BELOW-THE-HOOK LIFTING DEVICE
Engineering Note Cover Page

Lifting Device Numbers: 106

FNAL Site No.:________ (if applicable) Div. Specific No.: ________ (if applicable) Asset No. ________ (if applicable)

ASME B30.20 Group: (check one)
- ˇ Group I Structural and Mechanical Lifting Devices
- ˇ Group II Vacuum Lifting Devices
- ˇ Group III Magnets, Close Proximity Operated
- ˇ Group IV Magnets, Remote Operated

Device Name or Description: COT "H" FRAME

Device was: (check all applicable)
- ˇ Purchased from a Commercial Lifting Device Manufacturer
  mfg. name: ________
- ˇ Designed and Built at Fermilab
- ˇ Designed by Fermilab and Built by a Vendor
  Assy drawing number: ________
- ˇ Provided by a User or Other Laboratory
- ˇ Other. Describe:________

Engineering Note Prepared by: RAFAEL SILVA Date : 05/26/99

Engineering Note Reviewed by: BOB WOODS [signature] Date: 5/28/99

Lifting Device Data:

Capacity: 6,300 lb

Fixture Weight: 2 x 600 lb

Service: ˇ normal ˇ heavy ˇ severe (refer to B30.20 for definitions)

Duty Cycle: N/A 8, 16 or 24 hour rating (applicable to groups III, and IV)

Inspections Frequency: BEFORE USE

Rated Load Test by FNAL (if applicable): Date : 05/26/99 Load: ~8,500 lb

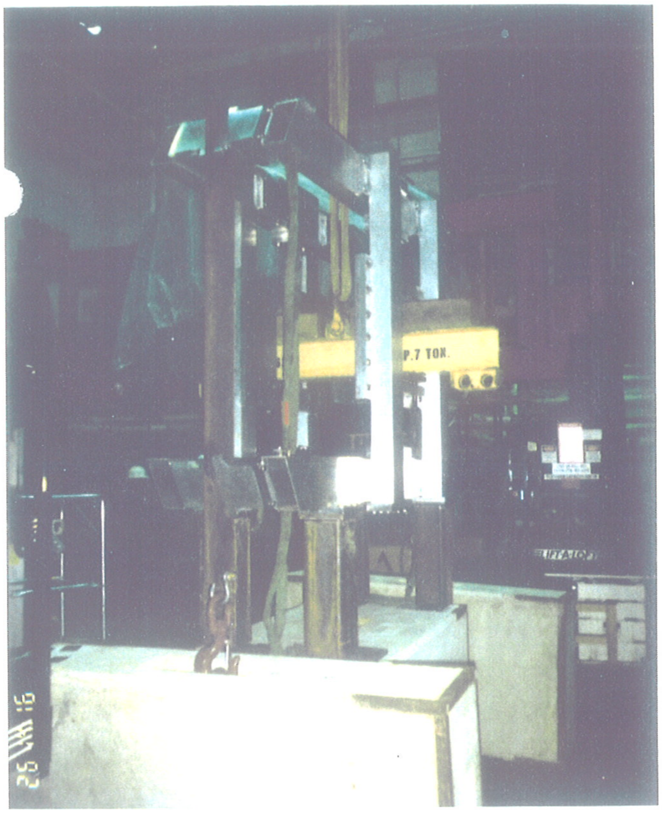
ˇ Check if Load Test was by Vendor and attach the certificate.

Satisfactory Load Test Witnessed by: RAFAEL SILVA

Signature (of Load Test Witness): [signature]

Notes or Special Information:

1. TO BE USED ONLY WITH CTC OR COT
2. ESTIMATED WEIGHTS: CTC + COT = 6,300 lb
   COT = 3,600 lb
   "H" FRAME = 600 lb EACH
   LOAD TEST REQ. = [(6300 + 2 x 600) x 1.25] - (2 x 600) = 8,175 lb
3. TEST LOAD = 2x CONCRETE BLOCKS + 2x STEEL BARS + SPREADER BAR = (2x4,050) + (2 x 140) + 160 = 8,540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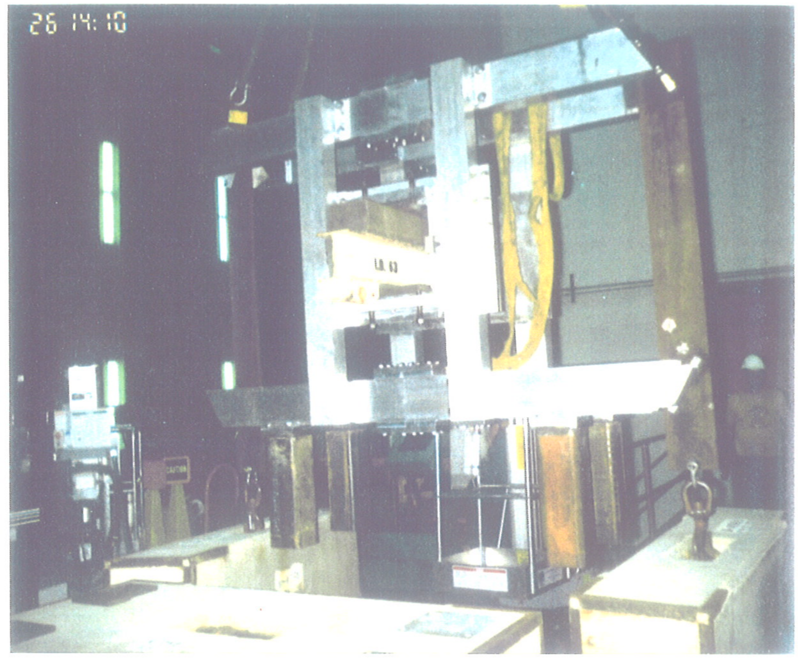
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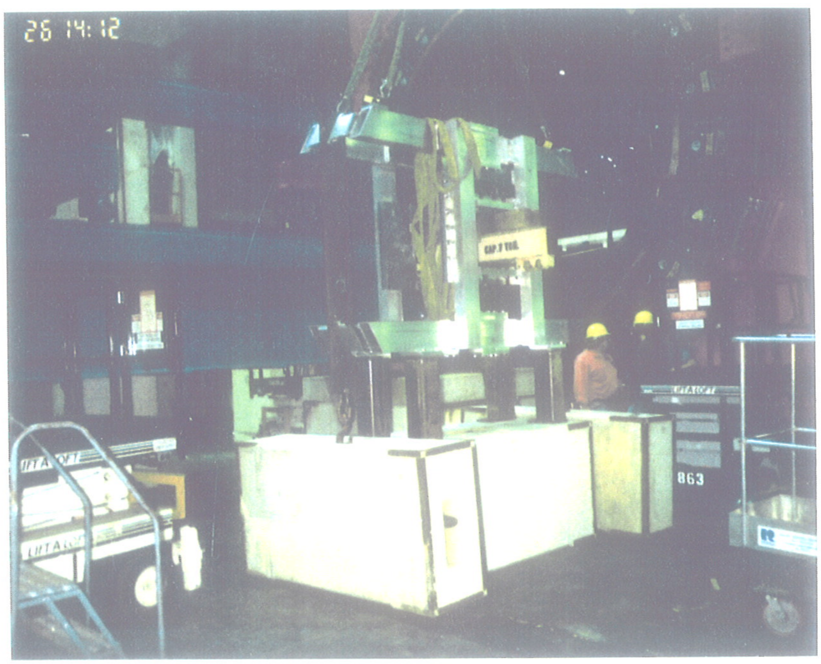
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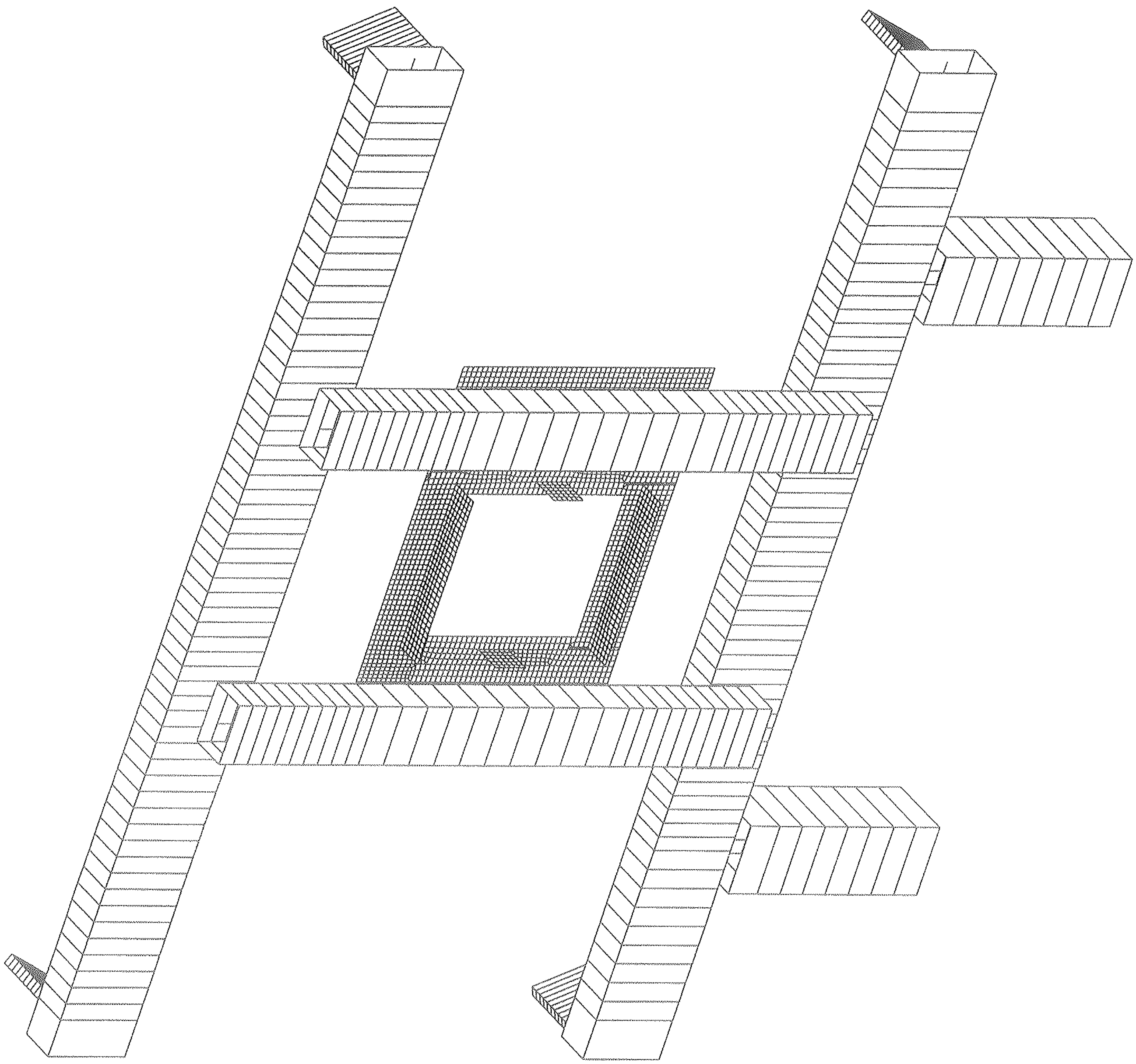
Fermilab	Particle Physics Division Engineering and Technical Teams

Engineering note number		Date	05/26/99

Experiment	**CDF / COT**
Project	COT "H" Frame
Author(s)	Rafael Silva (FNAL)
Reviewer(s)	Bob Woods (FNAL)
Abstract	Structural analysis of the COT "H" Frame.

Summary



1. Overview

The CDF/COT detector is going to replace the CDF/CTC detector. The 3D drawing of the COT assembly and its main structural components - end plates, outer cylinder, and inner cylinder - can be seen in the COT Gallows Engineering Note.

The COT was assembled vertically in the structure called COT Gallows. After that, the detector was removed from the COT Gallows, turned 90 degrees with the Flipping fixture, and placed on the COT Rotation fixture for the insertion of the sense and field planes.

When the sense and field planes are installed and the detector is ready to be moved from the Rotation fixture at IB4 to the pit at B0, it is necessary:

- to lift the detector from the Rotation fixture and load it onto a truck;
- to transport it from IB4 to B0;
- to unload it from the truck;
- to install it into the cryostat using the Insertion Beam Cart.

The H Frame is the structure designed to be attached to the COT to provide lifting points. In conjunction with a spreader bar, it provides for the use of crane. It also allows the use of the Insertion Beam Cart for installation into the cryostat. It is also necessary for the reverse operation of removing the CTC, which requires it to be compatible with both COT and CTC use.

The design started as a carbon copy of the CTC H Frame and it was revised and updated. Whenever applicable, the manufacturing of this fixture is required to meet or exceed the specifications and recommendations for fabrication of the AA and AWS D1.2 codes.

Note: Throughout this note, except for the list of drawings, drawing numbers are referred only by their 3 last digits. For instance, drawing number 2563.251-MD-339652 is referred as dwg#652.

2. Structural Analysis

The COT H Frame was design to meet the ANSI/ASME B30.20-1985 "Bellow-the-Hook Lifting Devices" standard and 1987 addenda. The two basic design recommendations of this standard and its addenda are:

- Minimum design factor of 3 over the rated load, based on yield strength (20-1.22, p.21) and
- Load test with 125% of the rated load (20-1.4.2, p.22).

2.1 Allowable stresses

The general design criteria adopted were the following:

<u>Hand Calculations:</u>

- *Stresses*:
  individual stress components should be in accordance with the most stringent of the following codes:
  - AA or AISC/ASD (whichever applicable)
  - ASME B30.20
- *Stability (if compressive forces are present)*:
  - AA or AISC/ASD (whichever applicable)

Finite Element Analysis:

- *Stresses*:
  Maximum Von Mises stresses (nodal averaging) < 1/3 of the Yield Strength (based on ASME B30.20).
- *Stability (if compressive forces are present)*:
  Buckling Load Factor (linear buckling) > 5 (see references below).

Published safety factors for buckling vary according to the application. A safety factor greater than 5 is comfortably above what is recommended by some very accepted references as, for instance, the ASME pressure vessel code (see sec. II, appendix 3, item 3-600 (c) (1), p.705). It addresses axial compression of thin cylinders which is experimentally known to be one of the cases that most diverges from buckling theories. Another example is the Aluminum Association standard (see tb. 3.3.3, p.17), which covers aluminum structures.

Some cases, individually and specifically analyzed, may require different safety factors. The most severe loading condition happens during operation. The general philosophy in this note is to verify the stresses in the most critical members and connections only.

2.1. Loads and Analysis

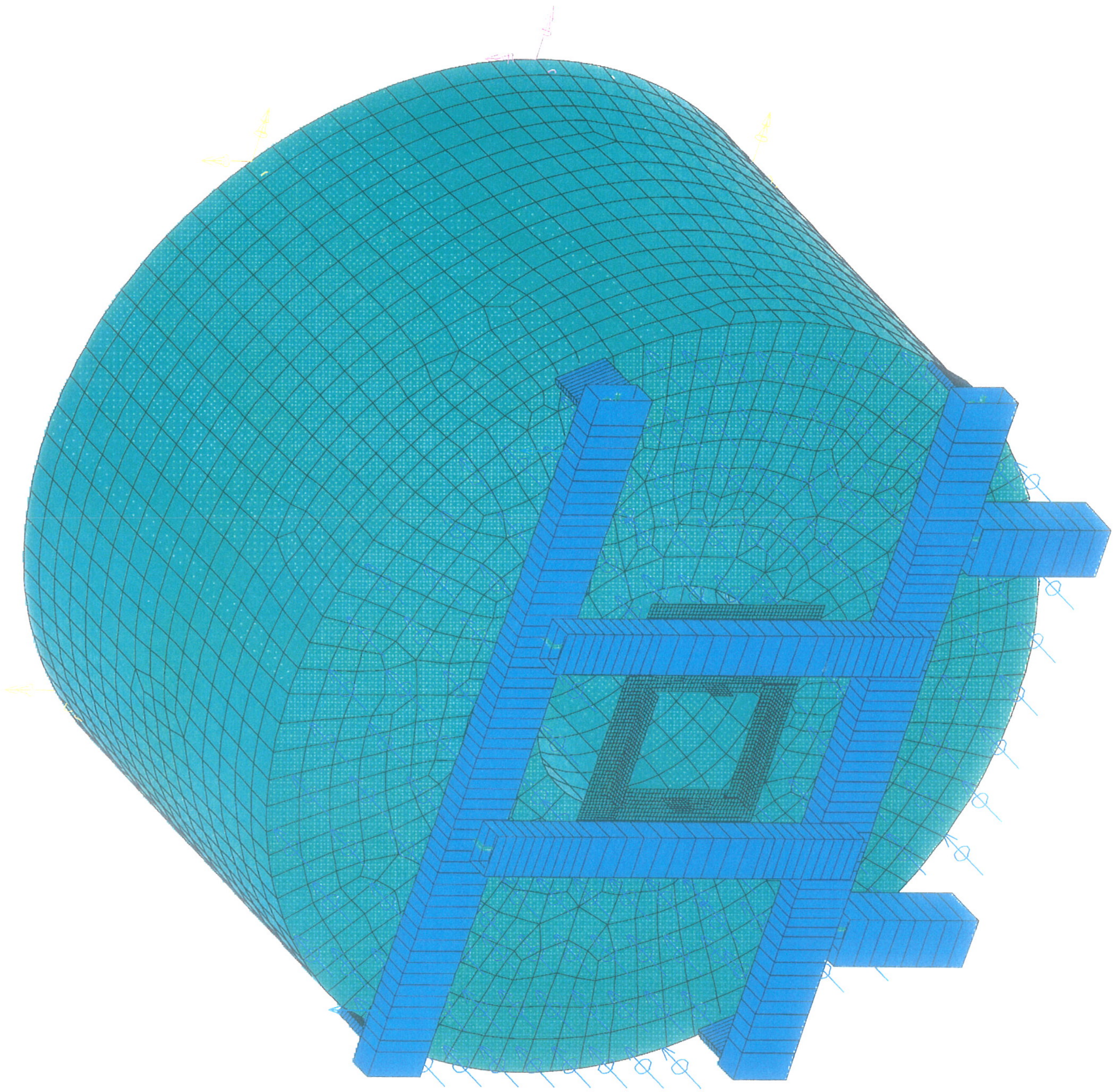
The CTC is heavier than the COT, and it also has the added weight of the CDT . The following are the estimated weight of the parts:

W_{COT} = 3,600 lb
W_{CTC} = 4,100 lb
W_{CDT} = 2,200 lb
W_{HFrame} = 600 lb (each)
$W_{Total\ (2*H+CTC+CDT)}$ = 7,500 lb

The following analysis is conservative and simplified. It is assumed that the structure has to withstand W_{Total}= 7,500 lb. The next page contains a table summarizing all cases analyzed, and the calculations follow.

Summary Of Analysis Of Members Under Maximum Load				Min.	Min.		Stresses			
				Yield	Tensile		ASME Allow.	Max.	Maximum / Allowable	SF
Item	Drawing	Part	Material	Fy (ksi)	Fu (ksi)	Condition	(ksi)	(ksi)	ASME	(i.r.t. Fy)
a	dwg#657	Center plate	6061-T651 plate	35.0	42.0	Von Mises (FEA)	11.7	5.8	***50%***	6.0
b	dwg#033	Vertical tube	6063-T52 tube	16.0	22.0	Von Mises (FEA)	5.3	3.9	***73%***	4.1
c	dwg#653&654	Upper horizontal tube	6063-T52 tube	16.0	22.0	Von Mises (FEA)	5.3	3.8	***71%***	4.2
d	dwg#655&656	Lower horizontal tube	6063-T52 tube	16.0	22.0	Von Mises (FEA)	5.3	3.8	***71%***	4.2
e	dwg#661	Lifting arm	6061-T651 plate	35.0	42.0	Von Mises (FEA)	11.7	3.1	***27%***	11.3
f	dwg#659&660	Temporary foot	A500B tubing	46.0	58.0	Von Mises (FEA)	15.3	0.2	***1%***	230.0

MEMBERS SUMMARY TABLE



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F.E.A. of the COT H Frame - Assembly

1. Model

When in use, the H Frames are attached to either the CTC or the COT. Modeling this attachment as rigid would probably yield reasonable results but would disregard the flexibility of the detectors. Replacing the detectors with loads at the arms would not add the rigidity of the detectors, severely amplifying the effects of that load. To analyze the H Frame accurately, the model should include the COT or CTC. A model of the COT existed already so it was just a question of adding it to the H Frame model. For a brief description of the COT/CTC models see annex.

A model of the H Frame attached to the COT was analyzed to observe the effect of this load and support condition on the COT. The most severe load for the H Frame is with the CTC, which has heavier end plates and the added weight of the CDT. The analysis was done modeling only one half of the H Frame + CTC and symmetry boundary conditions were applied.

2. Parameters used

- Program: SDRC I-DEAS Master Series v. 4.0 / Simulation.

- Analysis: Linear Statics

- Geometry, elements and properties:

CTC End Plate with electronics

E	$= 6x10^4$ psi	density	$= 2.409x10^{-4}$ lbf.sec^2/in^4	OD	= 107.670 in
ν	= 0.30	thickness	= 2.000 in	ID	= 31.843 in

Element: Shell, Parabolic, average mesh size: 4 in.

Outer Cylinder with CDT

E	$= 1x10^7$ psi	density	$= 8.679x10^{-4}$ lbf.sec^2/in^4	φ	= 107.670 in
ν	= 0.33	thickness	= .250 in		

Element: Shell, Parabolic, average mesh size: 4 in.

Inner Cylinder

E = 8.6×10^6 psi density = 2.150×10^{-4} lbf.sec^2/in^4 ϕ = 31.843 in

ν = 0.30 thickness = .097 in

Element: Shell, Parabolic, average mesh size: 4 in.

Center Plate

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4 thickness = 1.000 in

Element: Shell, Parabolic, mapped mesh.

Side lugs

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4 thickness = 1.500 in

Element: Shell, Parabolic, average mesh size: in.

Top and Bottom bars

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4 thickness = 1.875 in

Element: Shell, Parabolic, average mesh size: in.

Lifting Arm

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4

Element: Beam, Linear (7x6.38x1).

Horizontal tubing

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4

Element: Beam, Linear (8x4x¼).

Vertical tubing

E = 1×10^7 psi ν = 0.33 density = 2.539×10^{-4} lbf.sec^2/in^4

Element: Beam, Linear (6x4x¼).

Temporary Foot

E = 3×10^7 psi ν = 0.29 density = 7.3174×10^{-4} lbf.sec^2/in^4

Element: Beam, Linear (7x7x 3/8).

The connections between shell elements and beam elements were made by rigid elements.

3. Cases

- Boundary and loading conditions:

Case	restrains					loading [2]
	half of CTC	temporary foot	center plate		lifting points	lifting points
			horizontal bars	vertical bars		
1	symmetry [1]	-	Y	X	-	-
2	symmetry [1]	Y	-	-	-	-
3	symmetry [1]	-	-	-	Y	2050 lb in X

Notes: [1] symmetry = RX fixed, RY fixed, Z fixed and X free, Y free, RZ free.
[2] loading in addition to own weight, applied to each indicated point.

4. Results

The maximum (Von Mises) stress and safety factors are indicated in the table bellow. The minimum safety factor in relation to yield strength is 4.1.

	8 x 4 (horiz)		6 x 4 (vert)		center plate		lifting arm		temp. foot	
Aluminum alloy	6063-T52		6063-T52		6061-T651		6061-T651		A500B steel	
σy (ksi)	16.0		16.0		35.0		35.0		46.0	
AA allowable(ksi)	*6.5*		*6.5*		*16.0*		*16.0*		*27.1* (AISC)	
AA Table	*3.3.28*		*3.3.28*		*3.3.27*		*3.3.27*		*Chapter E*	
AA Spec. No. [3]	*14*		*14*		*4*		*4*		*E2-1*	
Case [1, 2]	σ	SF	σ	SF	σ	SF	σ	SF	σ	SF
1	**3.8**	**4.2**	**3.9**	**4.1**	**5.8**	**6.0**	**3.1**	**11.3**	0.01	9200.0
2	2.8	5.7	2.9	5.5	3.2	10.9	2.9	12.1	**0.2**	**230.0**
3	2.8	5.7	2.0	8.0	3.4	10.3	3.5	10.0	0.01	9200.0
Notes:	[1] σ = Maximum Von Mises, ksi.									
	[2] SF = ratio between σ and σy.									
	[3] Allowable for aluminum parts within 1.0 in. of a weld.									

As far as buckling, for all practical purposes, the AA allowable compressive stresses are higher than the allowable from ASME[1]. The maximum compressive stresses are equal or smaller than the Von Mises stresses as shown above.

Ang Lee performed buckling analyses in ANSYS as a cross check for the worst case scenario-case 1, and found no buckling. See results attached.

Hence, the H Frame members are *OK.*

[1] The ASME allowable for 6063-T5 is 5.3 ksi . For the 6x4 or 8x4 tubes, the allowable compressive stress from AA Tb. 3.3.28, Spec. No. 14, only gets that low for lengths in the order of 250 yards! Note that, for rectangular tubes, S/I=2/d. Also, the AISC recommends K.l/r < 200 and, with K=1, l < 322 in for the 6 x 4 anyway.

Allowable Stresses - Compression

AISC / ASD, 9th ed., p.5-42, sect. E2., allowable stresses:

Member: 7x3x3/8 structural tubing

K: Table C-C2.1, p.5-135:

$K := 1$ (conservative)

Mechanical properties of material (ksi):

$Fy := 46$ $\qquad E := 29000$

Unbraced length of column (in):

$l := 22.09$

Governing radius of gyration (in):

$r := 2.68$

Allowable stresses (ksi):

$$Cc := \sqrt{\frac{2\cdot\pi^2\cdot E}{Fy}} \qquad Cc = 111.6 \qquad \frac{K\cdot l}{r} = 8.2$$

$$Fa1 := \frac{\left[1 - \left[\frac{\left(\frac{K\cdot l}{r}\right)^2}{2\cdot Cc^2}\right]\right]\cdot Fy}{\frac{5}{3} + \frac{3\cdot\left(\frac{K\cdot l}{r}\right)}{8\cdot Cc} - \frac{\left(\frac{K\cdot l}{r}\right)^3}{8\cdot Cc^3}} \qquad Fa1 = 27.1 \qquad \text{(E2-1)}$$

$$Fa2 := \frac{12\cdot\pi^2\cdot E}{23\cdot\left(\frac{K\cdot l}{r}\right)^2} \qquad Fa2 = 2198.0 \qquad \text{(E2-2)}$$

$$Fa := \text{if}\left[\left[\left(\frac{K\cdot l}{r}\right) > Cc\right], Fa2, Fa1\right]$$

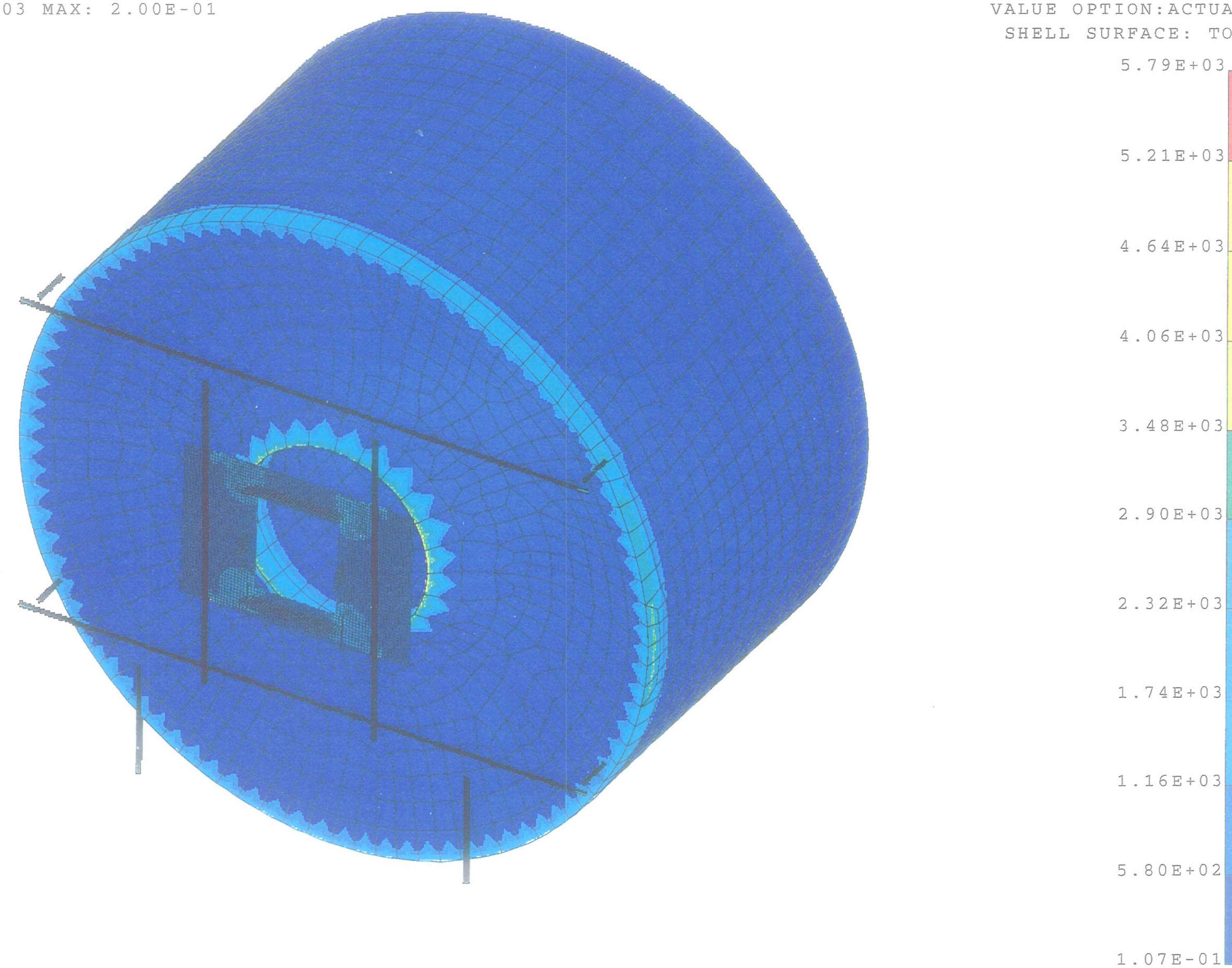
This means that if (K.l/r) > Cc, Fa = Fa2, otherwise Fa =Fa1.

Hence: $Fa = 27.1$

/cadwhs_local/server02/ms_rafael/H_frame_EN.mf1.Z

RESULTS: 3- B.C. 1,LOAD 1,STRESS_3
STRESS - VON MISES MIN: 1.07E-01 MAX: 5.79E+03
DEFORMATION: 1- B.C. 1,LOAD 1,DISPLACEMENT_1
DISPLACEMENT - MAG MIN: 1.81E-03 MAX: 2.00E-01
FRAME OF REF: PART

VALUE OPTION:ACTUAL
SHELL SURFACE: TOP



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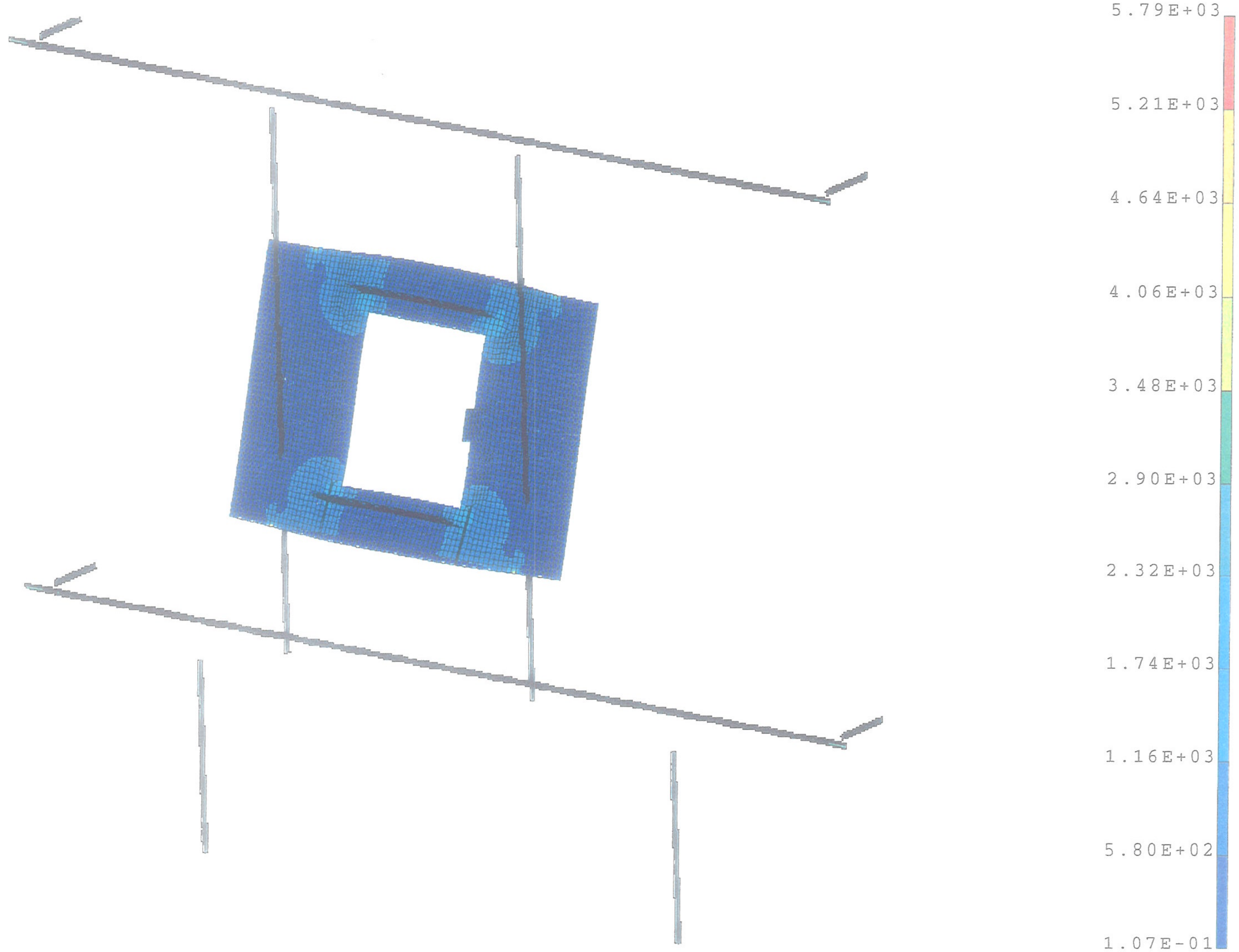
RESULTS: 3- B.C. 1,LOAD 1,STRESS_3
STRESS - VON MISES MIN: 1.07E-01 MAX: 5.79E+03
DEFORMATION: 1- B.C. 1,LOAD 1,DISPLACEMENT_1
DISPLACEMENT - MAG MIN: 1.81E-03 MAX: 2.52E-02
FRAME OF REF: PART

VALUE OPTION:ACTUAL
SHELL SURFACE: TOP



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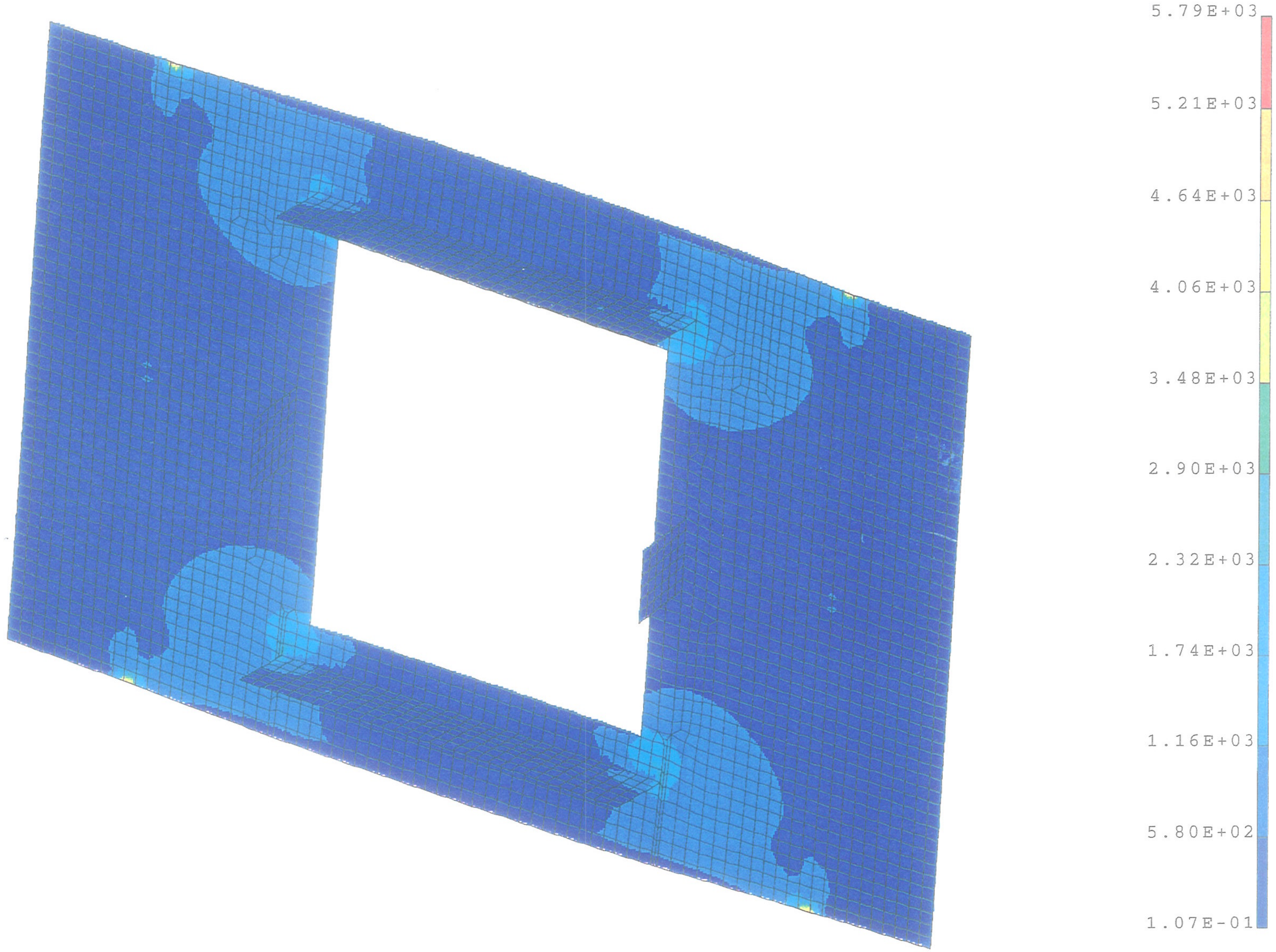
RESULTS: 3- B.C. 1,LOAD 1,STRESS_3
STRESS - VON MISES MIN: 1.07E-01 MAX: 5.79E+03
DEFORMATION: 1- B.C. 1,LOAD 1,DISPLACEMENT_1
DISPLACEMENT - MAG MIN: 1.81E-03 MAX: 2.52E-02
FRAME OF REF: PART

VALUE OPTION:ACTUAL
SHELL SURFACE: TOP



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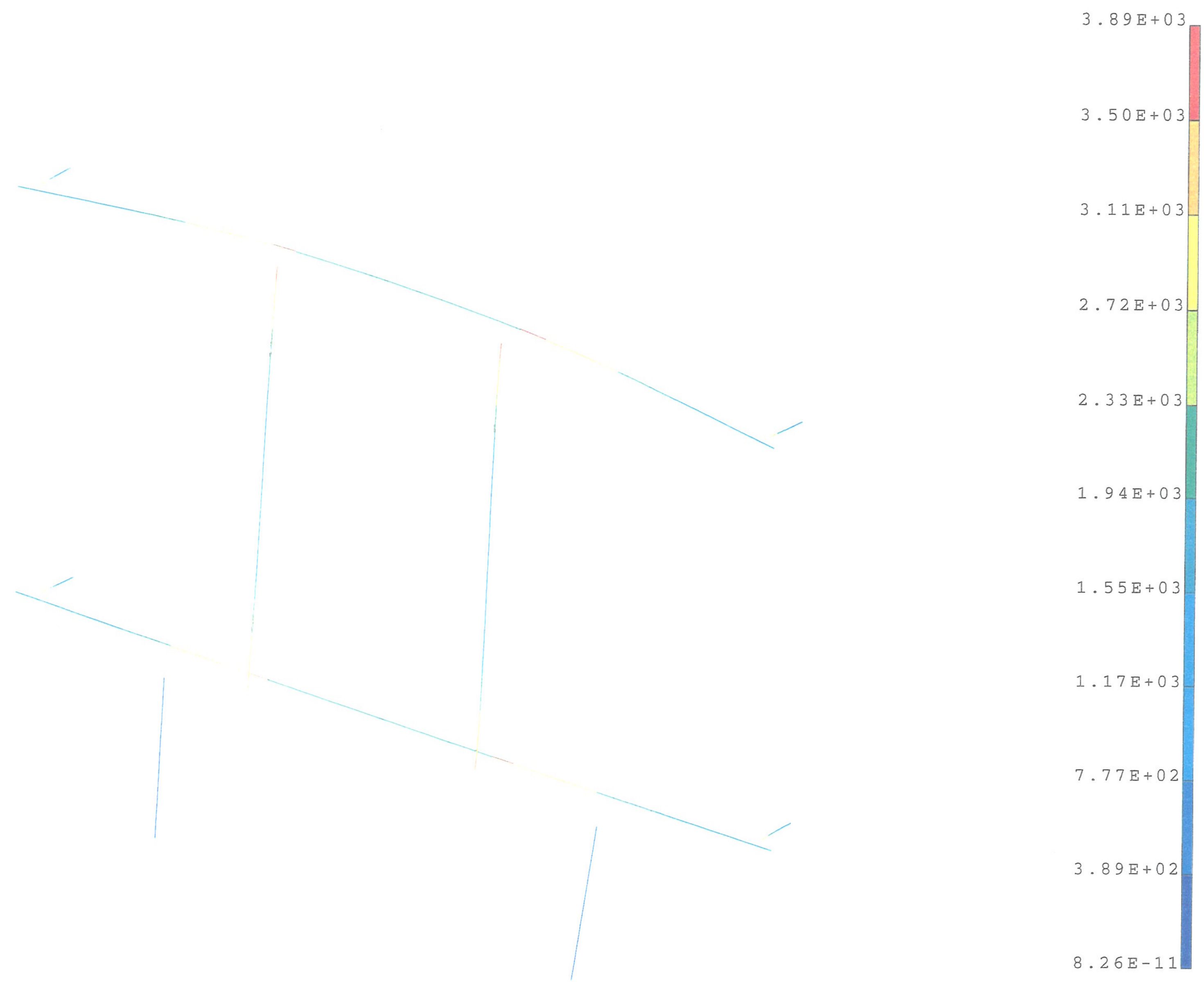
RESULTS: 4- B.C. 1,LOAD 1,ELEMENT FORCE_4
MAGNITUDE - MIN: 8.26E-11 MAX: 3.89E+03
Data component: VON MISES STRESS at maximum point

VALUE OPTION:ACTUAL



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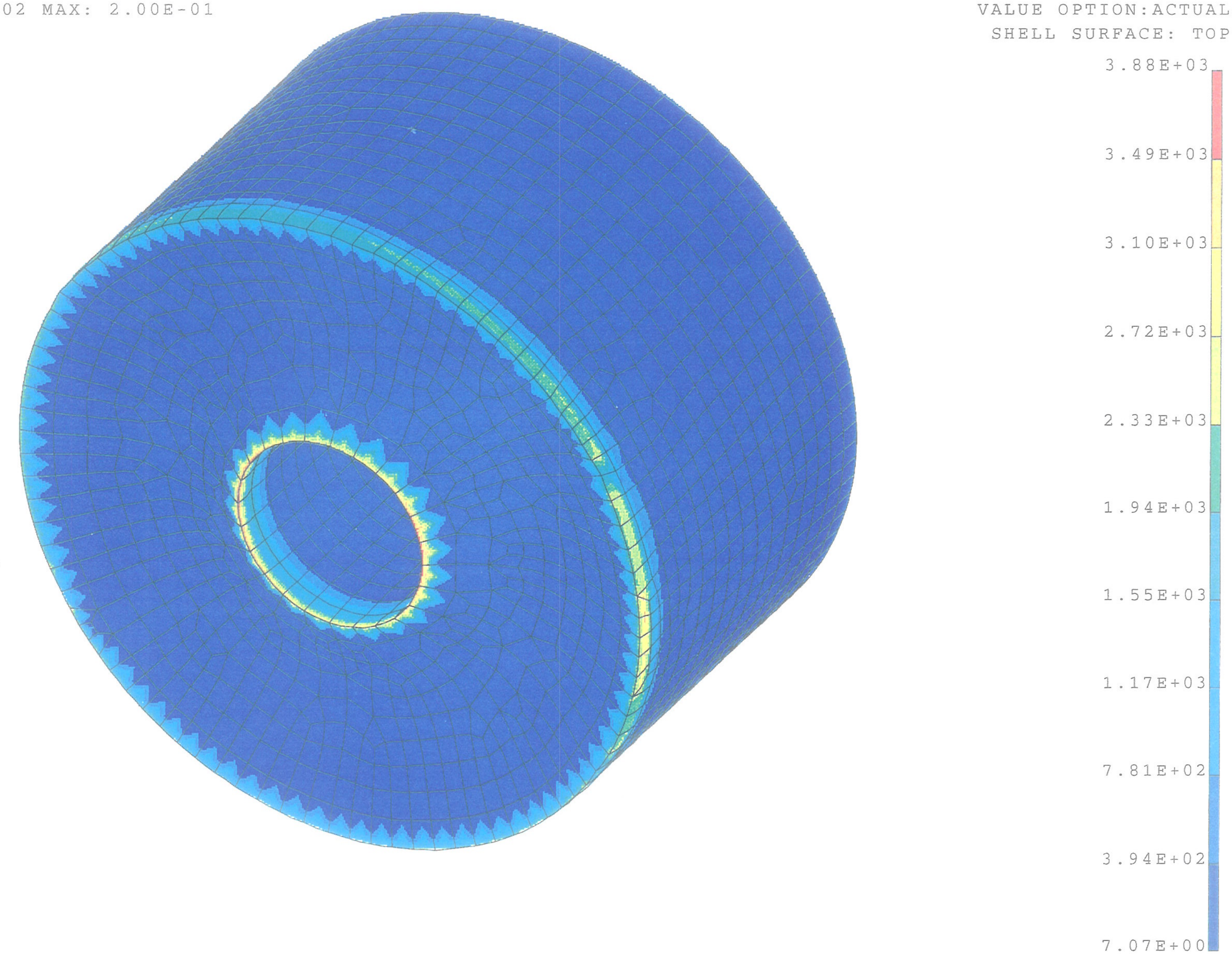
RESULTS: 3- B.C. 1,LOAD 1,STRESS_3
STRESS - VON MISES MIN: 7.07E+00 MAX: 3.88E+03
DEFORMATION: 1- B.C. 1,LOAD 1,DISPLACEMENT_1
DISPLACEMENT - MAG MIN: 8.37E-02 MAX: 2.00E-01
FRAME OF REF: PART



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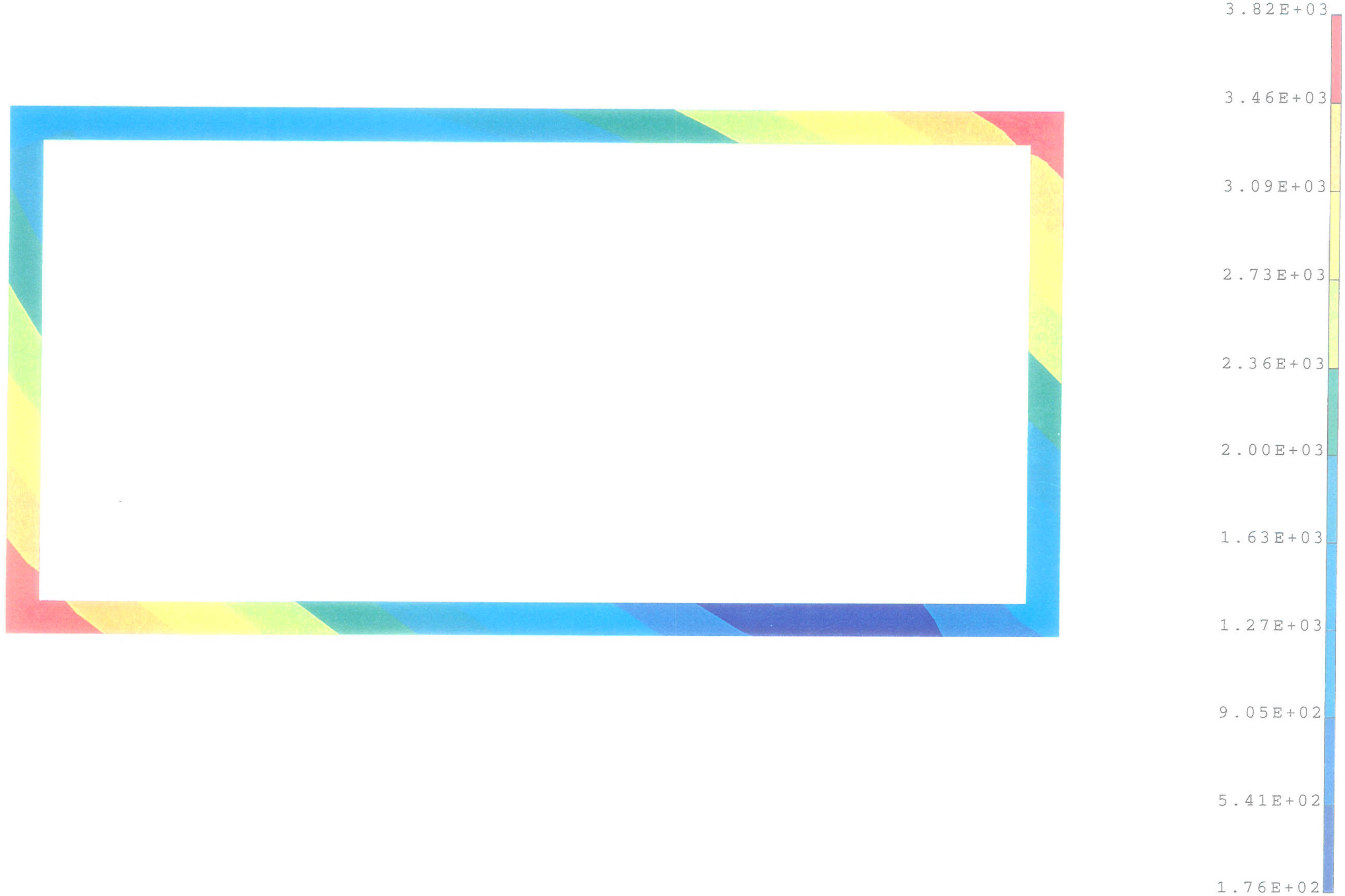
RESULTS: 4- B.C. 1,LOAD 1,ELEMENT FORCE_4
BEAM X-SECTION - VON MISES STRESS MIN: 2.03E+02 MAX: 3.88E+03
BEAM 2533 AT MAX POSITION STRESS
FX = -8.97E+02 FY = 3.78E+02 FZ = 1.09E+03
MX = -8.46E+02 MY = -1.56E+04 MZ = 1.05E+04

VALUE OPTION:ACTUAL

/cadwhs_local/server02/ms_rafael/H_frame_EN.mf1.Z

RESULTS: 4- B.C. 1,LOAD 1,ELEMENT FORCE_4
BEAM X-SECTION - VON MISES STRESS MIN: 1.76E+02 MAX: 3.82E+03
BEAM 2408 AT MAX POSITION STRESS
FX = -1.60E+02 FY = -3.78E+02 FZ = -8.89E+02
MX = -6.87E+03 MY = 2.82E+04 MZ = -1.11E+04

VALUE OPTION:ACTUAL



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RESULTS: 4- B.C. 1,LOAD 1,ELEMENT FORCE_4

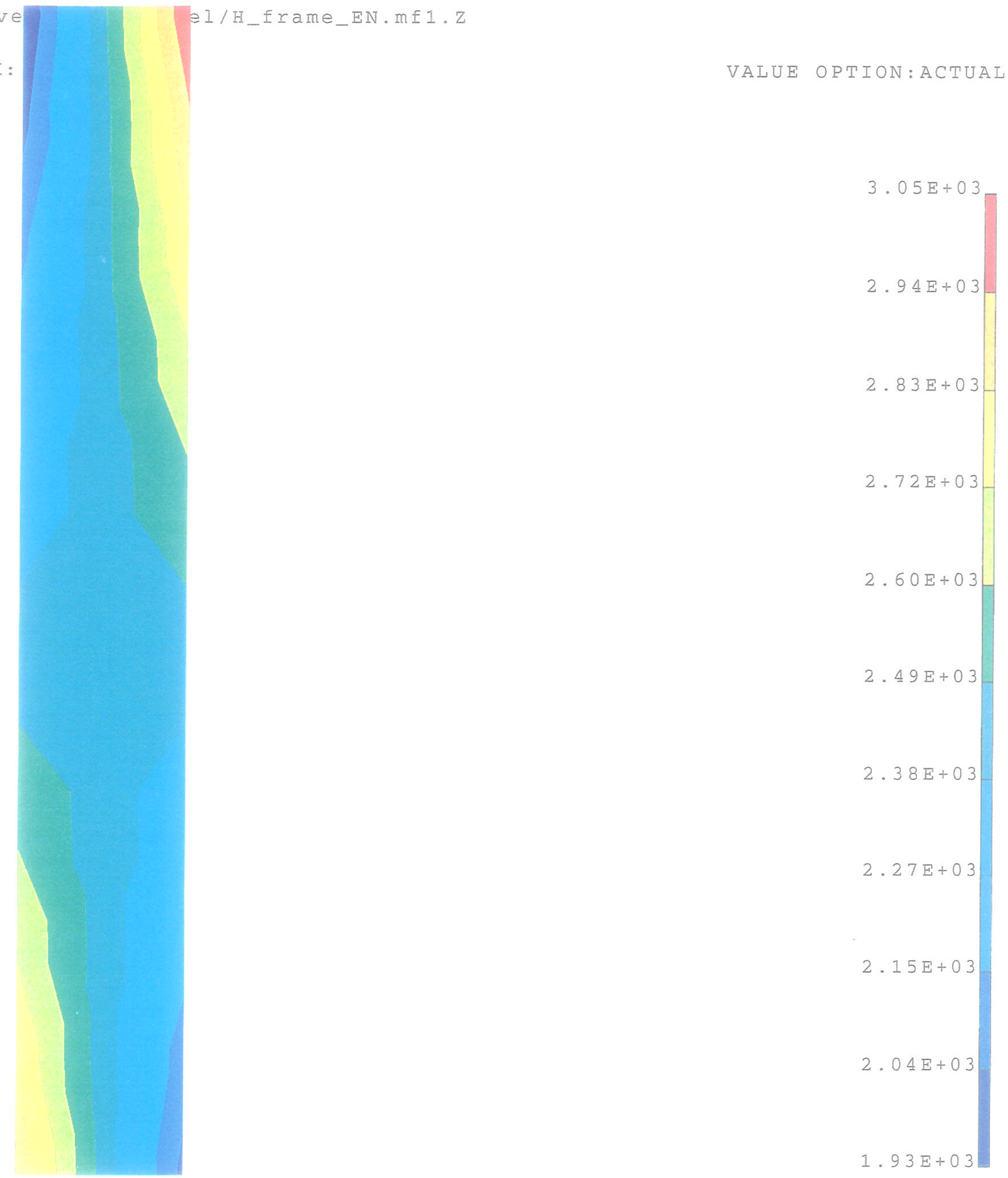
BEAM X-SECTION - VON MISES STRESS MIN: 1.93E+03 MAX:

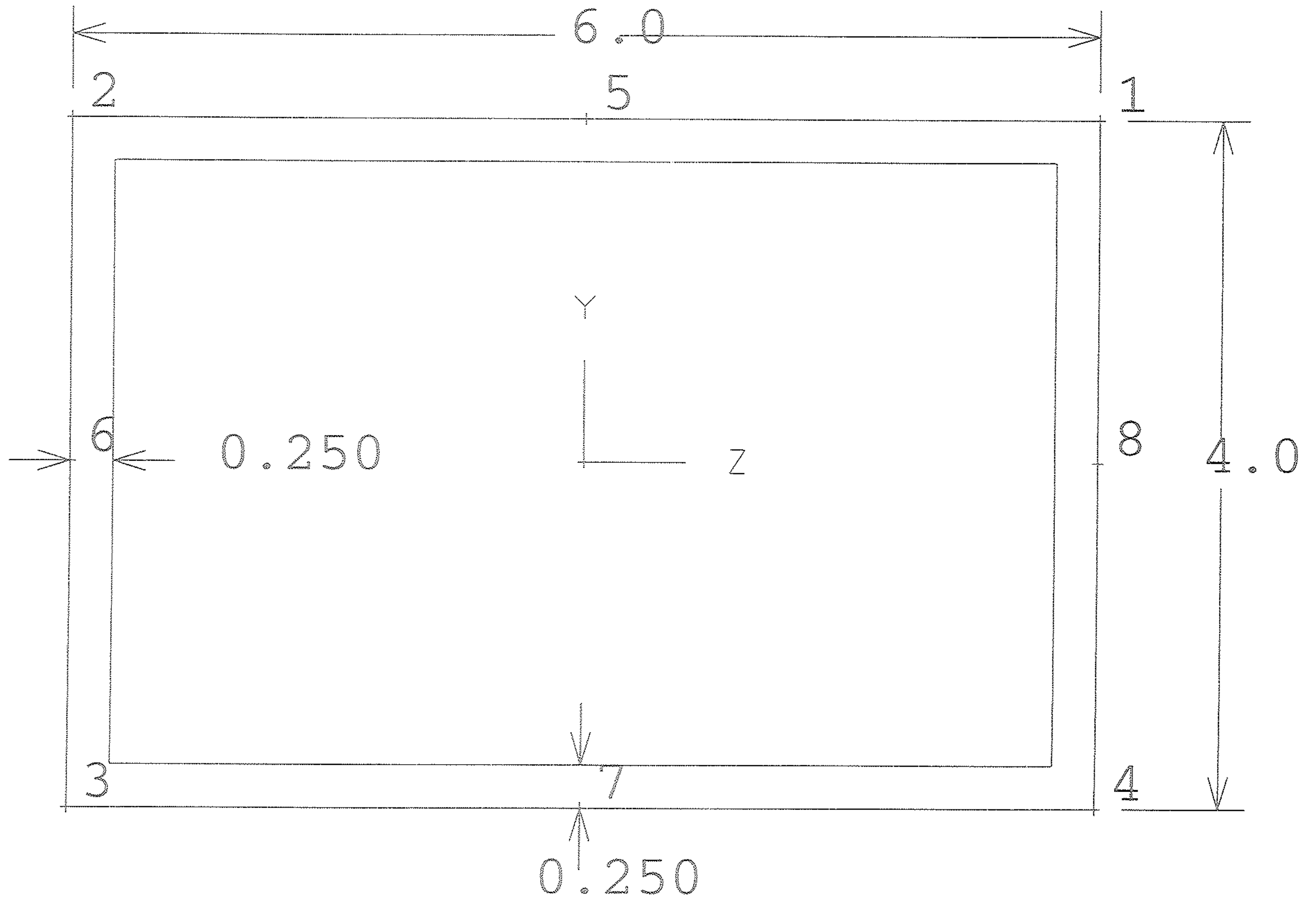
BEAM 6175 AT MAX POSITION STRESS

FX = -3.78E+02 FY = -7.21E+02 FZ = -5.13E+02

MX = -5.55E+01 MY = -2.82E+03 MZ = 4.36E+03

VALUE OPTION:ACTUAL

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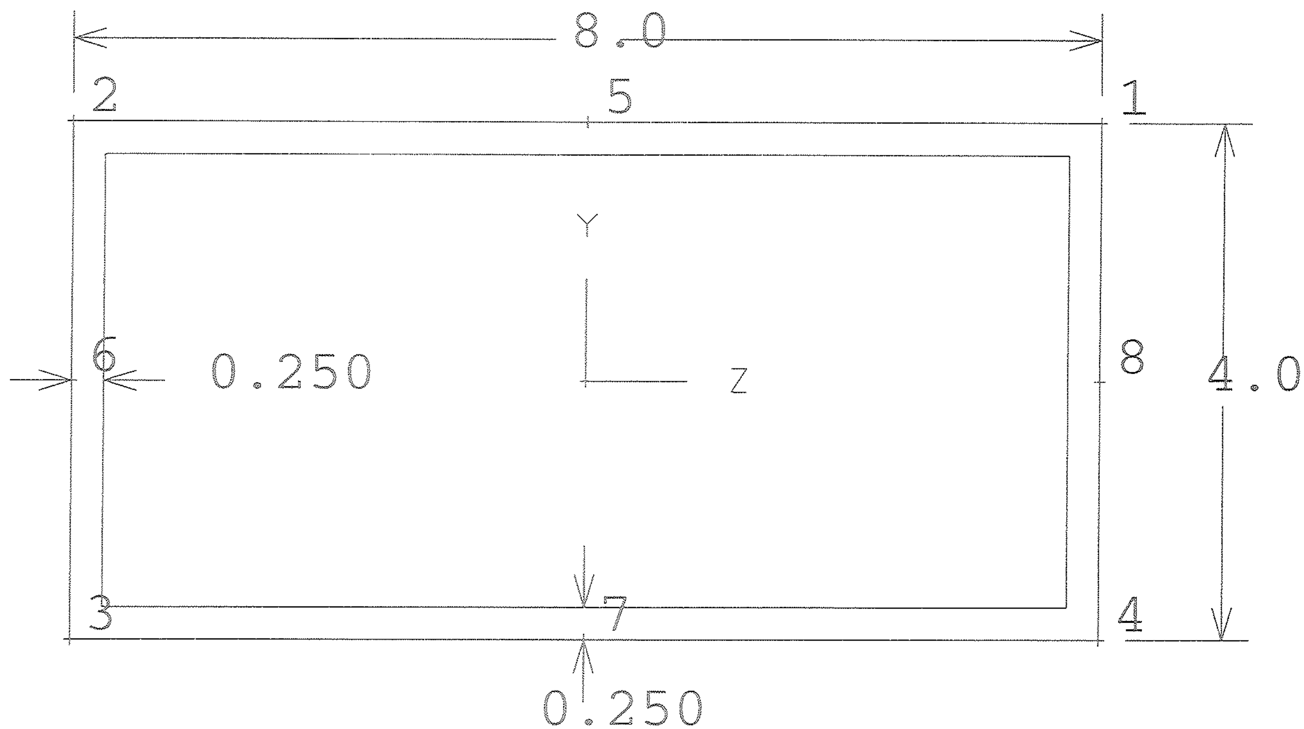
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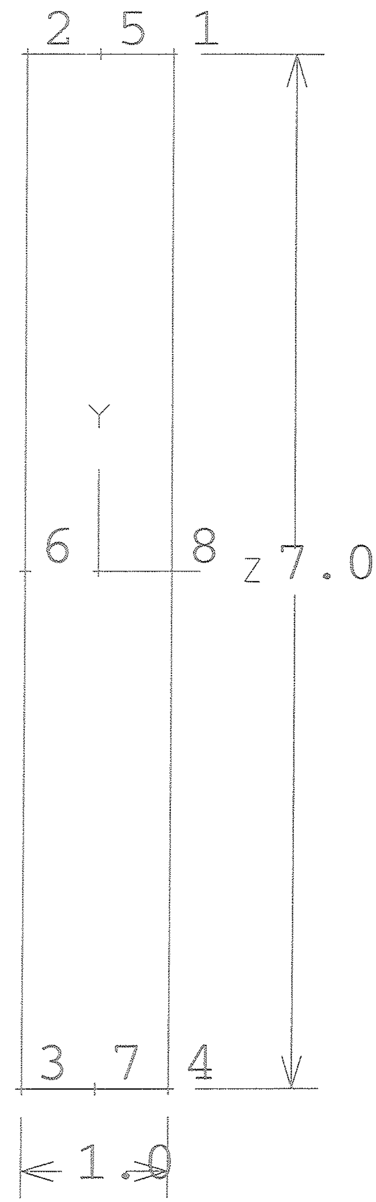

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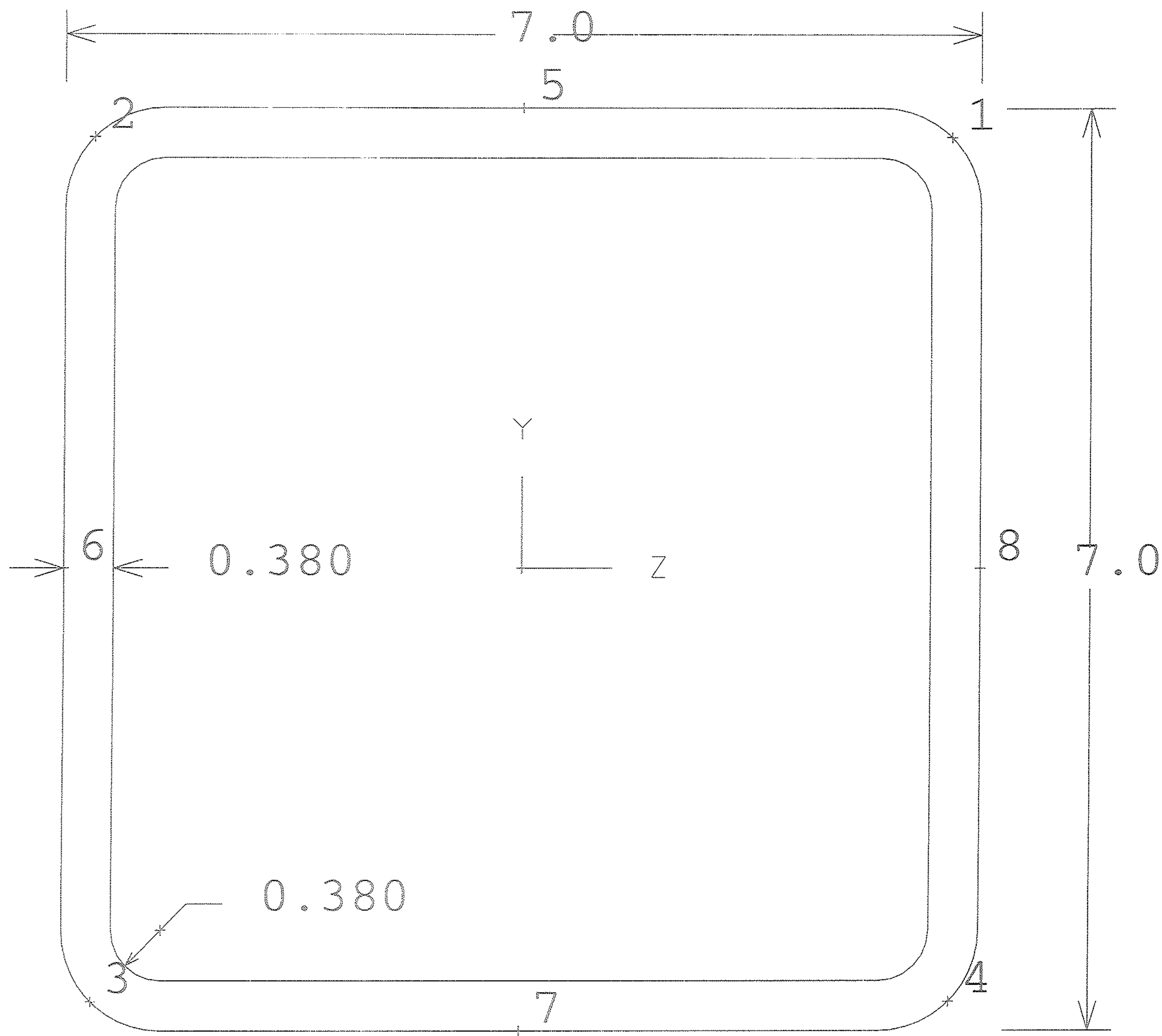
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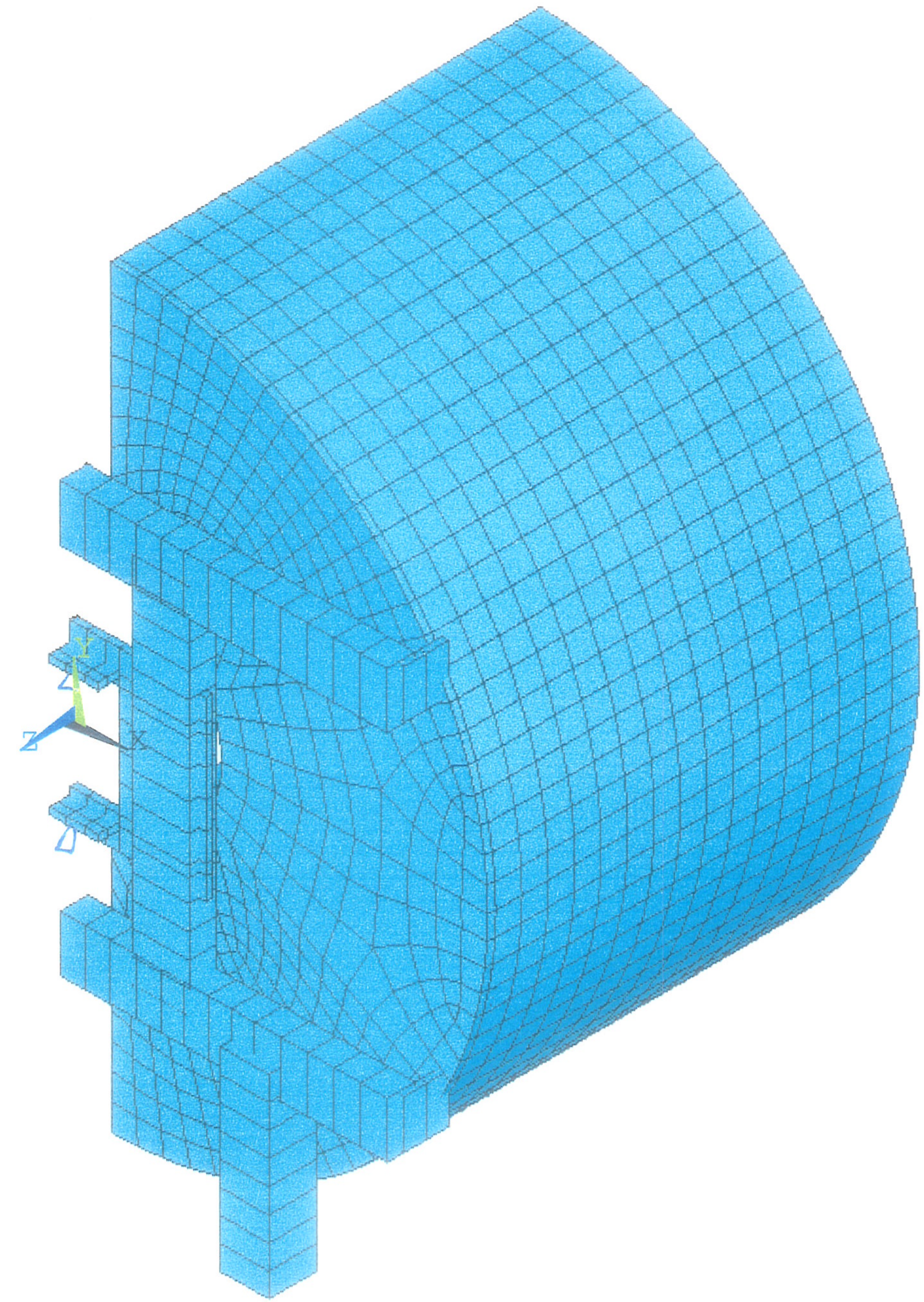
4
7

The Buckling Analysis for the H frame used in COT/CDF Structure (EAR 261)

Ang Lee

May 11, 1999

As requested by R. Silva, this analysis is to study the buckling factor for the H frame used in the COT/CDF structure. The buckling analysis is based on the two approaches: the first approach is to use the eigenvalue method to estimate the bucking factor, and second method is to utilize the large deformation approach by increasing the load gradually up to the point where the structure becomes unstable. The Figure 1 shows a H frame structure details with a COT attached. The frame is supported at the center plate, top and bottom as shown in Figure 1. The vertical load is about 7500 lbs including the weight of the COT and H frame. The Z force is about 4500 lbf over the end plate. Both methods show that the buckling safety factor for a given condition will at least have 5, compared with operation load. Therefore, it is concluded that the H frame will satisfy the concern in terms of the buckling issue.



h frame , Figure 1. H Frame structure

ANNEX

Brief background on COT modeling

Z deflection of the end plates

The COT end plate is difficult to model because of the slots. Models of the end plate were done by Vic Guarino (ANL) in Cosmos-M and Ang Lee (FNAL) in ANSYS. They predicted a maximum deflection in Z of about 1/4 in, more precisely .248 in. Later on, one of the end plates was load tested (with vacuum) up to about 2/3 of the full load and, extrapolating the deformation measured experimentally to the full load, the maximum deflection would be .268 in, 8% above the predicted value.

More recently, measurements were made with the detector assembled and resting on the rotation fixture in the IB4 clean room, during the pre-loading of the end plates. The plates are supported evenly at the ID but at the OD the area of the outer cylinder near the staves is considerably more rigid than were the cover plate openings are. That created a .005 in variation at layer 8, which practically disappeared by the end of layer 6. Measurements were made in gas extrusion slots - see "half" slots, "W" section on drawings 339032 sht 5 of 6 and 339037 sht 5 of 6, near the center, the ID and the OD. The relative deflection between these points was:

Center (Slot 4 ½) in relation to ID (Slot ½) = .239 in
Center (Slot 4 ½) in relation to OD (Slot 8½) = .215 in

X and Y deflection of the end plates

When the plates were at Brenner resting vertically on two points about 90 degrees apart, it was noticed a vertical contraction and horizontal expansion of the ID in the order of .005 in. The "ribs" between slots are about 1/8 in x 1 5/8 in x 4 1/2 in. The inertia moment of the "ribs" in the 1 5/8 in (Z) direction is approximately 170 times larger than across the 1/8 in width.

Modeling a solid plate vertically so it deforms as the real end plate requires the Elastic Modulus to be reduced from $1x10^7$ psi to $6x10^4$ psi.

Can modeling

The COT end plate was modeled as solid plate (with no slots) and reduced Elastic Modulus ($6x10^4$ psi) and density so the total weight would be 900 lb. With the outer cylinder and inner cylinder rigidly attached to the end plate, the load required to deform the end plate by .248 in in Z was then iteratively determined. Various support conditions were explored, as seen in the attached spreadsheet Can_FEA.xls. Half of the can was then attached to the H Frame model with boundary conditions of symmetry at the center. Last, the CTC end plate properties replaced the COT's.

	Plate	Outer	Inner		Plate	Outer	Inner
E	6.00E+04	1.00E+07	8.60E+06	extra x load	-	-	-
μ	0.33	0.33	0.3	extra y load	2x430	-	-
G	E/2.66	E/2.66	E/2.6	extra z load	80,000/45	-	-
ρ	0.098	0.098	0.083	End plate model,	load	support at ID and OD	Max. Def. Z
d ($x10^{-4}$)	2.53886	2.53886	2.15026	4 in mesh, shell	g in Y, extra z load	only in Z	224
weight	2x893	1025	100	elements	g in Y, extra z load	fixed	51

Deformations (mils) of can with end plate rigidly connected to inner and outer cylinder

Case (mesh size = 4 in)	Supports	Own Weight + Load in	Max. Def. Total	Max. Def. X	Max. Def. Y	Max. Def. Z	Von Mises (ksi)
4supports_fine (mesh = 2 in)	4	y	7	-	-	-	-
4supports	4	y	7	4	6	5	0.7
4supports_bend_long_arm	4	y + M<long arm>	8	5	7	7	1.5
3supports	3	y	20	10	19	11	1.4
4supports_at_45deg	4 at 45°	y	19	16	17	17	1.9
4supports_zload	4 at 45°	y and z	101	18	20	100	2.2
4supp_Zload	4	y and z	101	7	8	101	2.1
4supp_Zload_ctc_arm	4	y, z + M<ctc arm>	102	7	9	101	2.1
4supp_Zload_long_arm	4	y, z + M<long arm>	102	7	9	102	2.3
2supports	2	y	782	388	782	336	1.4

2.2. Analysis Of Connections:

Some of the connections required more accurate estimate of the actual loading. These connections were analyzed with loads obtained form the FEA model, as shown on the table in the following page. The criterion used was to select the node (or nodes) that generates the largest resultant load.

	joint D		joint E		joint H		joint 2A	
Node	7391	Local	18679	Local	7383	Local	18701	Local
FX	1087	Lx	134	Lx	953	(Ly)	-134	Lx
FY	889	Ly	-862	Ly	1	Lz	-858	Ly
FZ	-378	Lz	378	Lz	0	(Lx)	378	Lz
MX	6878	Mx	-6884	Mx	5	(My)	333	Mx
MY	5210	My	-1695	My	-5946	Mz	-176	My
MZ	15530	Mz	-1672	Mz	-12380	(Mx)	-51	Mz

FEA FORCES AND MOMENTS

	joint D		7391/A. Lee	avearges
Node	7391	A. Lee	%	
FX	1087	1302	-17%	
FY	889	897	-1%	
FZ	-378	-267	42%	8%
MX	6878	4912	40%	
MY	5210	2505	108%	
MZ	15530	16546	-6%	47%
				28%

FEA FORCES AND MOMENTS

2.2.1. Welded Connections

According to the ANSI/ASME B30.20-1985 "Bellow-the-Hook Lifting Devices" item 20-1.2.2(a), all welding shall be in accordance with ANSI/AWS D1.1. Extending this requirement to aluminum structures, AWS D1.2 should be used. AWS D1.2 determines that the allowable stresses in welds should be in accordance with the Aluminum Association standard.

All welds were sized to be equal or larger than the minimum size fillet weld from AWS D1.2 considering the parts to be joined. To avoid cracks (because of thickness of the center plate) and pre-heating, the welds were made with 4043 filler wire.

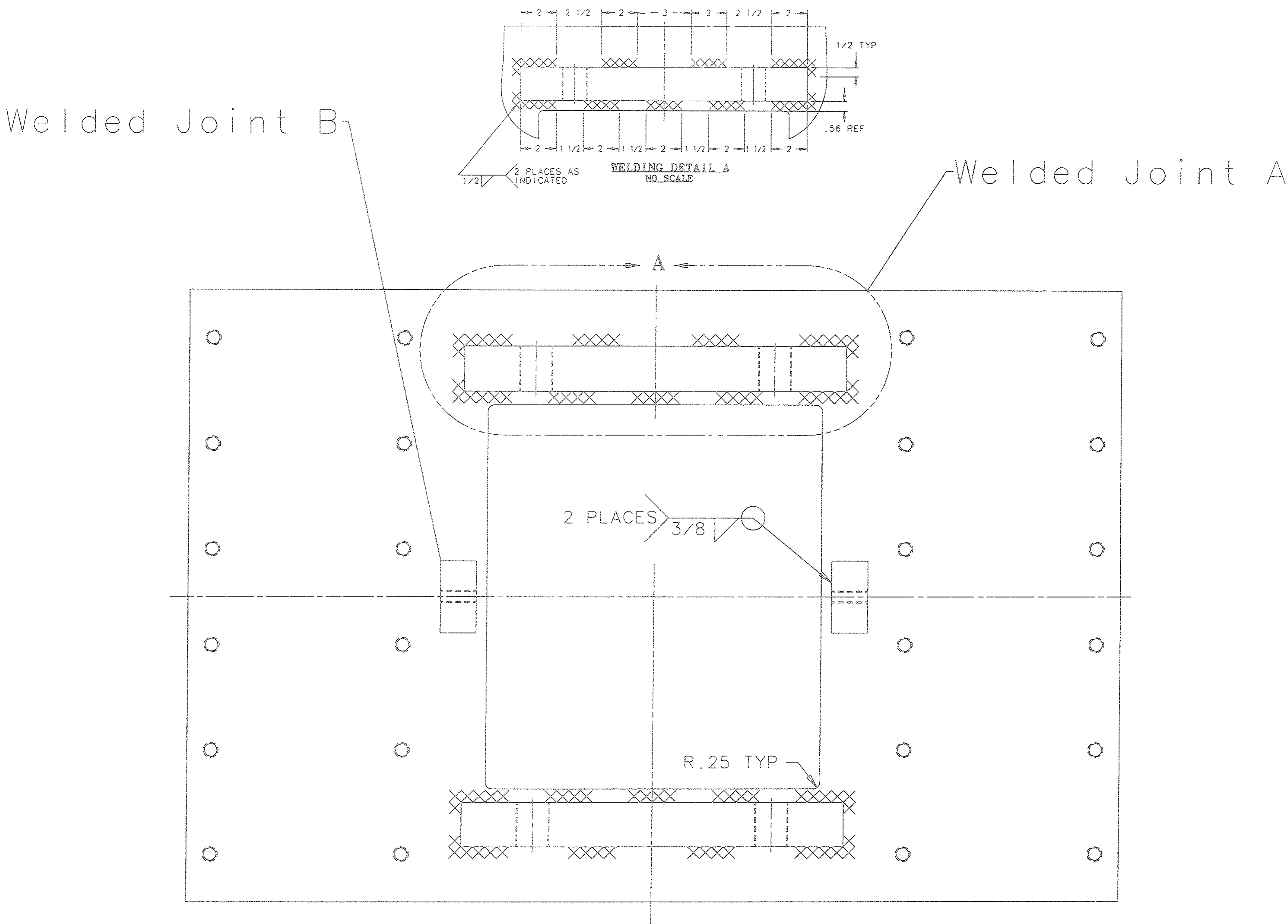
The Aluminum Association specifies the allowable shear stress for welds with the alloys 6061 (tempers T6, T651, T6510 and T6511) and 6063 (tempers T5 and T6) when welded with 4043 filler wire as *5.0 ksi*. This is also below the general 1/3 of yield specified by ANSI/ASME B30.20-1985 "Bellow-the-Hook Lifting Devices". Hence:

$F_{allowable} = 5.0$ **ksi.**

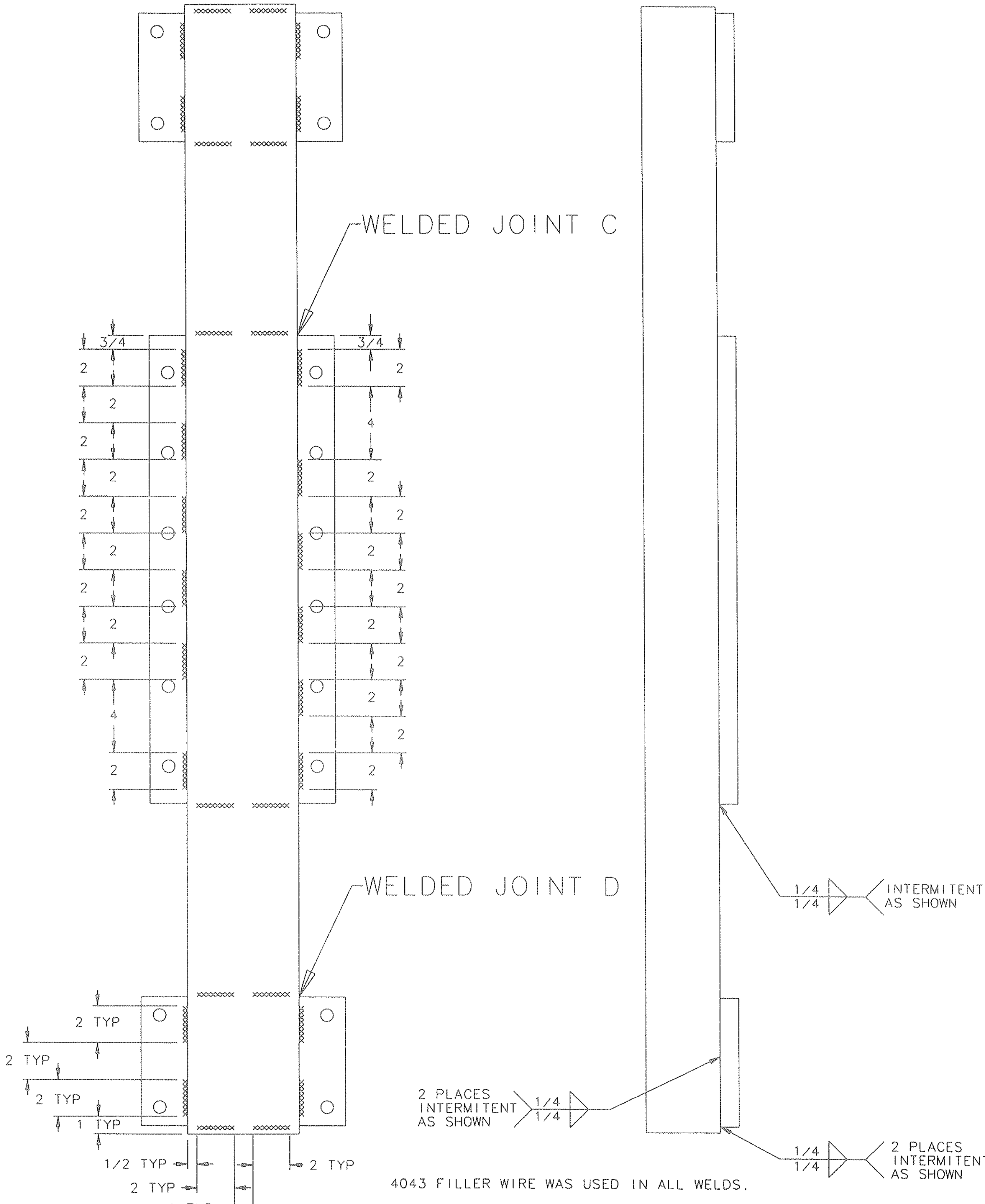
It should be noted that, in hand calculations, shear is not combined with normal stresses in bending of ***members*** because these two kinds of stresses are present in different parts of the members [1]. However, in ***welds*** under off-plane bending, both kinds of stresses may be present in the same region. So, they should be vectorially added.

The welded joints are identified in the next pages. The method used for calculation of stresses in welds in this note is the elastic vector analysis. For simplicity, on joints A, B, C and G, the loads and moments were conservatively assumed to be the applicable load divided by the number of joints (times the lever arm, if a moment). Joints D, E and H were analyzed using individual forces acting on the joint taken directly from de FEA, as shown previously. The welds on joint F have no structural function: they only keep the plate in place to facilitate screwing during assembly. The calculations are summarized in the welds summary table. All stresses are below the allowable stress of 5.0 ksi.

[1]See Roark and Young, Formulas for Stress and Strain, 6th ed., p.97 and Shigley and Mischke, Mechanical Engineering Design, 5th ed., p.51.



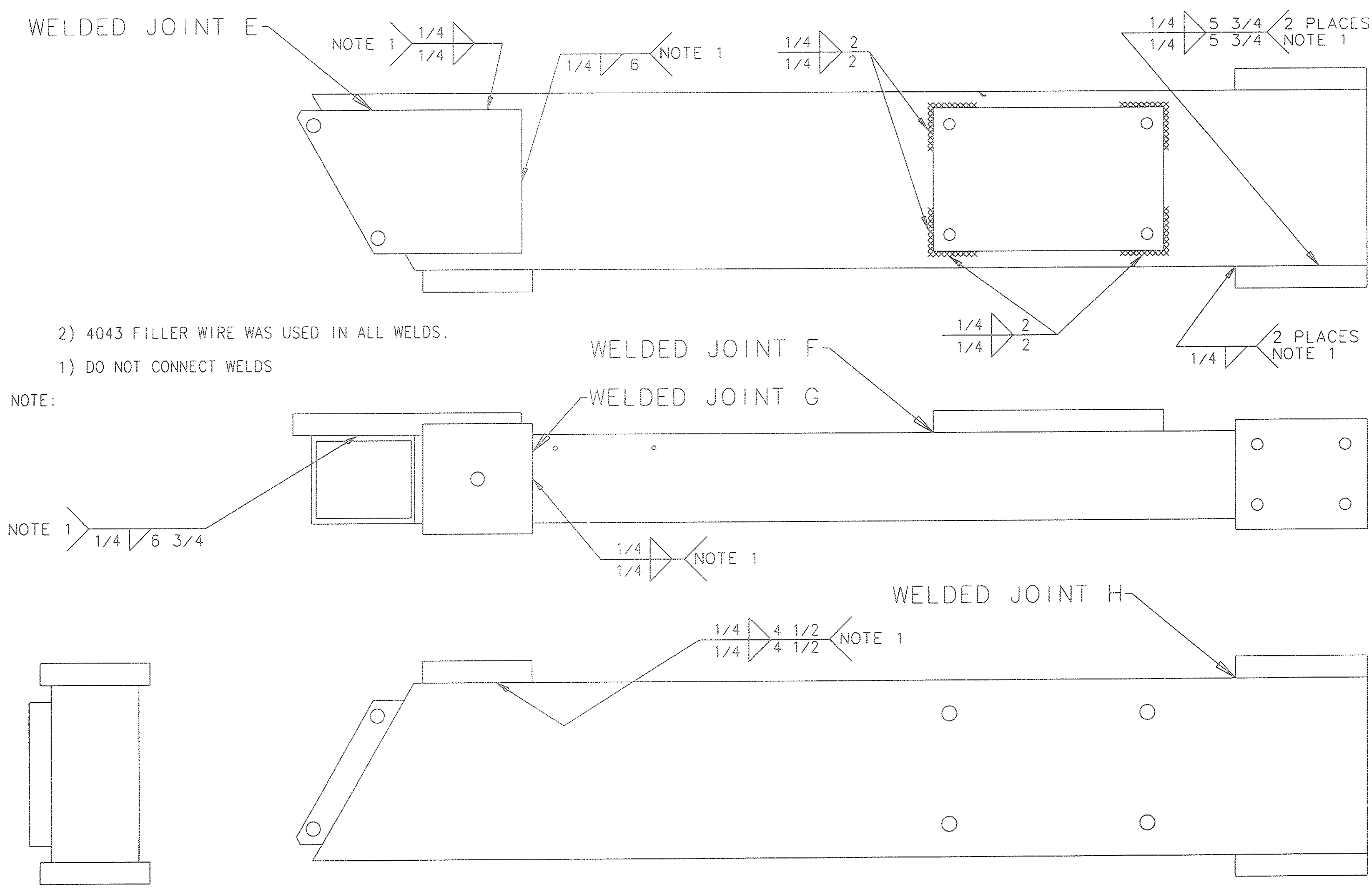
NOTE: 4043 FILLER WIRE WAS USED IN ALL WELDS.



4043 FILLER WIRE WAS USED IN ALL WELDS.

ALL WELDS ARE INTERMITENT AS SHOWN.

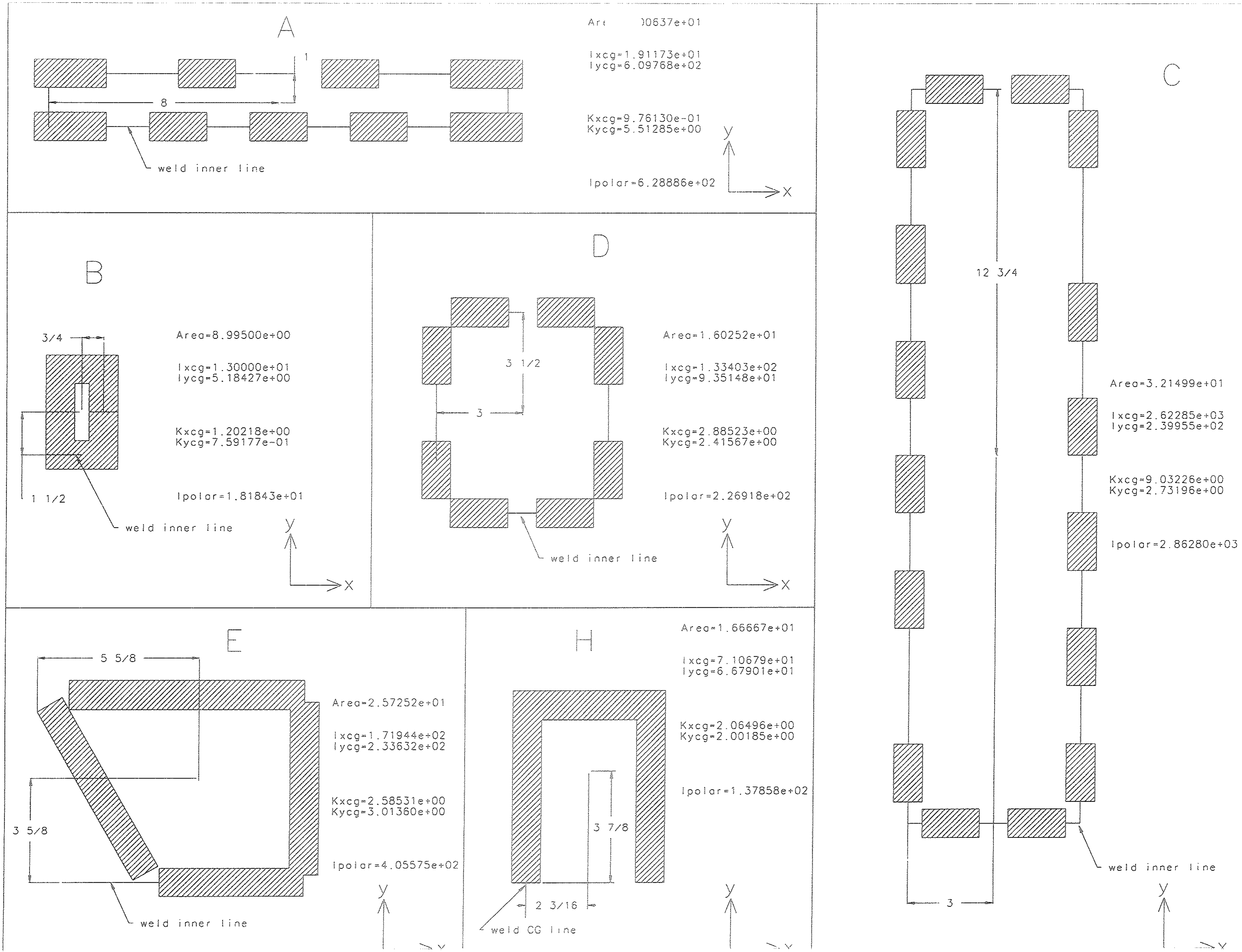
Plotted by rafael on 07-May-99, File: verticalbeam.pff



Plotted by rafael on 07-May-99, File: horiz_up_beam.pff

	A	B	C	D	E	F	G	H	I	J
1	Summary Of Analysis Of Welded Joints		Formula							
2	Joint	-	-	A	B	C	D (*)	E (*)	G	H (*)
3	Joint type	-	-	Tee	Tee	Lap	Lap	Lap	Lap	Lap
4	Weld type	-	-	Fillet	Fillet	Fillet	Fillet	Fillet	Fillet	Fillet
5	Base metals min. yield	Fy (ksi)	-	35.0	35.0	16.0	16.0	16.0	16.0	16.0
6	**AA allowable stess**	**(ksi)**	-	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**
7	Depth or leg	(in)	-	1/2	3/8	1/4	1/4	1/4	1/4	1/4
8	Eff. throat	(in)	-	0.4	0.3	0.2	0.2	0.2	0.2	0.2
9	Length	(in)	-	20.0	9.0	32.0	16.0	27.2	17.0	16.0
10	**Rw**	**(kips/in)**	-	**1.8**	**1.3**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**
11	Ix	(in^4/in)	-	11.9	13.0	2622.9	133.4	171.9		71.1
12	Iy	(in^4/in)	-	609.8	5.2	240.0	93.5	233.6		66.8
13	Ip	(in^4/in)	-	621.7	18.2	2862.8	226.9	405.6		137.9
14	xcg	(in)	-	8.0	0.8	3.0	3.0	5.6		2.2
15	ycg	(in)	-	1.0	1.5	12.8	3.5	3.6		3.9
16	Sx (Ix/ycg)	(in^3/in)	cell11/cell15	11.9	8.7	205.7	38.1	47.4		18.3
17	Sy (Iy/xcg)	(in^3/in)	cell12/cell14	76.2	6.9	80.0	31.2	41.5		30.5
18	Jx (Ip/ycg)	(in^3/in)	cell13/cell15	621.7	12.1	224.5	64.8	111.9		35.6
19	Jy (Ip/xcg)	(in^3/in)	cell13/cell14	77.7	24.2	954.3	75.6	72.1		63.0
20	Lx (X load)	(kips)	-		0.375		1.087	0.134	1.875	
21	sx (Lx / Length)	(kips/in)	cell20/cell9		0.042		0.068	0.005	0.110	
22	Ly (Y load)	(kips)	-	3.750		1.875	0.889	-0.862	1.875	-0.953
23	sy (Ly / Length)	(kips/in)	cell22/cell9	0.188		0.059	0.056	-0.032	0.110	-0.060
24	Lz (Z load)	(kips)	-				-0.378	0.378		0.001
25	sz (Lz / Length)	(kips/in)	cell24/cell9				-0.024	0.014		0.0001
26	ax (X lever arm)	(in)	-							
27	ay (Y lever arm)	(in)	-							
28	az (Z lever arm)	(in)	-	1.750	2.000					
29	Mx (Ly . az + Lz . ay)	(kips-in)	From hand calculations or FEA	6.6		6.6	6.9	-6.9		12.4
30	My (Lx . az + Lz . ax)	(kips-in)	From hand calculations or FEA		0.8		5.2	-1.7		-0.01
31	Mz (Lx . ay + Ly . ax)	(kips-in)	From hand calculations or FEA			30.5	15.5	-1.7		-5.9
32	Rzx (Mx / Sx)	(kips/in)	cell29/cell16	0.6		0.03	0.2	-0.1		0.7
33	Rzy (My / Sy)	(kips/in)	cell30/cell17		0.1		0.2	-0.04		-0.0002
34	Rx (Mz/Jx)	(kips/in)	cell31/cell18			0.1	0.2	-0.01		-0.2
35	Ry (Mz/Jy)	(kips/in)	cell31/cell19			0.03	0.2	-0.02		-0.1
36	Total Fx (sx + Rx)	(kips/in)	cell21+cell34		0.04	0.14	0.3	-0.01	0.1	-0.17
37	Total Fy (sy + Ry)	(kips/in)	cell23+cell35	0.2		0.1	0.3	-0.1	0.1	-0.2
38	Total Fz (sz + Rzx + Rzy)	(kips/in)	cell25+cell32+cell33	0.6	0.1	0.03	0.3	-0.2		0.7
39	**Vector Sum**	**(kips/in)**	((cell36^2)+(cell37^2)+(cell38^2))^(0.5)	**0.6**	**0.1**	**0.2**	**0.5**	**0.2**	**0.2**	**0.7**
40	***Maximum/Allowable***	***(%)***	*100*cell39/cell10*	***33***	***9***	***19***	***59***	***20***	***18***	***81***
41	***SF l.r.t. base metal yield strength***	-	*cell5*cell8/cell39*	***21.3***	***79.9***	***17.0***	***5.5***	***15.6***	***18.1***	***4.0***
42	(*) = loading from FEA									

WELDS SUMMARY TABLE


A
Ar( )0637e+01
Ixcg=1.91173e+01
Iycg=6.09768e+02
Kxcg=9.76130e-01
Kycg=5.51285e+00
Ipolar=6.28886e+02
8
1
weld inner line
B
3/4
1 1/2
Area=8.99500e+00
Ixcg=1.30000e+01
Iycg=5.18427e+00
Kxcg=1.20218e+00
Kycg=7.59177e-01
Ipolar=1.81843e+01
weld inner line
D
3 1/2
3
Area=1.60252e+01
Ixcg=1.33403e+02
Iycg=9.35148e+01
Kxcg=2.88523e+00
Kycg=2.41567e+00
Ipolar=2.26918e+02
weld inner line
C
12 3/4
3
Area=3.21499e+01
Ixcg=2.62285e+03
Iycg=2.39955e+02
Kxcg=9.03226e+00
Kycg=2.73196e+00
Ipolar=2.86280e+03
weld inner line
E
5 5/8
3 5/8
Area=2.57252e+01
Ixcg=1.71944e+02
Iycg=2.33632e+02
Kxcg=2.58531e+00
Kycg=3.01360e+00
Ipolar=4.05575e+02
weld inner line
H
Area=1.66667e+01
Ixcg=7.10679e+01
Iycg=6.67901e+01
Kxcg=2.06496e+00
Kycg=2.00185e+00
Ipolar=1.37858e+02
3 7/8
2 3/16
weld CG line
y
x

2.2.2. Bolted Connections

Referring to the drawing next page, joints 1, 2, 3 and 4 need to be checked. Joint 5 does not require analysis. The vertical adjusting screw and the lifting point require only proper thread engagement. All these joints are located in the same spots as the welded joints analyzed previously, except for joint 2A. Joint 2A has more space between the screws, smaller forces and smaller moments than joint 2, hence if joint 2 is OK joint 2A is also OK. The loading used is the same used for the welds, as in the table below:

bolted	welded
1	H
2	E
3	D
4	C
Adjusting	A
Lifting	G

All screws are connected to tapped holes. The tapped holes are made in 6061-T651 aluminum plate. For this reason, in spite of the used bolts being made out of carbon or stainless steel, the allowable stresses used are for 6061-T651 aluminum, as per AA tables 5.1.1a and 5.1.1c:

Joint	stresses (ksi)			dia (in)		length	load (kips)		
#	shear	tensile	bearing	nominal	root	(in)	shear	tensile	bearing
2A	12.0	18.0	35.0	5/8	0.5152	11/16	3.7	3.8	15.0
All others	12.0	18.0	35.0	5/8	0.5152	1.0	3.7	3.8	21.9

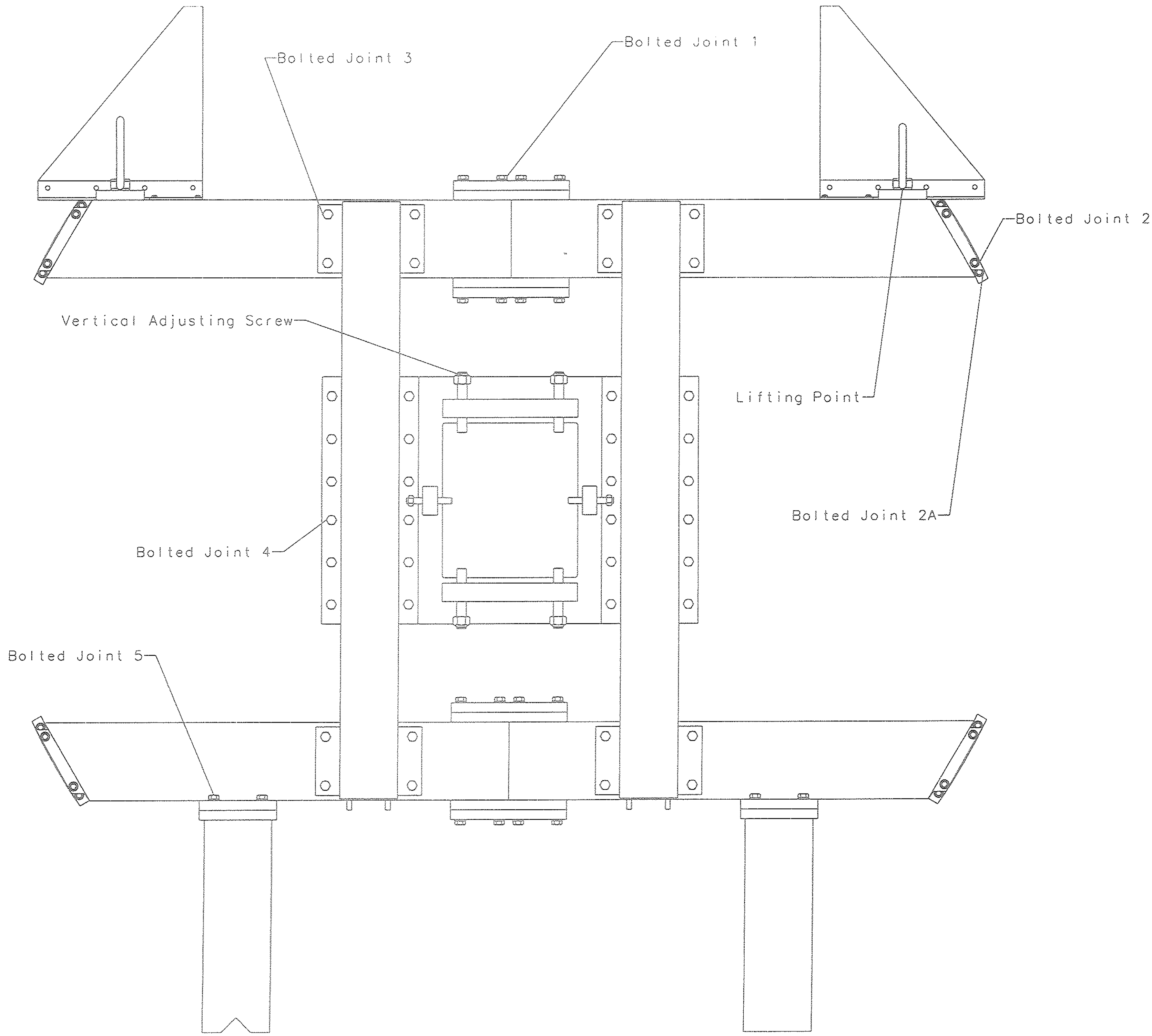
There are no bearing connections in this structure. The allowable tensile and shear loads are very close so the smaller of the two, the shear, is going to be used as the allowable to be compared with the resultant load on the joints. So:

$R_{allowable} = 3.7\ kips.$

All loads on the bolts are below this allowable.

The thread engagement and torque are also calculated. The minimum thread engagement was calculated to be .60 inches, which is OK for all joints. A test was done with 5/8-11 screws in tapped 1 inch thick aluminum and the threads were reusable up to at least 300 ft-lb and there was no failure up to 600 ft-lb. The calculations recommend 105 ft-lb, value that will be used.

The next pages contain the drawing identifying all the bolted joints, a summary of the analysis of bolted joints and the calculations.


Bolted Joint 3
Bolted Joint 1
Bolted Joint 2
Vertical Adjusting Screw
Lifting Point
Bolted Joint 2A
Bolted Joint 4
Bolted Joint 5

Summary Of Analysis Of Bolted Joints					
Joint	#	1	2	3	4
Nominal Bolt Diameter	(in)	5/8	5/8	5/8	5/8
Total combined Load	(kips)	1.4	1.9	2.3	1.0
Allowable (Shear) Load (R)	(kips)	3.7	3.7	3.7	3.7
Ratio Resultant / Allowable (%)	-	38%	51%	62%	26%

BOLTS SUMMARY TABLE

Bolted Joint: 1

File: Joint1.mcd

Calculations based on Structural Engineering Handbook, 3rd ed, Chap 8, McGraw-Hill.

Allowable shear load from AA (kips): $R := 3.7$

Tension from off plane bending around x:

Bending moment, from FEA (in-kips): $M := 12.38$

Number of columns: $m := 4$

Vertical spacing between bolts (in): $p := 2.75$

The horizontal spacing is not constant so, for simplification, it will be conservatively assumed to beconstant and equal to the smallest one:

Horizontal spacing between bolts (in): $g := 2.00$

Estimated number of rows: $n := \sqrt{\dfrac{6 \cdot M}{p \cdot m \cdot R}}$ $n = 1.35$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 3$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 1.375$

Calculation of $\Sigma y2$: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$$ $\Sigma y2 = 15.1$

Max. tension on bolt (kips): $Tz := \dfrac{M \cdot ycg}{\Sigma y2}$ $Tz = 1.1$

Shear fom in plane bending around z:

Bending moment, from FEA (in-kips): $M := -5.946$

Number of columns: $m := 2$

The vertical spacing is not constant so, for simplification, it will be conservatively assumed to beconstant and equal to the smallest one:

Vertical spacing between bolts (in): $p := 2.00$

Horizontal spacing between bolts (in): $g := 2.75$

Number of rows: $n := 4$

C.G.: $xcg := \frac{g}{2}\cdot(m-1)$ $xcg = 1.375$ $ycg := \frac{p}{2}\cdot(n-1)$ $ycg = 3$

Calculation of $\Sigma y2$: $buf := \frac{n-1}{2}$

$int := floor(buf)$ $int = 1.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac=0), int, (int+1))$ $k = 2.00$

$$\Sigma y2 := 2\cdot m\cdot \sum_{j=1}^{k} ((j-frac)\cdot p)^2 \qquad \Sigma y2 = 40.0$$

Calculation of $\Sigma x2$: $buf := \frac{m-1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac=0), int, (int+1))$ $k = 1.00$

$$\Sigma x2 := 2\cdot n\cdot \sum_{j=1}^{k} ((j-frac)\cdot g)^2 \qquad \Sigma x2 = 15.1$$

Max. x shear on bolt (kips): $Sx := \frac{M\cdot xcg}{\Sigma x2}$ $Sx = -0.5$

Max. y shear on bolt (kips): $Sy := \frac{M\cdot ycg}{\Sigma y2}$ $Sy = -0.4$

Direct shear:

Ly, from FEA (in-kips): $P := -.953$

Shear (kips): $Vy := \frac{P}{m\cdot n}$ $Vy = -0.1$

Combined loads:

Total resultant load (kips): $Tt := \sqrt{Tz^2 + (Sy+Vy)^2 + Sx^2}$ $Tt = 1.4$

Conclusion:

R (*3.7*) > **Tt** (*1.4*) $\Rightarrow$ bolts are ***OK***.

Bolted Joint: 2
File: Joint2.mcd

Calculations based on Structural Engineering Handbook, 3rd ed, Chap 8, McGraw-Hill.

Allowable shear load from AA (kips): $R := 3.7$

Tension from off plane bending around x:

Bending moment, from FEA (in-kips): $M := -6.884$
Number of columns: $m := 1$
Vertical spacing between bolts (in): $p := 5.09$
Horizontal spacing between bolts (in): $g := 2.94$

Estimated number of rows: $n := \sqrt{\dfrac{-6 \cdot M}{p \cdot m \cdot R}}$ $n = 1.48$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 0$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 2.545$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$$ $\Sigma y2 = 13.0$

Max. tension on bolt (kips): $Tzx := \dfrac{M \cdot ycg}{\Sigma y2}$ $Tzx = -1.4$

Tension from off plane bending around y:

Bending moment, from FEA (in-kips): $M := -1.695$
Number of columns: $m := 1$
Vertical spacing between bolts (in): $p := 2.94$
Horizontal spacing between bolts (in): $g := 5.09$

Estimated number of rows: $n := \sqrt{\dfrac{-6 \cdot M}{p \cdot m \cdot R}}$ $n = 0.97$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 0$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 1.47$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$ $\Sigma y2 = 4.3$

Max. tension on bolt (kips): $Tzy := \dfrac{M \cdot ycg}{\Sigma y2}$ $Tzy = -0.6$

Shear fom in plane bending around z:

Bending moment, from FEA (in-kips): $M := -1.672$

Number of columns: $m := 1$

Vertical spacing between bolts (in): $p := 5.09$

Horizontal spacing between bolts (in): $g := 2.94$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 0$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 2.545$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$ $\Sigma y2 = 13.0$

Calculation of Σx2: $buf := \dfrac{m - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.00$

$k := \text{if}((\text{frac} = 0), \text{int}, (\text{int} + 1))$ $\quad k = 0.00$

$$\Sigma x2 := 2 \cdot n \cdot \sum_{j=1}^{k} ((j - \text{frac}) \cdot g)^2 \qquad \Sigma x2 = 34.6$$

Max. x shear on bolt (kips): $Sx := \frac{M \cdot xcg}{\Sigma x2}$ $\quad Sx = 0.0$

Max. y shear on bolt (kips): $Sy := \frac{M \cdot ycg}{\Sigma y2}$ $\quad Sy = -0.3$

Direct shear:

Lx, from FEA (in-kips): $Lx := .134$

Shear (kips): $Vx := \frac{Lx}{m \cdot n}$ $\quad Vx = 0.1$

Ly, from FEA (in-kips): $Ly := -.862$

Shear (kips): $Vy := \frac{Ly}{m \cdot n}$ $\quad Vy = -0.4$

Direct tension:

Lz, from FEA (in-kips): $Lz := .378$

Tension (kips): $Tz := \frac{Lz}{m \cdot n}$ $\quad Tz = 0.2$

Combined loads:

Total resultant load (kips): $Tt := \sqrt{(Tzx + Tzy + Tz)^2 + (Sy + Vy)^2 + (Sx + Vx)^2}$

$Tt = 1.9$

Conclusion:

$\mathbb{R}$ (3.7) > **Tt** (1.9) $\Rightarrow$ bolts are ***OK***.

Bolted Joint: 3
File: Joint3.mcd

Calculations based on Structural Engineering Handbook, 3rd ed, Chap 8, McGraw-Hill.

Allowable shear load from AA (kips): $R := 3.7$

<u>Tension from off plane bending around x:</u>

Bending moment, from FEA (in-kips): $M := 6.878$
Number of columns: $m := 2$
Vertical spacing between bolts (in): $p := 5.0$
Horizontal spacing between bolts (in): $g := 9.0$

Estimated number of rows: $n := \sqrt{\frac{6 \cdot M}{p \cdot m \cdot R}}$ $n = 1.06$

Number of rows: $n := 2$

C.G.: $xcg := \frac{g}{2} \cdot (m - 1)$ $xcg = 4.5$ $ycg := \frac{p}{2} \cdot (n - 1)$ $ycg = 2.5$

Calculation of Σy2: $buf := \frac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$ $\Sigma y2 = 25.0$

Max. tension on bolt (kips): $Tzx := \frac{M \cdot ycg}{\Sigma y2}$ $Tzx = 0.7$

<u>Tension from off plane bending around y:</u>

Bending moment, from FEA (in-kips): $M := 5.210$
Number of columns: $m := 2$
Vertical spacing between bolts (in): $p := 9.0$
Horizontal spacing between bolts (in): $g := 5.0$

Estimated number of rows: $n := \sqrt{\dfrac{6 \cdot M}{p \cdot m \cdot R}}$ $n = 0.69$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 2.5$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 4.5$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$ $\Sigma y2 = 81.0$

Max. tension on bolt (kips): $Tzy := \dfrac{M \cdot ycg}{\Sigma y2}$ $Tzy = 0.3$

Shear fom in plane bending around z:

Bending moment, from FEA (in-kips): $M := 15.53$

Number of columns: $m := 2$

Vertical spacing between bolts (in): $p := 5.0$

Horizontal spacing between bolts (in): $g := 9.0$

Number of rows: $n := 2$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 4.5$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 2.5$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$ $\Sigma y2 = 25.0$

Calculation of Σx2: $buf := \dfrac{m - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := \text{if}((\text{frac} = 0), \text{int}, (\text{int} + 1))$ $k = 1.00$

$$\Sigma x2 := 2 \cdot n \cdot \sum_{j=1}^{k} ((j - \text{frac}) \cdot g)^2$$ $\Sigma x2 = 81.0$

Max. x shear on bolt (kips): $Sx := \frac{M \cdot xcg}{\Sigma x2}$ $Sx = 0.9$

Max. y shear on bolt (kips): $Sy := \frac{M \cdot ycg}{\Sigma y2}$ $Sy = 1.6$

Direct shear:

Lx, from FEA (in-kips): $Lx := 1.087$

Shear (kips): $Vx := \frac{Lx}{m \cdot n}$ $Vx = 0.3$

Ly, from FEA (in-kips): $Ly := .889$

Shear (kips): $Vy := \frac{Ly}{m \cdot n}$ $Vy = 0.2$

Direct tension:

Lz, from FEA (in-kips): $Lz := -.378$

Tension (kips): $Tz := \frac{Lz}{m \cdot n}$ $Tz = -0.1$

Combined loads:

Total resultant load (kips): $Tt := \sqrt{(Tzx + Tzy + Tz)^2 + (Sy + Vy)^2 + (Sx + Vx)^2}$

$Tt = 2.3$

Conclusion:

R *(3.7)* > **Tt** (2.3) $\Rightarrow$ bolts are ***OK***.

Bolted Joint: 4

File: Joint4.mcd

Calculations based on Structural Engineering Handbook, 3rd ed, Chap 8, McGraw-Hill.

Allowable shear load from AA (kips): $R := 3.7$

Tension from off plane bending around x:

Bending moment, from joint C (in-kips): $M := 6.6$

Number of columns: $m := 2$

The vertical spacing is not constant so, for simplification, it will be conservatively assumed to beconstant and equal to the smallest one:

Vertical spacing between bolts (in): $p := 4.0$

Horizontal spacing between bolts (in): $g := 8.0$

Estimated number of rows: $n := \sqrt{\dfrac{6 \cdot M}{p \cdot m \cdot R}}$ $n = 1.16$

Number of rows: $n := 6$

C.G.: $xcg := \dfrac{g}{2} \cdot (m - 1)$ $xcg = 4$ $ycg := \dfrac{p}{2} \cdot (n - 1)$ $ycg = 10$

Calculation of Σy2: $buf := \dfrac{n - 1}{2}$

$int := \text{floor}(buf)$ $int = 2.00$ $frac := (buf - int)$ $frac = 0.50$

$k := \text{if}((frac = 0), int, (int + 1))$ $k = 3.00$

$$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$$ $\Sigma y2 = 560.0$

Max. tension on bolt (kips): $Tz := \dfrac{M \cdot ycg}{\Sigma y2}$ $Tz = 0.1$

Shear fom in plane bending around z:

Bending moment, from joint C (in-kips): $M := 30.5$

Number of columns: $m := 2$

The vertical spacing is not constant so, for simplification, it will be conservatively assumed to beconstant and equal to the smallest one:

Vertical spacing between bolts (in): $p := 4.0$

Horizontal spacing between bolts (in): $g := 8.0$

Number of rows: $n := 6$

C.G.: $xcg := \frac{g}{2} \cdot (m - 1)$ $xcg = 4$ $ycg := \frac{p}{2} \cdot (n - 1)$ $ycg = 10$

Calculation of Σy2: $buf := \frac{n - 1}{2}$

$int := floor(buf)$ $int = 2.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 3.00$

$$\Sigma y2 := 2 \cdot m \cdot \sum_{j=1}^{k} ((j - frac) \cdot p)^2$$ $\Sigma y2 = 560.0$

Calculation of Σx2: $buf := \frac{m - 1}{2}$

$int := floor(buf)$ $int = 0.00$ $frac := (buf - int)$ $frac = 0.50$

$k := if((frac = 0), int, (int + 1))$ $k = 1.00$

$$\Sigma x2 := 2 \cdot n \cdot \sum_{j=1}^{k} ((j - frac) \cdot g)^2$$ $\Sigma x2 = 192.0$

Max. x shear on bolt (kips): $Sx := \frac{M \cdot xcg}{\Sigma x2}$ $Sx = 0.6$

Max. y shear on bolt (kips): $Sy := \frac{M \cdot ycg}{\Sigma y2}$ $Sy = 0.5$

<u>**Direct shear:**</u>

Ly, from FEA (in-kips): $P := 1.875$

Shear (kips): $Vy := \frac{P}{m \cdot n}$ $Vy = 0.2$

<u>**Combined loads:**</u>

Total resultant load (kips): $Tt := \sqrt{Tz^2 + (Sy + Vy)^2 + Sx^2}$ $Tt = 0.95$

<u>**Conclusion:**</u>

R (*3.7*) > **Tt** (*.95*) ⇒ bolts are <u>***OK***</u>.

Joint: All

File: Thread_all.mcd

Minimum thread engagement

Machinery's Handbook, 24th ed., p.1324. Data required: p.1544-1566.
Minimum thread engagement to assure failure on externally threaded part.

Internal thread (6061_T651 aluminum):

Basic major diameter (in) : $D := \frac{5}{8}$

Pitch (threads/in): $n := 11$

Max. minor diameter (in): $Kn := .5460$

Max. pitch diameter (in): $En := .5732$

Min. tensile strenth (ksi): $\sigma i := 42$

External thread (18-8 stainless steel):

Min. major diameter (in): $Ds := .6113$

Min. pitch diameter (in): $Es := .5589$

Max. tensile strength (ksi): $\sigma e := 80$

Hence:

$$Ats := .7854 \cdot \left(D - \frac{.9743}{n}\right)^2$$ so: $Ats = 0.226$

$$Ath := \pi \cdot \left(\frac{Es}{2} - \frac{.16238}{n}\right)^2$$ so: $Ath = 0.220$

$$At := \text{if}((\sigma e > 100), Ath, Ats)$$ so: $At = 0.226$

$$Le := \frac{2 \cdot At}{\pi \cdot Kn \cdot (.5 + (.57735 \cdot n \cdot (Es - Kn)))}$$ so: $Le = 0.453$

$$As := \pi \cdot n \cdot Le \cdot Kn \cdot \left[\frac{1}{2 \cdot n} + .57735 \cdot (Es - Kn)\right]$$ so: $As = 0.452$

$$An := \pi \cdot n \cdot Le \cdot Ds \cdot \left[\frac{1}{2 \cdot n} + .57735 \cdot (Ds - En)\right]$$ so: $An = 0.645$

$$J := \frac{As \cdot \sigma e}{An \cdot \sigma i}$$ so: $J = 1.334$

$$Q := J \cdot Le$$ so: $Q = 0.604$

$$Engagement := \text{if}((J > 1), Q, Le)$$ so: $Engagement = 0.604$

Joint: All

File: Torque_all.mcd

Torque Required

The calculations are based on the methodology presented by Shigley & Mischke, Chapter 8.
For permanent connections, the pre-load is based on ASD recommendations (Table 4, p.5-274) of tension required of 70% of tensile strength plus 5% for torque wrenches (total of 78.5%).
For reusable connections, the pre-load is based on Shigley & Mischke, Chapter 8, p. 349, equations 8-25 or 8-26, representing 75% of the proof load or, in the abscence of that, 85% of the yield strength.
As the screws are connected to tapped holes in aluminum, aluminum properties will be used.
Type of connection assumed in this case: **Reusable**.

Bolt Tensile/Proof/**Yield Stress** (ksi): $Fb := 35$

Req. Bolt Tension, ASD/**Shigley** (ksi): $Rb := .85 \cdot Fb$ $\quad Rb = 29.8$

Torque Factor, (Zn=.2,Blk=.3), p.347: $K := .3$

Major Screw Diameter (in): $d := \frac{5}{8}$

Pitch (threads/in): $n := 11$

Grip Threaded Length (in): $lt := 1.00$

Grip Unthreaded Length (in): $ld := 1.00$

Bolt Elastic Modulus (ksi): $Eb := 2.9 \cdot 10^{4}$

External Tensile Load (kips): $P := 0$

Threaded Member Elastic Modulus (ksi): $Et := 1 \cdot 10^{4}$

Threaded Member Thickness (in): $tt := 1.00$

Unthreaded Member Elastic Modulus (ksi): $Eu := 1 \cdot 10^{4}$

Unthreaded Member Thickness (in): $tu := 1.0$

Washer Diameter [D≅1.5xd] (in): $D := 1.75$

Half-Apex Angle (°): $a := 30$

$\alpha := \frac{\pi}{180} \cdot a$ $\quad \alpha = 0.524$ $\qquad Ad := \frac{\pi}{4} \cdot d^{2}$ $\quad Ad = 0.307$

$At := .7854 \cdot \left(d - \frac{.9743}{n}\right)^{2}$ $\quad At = 0.226$ $\qquad kb := \frac{Ad \cdot At \cdot Eb}{Ad \cdot lt + At \cdot ld}$ $\quad kb = 3.77 \cdot 10^{3}$

$$kt := \frac{\pi \cdot Et \cdot d \cdot \tan(\alpha)}{\ln\left[\left[\frac{(2 \cdot tt \cdot \tan(\alpha) + D - d) \cdot (D + d)}{(2 \cdot tt \cdot \tan(\alpha) + D + d) \cdot (D - d)}\right]\right]} \qquad ku := \frac{\pi \cdot Eu \cdot d \cdot \tan(\alpha)}{\ln\left[\left[\frac{(2 \cdot tu \cdot \tan(\alpha) + D - d) \cdot (D + d)}{(2 \cdot tu \cdot \tan(\alpha) + D + d) \cdot (D - d)}\right]\right]}$$

$kt = 36563.17$ $\qquad ku = 36563.17$

$KM := \frac{1}{\frac{1}{kt} + \frac{1}{ku}}$ $\quad KM = 1.83 \cdot 10^{4}$ $\qquad C := \frac{kb}{kb + KM}$ $\quad C = 0.171$

Total Bolt Load from Req. Bolt Tension (kips): $Fb := Rb \cdot At$ $\quad Fb = 6.7$

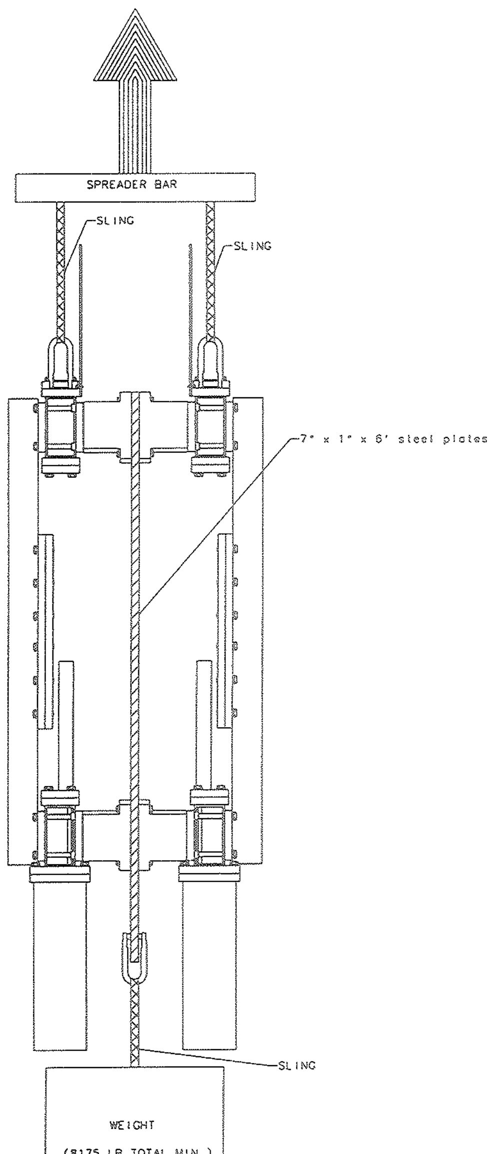
Preload - Clamping Force (kips): $Fi := Fb - C \cdot P$ $\quad Fi = 6.7$

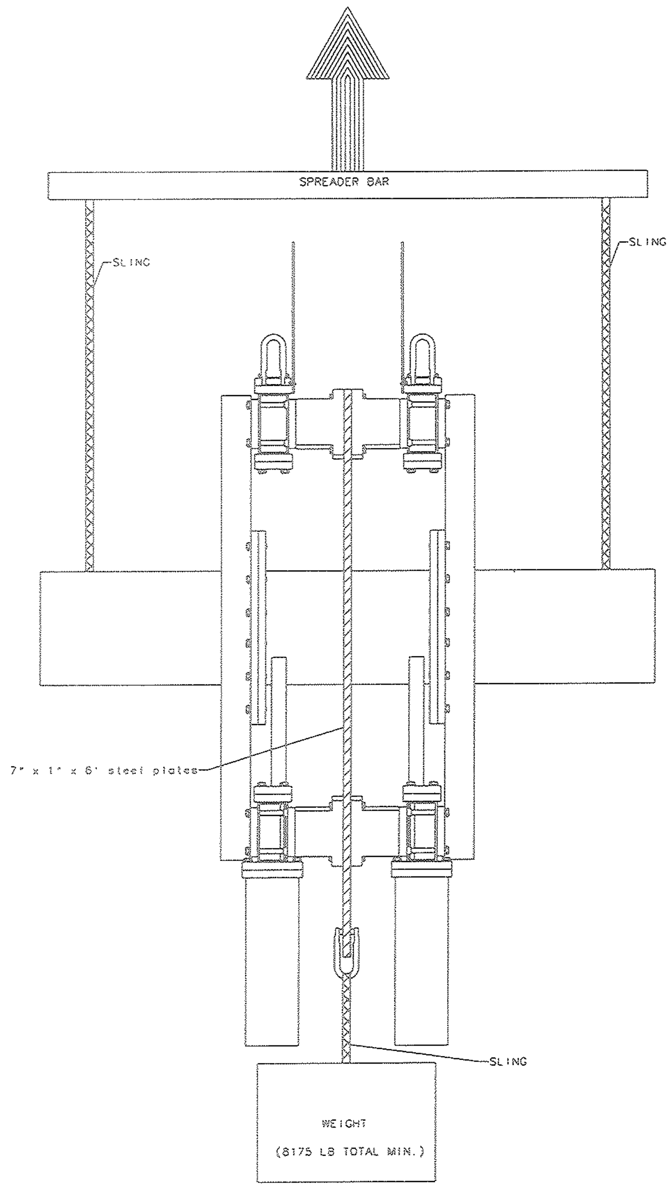
Torque Required (ft-lb): $T := \frac{K \cdot Fi \cdot 1000 \cdot d}{12}$ $\quad T = 105$

3. Load Test

The H Frames should be load tested at 125% of the operational load (6,300 lb + own weight = 7,500 lb) so the test load would be at least 8,175 lb plus own weight, totaling 9,375 lb. The frames should be put together, connected by the lifting arms (dwg # 661) and tested as shown in the next page.

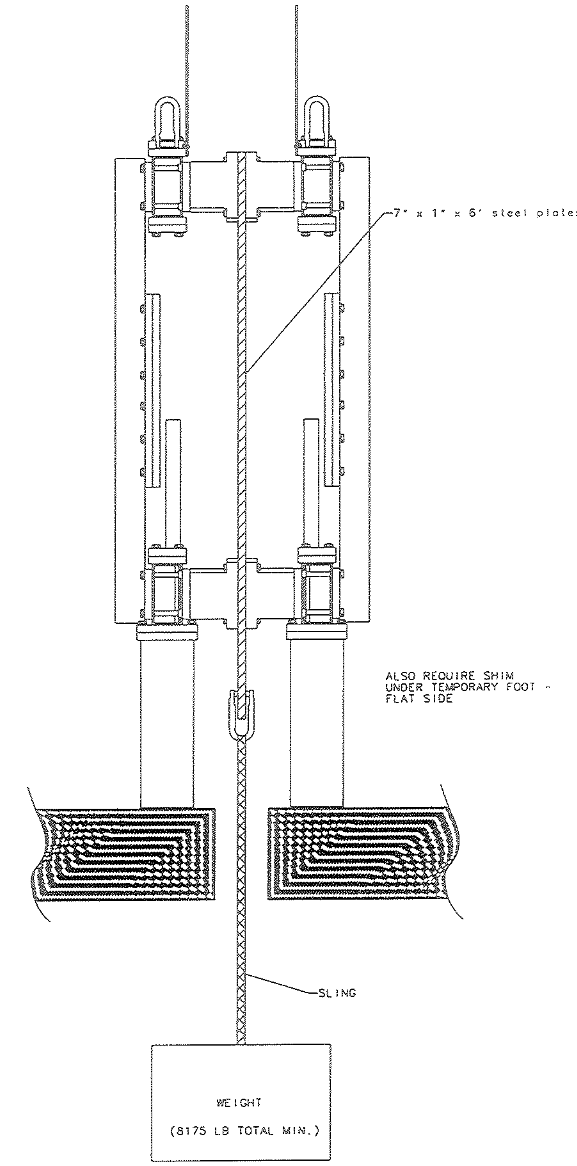
LIFTING TEST





OPERATIONAL TEST

STANDING TEST



Plotted by rafael ~~on 07-May-99, File:~~ H_frame3.pff

4. Drawings

Drawing Number:	Title:
2563.251-MD-339652	PPD/CDF COT H Frame Assembly
2563.251-MB-339458	PPD/CDF COT H Frame Vertical Adjusting Screw
2563.251-MB-339661	PPD/CDF COT H Frame Lifting Arm
2563.251-MB-339662	PPD/CDF COT H Frame Sling Protection Plate - Right Mounting Angle
2563.251-MB-339663	PPD/CDF COT H Frame Sling Protection Plate - Left Mounting Angle
2563.251-MB-339665	PPD/CDF COT H Frame Sling Protection Plate
2563.251-MB-382038	PPD/CDF COT H Frame Sandwich Plate
2563.251-MB-382073	PPD/CDF COT H Frame Horizontal Adjusting Screw
2563.251-MC-339659	PPD/CDF COT H Frame Temporary Foot - Guide Side
2563.251-MC-339660	PPD/CDF COT H Frame Temporary Foot - Flat Side
2563.251-MC-339664	PPD/CDF COT H Frame Center Plate Protection Channel
2563.251-MC-339666	PPD/CDF COT H Frame Center Plate Assembly
2563.251-MD-339653	PPD/CDF COT H Frame Upper Left Horizontal Tube Weldment
2563.251-MD-339654	PPD/CDF COT H Frame Upper Right Horizontal Tube Weldment
2563.251-MD-339655	PPD/CDF COT H Frame Lower Left Horizontal Tube Weldment
2563.251-MD-339656	PPD/CDF COT H Frame Lower Right Horizontal Tube Weldment
2563.251-MD-339657	PPD/CDF COT H Frame Center Plate Weldment
2563.251-MD-382033	PPD/CDF COT H Frame Vertical Tube Weldment

TUBESALES • WILLIAMS
TW
METALS

235 Tubeway Drive
Carol Stream, IL 60188
Ph: 630 / 690-0110
Fax: 630 / 690-2105

FAX COVER SHEET

FAX NUMBER: 840-3694

NO. OF PAGES: 3
(Including Cover Sheet)

COMPANY: Fermi

ATTENTION: Rafeal

DATE: 5/5/99

RE: T.R. for P.O.# 519674 to examine yield strength

FROM,
Stephanie Patton

ALUMAX
DISTRIBUTION & INDUSTRIAL PRODUCTS
CRESSONA, PA 17929 (717) 385-5000

CERTIFIED INSPECTION REPORT
AND TEST RESULTS
WROUGHT PRODUCTS

CODE NUMBER: 02500200
ORDER NUMBER: CT 698332

YARDE METALS, INC.
71 HORIZON DRIVE
BRISTOL CT 06010

INVOICE NO.
INVOICE DATE / /

GROSS WEIGHT: 1328
B/L NO: 808321
DATE SHIPPED / /

YARDE METALS - SOUTHINGTON
OLD PRATT AND WHITNEY BLDG.
45 NEWELL STREET
SOUTHINGTON CT 06489

VIA: OPEN TOP
FOB: DEST N

CUSTOMER P.O NO: P81124CG006
GOVT. CONTRACT NO.

AUTHORIZED SIGNATURE(S)
Elizabeth J. Chirico
ELIZABETH J. CHIRICO 12/11/98
QUALITY SYSTEMS MANAGER

Products as follows
ASTM B 221-96
QQ-A-200/9D AMS-QQ-A-200/9

MARKED

We hereby certify that the material covered by this report has been inspected and tested in accordance with the Seller's standard sampling plan or the requirements of any specifications of the material described in this report and has been found to meet the applicable requirements described herein, and that samples representative of the material met the composition limits and had the mechanical properties shown. Also, note that Mercury is not a normal contaminant in aluminum alloys. Neither Mercury nor any of its compounds are used in the manufacture of our extrusions.

ALUMAX DISTRIBUTION & INDUSTRIAL PRODUCTS

ORDER NUMBER	ALLOY AND TEMPER
698332	6063-T52

ITEM	ITEM DESCRIPTION	PRODUCT CODE	QUANTITY SHIPPED PCS., FT., ETC	WGT. IN LBS OR AS INDICATED
002	RECTANGULAR TUBE 4.000 X 6.000 X .250 WALL SEC 4.000 6.000 .250 LEN 24' WFC (W 5.586 F 07 C 7.20)	R41043	10 PC 240.0 FT 1 BNDL	1317

YARDE METALS, INC. CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE.
RECEIVED AND INSPECTED
DEC 21 1998
BY Darleene E. Madore
DARLEENE E. MADORE
CERTIFICATION CLERK

MECHANICAL PROPERTIES

LOT NUMBER	RACK FROM/TO	NUMBER OF TESTS	TENSILE MIN. (STRENGTH KSI*)	TENSILE MAX.	YIELD*** MIN	YIELD*** MAX.	CONDUCTIVITY MIN.	CONDUCTIVITY MAX.	ELONG % IN 2" OR 4D MIN.	ELONG % MAX.
698332-002	A /A	1	24.9	24.9	18.7	18.7			16.0	16.0

CHEMICAL COMPOSITION IN PERCENT MAXIMUM UNLESS SHOWN AS A RANGE

ALLOY	SILICON	IRON	COPPER	MANGANESE	MAGNESIUM	CHROMIUM	ZINC	TITANIUM
6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	0.10	0.10

OTH/EACH	OTH/TOT	ALUMINUM
0.05	0.15	REMAINDER

A BUSINESS UNIT OF ALUMAX SEMI-FABRICATED PRODUCTS GROUP
* KIPS PER SQUARE INCH. ONE KIP EQUALS ONE THOUSAND POUNDS.
** WHEN 2 OR MORE TESTS PER RACK ARE MADE, THE HIGHEST AND LOWEST VALUES ARE REPORTED.
*** YIELD STRENGTH IS DETERMINED BY THE 0.2% OFFSET METHOD

05 04 99 [signature] YARDE METALS INC

S9012SBJ007-2 T W METALS PO: D8081246 Part #:

1pc 137#

Tifton

TIFTON ALUMINUM COMPANY, INC.
P.O. BOX 188
DELHI, LOUISIANA 71232
An Alcoa Company

ALCOA

CERTIFIED INSPECTION REPORT

ORDER/ITEM NUMBER: 52719-01
LOT NUMBER: 52719-01
PURCHASE ORDER: 90126CB003
PIECES SHIPPED:
POUNDS SHIPPED:
LBS ORDERED: 1,000

CUSTOMER: YARDE METALS INC
71 HORIZON DRIVE
BRISTOL
CT 06010

SHIP TO: YARDE METALS- SOUTHINGTON
OLD PRATT & WHITNEY BLDG
45 NEWELL STREET
SOUTHINGTON
CT 06489

DESCRIPTION:
DIE NUMBER: TA -6192
PART NUMBER: 6192/61
FINISH: SEE ITEM COMMENTS
LENGTH: 24'04"
ALLOY/TEMPER: 6063-T52
COMMENTS: MILL / 4 X 8 X .250 TUBE
ASTMB221-96 / NOT MARKED

CHEMISTRY ALLOY			MECHANICAL PROPERTIES								
			ULTIMATE-KSI			YIELD-KSI			ELONG	HARDNESS	
TYPE	MIN	MAX	MIN	MAX	ACT	MIN	MAX	ACT	PCT	MIN	MAX
SI	.20	.60	22.0	30.0	26.0	16.0	25.0	20.2	18.0		
FE	.00	.35									
CU	.00	.10									
MN	.00	.10									
MG	.45	.90									
CR	.00	.10									
ZN	.00	.10									
TI	.00	.10									
OTHER EA.	.00	.05									
OTHER TOL.	.00	.15									

YARDE METALS, INC. CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE.
RECEIVED AND INSPECTED
MAR 09 1999
BY Darleene E. Madore
DARLEENE E. MADORE
CERTIFICATION CLERK

We hereby certify that the material covered by this report has been inspected in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the material description. The chemical composition limits and mechanical properties limits of the material are set forth above. Samples of the material have been found to meet these requirements. Inspection and test results are maintained on file.

Test Lab, Tifton Delhi:

CERTIFIED BY: [signature]

DATE: 3/01/99

FORM # 15
04-07-93

05-04-99 [signature] YARDE METALS Inc

S90325BU007-1 T W METALS PO: D8081246 Part #:

ZPC 330#

Central Steel & Wire Company

3000 WEST 51st STREET
CHICAGO, IL 60632-2198
1-773-471-3800
P.O. BOX 5100
CHICAGO, IL 60680-5100

PACKING LIST OR DELIVERY RECEIPT
ORIGINAL

WEIGHT SHOWN IS SHIPPING WEIGHT
FOR BILLING WEIGHT SEE INVOICE

99 MAY -5 P2:55

CUSTOMER ORDER	CODE	ID
296	21172 P 1/1	050599 131338

DEREK D SCHUMANN

SOLD TO: FERMI NATIONAL ACCELERATOR LAB
BOX 500 FELDOTT RD
BATAVIA IL 60510-5000

SHIP TO: SAME
KIRK & WILSON ST

456132
OUR ORDER NUMBER 456132

HOUSE & ROUTE: B4 3:30PM 05-06-99

SALESMAN: 053
ZONE: DD

OLIVIA (630) 840-417

QUANTITY ORDERED	SIZE AND DESCRIPTION	CODE	INV	WEIGHT
1 BAR (B3606)	1" X 8" FLAT EXTRUDED ALUM 6061 T6511 12 FT (BLUE) TAG ATTN: DON CARPENTER-MAB			113

CUSTOMER/DRIVER COMMENTS

alan long
5/7/99

BAY	SECTION	PACKING
8	21	1 Bar

COD ORDER
GROSS
DISCOUNT
NET TOTAL

9- 679

RECEIVED, ACKNOWLEDGED AND AGREED TO

EST BILL WT: 113#

MAX LIFT	UNLOAD
5,000	FORK R S

ALL SALES ARE SUBJECT TO THE TERMS AND CONDITIONS IN OUR STOCK LIST AND ON THE REVERSE SIDE

TOTAL P.02