533*0.2777*1 + 2*0.25*0.2777*1*(1 - 1))
= 1.046 in^2

Area available

A1 = larger of the following = .733 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.533*(1*0.375-1*0.2777) - 2*0.25*(1*0.375-1*0.2777)*(1-1)
= .733 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2777) - 2*0.25*(1*0.375-1*0.2777)*(1-1)
= .122 in^2

A2 = smaller of the following = 0.288 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.01987)*1*0.375
= .431 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.01987)*1*0.25
= .288 in^2

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

Area = A1 + A2 + A41
= 0.733 + 0.288 + 0.063
= 1.084 in^2

As Area > A the reinforcement is adequate for Pe = 15.76347 at 400 Deg F

Reinforcement check in the plane parallel to the long. axis

Area required

A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
= 0.5*(7.5*0.2777*1 + 2*0.25*0.2777*1*(1 - 1))
= 1.041375 in^2

Area available

A1 = larger of the following = .73 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.375-1*0.2777) - 2*0.25*(1*0.375-1*0.2777)*(1-1)
= .73 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2777) - 2*0.25*(1*0.375-1*0.2777)*(1-1)
= .122 in^2

Area = A1 + A2 + A41
= 0.73 + 0.288 + 0.063
= 1.081 in^2

As Area > A the reinforcement is adequate for Pe = 15.76347 at 400 Deg F

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	tr1 = 0.01987 in (E = 1)
Wall thickness per UG-45(b)(2):	tr2 = 0.0452 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 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.

N2-1ST ROW-RIGHT

Opening N2 Reinforcement Calculations Per UG-37

Located on: 84" F&D HAM HEAD
User input vessel thickness: .375 in
Liquid static head included: 0 psi
Flange description: Not installed

Nozzle material specification: SA 240 304L HIGH

Nozzle orientation: 69.7 degrees
End of nozzle to datum line: 16.7521 in
Nozzle calculated as hillside: yes
Projection outside vessel Lpr: 3.083 in

```
   tn ->|  |<-
         _              _         corrosion allow = 0 in
        | |<- d ->|  |         noz thick new tn= .25 in
tw1->|  | |<           |  |          nozzle id. new d= 7.5 in
     |/ | |   v        |  |\         fillet weld tw1 = .25 in
_____.- | |   _        |  | -._____  groove weld tw2 = .1875 in
_____\  |_| |_tw2      |_ |/______
               ^
<---- R ---->|                    To head center R= 22.66 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.787 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

$$\begin{aligned} \text{Theta1} &= \text{ArcCos}((Lo + Rn)/Rm) \\ &= \text{ArcCos}((22.66 + 3.75)/84.35505) \\ &= 71.75536 \end{aligned}$$

$$\begin{aligned} \text{Theta2} &= \text{ArcCos}((Lo - Rn)/Rm) \\ &= \text{ArcCos}((22.66 - 3.75)/84.35505) \\ &= 77.04626 \end{aligned}$$

$$\begin{aligned} d &= 2*Rm*\text{Sin}((\text{Theta2} - \text{Theta1})/2) \\ &= 2*84.35505*\text{Sin}((77.04626 - 71.75536)/2) \\ &= 7.787 \text{ in} \end{aligned}$$

Nozzle required thickness

$$\begin{aligned} trn &= P*Rn/(Sn*E - 0.6*P) \\ &= 83.26131*3.75/(16700*1 - 0.6*83.26131) \\ &= 0.0188 \text{ in} \end{aligned}$$

N2-1ST ROW-RIGHT

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.26131*84.25*1/(2*16700*1 - 0.2*83.26131)
  = 0.2101 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)
  = 7.787*0.2101*1 + 2*0.25*0.2101*1*(1 - 1)
  = 1.636 in^2
```

Area available

```
A1 = larger of the following                  = 1.284 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.787*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
  = 1.284 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
  = .206 in^2

A2 = smaller of the following                  = 0.289 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0188)*1*0.375
  = .433 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0188)*1*0.25
  = .289 in^2

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

Area = A1 + A2 + A41
  = 1.284 + 0.289 + 0.063
  = 1.636 in^2

As Area > A the reinforcement is adequate for MAWP = 83.26131 at 0 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
```

= 7.5*0.2101*1 + 2*0.25*0.2101*1*(1 - 1)
= 1.57575 in^2

Area available

A1 = larger of the following = 1.237 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
= 1.237 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
= .206 in^2

Area = A1 + A2 + A41
= 1.237 + 0.289 + 0.063
= 1.589 in^2

As Area > A the reinforcement is adequate for MAWP = 83.26131 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 = 0.0188 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.2101 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 in
The greater of tr2 or tr3:	tr5 = 0.2101 in
The lesser of tr4 or tr5:	tr6 = 0.2101 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2101 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:

N2-1ST ROW-RIGHT

(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.636 - (7.787 - 2*0.25)*(1*0.375 - 1*0.2101))*16700
= 7254.041 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.289 + 0 + 0.063 + 0)*16700
= 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
= 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7254.041 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.787 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((22.66 + 3.75)/84.3548)
= 71.7553

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((22.66 - 3.75)/84.3548)
= 77.04622

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*84.3548*Sin((77.04622 - 71.7553)/2)
= 7.787 in

N2-1ST ROW-RIGHT

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 83.06746*3.75/(16700*1 - 0.6*83.06746)
    = 0.0187 in
```

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.06746*84.25*1/(2*16700*1 - 0.2*83.06746)
  = 0.2096 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)
  = 7.787*0.2096*1 + 2*0.25*0.2096*1*(1 - 1)
  = 1.6322 in^2
```

Area available

```
A1 = larger of the following                 = 1.288 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.787*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
  = 1.288 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
  = .207 in^2

A2 = smaller of the following                 = 0.289 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0187)*1*0.375
  = .434 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0187)*1*0.25
  = .289 in^2

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

Area = A1 + A2 + A41
  = 1.288 + 0.289 + 0.063
  = 1.64 in^2

As Area > A the reinforcement is adequate for MAP = 83.06746 at 70 Deg F
```

N2-1ST ROW-RIGHT

Reinforcement check in the plane parallel to the long. axis

Area required

A = d*tr*F + 2*tn*tr*F*(1 - fr1)
= 7.5*0.2096*1 + 2*0.25*0.2096*1*(1 - 1)
= 1.572 in^2

Area available

A1 = larger of the following = 1.24 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
= 1.24 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
= .207 in^2

Area = A1 + A2 + A41
= 1.24 + 0.289 + 0.063
= 1.592 in^2

As Area > A the reinforcement is adequate for MAP = 83.06746 at 70 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 = 0.0187 in (E = 1)
Wall thickness per UG-45(b)(1):	tr2 = 0.2096 in
Wall thickness per UG-16(b):	tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):	tr4 = 0.28175 in
The greater of tr2 or tr3:	tr5 = 0.2096 in
The lesser of tr4 or tr5:	tr6 = 0.2096 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2096 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)

N2-1ST ROW-RIGHT

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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf

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

W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
= (1.6322 - (7.787 - 2*0.25)*(1*0.375 - 1*0.2096))*16700
= 7129.734 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
= (0.289 + 0 + 0.063 + 0)*16700
= 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
= (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
= 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7129.734 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.787 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

Theta1 = ArcCos((Lo + Rn)/Rm)
= ArcCos((22.66 + 3.75)/84.38945)
= 71.76306

Theta2 = ArcCos((Lo - Rn)/Rm)
= ArcCos((22.66 - 3.75)/84.38945)

3.12.1996

= 77.05163

d = 2*Rm*Sin((Theta2 - Theta1)/2)
= 2*84.38945*Sin((77.05163 - 71.76306)/2)
= 7.787 in

Nozzle required thickness

L/Do = 3.083/8 = .3854 Do/t = 8/0.01962 = 407.7472
From table G: A = 0.000437
From table HA-3: B = 4858.3

Pa= 4*B/(3*Do/t)
= 4*4858.3/(3*8/0.01962)
= 15.8866 psi

Nozzle required thickness trn = .01962 in

Required thickness tr from UG-37(d)(1) = .2789 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*(7.787*0.2789*1 + 2*0.25*0.2789*1*(1 - 1))
= 1.0859 in^2

Area available

A1 = larger of the following = .748 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.787*(1*0.375-1*0.2789) - 2*0.25*(1*0.375-1*0.2789)*(1-1)
= .748 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2789) - 2*0.25*(1*0.375-1*0.2789)*(1-1)
= .12 in^2

A2 = smaller of the following = 0.288 in^2

= 5*(tn - trn)*fr2*t
= 5*(0.25 - 0.01962)*1*0.375
= .432 in^2

= 5*(tn - trn)*fr2*tn
= 5*(0.25 - 0.01962)*1*0.25
= .288 in^2

N2-1ST ROW-RIGHT

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

Area = A1 + A2 + A41
  = 0.748 + 0.288 + 0.063
  = 1.099 in^2

As Area > A the reinforcement is adequate for Pe = 15.82647 at 400 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
  = 0.5*(7.5*0.2789*1 + 2*0.25*0.2789*1*(1 - 1))
  = 1.045875 in^2
```

Area available

```
A1 = larger of the following                 = .721 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.375-1*0.2789) - 2*0.25*(1*0.375-1*0.2789)*(1-1)
  = .721 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2789) - 2*0.25*(1*0.375-1*0.2789)*(1-1)
  = .12 in^2

Area = A1 + A2 + A41
  = 0.721 + 0.288 + 0.063
  = 1.072 in^2

As Area > A the reinforcement is adequate for Pe = 15.82647 at 400 Deg F
```

UG-45 Nozzle Neck Thickness Check

```
Wall thickness per UG-45(a):         tr1 = 0.01962 in (E = 1)
Wall thickness per UG-45(b)(2):      tr2 = 0.0454 in
Wall thickness per UG-16(b):         tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):       tr4 = 0.28175 in
The greater of tr2 or tr3:           tr5 = 0.0625 in
The lesser of tr4 or tr5:            tr6 = 0.0625 in

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

Available nozzle wall thickness new, tn = 0.25 in

The nozzle neck thickness is adequate for Pe.
```

N4-2ND ROW-RIGHT

Opening N4 Reinforcement Calculations Per UG-37

```
Located on:                     84" F&D HAM HEAD
User input vessel thickness:    .375 in
Liquid static head included:    0 psi
Flange description:             Not installed

Nozzle material specification:  SA 240 304L HIGH

Nozzle orientation:             28.03 degrees
End of nozzle to datum line:    16.6279 in
Nozzle calculated as hillside:  yes
Projection outside vessel Lpr:  3.057 in
```

```
  tn ->|  |<-
        _         _             corrosion allow = 0 in
       | |<- d ->| |            noz thick new tn= .25 in
tw1->| |<|       | |            nozzle id. new d= 7.5 in
     |/| | v     | |\           fillet weld tw1 = .25 in
_____.-| |--     | |-.______    groove weld tw2 = .1875 in
______\|_|_tw2   |_|/______
           ^
<---- R ---->|                  To head center R= 23.01 in
```

Reinforcement Calculations For Nozzle MAWP

Limits of reinforcement UG-40

Parallel to the vessel wall d = 7.796 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((23.01 + 3.75)/84.35505)
       = 71.50487

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((23.01 - 3.75)/84.35505)
       = 76.8022

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*84.35505*Sin((76.8022 - 71.50487)/2)
  = 7.796 in
```

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 83.26131*3.75/(16700*1 - 0.6*83.26131)
    = 0.0188 in
```

N4-2ND ROW-RIGHT

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.26131*84.25*1/(2*16700*1 - 0.2*83.26131)
  = 0.2101 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)
  = 7.796*0.2101*1 + 2*0.25*0.2101*1*(1 - 1)
  = 1.6379 in^2
```

Area available

```
A1 = larger of the following                = 1.286 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.796*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
  = 1.286 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
  = .206 in^2

A2 = smaller of the following                = 0.289 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0188)*1*0.375
  = .433 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0188)*1*0.25
  = .289 in^2

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

Area = A1 + A2 + A41
  = 1.286 + 0.289 + 0.063
  = 1.638 in^2

As Area > A the reinforcement is adequate for MAWP = 83.26131 at 0 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
```

N4-2ND ROW-RIGHT

= 7.5*0.2101*1 + 2*0.25*0.2101*1*(1 - 1)
= 1.57575 in^2

Area available

A1 = larger of the following = 1.237 in^2

= d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 7.5*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
= 1.237 in^2

= 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
= 2*(0.375+0.25)*(1*0.375-1*0.2101) - 2*0.25*(1*0.375-1*0.2101)*(1-1)
= .206 in^2

Area = A1 + A2 + A41
= 1.237 + 0.289 + 0.063
= 1.589 in^2

As Area > A the reinforcement is adequate for MAWP = 83.26131 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 = 0.0188 in (E = 1)
Wall thickness per UG-45(b)(1): tr2 = 0.2101 in
Wall thickness per UG-16(b): tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4): tr4 = 0.28175 in
The greater of tr2 or tr3: tr5 = 0.2101 in
The lesser of tr4 or tr5: tr6 = 0.2101 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2101 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:

N4-2ND ROW-RIGHT

```
(1) Inner fillet weld in shear
(Pi/2)*Nozzle O.D.*Leg*Si = 1.57*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf
```

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

```
W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
  = (1.6379 - (7.796 - 2*0.25)*(1*0.375 - 1*0.2101))*16700
  = 7260.986 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
  = (0.289 + 0 + 0.063 + 0)*16700
  = 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
  = (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
  = 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7260.986 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.796 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in
```

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((23.01 + 3.75)/84.3548)
       = 71.50481

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((23.01 - 3.75)/84.3548)
       = 76.80215

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*84.3548*Sin((76.80215 - 71.50481)/2)
  = 7.796 in
```

N4-2ND ROW-RIGHT

Nozzle required thickness

```
trn = P*Rn/(Sn*E - 0.6*P)
    = 83.06746*3.75/(16700*1 - 0.6*83.06746)
    = 0.0187 in
```

Required thickness tr from UG-37(a)(1)

```
tr= P*L*M/(2*S*E - 0.2*P)
  = 83.06746*84.25*1/(2*16700*1 - 0.2*83.06746)
  = 0.2096 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)
  = 7.796*0.2096*1 + 2*0.25*0.2096*1*(1 - 1)
  = 1.634 in^2
```

Area available

```
A1 = larger of the following                = 1.289 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.796*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
  = 1.289 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
  = .207 in^2

A2 = smaller of the following               = 0.289 in^2

  = 5*(tn - trn)*fr2*t
  = 5*(0.25 - 0.0187)*1*0.375
  = .434 in^2

  = 5*(tn - trn)*fr2*tn
  = 5*(0.25 - 0.0187)*1*0.25
  = .289 in^2

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

Area = A1 + A2 + A41
  = 1.289 + 0.289 + 0.063
  = 1.641 in^2

As Area > A the reinforcement is adequate for MAP = 83.06746 at 70 Deg F
```

N4-2ND ROW-RIGHT

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = d*tr*F + 2*tn*tr*F*(1 - fr1)
  = 7.5*0.2096*1 + 2*0.25*0.2096*1*(1 - 1)
  = 1.572 in^2
```

Area available

```
A1 = larger of the following                 = 1.24 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.5*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
   = 1.24 in^2

   = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 2*(0.375+0.25)*(1*0.375-1*0.2096) - 2*0.25*(1*0.375-1*0.2096)*(1-1)
   = .207 in^2

Area = A1 + A2 + A41
   = 1.24 + 0.289 + 0.063
   = 1.592 in^2

As Area > A the reinforcement is adequate for MAP = 83.06746 at 70 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 = 0.0187 in (E = 1)
Wall thickness per UG-45(b)(1):     tr2 = 0.2096 in
Wall thickness per UG-16(b):        tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):      tr4 = 0.28175 in
The greater of tr2 or tr3:          tr5 = 0.2096 in
The lesser of tr4 or tr5:           tr6 = 0.2096 in

Req'd per UG-45 is the larger of tr1 or tr6 = 0.2096 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)

N4-2ND ROW-RIGHT

```
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*8*0.25*8183 = 25694.62 lbf

(3) Nozzle wall in shear
(Pi/2)*Mean nozzle dia.*tn*Sn = 1.57*7.75*0.25*11690 = 35559.52 lbf

(4) Groove weld in tension
(Pi/2)*Nozzle O.D.*tw*Sg = 1.57*8*0.1875*12358 = 29103.09 lbf
```

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

```
W = (A - (d - 2*tn)*(E1*t - F*tr))*Sv
  = (1.634 - (7.796 - 2*0.25)*(1*0.375 - 1*0.2096))*16700
  = 7134.934 lbf

W1-1 = (A2 + A5 + A41 + A42)*Sv
  = (0.289 + 0 + 0.063 + 0)*16700
  = 5878.4 lbf

W2-2 = (A2 + A3 + A41 + A43 + 2*tn*t*fr1)*Sv
  = (0.289 + 0 + 0.063 + 0 + 2*0.25*0.375*1)*16700
  = 9009.65 lbf

Load for path 1-1 lesser of W or W1-1 = 5878.4 lbf
Path 1-1 Thru (1) & (3) = 25694.62 + 35559.52 = 61254.14 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 = 7134.934 lbf
Path 2-2 Thru (1), (4) = 25694.62 + 29103.09 = 54797.71 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 = 7.796 in
Normal to the vessel wall outside 2.5*(tn-Cn) + te = .625 in
Normal to the vessel wall inside 2.5*(tn-Cn-C) = .625 in
```

Determination of Chord Length

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((23.01 + 3.75)/84.38935)
       = 71.51266

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((23.01 - 3.75)/84.38935)
```

N4-2ND ROW-RIGHT

```
        = 76.80766

 d = 2*Rm*Sin((Theta2 - Theta1)/2)
   = 2*84.38935*Sin((76.80766 - 71.51266)/2)
   = 7.796 in
```

Nozzle required thickness

```
   L/Do = 3.057/8 = .3821            Do/t = 8/0.01961 = 407.9551
   From table G:                        A = 0.000441
   From table HA-3:                     B = 4866.1

 Pa= 4*B/(3*Do/t)
   = 4*4866.1/(3*8/0.01961)
   = 15.904 psi

 Nozzle required thickness trn = .01961 in
```

Required thickness tr from UG-37(d)(1) = .2787 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*(7.796*0.2787*1 + 2*0.25*0.2787*1*(1 - 1))
   = 1.0864 in^2
```

Area available

```
 A1 = larger of the following                 = .751 in^2

   = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 7.796*(1*0.375-1*0.2787) - 2*0.25*(1*0.375-1*0.2787)*(1-1)
   = .751 in^2

   = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
   = 2*(0.375+0.25)*(1*0.375-1*0.2787) - 2*0.25*(1*0.375-1*0.2787)*(1-1)
   = .12 in^2

 A2 = smaller of the following                 = 0.288 in^2

   = 5*(tn - trn)*fr2*t
   = 5*(0.25 - 0.01961)*1*0.375
   = .432 in^2

   = 5*(tn - trn)*fr2*tn
   = 5*(0.25 - 0.01961)*1*0.25
   = .288 in^2
```

N4-2ND ROW-RIGHT

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

Area = A1 + A2 + A41
  = 0.751 + 0.288 + 0.063
  = 1.102 in^2

As Area > A the reinforcement is adequate for Pe = 15.82647 at 400 Deg F
```

Reinforcement check in the plane parallel to the long. axis

Area required

```
A = 0.5*(d*tr*F + 2*tn*tr*F*(1 - fr1))
  = 0.5*(7.5*0.2787*1 + 2*0.25*0.2787*1*(1 - 1))
  = 1.045125 in^2
```

Area available

```
A1 = larger of the following                 = .722 in^2

  = d*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 7.5*(1*0.375-1*0.2787) - 2*0.25*(1*0.375-1*0.2787)*(1-1)
  = .722 in^2

  = 2*(t+tn)*(E1*t-F*tr) - 2*tn*(E1*t-F*tr)*(1-fr1)
  = 2*(0.375+0.25)*(1*0.375-1*0.2787) - 2*0.25*(1*0.375-1*0.2787)*(1-1)
  = .12 in^2

Area = A1 + A2 + A41
  = 0.722 + 0.288 + 0.063
  = 1.073 in^2

As Area > A the reinforcement is adequate for Pe = 15.82647 at 400 Deg F
```

UG-45 Nozzle Neck Thickness Check

```
Wall thickness per UG-45(a):        tr1 = 0.01961 in (E = 1)
Wall thickness per UG-45(b)(2):     tr2 = 0.0454 in
Wall thickness per UG-16(b):        tr3 = 0.0625 in
Std pipe wall per UG-45(b)(4):      tr4 = 0.28175 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.
```

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-048

PAGE 1 OF 14

REV.	DEO #	DATE	BY:	CHECK
0	0024	3-27-96	G ARENA	RDC

TITLE: DESIGN OF HAM NOZZLE JACKING BOLT ASSEMBLIES

By: G ARENA

DEPT.: 744

PROJECT: LIGO VACUUM EQUIPMENT

PROJECT NO: V59049

PURPOSE: SEE BODY OF CALCULATION

METHOD:

ASSUMPTIONS:

INPUTS:

REFERENCES:

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS:

NOTES:

1.0 OBJECTIVE

The objective of this calculation is to perform the structural design and analysis for the Jacking Bolt Assemblies on the Horizontal Access Module Chamber (HAM) bellows nozzle.

2.0 METHOD OF ANALYSIS / COMPUTER PROGRAMS & VERSION

No computer programs are used in the execution of this calculation:

Jacking Bolts are placed in locations that will permit operation without interferences with other components. The overall design must not permit any of the components to extend over the flange face because of restrictions in the removal of the adjacent adapter.

The Jacking Bolt Assembly components are designed to AISC allowable stresses and by manual design methods for the greater of two conditions:

- Installation and equipment servicing during which time bellows spring forces act but no pressure loads exist.
- HAM Vessel free standing full vacuum pressure test with bellows pressure loads acting on the jacking assemblies.

Welds are sized by traditional manual calculations found in standard engineering texts.

3.0 GENERAL ASSUMPTIONS

—————— None requiring confirmation ——————

4.0 REFERENCES

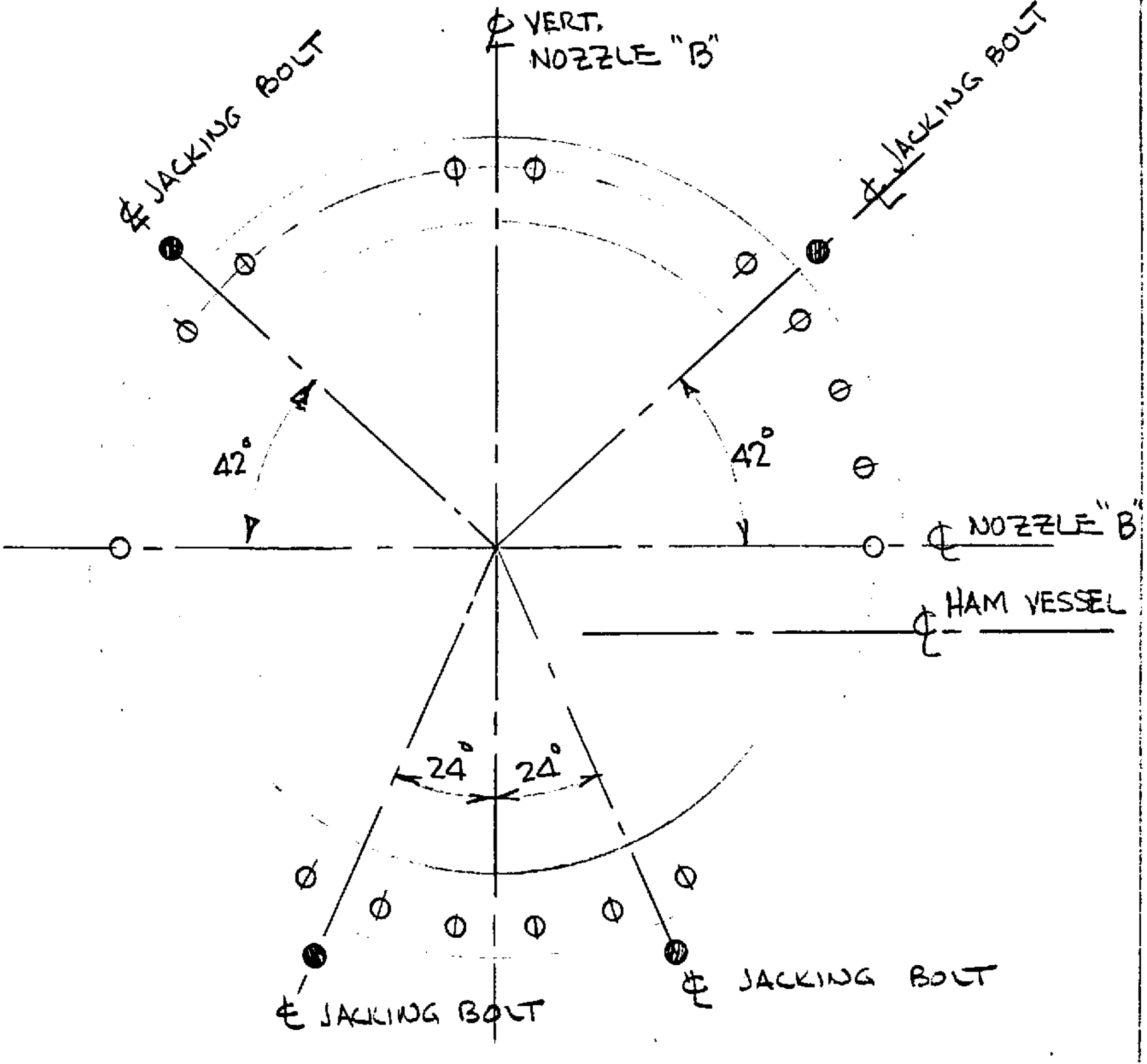
1. ASME Boiler and Pressure Vessel Code, Section VIII, Division I, 1995 Edition
2. Roark & Young, Formulas for Stress and Strain, Fifth Edition
3. Blodgett, Design of Welded Structures
4. LIGO Vacuum Equipment Structural Design Criteria, Doc. No. V049-1-066
5. AISC Steel Construction Manual

6.0 CONCLUSIONS

The Jacking Bolt orientation around the HAM nozzle and the assembly component details are found in the body of this calculation.

The location of the "D" nozzle (electrical/instr. feedthroughs, utility) located on the vertical centerline of the HAM vessel may require relocation due to possible interference with the jacking bolts and/or its close proximity to the "B" nozzle juncture (approx. 1")

JACKING BOLT ORIENTATION



DESIGN LOADS

MAXIMUM WORKING SPRING RATE FOR 2" TRAVEL

6218 #/IN (HYSPAN BELLOWS)

USE 7500 #/IN FOR DESIGN

WORST CONDITION FOR 3 BOLTS LOADED

(4^{TH} BOLT ASSUMED INEFFECTIVE)

$$2F_1 + F_2 = 15000^{\#}$$

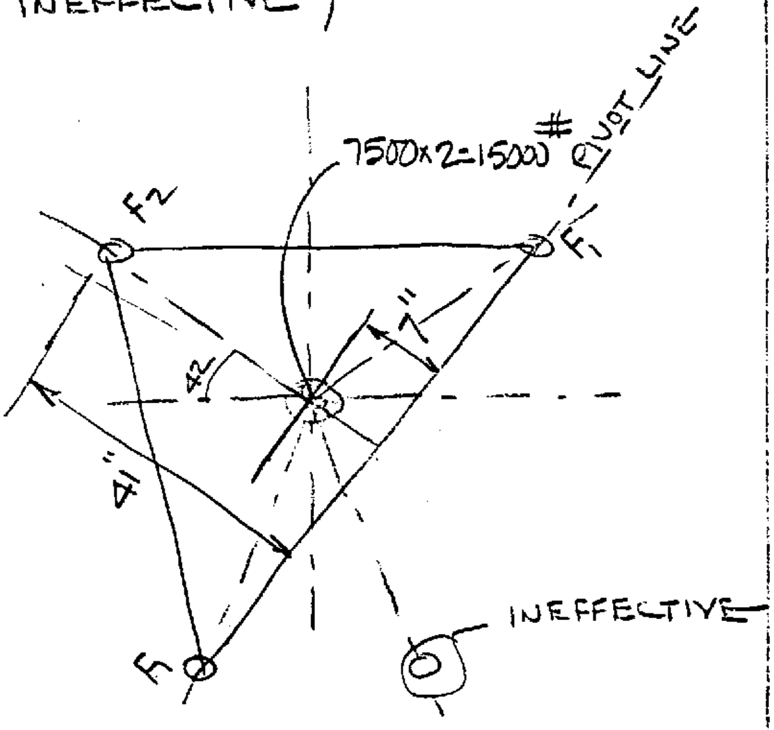
$$2F_1 \times 7 + 41 F_2 = 0$$

$$F_2 = \frac{14}{41} F_1 = .341 F1$$

$$2F_1 + .341 F_1 = 15000$$

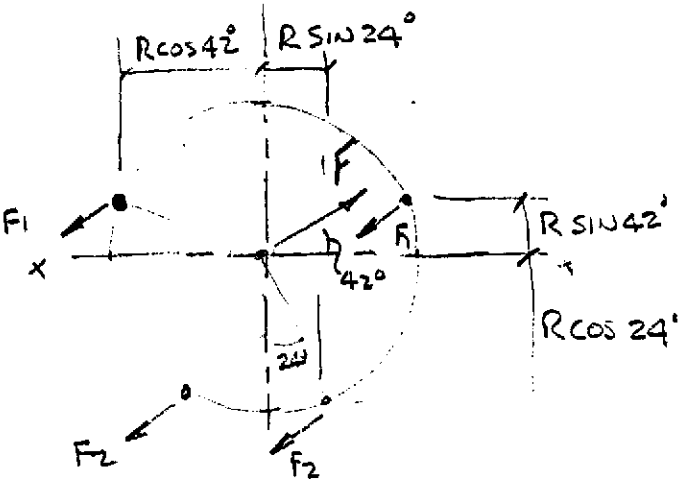
$$F_1 = \underline{6406}^{\#}$$

$$F_2 = 2188^{\#}$$



USE $\underline{\underline{6400^{\#}/\text{ROD}}}$ FOR DESIGN LOAD

DESIGN LOADS (VACUUM TEST)



$$F = \frac{\pi \overline{D_m}^2}{4} \times 15\,PSIA$$

$$= \frac{\pi}{4}\overline{62.5}^2 \times 15 = \underline{46020}^{\#}$$

$$\cancel{2}F_1 + \cancel{2}F_2 = \overset{23010}{\cancel{46020}}$$

$$\Sigma M_x = 0$$

$$2F_1 \cancel{R}\sin 42 - \cancel{2}F_2 \cancel{R}\cos 24 = 0$$

$$F_1 \sin 42 = F_2 \cos 24$$

$$F_2 = F_1 \frac{\sin 42}{\cos 24} \Rightarrow F_1 + F_1 \frac{\sin 42}{\cos 24} = 23010$$

$$F_1 = \frac{23010}{\left(1 + \frac{\sin 42}{\cos 24}\right)} = \underline{13282}^{\#}$$

$$F_2 = \underline{9728}^{\#}$$

$$\Sigma M_y$$

$$F_1 \cos 42 - F2 \sin 24 = 0$$

$$F_1 + F_1 \frac{\cos 42}{\sin 24} = 23010 \Rightarrow F_1 = \frac{23010}{\left(1 + \frac{\cos 42}{\sin 24}\right)} = \underline{8139}^{\#}$$

$$F_2 = \underline{14871}^{\#}$$

$$F_{1\,AVE} == \frac{13282 + 8139}{2} = 10710^{\#}$$

$$F_2\,AVE = \frac{14871 + 9728}{2} = 12300^{\#}$$

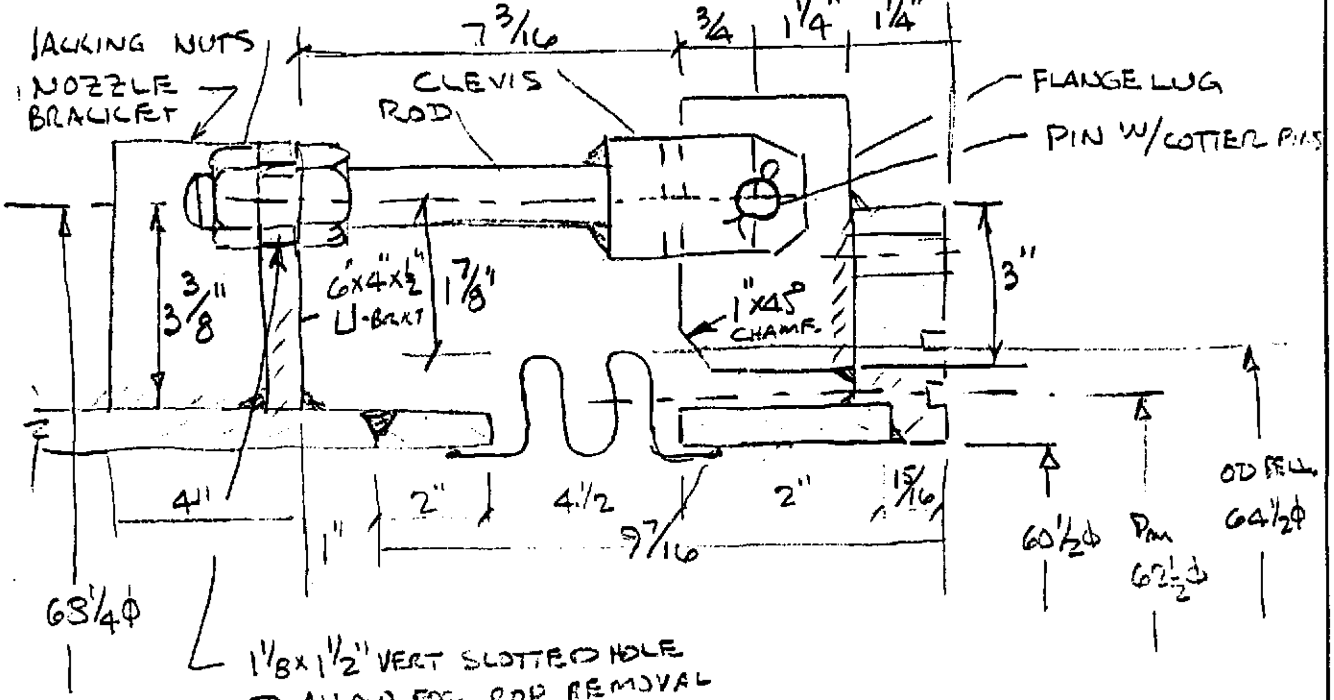
$$\Sigma F_Z \Rightarrow 2(10710) + 2(12300) \overset{?}{=} 46020$$

$$46020 \quad \checkmark\!\!= 46020 \quad \underline{OK}$$

DESIGN LOAD = 12,300# /ROD

— VACUUM TEST LOAD GOVERNS —

COMPONENT DESIGN



ROD (IN COMPRESSION) $\boxed{1''\phi \times 8 \text{ THD/IN}}$

ONE END FIXED OTHER END PINNED K=.8 USE K=1.0

MAT'L A320-B8 (304 S/S) $F_Y = 80$ KSI

ROOT DIA OF THDS = 0.838" $r = \frac{.838}{4} = .21$

L EFFECTIVE = $7\frac{3}{16} + \frac{3}{4} - 1'' = 7\frac{3}{16}''$

F_c @ $\frac{KL}{r} \Rightarrow \frac{1 \times 6.9375}{.21} = 33.04 \Rightarrow 35$

FROM AISC @ $F_y = 90$ $F_c = 44.67$ KSI

$F_c = 44.67 \times \frac{80}{90} = 39.71$ KSI MAX

$f_c = \frac{P}{A} = \frac{12.3}{\frac{\pi(.838)^2}{4}} = \underline{22.3 \text{ KSI}} < \underline{39.71 \text{ KSI}}$ OK

PIN (DOUBLE SHEAR) A320 B8 $F_Y = 100$ KSI

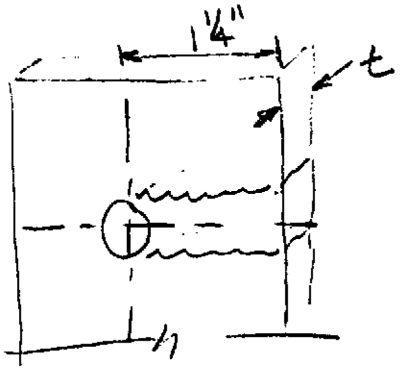
$F_S = .4\ F_Y = 40$ KSI

$A_{REQ'D} = \frac{P}{2\ F_S} = \frac{12300}{80,000} = .15 \text{ IN}^2 \Rightarrow D_{REQ.} = .44''$

$\boxed{\text{USE } \frac{1}{2}''\phi \text{ PIN}}$

FLANGE LUG A240-TP304 S/S $F_Y = 30$ KSI

SHEAR OUT AT PIN HOLE



$$f_s = \frac{P}{A_{TOTAL}} = \frac{12300}{2 \times 1.25 \times t}$$

$F_s = .4\,F_Y = 12$ KSI

$$t = \frac{12300}{2.5 \times 12000} = .41''$$

BEARING AT PIN HOLE $F_B = 1.35\,F_Y = 40500$ PSI

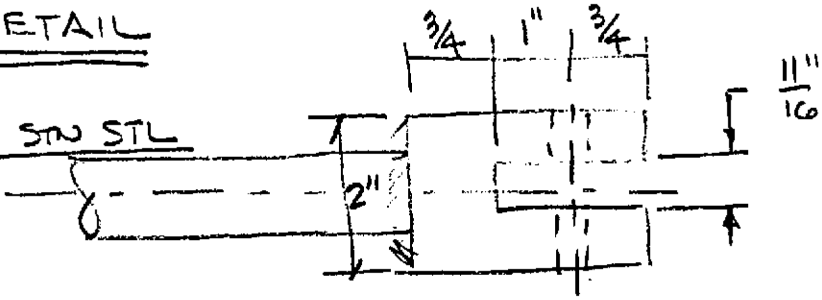
$$f_B = \frac{P}{A_{PROJ}} = \frac{12300}{(.5)(.5)} = 49200 > 40500 \quad \text{NG}$$

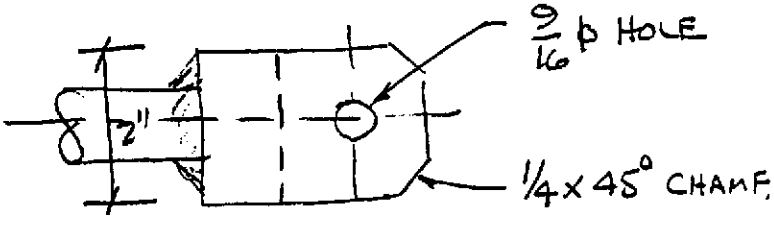
@ 5/8 R $f_B = \frac{12300}{.625 \times .5} = 39360 < 40500$ OK

$\boxed{\text{USE } t = 5/8''}$

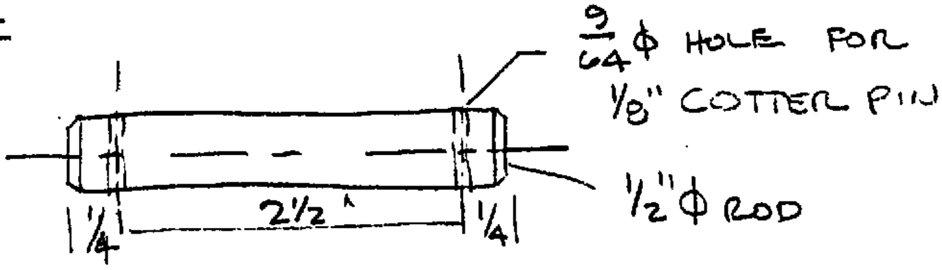
CLEVIS DETAIL

A240 TP304 STN STL





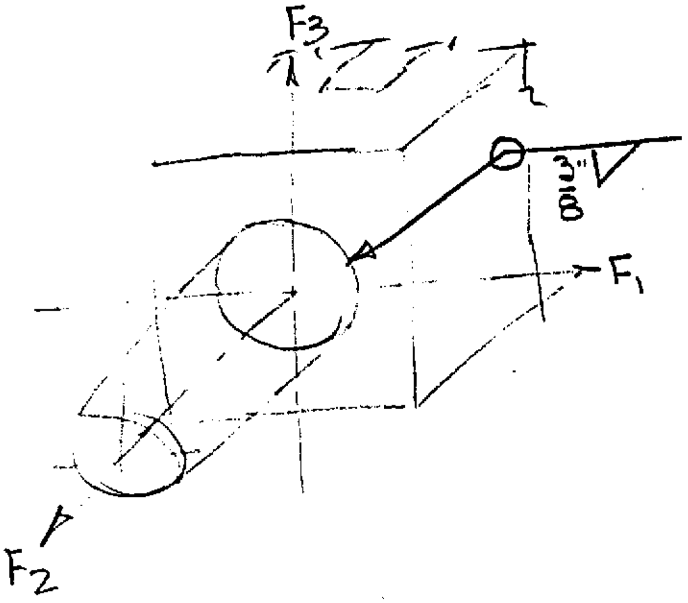
PIN DETAIL



filename: FULLCIR.WR1

FULL CIRCULAR/TRUNNION FILLET WELD

Between part ROD and part CLEVIS



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
0.00	12300.00	0.00	0.00	0.00	0.00

GEOMETRIC DIMENSIONS (FOR FLAT PLATES, INPUT D=100*d)

dw	Dp
0.838	1000.000

SECTION PROPERTIES

A	Sw	Jw	WELD STRESS (PSI)
2.633	0.552	1.103	18000

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

4672

REQUIRED FILLET WELD SIZE (INCHES)

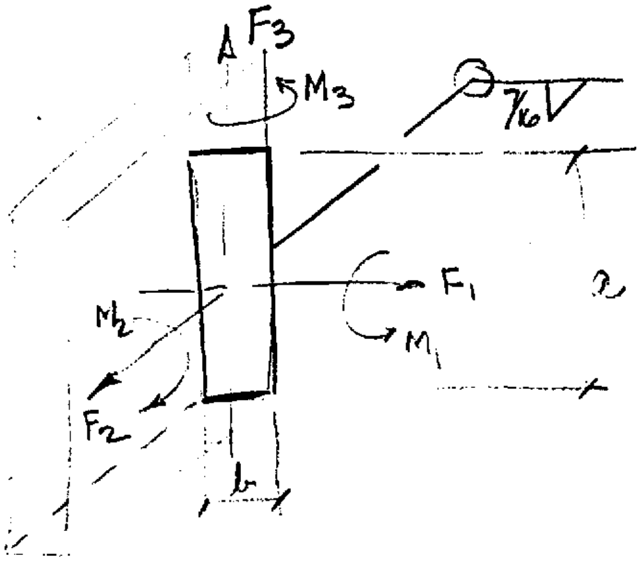
w
0.367

USE 3/8 FILLET WELD

filename: FULLRECT.WR1

ALL AROUND RECTANGULAR OR SQUARE FILLET WELD

Between part FLANGE LUG and part FLANGE



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
0.00	12300.00	0.00	18451.00	0.00	0.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS (PSI)	SKEWED ANGLE(90°>&<120°)
3.000	0.625	18000	90.000

SECTION PROPERTIES

A	Sw1	Sw3	J	C1	C3
7.250	4.875	2.005	7.939	1.500	0.313

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

f
5481

REQUIRED FILLET WELD SIZE (INCHES)

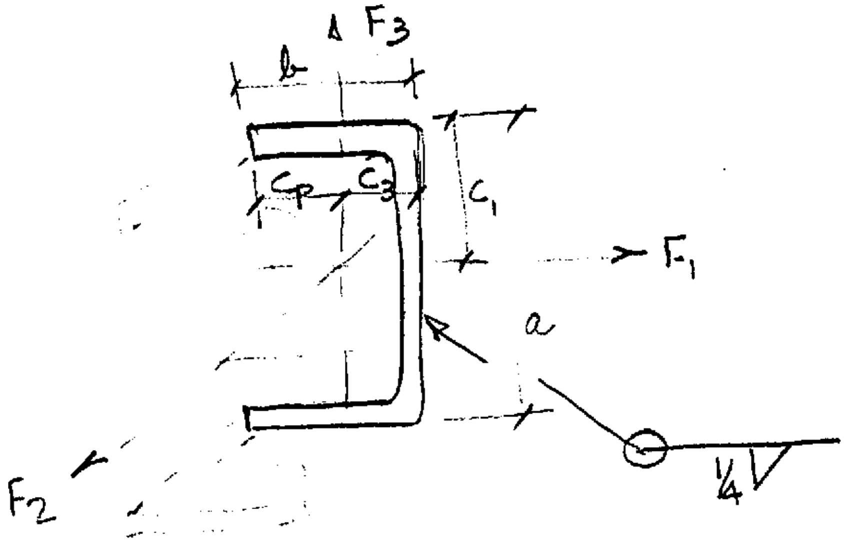
w
0.431

USE $\frac{7}{16}$ FILLET WELD

filename: CHNL_WLD.WR1

CHANNEL-SHAPED FILLET WELDS
NOTE: FOR ALL AROUND WELD USE (f)/2 TO SIZE WELD LEG

Between part HAM NOZZLE and part NOZZLE BRACKET



LOAD INPUT (LBS., INCH-LBS.)

F1	F2	F3	M1	M2	M3
12300.00	0.00	0.00	0.00	0.00	41513.00

GEOMETRIC DIMENSIONS

a	b	WELD STRESS	SKEWED ANGLE(90°>ß<135°)
6.000	4.000	18000	90.000

SECTION PROPERTIES

A	Sw1	I3	J	C1	C3
14.000	30.000	24.381	114.381	3.000	1.143

Cp
2.857

EFFECTIVE THROAT CORRECTION FACTOR

Mf
1.00

MAXIMUM WELD LOAD (f) - #/INCH

f
4944

EQUIRED FILLET WELD SIZE (INCHES)

w
0.388

$\frac{w}{2} = .20$ USE 1/4" FILLET ALL AROUND

OR

7/16 FILLET OUTSIDE EDGES
(3 SIDES)

NOZZLE SHELL STRESS DURING FULL VACUUM TEST

```
                  bracket WRC bulletin 107 design

    ASME Code Addenda used - A90
    Internal design pressure        P  =-15 psi
    Design temperature is              = 70 deg F
    Corrosion allowance             C  = 0 in.
    Shell inner diameter, new       Di = 60.5 in.
    Shell thickness, new            t  = .5 in.
    Mat'l is exempt from impact testing per UHA-51(a)
    Allowable tensile stress          S = 18800 psi for SA 240 304 HIGH A88^
    Lug length, circ direction     2C1 = 6 in.
    Lug length, long direction     2C2 = 4 in.
    Lug interface radius               = .5 in.


Applied Loads

    Radial load                  Pr = 0 lbf
    Circumferential moment       Mc = 0 lb-in
    Longitudinal moment          ML = 41513 lb-in
    Circumferential shear        Vc = 0 lbf
    Longitudinal shear           VL = 12300 lbf


Stresses at the lug interface per WRC bulletin 107

    Geometric factor gamma = 61
    Stress concentration factor Kn (tension) = 1
    Stress concentration factor Kb (bending) = 1
    Beta1 = 9.836066E-02,   Beta2 =  9.836066E-02

 ___________________________________________________________________________
| From| Value  |beta|      Circumferential (hoop) stress psi
| Fig.| read   |    |-----------------------------------------------------
|     |        |    |   Au     Al     Bu     Bl     Cu     Cl     Du     Dl
|-----|--------|----|-----------------------------------------------------
| pressure stress*  |  -908   -908   -908   -908   -908   -908   -908   -908
| 4C* | 10.216 |.098|     0      0      0      0
| 3C* |  8.586 |.098|                               0      0      0      0
| 2C-1|  .075  |.098|     0      0      0      0
| 1C  |  .109  |.098|                               0      0      0      0
| 3A* |  2.148 |.098|                               0      0      0      0
| 1A  |  .09   |.109|                               0      0      0      0
| 3B* |  6.858 |.098| -5559  -5559   5559   5559
| 1B  |  .042  |.098|-14000  14000  14000 -14000
|-------------------|-----------------------------------------------------
|Total hoop stress  |-20467   7533  18651  -9349   -908   -908   -908   -908
|-------------------|-----------------------------------------------------
|Primary membrane   | -6467  -6467   4651   4651   -908   -908   -908   -908
|circ. stress*      |
|___________________|_____________________________________________________


    Maximum primary membrane circ. stress =-6467 psi
    Allowable primary membrane circ. stress = +-1.5*S = +- 28200 psi
```

The maximum primary membrane circ. stress is within allowable limits

From Fig.	Value read	beta	Longitudinal (axial) stress psi							
			Au	Al	Bu	Bl	Cu	Cl	Du	Dl
pressure stress*			-454	-454	-454	-454	-454	-454	-454	-454
4C*	10.216	.098					0	0	0	0
3C*	8.586	.098	0	0	0	0				
1C-1	.111	.098	0	0	0	0				
2C	.074	.098					0	0	0	0
4A*	3.234	.098					0	0	0	0
2A	.047	.111					0	0	0	0
4B*	2.074	.098	-1797	-1797	1797	1797				
2B	.062	.105	-19288	19288	19288	-19288				
Total Axial stress			-21539	17037	20631	-17945	-454	-454	-454	-454
Primary membrane long. stress*			-2251	-2251	1343	1343	-454	-454	-454	-454

Maximum primary membrane long. stress =-2251 psi
Allowable primary membrane long. stress = +-1.5*S = +- 28200 psi

The maximum primary membrane long. stress is within allowable limits

Loading	Shear stress psi							
	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
torsion moment Mt	0	0	0	0	0	0	0	0
Circ. load Vc	0	0	0	0				
Long. load Vc					-2050	-2050	2050	2050
Total Shear stress	0	0	0	0	-2050	-2050	2050	2050

	Combined stress intensity, psi							
At point -->	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
Combined stress	-21539	17037	20631	-17945	4125	4125	4125	4125

Maximum combined stress =-21539 psi
Allowable combined stress = +-3*S = +- 56400 psi

The maximum combined stress is within allowable limits.

Hyspan

Hyspan Precision Products, Inc.
1685 Brandywine Avenue
Chula Vista, California 91911, U.S.A.

Telephone (619) 421-1355
Telecopier (619) 421-1702

Y049-1-048
PAGE 14 OF 14

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To: PROCESS SYSTEMS INTERNATIONAL
WESTBOROUGH, MASS.

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Date: 2/9/96

Total number of pages including this page 3

ATTN: GUY ARENA

QD-9317

Reference: HORIZONTAL ACCESS MODULE CHAMBER (HAM) NOZZLE BELLOWS DESIGN

GUY,

THE FOLLOWING ARE PRELIMINARY BELLOWS DESIGN CALCULATIONS FOR BOTH THE OPERATING & MAINTENANCE MODES DESCRIBED IN YOUR 1/24/96 FAX. NOTE THE AXIAL SPRING RATE OF 6,218 lbs./in. EQUATES TO AN APPROX. 65.5 lbs PER INCH LOAD ON THE CIRCUMFERENCE OF THE FLANGE I.D. PLEASE LET US KNOW IF YOU HAVE ANY QUESTION &/OR WE CAN BE OF FURTHER HELP. HYSPAN LOOKS FORWARD TO RECEIVING YOUR FORMAL REQUEST FOR THIS PROJECT.

REGARDS,

From: MARTY KOESTER