VOLUME II ATTACHMENTS

ATTACHMENT 1 Part II

LIGO-C960964-01-V

1. STRUCTURAL CALCULATIONS

TITLE	DOCUMENT NO.	REVISION
I. LIGO Vacuum Equipment Structural Design Criteria	V049-1-066	0
II. 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	1
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	1
NASTRAN Buckling Analysis	V049-1-040	0
BSC Support Clevis	V049-1-069	0
Nozzle D Analysis For 200 kg Force	V049-1-104	0
BSC Point Loads	V049-1-111	0

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Pr. No.	Bending Stress Cy-	/ Cy+	Recovery Distances / Cz-	/ Cz+	Ctors	Shear Stress Fact. 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 No	Nodes From/ To / Ref	Prop No	Mat No	Pincodes I / J	Rigid End Offset I / J	Length	Beam Type

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Filename=BSCSUPP
Title =Beam Splitter Chamber Support Structure

Beam No	Nodes From/	To /	Ref	Prop No	Mat No	Pincodes I / J	Rigid End Offset I	/ J	Length	Beam 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 No	Global/Local	Restraint 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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*** WARNING - Node 14 not connected to any element ***
*** WARNING - Node 20 not connected to any element *** EXTRA NODE (NOT REQ'D)

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RENUMBER NODES Version 3.0 12/31/93

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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								

ASSEMBLE STIFFNESS MATRIX Version 3.0 12/31/93

Filename=BSCSUPP
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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 NO	SIZE (Byte)	BLCK NO	SIZE (Byte)	BLCK NO	SIZE (Byte)	BLCK NO	SIZE (Byte)
1	14208						

ASSEMBLE STIFFNESS MATRIX Version 3.0 12/31/93

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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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Filename=BSCSUPP
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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

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SOLVE DISPLACEMENTS Version 3.0 12/31/93

Filename=BSCSUPP
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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

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SOLVE DISPLACEMENTS Version 3.0 12/31/93

Filename=BSCSUPP
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L O A D C A S E 1
MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

DISPLACEMENTS

	Translations			/	Rotations		
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

SOLVE BEAM LOADS/STRESSES Version 3.0 12/31/93

Filename=BSCSUPP
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Load Case 1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads LLoads Stress	Node Node Node	Fx Axial Axial Corner1	Fy Y-Shear Y-Shear Corner2	Fz Z-Shear Z-Shear Corner3	Mx Torsion Torsion Corner4	My Y-Bending Y-Bending Maximum	Mz Z-Bending Z-Bending 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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SOLVE BEAM LOADS/STRESSES Version 3.0 12/31/93

Filename=BSCSUPP
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Load Case 1:MAXIMUM UNBALANCED LOADS COMBINED WITH DEAD WT + EQ(.056G)

GLoads LLoads Stress	Node Node Node	Fx Axial Axial Corner1	Fy Y-Shear Y-Shear Corner2	Fz Z-Shear Z-Shear Corner3	Mx Torsion Torsion Corner4	My Y-Bending Y-Bending Maximum	Mz Z-Bending Z-Bending 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

================ 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 LLoads Stress	Node Node Node	Fx Axial Axial Corner1	Fy Y-Shear Y-Shear Corner2	Fz Z-Shear Z-Shear Corner3	Mx Torsion Torsion Corner4	My Y-Bending Y-Bending Maximum	Mz Z-Bending Z-Bending 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 =================

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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 LLoads Stress	Node Node Node	Fx Axial Axial Corner1	Fy Y-Shear Y-Shear Corner2	Fz Z-Shear Z-Shear Corner3	Mx Torsion Torsion Corner4	My Y-Bending Y-Bending Maximum	Mz Z-Bending Z-Bending 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

SOLVE BEAM LOADS/STRESSES Version 3.0 12/31/93

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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

SOLVE BEAM LOADS/STRESSES Version 3.0 12/31/93

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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

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, EL 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

$f_b = 22.4$ KSI $< F_b = 30.4$ KSI 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_x	18.4	5.8	15.6	6.5	
F_y	-3.5	35.0	10.5	-28.0	{ + = COMP, - = TEN }
F_z	15.5	2.6	16.3	.3	
$TEN = 1.25 F_y$	4.4	—	—	35	PRYING
$V = (F_x^2 + F_z^2)^{\frac{1}{2}}$	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 SHEETS

BEARING FOR COMPRESSIVE FORCES

AT NODE 4 $F_y = 35.0^K$

FOR 14 x 14 BASE PLATE

$f_p = \frac{35}{14 \times 14} = .18$ KSI ok

$<< f'_c = 3000$ psi FOR CONCRETE

HILTI HVA ADHESIVE ANCHORS WILL BE USED - 4 PER BASE PLATE

USE 1 IN ANCHORS w/ 8 1/4" EMBEDMENT

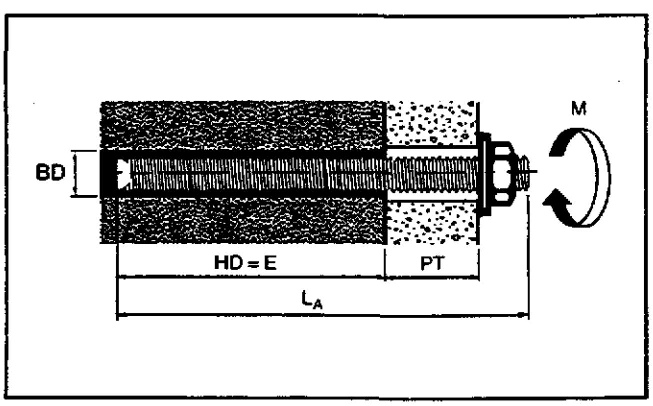
$T_{ALL} = 10.96^K$ (BOND IN 3000 psi CONC.)

$T_{ALL} = 12.12^K$ (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

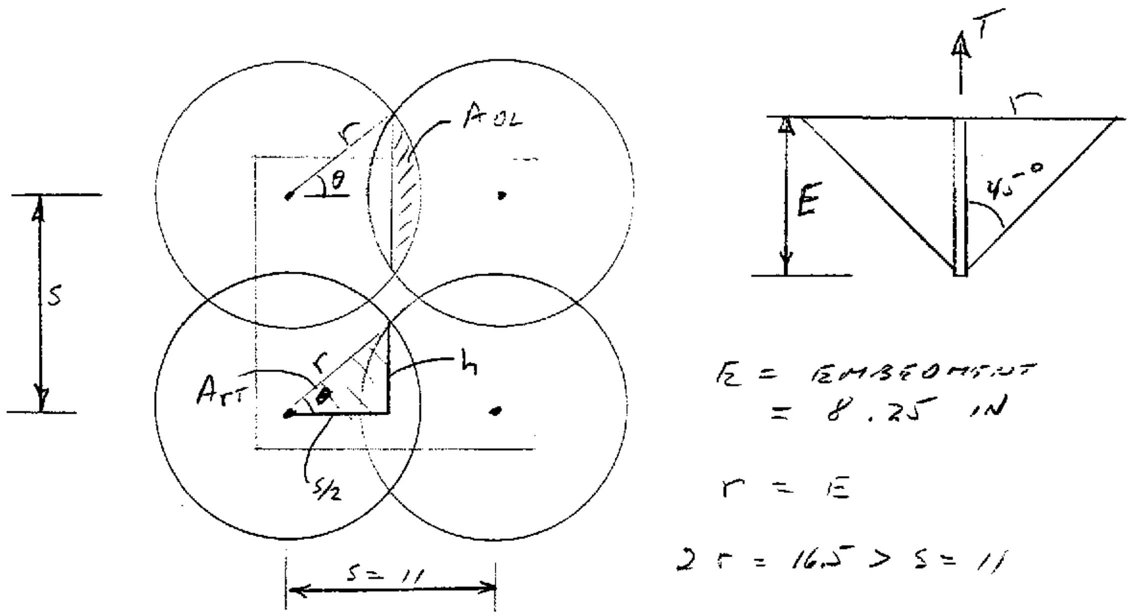
∴ USE CUSTOM ROD FOR LARGE GROUT PAD

TENSILE CAPACITY OF 4-BOLT CLUSTER DUE TO CONCRETE CONE FAILURE. CONSIDER OVERLAPPING CONES

ANCHOR SPACING

$S = 11$ IN > AS = 8 1/4 PER HILTI CATALOG

SURFACE AREA OF INTERSECTING CONES



E = EMBEDMENT = 8.25 IN

r = E

$2r = 16.5 > S = 11$

$$\theta = \cos^{-1}\left(\frac{S/2}{r}\right) = \cos^{-1}\left(\frac{5.5}{8.25}\right) = .841 \text{ RAN}$$

$$= 48.2°$$

$$h = r \sin \theta = 8.25 \sin(.841 \text{ RAD}) = 6.15 \text{ IN}$$

$$A_{rT} = S/2 \,(h/2) = \frac{11}{2}\left(\frac{6.15}{2}\right) = 16.91 \text{ IN}^2$$

$$A_{2\theta} = \pi r^2 \left(\frac{2\theta}{2\pi}\right) = r^2\theta = (8.25)^2(.841) = 57.25 \text{ IN}^2$$

$$A_{OL} = A_{2\theta} - 2A_{rT} = 57.25 - 2(16.91) = 23.43 \text{ IN}^2$$

FOR EA CONE: $A_{CONE} = \pi r^2 - 2A_{OL} = \pi(8.25)^2 - 2(23.43) = 167 \text{ IN}^2$

TOTAL CONE AREA

$A_T = 4 A_{CONE} = 4(167) = 668$ IN

CONCRETE STRENGTH FOR THE 4 BOLT ANCHORAGE

$T_U = 4 \phi_c \sqrt{f'_c} \; A_T$

$f'_c = 3000$ psi

$\phi_c = .65$

$T_u = 4(.65)(3000)^{\frac{1}{2}}(668)$

$= 95\,113$ LB

MAXIMUM TENSILE FORCE IN COL

$F_Y = 28.0^K$

PER ACI CODE, CHAP. 9, LOAD FACTOR = 1.7

$1.7F_Y = 47.6 < T_U = 95.1$ K OK

ALLOWABLE LOAD PER ANCHOR BASED ON CONCRETE CONE FAILURE

$T_{ALL} = \frac{T_U}{4(1.7)} = \frac{95.1}{4(1.7)}$

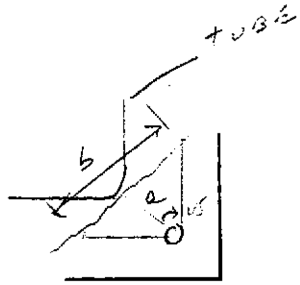
$= 14.0$ K

$> 10.96^K$ (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 $f_b = \dfrac{6M}{b\,t^2}$

$= \dfrac{6(18.6)}{4(1)^2}$

$= 27.8$ KSI $\approx .75 F_y = .75(36)$
$= 27$ KSI

SAY ok

TUBESTEEL TO BASE PLATE WELD

$T = 28.0^{K} = F_y$ MAX TENSION

TRY 5/16 FILLET,

$\ell = 4(8) = 32$

$A_w = .707\left(5/16\right)(32)$

$= 7.07\ IN^2$

WELD STRESS DUE TO SHEAR LOADS

$V = 24.0^{K}$ MAX SHEAR ON ANOTHER BASE PLATE

$f_v = \frac{T}{A_w} + \frac{V}{A_w} =$

$= \frac{28.0}{7.07} + \frac{24.0}{7.07}$

$= 4.0 + 3.4 \doteq$

$= 7.4$ KSI OK

LEG TO VESSEL CONNECTION

PAD WELD - DESIGN FOR RESULTANT FORCE AND IN PLANE MOMENT AT TOP OF SUPPORT LEG

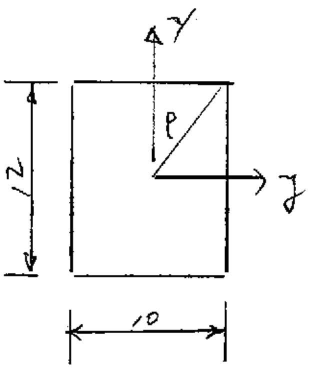
$$F = (F_x^2 + F_y^2 + F_z^2)^{\frac{1}{2}}$$

$$= (20.3^2 + 3.2^2 + 16.6^2)^{\frac{1}{2}}$$ (BEAM 4, NODE 6)

$$= 26.4^K$$ MAX FORCE

$M_z = 315$ IN-K, MAX AT BEAM 2, NODE 3 ($M_x = M_y = 0$ DUE TO PIN RELEASE)

ASSUME WELD IS 3/8 IN FILLET ALL AROUND ON 10 x 12 PAD



$$A = 3/8\,(.707)(10+12)(2) = 11.67\ in^2$$

$$I_z = \frac{3}{8}\left(2 \times \frac{12^3}{12} + 2 \times 10 \times 6^2\right)$$

$$= 3/8\,(1008) = 378\ in^4$$

$$I_y = \frac{3}{8}\left(2 \times \frac{10^3}{12} + 2 \times 12 \times 5^2\right)$$

$$= 3/8\,(767) = 288\ in^4$$

$$J = I_y + I_z = 666\ in^4$$

$$\rho = (6^2 + 5^2)^{\frac{1}{2}} = 7.81\ in$$

WELD SHEAR STRESS

$$f_v = \frac{F}{A_w} + \frac{M_z\,\rho}{J}$$

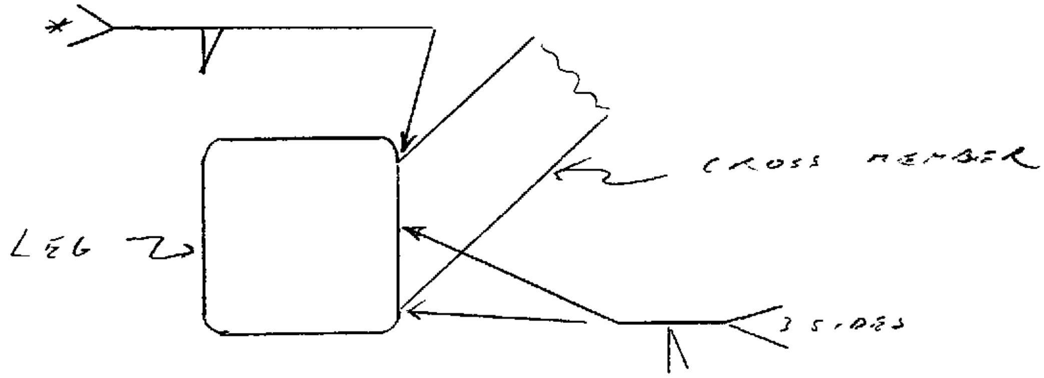
$$= \frac{26.4}{11.67} + \frac{315\,(7.81)}{666}$$

$$= 2.26 + 3.69 = 5.96\ KSI$$ 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	TITLE: Design of Temporary Covers	
0	0128	4/17/96	RDC	WDB		
					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:

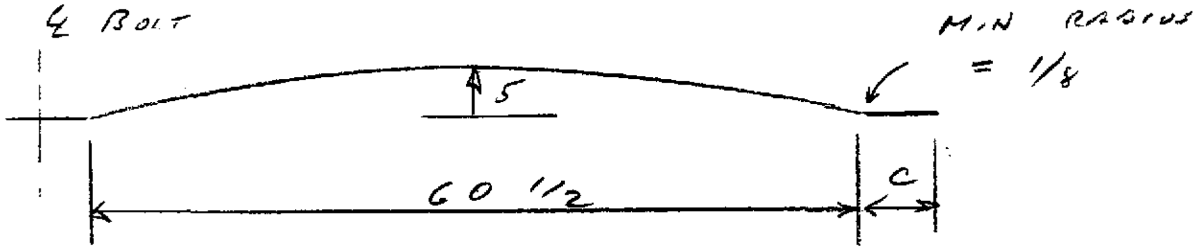
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1, Pressure Vessels
2. DOC. NO. V049-1-066, LIGO VACUUM EQUIP., STRUCT. DESIGN CRITERIA,

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)

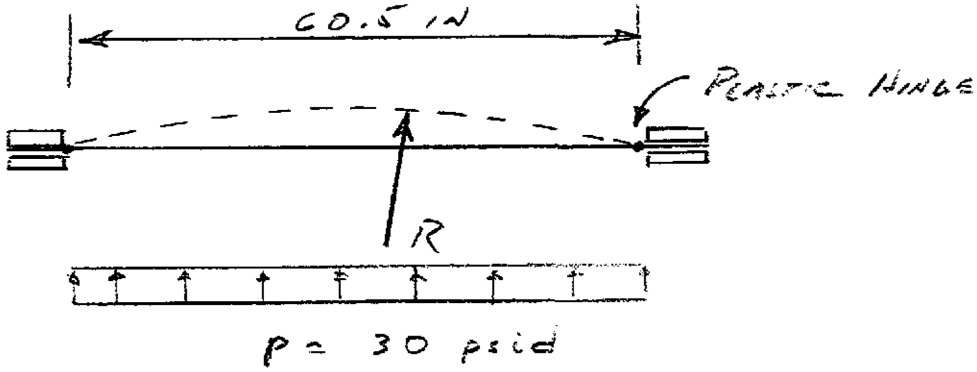
BOLT PATTERN & SIZE IS SAME AS FLANGE BOLT PATTERN & SIZE

REV 0
DOC. NO V049-1-025
P. 2 OF 5

TEMPORARY COVER FOR 60 IN PORT

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

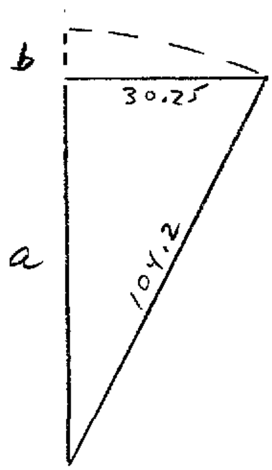
$$\sigma = S_y = 25 \text{ KSI FOR } 304L$$

$$p = 30$$

$$t = 1/16 = .0625$$

$$25{,}000 = \frac{30\,R}{2(.0625)}$$

$$R = 104.2 \text{ IN}$$



$$a = \left(104.2^2 - 30.25^2\right)^{\frac{1}{2}}$$

$$= 99.7$$

$$b = 104.2 - a$$
$$= 104.2 - 99.7$$
$$= 5.0 \text{ IN}$$

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 VIII, (1), APP 1-1

$$t = \frac{P R_o}{2SE + .8P}$$ FOR SPHERICAL SHELL

$$P = 14.7$$

$$R_o = 104.2 + .06$$
$$= 104.3$$

REV 0
DOC. NO. V049-1-025

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

$$\tau = \frac{\pi \left(\frac{60.5}{2}\right)^2 (14.7)}{\pi (60.5)(.0625)}$$

$$= 3600 \text{ psi}$$

ok

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-026 PAGE 1 OF 3
REV.	DEO #	DATE	BY:	CHECK	Beam Splitter Chamber - Evaluation of Nozzle to Shell Welds	
0	0024	12/6/95	RDC	AGR		
					BY: R.D.Ciatto	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.

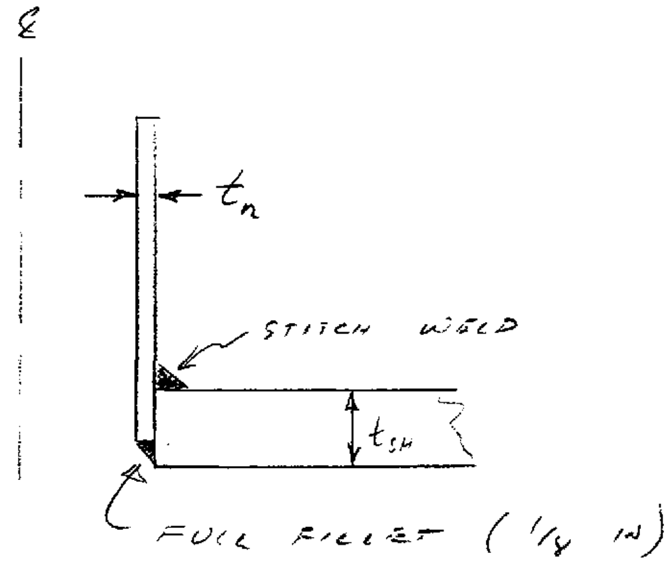
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Nozzle welds are acceptable.

NOTES:

FILED:\F:\TEMPLATE\ENGFORMS\ENGCALC

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

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

WELD THROAT AREA

$$A_w = \pi\ 14 \times .707(.125)$$

$$= 3.89\ \text{IN}^2$$

WELD SHEAR STRESS

$$f_v = \frac{F}{A_w}$$

$$= \frac{2263}{3.89}$$

$$= 582\ \text{psi}\quad \text{ok}$$

THE 60 IN NOZZLES ARE WELDED TO THE SHELL USING 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

$W = 15000$ LB

INCLUDES SUPPORTS & REMOVABLE FLOOR.

SHIPPING ACCELERATIONS FOR AIR-RIDE TRUCK.

VERT $a_v = 1.0\ g$

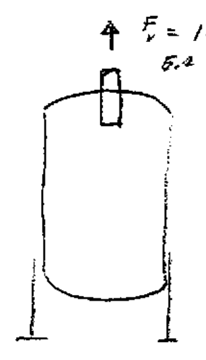
HORIZ. $a_H = .5\ g$

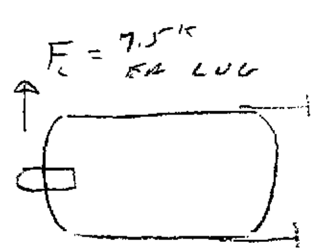
ASSUME THAT THESE ACCELERATIONS ALSO APPLY TO LIFTING IN SHOP

$\therefore$ VERTICAL LOAD = DL + SHIPPING LOAD

$= F_v = W + W = 2W$
$= 30000$ 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

$$SI = \frac{15000}{6250} \times 1590$$

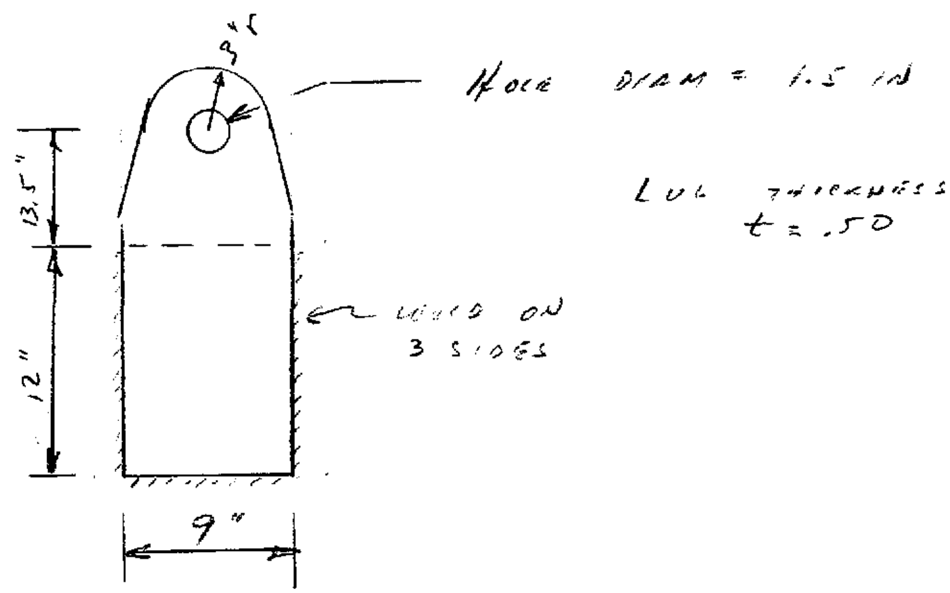
$$= 3800 \text{ psi} \quad OK$$

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



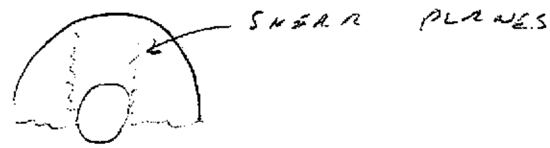
TENSILE STRESS AT PIN HOLE

$A_{NET} = (6 - 1.5)(.5) = 2.25\ in^2$

$f_t = \frac{15}{2.25} = 6.67\ ksi$ ok

FOR $t = .5$

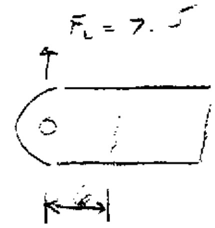
SHEAR STRESS



$A_v = 2\left(\frac{6}{2} - 1.5\right)(1.5) = 4.5\ in^2$

$f_v = \frac{15}{4.5} = 3.33\ ksi$

BENDING STRESS



$M = 13.5(7.5) = 101.25\ in\text{-}k$

$f_b = \frac{6M}{t\,b^2} = \frac{6(101.25)}{1(9)^2} = 15.0\ ksi$ ok

WELD - TRY 1/4 IN FILLET WELD

$A_w = .707(.25)(12 + 12 + 9)$
$= 5.8\ in^2$

NOTE: DWG V049-V-001 SH 5 SHOWS A WELD PAD BETWEEN LUG & VESSEL W/ 3/16 WELD ALL AROUND TO VESSEL

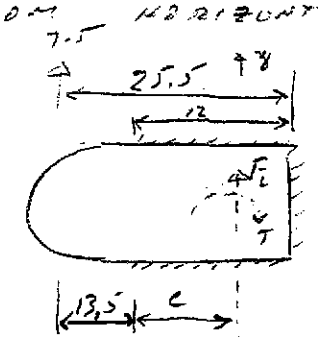
$A_w = 3/16(.707)(2 \times 12 + 2 \times 13.5)$

$= 6.8\ in^2 > 5.8$ ok

FOR VERTICAL LOAD, WELD STRESS IS

$$f_v = \frac{15}{A_w} = \frac{15}{5.8} = 2.6 \text{ KSI} \quad \text{ok}$$

TORSIONAL SHEAR STRESS DUE TO LIFT FROM HORIZONTAL POSITION



$$c = \frac{12 \times 9 + 2 \times 12 \times 6}{2 \times 12 + 9}$$

$$= 7.64 \text{ in}$$

$$F_L = 7.5^K$$

$$T = 7.5(13.5 + 7.64) = 158.6 \text{ in}^K$$

$$I_x = \left[\frac{9^3}{12} + 2(12)(4.5)^2\right](.25)(.707)$$

$$= 386.6(.25) = 96.6 \text{ in}^4$$

$$I_y = \left[9(12-7.64)^2 + 2 \times \frac{12^3}{12} + 2 \times 12 \times 1.64^2\right](.707)(.25)$$

$$= 370.2(.25) = 92.6 \text{ in}^4$$

$$J = I_x + I_y = 96.6 + 92.6 = 189.2 \text{ in}^4$$

$$\rho_{MAX} = (7.64^2 + 4.5^2)^{\frac{1}{2}} = 8.90 \text{ in}$$

WELD SHEAR STRESS

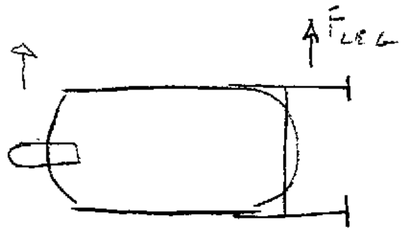
$$\tau = \frac{F_L}{A_w} + \frac{T \rho_{MAX}}{J}$$

$$= \frac{7.5}{5.8} + \frac{158.6(8.90)}{189.2}$$

$$= 1.3 + 7.43 = 8.7 \text{ KSI}$$

ok

LIFTING FORCE ON LEGS WHEN BSC IS IN HORIZONTAL POSITION



$F_{LEG} = 7.5^K$ 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 CONNECTION (3/16 FILLET ALL AROUND)

FOR VERT LOAD

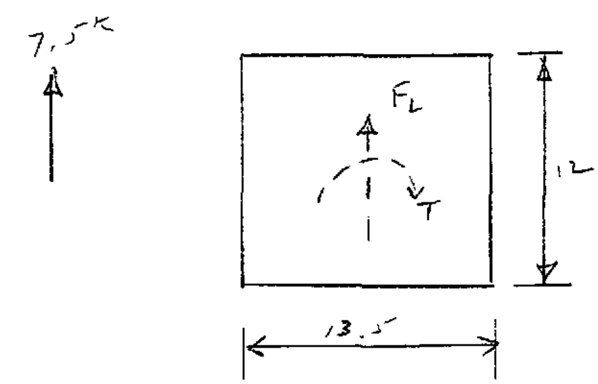
$T = 15\ K$

$A_w = .707 \times \frac{3}{16} (2 \times 12 + 2 \times 13.5)$

$= 6.76\ IN^2$

$f_t = \frac{15}{6.76} = 2.21\ KSI$ OK

FOR HORIZ CASE



$T = 7.5(25.5 + 1.5 - \frac{13.5}{2})$

$= 151.9$

$I_x = 3/16 (.707)\left[2 \times \frac{12^3}{12} + 2 \times 13.5 \times 6^2\right]$

$= 3/16 (891) = 167\ IN^4$

$I_y = 3/16 (.707)\left[2 \times \frac{13.5^3}{12} + 2 \times 12 \times \left(\frac{13.5}{2}\right)^2\right]$

$= 3/16 (1063) = 199$

$J = I_x + I_y = 366\ IN^4$

$\rho = \left[6^2 + \left(\frac{13.5}{2}\right)^2\right]^{\frac{1}{2}} = 9.03\ IN$

WELD SHEAR STRESS

$\tau = \frac{7.5}{6.76} + \frac{151.9(9.03)}{366}$

$= 1.1 + 3.74$

$= 4.8\ KSI$ OK

REV 0
Doc No V049-1-027

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	4/20/96	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	Beam Splitter Chamber - Shipping Loads	
0	0128	12/6/95	RDC	[illegible]		
					BY: R.D. C[illegible]	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

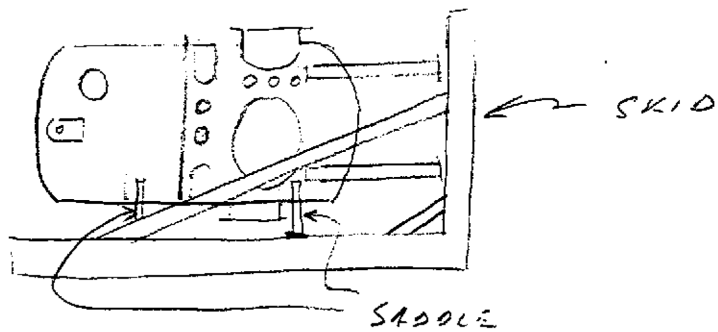
CALCULATIONS: (SEE ATTACHED)

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 (1 G) 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 (BSCUPPSR) IS USED TO EVALUATE THE SHELL. THE FILE WAS COPIED TO

FILE: BSC-1H,A

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

$$F_{Y\,564} = F_{Y\,569} = 750 \text{ LB}$$

$$F_{Y\,565 \ldots 568} = 1500 \text{ LB}$$

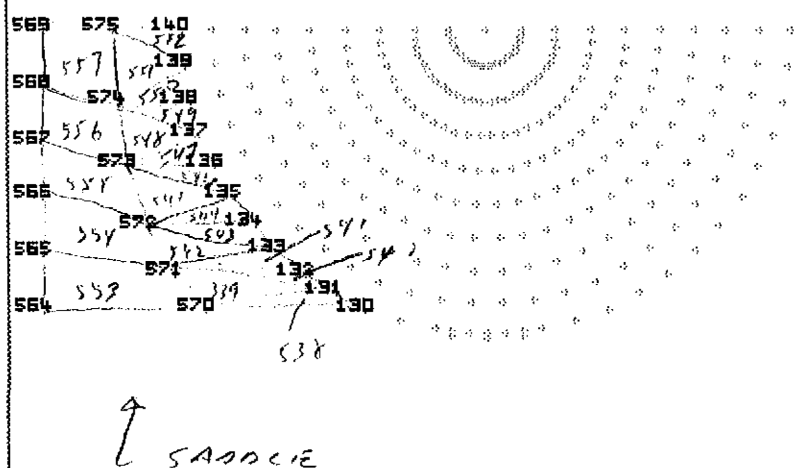
THE WOOD SADDLE IS 1 IN THICK. IT IS INPUT IN MATL 4 AND PLATE LAYER NO. 6.

PLOTS ON THE FOLLOWING SHEETS SHOW THAT THE MAX STRESS INTESITY IN THE 1/4 IN SHELL IS ONLY 2070 psi AND THE MAX DEFLECTION IS .01 IN

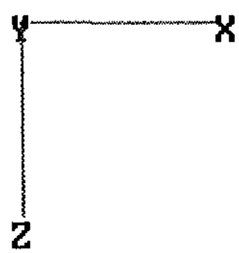
WHEN COMBINED WITH VACUUM (LOAD CASE 3) THE SHIPPING LOAD STRESS IN THE SHELL IS ONLY 2600 psi (SEE PLOT ON P. 7. THIS SHOWS THAT THE VERTICAL SHOCK COULD BE 5 GS OR MORE WITHOUT DAMAGING THE 1/4 IN SHELL

(LOAD CASE 2 IS VACUUM ALONE.)

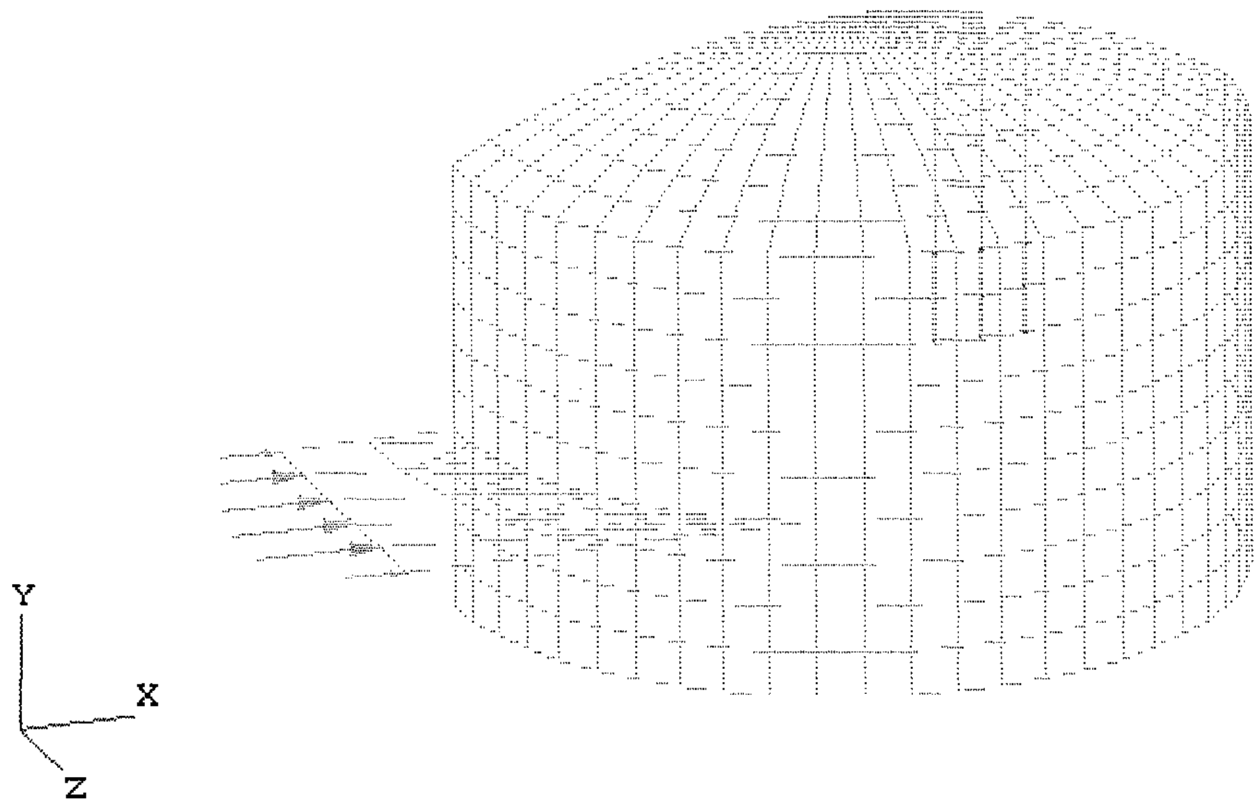
```
?#,130,140
Next Node 573
?D
Next Node 572
?-58.14,24,34
 572)     -58.14          24          34
Next Node 573
?-61.625,24,23.45
 573)    -61.625          24       23.45
Next Node 574
?-63.545,24,12.05
 574)    -63.545          24       12.05
Next Node 575
?-64.25,24,0
 575)     -64.25          24           0
Next Node 576
?#,130,140
Next Node 576
?#,564,575
Next Node 576
?
```




```
Auto    Blwup  Chge  Del
Exit    Gen    Help  List
Mult    Prnt   Rot   SCrn
Select  Undel  #
```



IMAGES-3D
Ver. 3.0



Revision 0
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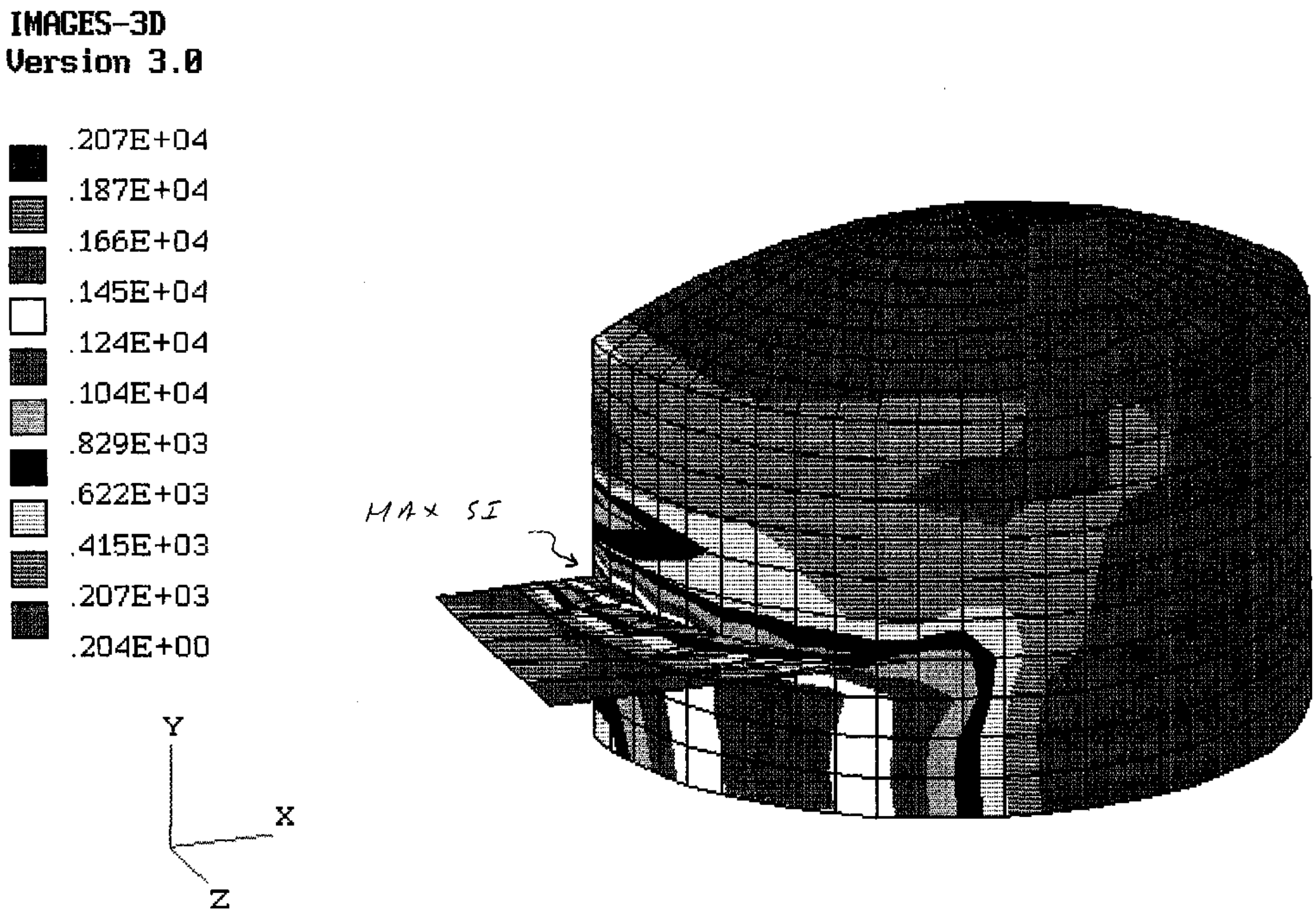
Load Case
1

Wireframe Plot

11/30/95
11:29: 2



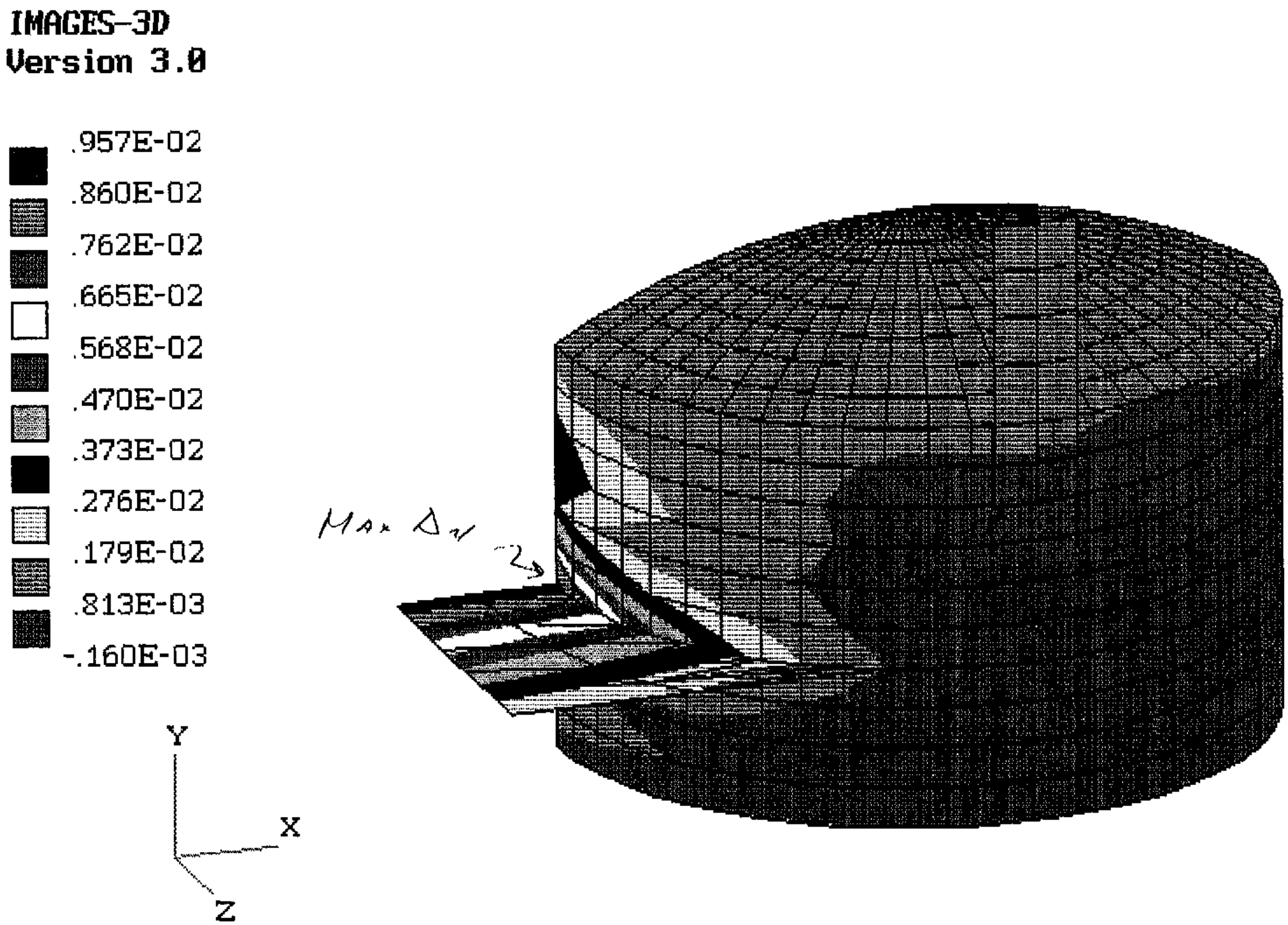
Load Case 1

Stress Contour Plot

Surf: Bottom

Stress Intensity

11/30/95 11:25: 6



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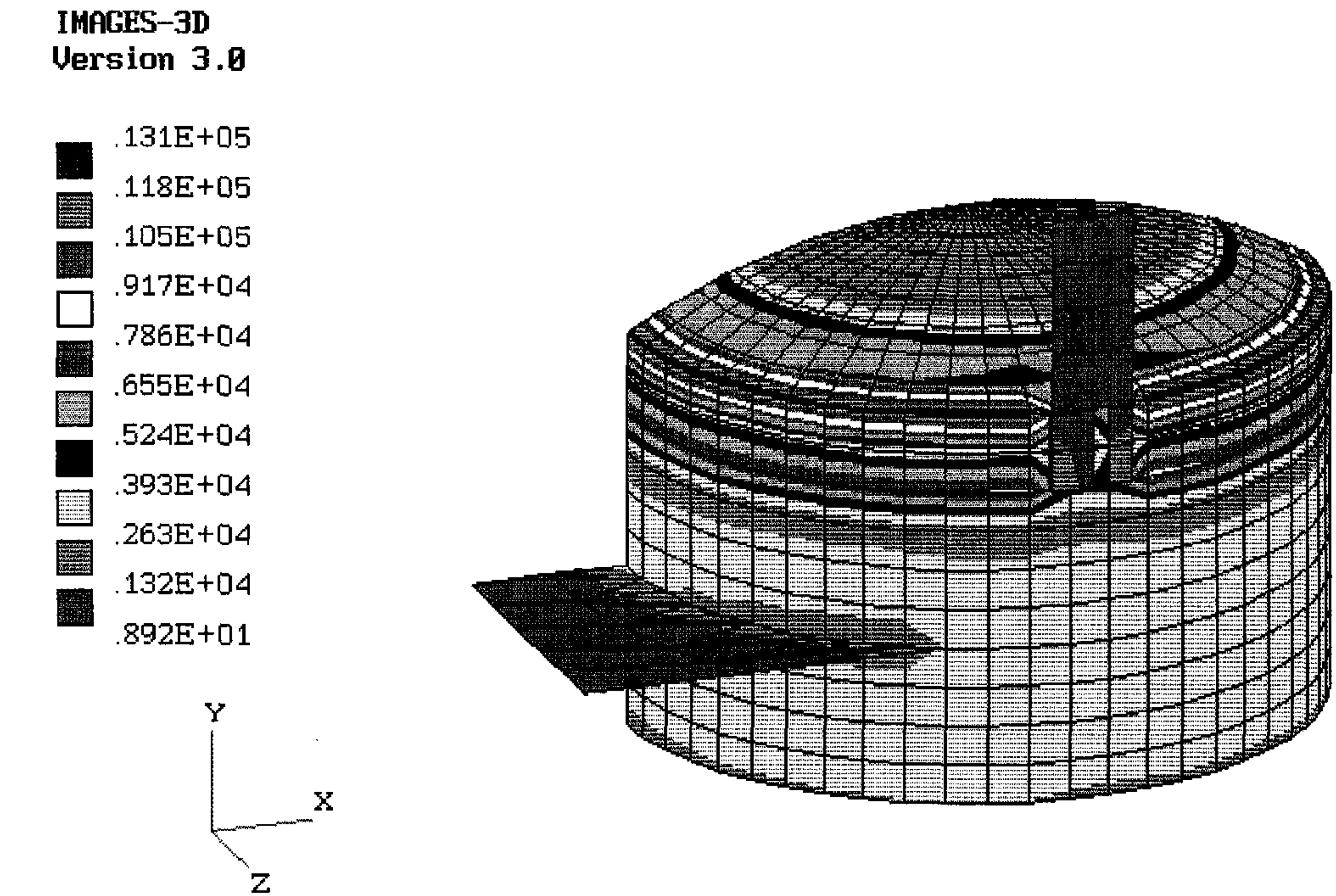
Page 7 of 8

Load Case 1

Displacement Contour Plot
DX

11/30/95
11:27:37



Load Case 3

Stress Contour Plot

Surf: Top

Stress Intensity

4/20/96
9:21:40

Rev 0
Doc. No. V049-1-028
P. 8 of 8

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-029 PAGE 1 OF 5
REV.	DEO #	DATE	BY:	CHECK	TITLE: Beam Splitter Chamber - Deflections	
0	0024	12/6/95	RDC			
1	0237	8/2/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Compute estimated deflections at Beam Splitter 60.5 in Nozzles for vacuum loads.

METHOD: Combine shell deflections with support deflections to obtain maximum estimated deflections at ports.

ASSUMPTIONS: Bellows deflects with negligible force.

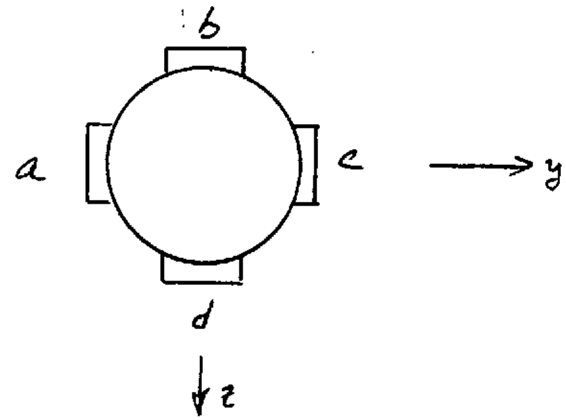
INPUTS: LIGO project drawing V049-4-001 - Beam Splitter Chamber.
LIGO project drawing V049-5-001 - Equipment Arrangement - Corner Station - Washington
Calc. No. V049-1-066, Structural Design Criteria
Calc. No. V049-1-022, BSC, FE Analysis of Lower Section
Calc. No. V049-1-024, BSC, Design of Support Legs and Base Plates

REFERENCES: See INPUTS

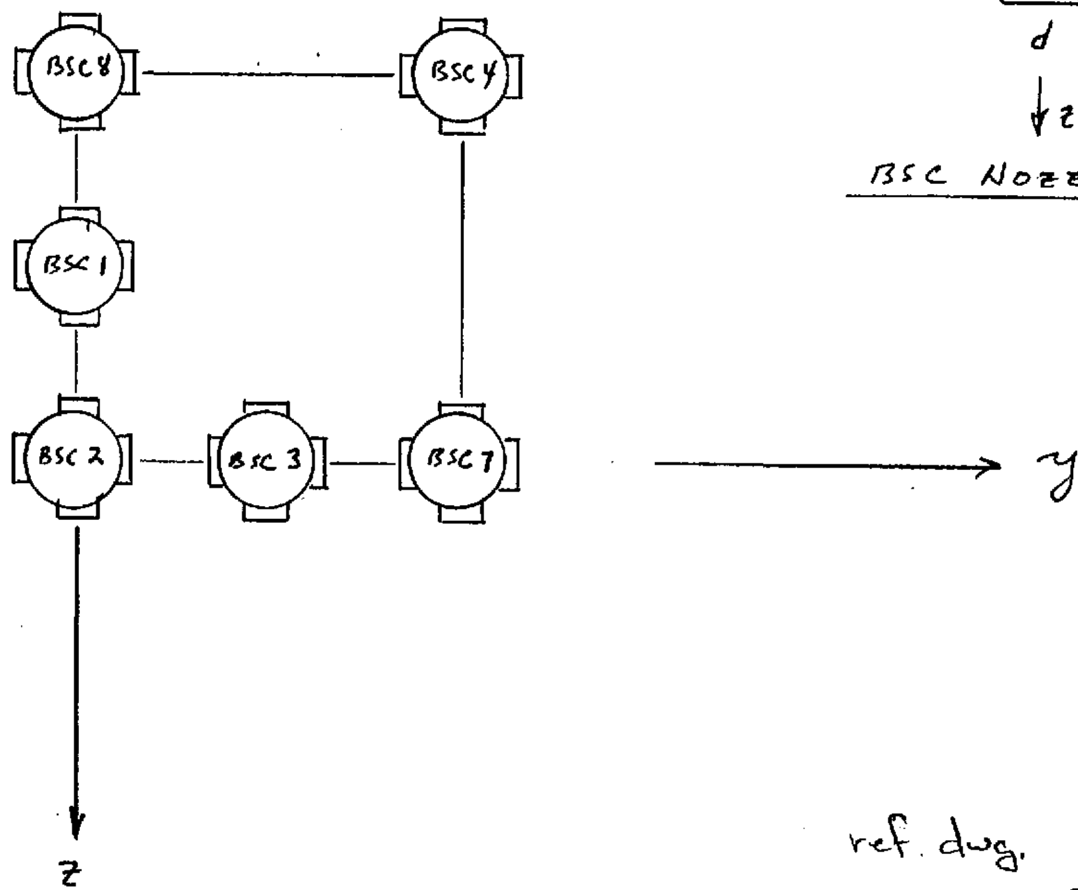
CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS:

NOTES: The basis for the Rev. 1 deflections is the final support structure.



BSC NOZZLE ORIENTATION



CORNER STATION KEY PLAN

ref. dwg.
V049-5-001

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Doc. No. V049-1-029
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22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

OPERATING CONDITIONS

1. ALL VACUUM

2. VERTEX SECTION VENTED

3. DIAGONAL SECTION VENTED

DEFLECTIONS RESULT FROM

- SHELL DISPLACEMENT max $\delta \mathrel{\hat{=}} .125$
  ref. calc. V049-1-022
- SUPPORT DISPLACEMENT

$$\delta_{max} = \delta_x = .1524'' \approx .15''$$

ref. calc. V049-1-024 pg. 18 of 35

DEFLECTIONS ARE IN INCHES

BSC No.	Op. Cond. No.	Port a Δy	Port a Δz	Port b Δy	Port b Δz	Port c Δy	Port c Δz	Port d Δy	Port d 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								

BSC No.	Op. Cond. No.	Port a Δy	Port a Δz	Port b Δy	Port b Δz	Port c Δy	Port c Δz	Port d Δy	Port d Δz
7	1	.125	-.15		-.025	-.125	-.15		-.275
	2	.275	-.15	.15	-.025	.025	-.15	.15	-.275
	3	.125	-.15		-.025	-.125	-.15		-.275
8	1	.275		.15	.125	.025		.15	-.125
	2	.275	-.15	.15	-.025	.025	-.15	.15	-.275
	3	.275		.15	.125	.025		.15	-.125

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-040 PAGE 1 OF 7
REV.	DEO #	DATE	BY:	CHECK	TITLE: Buckling Analysis of Beam Splitter Chamber	
0	0128	1/29/96	KM	RDC		
					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: BMSPY*.INP

FILED:\F:\TEMPLATE\ENGFORMS\ENGCALC

1.0 Hand Analysis

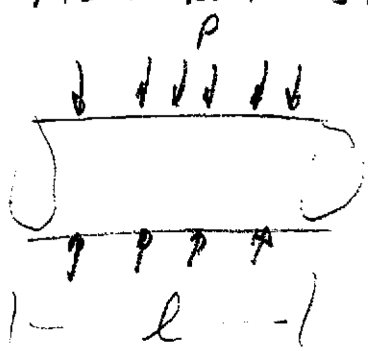
Assumption - (1) Extra material at nozzles replaces stiffness of vessel material removed

(2) pressure uniform over cylinder

(3) stiffeners 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

$$P_{cr} = .807 \frac{E t^2}{\ell r} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 \frac{t^2}{r^2}}$$

$t = 0.5''$ $\quad \ell = 91''$ $\quad \nu = 0.3$

$r = 52.75''$ $\quad E = 29(10^6)$ 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

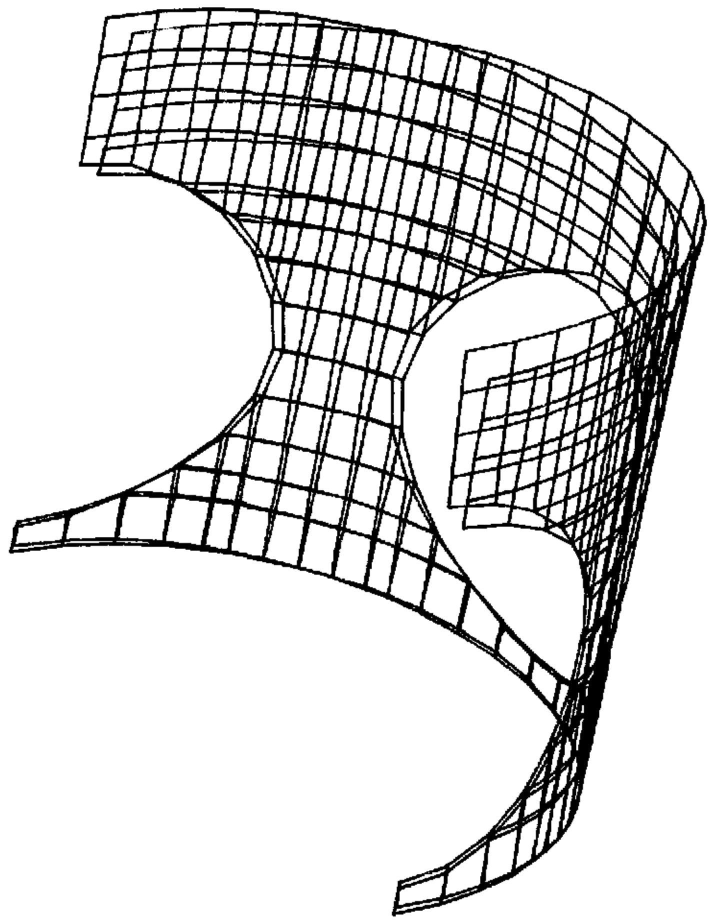
j. Except as describe above all other stiffeners are ignore

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 - opposite bellows (Fig 3)	6.1
2 - adjacent bellow	5.9

5 1/29/96 MAX-DEF. = 1.00000000 5



HAM 1/1 SYMM MODEL

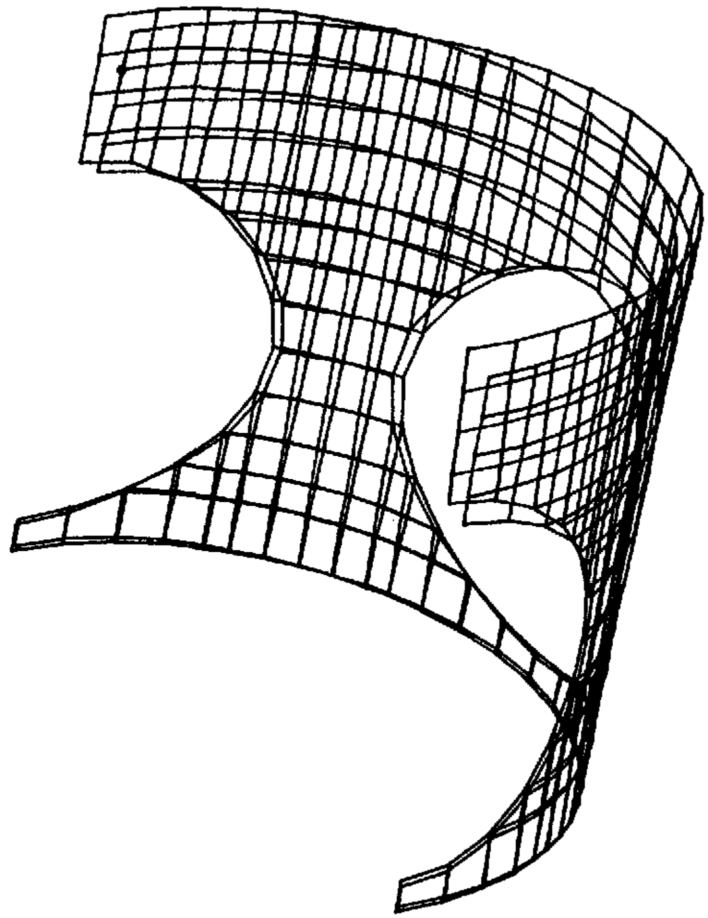
BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2 MODE 5 EIGENV. 7.043044 MASS MODEL

Fig 1 · 4 Bellows Buckling Shape

Rev 0
Doc. No. Y0149-1-040
Pg 5 of 7

5/7

6 1/29/96 MAX-DEF. = 1.00000000 5



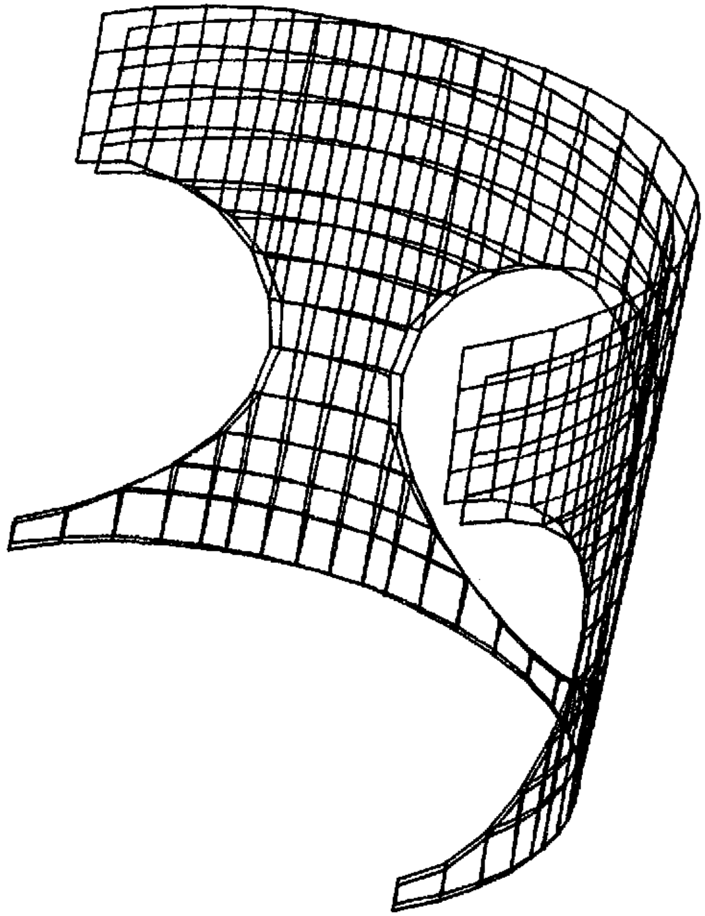
HAM 1/1 SYMM MODEL

BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2 MODE 6 EIGENV. 6.475190 MASS MODEL

Fig 2 3 Bellows Buckling Shape

Rev 0
Doc. No. V049.1-040
p. 6 of 7

6   1/29/96   MAX-DEF. = 1.00000000   6



HAM 1/1 SYMM MODEL

BUCKLING SOLUTION
MODAL DEFOR. SUBCASE 2   MODE 6   EIGENV. 6.128821 MASS MODEL

Doc. No. V049-1-010
Rev 0
p. 7 of 7

Fig 3 2 Bellows [illegible]

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-069
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 9
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

ASSUMPTIONS: 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

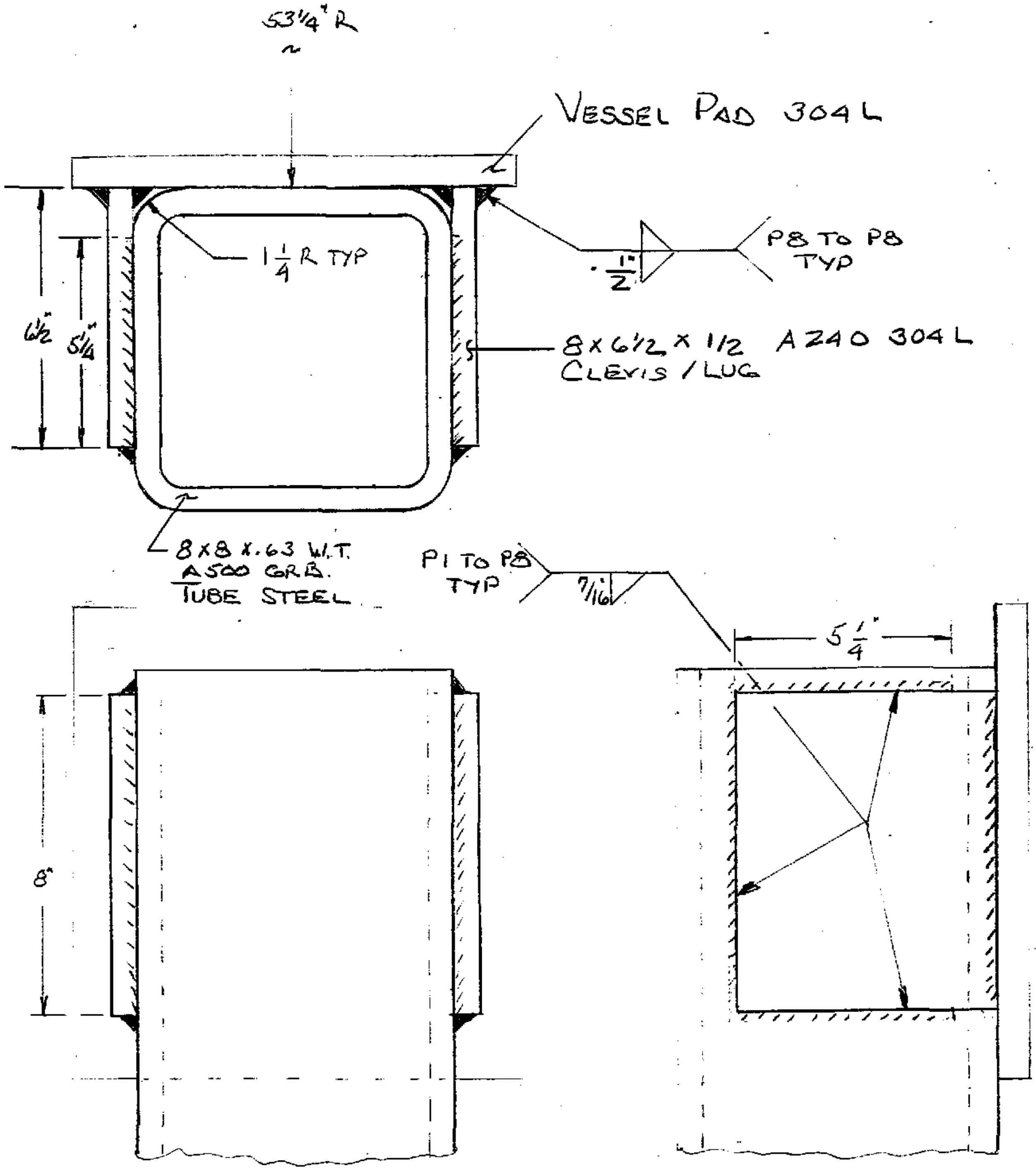
CALCULATIONS: (SEE ATTACHED)

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 304/304 L MATERIAL. I.E. 304 L 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 AHA-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:

$\tau \leq$ .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.

$$\therefore \tau \leq .30 \times 75000 \left(\frac{St_{HOT}}{St_{COLD}}\right)$$

$$\tau \leq .30 \times 75000 \left(\frac{63450}{82800}\right) = 17{,}242 \text{ PSI}$$

- CONCLUSION:

  - $\tau_{TORSION} \leq .8\,S_m = 7{,}480$ PSI

  - $\tau_{PURE} \leq .6\,S_m = 5{,}610$ PSI

2.3 - SUMMARY:

- TORSIONAL SHEAR: $\tau \leq 7{,}480$ PSI $= .8\,S_m$ (ALLOWED)

- PURE SHEAR: $\tau \leq 5{,}610$ PSI $= .6\,S_m$ (ALLOWED)

- LOCAL PRIMARY MEMBRANE STRESS: $P_L \leq 1.5\,S_m$ (REF: AD 140 (c))

  $P_L \leq 1.5(.5\,S_m) = 1.5(.5)(18{,}700) = 14{,}025$ PSI

- PRIMARY BENDING STRESS: $P_b \leq 1.5\,S_m$ (REF: AD 140 (d.))

  $P_b \leq 14{,}025$ PSI

- $P_L + P_b \leq 1.5\,S_m = 14{,}025$ PSI

3 - SUPPORT WELD ANALYSIS

REF: BSC SUPPORT DESIGN SKETCH
PSI DWG. V049-4-043
" " V049-4-001

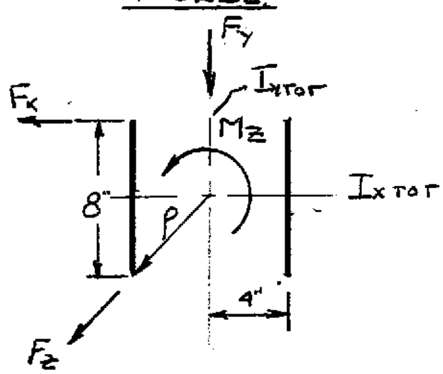
- THE FOLLOWING ARE THE WORSE CASE LOADS FOR BEAM #2, NODE 3 AS CALCULATED IN REF. DOC. NO. V049-1-024, P.19

$F_x = 220\#$; $F_y = 11{,}930\#$; $F_z = 2444\#$

$M_z = 314{,}500$ IN-#

3.1 - CLEVIS / LUG TO VESSEL WELD

MODEL:



$\rho = [8^2+8^2]^{1/2} = 5.65''$

$I_{xTOT} = \frac{4bh^3}{12} = \frac{4(.707)(.5)(8)^3}{12} = 60.3$ IN⁴

$I_{yTOT} = 2\left\{\frac{8[2(.707)(.5)]^3}{12} + (2)(.707)(.5)(8)(4)^2\right\} = 181.5$ IN⁴

$J = I_{xTOT} + I_{yTOT} = 60.3 + 181.5 = 241.8$ IN⁴

- TORSION: $T = M_z = 314{,}500$ IN-#

$\tau = \frac{T\rho}{J} = \frac{314{,}500(5.65)}{241.8} = 7{,}349$ PSI $< .8S_m = 7{,}480$ PSI ∴ 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 ∴ OK

$\sigma_{sy} = F_y/A_s = (11{,}930)/11.31 = 1055$ PSI $< .6S_m = 5610$ PSI ∴ 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

$< .8S_m = 7{,}480$ PSI ∴ 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:

$$\sigma = \sqrt{216^2 + 7444^2} = 7447 \text{ PSI} < .8S_M = 7480 \text{ PSI}$$

$\therefore$ OK

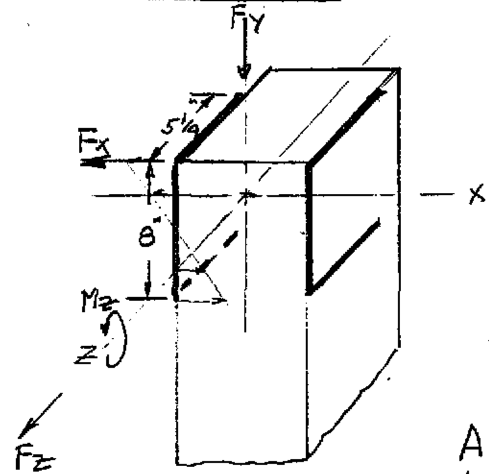
3.2 - 8X8 STEEL TUBE LEG TO CLEVIS/LUG

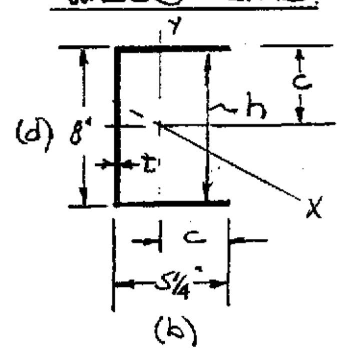
- SHEAR: $F_S = \sqrt{F_Y^2 + F_Z^2} = \sqrt{(11930)^2 + (2449)^2} = 12,178\#$

$$\sigma_S = \frac{F_S}{A_S} = \frac{12,178}{2[.707(.4375)(8 + 2 \times 5.25)]} = 1,064 \text{ PSI}$$

$< .6 S_M = 5,610$ PSI $\therefore$ OK

- BENDING:





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
$\therefore$ OK

WHERE;

$$I = \frac{bd^3 - h^3(b-t)}{12}$$ REF: MACHINERY HDBK; 17ED; P.364

$$I = [(5.25)(8)^3 - (7.38)^3(5.25 - .31)]/12 = 58.5 \text{ IN}^4$$

$b = 5.25"$; $d = 8"$; $t = .707(.4375) = .31"$

$h = 8 - 2 \times (.707)(.4375) = 7.38"$

$C = 4"$

- TENSILE / COMPRESSIVE

$$\sigma_{T/C} = \frac{F_X}{A_S} = \frac{220}{11.44} = 19 \text{ PSI}$$

- COMBINED STRESS:

$$\sigma = \frac{(10{,}746 + 19)}{2} \pm \sqrt{\left(\frac{10746+19}{2}\right)^2 + (1064)^2}$$

$$\sigma_{1,2} = 5383 \pm 5487$$

$$\sigma_1 = 10{,}870 \text{ PSI} \; ; \; \sigma_2 = -104 \text{ PSI} \; ; \; \sigma_3 = 0$$

- MAX STRESS INTENSITY:

$$S_{MAX} = 10{,}780 - (-104) = 10{,}884 \text{ PSI}$$

$$< 1.5 S_m = 14{,}025 \text{ PSI} \quad \therefore \text{ OK}$$

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-104 PAGE 1 OF 9
REV.	DEO #	DATE	BY:	CHECK	TITLE: Beam Splitter Chamber - Nozzle D Analysis for 200 kg Force	
0	0293	7/2/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744
PROJECT: LIGO Vacuum Equipment					PROJECT NO: V59049	

PURPOSE: Evaluate nozzle D of the BSC for 200 kg load specified by the LIGO project.

METHOD: Hand calculations for overall stress analysis of nozzle and FE analysis to determine detailed stresses.

ASSUMPTIONS:
1. Force is transverse to nozzle centerline.
2. Force is applied uniformly about circumference at end of nozzle.

INPUTS: LIGO project drawing V049-4-001 - Beam Splitter Chamber.
Calc. No. V049-1-066, Structural Design Criteria

REFERENCES: See INPUTS

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: The resulting stresses from the imposed nozzle D forces are low and the structural integrity of the nozzle and shell are not affected by this load.

NOTES: See load cases 4 and 5 of computer file BMSPLI12.* for the Images FE model results.

ANALYSIS OF 200 Kg FORCE ON NOZZLE D RESULTING FROM LIGO BELLOWS

ASSUMPTIONS

FORCE IS TRANSVERSE TO NOZZLE ℄

FORCE IS APPLIED UNIFORMLY

SHEAR FORCE

$V = 200\ Kg$

$= 2.205(200) = 441\ LB$

NOZZLE D CROSS SECTION AREA

$A = \pi D t$

$D =$ MEAN DIAM

$= 14'' - t$

$t = .125$

$D = 13.875$

$A = \pi(13.875)(.125)$

$= 5.45\ IN^2$

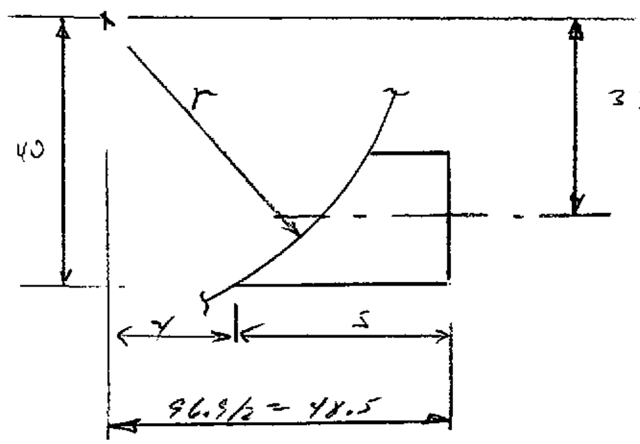
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

AVERAGE SHEAR STRESS

$$\tau = \frac{V}{A} = \frac{441}{5.45}$$

= 81 PSI – NEGLIGIBLE

BENDING MOMENT AT NOZZLE TO SHELL WELD



REF DWG V049-4-001 FOR DIMENSIONS

r = 52 IN

$y^2 + 40^2 = 52^2$
$y = 33.2$

$S = 48.5 - 33.2$
$= 15.3''$ = MAX MOMENT ARM AT SHELL

$M = 441(15.3) = 6747$ IN-LB

C

$$I = \pi R^3 t$$

$$R = \frac{13.875}{2} = 6.94^{\,IN}$$

$$I = \pi (6.94)^3 (.125)$$

$$= 131 \; IN^4$$

BENDING STRESS IN NOZZLE

$$f_b = \frac{MR}{I} = \frac{6747\,(6.94)}{131}$$

$$\approx 360 \;\text{psi} \; - \text{NEGLIGIBLE}$$

SHEAR STRESS IN NOZZLE TO SHELL WELD DUE TO BENDING MOMENT. MAX FORCE PER IN

$$F_V = \frac{MR}{I}$$

$$I = \frac{131}{.125}\, t = 1048\, t \;\; IN^4$$

$$F_V = \frac{6747\,(6.94)}{1048} \approx 45 \frac{\#}{IN}$$

MAX SHEAR STRESS FOR 1/8" FILLET WELD

$$f_V = \frac{45}{.125\,(.707)} = 505 \;\text{psi} \quad \text{ok}$$

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22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

d

FROM CALC V049-1-026, P. 3, THE MAX WELD SHEAR STRESS DUE TO THE END CAP PRESSURE IS 582 psi

TOTAL MAX WELD SHEAR STRESS IS

$$f_v = 505 + 582$$

$$= 1087. \text{ psi}$$

FINITE ELEMENT ANALYSIS OF THE 200 Kg SHEAR LOAD

THE FE MODEL, BHSPLI12 WILL BE USED TO ANALYZE THE EFFECTS OF THE SHEAR FORCE. LOAD CASE 4 WILL EVALUATE THE X-DIRECTION LOADS AND LOAD CASE 5 WILL EVALUATE THE Z DIRECTION LOADS, THE LOAD WILL BE APPLIED TO THE 8 NODES AROUND THE NOZZLE AT THE CONFLAT FLANGE. SEE PLOT ON FOLLOWING SHEET.

$$F_i = 55.125 \#$$

FROM NODE 2047 TO NODES 2054

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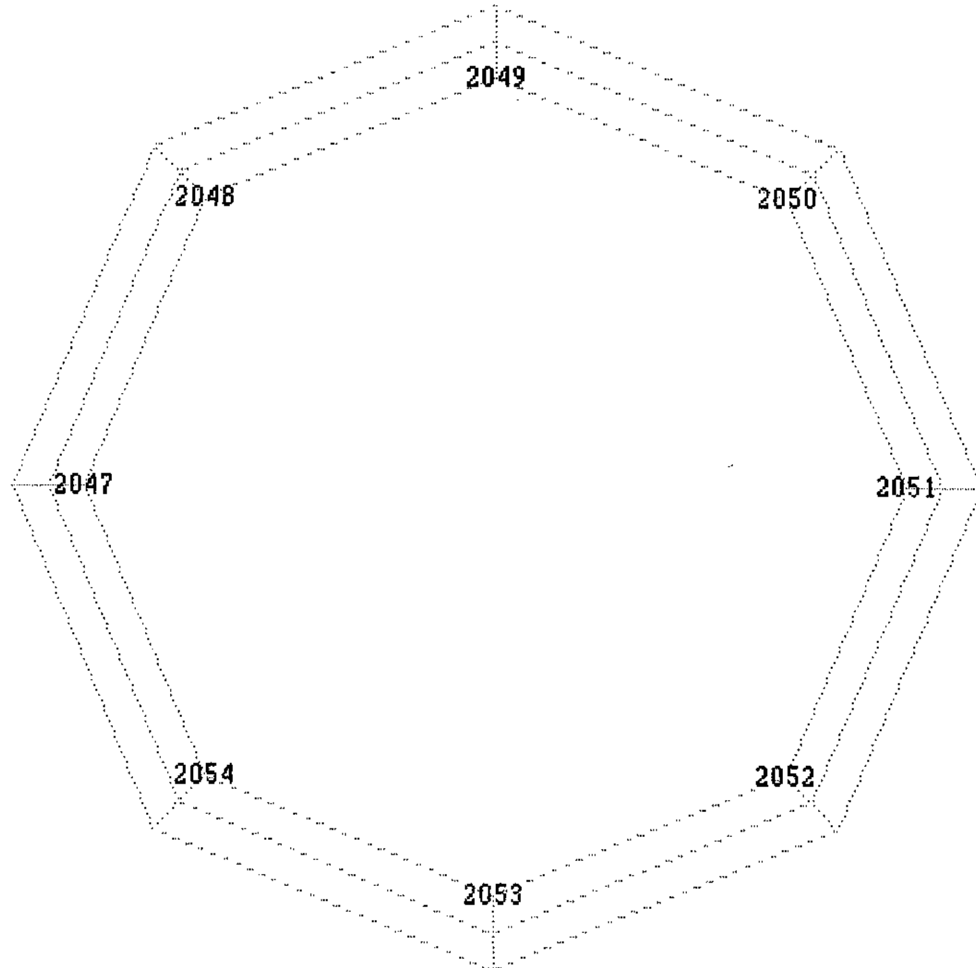
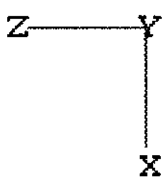
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

IMAGES-3D
Ver. 3.0
Geometry Plot

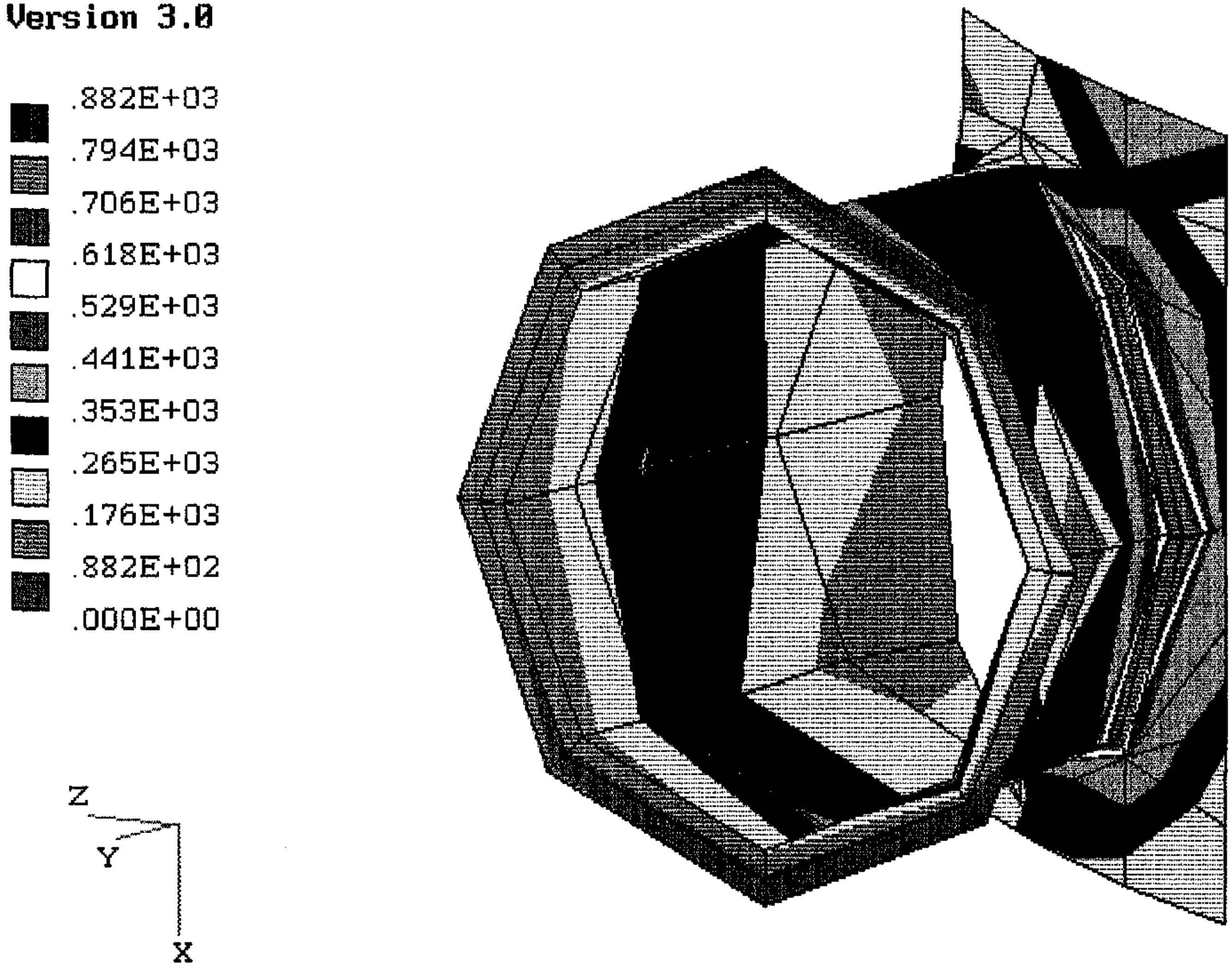
Y range
?48,51
Z range
?23,44
?i
X range
?-55,-35
Y range
?48.5,51
Z range
?23,44
?r,20
?





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

IMAGES-3D
Version 3.0



Revision No. 0
Doc. No. V049-1-104

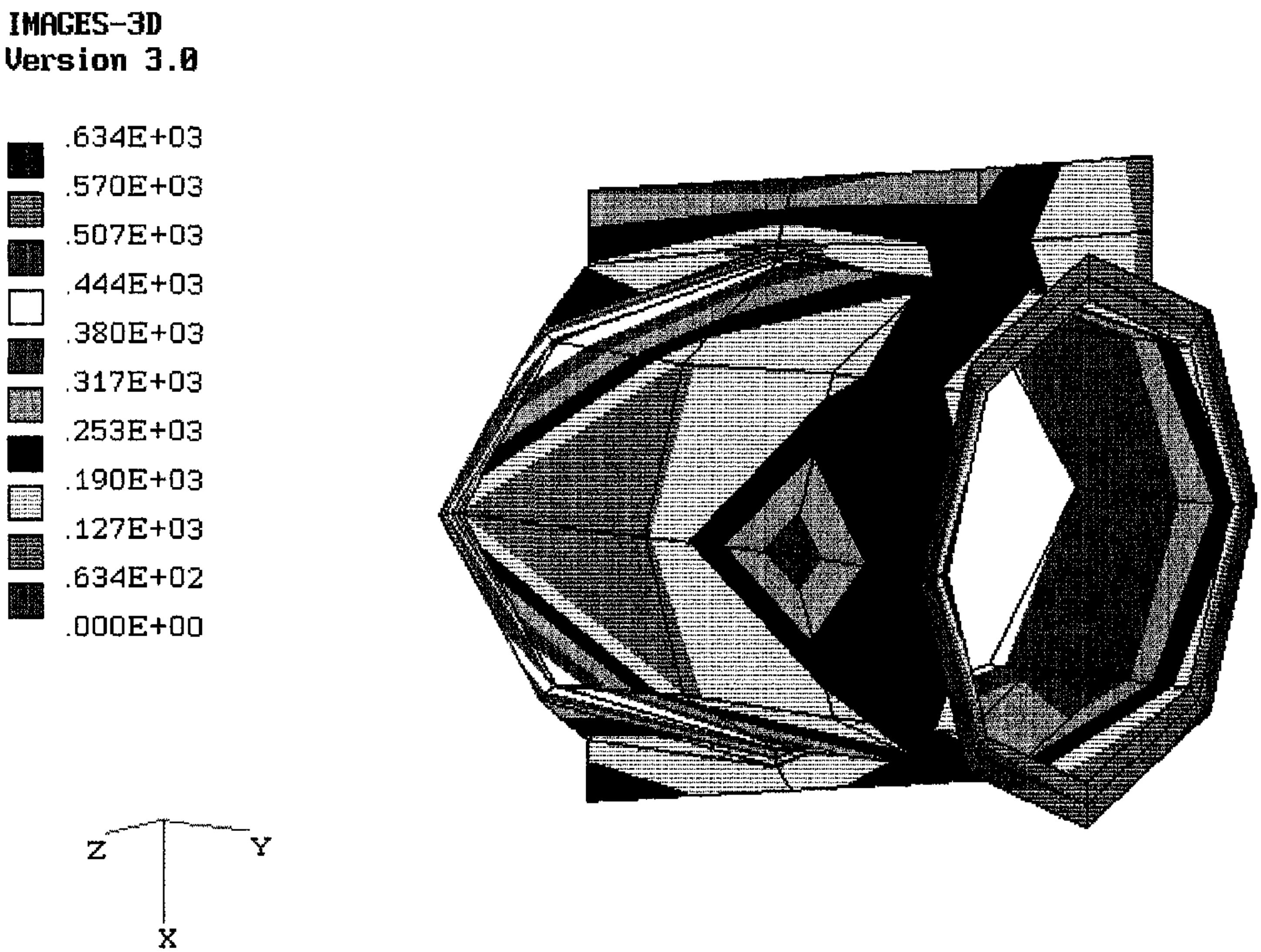
Load Case 5

Stress Contour Plot

Surf: Top

Stress Intensity

7/1/96
16:1:57



Load Case 4

Stress Contour Plot

Surf: Bottom

Stress Intensity

7/ 1/96
16: 7:51

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-031 PAGE 1 OF 2
REV.	DEO #	DATE	BY:	CHECK	Vacuum Equipment Seismic Acceleration	
0	0128	12/6/95	RDC	WDB		
					BY: R.D. CIATTO	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 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 FACTOR 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)

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Pg. 2 of 2

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AMPAD

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-032 PAGE 1 OF 23
REV.	DEO #	DATE	BY:	CHECK	TITLE: Component Interface Loads	
0	139	12/29/95	RDC	AGR		
					BY: R. D. Cirotto	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 (BSC's) ARE ON BSC 7 & BSC 8 OF THE WASHINGTON CORNER STATION - SEE PAGES 7 & 8
THE MAX FLANGE TENSION IS 29.5K ON THE 60.5 IN FLANGE

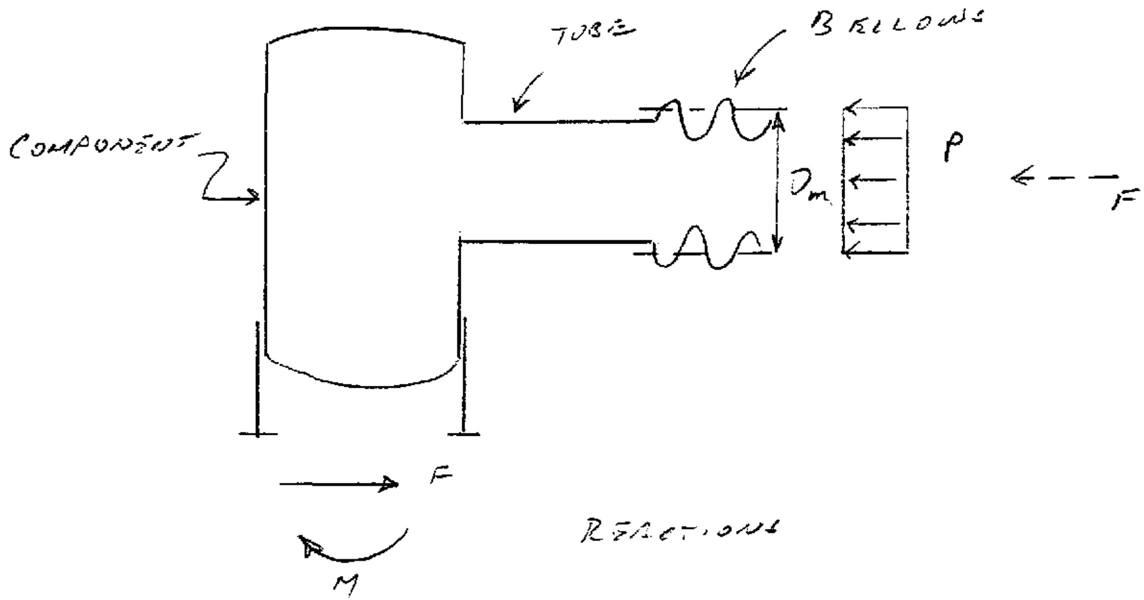
THE MAXIMUM UNBALANCED FORCE ON THE HORIZ. ACCESS MODULES (HAM's) ARE ON HAMS AT THE ENDS OF THE VACUUM SYSTEM. F = 45.5K, NO TENSION ON FLANGES

FOR GATE VALVES, BOLTED FLANGES CAN HAVE TENSILE LOADS FROM FULL VACUUM. THE SAME IS TRUE FOR WELDED FLANGES.

F = 29.5K FOR 48.25" VALVE
F = 25.4K " 44.63" VALVE

FOR THE 80K PUMPS THE MAXIMUM FLANGE FORCE IS 25.4K 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

$$D_M = 44.63 + 2.25 = 46.88 \text{ IN}$$

$$F = P \, \pi \frac{D_M^2}{4}$$

$$= -14.7 \frac{\pi}{4} (46.88)^2$$

$$= 25,370 \text{ LB} = 25.4 \text{ K}$$

NEGLECT POS/NEG SIGN FOR NOW, VAC LOAD PULLS FROM SUPPORTED COMPONENT TOWARD BELLOWS WHERE THERE IS A CLOSED VALVE OR IT PUSHES ON BACK SIDE OF VESSEL TOWARD BELLOWS.

48.25 IN TUBE

$$D_M = 48.25 + 2.25 = 50.5 \text{ IN}$$

$$F = 14.7 \frac{\pi}{4} (50.5)^2 = 29\,440 \text{ LB} = 29.44 \text{ K}$$

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

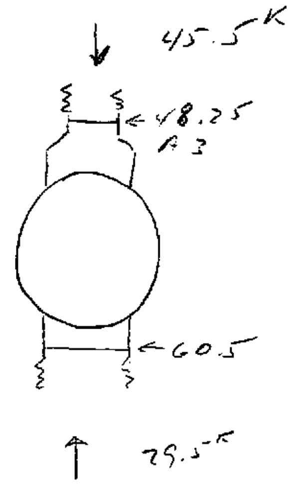
$$D_M = 72.25 + 2.25 = 74.5 \text{ IN}$$

$$F = 14.7 \pi \frac{(74.5)^2}{4} = 64080 \text{ LB} = 64.1 \text{ K}$$

WASHINGTON CORNER STATION
REF. DWG V049-5-001 FOR LAYOUT OF EQUIPMENT & BELLOWS

BEAM SPLITTER CHAMBERS

BSC 1

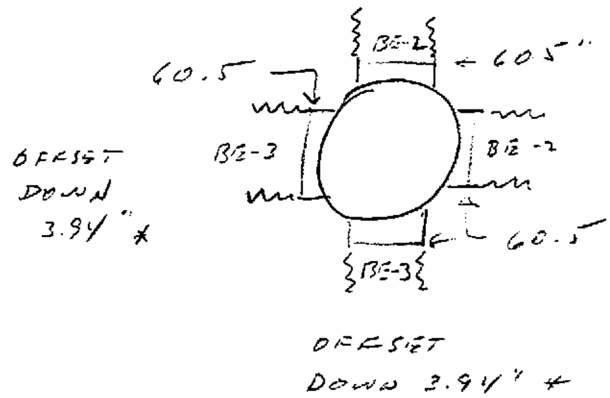


NET FORCE

$$F = 45.5 - 29.5 = 16^{K}$$

NO TENSION ON FLANGES

BSC 2

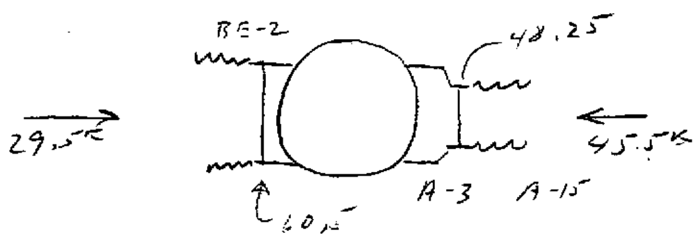


NO UNBALANCED LOADS EXCEPT FOR OFFSETS

NO TENSION ON FLANGES

* NO EFFECT - BELLOWS ELEVATION SAME AS BSC PORT

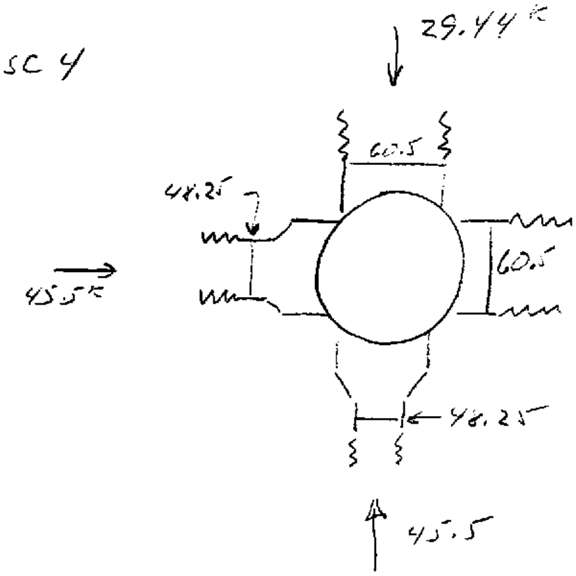
BSC 3



NET FORCE = 16^K

NO TENSION ON FLANGES

BSC 4

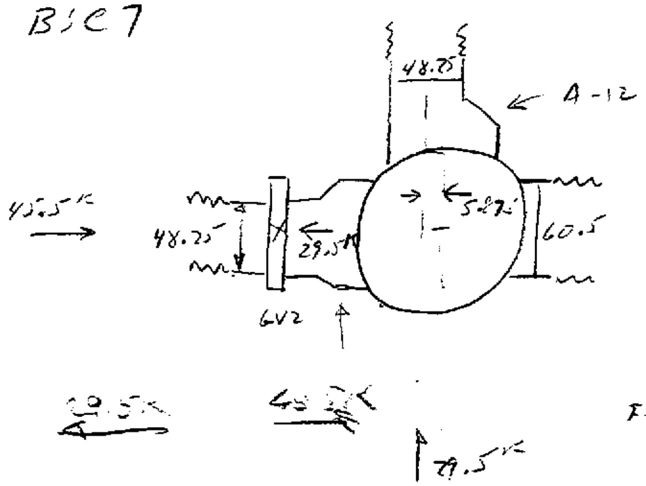


← 29.44K
OFFSET DN
3.94" (NO EFFECT)

UNBALANCED FORCES
F = 45.5 - 29.5 = 16K
EW DIRECTION

NO TEN. ON FLANGES

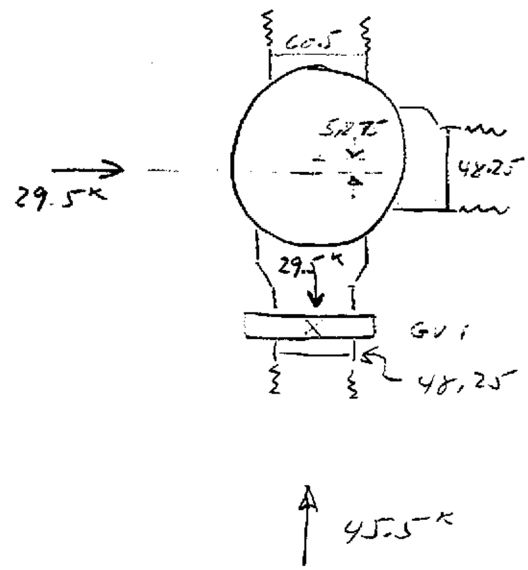
BSC 7



29.5K TEN ON LEFT
FLANGE WHEN BSC
IS VENTED

WHEN LEFT SIDE OF GV2
IS VENTED, UNBALANCED
FORCE TO RIGHT IS 45.5K

BSC 8



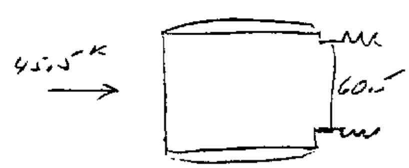
29.5K TEN ON LOWER FLANGE WHEN BSC IS VENTED

WHEN AREA BELOW GV1 IS VENTED, UNBALANCED LOAD IS 45.5K TOWARD TOP OF DIAGRAM.

WASHINGTON CORNER STATION CONT.

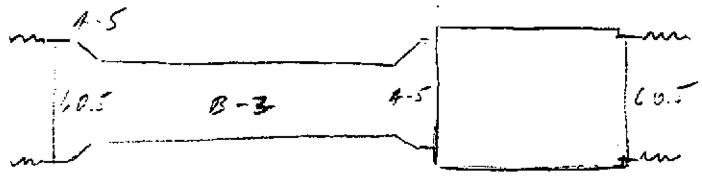
HORIZONTAL ACCESS MODULES

HAM1



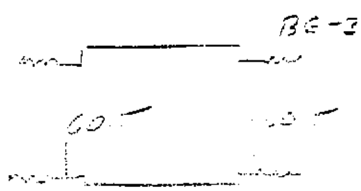
NO TENSION ON FLANGES

HAM 2



NO UNBALANCED FORCE

HAM 3



*OFFSET UP 3.94

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 = 45.5 K

HAM 7 - " " " " " "

HAM 8 - " " HAM 2 - NO UNBALANCED FORCE

HAM 9 - SAME AS HAM 3 - " " " *

HAM 10 - " " " " " " *

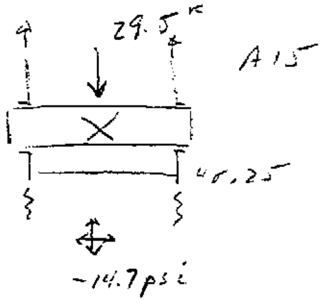
HAM 11 - SAME AS HAM 2 " " "

HAM 12 - SAME AS HAM 1 - UNBALANCED FORCE = 45.5K

WASHINGTON CORNER STATION CONT.

GATE VALVES

GV1

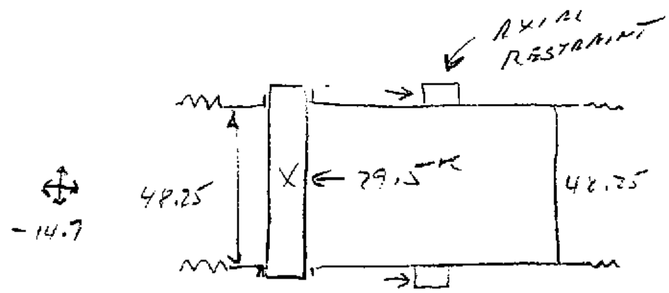


TENSILE FORCE ON VALVE BOLTED FLANGE IS 29.5 K

OR COMPRESSIVE LOAD ON FLANGE IS 29.5 K WHEN OTHER SIDE IS VENTED

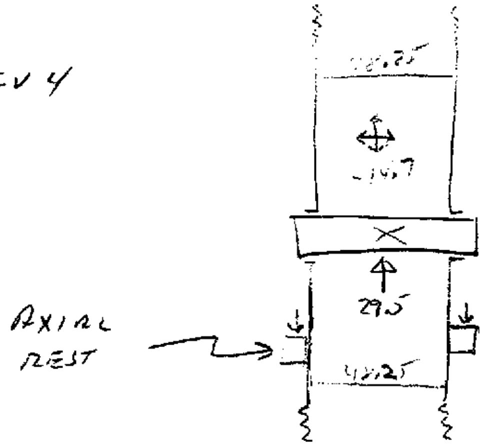
GV2 - SAME AS GV1

GV3



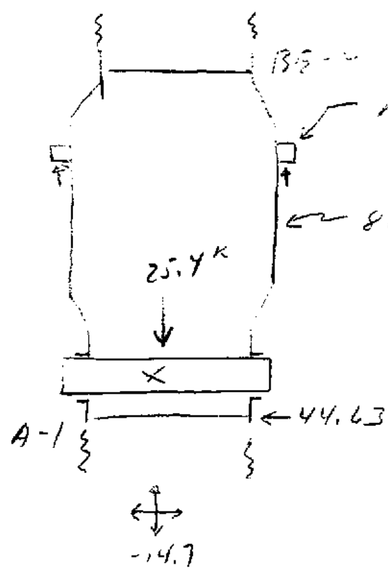
FORCES ON BOLTED FLANGES ARE SAME AS GV1

GV 4



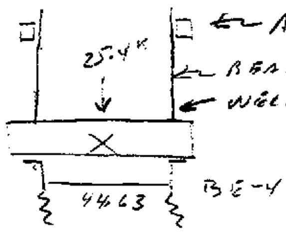
Forces on bolted flanges are same as GV1

GV 5



Flange in tension for case shown

GV 6



TENSION OR COMP ON WELDED NOZZLE CONNECTION. NO LOAD ON BOLTED FLANGE.

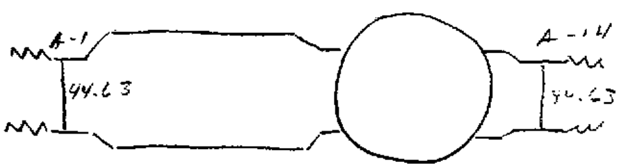
GV 7 - SAME AS GV 5

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

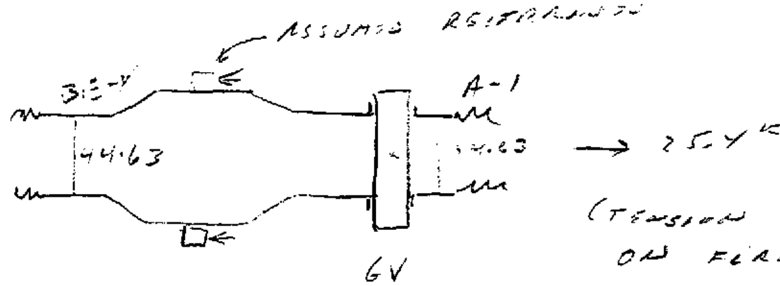


NO UNBALANCED LOAD

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.)

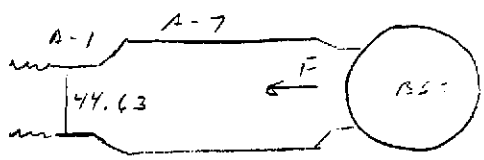
80K SHORT PUMPS



VALVE AT BEAM TUBE ANCHOR WELDED ON ONE SIDE. SEE GV6 ON PREVIOUS SHEET

WASHINGTON/LOUISIANA END STATIONS
REF DWG V049-5-005

BSC



F = 25.4K
ON TEN ON BSC FLANGE

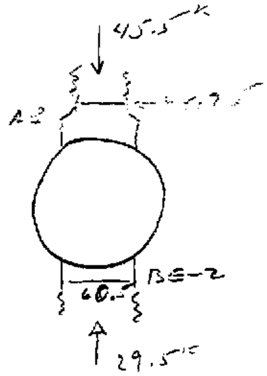
GATE VALVES. ALL VALVES HAVE 44.63 IN ID FLANGES. TENSION FORCE = 25.4K. VALVE AT BEAM TUBE ANCHOR WELDED ON ONE SIDE. SEE GV6 FOR WA MS

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 - 29.5 = 16K

NO TEN ON FLANGES

BSC 2 - SAME AS WA(S BSC 2 - NO UNBALANCED LOADS

BSC 3 - SAME AS BSC 1, ABOVE, 16K UNBAL FORCE, NO TENSION ON FLANGES.

HORIZ. ACCESS MODULES

HAM 1 - SAME AS WAS HAM 1. 45.5K UNBAL. LOAD.

HAM 2 - " " " HAM 2. NO UNBAL. FORCE

HAM 3 - " " " " 3, " " " *

HAM 4 - " " " " 4, " " " *

HAM 5 - " " " " 5, " " "

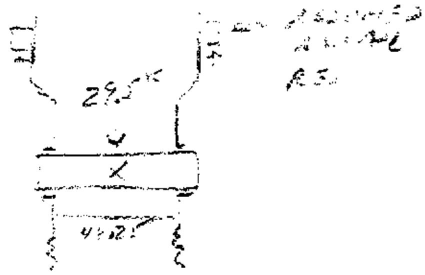
HAM 6 " " " " 6, 45.5K UNBAL LOAD

* OFFSET = 3.94" ON BSC SIDE

LA CORNER STA CONT.

GATE VALVES

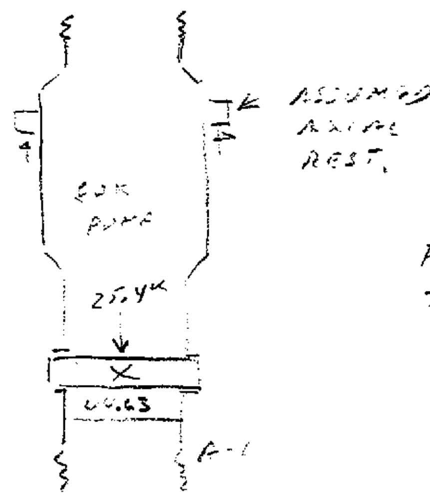
GV1



FORCE ON FLANGE = 29.5^K TEN OR COMP

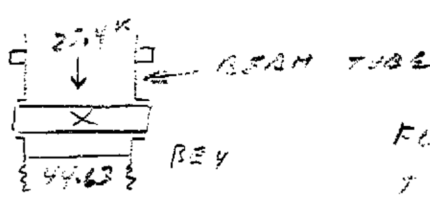
GV2 - SAME AS GV1

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

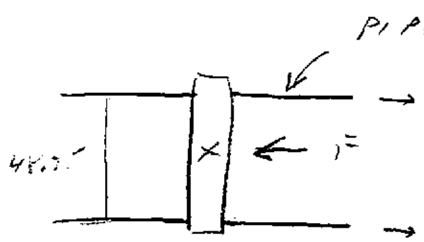
GV6 - " " GV4 " " " " "

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 THIS LOCATION IS A BUTT WELDED 44" VALVE

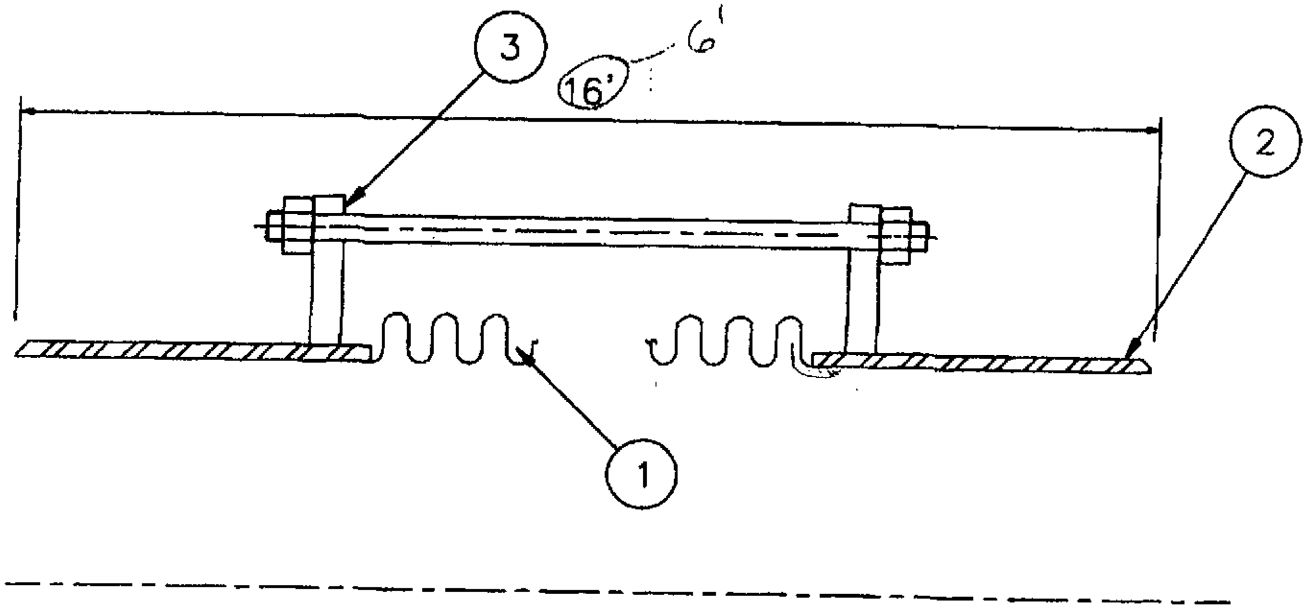


$F = 29.5^K$
(ASSUMES BELLOWS)

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
–
–

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 48"ø 1/4" THK	A240–304L
1	1	BELLOWS 48"ø 1-PLY 20Ga	A240–304L

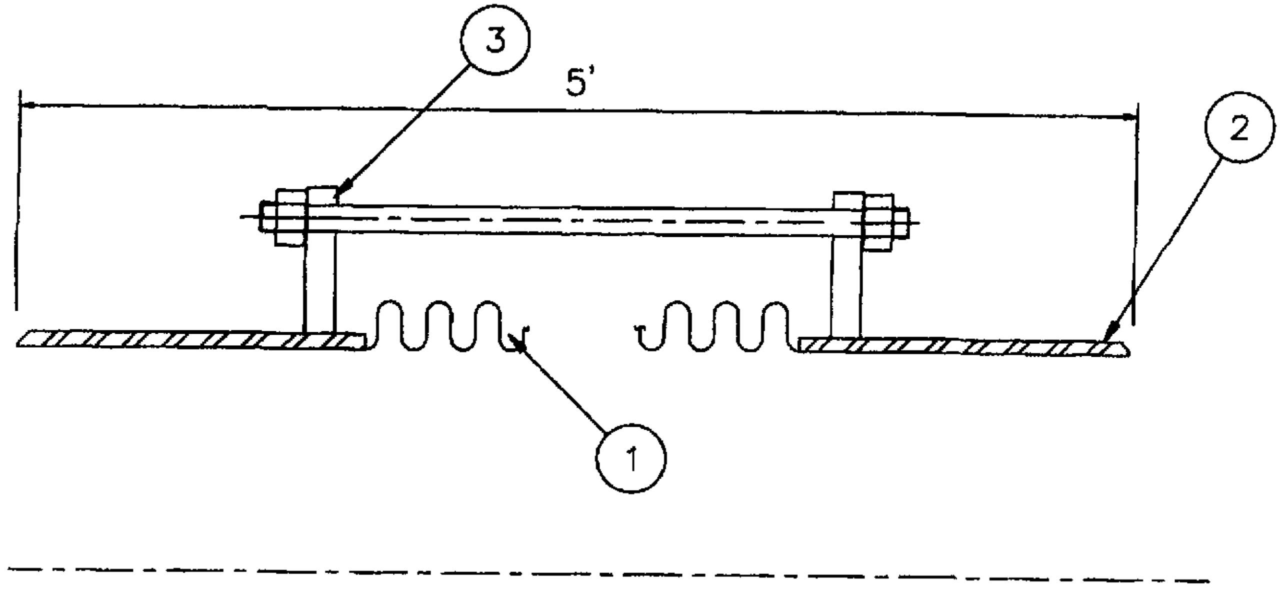
GENERAL SPECIFICATIONS	
DESIGN PRESS.	15 PSIG/FV
DESIGN TEMP.	347F
SERVICE	–
EFF. AREA	1983 In. sq
EXPANSION	–
COMPRESSION	1 3/4"
LATERAL OFFSET	–
ANGULAR ROT.	–
TEST PRESSURE	SOAP & AIR
WEIGHT	182 LBS.

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

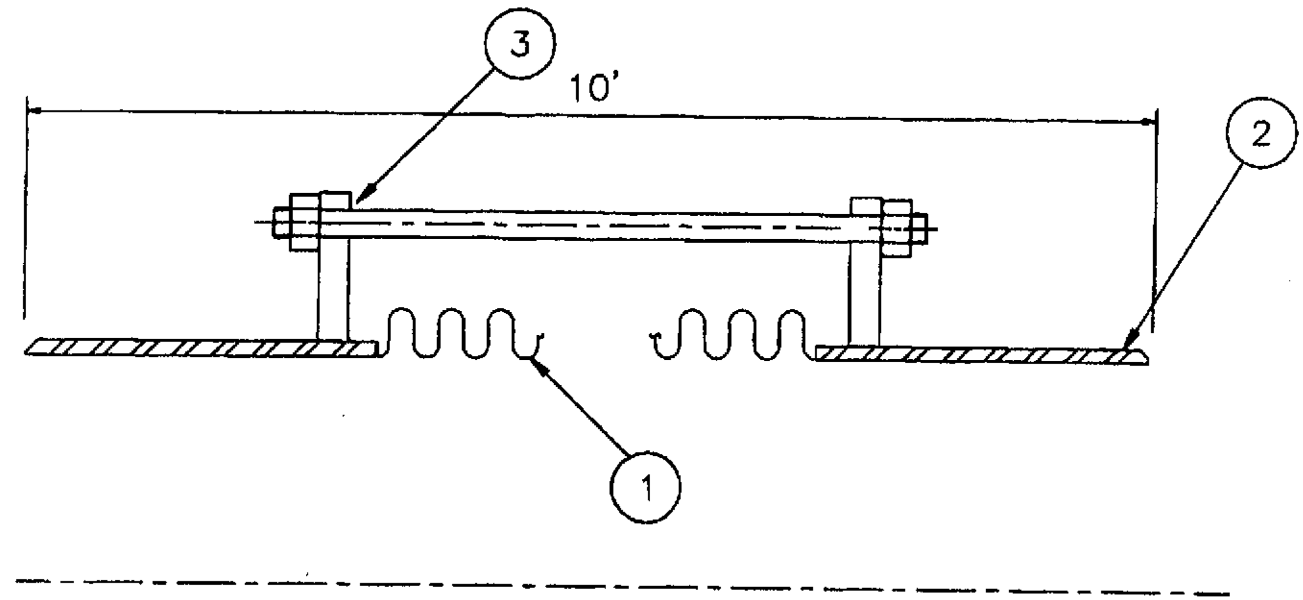
GENERAL SPECIFICATIONS	
DESIGN PRESS.	15 PSIG/FV
DESIGN TEMP.	347°F
SERVICE	–
EFF. AREA	3043 in sq
EXPANSION	–
COMPRESSION	1 3/4"
LATERAL OFFSET	–
ANGULAR ROT.	–
TEST PRESSURE	SOAP & AIR
WEIGHT	225 LBS.

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.: B	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.

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

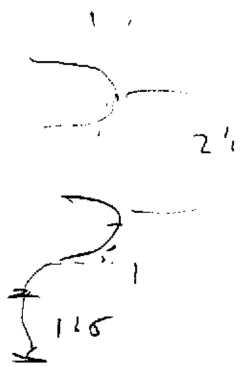
48in E.J.
RUN BY: LDC

20 ga.

INPUTED DATA

1)	Db	= I.D. OF BELLOWS	= 48	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	= 2,979.37	lbf/in
WORKING SPRING RATE	= 1,604.44	lbf/in
LATERAL SPRING RATE	= 6.077E+05	lbf/in
LATERAL MOMENT RATE	= 1.215E+06	in-lbs/in
ANGULAR MOMENT RATE	= 8,838.58	in-lbs/deg
TORSION MOMENT RATE	= 3.955E+07	in-lbs/deg

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	= 19,316	cycles
SQUIRM PRESSURE COLD /2.25	= 838	psig
SQUIRM PRESSURE HOT / 2.25	= 795.5	psig
EQUIV. PIPE WALL THICKNESS	= .8706	in

STRESSES EJMA

S1	= 7644	psi
S1'	= N/A	
S2	= 3804	psi
S2'	=N/A	
S2''	=N/A	
S3	= 480.5	psi
S4(.35)	= 7007	psi
S5	= 784.7	psi
S6	= 140900	psi
ST	= 156000	psi

EJMA FACTORS

Cp	= .6501	
Cf	= 1.463	
Cd	= 1.74	
Cr	= N/A	
Ct	= 1 0	
EA	= 1983	in^2
Wt.	= 17.34	lbs.
LCW	= N/A	

SENIOR FLEXONICS
CIRCULAR BELLOWS
(UNREINFORCED SINGLE)

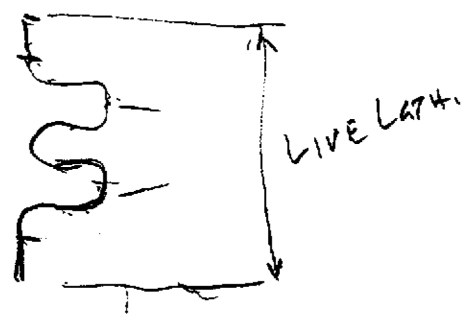
BD
CUSTOMER: PROCESS SYSTEMS
JOB #:
DATE : 5/25/95

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

DEFL w/ FIGAT.

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

1)	Db	= I.D. OF BELLOWS	= 72	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	= 4,290.03	lbf/in
WORKING SPRING RATE	= 2,289.71	lbf/in
LATERAL SPRING RATE	= 1.893E+06	lbf/in
LATERAL MOMENT RATE	= 3.787E+06	in-lbs/in
ANGULAR MOMENT RATE	= 27,539.77	in-lbs/deg
TORSION MOMENT RATE	= 1.333E+08	in-lbs/deg

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	= 15,230	cycles
SQUIRM PRESSURE COLD /2.25	= 1206	psig
SQUIRM PRESSURE HOT / 2.25	= 1145	psig
EQUIV. PIPE WALL THICKNESS	= .8706	in

STRESSES EJMA

S1 = 9360	psi
S1' = N/A	
S2 = 5581	psi
S2' =N/A	
S2''=N/A	
S3 = 477.1	psi
S4(.35)= 7215	psi
S5 = 759.1	psi
S6 = 147900	psi
ST = 163400	psi

EJMA FACTORS

Cp = .6792	
Cf = 1.535	
Cd = 1.67	
Cr = N/A	
Ct = 1 0	
EA = 4330	in^2
Wt.= 26	lbs.
LCW= N/A	

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-042 PAGE 1 OF 37
REV.	DEO #	DATE	BY:	CHECK	Bolted Flange Analysis For Tensile Forces	
0	[illegible]	4/25/96	RDC	AGR		
					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 REVIEWED 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

$$F = 29.44 + \pi \frac{76^2}{4}\left(\frac{2}{1000}\right) = 32.76^K$$

↑ 2 PSI PURGE

PER BOLT

$N = 36$

$$F_b = \frac{32.76}{36} = .91^K$$

BOLT CIRCLE DIAM

D_b = C = 77.72" REF P. 5 OF CALC-019

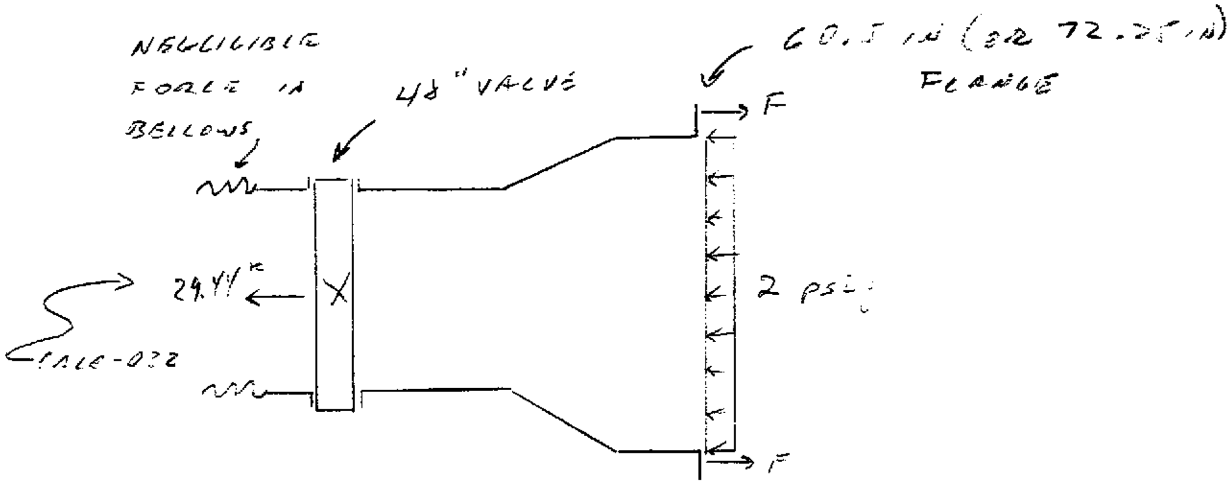
SPACING $S = \frac{\pi D_b}{36} = 6.78$ IN

FORCE PER IN $f = \frac{.91}{6.78} = 135$ 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

$$S = \frac{\pi (65.75)}{30}$$

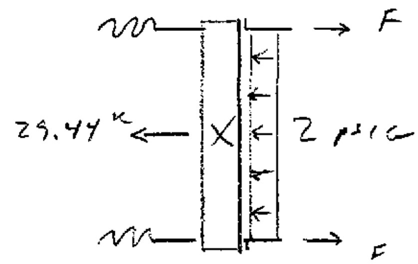
= 6.89 IN

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 VENTING IS 29.44^K (PAGE 032)



← GASKET DIAM. *

$$F = 29.44 + \pi \frac{52^2}{4} \frac{2}{1000} = 33.7^K$$

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

↙ G FROM CALC 019, P. 19

$$F = 25.37 + \pi \frac{48^2}{4} \left(\frac{2}{1000} \right)$$

$= 29.0^{K}$

$$F_B = \frac{29}{24} = 1.21^{K}$$

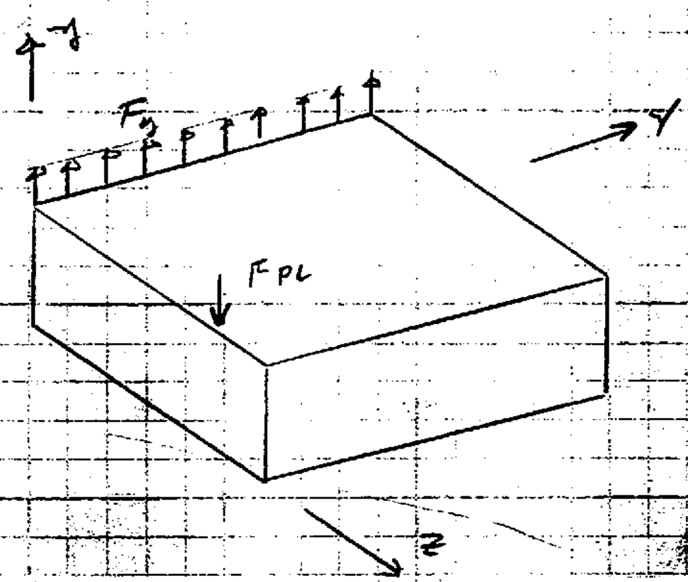
$$S = \frac{\pi (49.75)}{24} = 6.51$$

$$f = \frac{1.21}{6.51} = .186 = 186 \text{ LB/IN}$$

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

$F_y = 52.1$ LB/IN & $F_{y_i} = 13.4$ LB

AT INTERIOR NODES

$$F_{y_i} = 13.4\left(\frac{159}{52.1}\right) = 51.2 \text{ LB}$$

@ 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

$$F_{yi} = -375 \times \frac{4250}{6000} \leftarrow \text{CALC 17, P. 3}$$

$$= -266 \text{ LB}$$

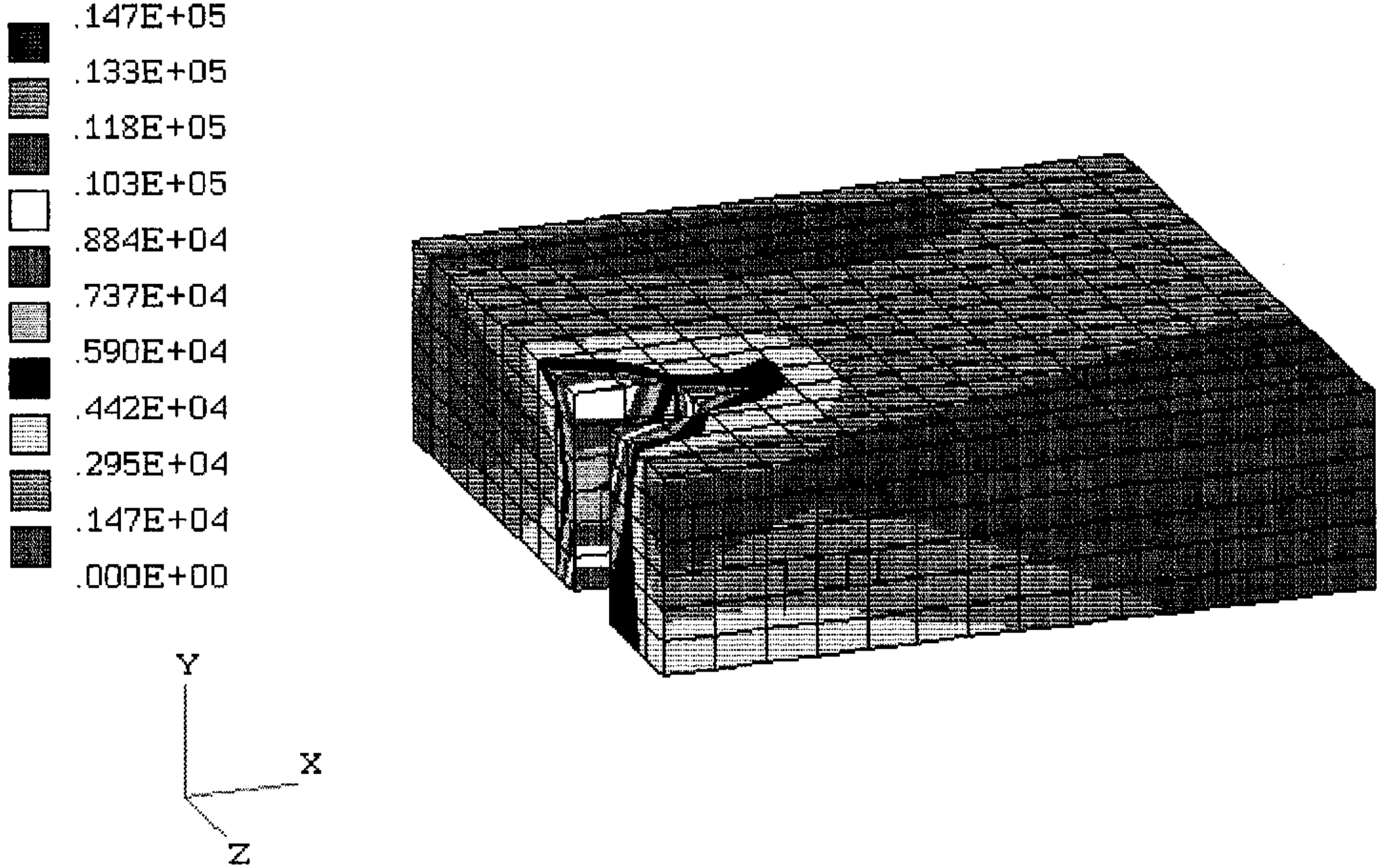
@ NODES 1374, 1375, 1377, 1378,
1389 TO 1393
1404 TO 1408

$$F_y = \frac{-266}{2} = -133 \text{ LB}$$

@ NODES 1359, 1360, 1362, 1313

IMAGES-3D
Version 3.0

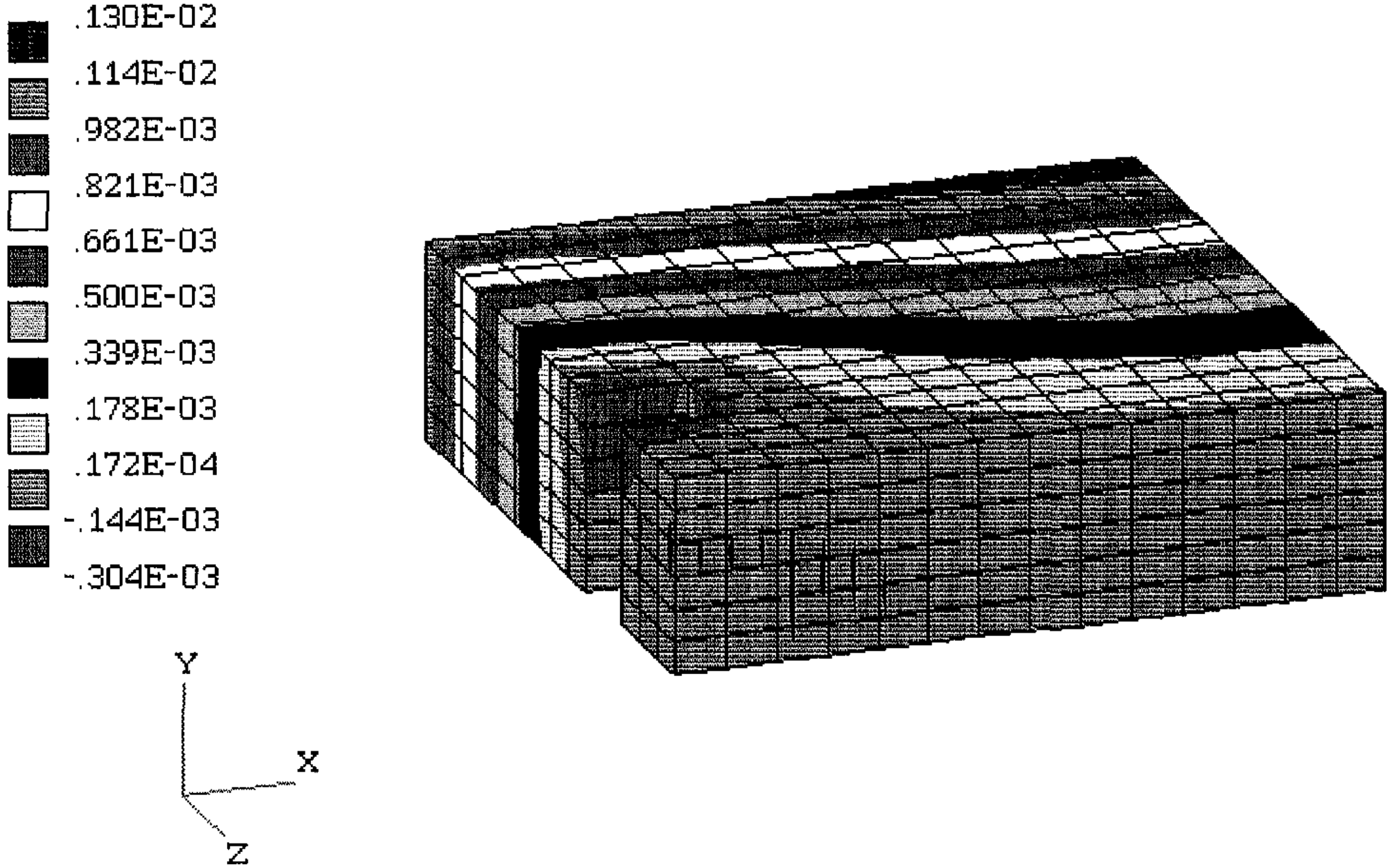
48 1/4 IN FLANGE



Load Case	**Stress Contour Plot**	**1/ 5/96**
1	**Stress Intensity**	**7:51: 9**

IMAGES-3D
Version 3.0

48 1/4 in FLANGE



Load Case
1

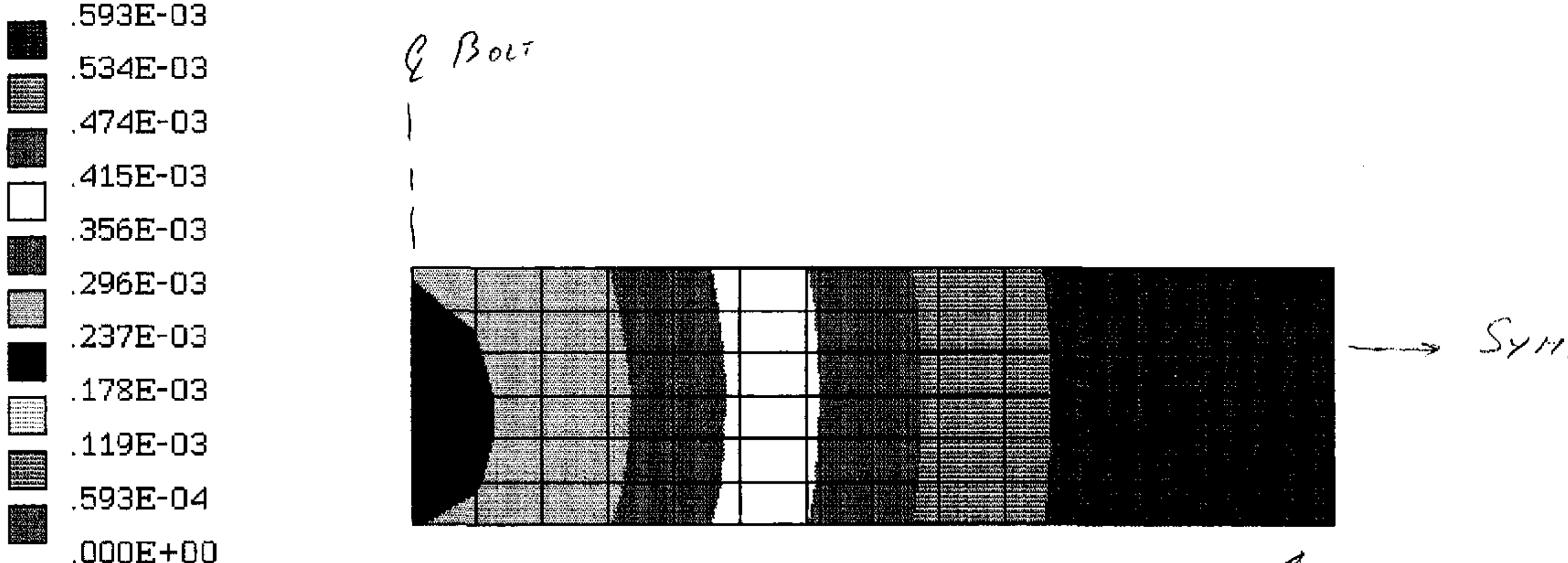
Displacement Contour Plot
DY

1/ 5/96
7:29:53

IMAGES-3D
Version 3.0

DISPLACEMENTS AT OUTER O-RING

48 1/4 IN FLANGE

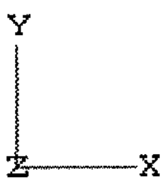


IF MATING FLANGE DISPLACES SAME AMOUNT

$\Delta = 2(.593)(10)^{-3} = .00119$

COMPARE TO MIN COMPRESSION OF O-RING FROM PARKER HANDBOOK (.058 IN)

$RATIO = \frac{.058}{.00119} = 49$



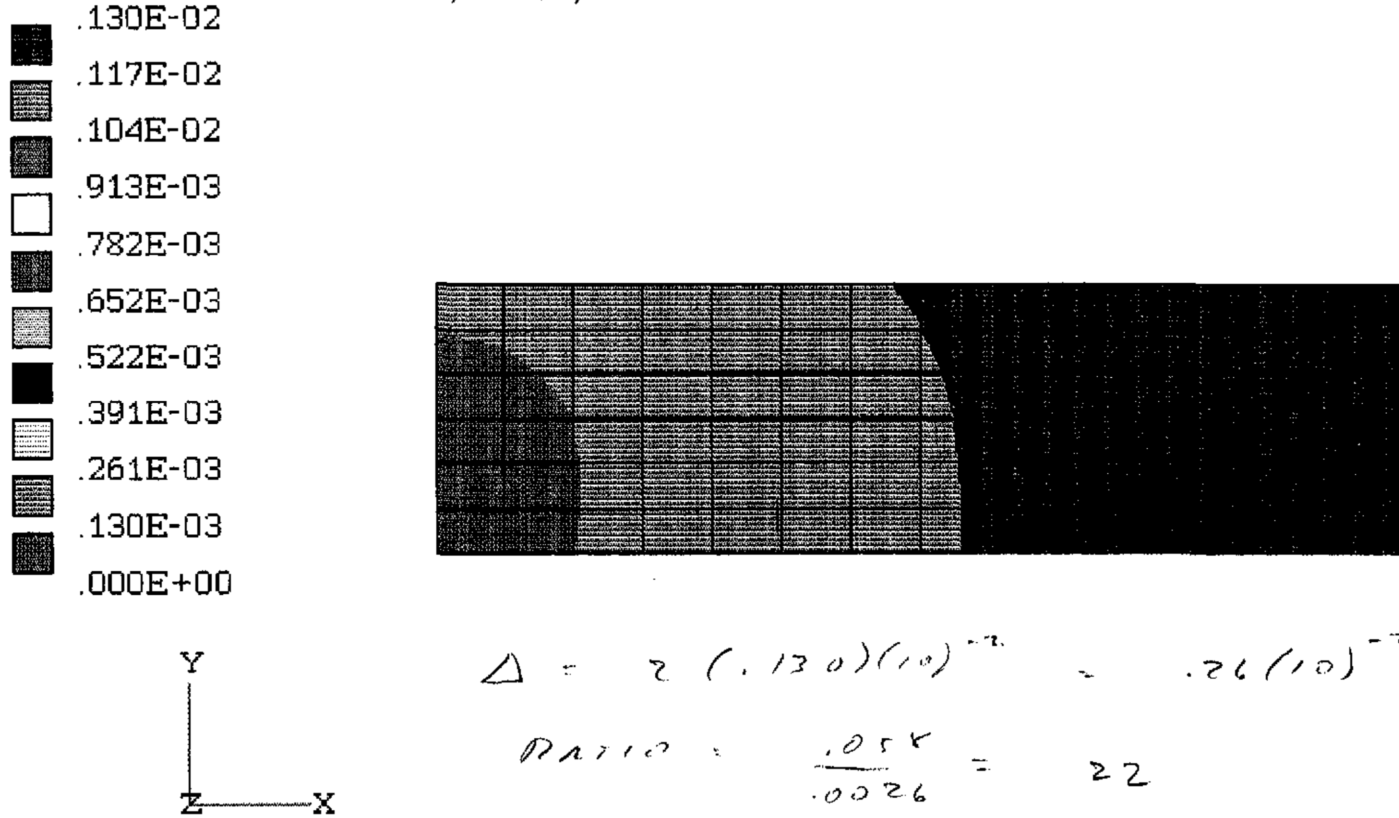
Load Case **1**

Displacement Contour Plot
DY

1/ 5/96
7:34:52

IMAGES-3D
Version 3.0

Displacements at Inner O-Ring 4" 1/4 in flange



$\Delta = 2(.130)(10)^{-2} = .26(10)^{-2}$

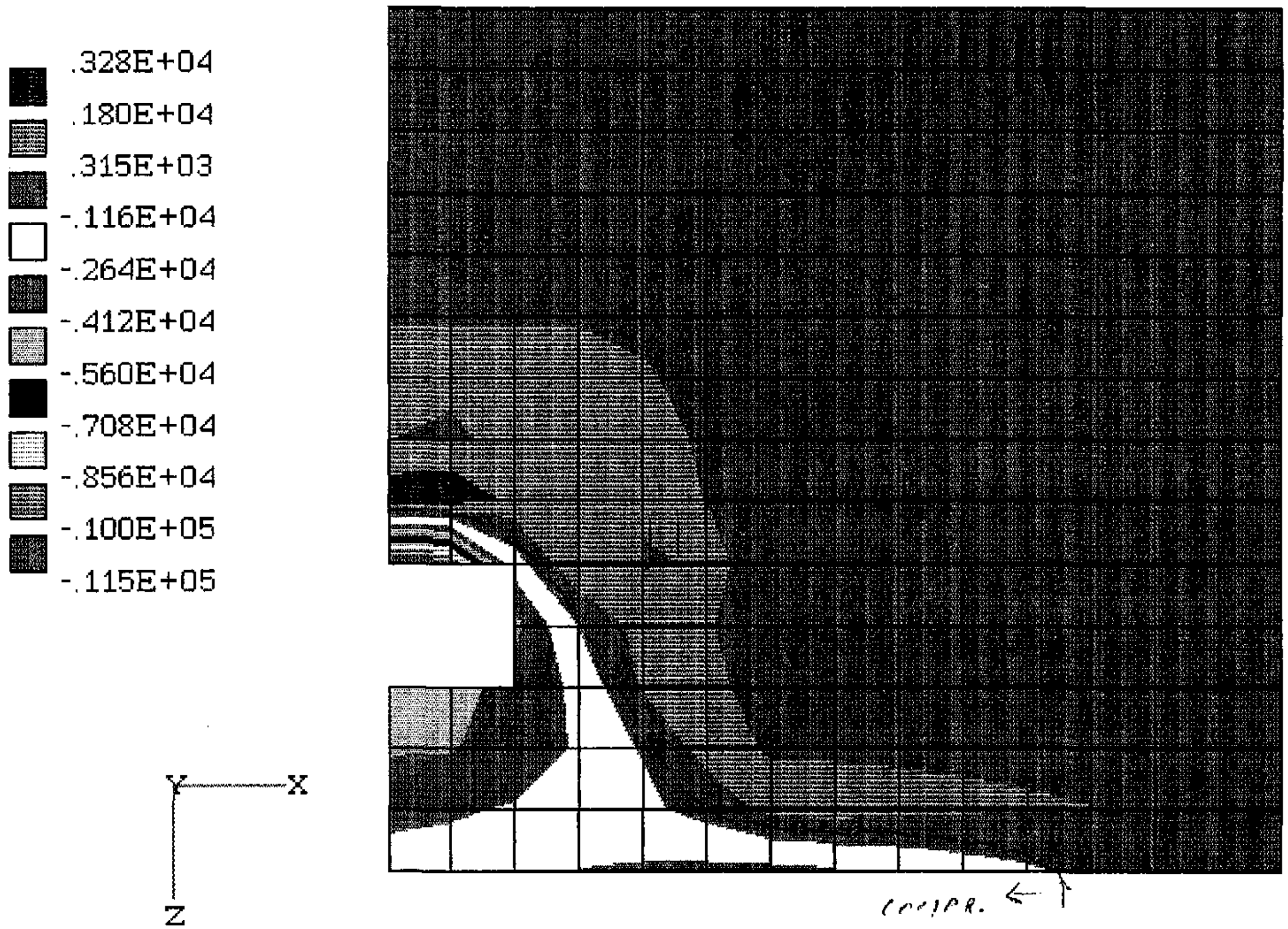
Ratio $= \frac{.058}{.0026} = 22$

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



Load Case
1

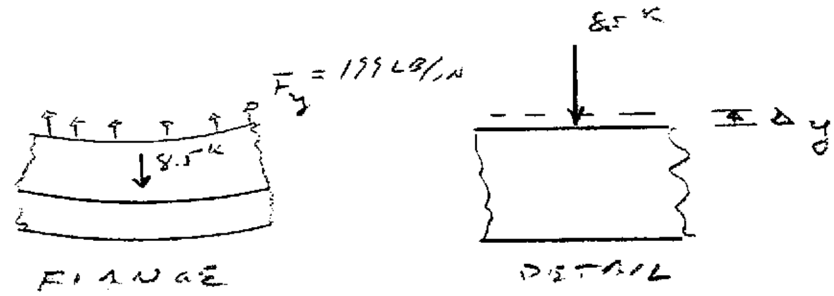
Stress Contour Plot
Gl St: S22

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 FLANGE C.* 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 FLANGE C.* OUTPUT TO THE PRELOAD STRAIN (STRESS).



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 BOLT.

THE TENSILE STRESS AREA FOR THE BOLT IS .462 IN²* FOR THE 7/8 IN BOLT. FORCE IS

* REF AISC, P. 4-147

$$F = .462(500) = 230 \text{ LB}$$

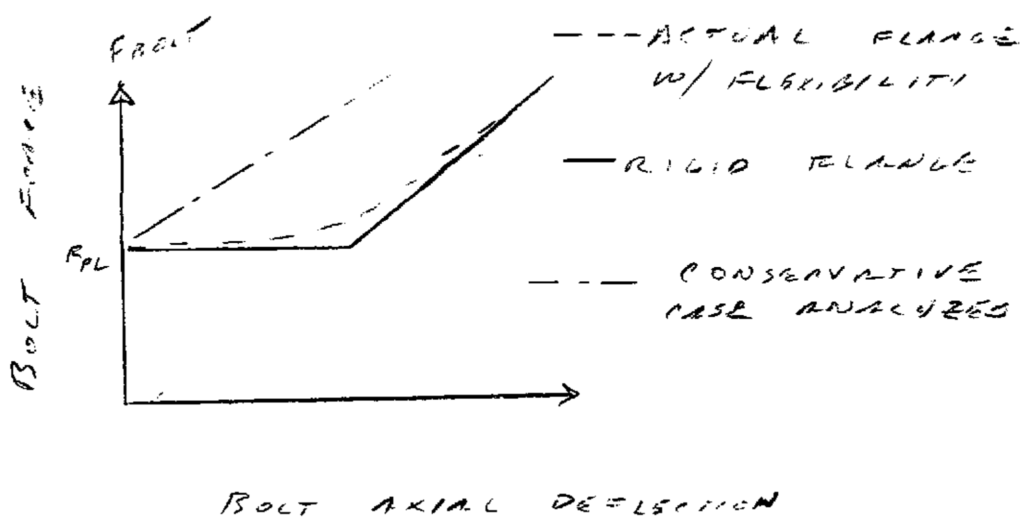
TO OBTAIN A CONSERVATIVE BOLT STRESS, THE NOMINAL BOLT FORCE FROM THE TENSION, F_T, ON THE 48 1/4 IN FLANGE WILL BE ADDED TO THE PRELOAD

$$F_{TOTAL} = F_B + F_{PL}$$
$$= 1.72 + 8.50^K$$
$$= 10.22^K$$

STRESS

$$f_t = \frac{10.22}{.462} = 22.1 \text{ KSI} < S = 25 \text{ KSI} \quad @ \ 485°F$$

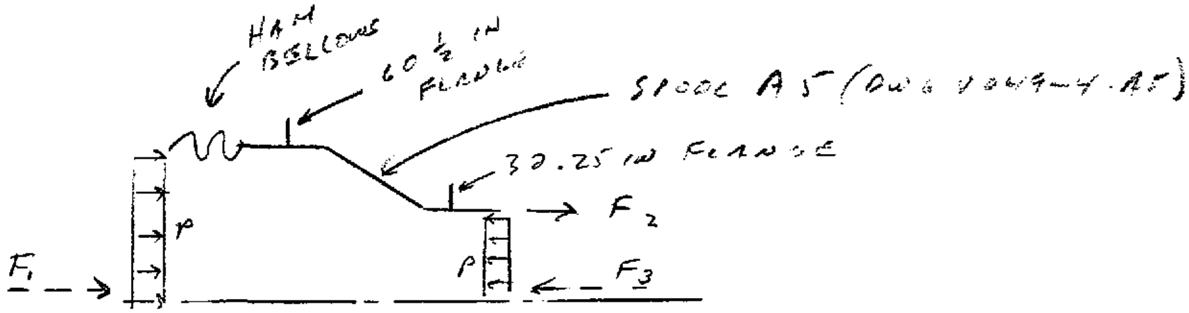
OK



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

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)

$F_3 = pA$

$A = \pi r_0^2$

$r = \frac{G}{2} = \frac{34}{2} = 17$ 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

$$F_3 = -14.7\pi\left(\frac{31}{2}\right)^2 \quad \text{DWG V049-4-016}$$

$$= -11.10 \text{ K}$$

$$F_2 = -11.10 - (-45.46) = 34.36^K$$

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 CHANGED 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

$$d = 30.25$$

$$f = \frac{F_2}{\pi d}$$

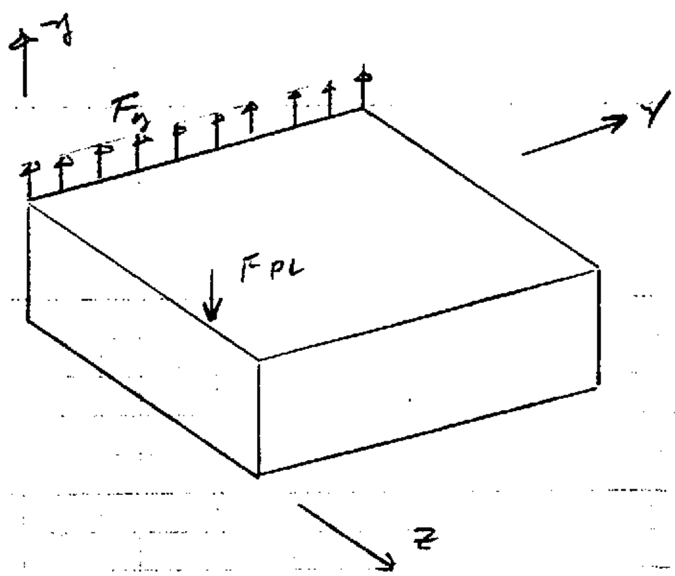
$$= 362 \text{ LB/IN}$$

30 1/4 IN FLANGE CONT.

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 FLANGEC.* MODEL

NODAL FORCE AT SHELL



FROM CALC 017, P.2

$F_y = 52.1$ LB/IN ∴ $F_{yi} = 13.4$ 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 FLANGEL FILE

A PRELIMINARY RUN OF FLANGEL SHOWED THAT IT IS NECESSARY TO INCREASE THE PRELOAD TO 10000 LB FOR THE 30 1/4 IN FLANGE

CHANGE BOLT PRELOAD FROM 8500 TO 10000 LB FOR THE 30 IN FLANGE

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	↓

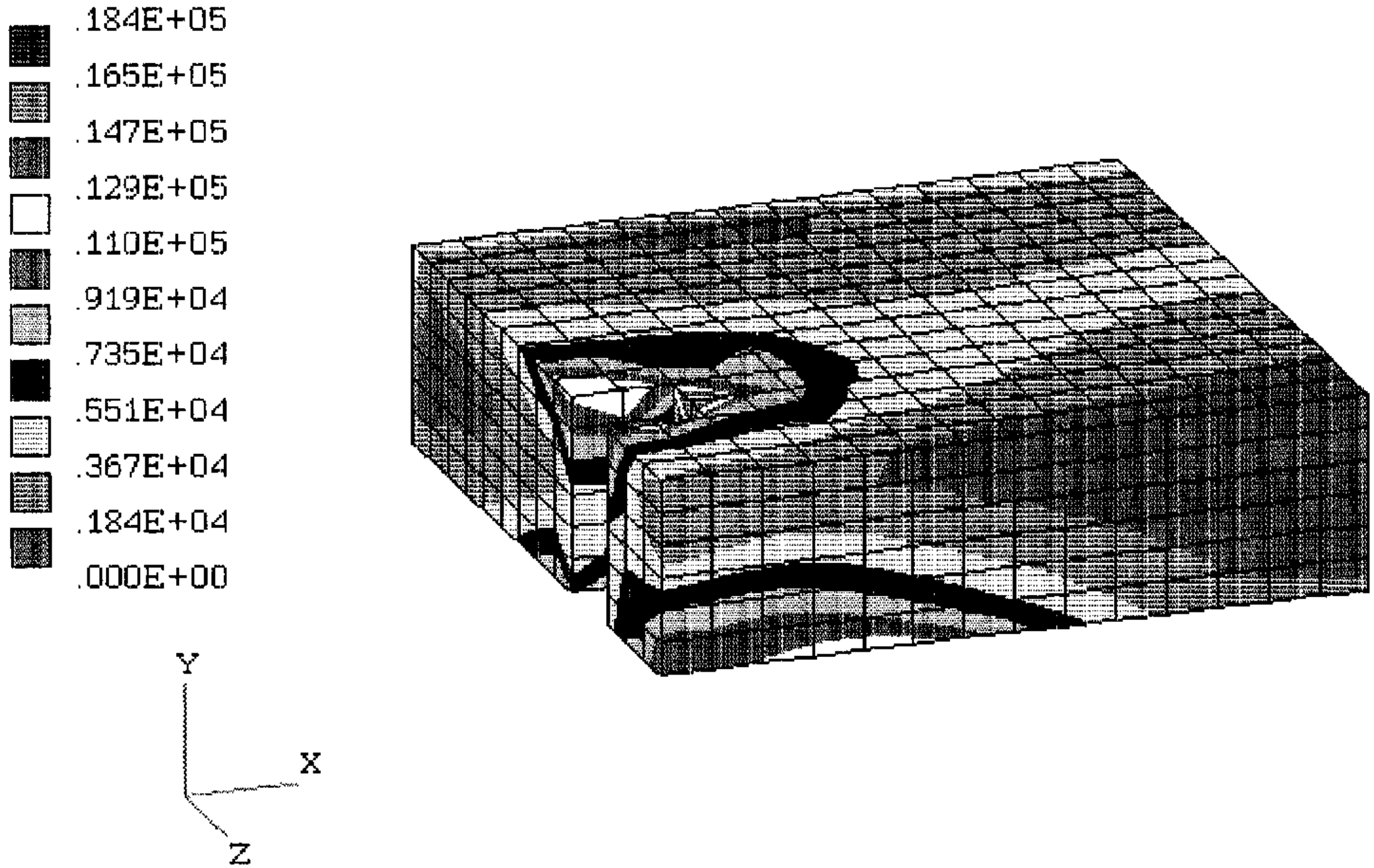
$\frac{10}{8.5} = 1.176$ = FACTOR ON 8500 LB BOLT LOAD

REF. P. 8 THIS CALC

* REF P. 8 OF THIS CALC

IMAGES-3D
Version 3.0

30 1/4 IN FLANGE



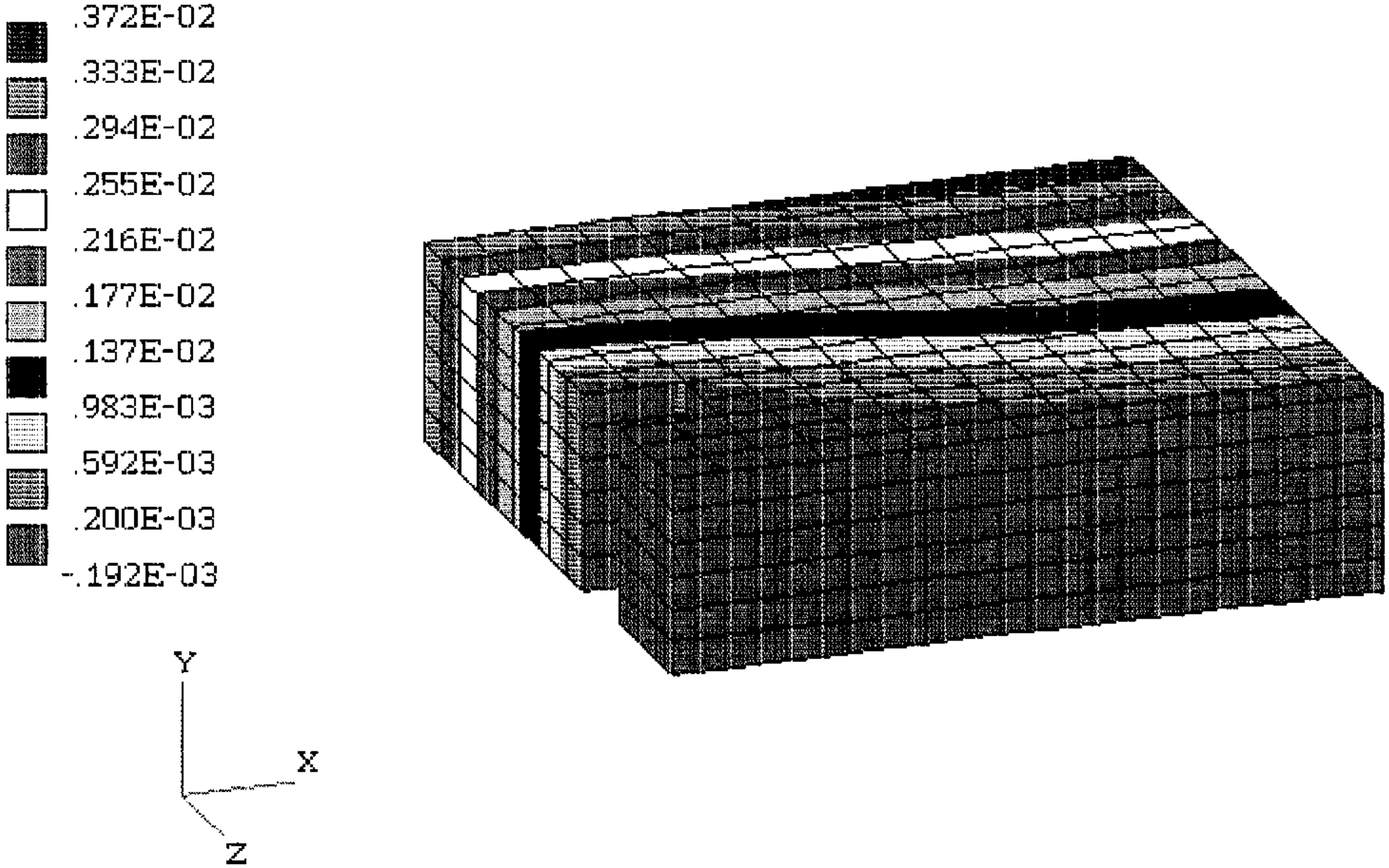
Load Case
1

Stress Contour Plot
Stress Intensity

2/ 2/96
9:13:50

IMAGES-3D
Version 3.0

30 1/4 IN FLANGE



Revision 0
Doc. No. V049-1-042

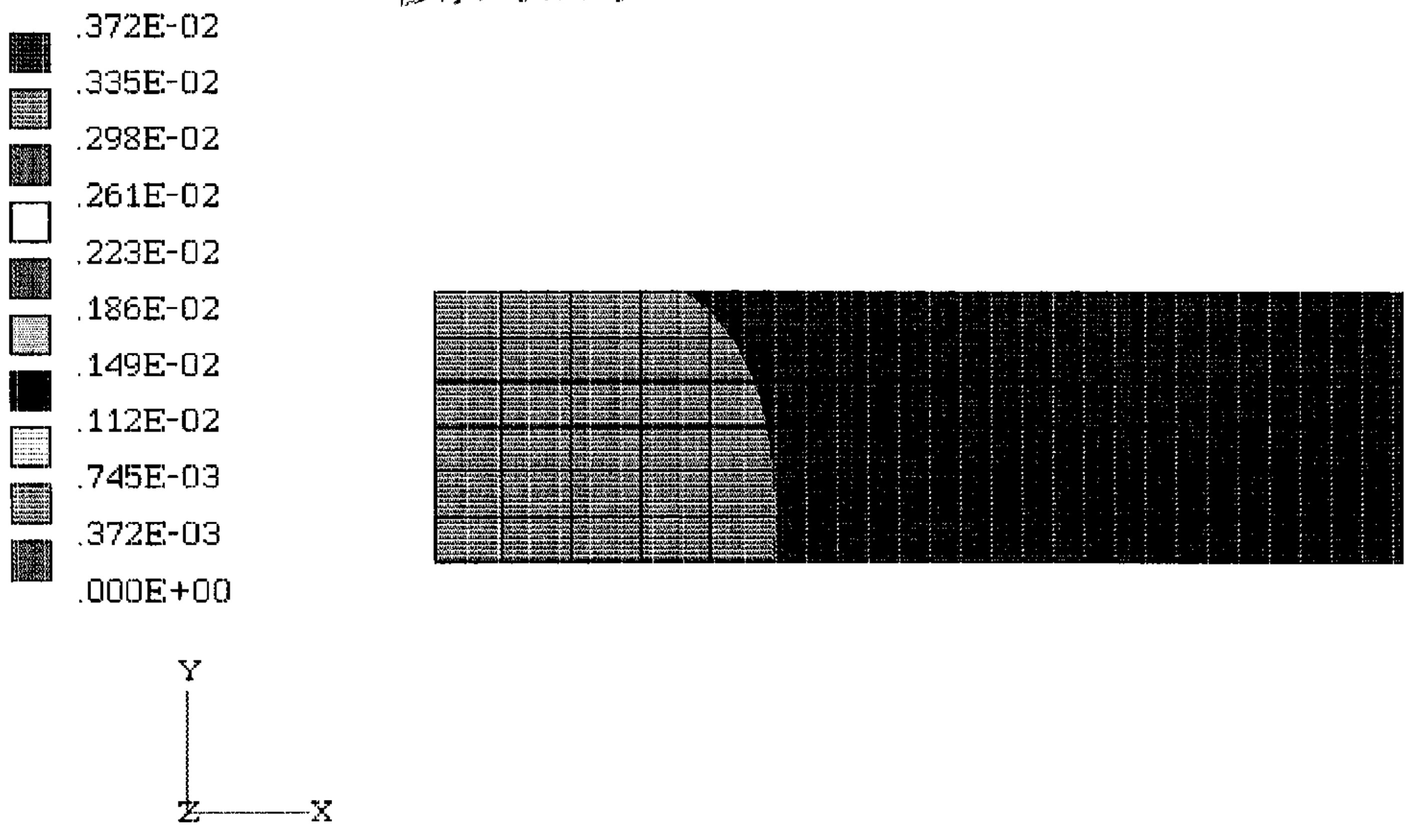
Load Case 1

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

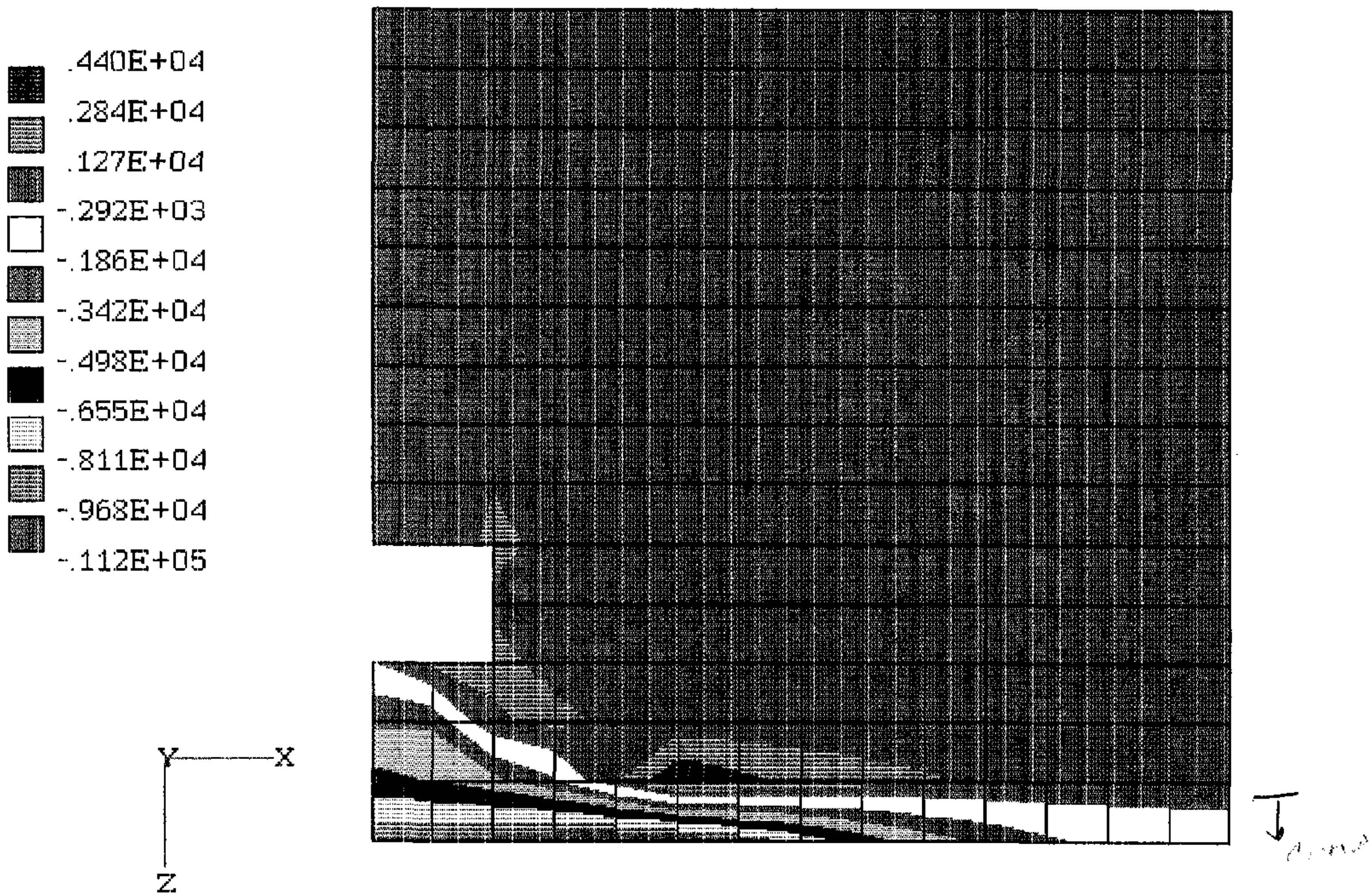


Load Case
1

Displacement Contour Plot
DY

2/ 2/96
9:21: 9

IMAGES-3D
Version 3.0



Load Case
1

Stress Contour Plot
GI St: S22

2/ 2/96
9:24: 0

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

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

$$\Delta = .00372 \text{ IN}$$ 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.

$$RATIO = \frac{.058}{.0074} = 7.8$$

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.

$$\Delta_y \cong .00015 \text{ AT NUT}$$

$$\text{BOLT STRAIN} \quad \epsilon = \frac{.00015}{1} = .00015$$

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 = $.462 \text{ IN}^2$

TOTAL STRESS IS

$$f_a = 21.6 + 4.4 = 26 \text{ KSI} \quad \text{SAY OK} \approx 25$$

OR WHEN THE BOLT APPLIED LOAD IS ADDED TO PRELOAD

$$f_a = \frac{10 + 1.72}{.462}$$

$$= 25.4 \text{ KSI} \approx 25 \text{ OK}$$

CHANGE NO. OF BOLTS TO 24

$$F_B = \frac{34.36}{24} = 1.43$$

$$f_a = \frac{10 + 1.43}{.462} = 24.7 < 25$$

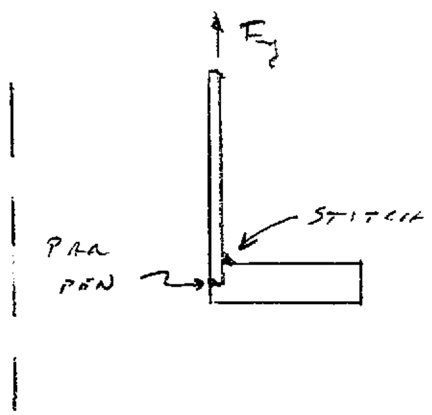
BOLT SPACING IS

$$S = \frac{\pi C}{24} = \frac{\pi (36)}{24}$$

$$= 4.71 \text{ IN} \quad \text{OK}$$

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.

$$f_a = \frac{F_y}{.125}$$

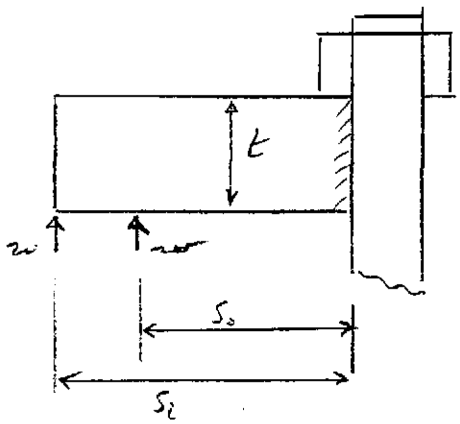
$$= \frac{362}{.125} = 2900 \text{ psi}$$

REF p.17 OF THIS CALC FOR F_y = 362 LB/IN

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

CONFIRMATORY HAND CALC TO VERIFY IMAGES RESULTS FOR FLANGE TENSION.

DEFLECTION & STRESS IN A 1 IN STRIP FLANGE FOR O-RING FORCE



CLAMPING ASSUMED ABOUT ENTIRE RING

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 A5-13 THE MAX "SQUEEZE" IS 25%. 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)

$$S_o = \frac{36}{2} - .5 - \left(\frac{34}{2} + \frac{.34}{2}\right) = .37 \text{ IN}$$

$$S_i = \frac{36}{2} - .5 - \left(\frac{31}{2} + \frac{.34}{2}\right) = 1.83 \text{ IN}$$

* .275 CROSS SECTION

SINCE S_o IS SMALL, IGNORE INNER O-RING FORCE.

DEFLECTION

$$\Delta = \Delta_b + \Delta_s$$

Δ_b = BENDING DEFL

$$= \frac{w S_i^3}{3EI}$$

$$= \frac{170(1.83)^3}{3(28.8 \times 10^6)\left(\frac{t^3}{12}\right)}$$

$$= \frac{1.45(10)^{-4}}{t^3}$$

Δ_s = SHEAR DEFLECTION

$$= \frac{w S_i}{A G}$$

$$A = t(1) = t$$

$$G = \frac{28.8(10)^6}{2(1+\nu)} = 11.1(10)^6 \text{ psi}$$

$$\Delta_s = \frac{170(1.83)}{t(11.1 \times 10)^6} = \frac{.28(10)^{-4}}{t}$$

$$\Delta = \frac{1.45(10)^{-4}}{t^3} + \frac{.28(10)^{-4}}{t}$$

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, PA5-13). FOR MATING FLANGE, 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 20 1/4 IN FLANGE

$$w = 170 + 362 = 532$$

RATIOS ARE

IMAGES GIVES MORE CONSERVATIVE 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

$$M = w \, S_i =$$

$$= 532(1.83) = 974$$

$t = 1$

$$S_b = \frac{974(.5)}{1^3/12} =$$

$$= 5844 \text{ psi}$$

$t = 7/8$

$$f_b = \frac{974\left(\frac{.875}{2}\right)}{(.875)^3/12}$$

$= 7630$ psi

$t = 3/4$

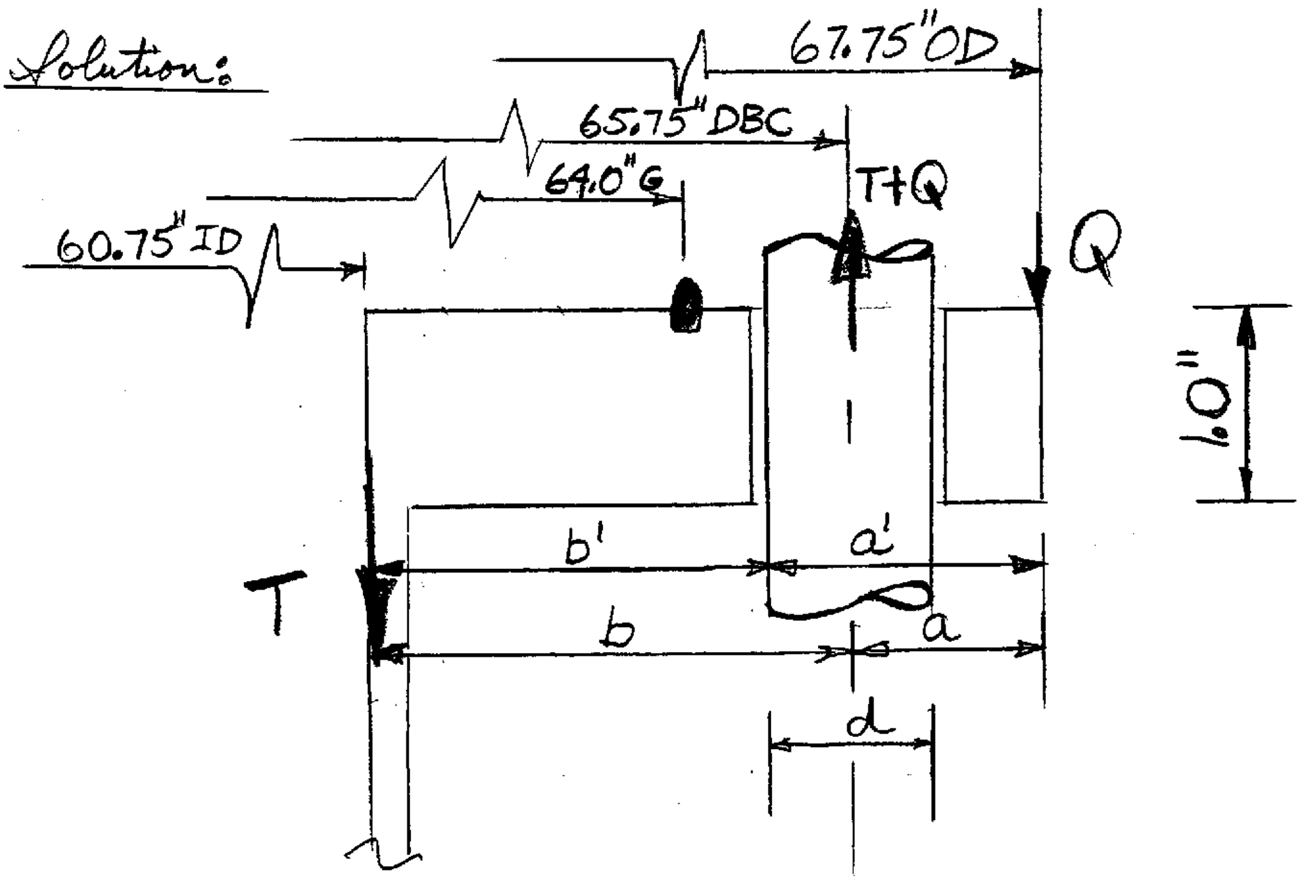
$$f_b = \frac{974\left(\frac{.75}{2}\right)}{\frac{.75^3}{12}}$$

$= 10400$ psi

Given: LIGO flanges of various sizes

Req'd: look @ a typical flange say a 60 1/4" 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

$$P = \frac{\pi(65.75)}{30} = 6.89'' \quad \text{trib width per bolt.}$$

$$d' = 1.0'' \; ; \; \delta = 1 - \frac{d'}{P} = 1 - \frac{1}{6.89} = .855$$

$$d = .875 \text{ bolt diameter}$$

$$\rho = b'/a' = \frac{2.0625}{1.4375} = 1.4348$$

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

now since $\sigma_{allow\ bolts} = 25\,ksi$

then $B = 25(.755)^2/4\ \pi = 11.192K$ ← root diameter of bolt (7/8" OD)

$T = 35.9/30 = 1.2K$ 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 $t_{flg\ req'd} = \sqrt{\frac{8(1.2)(2.0625)}{6.89(36)(1+.855(1.0))}}$ (T = 1.2)

for the actual force T

$= .2075'' < 1.0''$ actual flg thickness 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 $\alpha = 0$

$$\therefore \quad Q = B\delta\alpha\rho\left(\frac{t}{t_c}\right)^2 \equiv 0$$

or there is no prying force of any significance.

TEST PRESSURE TO OBSERVE FLANGE BEHAVIOR UNDER TENSION
10" TEST CHAMBER - REF DWG V049-4-030

HYDROPRESSURE REQUIRED TO GIVE
3K PER BOLT

NOTE: MAX BOLT LOAD = 1.72K FOR 30 1/4" FLANGE
SAY 2K. INCREASE BY 50% FOR
HYDROTEST

$1.5 \times 2^K = 3^K$

$pA = 3N$

$N = 6$ BOLTS

$A = \pi r^2$

$r = 5$

$p\,\pi(5)^2 = 3(6) = 18^K$

$p = .229\ K/IN^2$

$= 230$ psi

HOOP STRESS IN CYL

$\sigma_\theta = \frac{pr}{t} =$

$t = 3/16$

$\sigma_\theta = \frac{230(5)}{3/16} = 6133$ psi ok

FOR 1/8 IN FILLET CONNECTING FLANGE TO CYL

$A_w = \pi(10)(.125)(.707) = 2.8\ IN^2$

WELD STRESS

$f_v = \frac{18}{2.8} = 6.5$ KSI 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

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

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1- 122 PAGE 1 OF 8
REV.	DEO #	DATE	BY:	CHECK	TITLE: **44" Gate Valve Weld Stub/Beam Tube Buckling Stress Evaluation**	
0	349	11/6/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: This is an information calculation that evaluates the effects of a partial penetration weld on the buckling resistance of the GNB gate valve weld stub. It also evaluates the potential buckling of the end of the CBI tube at the anchor in the beam tube.

METHOD: Hand calculations are performed using the compressive stress formulas of the ASME Code.

ASSUMPTIONS: For the calculation of the bending stress due to valve weight, the "soft" support under the valve is neglected. This is conservative since the reaction provided by this support relieves the cantilever effect of the valve.

INPUTS:
1. Vacuum Pressure = -14.7 psi
2. Maximum Temperature = 400°F
3. Valve Weight = 8000 lb

REFERENCES:
1. ASME Boiler & Pressure Vessel Code, Section VIII, Div. 1
2. GNB Calculation, "Duct Neck Welds", Oct. 25, 1996.
3. AISI Stainless Steel Cold-Formed Structural Design Manual

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Bending stresses due to the weight of the valve are compressive at the bottom the weld stub and beam tube. Although these stresses are low (< 700 psi), they add to the axial compressive stresses due to *external* pressure. The combined stresses are less than the compressive stress allowed by the ASME Code.

NOTES: The weld stub has adequate buckling resistance even with the partial penetration longitudinal weld in the stub.

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REVISION HISTORY

Rev. 0 Original Issue - Nov. 1996

WELD STUB - AS DESIGNED CONDITION

GET MAX ALLOW COMPRESSIVE STRESS OF WELD STUB PER SECT VIII -1, UG-23(b)

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

$$R_o = \frac{D_o}{2} = \frac{45.12}{2} + .135$$

$= 24.7$ REF GNB WELD STUB DWG 103224

$t = .135$

$$A = \frac{.125}{(24.7/.135)} = 6.83\,(10)^{-4}$$

$B = 5250$ - FIG HA-3 FOR 304L (@ 400°F - SECT II, P. 681) MAX TEMP = 150°C - 302°F ∴ CONSERVATIVE

MAX AXIAL STRESS AT END OF WELD STUB

$$\sigma = \frac{pr}{2t} = \frac{14.7(24.7)}{2(.135)} = 1345 \text{ psi}$$

FROM BENDING, $\sigma = 263$ psi REF: GNB CALC

TOTAL $\sigma = 1345 + 263 = 1608$ psi

$\sigma < B$ ∴ REQUIREMENT OF UG-23(b) ARE MET

WELD STUB - REDUCED THICKNESS.

ANALYZE MAX ALLOW COMP STRESS USING $t = .070$ WHICH IS THE THICKNESS OF THE PAR. PEN. WELD. THIS WILL RESULT IN THE LOWER BOUND ALLOW. COMP. STRESS (LONG.)

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

$$= \frac{.125}{(24.7/.070)} = 3.5(10)^{-4}$$

$$B = 4500$$

AXIAL COMP STRESS FROM PRESSURE

$$\sigma = \frac{pr}{2t} = \frac{14.7(24.7)}{2(.070)} = 2594 \text{ psi}$$

AXIAL STRESS FROM BENDING

$$I = \pi r^3 t =$$

$$r = \text{MEAN RAD} = \frac{49.12}{2} + \frac{.070}{2} = 24.595$$

$$I = \pi (24.595)^3 (.070) = 3272 \text{ IN}^4$$

$$M = WL = 8000(10.63) = 85040 \text{ IN-LB}$$
AT END OF WELD STUB

$$\sigma = \frac{M r_o}{I}, \text{ SAY } r_o = 24.595$$

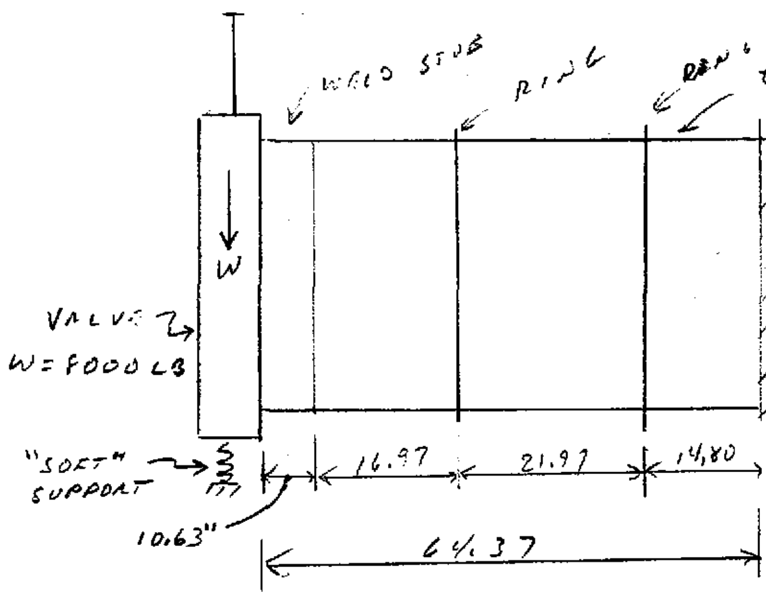
$$\sigma = \frac{85040(24.595)}{3272} = 639$$

TOTAL STRESS AT END OF WELD STUB

$$\sigma = 2594 + 639 = 3233 < 4500 \text{ OK}$$

STRESS AT CBI ANCHOR

CONSIDER STRESS IN CBI TUBE AT 1ST SUPPORT (ANCHOR) - "SOFT" SUPPORT NEGLECTED



D_i = 49.12 IN

REF CBI DWG 95371 4 SHEET 2

BENDING STRESS AT CBI ANCHOR (t = .070)

$$M = 8000(64.37) = 515000 \text{ IN-LB}$$

$$\sigma = \frac{515000(24.595)}{3272} = 3871 \text{ psi}$$

ADD PRESS STRESS

$$\sigma = 3871 + 2594 = 6465 \text{ psi} > B = 4500$$

TOO HIGH

BUT CBI TUBE IS .120 MIN THICK. W/ FP WELD
∴ ABOVE CASE IS TOO CONSERVATIVE FOR CBI TUBE

$$\sigma = \frac{14.7(24.56)}{2(.120)} = 1500 \text{ psi FOR PRESS.}$$

$I = \pi (24.56)^3 (.120) = 5585 \ IN^4$

$\sigma = \frac{515000 (24.62)}{5585} = 2270$

TOTAL STRESS $\sigma = 2270 + 1500 = 3770$ psi

CHECK ALLOW. COMP STRESS PER UG-23(b)

$A = \frac{.125}{24.7/.12} = 6.07(10)^{-4}$

$B = 5000$ FROM FIG HA-3

$\sigma < B$ FOR $t = .12$ OK

ALTERNATE CODE EVALUATION

ALLOWABLE COMPRESSIVE STRESS PER AISI STAINLESS STEEL COLD-FORMED STRUCTURAL DESIGN MANUAL - 1974 EDITION - SECTION 3.8

$F_r = .154\,F_y + \frac{1214}{D/t}$ ← =.070 FOR STUB

$F_y = 17.5^*$ KSI @ 400°F FOR 304L

$D/t = \frac{(49.12 + .07)}{.07} = 703$ (WORST CASE) $t = .070$

$F_r = .154(17.5) + \frac{1214}{703}$

$= 4.47$ KSI

FROM p. 5, $\sigma = 3233 < 4420$ psi

OK FOR WORST CASE STRESS

* ASME CODE SECT II, PART D, TABLE Y-1

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-071
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 19
	0128	3-18-96	AGR	RDC	TITLE: PIPE BRIDGE CORNER STATION	
					By: ART ROUSSOPOULOS	DEPT.: 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: ANALYZE PROPOSED PIPE BRIDGE FOR AISC COMPLIANCE.

METHOD: • STAAD 3 STRUCTURAL COMPUTER SOFTWARE

A JMPTIONS: 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

REFERENCES: Doc. No. V049-1-066, LIGO VAC. EQUIP. STRUCT. DESIGN CRITERIA
• 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.

N ES: STAAD 3 FILE NAME ARTROU.STD FILED IN DIRECTORY \41896\

TABLE OF CONTENTS

1.- STAAD 3 INPUT:

- DENSITY = .283 #/IN³
- MODULUS OF ELASTICITY E = 28X10⁶ 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#

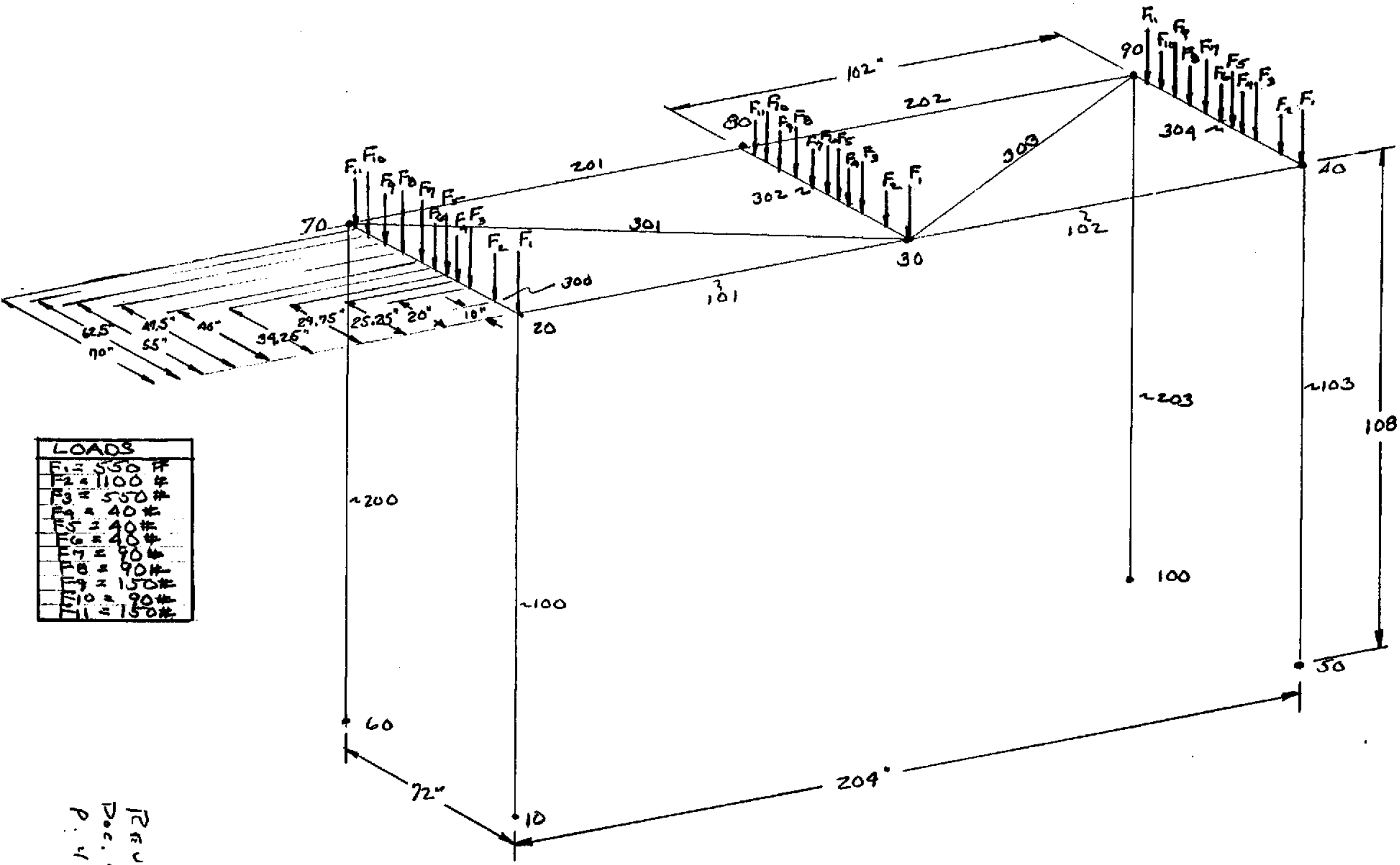
  - PIPE BRIDGE STEEL TUBE (SEE MODEL P.3+4)
    ELEMENT DEADWEIGHT:
    - 100, 200, 103 + 203: 8X6X1/4 X 108" LONG EACH
      WT = [(22.42#/FT)/12] X 108 = 201.8# EACH
    - 300, 302 + 304: 8X6X1/4 X 72" LONG EACH
      WT = (22.42/12) X 72 = 134.5# EACH
    - 101, 102, 201 + 202: 8X6X1/4 X 102" LONG 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_Y = 109.3(.06) = 6.6#

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

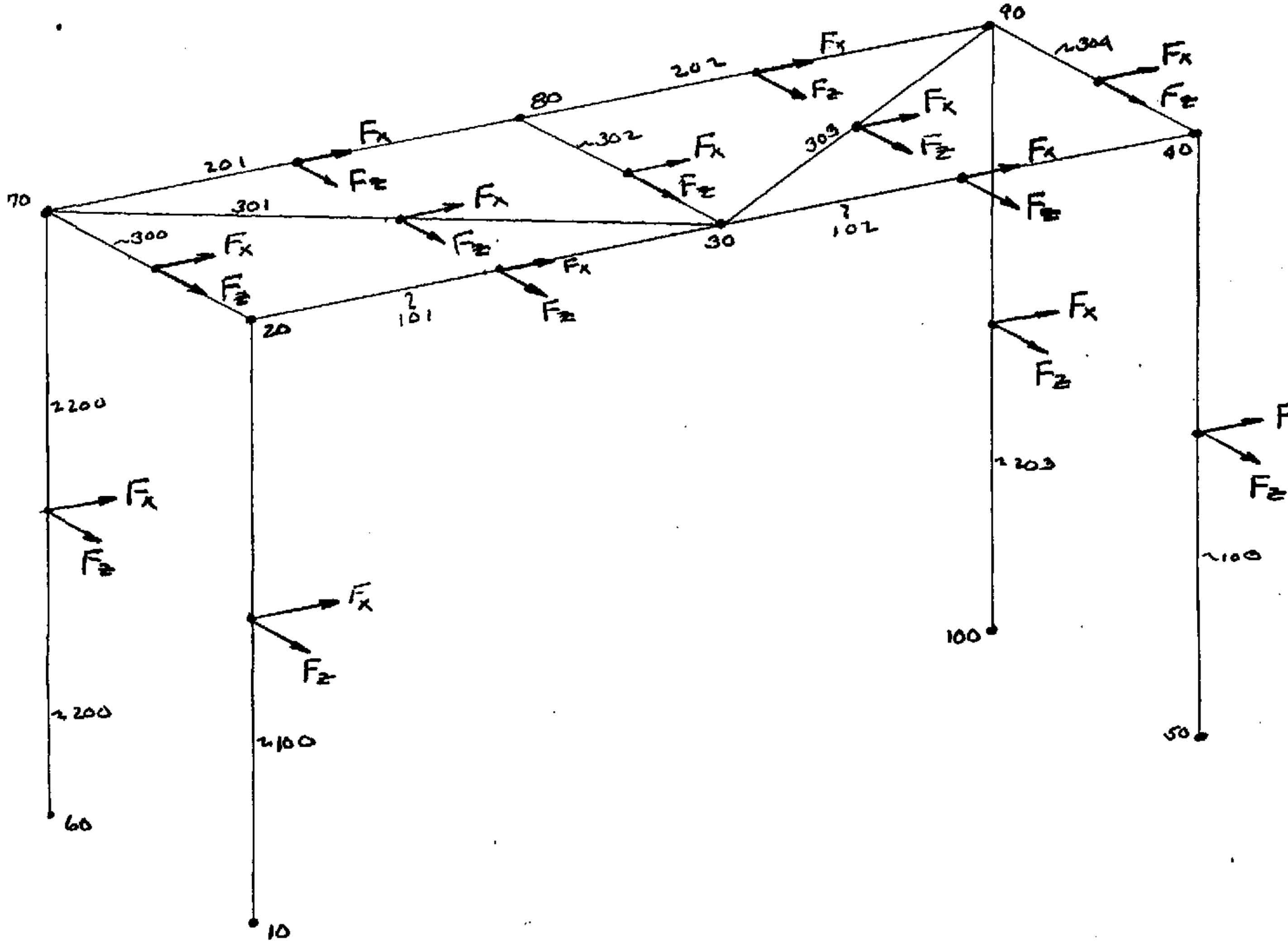
STAAD MODEL FOR PIPEBRIDGE, REF. DWG. VO 4-043

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 #

STAAD3 - MODEL FOR PIPEBRIDGE
SEISMIC LOADS



REV 0
DOC. NO. V049-1-071

Rev 0
Doc. No. V049-1-071
P. 5 of 19

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 8X6X1/4 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

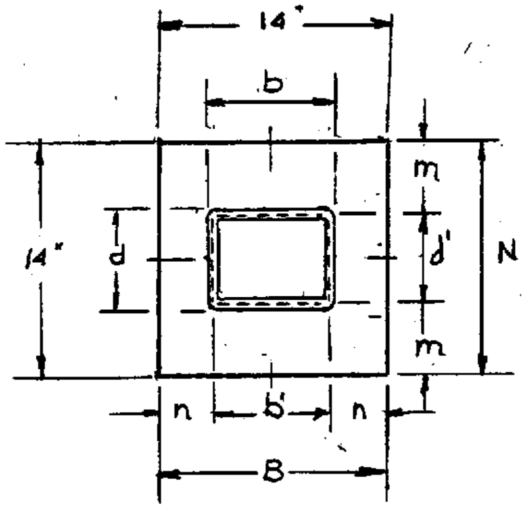
- VERTICAL LOADS ARE ALL COMPRESSIVE ∴ ONLY HORIZONTAL SHEAR LOADS ARE IMPOSED ONTO ANCHOR BOLTING.
- ANALYZE NODE 50 FOR WORSE CASE LOADING
  - MAXIMUM SHEAR LOAD:

$$F_{S\,MAX} = [F_x^2 + F_z^2]^{1/2} = [(-516)^2 + (-186)^2]^{1/2} = 549\ \# \text{ (TOTAL)}$$

2.- CON'T

- ALLOWABLE LOAD (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.- BASE PLATE QUALIFICATION REF: AISC P. 3-106

• REQUIRED PLATE THICKNESS:

$t_p = 2(m \text{ or } n)\left[f_p/F_y\right]^{1/2} = 2(5.125)\left[(21)/(36000)\right]^{1/2} = .25"$

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 6 X 4 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.
 .02. 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.
 .29. 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

JOINT	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

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

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

162. PARAMETER
163. CODE AISC
164. MAIN 0. ALL
165. WELD 1. ALL
166. CHECK CODE ALL

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

ALL UNITS ARE - POUN INCH (UNLESS OTHERWISE NOTED)

MEMBER	TABLE	RESULT/ FX	CRITICAL COND/ MY	RATIO/ MZ	LOADING/ 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

REV 0
DOC. No. V049-1-071
P.15 OF 19

STAADD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

MEMBER	LOCATION/ LOADING	WELD TYPE/ HOR STRESS	WELD SIZE/ VERT STRESS	COMB STRESS/ DIR STRESS
100	STA 3	1 174.71	1/16 156.16	3084.49 3075.57
100	END 3	1 82.51	2/16 82.92	12567.55 12567.00
101	STA 3	1 802.92	1/16 1297.58	11632.56 11532.04
101	END 3	1 270.60	3/16 397.90	9936.68 9925.02
102	STA 3	1 290.05	3/16 499.31	10057.32 10040.73
102	END 3	1 439.51	2/16 800.91	13151.09 13119.32
103	STA 3	1 46.28	3/16 134.26	12733.40 12732.61
103	END 3	1 148.52	1/16 412.45	3300.42 3271.18
200	STA 3	1 100.30	1/16 73.23	775.38 765.37
200	END 3	1 90.62	1/16 82.91	12369.77 12369.16
201	STA 3	1 858.48	1/16 932.89	3032.48 2754.75
201	END 3	1 424.80	2/16 414.50	8085.26 8063.44
202	STA 3	1 444.35	2/16 535.50	8114.59 8084.70
202	END 3	1 439.91	2/16 587.44	7635.14 7599.78
203	STA 3	1 30.86	2/16 151.09	12144.24 12143.26
203	END 3	1 71.40	1/16 311.87	1119.99 1073.32

REV0
DOC. NO. V049-1-071
P.16 OF 19

STAAD-III WELD DESIGN
****

ALL UNITS ARE - INCH POUN

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

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

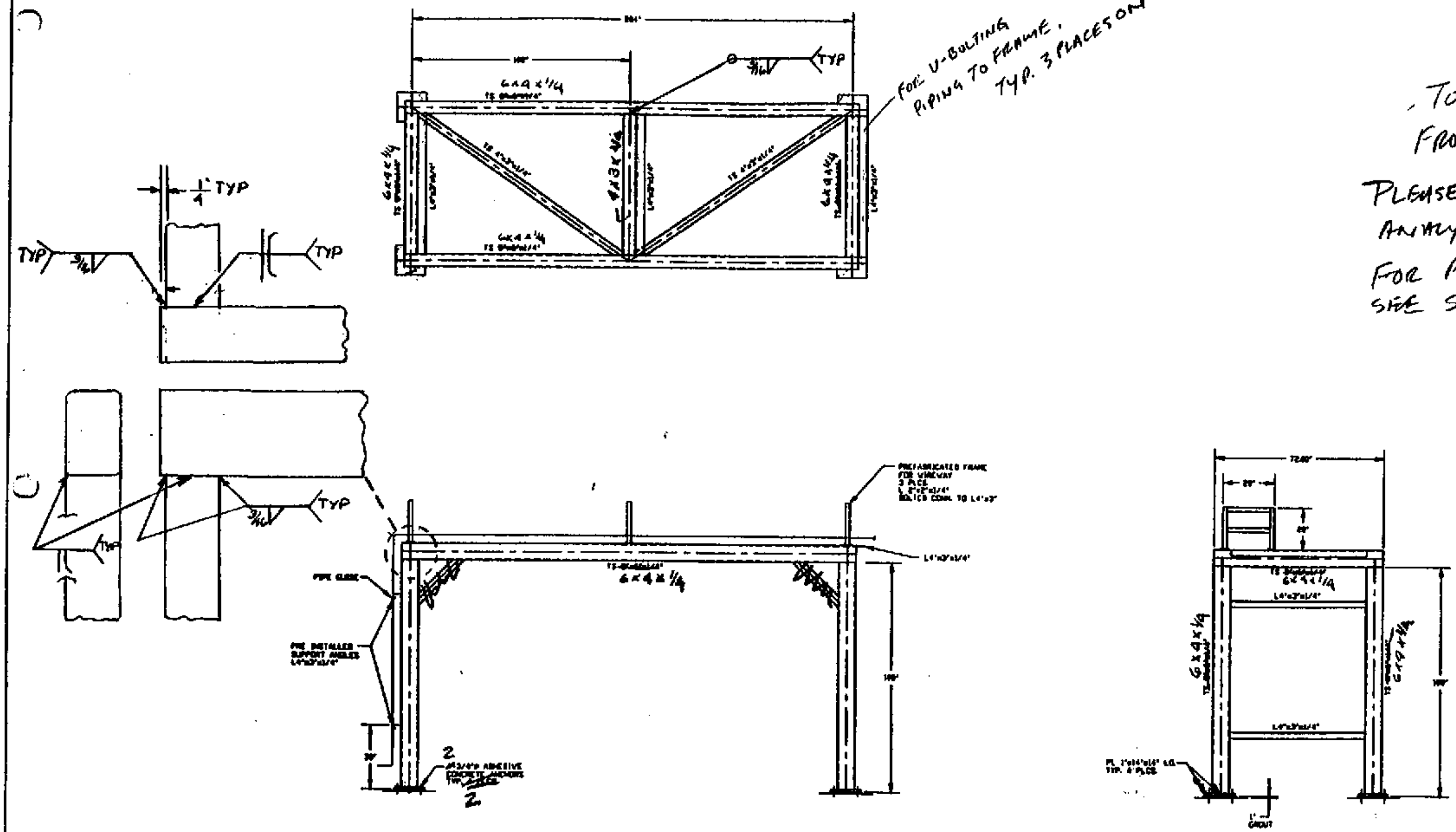
*************** END OF STAAD-III ***************

**** 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        *
*********************************************************
```

5 MAR 96

To: R. Ciatto
From: D. Curtis
Please Review & Provide Analysis,
For Pipe & Elect. Loadings see SHTS. 2 & 3 OF 3



NOTE: ALL WELDS SHALL BE 3/16" FILLET OR AS NOTED

SHT. 1 OF 3

PROCESS SYSTEMS INTERNATIONAL, INC.

PROPOSED PIPE BRIDGE
CORNER STATION
LIGO VACUUM EQUIPMENT

DO NOT SCALE THIS DRAWING

V049-4-043

REV 0
DOC. NO. V049-1-047
P. 19 OF 19

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-107 PAGE 1 OF 31
REV.	DEO #	DATE	BY:	CHECK	TITLE: Welds for 60.5 in Nozzle to Shell Joints	
0	6753	8/1/96	RDC	WDB		
					BY: R. D. Ciatto	DEPT.: 744

<u>PROJECT:</u> LIGO Vacuum Equipment

<u>PROJECT NO:</u> V59049

<u>PURPOSE:</u> Evaluate nozzle to shell welded joints in BSCs and HAMs for the 60.5 nozzles using an alternative design to the full penetration butt weld.

<u>METHOD:</u> Hand calculations are used to determine the weld stresses from the moments and forces obtained from the BSC and HAM FE analyses.

<u>ASSUMPTIONS:</u> N/A

<u>INPUTS:</u> LIGO project drawing V049-4-001 - Beam Splitter Chamber.
LIGO project drawing V049-4-002 - Horizontal Access Module
Calc. No. V049-1-066, Structural Design Criteria
Calc. No. V049-1-022, BSC, FE Analysis of Lower Section, V049-1-039, HAM FE Analysis

<u>REFERENCES:</u> See INPUTS

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

<u>CONCLUSIONS:</u> The nozzle to shell welds shown in this calculation have the strength required to resist the discontinuity forces computed in the FE analysis. The calculation results were verified by bend tests that simulated the proposed configuration of the connection.

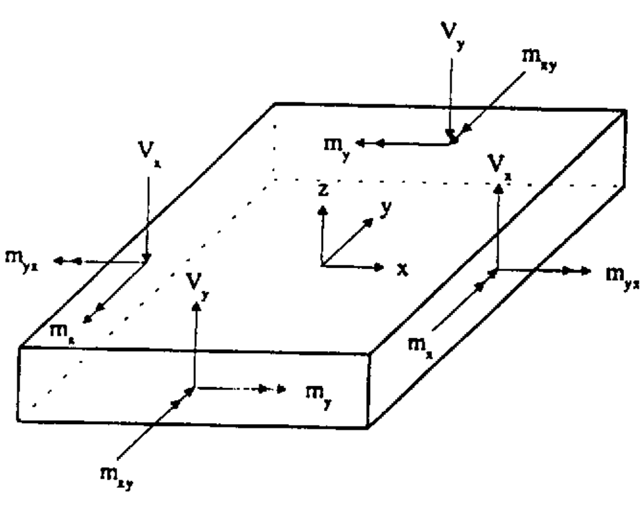
<u>NOTES:</u> See the attachment to this calculation for sketches of the revised nozzle to shell weld connection.

TABLE OF CONTENTS

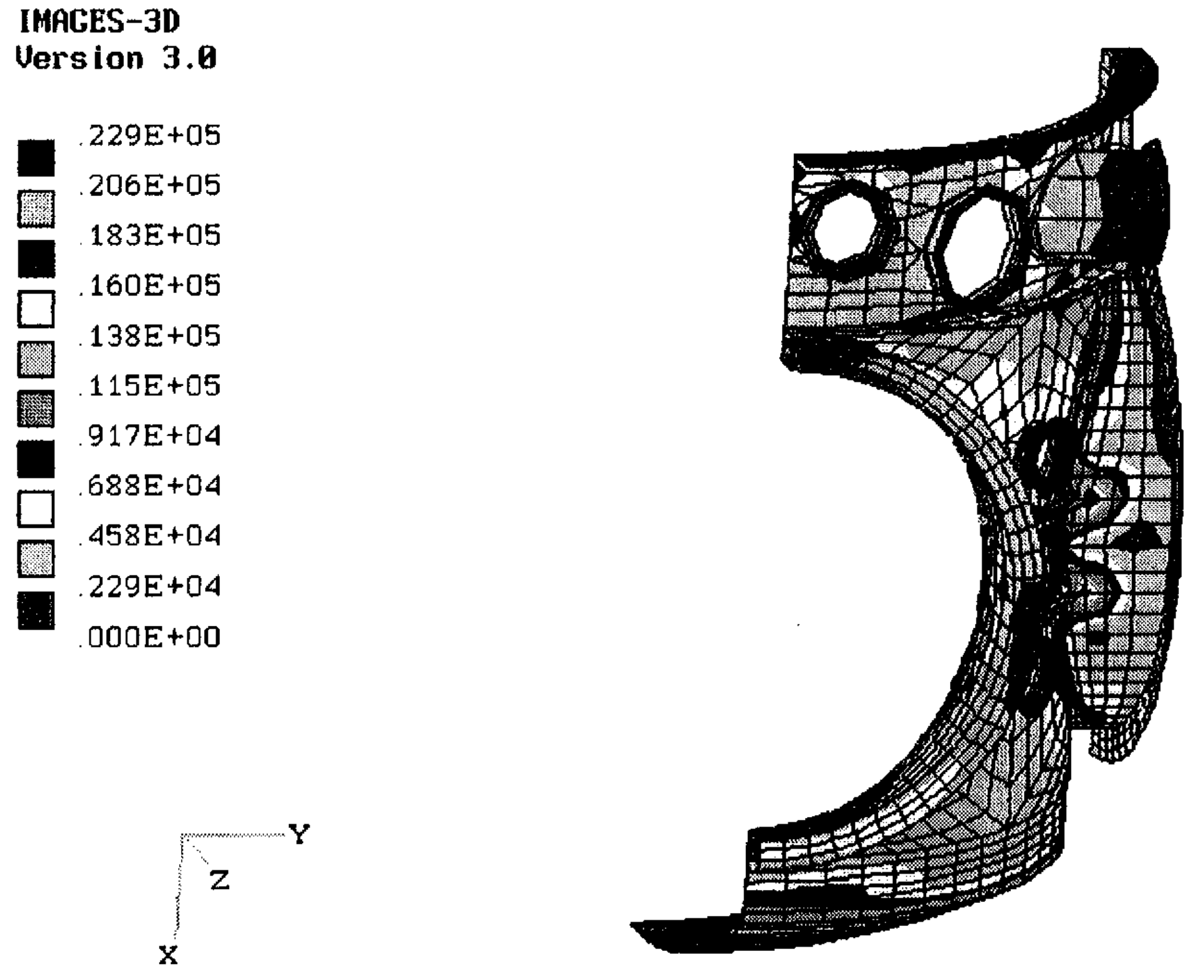
THE CURRENT WELD DESIGN FOR THE BEAM SPLITTER NOZZLE-TO-SHELL WELD AT THE 60.5 IN PORTS IS A FULL PEN WELD. THE STRESSES COMPUTED DIRECTLY BY IMAGES ARE APPROPRIATE FOR THE EVALUATION OF THIS WELD AS PERFORMED IN CALC V049-1-022 FOR THE BSC

THAT CALC SHOWED THAT THE MAX SI AT THE NOZZLE SHELL JUNCTION IS 23.5 KSI AT THE BOTTOM OF THE NOZZLE. A REVIEW OF THE BHSPLI12 IMAGES FILE CONFIRMED THAT ALL OTHER LOCATIONS AT THIS WELD HAD LOWER STRESSES. THE REVIEW WAS PERFORMED BY OBSERVING STRESS INTENSITY CONTOUR PLOTS OF THE BEAM SPLITTER MODEL FOR THE 3 LOAD CASES THAT HAD BEEN EVALUATED.

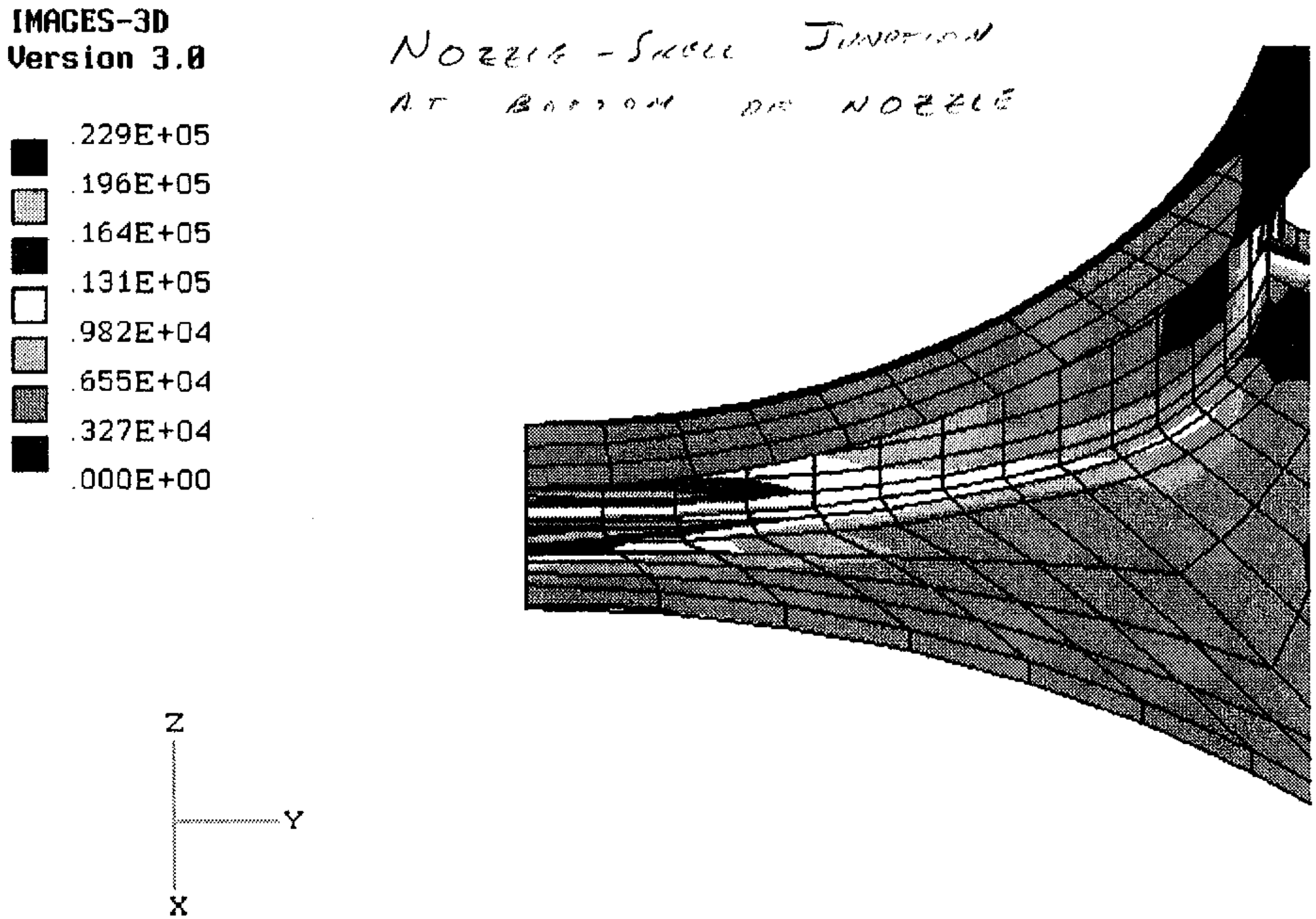
THE MOST HIGHLY STRESSED ELEMENT FOR THE BEAM SPLITTER IS PLATE 1 (P1). TO EVALUATE THE ALTERNATE WELDED CONNECTION, THE PLATE LOADS PER UNIT LENGTH HAVE BEEN PRINTED FOR P1.



Sign convention for Plate Loads/Unit Length



Load Case 1 | Stress Contour Plot | Surf: Top | Stress Intensity | 7/30/96 15:27:43



Load Case 1

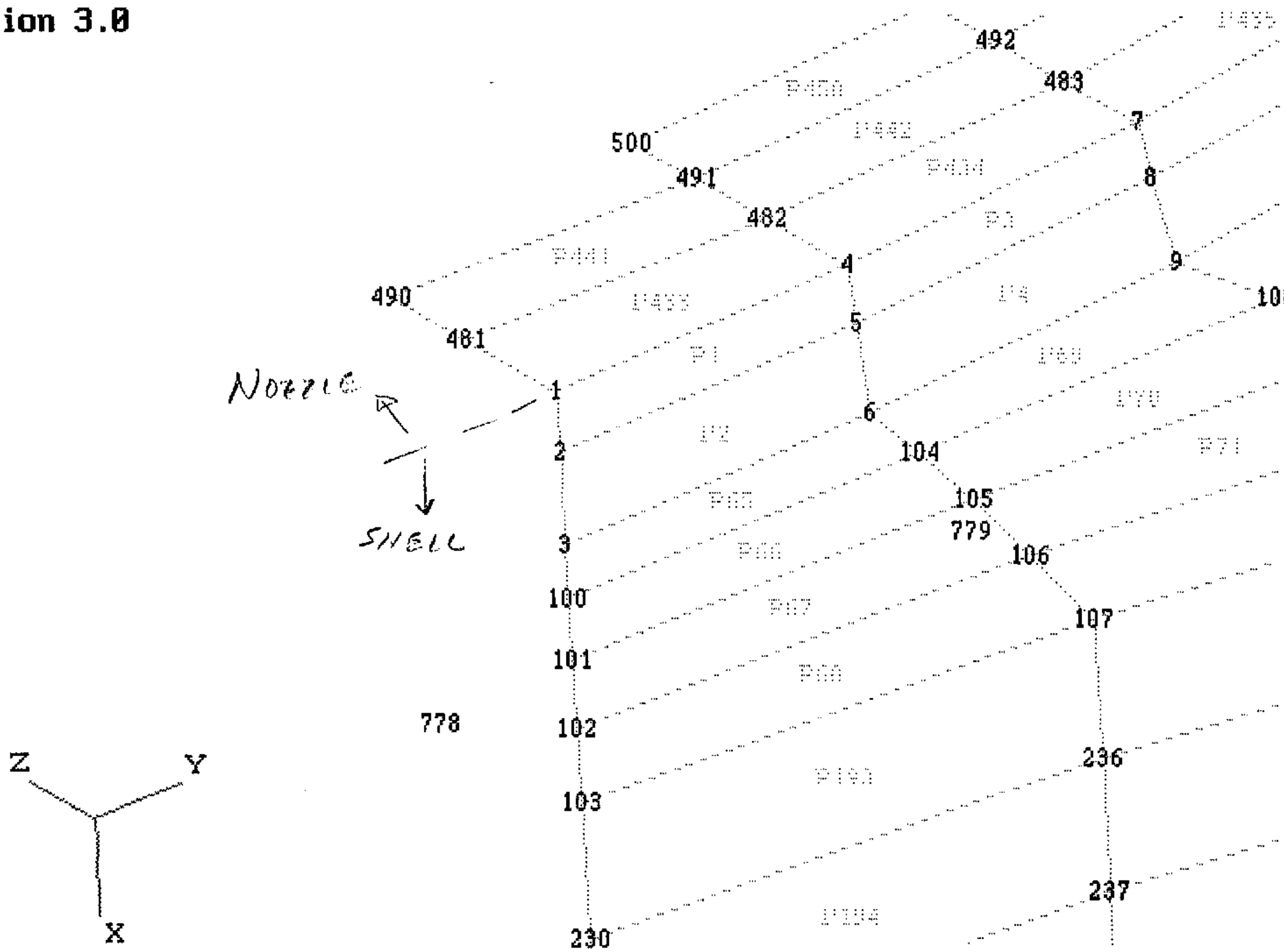
Stress Contour Plot

Surf: Top

Stress Intensity

7/30/96
15:46:47

IMAGES-3D
Version 3.0



?

Auto	**Blowup**	**Contour**	**Displ**	**Elem#**	**Exit**	**Help**	**Lcase**
Node#	**Move**	**Rotate**	**Range**	**Scale**	**Shade**	**Slice**	**Stress**

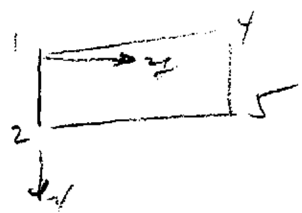
```
                          PLATE LOADS AND/OR STRESSES

  Lloads          fx         fy         fxy        mx         my         mxy
  Lloads          f1         f2         Angle      m1         m2         Angle
  Lloads          Vx         Vy
  Stress Surf  Sigma   X  Sigma   Y    Tau XY   Sigma  1   Sigma  2     Angle
  Stress       Sigma   Z  Von Mises    Tau XZ     Tau YZ
  ------ ---- ---------- ---------- ---------- ---------- ---------- ----------
                                ***PLATE NO.    1***
  LLoads       -.3926E+03 -.9719E+04 -.6371E+02  .4350E+03  .2220E+03 .1080E+02
  LLoads       -.3922E+03 -.9720E+04       -.39  .4355E+03  .2214E+03       2.89
  LLoads        .2171E+03 -.3003E+02
  Stress  TOP   .9654E+04 -.1411E+05  .1317E+03  .9655E+04 -.1411E+05        .32
                           .2070E+05
  Stress  MID -.7853E+03 -.1944E+05 -.1274E+03 -.7844E+03 -.1944E+05       -.39
                           .1906E+05  .6513E+03 -.9008E+02
  Stress  BOT -.1122E+05 -.2477E+05 -.3865E+03 -.1121E+05 -.2478E+05      -1.63
                           .2149E+05
```

SHIFT
COMMANDS F2 F3 F4 F5 F6 scroll speed
↑↓ auto scroll

PLATE P1

NODES ARE 1, 2, 5, 4

I, J, K, L



LOCX = 0 => LOCAL Y-AXIS IS
FROM I TO J = 1 TO 2

LOADS PER UNIT LENGTH FOR PLATE 1
FROM BMSPLZ12.30U FILE

$f_x = 393$

$f_y = 9719$

$f_{xy} = 64$

$m_x = 435$

$m_y = 222$

$m_{xy} = 11$

$f_1 = 393$

$f_2 = 9720$

$m1 = 436$

$m2 = 221$

$V_x = 217$

$V_y = 30$

MAXIMUM BENDING MOMENT $m_y = 435$ IN-LB/IN

CHECK BENDING STRESS

$$f_b = \frac{6 m_y}{t^2}$$

$$= \frac{6(435)}{.5^2}$$

$$= 10440 \text{ psi}$$

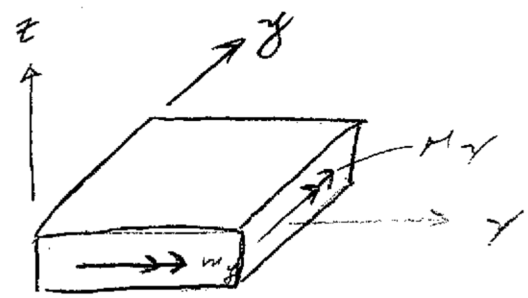
DIRECT STRESS DUE TO MEMBRANE LOAD

$$f_a = \frac{f_y}{t} = \frac{393 \text{ LB/IN}}{.5}$$

$$= 786$$

TOTAL SURFACE STRESS

$f = 10440 + 786 = 11226$ OK $= \sigma_{y\,BOT}$

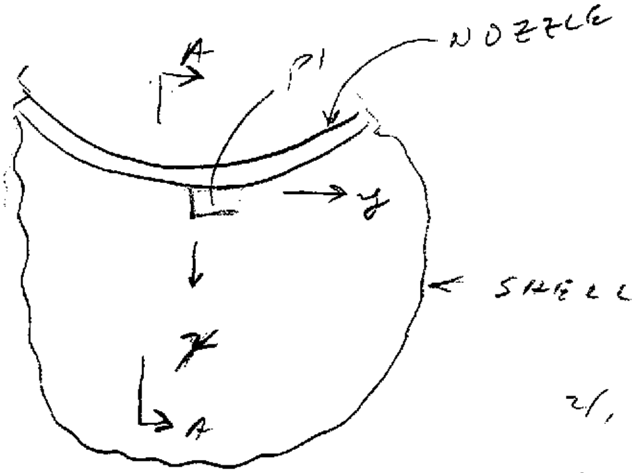


$$\frac{6 m_y}{t^2} - \frac{f_y}{t} = \frac{6(222)}{.5^2} + \frac{9719}{.5}$$

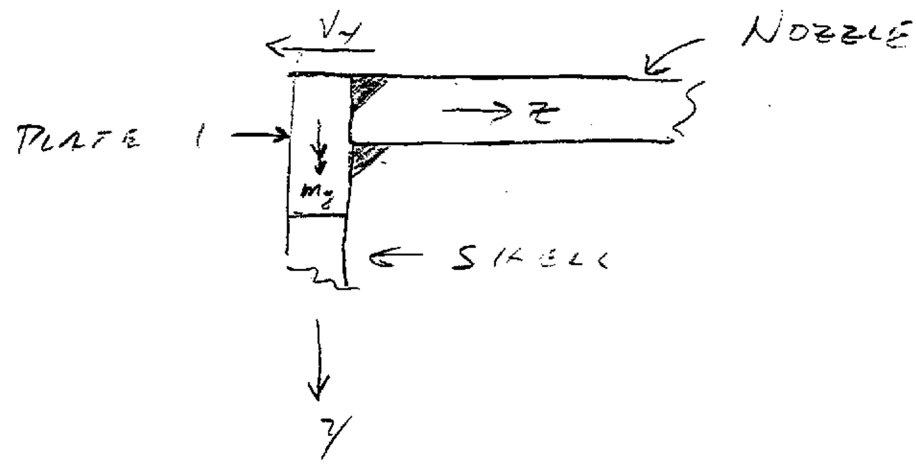
$$= 5328 + 19438 = 24766$$

CHECKS W/ σ_y ON BOT OK

PARTIAL END VIEW OF NOZZLE
LOOKING IN



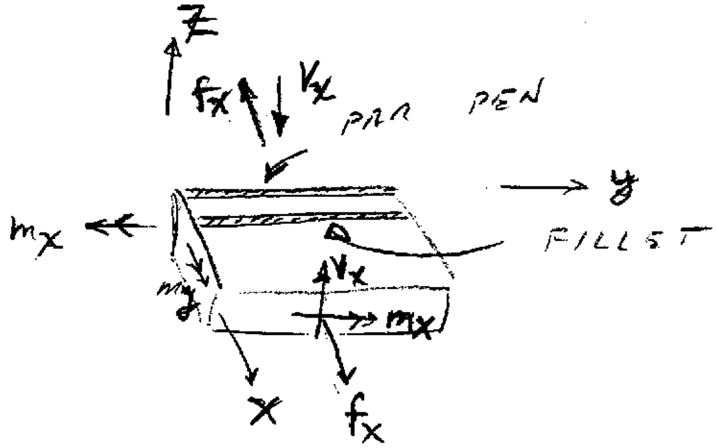
x, y, z ARE
LOCAL AXES



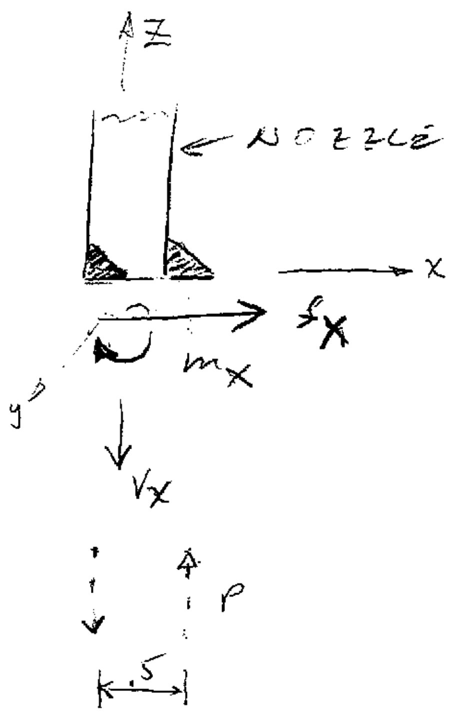
A - A

K

ISOMETRIC VIEW OF P1 SHOWING PROPOSED WELD



FROM THE ABOVE SKETCH, IT IS OBSERVED THAT m_y IS REACTED BY A FORCE COUPLE IN THE WELDS. IN ADDITION, f_y SHEARS THE WELDS AND V_y STRESSES THE WELDS IN TENSION OR COMPRESSION.



IT MAY BE ASSUMED THAT THE PAR PEN WELD RESISTS V_X (TEN), f_Y (SHEAR)

AND ONE OF THE FORCES FROM THE COUPLE RESULTING FROM m_X WHICH WILL IMPOSE TENSION.

$$m_X = 435 \text{ IN-LB/IN}$$

THE COUPLE FORCES ARE .5 IN APART.

$$P(.5) = 435$$

$$P = \frac{435}{.5} = 870 \ \frac{LB}{IN}$$

$$V_Y = 217 \text{ LB/IN}$$

TENSILE STRESS IN PAR PEN WELD WHICH IS .25 IN WIDE

$$f_t = \frac{P + V_Y}{.25}$$

$$= \frac{870 + 217}{.25} = 4348 \text{ psi}$$

SUPER POSE THE WORST CASE FLANGE TENSION FORCE WHICH IS 362 LB/IN FOR THE 30.25 IN FLANGE (REF CALC 042, P.17)

$$f_t = 4348 + \frac{362}{.25} = 4348 + 1448$$

$$= 5800 \text{ psi}$$

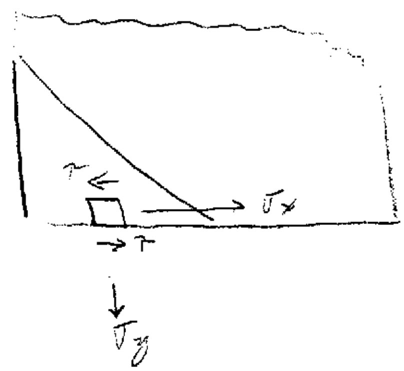
SHEAR STRESS IN PAR PEN WELD

$$\tau = \frac{f_x}{.25}$$

$$= \frac{393}{.25}$$

$$= 1572 \text{ psi}$$

COMPUTE PRINCIPAL STRESS IN PAR PEN WELD



$$\sigma_{1,2} = \frac{1}{2}(\sigma_x + \sigma_y) \pm \left\{\left[\frac{1}{2}(\sigma_x - \sigma_y)\right]^2 + \tau^2\right\}^{\frac{1}{2}}$$

$$\sigma_x = 0$$

$$\sigma_y = f_t = 5800$$

$$\tau = 1572$$

$$\sigma_{1,2} = \frac{5800}{2} \pm \sqrt{\left(\frac{5800}{2}\right)^2 + 1572^2}$$

$$= 2900 \pm 3300$$

$$\sigma_1 = 6200 \text{ psi} \checkmark$$

$$\sigma_2 = -400 \text{ psi} \checkmark$$

THE MAX STRESS INTENSITY IS

$$SI = \sigma_1 - \sigma_2 = 6600 \text{ psi}$$ OK

k

SHEAR STRESS IN THE STITCH FILLET WELD. ASSUME 1/4 IN

$$\tau = \frac{P}{.707(.25)} \times \frac{S}{L}$$

$P = 870 \frac{LB}{IN}$

S = WELD SPACING - ASSUME 4 IN

L = WELD LENGTH - ASSUME 3 IN

$$\tau = \frac{870}{.707(.25)} \times \frac{4}{3}$$

≈ 6600 psi

FOR THE PARTIAL PENETRATION WELD TRY A 1/8" THROAT THICKNESS

SHEAR STRESS

$$\tau = \frac{f_y}{.125}$$

$$= \frac{393}{.125} =$$

$$= 3144 \text{ psi}$$

TENSILE STRESS

$$f_t = \frac{P + V_Y}{.125}$$

$$= \frac{870 + 217}{.125}$$

$$= 8696 \text{ psi}$$

ADD WORST CASE TENSILE FORCE FROM EXTERNAL LOAD (362 LB/IN)

$$f_t = 8696 + \frac{362}{.125} = 8696 + 2896$$

$$= 11592$$

PRINCIPAL STRESS FOR 1/8" PAR PEN WELD

$$\sigma_{1,2} = \frac{11552}{2} \pm \sqrt{\left(\frac{11552}{2}\right)^2 + 3144^2}$$

$$= 5800 \pm \sqrt{5800^2 + 3144^2}$$

$$= 5800 \pm 6594 \text{ psi}$$

$$\sigma_1 = 12400 \text{ psi}$$

$$\sigma_2 = -800 \text{ psi}$$

MAX STRESS INTENSITY AT 1/8" PAR PEN WELD

$$SI = \sigma_1 - \sigma_2 = 12400 - (-800)$$

$$= 13200 \text{ psi}$$

THIS STRESS MAY BE CONSIDERED A PRIMARY LOCAL MEMBRANE STRESS SINCE IT ACCOUNTS FOR DISCONTINUITY MOMENT AND FORCE AT THE NOZZLE SHELL JUNCTION. ∴ IT IS IN THE P_L CATEGORY PER ASME VIII - 2, PAR 4-132.

$$P_L = 13200 < 1.5 S_m = 28.0 \text{ KSI} @ 400°F$$

FOR DUAL GRADE 304/304L

NOTE 308L WELD WIRE HAS HIGHER STRENGTH THAN EITHER 304 OR 304L.

TRY A 3/16 STITCH FILLET WELD ON THE OUTSIDE OF THE SHELL

$$\tau = \frac{P}{.707(3/16)} \quad \frac{S}{L}$$

$S = 4$ IN

$L = 3$ IN

$$\tau = \frac{870}{.707(.1875)} \times \frac{4}{3}$$

$= 8750$ PSI

SINCE THIS WELD RESISTS PURE SHEAR AT THE MIN THROAT, IT WILL BE COMPARED TO $.6\,S_M$ IN ACCORDANCE WITH AD 132.2 OF THE CODE (SECT VIII, DIV 2).

$\tau = 8.75$ KSI $< .6S_M = .6(18.7) = 11.2$ KSI

OK

HAM NOZZLE

THE MAXIMUM STRESS IS AT PLATE ELEMENT P1828. THE ELEMENT LISTING OF THIS ELEMENT IS

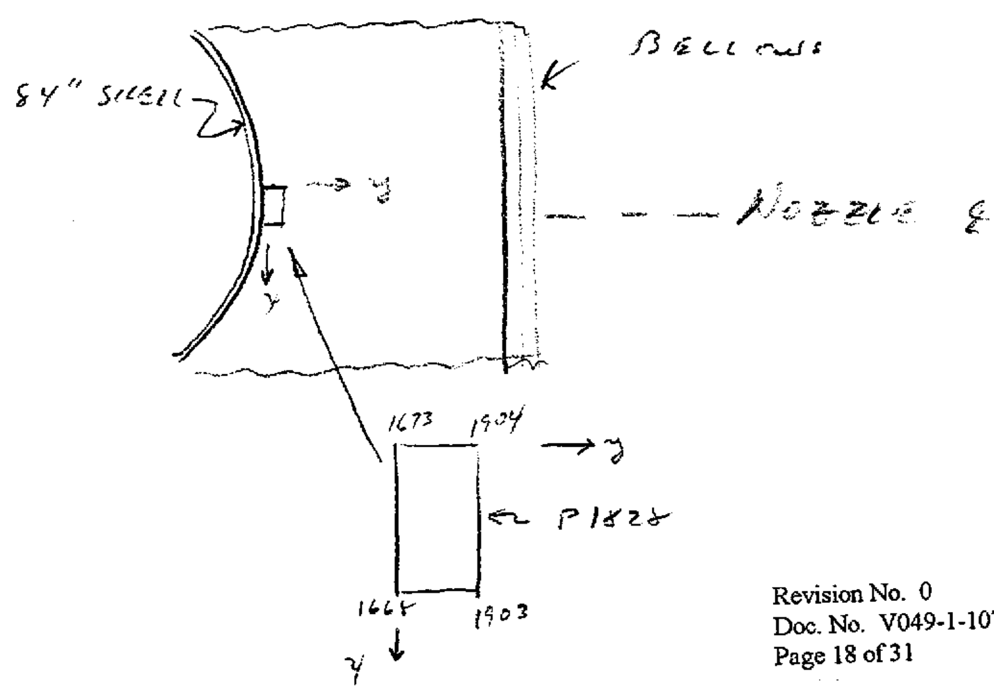
LOC X

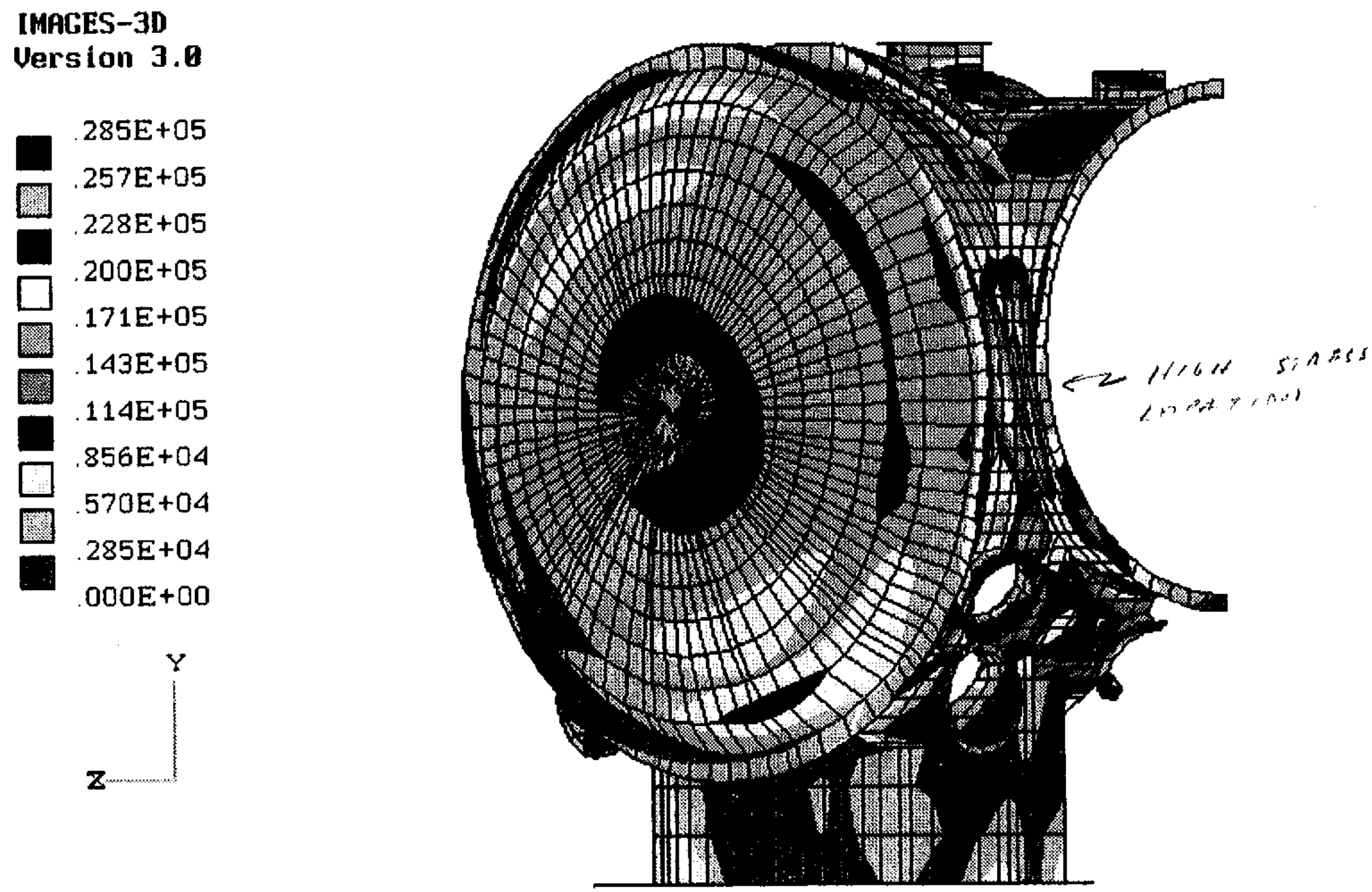
1828) P 1673, 1668, 1903, 1904, 2, 0

FOR THE HAM6 IMAGES FILE.

THIS ELEMENT IS LOCATED AT THE NOZZLE SHELL JUNCTION ON THE 60 IN NOZZLE WHICH IS ADJACENT TO THE BELLOWS. THE MAX STRESS IS FOR LOAD CASE 1 WHICH ACCOUNTS FOR THE UNBALANCED FORCE FROM HAVING THE COVER ON ONE SIDE AND THE BELLOWS ON THE OTHER. THE MAX SI AT P1828 IS 28.5 KSI AS SHOWN ON THE FOLLOWING PLOTS.

SINCE LOC X = 0, THE LOCAL Y AXIS IS DEFINED BY THE LINE FROM I TO J (1673 TO 1668). THE ELEMENT IS ORIENTED AS FOLLOWS.



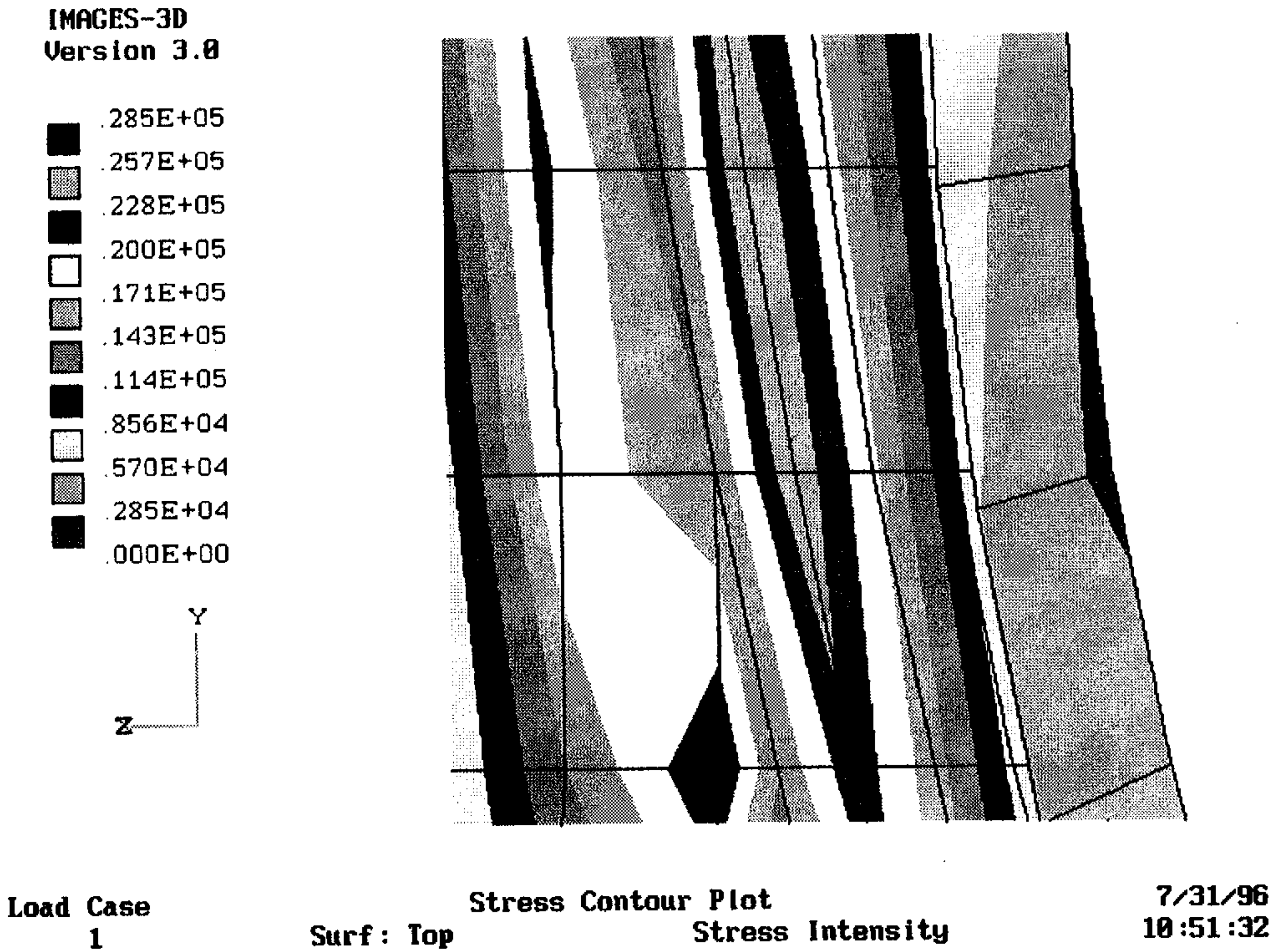


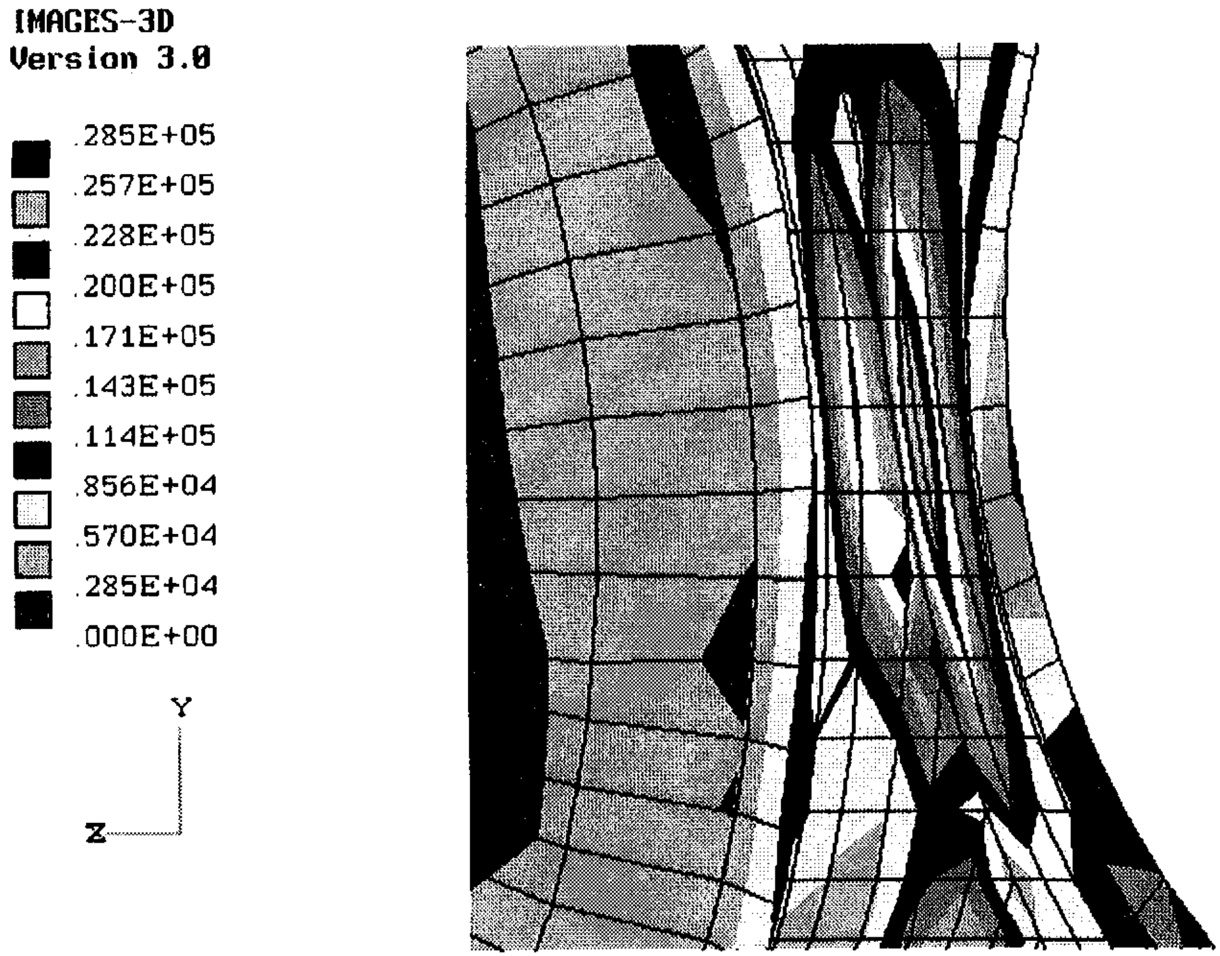
Load Case **1**

Stress Contour Plot

Surf: Top **Stress Intensity**

7/31/96
9: 6:43


IMAGES-3D
Version 3.0
.285E+05
.257E+05
.228E+05
.200E+05
.171E+05
.143E+05
.114E+05
.856E+04
.570E+04
.285E+04
.000E+00
Y
Z
Load Case
1
Stress Contour Plot
Surf: Top
Stress Intensity
7/31/96
10:51:32



Load Case 1

Stress Contour Plot

Surf: Top

Stress Intensity

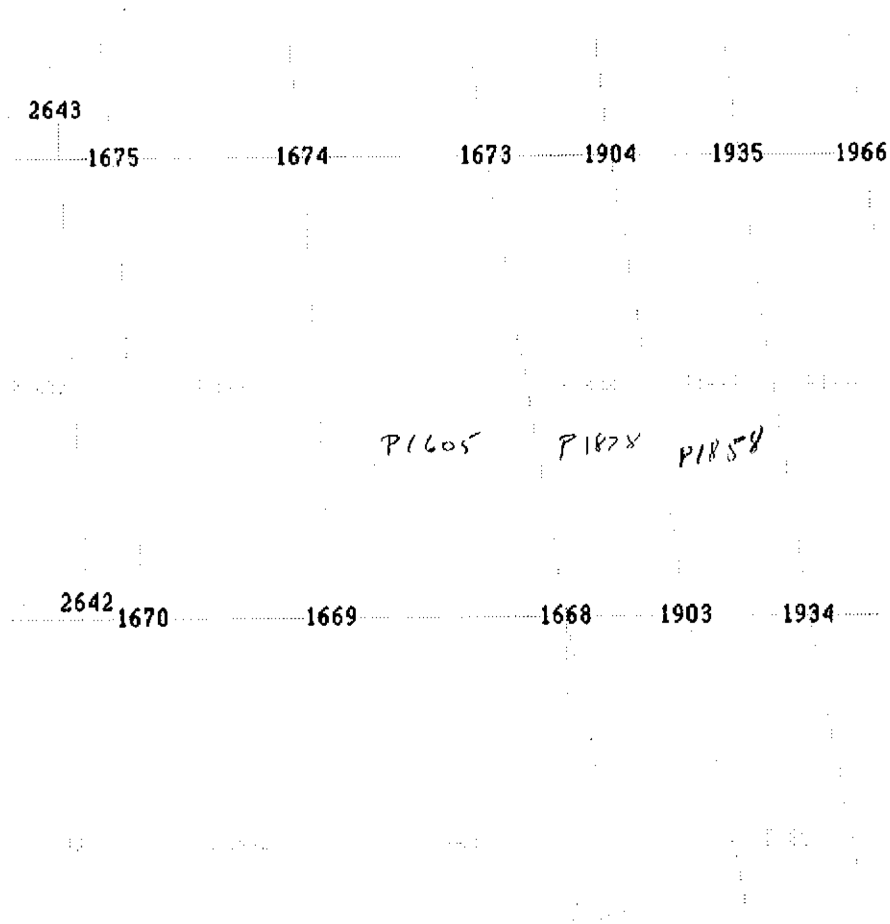
7/31/96
9:36:49

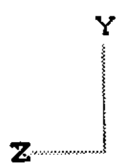
IMAGES-3D
Version 3.0

Select an option

1-Plate or 1,F,T
2-Axi-Shell or 2,F,T
3-Axi-Solid or 3,F,T
4-Solid or 4,F,T
5-No element numbers
6-All elemt. numbers
7-Exit or 7,Size

?7,1
?b
?#
?





Auto	Blowup	Contour	Displ	Elem#	Exit	Help	Lcase
Node#	Move	Rotate	Range	Scale	Shade	Slice	Stress

PLATE NO. 1828

LLoads	-.6605E+04	-.6634E+02	.1845E+03	.4388E+03	.1172E+04	.5480E+02
LLoads	-.6114E+02	-.6610E+04	88.39	.1176E+04	.4347E+03	85.75
LLoads	.6542E+02	-.1700E+03				

PROCESS ENGINEERING INC. S/N:802506A 07/31/96
PAGE 532 Run ID= 13:43:20

================= I M A G E S - 3 D =================

===

SOLVE PLATE LOADS/STRESSES Version 3.0 12/31/93

Filename=HAM6
Title =

Load Case 1:ONE BAFFLE LOADING

F2 F3 F4 F5 F6

Filename=HAM6
Title =

Load Case 1:ONE BAFFLE LOADING

Lloads		fx	fy	fxy	mx	my	mxy
Lloads		f1	f2	Angle	m1	m2	Angle
Lloads		Vx	Vy				
Stress	Surf	Sigma X	Sigma Y	Tau XY	Sigma 1	Sigma 2	Angle
Stress		Sigma Z	Von Mises	Tau XZ	Tau YZ		
------	----	----------	----------	----------	----------	----------	----------
Stress	TOP	-.2680E+04	.2799E+05	.1684E+04	.2808E+05	-.2772E+04	86.87
			.2957E+05				
Stress	MID	-.1321E+05	-.1327E+03	.3689E+03	-.1223E+03	-.1322E+05	88.39
			.1316E+05	.1963E+03	-.5099E+03		
Stress	BOT	-.2374E+05	-.2826E+05	-.9462E+03	-.2355E+05	-.2845E+05	-11.37
			.2634E+05				

PLATE NO. 1829

F2 F3 F4 F5 F6

FROM THE HAM6.30U FILE

f_x = 1605 LB

f_y = 66

f_{xy} = 185

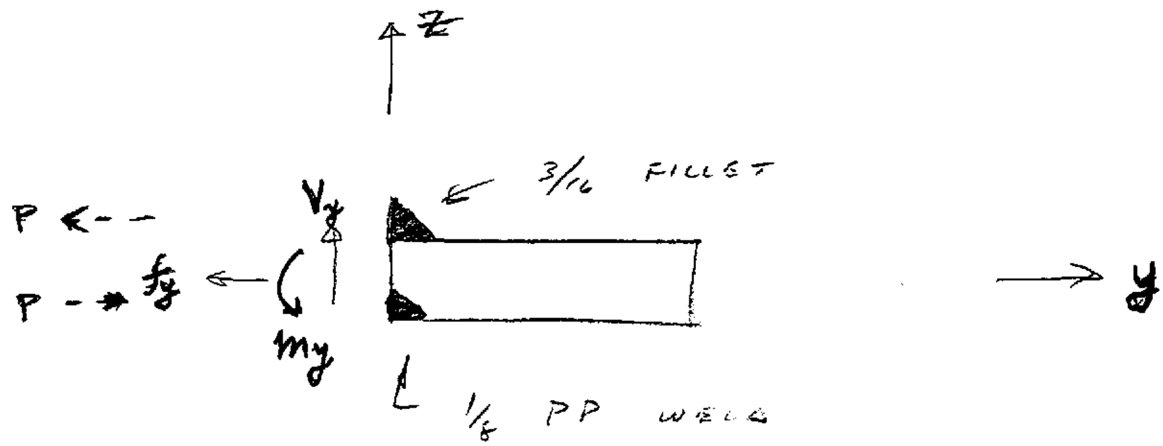
m_x = 439 IN-LB

m_y = 1172

m_{xy} = 55

V_x = 65 LB

V_y = 170



AS BEFORE, LET THE PP WELD RESIST V_y (SHEAR) AND f_y (TENSION). M_y IS RESISTED BY THE FORCE COUPLE REACTED BY THE WELDS.

$$P(.5) = M_y$$

$$P = \frac{1172}{.5} \text{ \#/IN}$$

$$= 2344 \text{ \#/IN}$$

TENSILE STRESS IN PP WELD

$$f_t = \frac{P + f_y}{.125} =$$

$$= \frac{2344 + 66}{.125}$$

$$= 19280 \text{ psi}$$

SUPERPOSE WORST CASE FLANGE TENSION FORCE, 362 LB/IN

$$f_t = 19280 + \frac{362}{.125} = 19280 + 2896$$

$$= 22176 \text{ psi}$$

SHEAR STRESS IN PP WELD

$$\tau = \frac{V_y}{.125} = \frac{170}{.125}$$

$$= 1360 \text{ psi}$$

PRINCIPAL STRESS FOR 1/8" PAR PEN WELD

$$\sigma_{1,2} = \frac{22176}{2} \pm \sqrt{\left(\frac{22176}{2}\right)^2 + 1360^2}$$

$$= 11088 \pm (11088^2 + 1360^2)^{\frac{1}{2}}$$

$$= 11088 \pm 11171$$

$$\sigma_1 = 22260 \text{ psi}$$

$$\sigma_2 = -80 \text{ psi}$$

$$SI = 22260 - (-80) = 22340$$

$$< 1.5 S_M = 28.0 \text{ KSI @ } 400°F$$

FOR THE 3/16 STITCH FILLET WELD ON THE OUTSIDE

$$\tau = \frac{P}{.707(3/16)} \quad \frac{S}{L}$$

$$= \frac{2344}{.707(3/16)} \times \frac{4}{3}$$

$$= 23576 > 11.2 \text{ KSI}$$

✓

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

CHECK THE WELD USING THE AISC CRITERIA FOR FILLET WELDS

$\tau < .30\ F_u$ OF WELD METAL

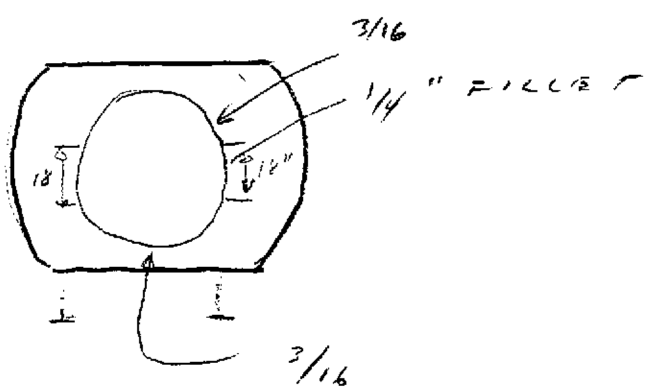
$F_u = 85$ KSI FOR 308L FILLER

$\tau = 23.6 < .30(85) = 25.5$ KSI *

BUT WELD METAL STRENGTH IS GREATER THAN THE BASE METAL

* @ 70°F - $F_u < 85$ FOR ELEVATED TEMP.

NOTE THIS FILLET WELD WILL BE CHANGED TO A 1/4" FOR 18" AT THE MID HEIGHT OF THE NOZZLE.



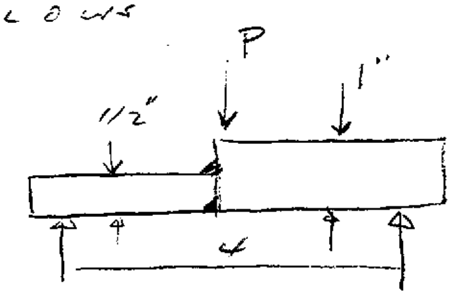
MAKE IT CONTINUOUS FOR THIS LENGTH

$$\tau = \frac{2344}{.707(.25)} = 13.3 \text{ KSI} \geq 11.2 \text{ KSI}$$

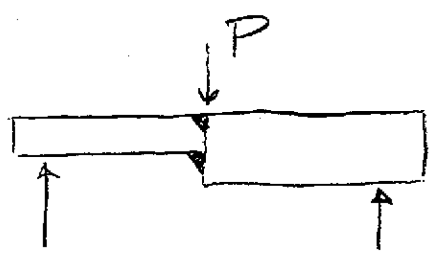
THE INTEGRITY OF THE 1/4 PAR PEN WELD COMBINED WITH THE 3/16 FILLET WELD WAS VERIFIED IN BEND TESTS OF SEVERAL SPECIMENS.

SEE THE ATTACHMENT FOR THE TEST SEQUENCE. THE TESTS WERE PERFORMED ON 8/9/96. THE OBJECTIVE OF THE TESTS WAS TO SHOW THAT THE CONNECTION DEVELOPS MOST OF THE MOMENT CAPACITY OF THE 1/2" SHELL. THIS IS IMPORTANT SINCE THE FILLET WELD STRENGTH IS CLOSE TO ITS ALLOWABLE.

TO DEVELOP BENDING MOMENT AT THE WELD, THE SPECIMENS WERE LOADED AS FOLLOWS



PARTIAL PEN IN TENSION



FILLET IN TENSION

THE LOAD P WAS APPLIED BY AN ENERPAC TEST MACHINE WITH A 2 IN Φ HYDRAULIC PISTION. THE PRESSURE WAS NEVER BELOW 1000 PSI FOR ANY TEST

$$P = pA = 1000\ \pi\ (1)^2$$

$$P_{MIN} = 3142 \text{ LB}$$

THE MIN MOMENT AT THE WELD IS

$$M = \frac{PL}{4}$$

$$= 3142 \left(\frac{4}{4}\right) = 3142 \text{ IN-LB}$$

FOR THE SA 240 TP 304/304L MATERIAL, THE MIN YIELD STRESS AT ROOM TEMP IS

S_y = 30 KSI AND THE

ULT STRENGTH IS

S_u = 75 KSI

THE YIELD MOMENT OF THE 1/2 IN SECTION IS

$$M_y = \frac{bt^2}{6} S_y$$

b = 1 IN FOR SPECIMENS

t = .5 IN

$$M_y = \frac{1(.5)^2}{6}(30000)$$

$$= 1250 \text{ IN-LB}$$

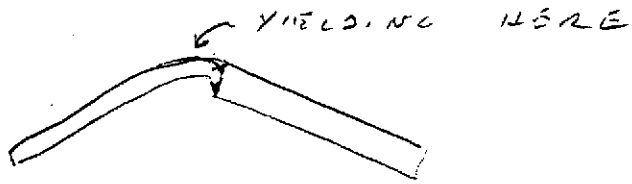
THE FULL PLASTIC MOMENT IS

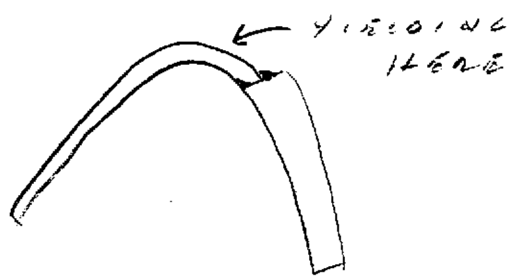
$$M_p = \frac{bt^2}{4} S_y$$

$$= 1875 \text{ IN-LB}$$

THEREFORE, THE WELDS DEVELOPED MOMENTS THAT ARE GREATER THAN THE MOMENT CAPACITY OF THE BASE METAL AND THERE WAS CONSIDERABLE STRAIN HARDENING OF THE BASE METAL.

THE DEFORMED SPECIMENS SHOWED YIELDING OF THE 1/2" SECTION





IT IS CONCLUDED THAT THE REVISED NOZZLE TO SHELL WELDED CONNECTION WILL DEVELOP FULL STRENGTH OF THE SHELL.

Attachment

PROCESS SYSTEMS INTERNATIONAL, INC.

LIGO PROJECT

Doc. No. V049-I-85

To: Phil Ferland

From: Ray Ciatto RDC

Subject: Welded Joints at Nozzle to Shell Connections

Date: August 2, 1996

A modified welded joint for the 60.5 in nozzle to shell connection has been designed for the BSC and HAM. The joint will consist of a partial penetration weld on the inside and an intermittent fillet weld on the outside as shown on the attached sketches which are included in the supporting calculation for the modified joint.

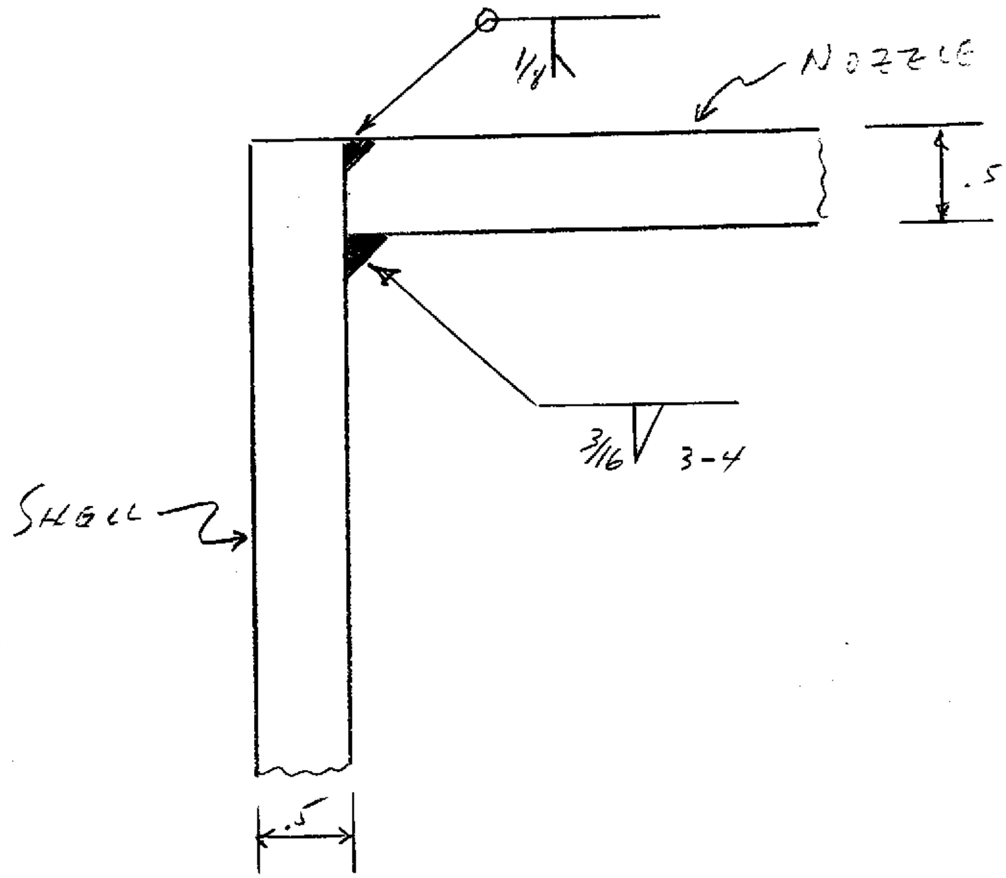
I request that bend tests of this weld configuration be performed; these are necessary to qualify the connection. The requirements for these bend tests are also attached. So that we may compute the maximum bending moment, we should note the maximum force applied by the test machine.

Please call if you have any questions on the weld tests.

cc: Rich Bagley, Dave Evers, Roberto Than, Dave McWilliams, Paul Hendry, Lynne Long/project file, Tom Starr, Stu Motew, Dick Curtis, Walt Bilynsky

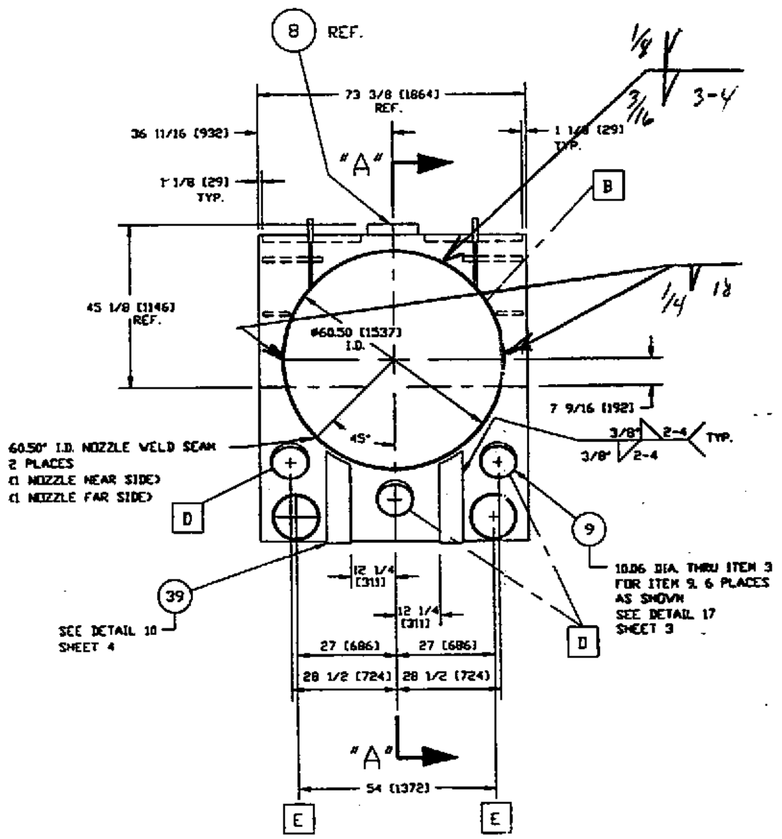
WELDS FOR 60.5" IN NOZZLE TO SHELL JOINTS IN BSCs AND HAMs.

BSC WELD



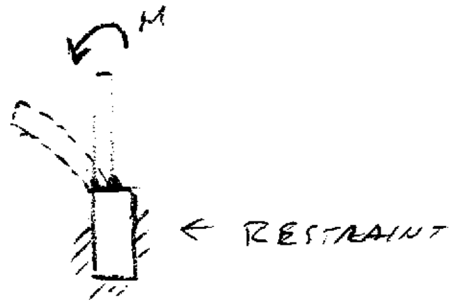
HAM WELD

SAME AS BSC WELD EXCEPT THAT FILLET WELD SHOULD BE 1/4 IN FOR AN 18" LENGTH AT MID HEIGHT OF NOZZLE.



QC

TEST A - FILLET WELD IN TENSION



3 TESTS

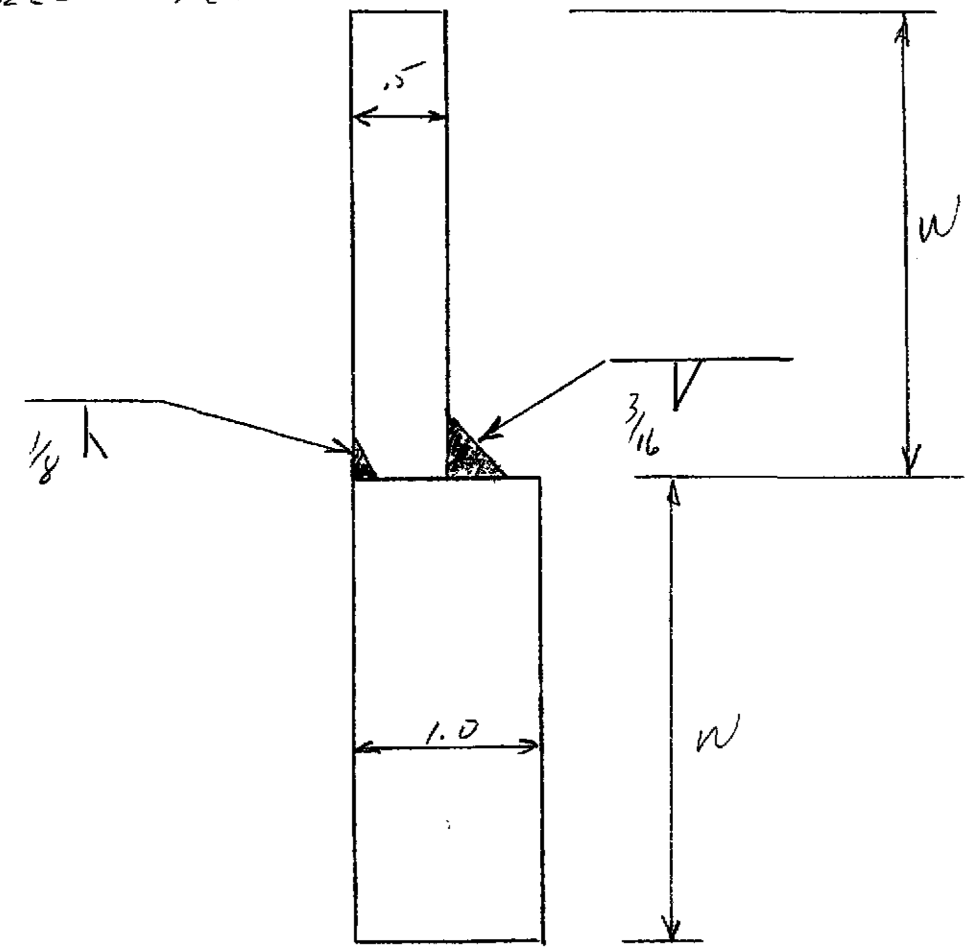
TEST B - PAR PEN WELD IN TENSION

3 TESTS

TESTS C AND D - SAME AS TESTS A & B BUT INCREASE PP WELD TO 3/16" AND INCREASE FILLET TO 1/4"

NOTE: AN ALTERNATE METHOD OF LOADING THE SPECIMENS TO OBTAIN THE MAXIMUM MOMENT AT THE WELD IS ACCEPTABLE.

WELD TEST



BASE METAL SA 240 304/304L

PLATE WIDTH, W, REQUIRED FOR TEST SHALL BE DETERMINED.

PLATES SHALL BE FLAT. AFTER WELDING CUT INTO COUPONS FOR BEND TESTS.

PERFORM 3 BEND TESTS THAT APPLY TENSILE STRESS TO PAR PEN WELD AND 3 TESTS THAT APPLY TENSILE STRESS TO FILLET WELDS.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-039 PAGE 1 OF 19
REV.	DEO #	DATE	BY:	CHECK	TITLE: HAM Finite Element Analysis	
0	0128	11/29/4	KM	RDC		
					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.*

FILED:\F:\TEMPLATE\ENGFORMS\ENGCALC

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	$3S_m$ = 56.1 KSI
	P_L = 26.5 KSI	$1.5S_m$ = 28.0 KSI
	Bolt Force = 8683 lb	10,760 lb
2. Two Bellow Design		
	P_L+P_B+Q = 16.5 KSI	$3S_m$ = 56.1 KSI
	P_L = 15.8 KSI	$1.5S_M$ = 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 $P A_{nozzle}$

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 bundle. 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

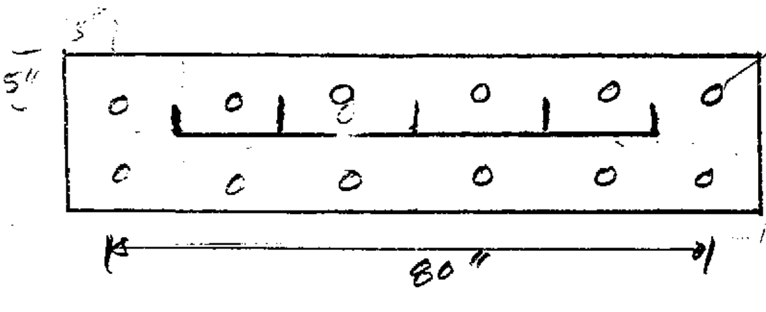
These stresses are discontinuity stresses and the maximimum allowable stress for combined bending and membrane are

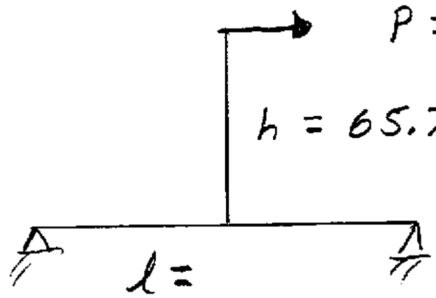
$P_L + P_b + Q = 28.6 < 3 S_m = 56.1$ KSI ok

For membrane alone

$P_L = 26.5$ KSI $< 1.5 S_m = 27.8$ KSI ok

The maximum anchor load due to the off balance load is calculated as follows





Assume only outer bolts take load

$$F_{bolt} = \frac{Ph}{l(2\text{ bolts})} = \frac{(21129^{\#})(65.75'')}{(80'')(2\text{ bolt})}$$

$$F_{bolt} = 8683^{\#}$$

For 3000 psi concrete, and a 1" Hilti adhesive anchor embedded 8 1/4" $F_{allowab} = 10960^{\#}$

$$F.S = \frac{10960}{8683} = 1.26 \quad \text{OK}$$

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.

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

2.3 SEISMIC

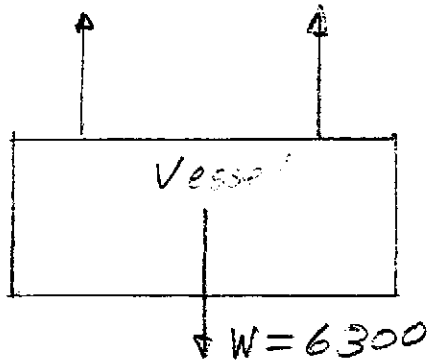
The seismic acceleration from (ASCE 7-9.5) are 0.05625 G in each direction. The weight of the HAM model is 6269#

$$F_{seismic} = (.05625)(6269) = 352^{\#}$$

This is a small force compared to the unbalance force due to the external pressure which is 42,258#. 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 vertical Force on lug 1575#

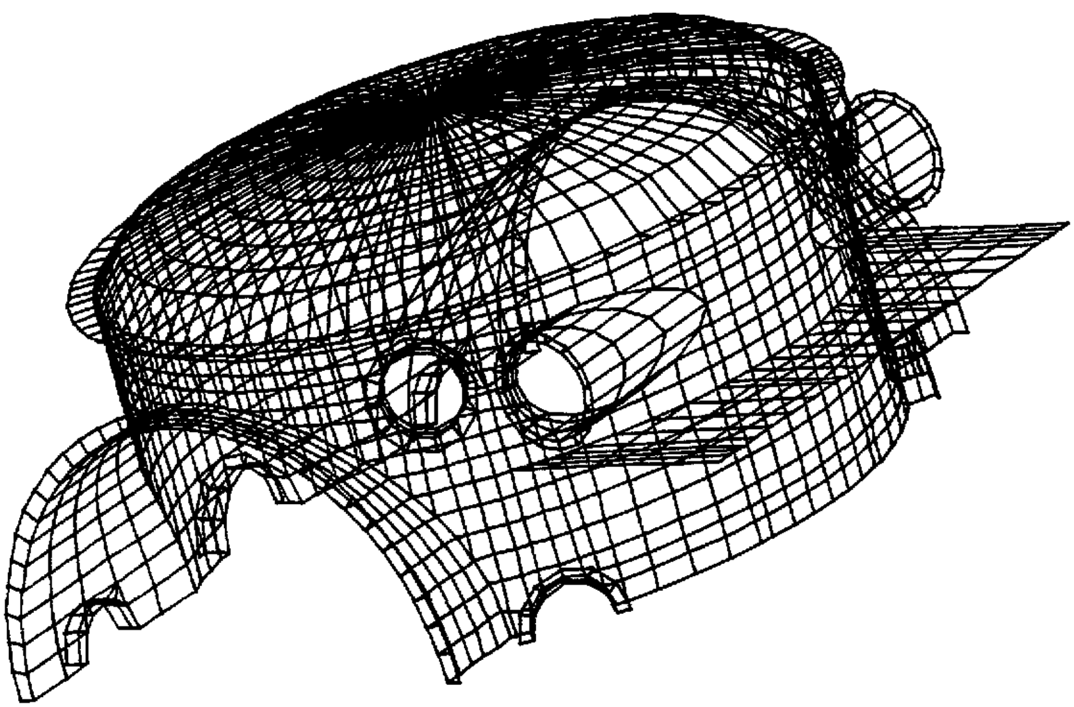


Fig 1 - FE Model

IMAGES-3D
Version 3.0
L Case 1
S= .300E+02

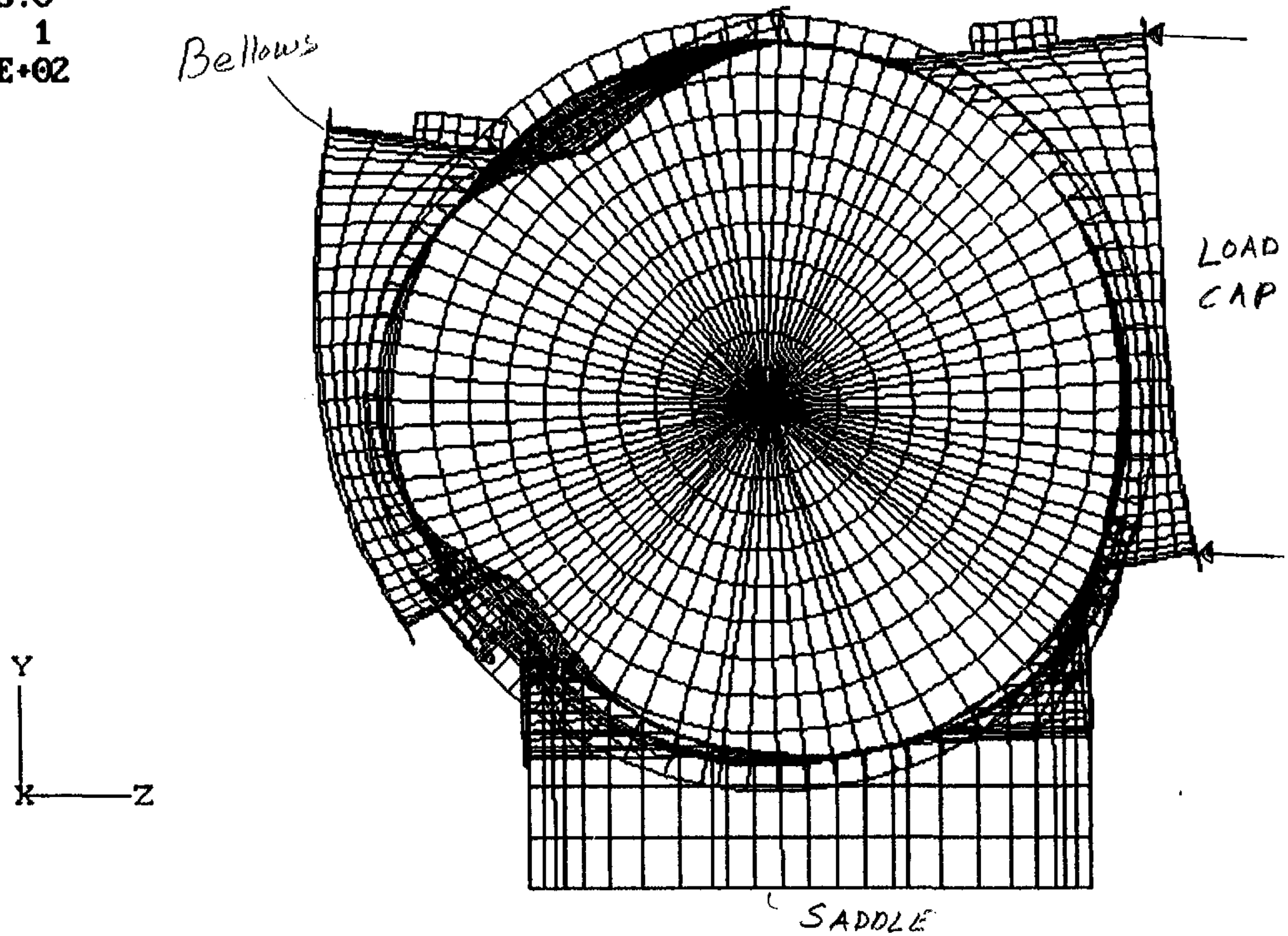
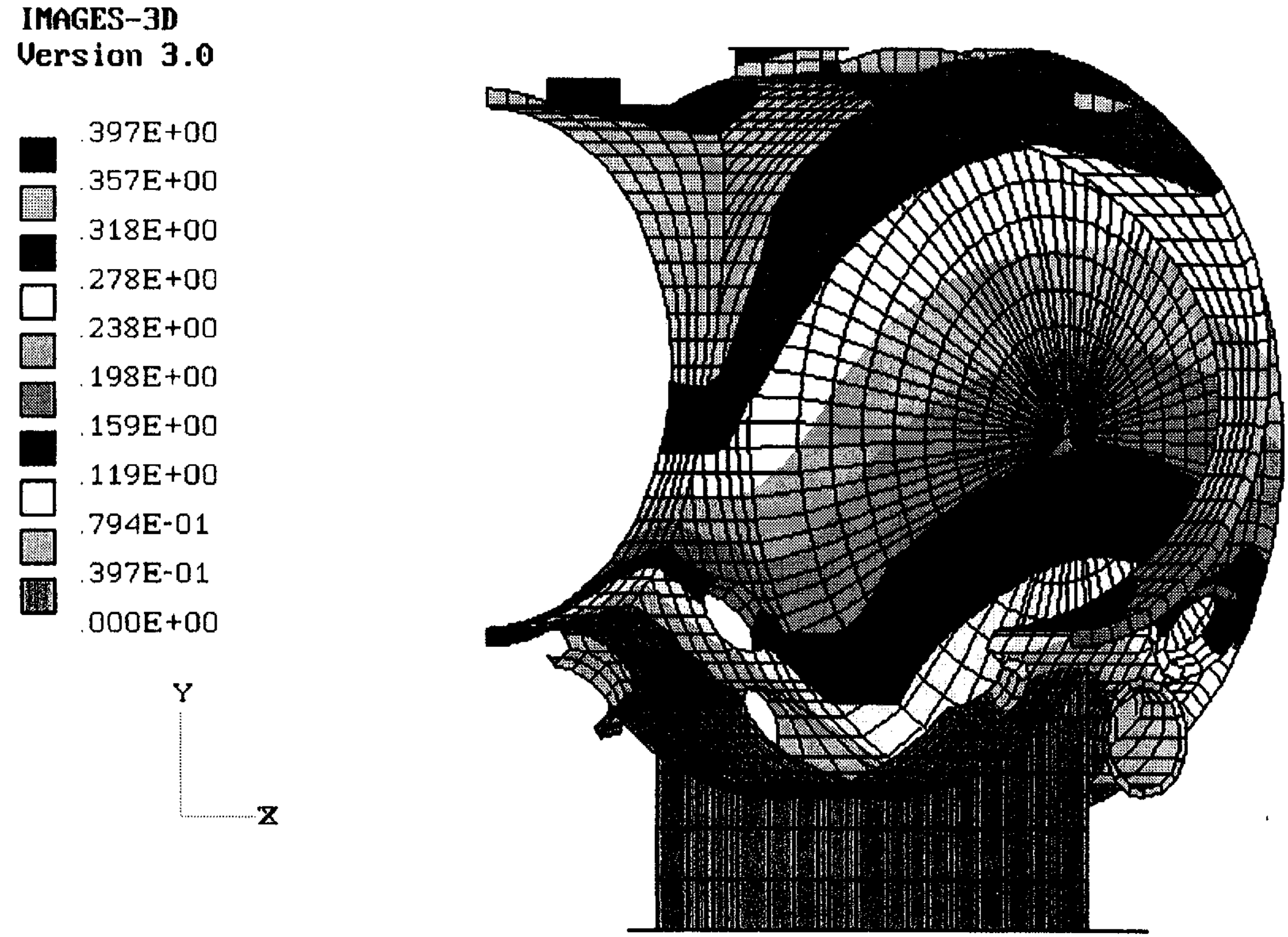


Fig 2 **Deflected Shape - Wireframe Plot**

12/20/95
9: 8:53



Load Case 1   Fig 3   Displacement Contour Plot DS   1/20/96 17:26:51

1- Bellows Model

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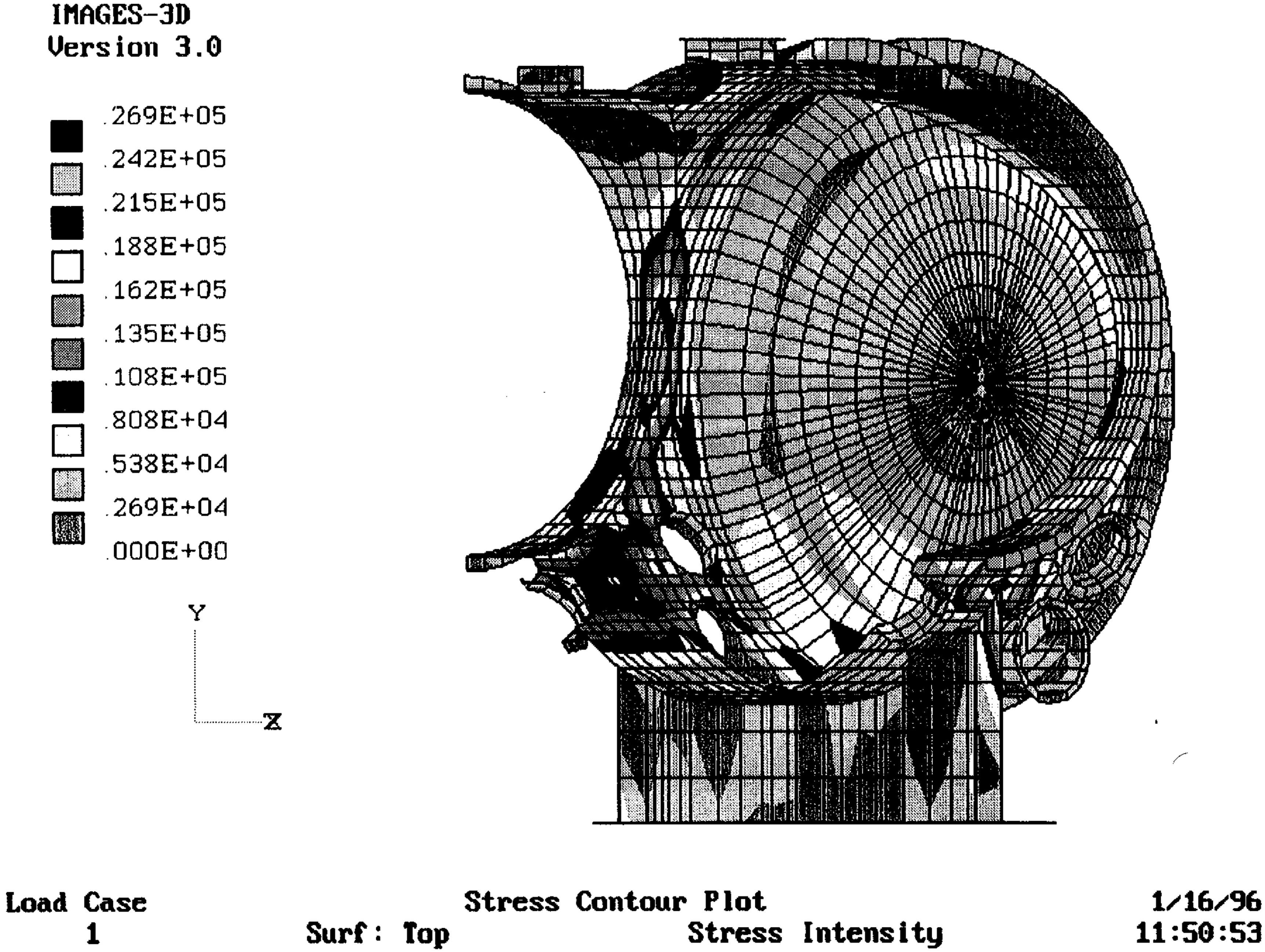
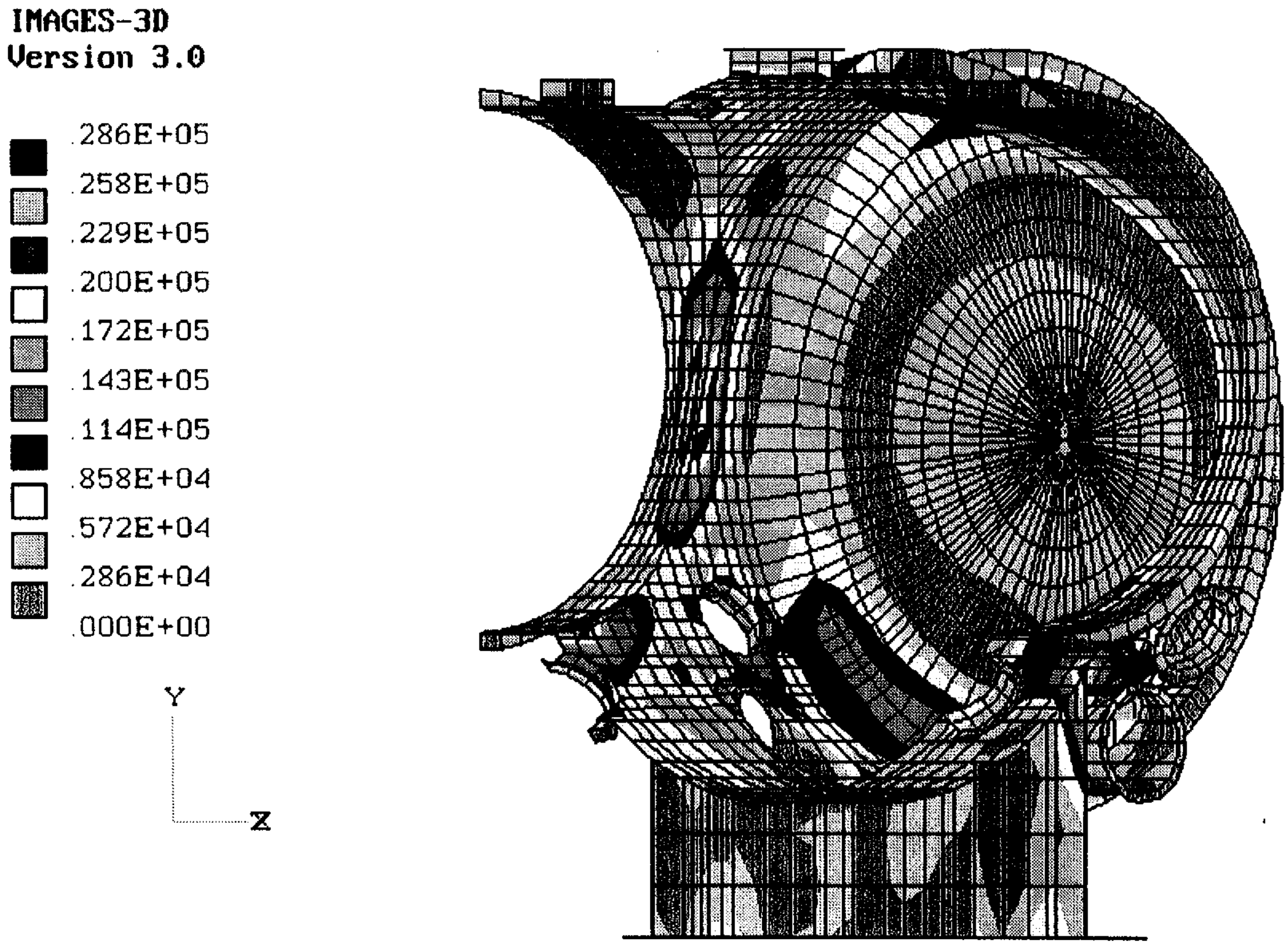


Fig 4 One Bellows Model



Load Case 1

Stress Contour Plot

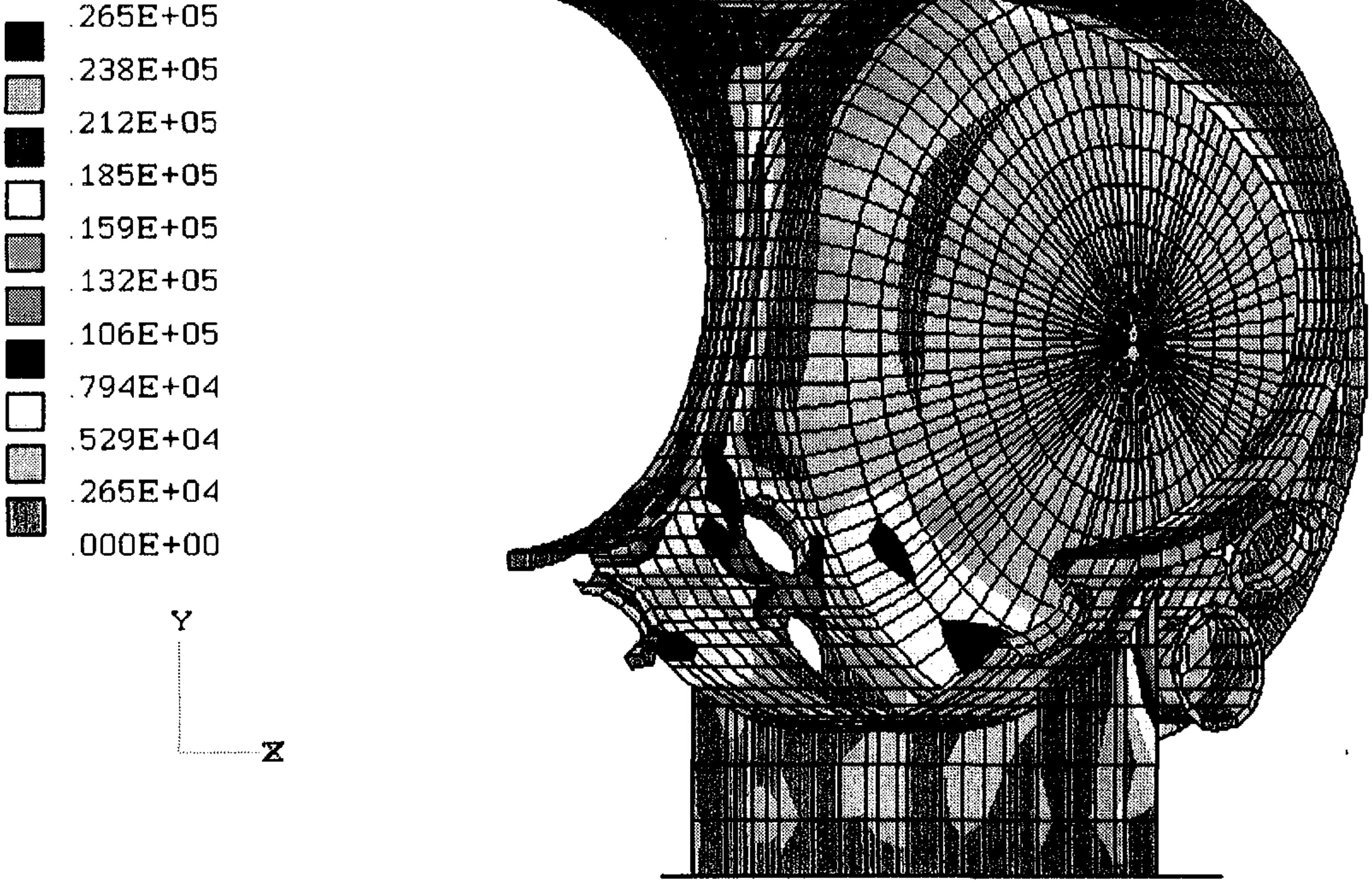
Surf: Bottom Stress Intensity

1/16/96
12:15: 4

Fig 5 One Bellows Model

6

IMAGES-3D
Version 3.0

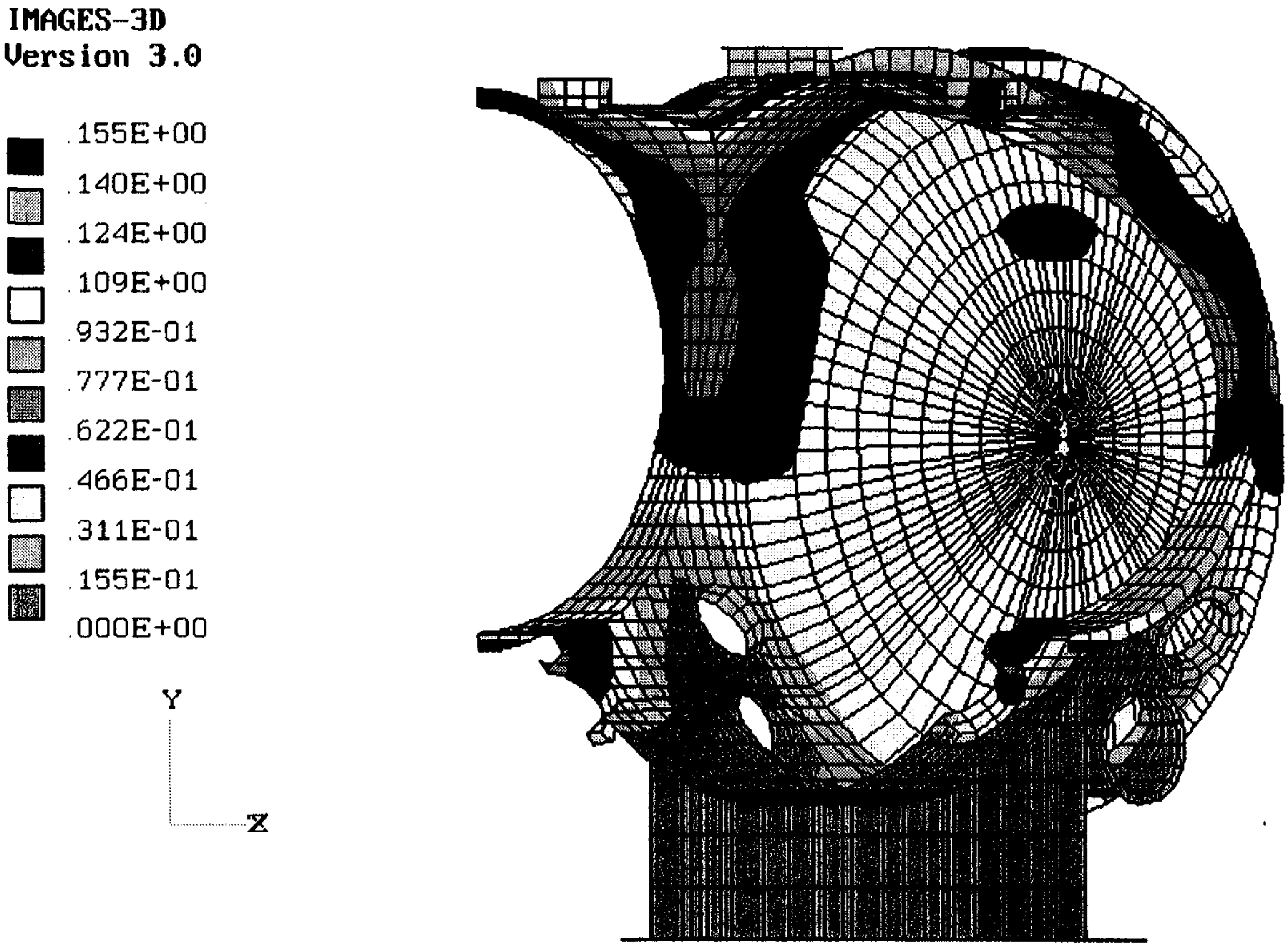


Load Case 1

Stress Contour Plot
Membrane Stress Intensity

1/16/96
12: 5:39

Fig 6 One Bellows Model

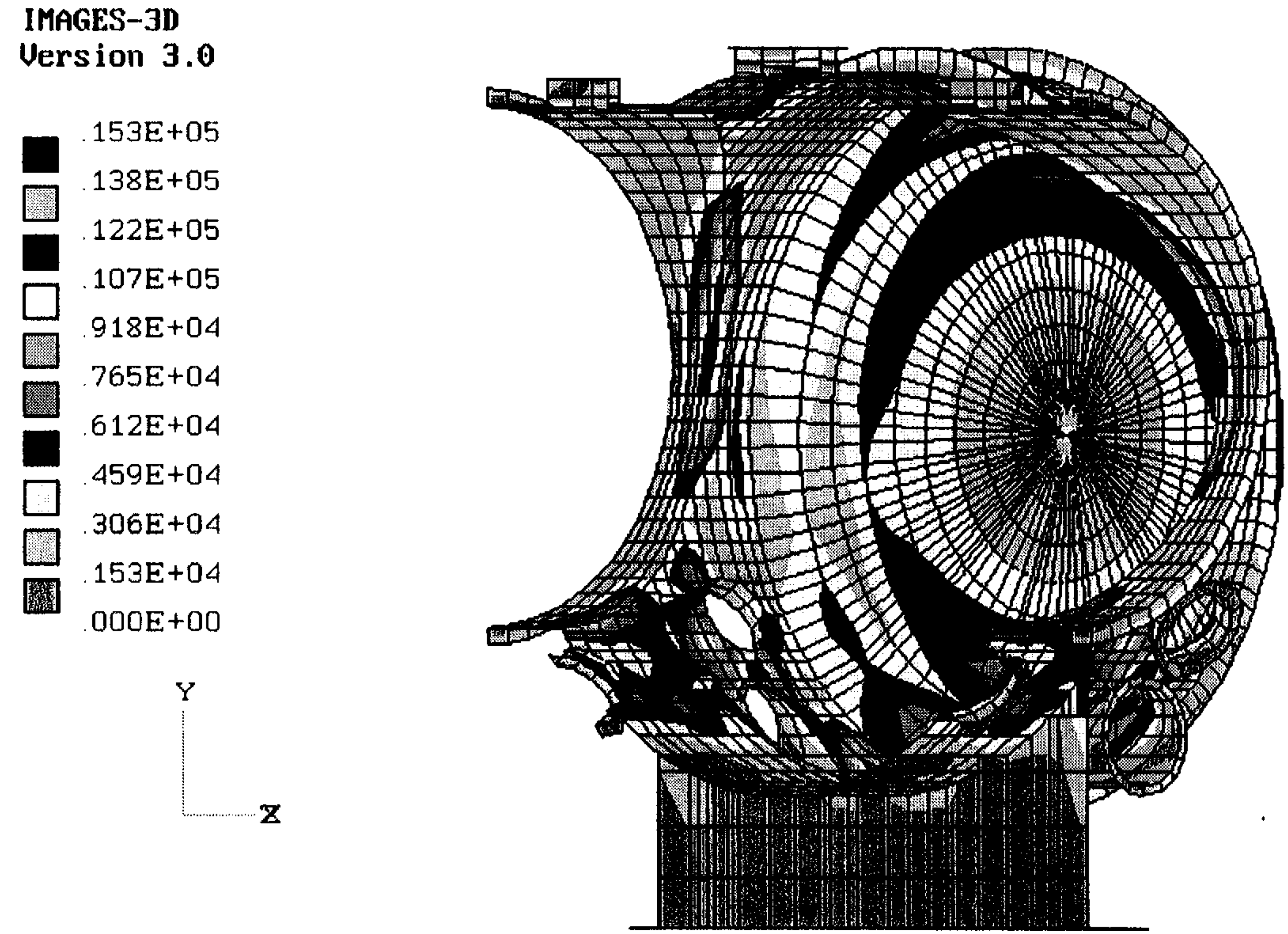


Load Case
2

Displacement Contour Plot
DS

1/20/96
17:34:46

Fig 7 Two Bellows Model



Load Case 2

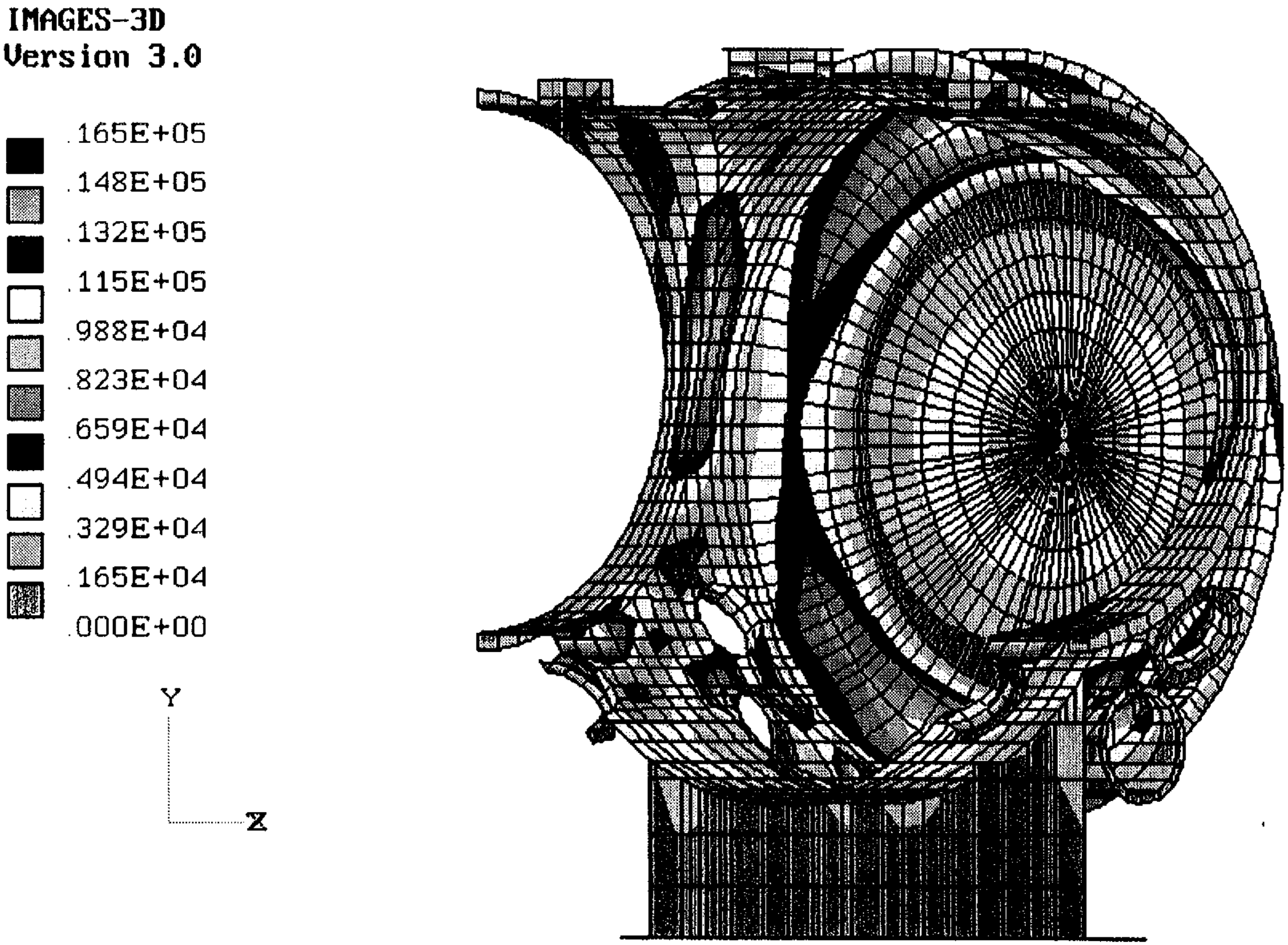
Stress Contour Plot

Surf: Top

Stress Intensity

1/16/96
12:53:58

Fig 8 Two Bellows Model

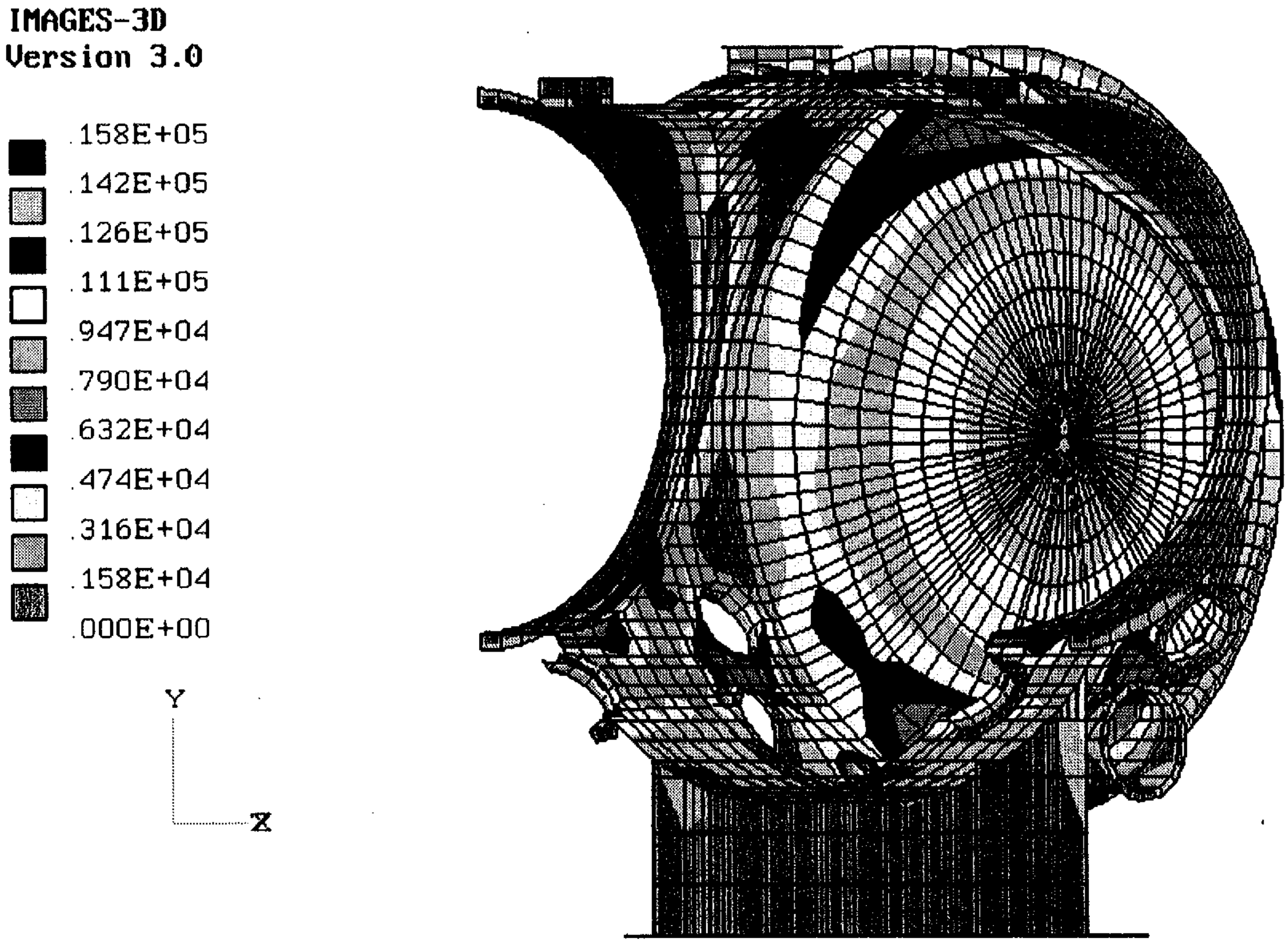


Load Case
2

Stress Contour Plot
Surf: Bottom Stress Intensity

1/16/96
13:19:28

Fig 9 Two Bellows Model



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)

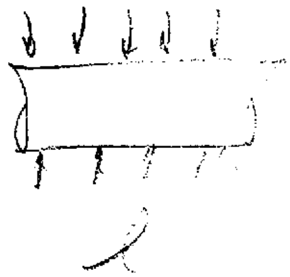
CONCLUSIONS: The minimum factor of safety against elastic buckling for vacuum loading is 3.58.

NOTES:

COMPUTER FILE: HAMLD.INP

1.0 Hand Analysis

Assumptions: (1) Extra material at 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

$$P_{cr} = .807 \frac{E t^2}{l r} \sqrt[4]{\frac{1}{(1-\nu)^2} \frac{t^2}{r^2}}$$

$t = 0.5"$ $l = 74.8$ $\nu = 0.3$

$r = 42.25"$ $E = 29(10^6)$ psi

$$P_{cr} = 216.1 \text{ psi}$$

$$F.S = \frac{P_{cr}}{14.7} = \underline{\underline{14.7}}$$

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

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 reinforced arms 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 support

i. Two configurations are model. A two bellows config and a one bellow

2.1 Results

Model	Factor Safety
2 − bellows	11.8
1 − bellow "seal"	11.9

3.01 Alternative Model

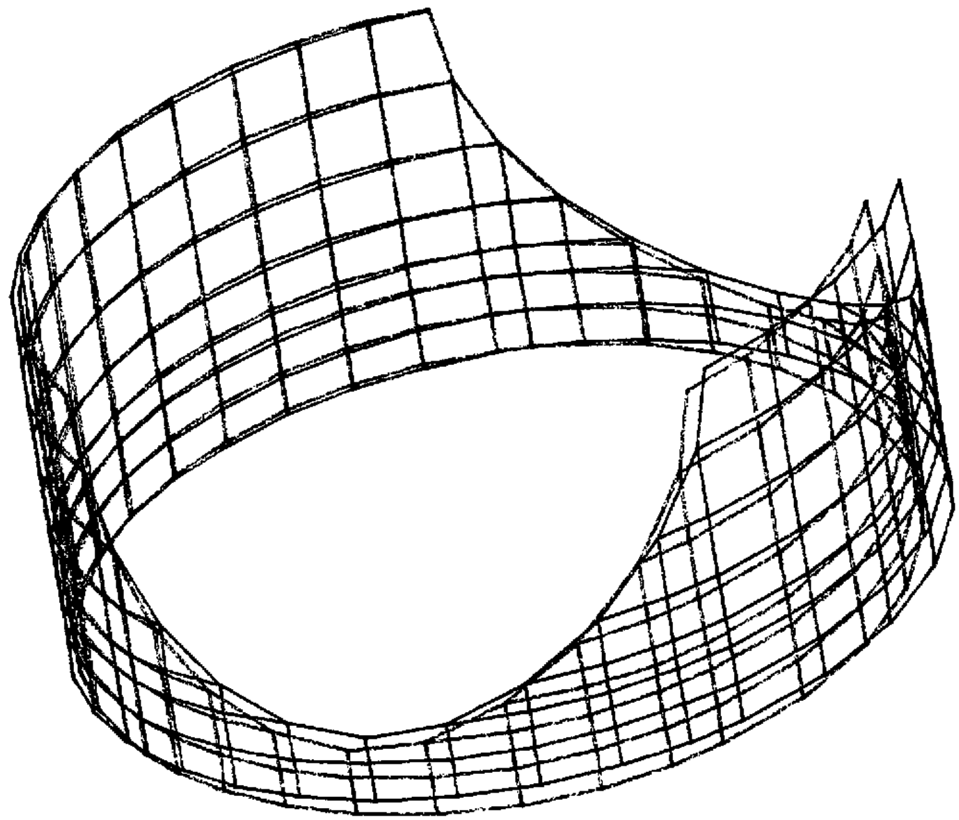
Analysis on Static Stress model. (See Fig 2)
reference Calc. V049-1-039

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

5 2/12/95 MAX-DEF. = 1.00000000



HAM 1/1 SYMM MODEL

BUCKLING SOLUTION

MODAL DEFOR. SUBCASE 2 MODE 5 EIGENV. 11.76245 MASS MODEL

Fig 1 - 5n e bellows buckling Shape

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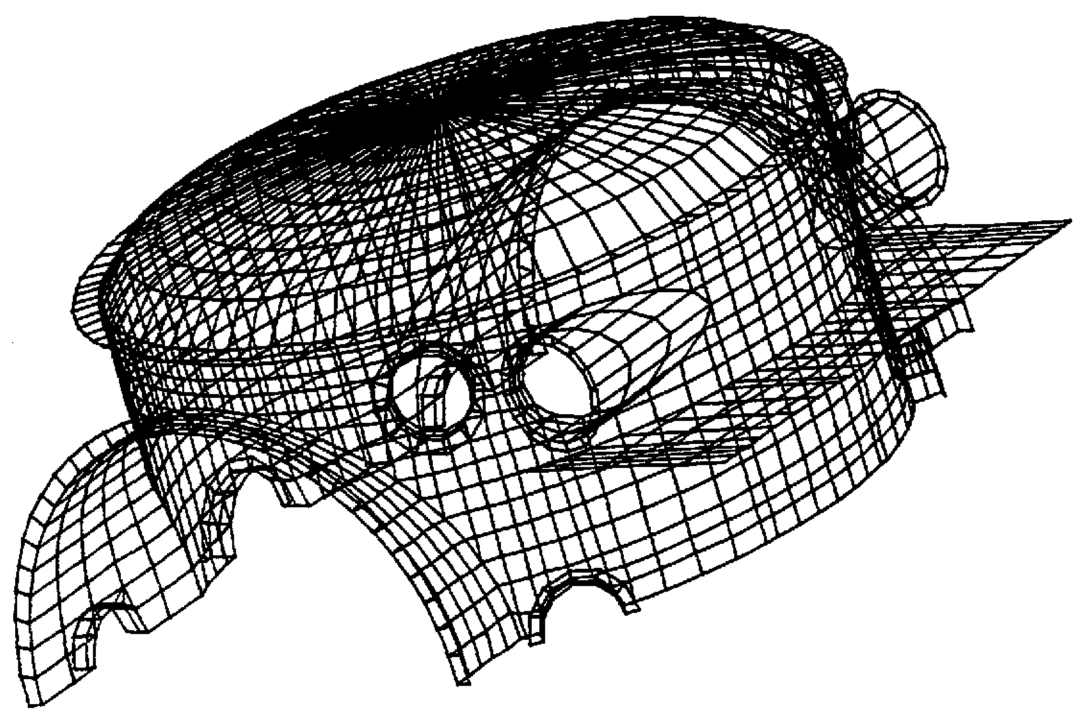


Fig. 2 – F.E. Model

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-073
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 29
0	0024	4-1-96	AGR	ROC	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

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

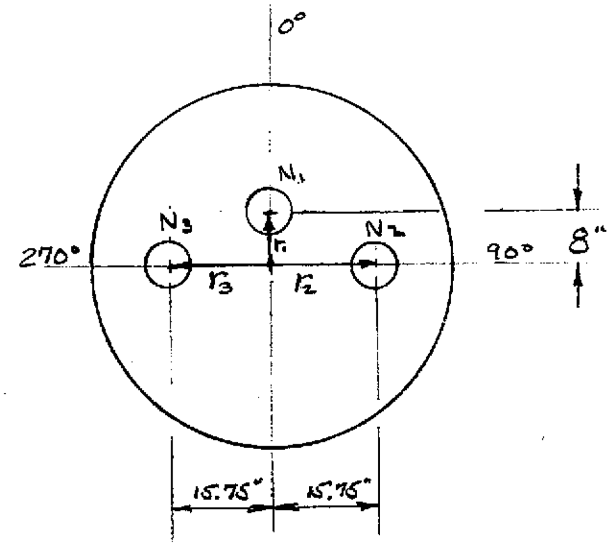
1.- SCOPE:

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

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.

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

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

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
```

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)

```
        = 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
```

```
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
```

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:

(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
```

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
```

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)

```
        = 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					ENGINEERING CALCULATIONS	NO: V049-1-074
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 38
0	0029	3-30-96	AGR	RDC	TITLE: 84" F+D HEAD/NOZZLE DESIGN FOR HAM	
					By: AAT ROUSSOPOULOS	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" SEE DOC. NO. V049-1-066

REFERENCES: DOC. NO. V049-PL-73
DWG. NO. V049-4-040
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

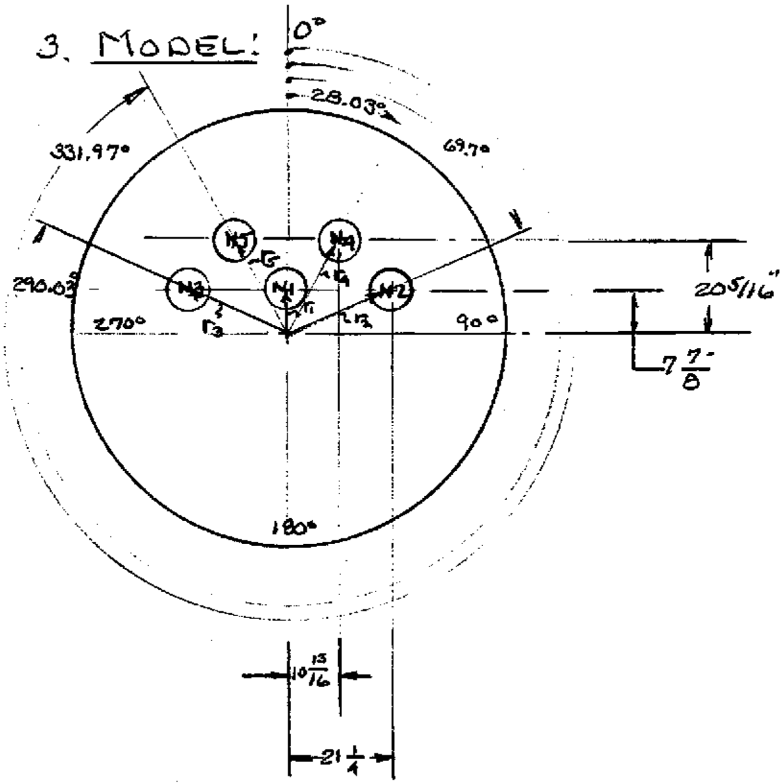
1.- SCOPE:

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: $\Theta_3 = 290.7°$	$r_3 = 22.66"$
N4: $\Theta_4 = 28.03°$	$r_4 = 23.01"$
N5: $\Theta_5 = 331.97°$	$r_5 = 23.01"$

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

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	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

Weight (lbs) Contributed by Vessel Elements

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

3.12.1996

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
```

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)
```

= 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:

(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
```

3.12.1996

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)

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)

```
        = 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             Do/t = 8/0.01987 = 402.617
  From table G:                        A = 0.000401
  From table HA-3:                     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.

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

```
Theta1 = ArcCos((Lo + Rn)/Rm)
       = ArcCos((22.66 + 3.75)/84.35505)
       = 71.75536

Theta2 = ArcCos((Lo - Rn)/Rm)
       = ArcCos((22.66 - 3.75)/84.35505)
       = 77.04626

d = 2*Rm*Sin((Theta2 - Theta1)/2)
  = 2*84.35505*Sin((77.04626 - 71.75536)/2)
  = 7.787 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
```

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
```

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)

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)

= 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

```
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
```

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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)
```

```
= 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
```

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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)

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)

= 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

```
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
REV.	DEO #	DATE	BY:	CHECK		PAGE 1 OF 14
0	0024	3-27-96	GARENA	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

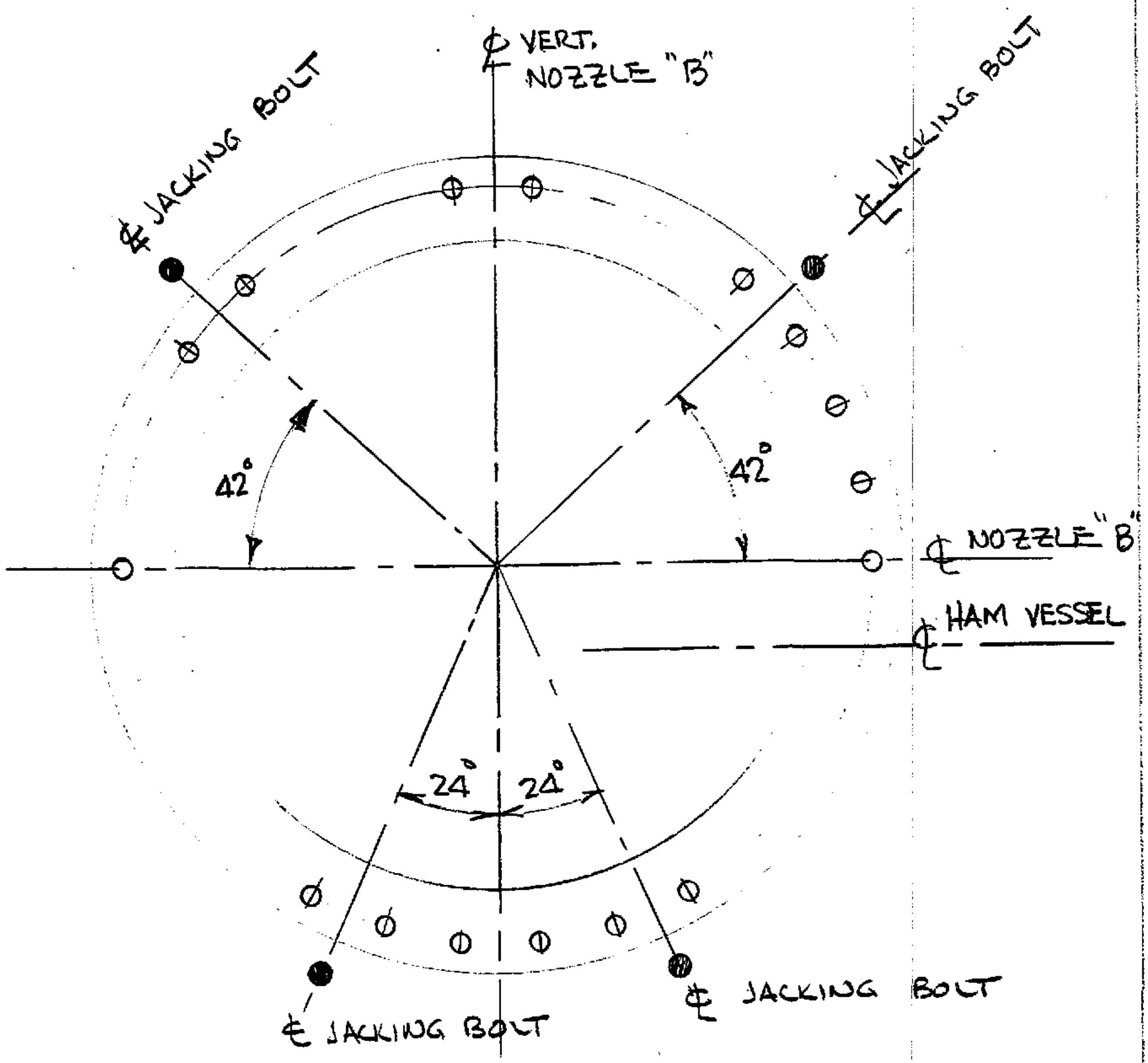
1. ASME Boiler and Pressure Vessel Code, Section VIII, Division I, 1995 Edition
2. Roark & Young, Formulas for Stress and Strain, Fifth Edition
3. Blodgett, Design of Welded Structures
4. LIGO Vacuum Equipment Structural Design Criteria, Doc. No. V049-1-066
5. AISC Steel Construction Manual

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 (CHYSPAN BELLOWS)

USE 7500 #/IN FOR DESIGN

WORST CONDITION FOR 3 BOLTS LOADED

(4^{TH} BOLT ASSUMED INEFFECTIVE)

$2F_1 + F_2 = 15000^{\#}$

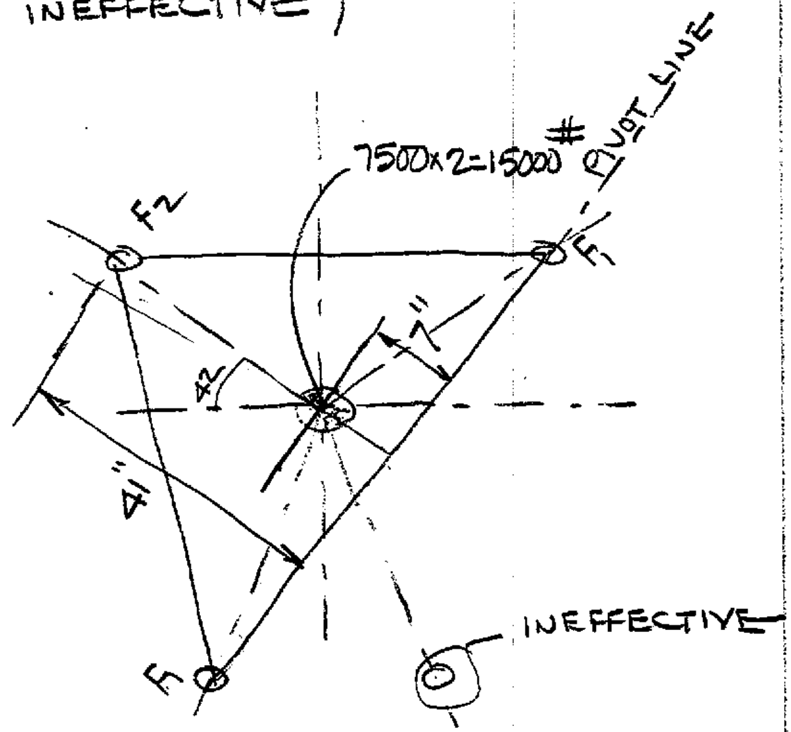
$2F_1 \times 7 + 41 F_2 = 0$

$F_2 = \frac{14}{41} F_1 = .341 F1$

$2F_1 + .341 F_1 = 15000$

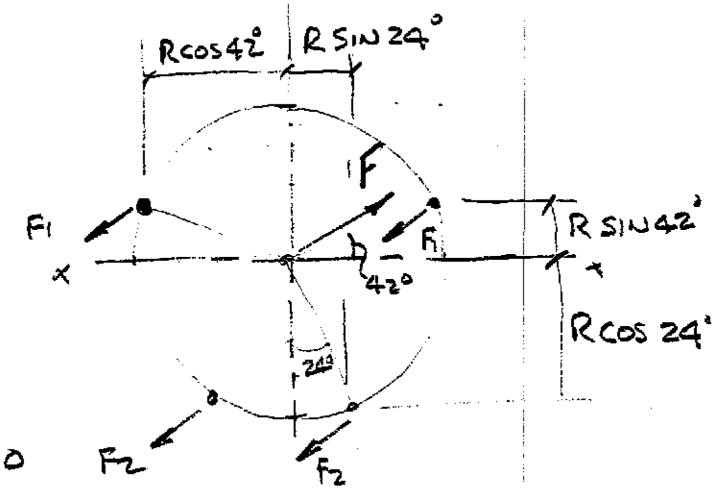
$F_1 = \underline{6406}^{\#}$

$F_2 = 2188^{\#}$



USE **6400#/ROD** FOR DESIGN LOAD

DESIGN LOADS (VACUUM TEST)



$F = \frac{\pi \overline{D_m}^2}{4} \times 15\,PSIA$

$= \frac{\pi}{4}\, \overline{62.5}^2 \times 15 = \underline{46020}^{\#}$

$\cancel{2}F_1 + \cancel{2}F_2 = \cancel{46020}$ 23010

$\Sigma M_x = 0$

$\cancel{2}F_1 \cancel{R}\sin 42 - \cancel{2}F_2 \cancel{R}\cos 24 = 0$

$F_1 \sin 42 = F_2 \cos 24$

$F_2 = F_1 \frac{\sin 42}{\cos 24} \Rightarrow F_1 + F_1 \frac{\sin 42}{\cos 24} = 23010$

$F_1 = \frac{23010}{\left(1 + \frac{\sin 42}{\cos 24}\right)} = \underline{13282}^{\#}$

$F_2 = \underline{9728}^{\#}$

ΣM_y

$F_1 \cos 42 - F2 \sin 24 = 0$

$F_1 + F_1 \frac{\cos 42}{\sin 24} = 23010 \Rightarrow F_1 = \frac{23010}{\left(1 + \frac{\cos 42}{\sin 24}\right)} = \underline{8139}^{\#}$

$F_2 = \underline{14871}^{\#}$

$F_{1\,AVE} = \frac{13282 + 8139}{2} = 10710^{\#}$

$F_{2\,AVE} = \frac{14871 + 9728}{2} = 12300^{\#}$

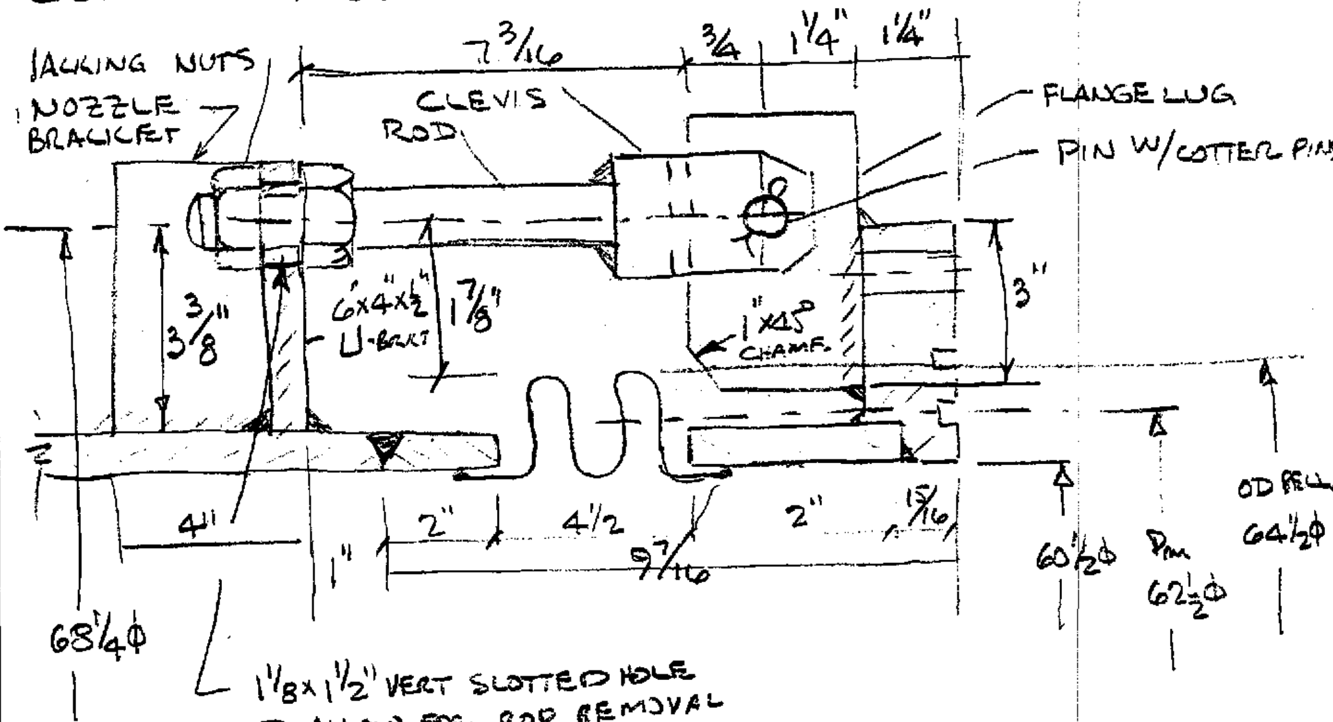
$\Sigma F_z \Rightarrow 2(10710) + 2(12300) \overset{?}{=} 46020$

46020 $\overset{\checkmark}{=}$ 46020 OK

DESIGN LOAD = 12,300# / ROD

— VACUUM TEST LOAD GOVERNS —

COMPONENT DESIGN



ROD (IN COMPRESSION) 1" Φ x 8 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

$f_c = \frac{P}{A} = \frac{12.3}{\frac{\pi(.838)^2}{4}} = 22.3 \text{ KSI} < 39.71 \text{ KSI}$ OK

PIN (DOUBLE SHEAR) A320 B8 $F_y = 100$ KSI

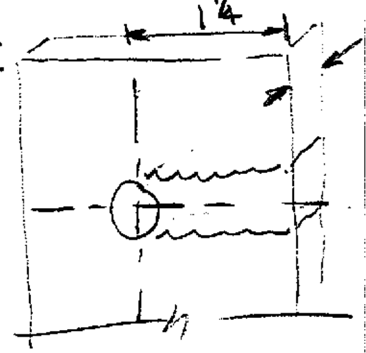
$F_s = .4 F_y = 40$ KSI

$A_{REQ'D} = \frac{P}{2 F_s} = \frac{12300}{80{,}000} = .15 \text{ IN}^2 \Rightarrow D_{REQ} = .44"$

USE 1/2" Φ 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

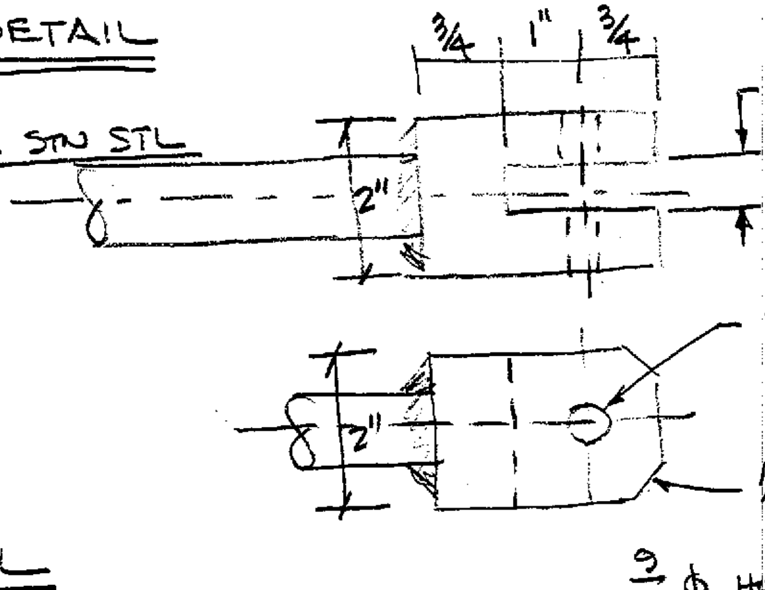
$$f_B = \frac{P}{A_{PROJ}} = \frac{12300}{(.5)(.5)} = 49200 > 40500 \quad NG$$

@ 5/8 R $$f_B = \frac{12300}{.625 \times .5} = 39360 < 40500 \quad OK$$

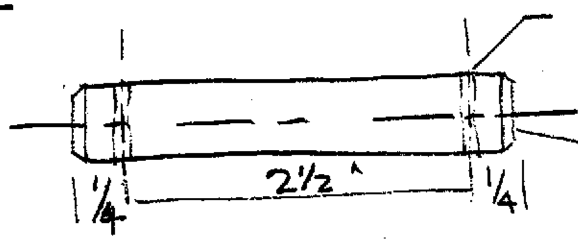
USE t = 5/8"

CLEVIS DETAIL

A240 TP304 STN STL



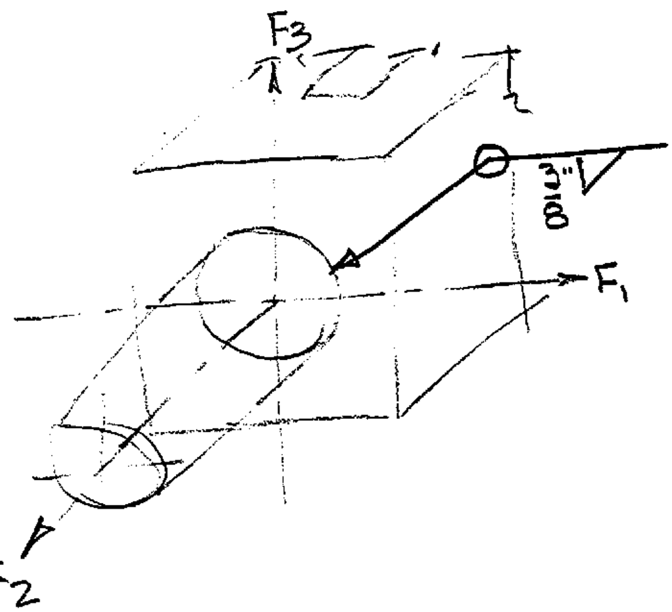
PIN DETAIL



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)

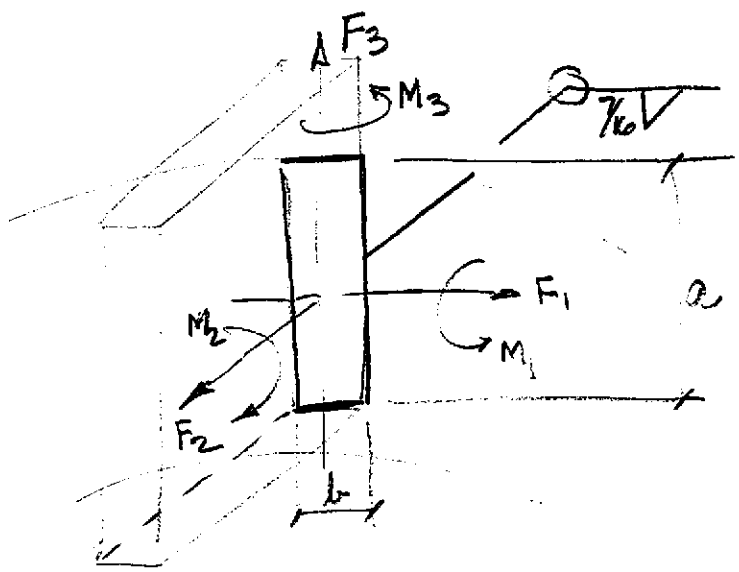
w
0.367

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°>ß<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

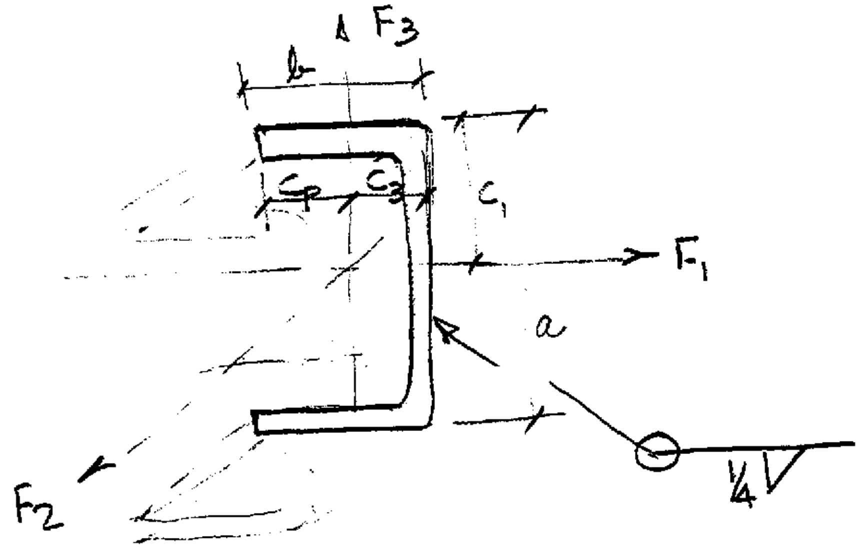
REQUIRED FILLET WELD SIZE (INCHES)

w
0.431 USE 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

REQUIRED 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 Fig.	Value read	beta	Circumferential (hoop) stress psi							
			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 circ. stress*			-6467	-6467	4651	4651	-908	-908	-908	-908

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.

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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