BELOW-THE-HOOK LIFTING DEVICE
Engineering Note Cover Page

Lifting Device Numbers:

FNAL Site No.:_______ (if applicable)   Div. Specific No.: 159 (if applicable)   Asset No. _______ (if applicable)

ASME B30.20 Group: (check one)

- ˇ Group I — Structural and Mechanical Lifting Devices (circled)
- ˇ Group II — Vacuum Lifting Devices
- ˇ Group III — Magnets, Close Proximity Operated
- ˇ Group IV — Magnets, Remote Operated

Device Name or Description: GCM COIL LIFTING FIXTURE

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 (circled)
  Assy drawing number: ____________
- ˇ Provided by a User or Other Laboratory
- ˇ Other. Describe:____________

Engineering Note Prepared by: INGRID FANG   Date : 5/17/06

Engineering Note Reviewed by: [signature] Bob Wands   Date: 5/17/06

Lifting Device Data:

Capacity: 14000

Fixture Weight: ____________

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

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

Inspections Frequency: ____________

Rated Load Test by FNAL (if applicable): Date : 5/17/06   Load: 17,880

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

Satisfactory Load Test Witnessed by: MICHAEL P. ANDREWS

Signature (of Load Test Witness): [signature]

Notes or Special Information:

January 17, 2005

Analysis of CCM Lifting Fixture

Ingrid Fang
Bob Wands

Introduction and Summary

The CCM magnet will be disassembled and moved from its current location into storage. The superconducting coil assemblies must be handled in a way which preserves the possibility of using them again in the future.

The total weight of a single CCM coil is 12,000 lbs.

For the original installation more than twenty years ago, a lifting fixture was created by modifying the same fixture that was used to wind the coils. This fixture attached directly to each of the twelve coil feet (the safest places to attach to the coil assembly, since the feet communicate directly with the robust inner cryostat, and not the thin vacuum shell).

The fixture was used not only to lift the coils, but also to rotate them. This was achieved by adding trunnions to the opposite ends of one span. This rotation allowed the fixture to handle both the upper and lower coils of the magnet.

The fixture as originally used was analyzed according to the requirements of the ASME B30.20-1993 standard for below-the-hook lifting devices. The analysis shows that, for the two rotating load cases, if the material is specified as A36 steel, then the plates to which the trunnions attach are overstressed, as is the long span of beam between trunnions, and the trunnions themselves. In short, as originally constructed, the lifting fixture was operating in some cases with a safety factor of approximately 1.1 based on the yield stress.

Three major modifications were made.

1. The trunnions were specified as ASTM A514 T-1 Gr. Q steel
2. The trunnion plates were increased in thickness and specified as ASTM A514 T-1 Gr. Q steel
3. The long span between trunnions was reinforced by the addition of a 6x6x0.5 A500 Gr. B rectangular tube welded along its upper surface

The resulting structure meets the ASME B30.20-1993 standard for below the hook lifting fixtures.

Geometry and Loading

The geometry for this analysis is shown in drwg. No. 9204.200-ME-435680, which represents the final design including the modifications resulting from this analysis.

The basic structure consists of a spider of six W6x20 beams, spanned at their outer ends by six W6x20 beams. Each junction is reinforced by diagonal W6x12 beams. Half-inch steel plates are welded to the bottom of each of the six corners of the basic structure. Identical plates are welded to the basic structure at the midpoint between junctions, and reinforced with 1/2 inch gussets.

Trunnions are attached to each end of one span, to facilitate rotation. This span sees large loads in the rotational load cases, and is reinforced by the addition of a 6x6x0.5 rectangular tube.

The trunnions attach to the span through steel plates. These plates were increased in thickness from the original design, and specified as the high strength low alloy steel, T-1, as were the trunnions.

The total weight of a CCM coil assembly was estimated by J. Kilmer at 12,000 lbs. This weight was divided evenly over the twelve attachment locations.

Allowable Stresses

The applicable Fermilab standard is ASME B30.20-1993, "Below-the-Hook Lifting Devices." Paragraph 20-1.2.2 of this standard states "A lifter shall be designed to withstand the forces imposed by its rated load, with a minimum design factor of 3, based on yield strength, for load bearing structural components."

Therefore, the maximum primary stress in the lifting fixture must be kept below $F_y/3$ = 12 ksi for A36 steel (F_y = 36ksi), 33 ksi for ASTM 514 T-1 Gr. Q steel (F_y = 100 ksi), and 15 ksi for ASTM A500 Gr. B steel (F_y = 46 ksi)

Allowable weld stresses were limited to 1/3 of the yield of the weaker of the two materials at a connection.

The Finite Element Model

A finite element model of the lifting fixture was created using about 45k four-node shell elements. This model is shown in Fig. 1.

Loading was simulated by applying nodal forces to the outer perimeters of the plates which attach to the CCM coil feet, as shown in Figs 2 and 3 for the horizontal and vertical fixture orientations. In addition to these forces, the weight of the fixture was also included in the model by specifying the steel density and appropriate gravitational acceleration.

The lifting eyes for the pick points in Load Case 1 were not explicitly modeled. Instead, a single node was constrained corresponding to the location of each pick point. Stress calculations for the lifting eye are given in Appendix I.

For the trunnion support cases, each trunnion was constrained at the midpoint of its six inch length, over an arc of 180 degrees oriented such that the constraints put the surface of the trunnion in compression.

Three load cases were considered:

1. Lift by four pick points in horizontal orientation
2. Lift by trunnions in horizontal orientation during rotation
3. Lift by trunnions in vertical orientation during rotation .

These three load cases are shown in Fig. 4.

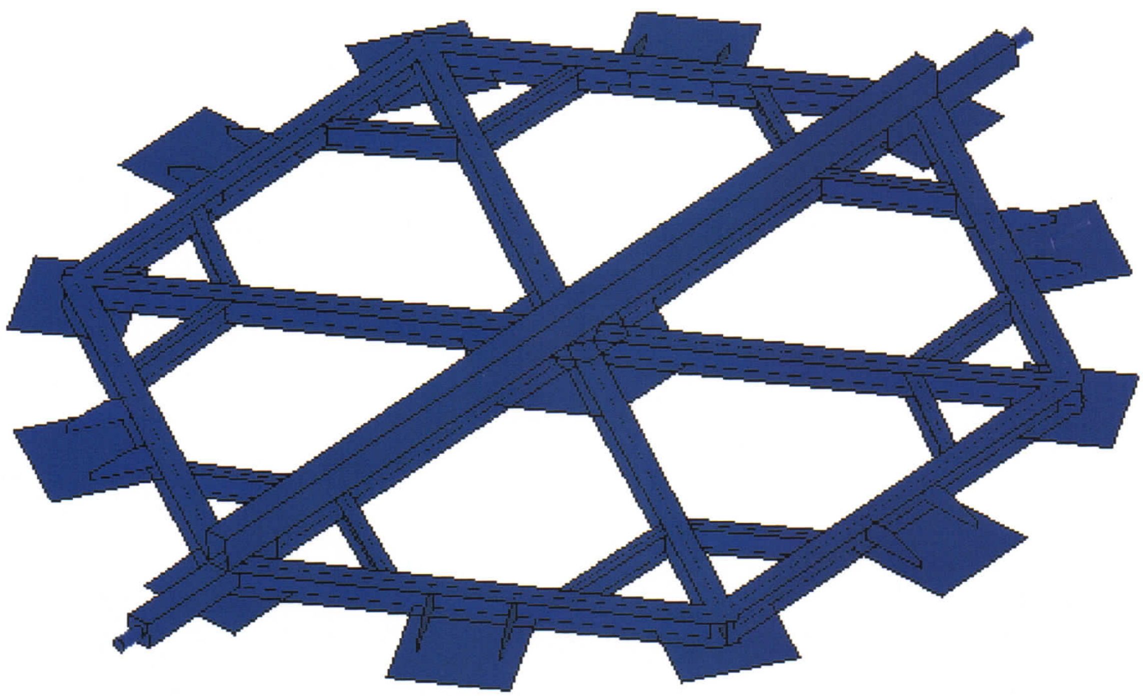


Figure 1. Finite Element Model of CCM Lifting Fixture

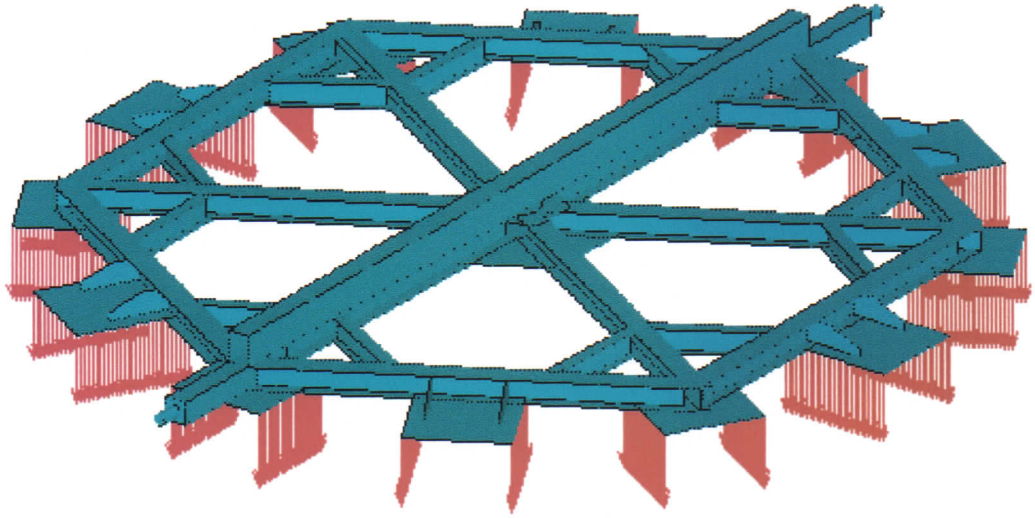


Figure 2. Force Application for Horizontal Orientations

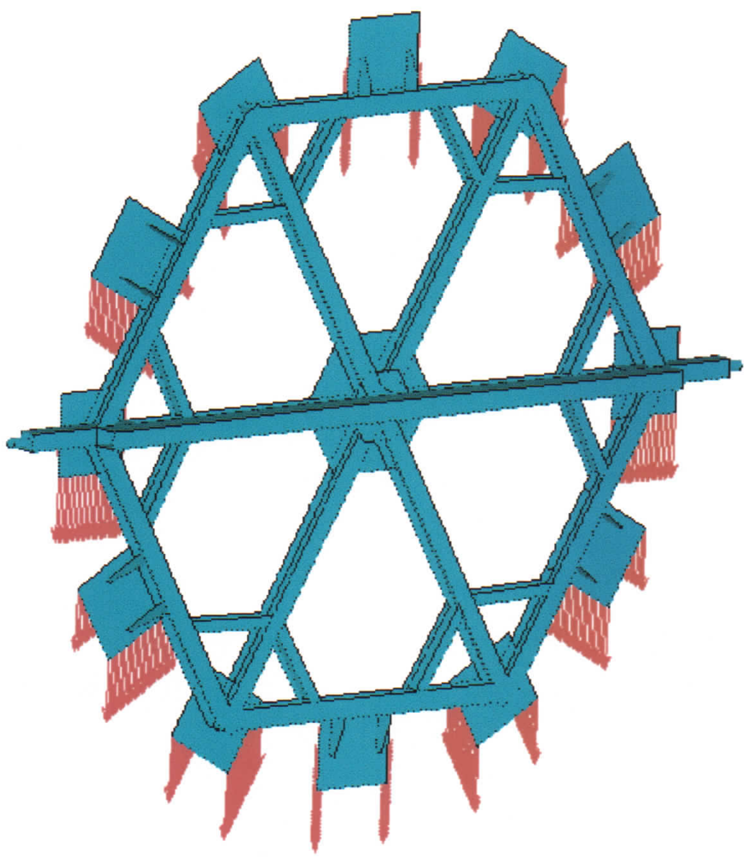
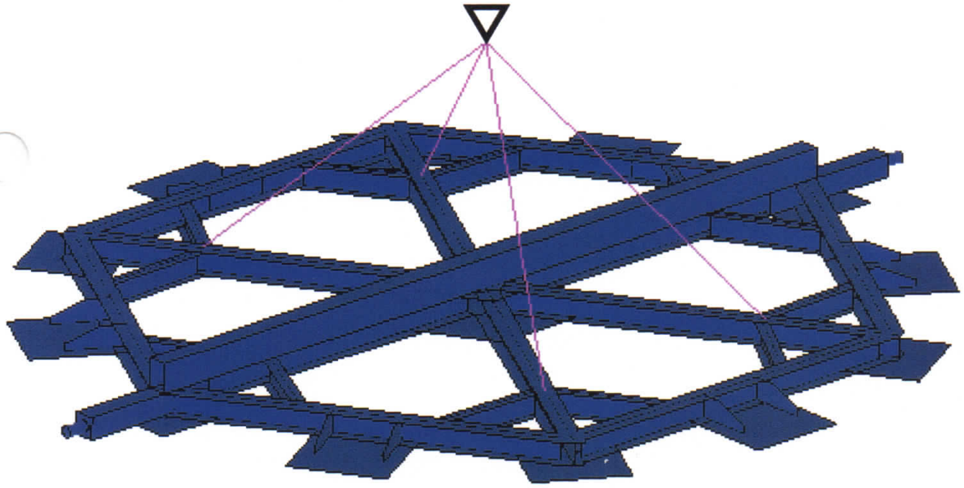
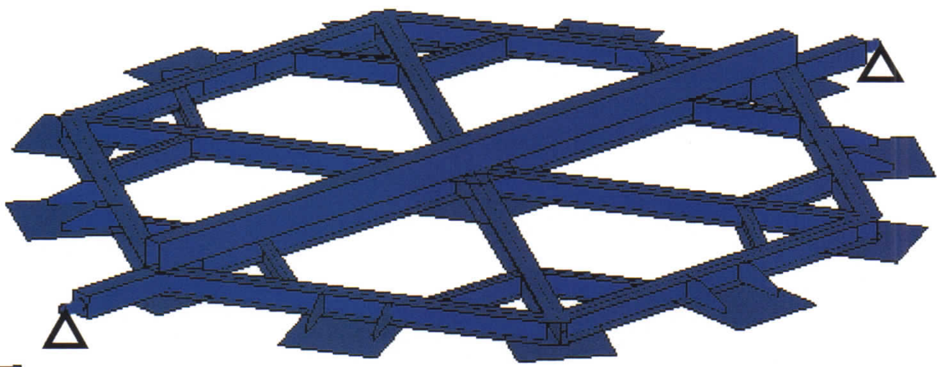


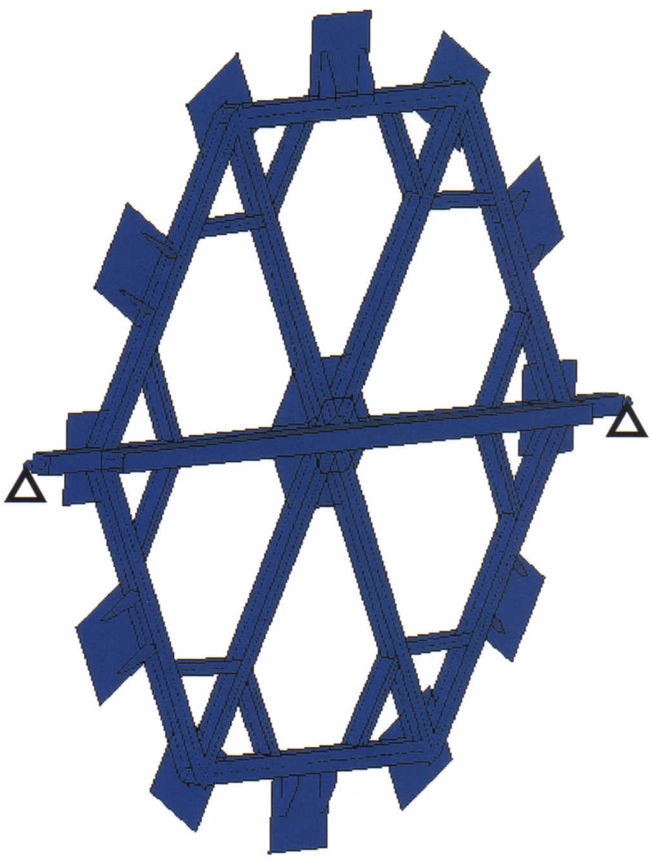
Figure 3. Force Application for Vertical Orientation



Load Case 1. Lift by Four Pick Points in Horizontal Orientation



Load Case 2. Lift by Trunnions Horizontal Orientation



Load Case 3. Lift by Trunnions in Vertical Orientation

Figure 4. The Three Load Cases

Results

Load Case 1

The deformed shape of the lifting fixture for load case 1 is shown in Fig. 5. The maximum deflection is 0.12 inches, and occurs at the end of the span between trunnions.

The stresses in the fixture for load case 1 are shown in Fig. 6. The maximum stress intensity is greatest at the four pick points; this is because the lifting eyes were not explicitly modeled. Instead, a single node at each location was used to attach the spar element which simulated the lifting sling. Therefore, at each pick point, the model produces fictitious stress concentrations which are ignored.

In the regions away from the concentrations, all stresses are below the 12 ksi limit for A-36 steel.

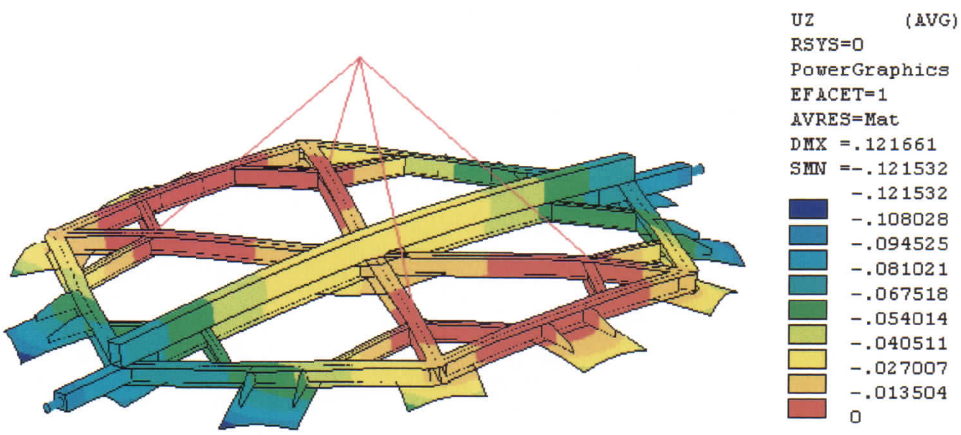


Figure 5. Vertical Deformation for Load Case 1

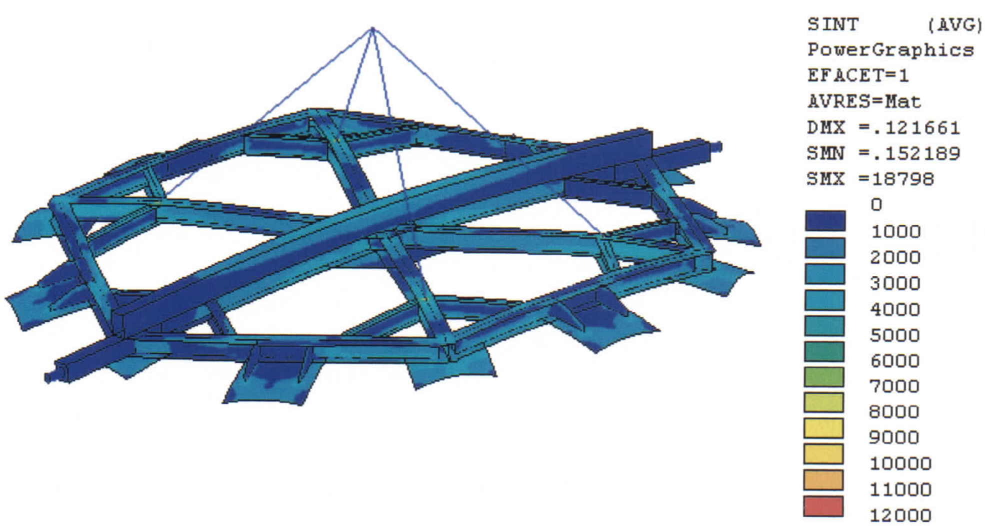


Figure 6. Stresses in Fixture for Load Case 1

Load Case 2

The deformed shape of the lifting fixture for load case 2 is shown in Fig. 7. Because the fixture is supported on the trunnions, the center deflects 0.88 inches downward.

The stresses in the fixture for load case 2 are shown in Fig. 8 for the A36 and A500 steel components. Small concentrations appear at locations where members are attached to each other at the center; however, a short distance away from these locations, the stresses are 12 ksi or below.

Fig. 9 shows the T1 steel plate and trunnion. The stress plot shows the areas of highest stress; these stresses are below the 33 ksi limit for the T1 steel. To ensure that stress averaging has not reduced the apparent stresses, the trunnion and plate were considered separately, and their primary stresses linearized across the most highly stressed sections of each. The figure shows the results of linearizing the stresses. The linearized primary stresses are 9.3 ksi and 25.9 ksi for the trunnion and plate, respectively.

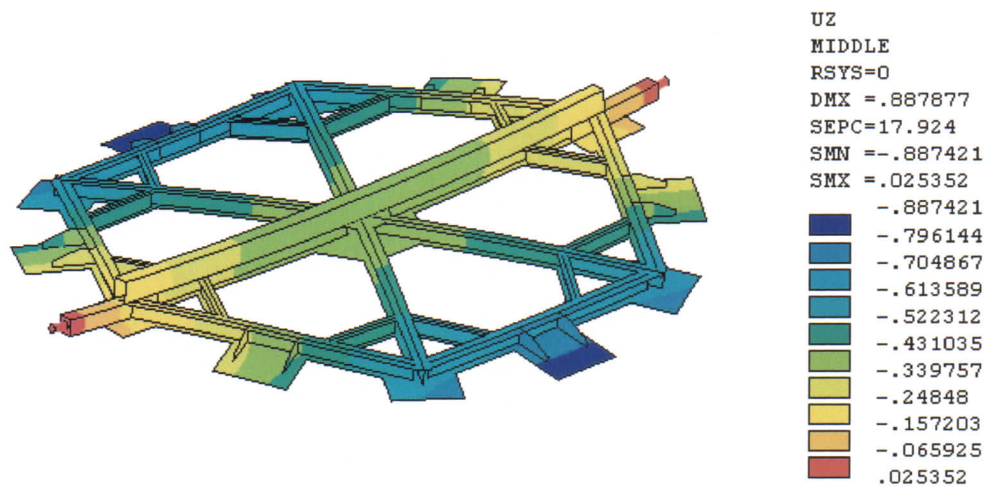


Figure 7. Vertical Deformation for Load Case 2

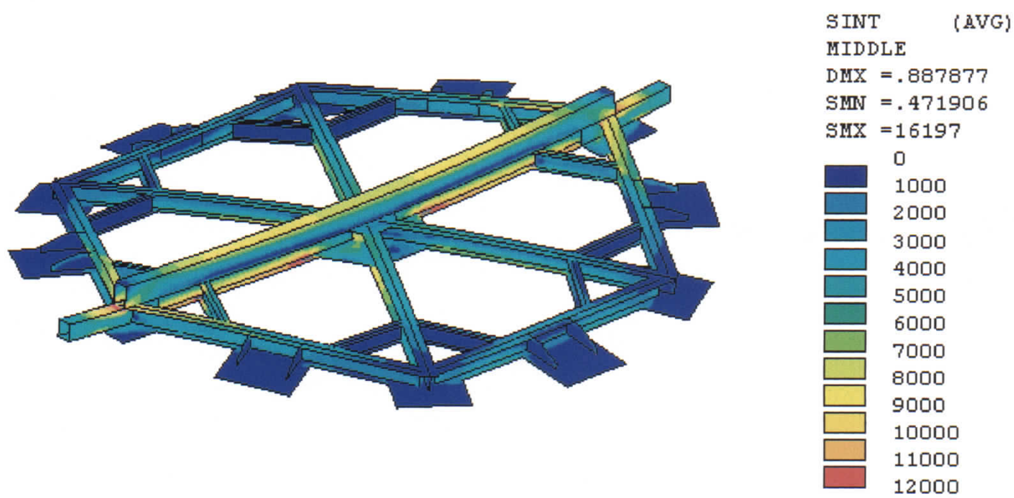


Figure 8. Stresses in Fixture for Load Case 2

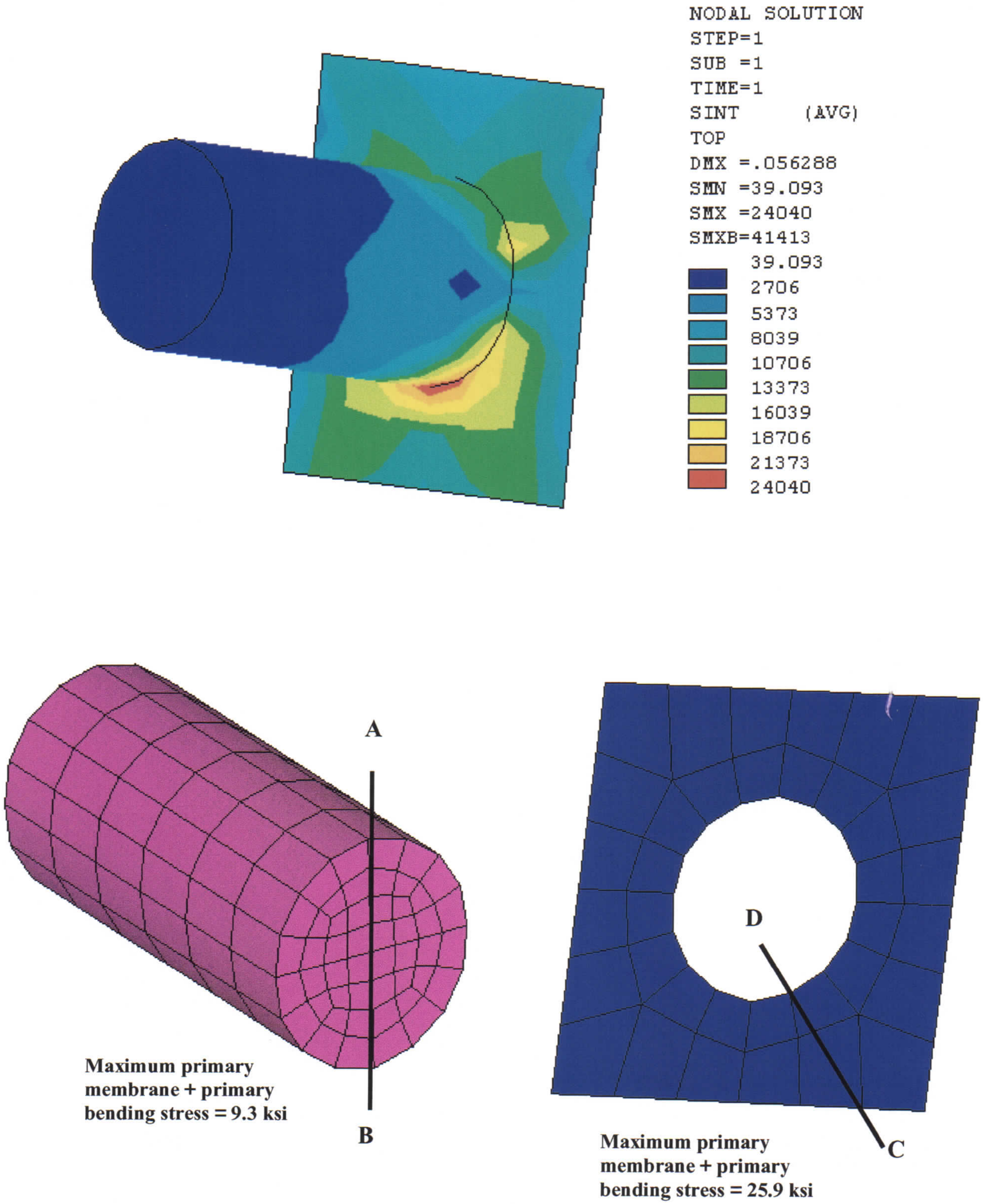


Figure 9. Stresses in Trunnion and Plate – Horizontal Load Case

Load Case 3

The deformed shape of the lifting fixture for load case 2 is shown in Fig. 10. The maximum deflection is 0.13 inches, and occurs at the four loaded plates nearest the trunnions. This displacement is a combination of the deformation of the centerspan between trunnions, and the local deformations of the short faceting beams to which the plates are attached.

The stresses in the fixture for load case 3 are shown in Fig. 11 for the A36 and A500 steel components. As in the case of load case 2, highly localized concentrations appear at locations where members are attached to each other, this time toward the end of the trunnions (these occur at the ends rather than the center because in this orientation the depth of the fixture is very large, essentially the diameter, which moves the highly stresses regions toward the ends); however, a short distance away from these locations, the stresses are 12 ksi or below.

Fig. 12 shows the T1 steel plate and trunnion. The stress plot indicates the areas of highest stress; these stresses as plotted include stress concentrations. (It should be noted that the T1 plate is not square, and in this orientation the trunnion reaction produces higher plate stresses than in the horizontal orientation). This plot was used as a guide to identify the most highly stressed section in each component. The stresses across these sections were linearized to exclude the effects of concentrations. The figure shows the results. The linearized primary stresses are 18 ksi and 31.5 ksi for the trunnion and plate, respectively.

The stress in the trunnion is substantially larger than it is in the horizontal load case. This is because the trunnions were used in the finite element model to rotationally constrain the fixture. While there is very little torque around the trunnions in the horizontal load case, in the vertical load case the torque is considerable, due to the offset of the forces from the trunnion axis. It is unlikely that the trunnions will be used to resist torques in practice; this will most likely be done with slings attached to other parts of the structure. However, even with this large torque included in the model, the resulting stresses are below the T1 allowable of 33 ksi.

Welds (all load cases)

Welds were checked by extracting nodal forces from the finite element model at the weld locations, and performing hand calculations of weld strength. The weld stress was limited to 1/3 of the base metal strength of the weakest material at a connection.

Each weld in the structure was examined for each load case, and found to be adequate.

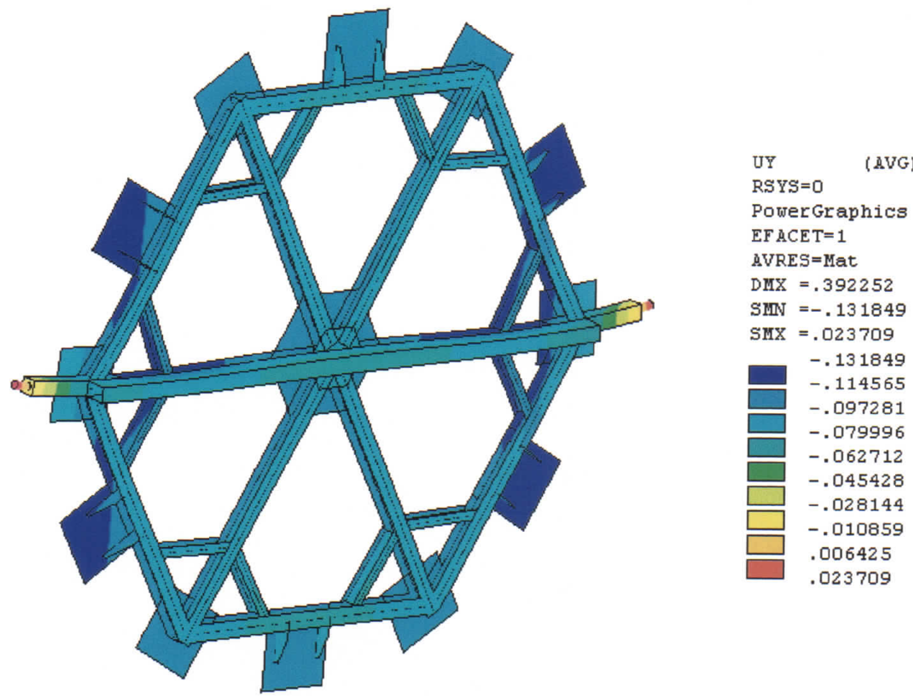


Figure 10. Vertical Deformations for Load Case 3

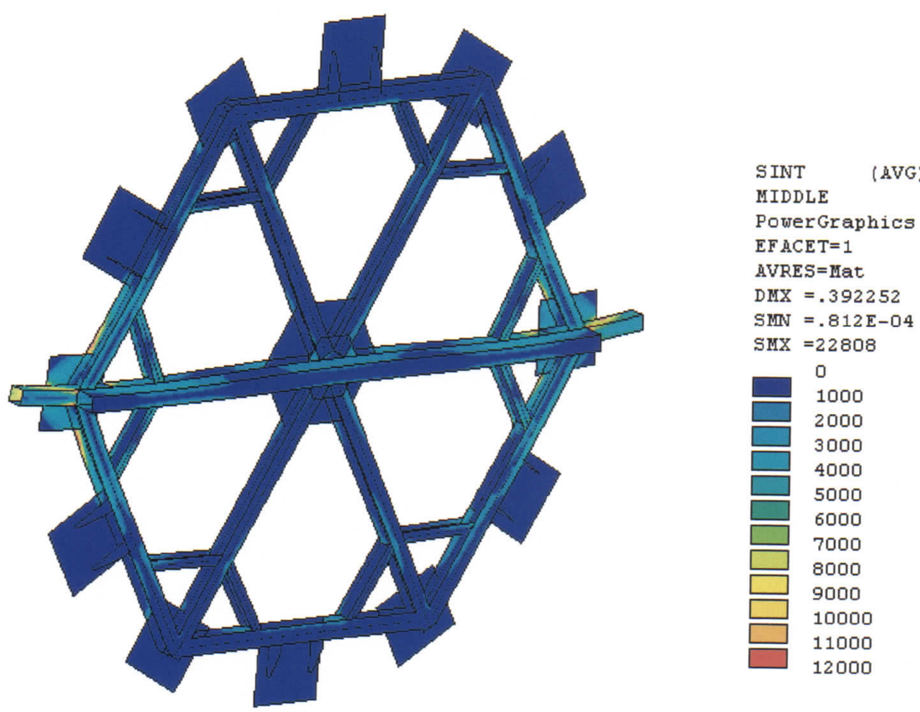


Figure 11. Stresses in Fixture for Load Case 3

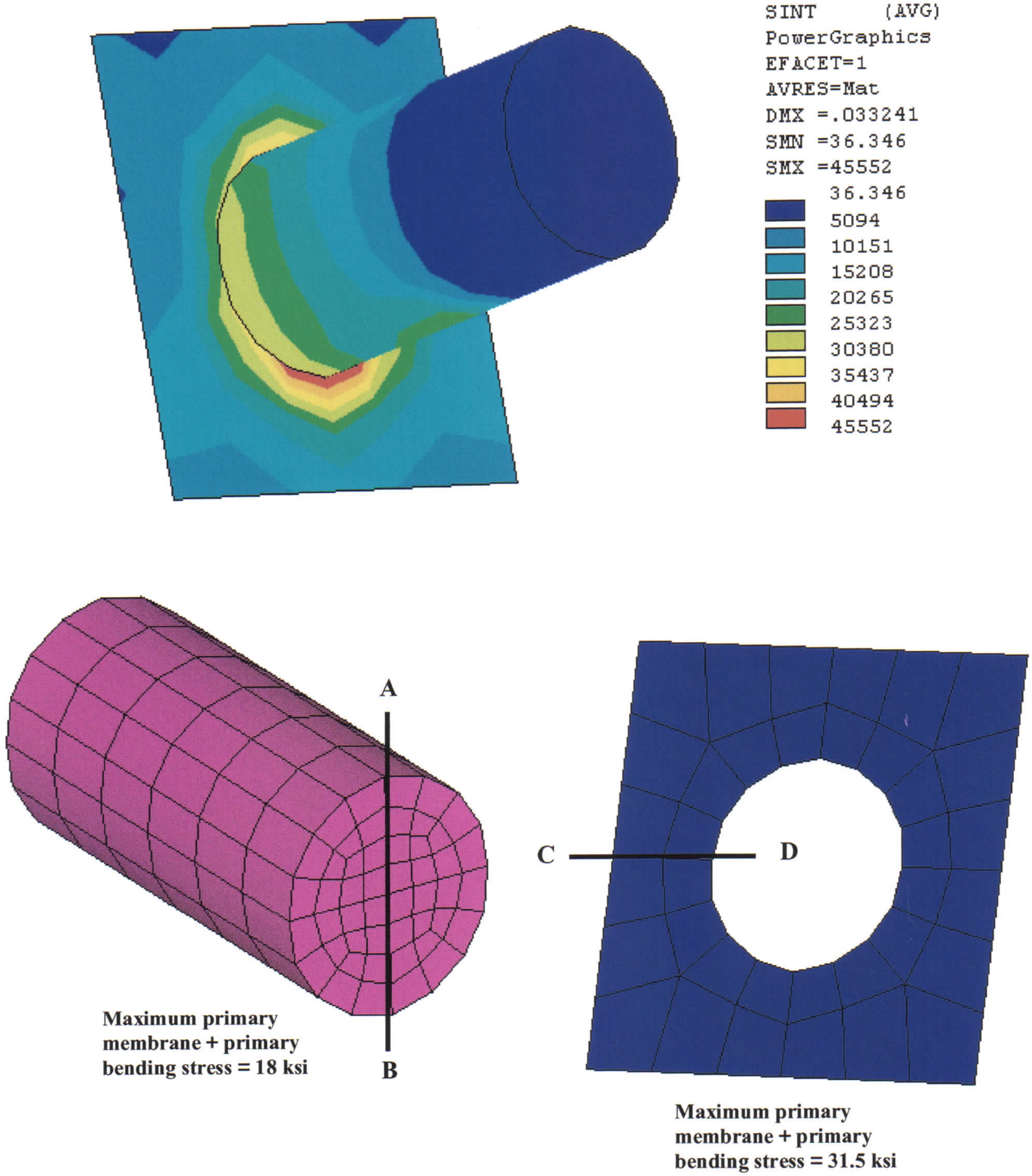


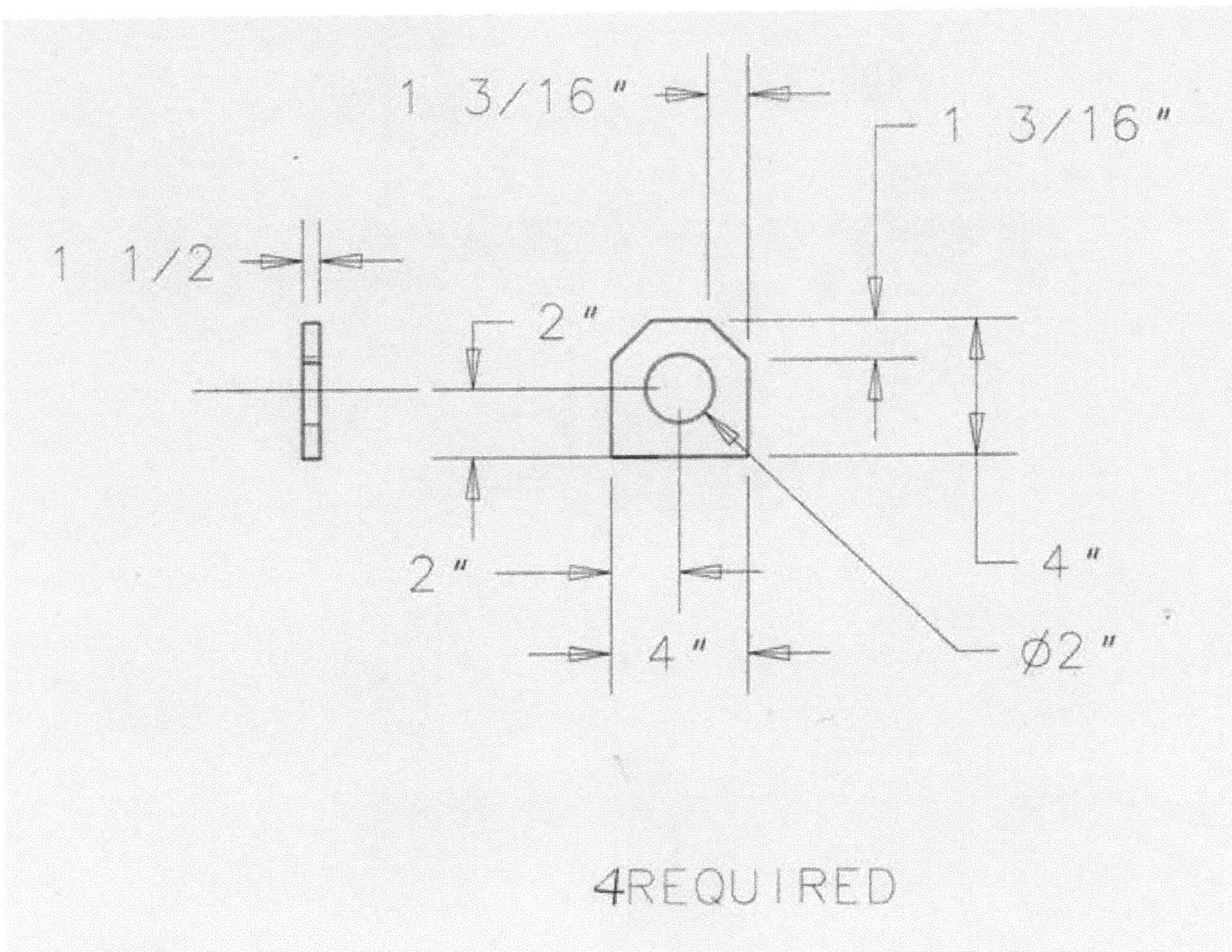
Figure 12. Stresses in Trunnion and Plate – Vertical Load Case

Conclusion

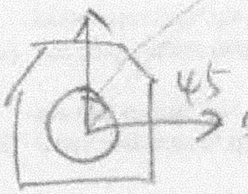
The CCM lifting fixture, modified as recommended in this report, meets the Fermilab below-the-hook lifting device requirements.

Appendix I

Design of Lifting Lugs



Lifting Lug: $12000/4 = 3000$ lbs ①



$F_x = 3000$ lbs

$F_y = 3000$ lbs

$F_z = 10\% \times 3000 = 300$ lbs

— shear $f_{vy} = \frac{3000}{(4-2)\times 1.5} = \frac{3000}{2.5} = 1200$ psi

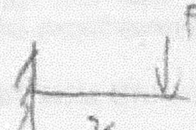
$f_{vx} = \frac{3000}{((1.1875)\times 1.5} = \frac{3000}{1.78} = 1685$ psi

$f_v = \sqrt{f_{vy}^2 + f_{vx}^2} = \sqrt{1200^2 + 1685^2} = 2.06$ ksi < 12 ksi

$F_v = \frac{1}{3} \times 36 = 12$ ksi

OK

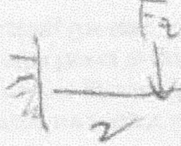
— Bending:



$M = 3000 \times 2 = 6000$ lbs

$S = \frac{bh^2}{6} = \frac{1/2 \times 4^2}{6} = 4$ in^3

$f_{bx} = \frac{M}{S} = \frac{6000}{4} = 1500$ psi



$M = 3000 \times 2 = 6000$ lbs

$S = \frac{4 \times 1.5^2}{6} = 1.5$ in

$f_{bz} = \frac{6000}{1.5} = 4000$ psi

(2)

Tensile:

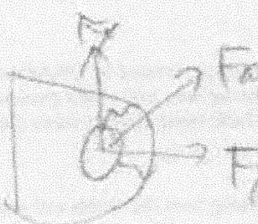
$$f_a = \frac{F}{A} = \frac{3000}{(4 \times 1\tfrac{1}{4}) - (2 \times 1\tfrac{1}{4})} = \frac{3000}{2.5} = 1200 \text{ psi}$$

Combined stress

$$\frac{f_a}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0$$

$$\frac{1.2}{12} + \frac{1.5}{12} + \frac{4}{12} = 0.55 < 1.0 \quad \text{OK}$$

Tear out shear



$$F_{xy} = \sqrt{F_x^2 + F_y^2}$$

$$= \sqrt{2} \times 3000$$

$$= 4242 \text{ lbs}$$

$$f_v''' = \frac{4242}{2 \times 1.1875 \times 1.5} = 1.190 \text{ ksi}$$

< 12 ksi

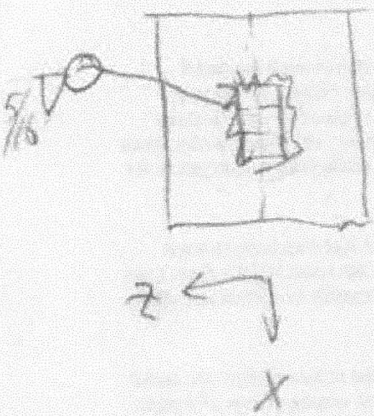
OK

Bearing stress

$$f_p = \frac{F_{xy}}{dt} = \frac{4242}{1 \times 1.5} = 2828 \text{ psi} < 12 \text{ ksi}$$

OK

Design the welds   Fillet weld   ③



$F_x = 3000\ lbs$ (Shear)

$F_y = 3000\ lbs$ (Tension)

$F_z = 300\ lbs$ (Shear)

$M_z = 6000\ lbs$ (Bending)

$M_x = 6000\ lbs$ (Bending)

$$f_t = \frac{3000}{(1.5+4)\times 2} = \frac{3000}{11} = 273\ lb/in$$

$$f_{vx} = \frac{3000}{8} = 375\ lb/in$$

$$f_{vz} = \frac{300}{3} = 100\ lb/in$$

$$f_t' = \frac{M}{S_w} = \frac{6000}{bd + \frac{d^2}{3}} = \frac{6000}{(1.5\times 4) + \frac{4^2}{3}} = \frac{6000}{11.33} = 529\ lb/in$$

$$f_t'' = \frac{M}{S_w} = \frac{6000}{bd + \frac{d^2}{3}} = \frac{6000}{(4\times 1.5) + \frac{1.5^2}{3}} = \frac{6000}{6.75} = 888.8\ lb/in$$

$$f_v = \sqrt{(f_t + f_t' + f_t'')^2 + f_{vx}^2 + f_{vz}^2}$$

$$= \sqrt{(273+529+889)^2 + 375^2 + 100^2} = 1734\ lb/in$$

allowable:

(6)

$12 \times 0.707 \times \frac{5}{16} = 2.6$ kip/in < 1.734 kip/in

O/K

The following drawing is part of Lifting Fixture 159 documentation but is not available electronically.

Please refer to Lifting Device Book #8 to view this drawing.

9204.200-ME-435680