Fermilab

Particle Physics Division

Mechanical Department Engineering Note

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Project: MINERvA

Project Internal Reference:

Title: MINERvA Water Detector Lifting Fixture and Support

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Key Words: MINERvA, Water Detector, Lifting Fixture

Abstract/Summary:

As stated in the introduction to the finite element analysis section of this note, the MINERvA detector consists of series of closely spaced detector planes. The Water Detector will be inserted into an eleven inch gap intentionally left between planes in this Detector. The pulley system that connects the crane hook to the crane cabling is too large to fit into this eleven inch gap. This means that the insertion of the Water Detector into the Main detector will have to be a two step process.

First, the crane hook will attached directly to the top of this support structure and the Water Detector will be lowered onto two temporary support columns that are bolted to the existing support rails of the main Detector. The support structure will be bolted to the top of these columns and the crane hook will be removed from the top of the support

structure. Next, a lifting sling will be attached between the crane hook and the lifting structure. The temporary columns will be removed while the crane is supporting the Water Detector. Finally, the Water Detector will be lowered into final position and bolted to the support plates that were bolted to the Main Detector support rails to hold the temporary columns.

The following manual calculations verify that the support structure will meet both AISC Steel specifications and ASME Codes. The attached Finite Element Analysis also proves that the stresses in this support structure are below the allowable for both codes.

Applicable Codes:

Manual of Steel Construction, ASD, Ninth Edition, American Institute of Steel Construction, Inc. 1989

Design of Below-the-Hook Lifting Devices, ASME BTH -1-2005, American Society of Mechanical Engineers, 2006

Below-the Hook Lifting Devices, ANSI/ASME B30-20, American Society of Mechanical Engineers, 1993

Engineering Manual, Fermi National Accelerator Laboratory, 07/09 Edition

MINERVA 10 FT. WATER DETECTOR — LIFTING FIXTURE/SUPPORT DESIGN — R. J. WOODS — MAY 10, 2011 — 1

DETECTOR WITH WATER = 5000#
STAND (HSS 8x8x½) = 1000# AREA = 14.4 IN^2 S = 32.9 IN^3

SPAN BETWEEN SUPPORTS = 156"
SPACING OF DETECTOR ATTACHMENT POINTS = 48.11"

CASE #1 — STATIC SUPPORT

M = P x a
= 3000(53.945#)
= 161835 #-IN

a = (156 - 48.11)/2
= 53.945"

FOR LIFTING FIXTURE $F_b = 0.33 F_y$
= 0.33 (46)
= 15.33 KSI

S_x REQ'D = 161835/15,333
= 10.6 IN^3

S_x OF HSS 8x8x½ TUBE = 32.9 IN^3 > 10.6 IN^3 ok

MAXIMUM SHEAR STRESS = 14.4 (15,333 psi)
= 220795#
ACTUAL SHEAR STRESS = 3000# < 220795# ok

CASE #2 — LIFTING FIXTURE ℓ = 24.055

M = Pℓ/4 = 6000 (24.055)/4
= 36083 #-IN

S_x REQ'D = 36083/15,333
= 2.4 IN^3 < 32.9 IN^3 ok

ACTUAL SHEAR STRESS = 3000# < 220795# ok

USE HSS 8x8x½

BASE PLATE
SIZE = 12 5/16 x 10 x ½ LOAD = 3000# VERT
3600# HORIZ

P_H = 600# M_{TOT} = 600(59.75)
= 35850 #-IN

M℄ PLATE = 35850/2 = 17925 #-IN

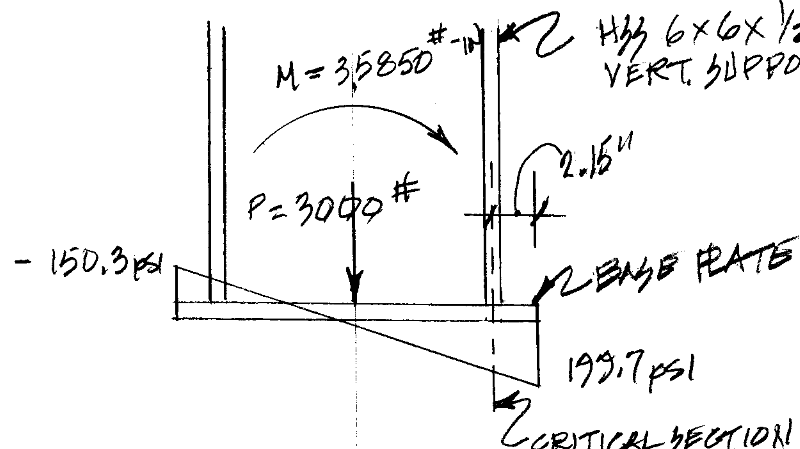
$I_{℄} = \frac{12.3125(10)^3}{12} = 1026\ IN^4$

$Mc/I = \frac{35850(5)}{1026} = 175$ PSI

$P/A = 3000 / 12.3125 \times 10$
$= 24.4$ psi

$P/A \pm \frac{Mc}{I} = 24.7 + 175$; $24.7 - 175$
$= 199.7$ psi ; -150.3 psi

CRITICAL SECTION $= (10 - 0.95(6))/2$
$= 2.15''$ 2.15



BEARING STRESS @ CRITICAL SECTION:
$-150.3 - (199.7) = 350$ psi
$350 \text{ psi} / 10\text{IN} = 35 \#/\text{IN}$

$199.7 - 2.15(35) = 124.5$ psi 124.5
LOAD $= 2.15 \frac{(124.5 + 199.7)}{2} = 348.5\#$ 348.5

C.G OF LOAD $= \frac{2.15(2(199.7) + 124.5)}{3(199.7 + 124.5)} = 1.16''$

$M_{PL} = 348.5(1.16) = 404.3$ #-IN/IN
$t_{PL} = \sqrt{6M/F_B} = \sqrt{\frac{6(404.3)}{0.75(36{,}000)}} = 0.300''$
USE 1/2" THICK PLATE > 0.300" <u>OK</u>

ANCHOR BOLTS:
SPACING = 4.5"
TENSION PER BOLT = 35850/4.5(2) = 3983 #
ALLOW TENSION ON 3/4"φ GRADE 5 = 19,400# > 3983#
SHEAR/BOLT DUE TO HORIZONTAL LOAD =
3600/4 = 900#
ALLOW SHEAR ON 3/4"φ GRADE 5 = 7500# > 900#
COMBINED LOADS
$3983/19{,}400 + 900/7500 \overset{?}{\leq} 1.0$
$0.325 < 1.0$ <u>OK</u>
USE 4 - 3/4"φ GRADE 5 BOLTS

WELD BETWEEN TUBE & PLATE:

TENSION = M @PLATE / 6"
= 17925 / 6 = 2988#

SHEAR = 3600# TOTAL = 1800#/FACE (FROM ANSYS)

TRY 1/4" WELD, 6" LONG

ALLOW. TENSION = 0.60 (46,000)(.707)(1/4)
= 4878#/IN = 29270# FOR 6"

ALLOW. SHEAR = 0.3(70,000)(.707)(1/4)
= 3712#/IN = 22 272# FOR 6"

COMBINED LOAD:

$2988/29278 + (1800)/22\,272 \overset{?}{\leq} 1.0$

$0.183 < 1.0$ OK

USE 6" OF 1/4" WELD EA. SIDE OF TUBE

TEMPORARY VERTICAL SUPPORT STRUT:

VERTICAL LOAD = 3000#
HORIZONTAL LOAD = 3600# ⊥ RAIL
= 600# // RAIL

HORIZONTAL LOAD MOMENTS:

⊥ RAIL = 3600(22.875)
= 82 350#-IN

$S = 16.8\ IN^3$ FOR HSS 6 x 6 x 1/2
b = 6" t = 0.5" b/t = 6/0.5 = 12
FROM TAB. B5.1 p. 5-36, MEMBER IS COMPACT
IF $b/t < 190/\sqrt{F_y} = 190/(\sqrt{46}) = 28 > 12$
∴ TUBE IS COMPACT
$F_b = 0.66 F_y = 0.66(46,000)$
$= 30,360$ PSI
$f_b = 82,350/16.8 = 4902$ PSI $< 30,360$ OK

// RAIL = 600 (82.625")
= 49575 #-IN
$f_b = 49575/16.8 = 2951$ PSI $< 30,360$ OK

AXIAL LOAD

AREA OF TUBE = 10.4 IN²

FOR BOX SECTION, $l/r_{EQUIV} = \sqrt{\frac{5.1\, l\, S_x}{\sqrt{J}\, F_y}}$ P 5-147

$$l/r_{EQUIV} = \sqrt{\frac{5.1(22.875)(16.8)}{\sqrt{85.6}(50.5)}}$$

$= 5.4$

$K = 2.0$

$Kl/r = 2.0(5.4) = 10.9$

$C_c = 111.6$ FOR $F_y = 46$ p 5-120

$111.6 > 10.9 \therefore$

$$F_a = \frac{\left[1 - \frac{(Kl/r)^2}{2C_c^2}\right]F_y}{5/3 + \frac{3(Kl/r)}{8C_c} - \frac{(Kl/r)^3}{8C_c^3}}$$ E2-1 p 5-42

$$= \frac{\left[1 - \frac{(10.9)^2}{2(111.6)^2}\right]46}{5/3 + \frac{3(10.9)}{8(111.6)} - \frac{(10.9)^3}{8(111.6)^3}}$$

$= 26.88$ KSI $= 26,880$ psi

$f_a = 3000/10.4 = 289$ psi $< 26,880$ psi ok

COMBINED LOADS:

$$f_{bx}/F_{bx} + f_{by}/F_{by} + \frac{f_a}{F_a} \overset{?}{\leq} 1.0$$

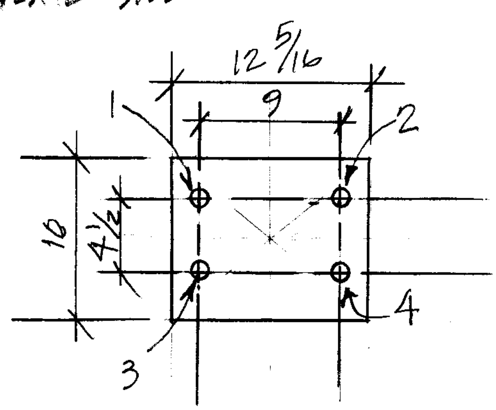
$4902/30,360 + 2951/30,360 + 289/26,880$

$= 0.269 < 1.0$ OK

USE HSS 6×6×1/2

BASE PLATE & TOP PLATE:

PLATE SIZE = 12 5/16 × 10"



BOLT LOADS:

TENSION: MAXIMUM ON BOLTS 1 & 3

$M \perp = 82350$ #-IN

$82350/9 = 9150$ # (FOR 2 BOLTS)

$= 9150/2$

$= 4575$ #/BOLT

$M \parallel = 49575$ #-IN

$49575/4.5 = 11017$ # (FOR 2 BOLTS)

$= 11017$ #/2

$= 5508$ #/BOLT

TOTAL TENSION = 4575 + 5508 = 10083 #

FROM TABLE 1-A p 4-3 ALLOW. TENSION ON 3/4" ϕ A325 BOLT = 19.4 K = 19,400 # > 10083 # OK

SHEAR:

LOAD/BOLT = 3600/4

= 900 #

$f_V = 900/.4418$

$= 2037$ psi

$F_V = 21{,}000$ psi (FROM TABLE 1-D p 4-5)

COMBINED LOADS

$$f_{T_1}/F_T + f_{T_2}/F_T + f_V/F_V \overset{?}{\le} 1.0$$

$$4575/19{,}400 + 5508/19{,}400 + 2037/21{,}000 = 0.6167 < 1.0 \text{ OK}$$

USE 3/4" ϕ A325 BOLTS

TOP CONNECTION BETWEEN TARGET & FRAME

VERT. LOAD = 5000 #/2 SUPPORTS = 2500 #/SUPPORT (WEIGHT OF FULL TARGET MINUS LIFTING FIXTURE)

CATAGORY A (2-2.1) p.11

MIN. WELD SIZE = 3/16" (TAB. 3-3) p.27

MAX. WELD SIZE = 8/16 − 1/16 = 7/16" p.27

$N_d = 2.00$ (3-1.3) p.13

$$F_V = \frac{0.60(70{,}000)}{1.20(2.00)} = 17{,}500 \text{ psi} \quad (3\text{-}53) \text{ p.26}$$

ALLOWABLE LOAD = 0.707(5/16)(17,500) = 3866 #/IN OF WELD

SIZE OF BLOCK = 3" x 3"

LENGTH OF WELD = 3" − (2(½")) = 2"

FOR 2 SIDES − 2 x 2 = 4" OF USEABLE WELD

ALLOWABLE LOAD = 4(3866#)

= 15,466 # > 2500# ok

USE 5/16" WELD ON ALL SIDES OF BLOCK

CHECK CLEVIS PIN:

McMASTER # 98306A566

MATERIAL = C1010 STEEL

$F_y = 44,000$ psi

PIN ϕ = 0.75" $A = \frac{\pi(0.75)^2}{4} = 0.4418\ IN^2$

ALLOWABLE SHEAR = 44,000/3(0.4418)

= 6480# SINGLE SHEAR

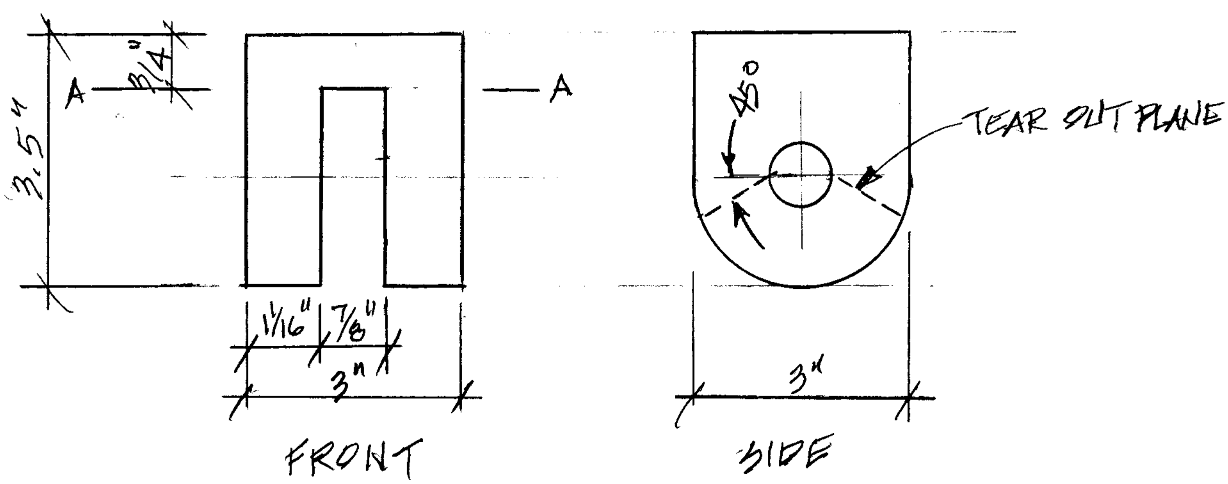
= 12960# DOUBLE SHEAR

> 2500# ok

CHECK BRACKET:

MATERIAL = A36 STEEL

$F_y = 36,000$ psi



TENSION @ PLANE A-A:

AREA = 2(1.0625x3) = 6.375 IN²

ALLOWABLE TENSION = 36,000/3 = 12,000 psi

$P_{ALLOW} = 6.375(12,000)$

= 76,500# > 2,500# ok

TEAROUT AREA = $(1.5 - 0.9/2)(1.0625)$
$= 1.12 \text{ IN}^2$

$F_V = 36{,}000/3 = 12{,}000$ PSI

$f_V = (2500/2)/1.12 = 1116 \text{ PSI} < 12{,}000 \text{ PSI}$

OK

USE BRACKET AS SHOWN.

CHECK BOLTS CONNECTING TEMPORARY VERTICAL SUPPORT TO RAIL.

LOADS: (FROM PAGE 3)

MOMENT // RAIL = 49575#"

BOLT SPACING = 8"

TOTAL LOAD = 49576/8 = 6197#

FOR DOUBLE SHEAR, LOAD = 6197/2
= 3098.5#

MOMENT ⊥ RAIL = 82350#-"

SPACING = 4" + 0.5(2) = 5"

TOTAL LOAD = 82350/5 = 16470

LOAD PER BOLT = 16470/2
= 8235#

COMBINED LOAD = 3098 + 8235#
= 11,333#

USE 7/8"⌀ A325 N BOLTS
ALLOWABLE = 12,600# (TAB 1-D) p 4-5

WELD BETWEEN HORIZONTAL & VERTICAL PLATES

M = 82350#-IN

DISTANCE BETWEEN PLATES = 5"

LOAD = 82350/5
= 16470#

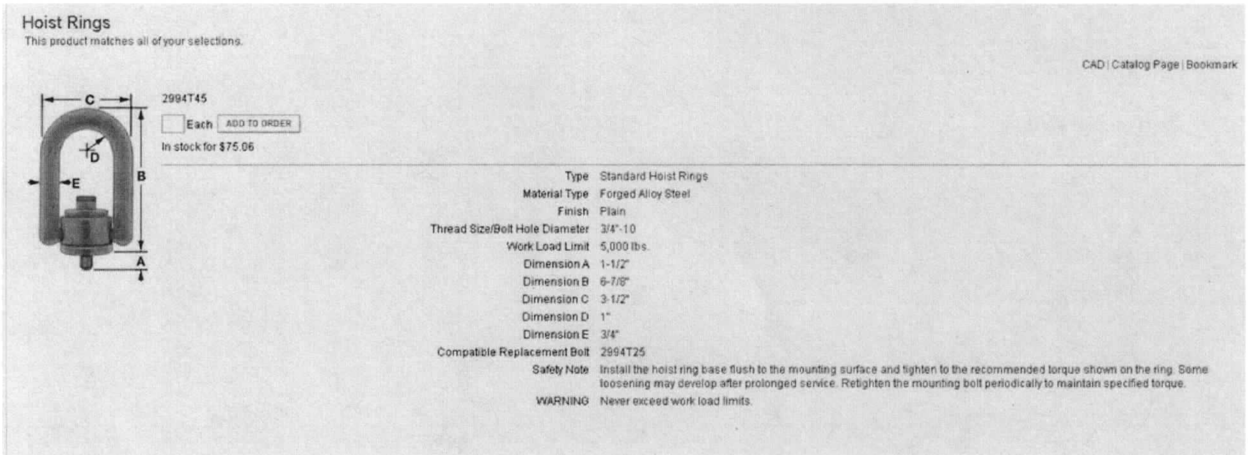
FOR 5/16" WELD, ALLOW. = 0.3(.707)(70)(5/16)
= 3.5 K/IN

16470/3500 = 4.7" WELD LENGTH

USE CONTINUOUS WELD (10") > 5" OK

Check McMaster # 2994 T 45 Hoist Ring for imposed load:

From McMaster-Carr Catalog:



Hoist Rings

This product matches all of your selections.

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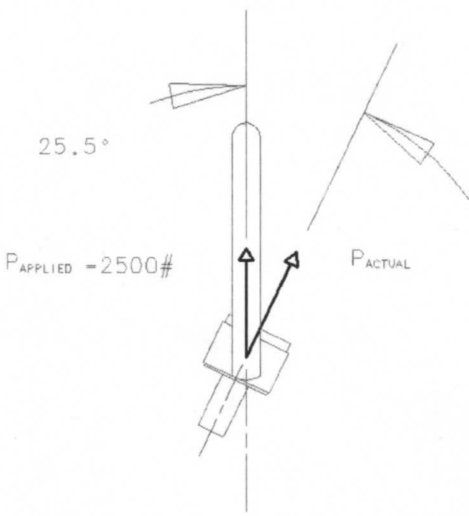
2994T45

Each ADD TO ORDER

In stock for $75.06

Type	Standard Hoist Rings
Material Type	Forged Alloy Steel
Finish	Plain
Thread Size/Bolt Hole Diameter	3/4"-10
Work Load Limit	5,000 lbs.
Dimension A	1-1/2"
Dimension B	6-7/8"
Dimension C	3-1/2"
Dimension D	1"
Dimension E	3/4"
Compatible Replacement Bolt	2994T25
Safety Note	Install the hoist ring base flush to the mounting surface and tighten to the recommended torque shown on the ring. Some loosening may develop after prolonged service. Retighten the mounting bolt periodically to maintain specified torque.
WARNING	Never exceed work load limits.



HOIST RING LOADING

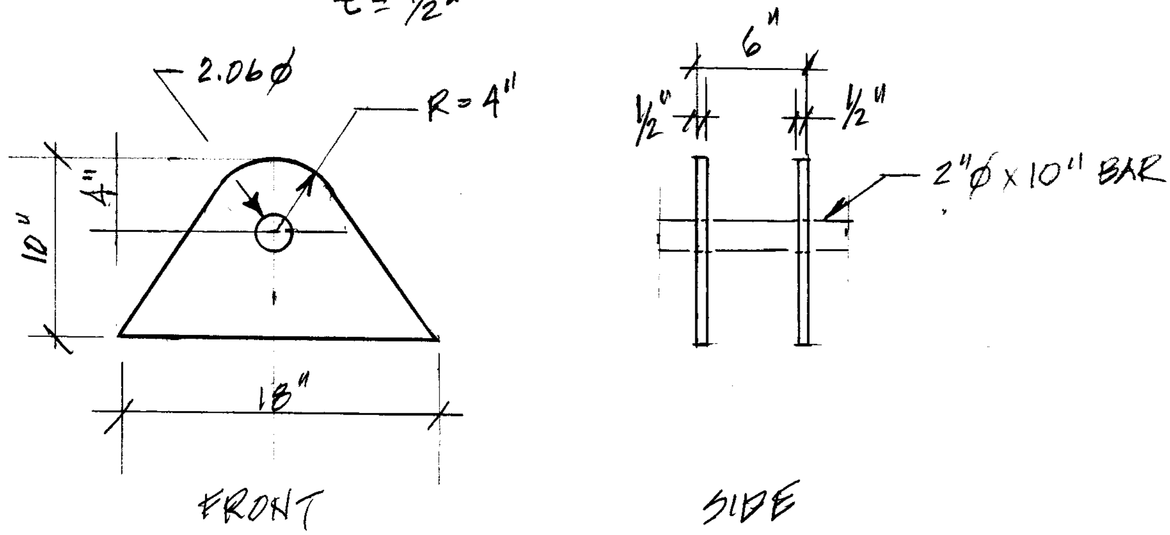
Vertical load on hoist ring = 2500#

Load angle =25.5 degrees

Tension load on hoist ring = P_{ACTUAL}=2500/cos 25.5 = 2770# < 5000# working load **OK**

Use McMaster # 2994 T 45 Hoist ring.

CRANE LIFTING LUG:
$t = 1/2"$



BAR FOR CRANE HOOK:

$A = \pi d^2/4 = \pi (2)^2/4 = 3.14 \text{ IN}^2$

$S = \pi d^3/32 = \pi (2)^3/32 = 0.393 \text{ IN}^3$

LOAD:
DETECTOR WILL ONLY BE LIFTED WHEN EMPTY.

WEIGHT OF EMPTY DETECTOR (FROM DWG. MD-486311) = 2608#
WEIGHT OF FIXTURE (FROM FEA) = 1000#
3608 = TOTAL WEIGHT
USE 3700#

$M = 3700(5)/4 = 4625 \text{ \#-IN}$

$f_b = 4625/0.393 = 11800 \text{ PSI}$

$F_b = 36{,}000 \text{ PSI}/3 = 12{,}000 \text{ PSI} > 11{,}800 \text{ PSI}$ OK

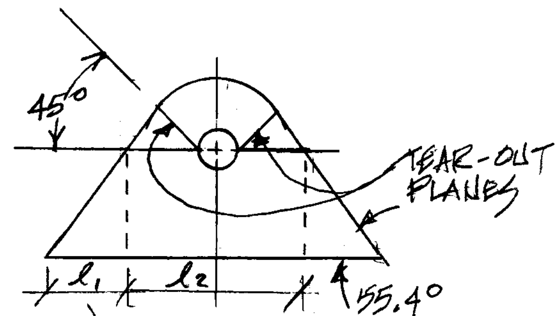
SHEAR LOAD = 3700 / 2 = 1850#

$f_v = 1850/3.14 = 589 \text{ PSI} < 12{,}000 \text{ PSI}$ OK

USE 2" Ø BAR

TRIANGULAR PLATES:

PIN TEAR-OUT:



AREA $= 0.5'' \times (4'' - 1.03'')(2)$
$= 2.97 \text{ IN}^2$

ALLOWABLE SHEAR $= 2.97(12{,}000)$
$= 35{,}640\# > 3700\#/2 = 1850\#$ **OK**

WELD OF LUG TO TUBE:

ALLOWABLE TENSION $= 12{,}000\,(.707)(1/4)$
$= 2121\#/\text{IN}$

FOR 18" WELD, $P_{ALLOW} = 2121(18)$
$= 38178\# > 1850\#$
OK

MAXIMUM PLATE TENSION:

ANGLE OF PLATE SIDE $= 55.4°$
$90° - 55.4° = 34.6°$
$l_1 = \tan 34.6 (6'') = 4.14''$
$l_2 = 18 - 2(l_1) = 18 - 2(4.4)$
$= 9.72''$
TENSION AREA $= 0.5(9.72) = 4.86 \text{ IN}^2$
ALLOWABLE TENSION $= 4.86\,(12000)$
$= 58{,}320\# > 1850\#$ **OK**

Minerva Lifting Fixture/Stand Analysis

By Ingrid Fang and Bob Woods

May 26, 2011

Introduction

The purpose of this analysis is to investigate the design of a combination lifting fixture and stand that will be used to install the Minerva Water Target into the existing Minerva Detector.

The existing Minerva Detector is made up of a series of closely spaced detector planes. The Water Target will be installed between an eleven inch gap in the Detector. Since the building crane hook will not fit in this gap, the installation will be a two step process.

The first step will be using this lifting fixture connected directly to the building crane to position the target over the gap in the existing detector and lowering it onto temporary tube supports.

The second step will be removing the crane hook from the top of the lifting fixture and installing a sling between the crane hook and the lifting lug of the lifting fixture. The Target can now be lowered to its final location resting on the detector support rails.

Two cases have been studied based on the two steps required for the installation.

“Case-1” represents the step of aligning the target over the gap in the existing detector.

“Case-2” represents the lowering of the target to its final position within the detector.

Table 1
Mesh Density and Loads

	Nodes	Elements	Dead Load (lbs)	Live Load (lbs)
Case-1	1393684	597359	1132	5000 V + 500 H
Case-2	1393684	597359	1132	5000 V

Dead load is the weight of the lifting Fixture/Stand.

V stands for the vertical load of the target.

H stands for a simulated 10% of the vertical load to analyze the frame stability.

Figure 1a. Meshing

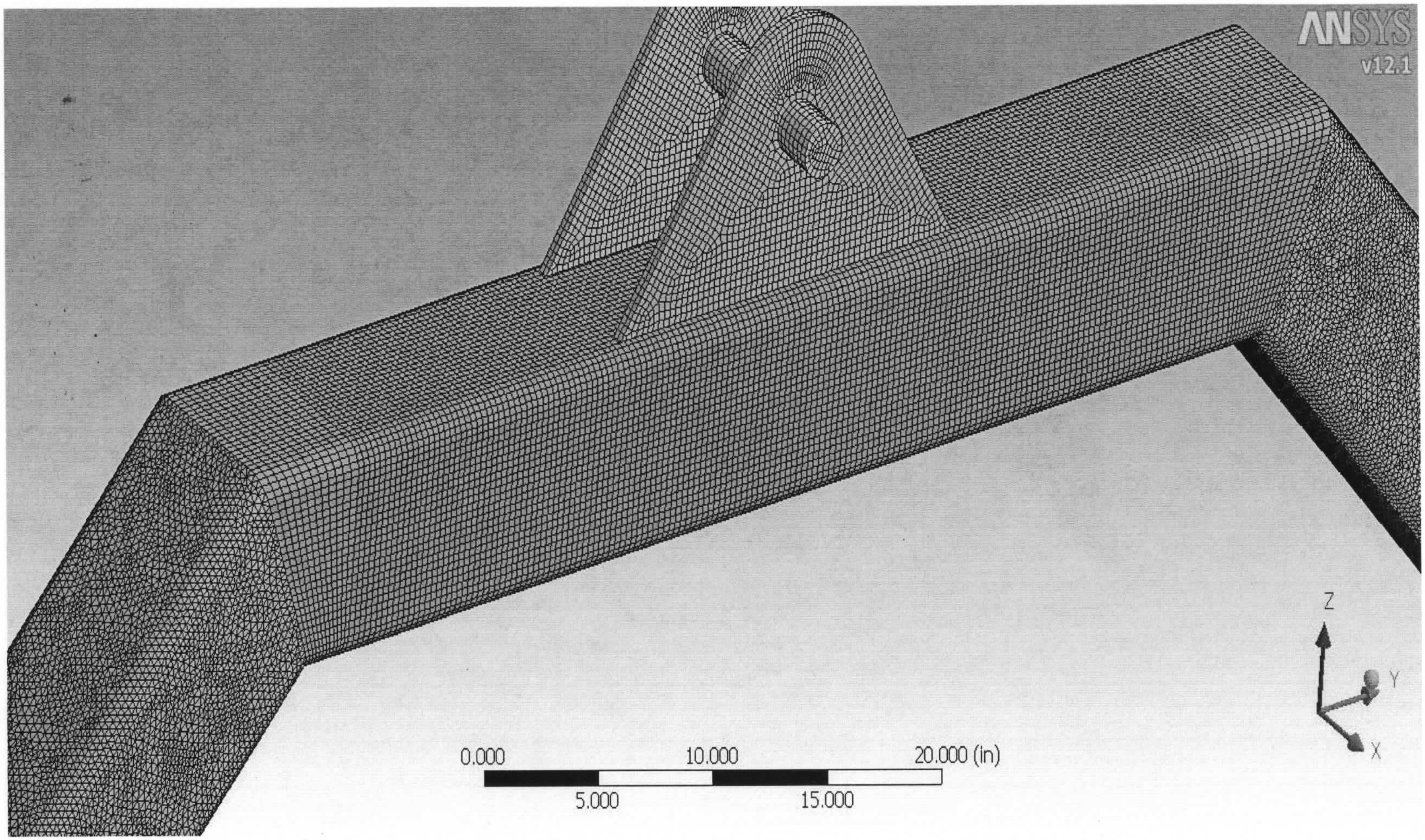


Figure 2a. Meshing

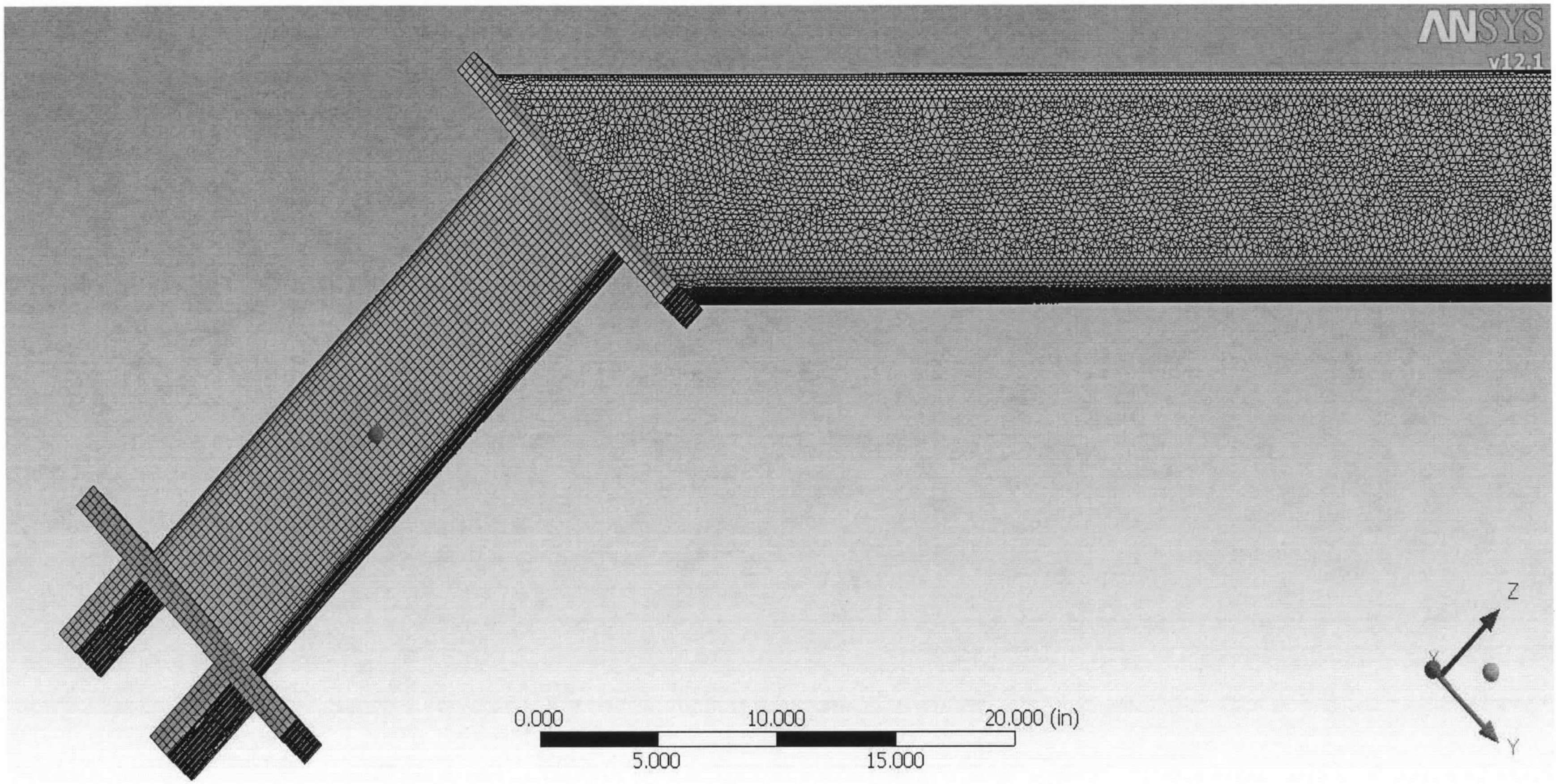


Figure 3. Boundary Condition for Case-1

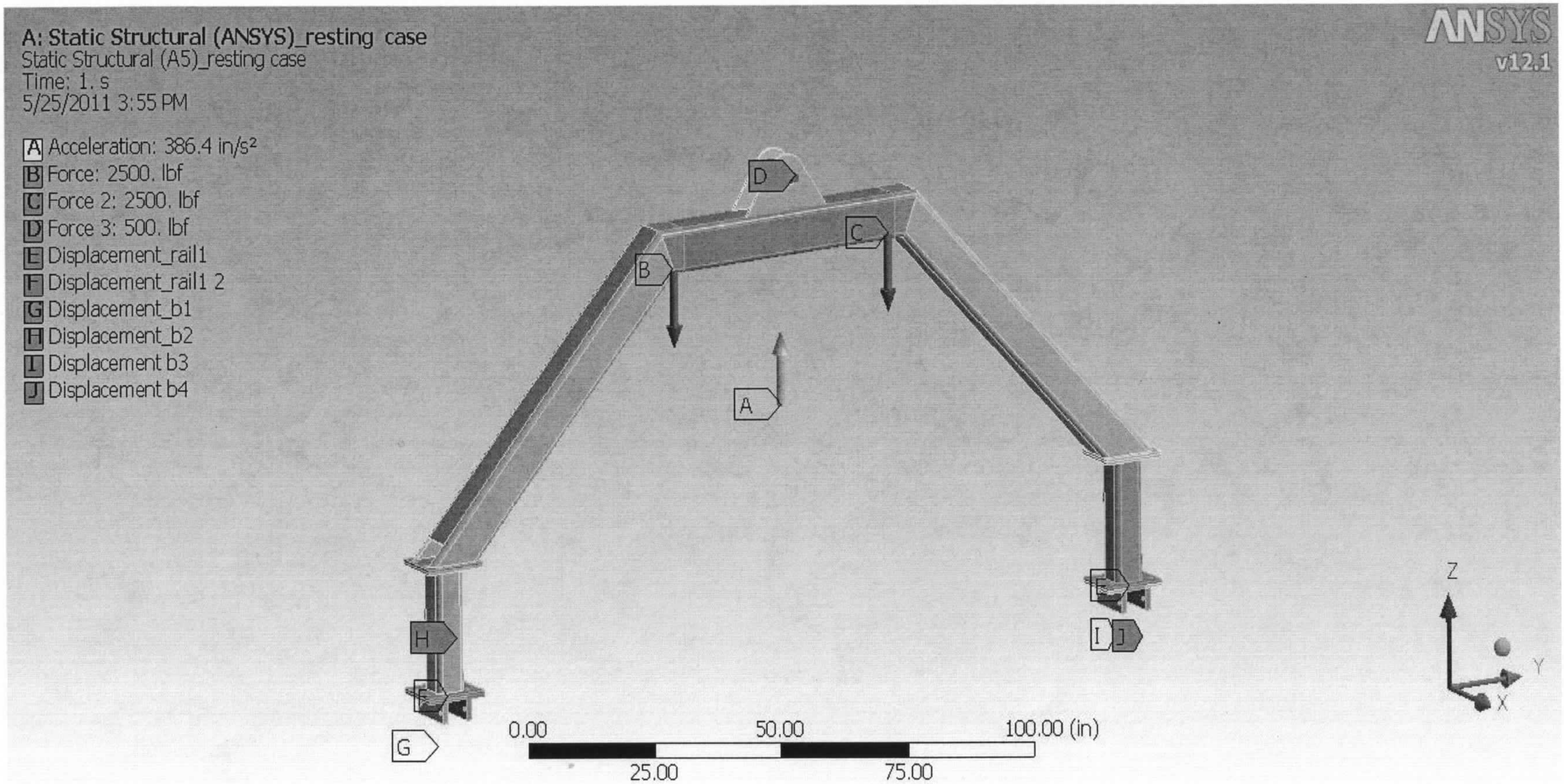


Figure 4. Boundary Condition for Case-2

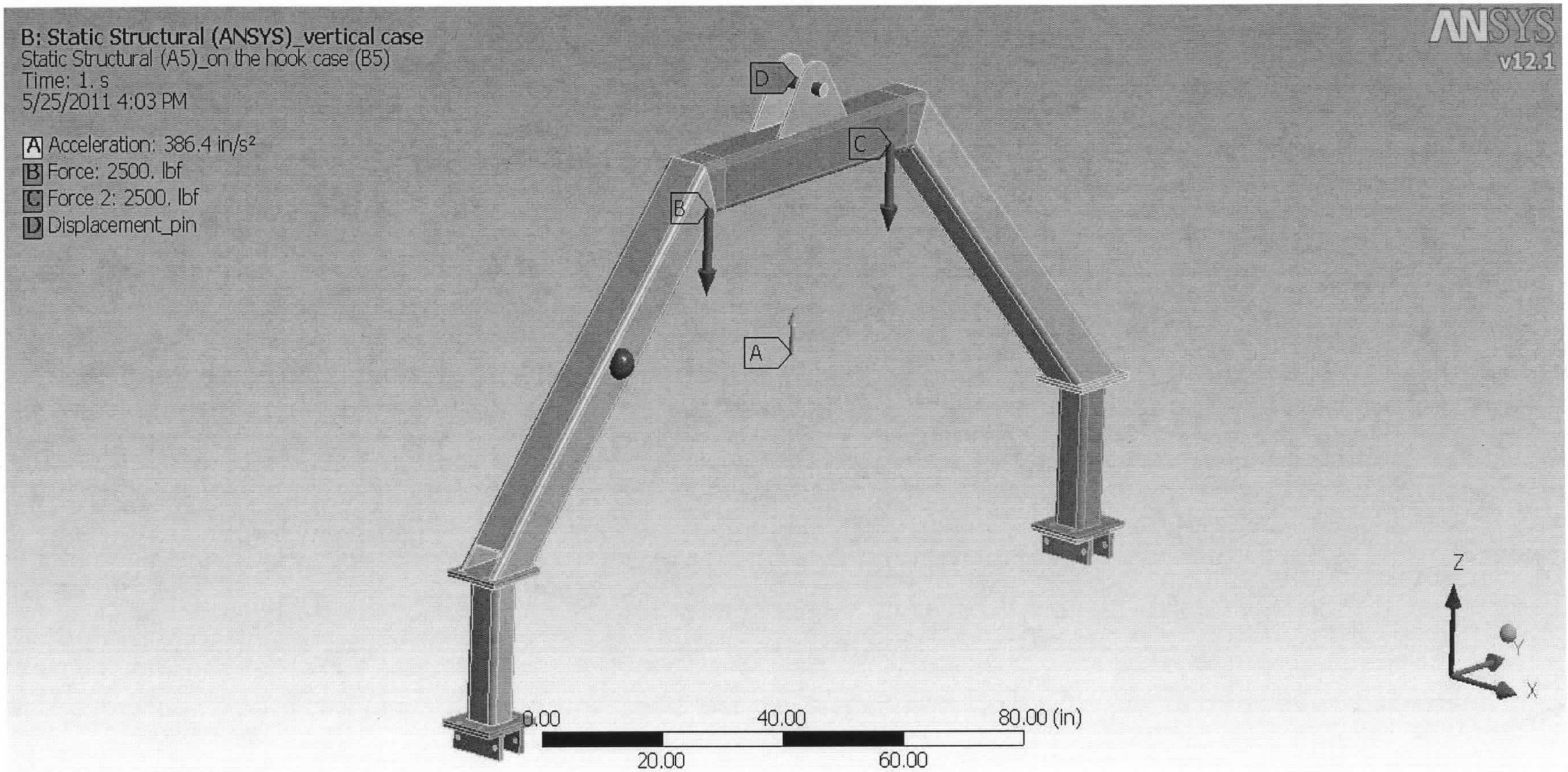


Figure 5. Total Deformation for Case-1

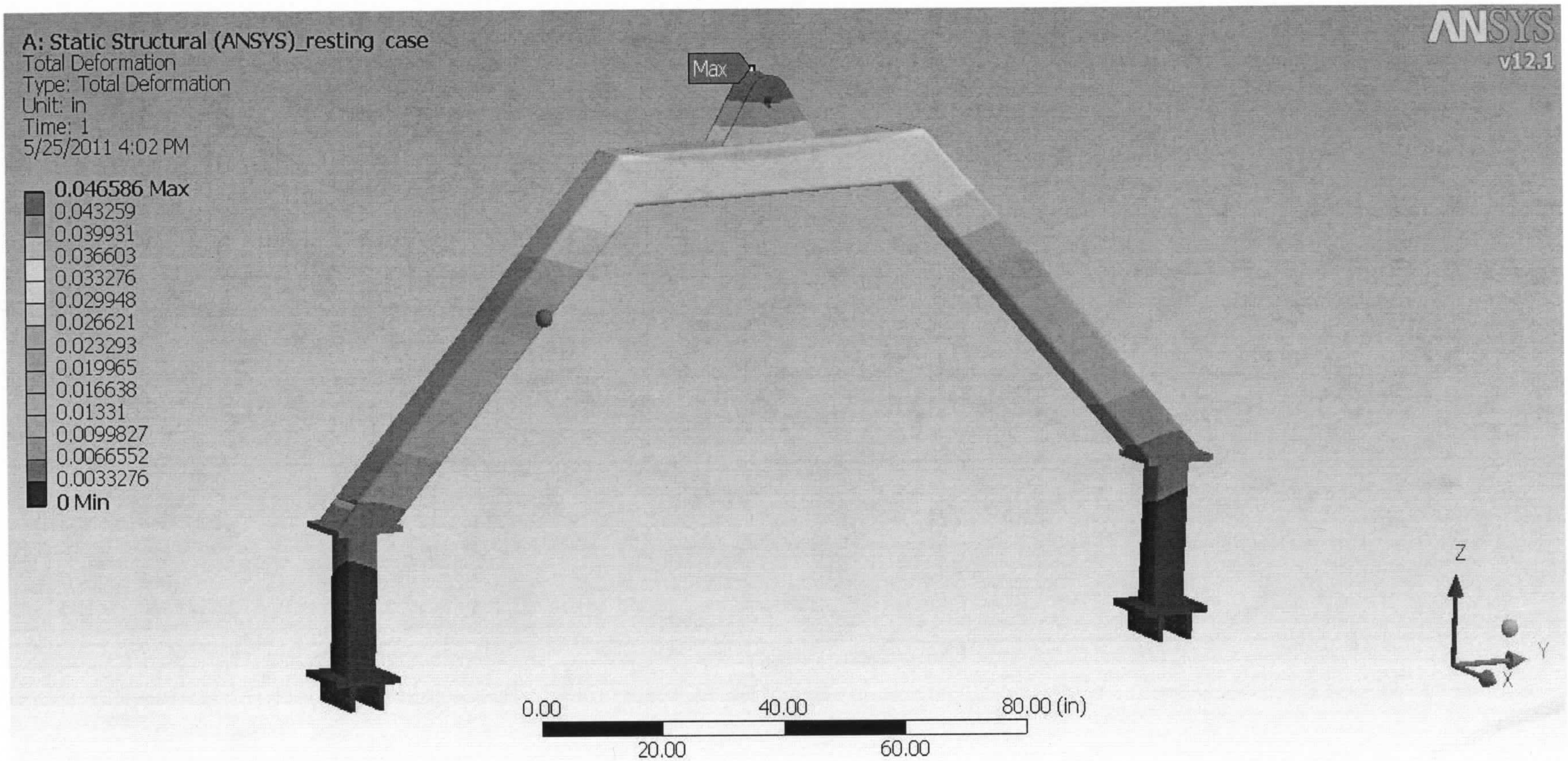


Figure 6. Total Deformation for Case-2

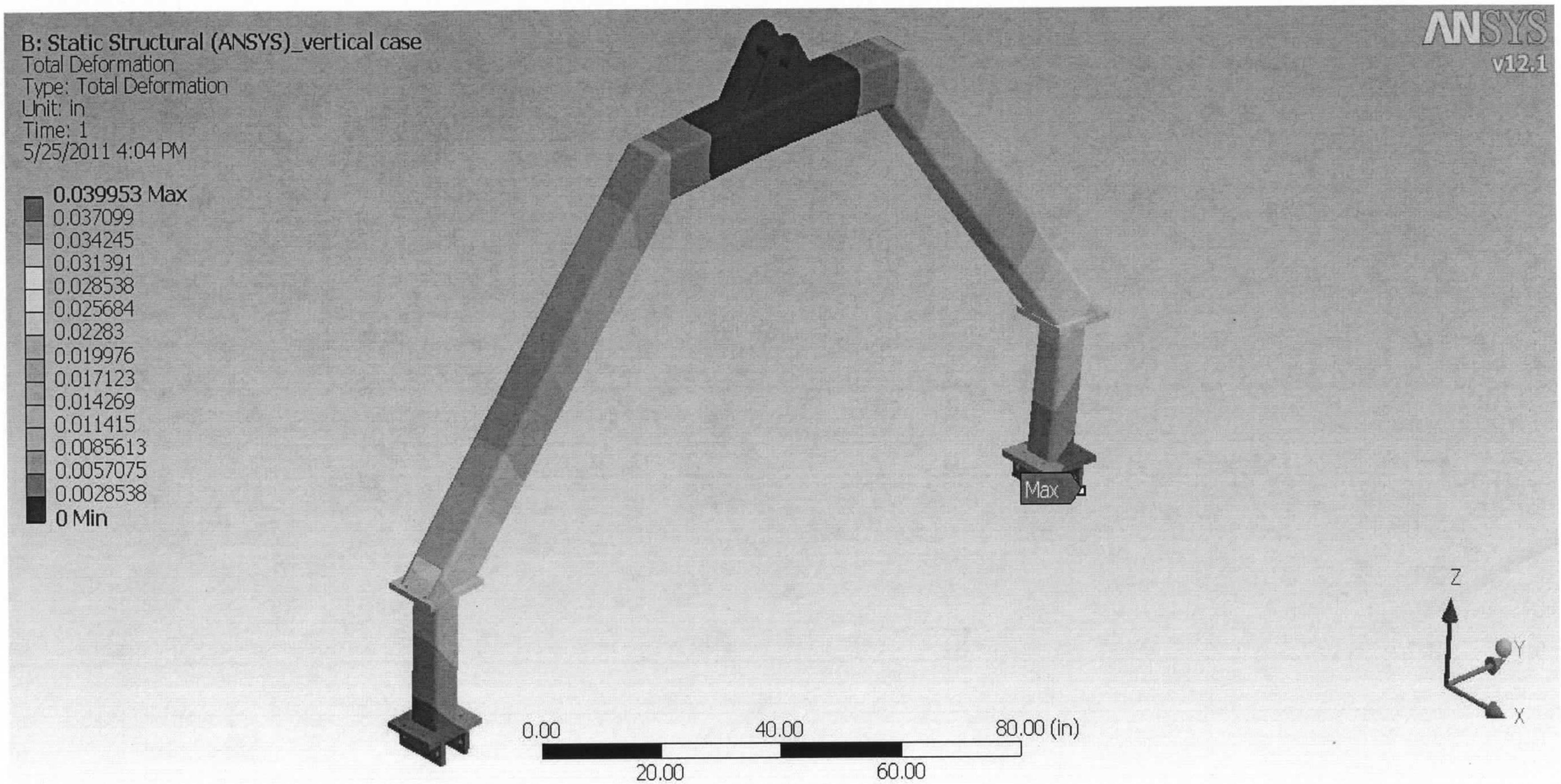


Figure 7. von-Mises Stress for Case-1

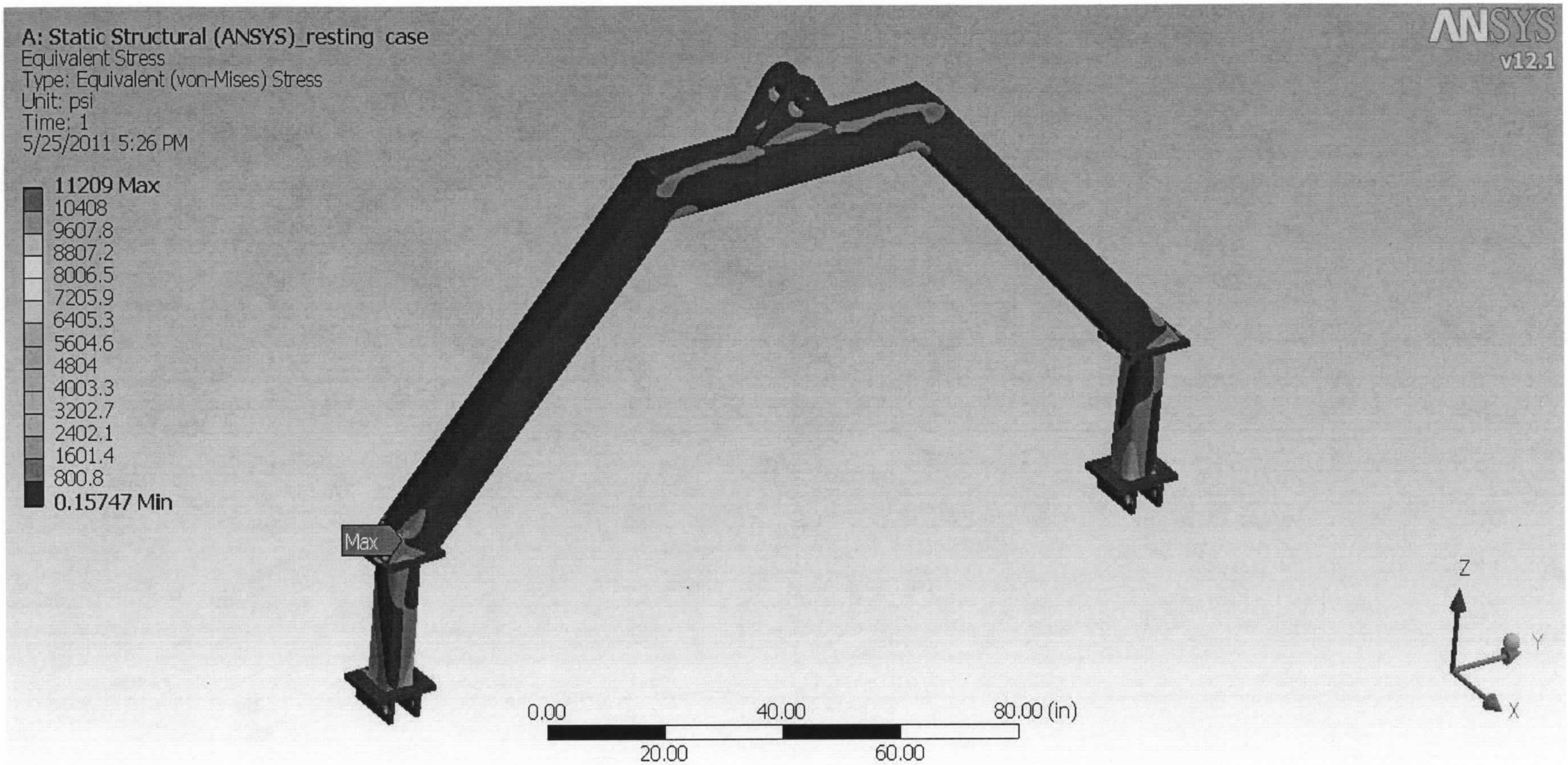


Figure 8. von-Mises Stress for Case-2

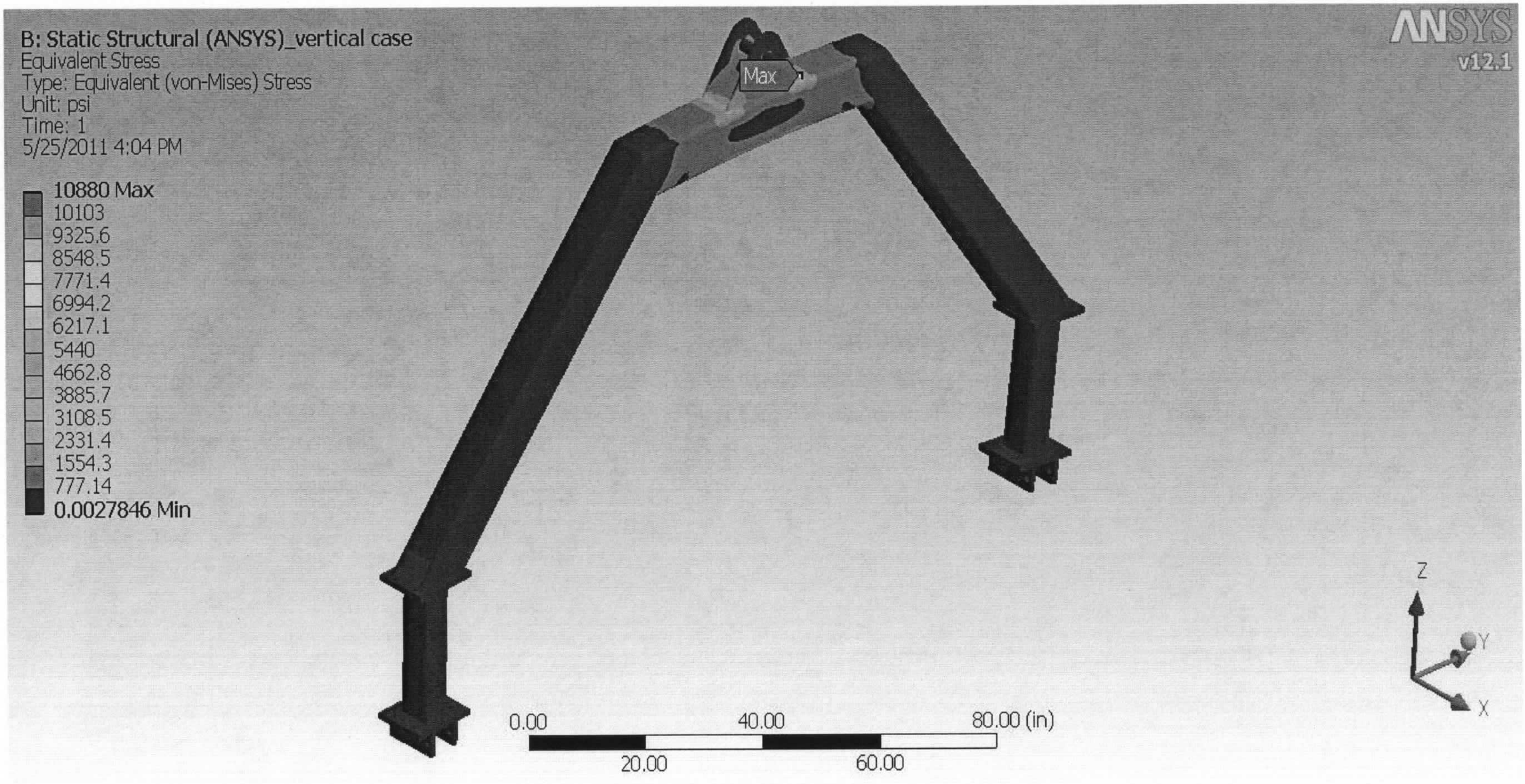


Figure 9. Forces at connections

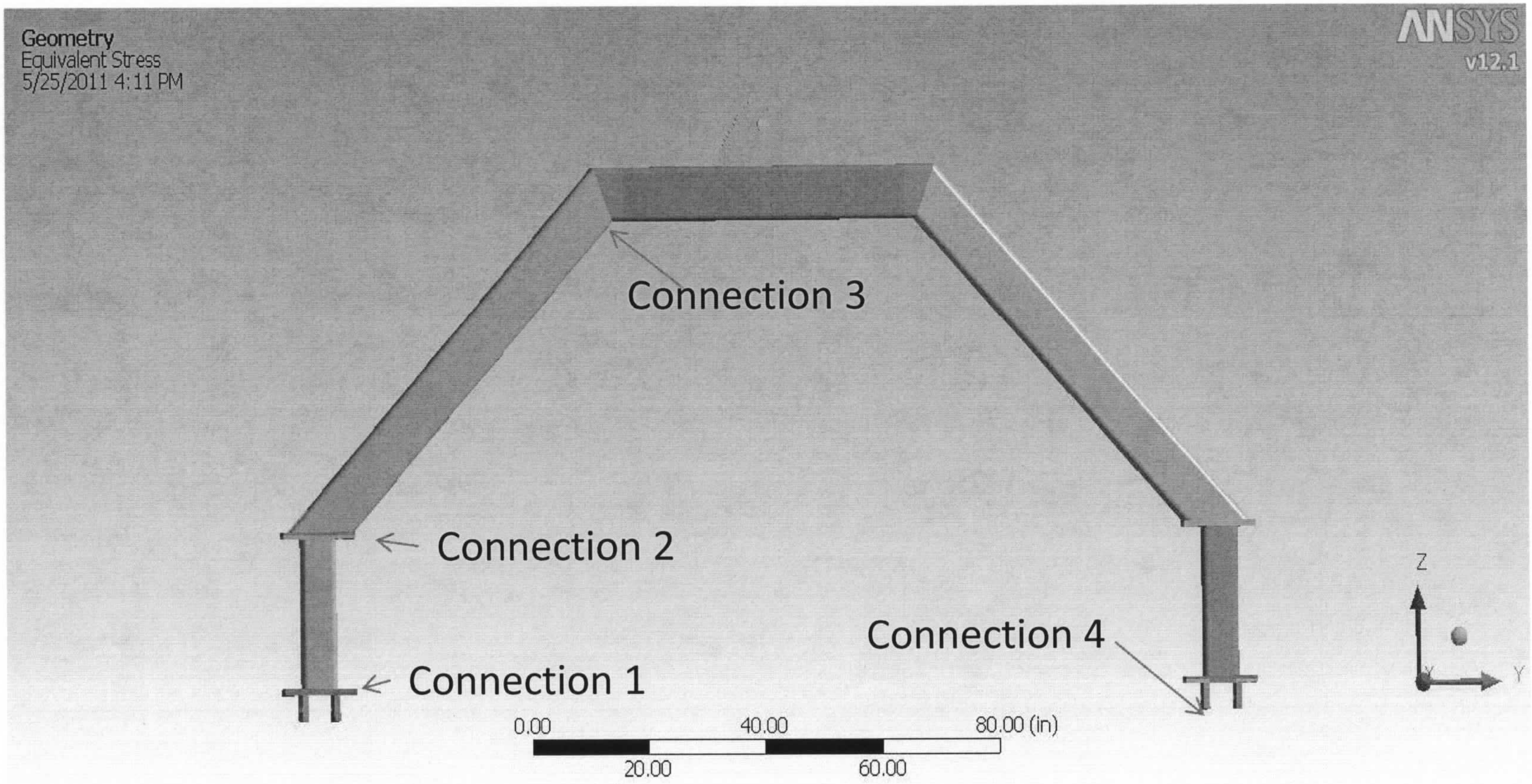


Figure 10. Local Coordinates at Connection 3

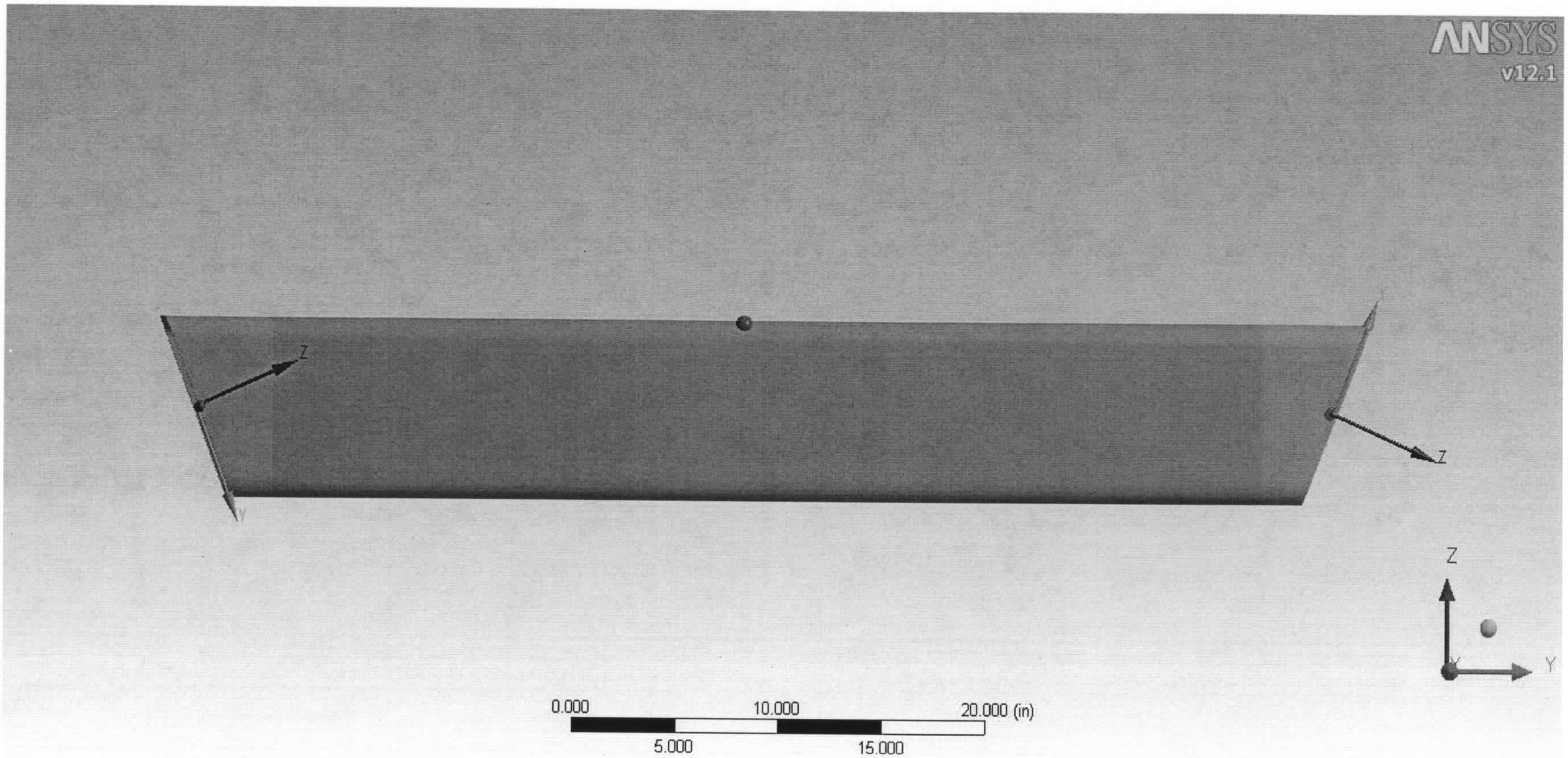


Table 2
Loads at the Connection1

connection1	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (lbs-in)	My (lbs-in)	Mz(lbs-in)
Case-1-left side	283	1144	5321	-47768	25318	-8186
Case-1-right side	272	-1153	5422	47612	25141	8091
Case-2-left side	0	0	47	10	0	0
Case-2-right side	0	0	-47	-10	0	0

Table 3
Loads at the Connection2

connection2	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (lbs-in)	My (lbs-in)	Mz(lbs-in)
Case-1-left side	-250	-2321	-2929	-19976	-14939	6928
Case-1-right side	-250	2321	-2929	19969	-14936	-6927
Case-2-left side	0	0	137	-6	0	0
Case-2-right side	0	0	137	6	0	0

Table 4
Loads at the Connection3

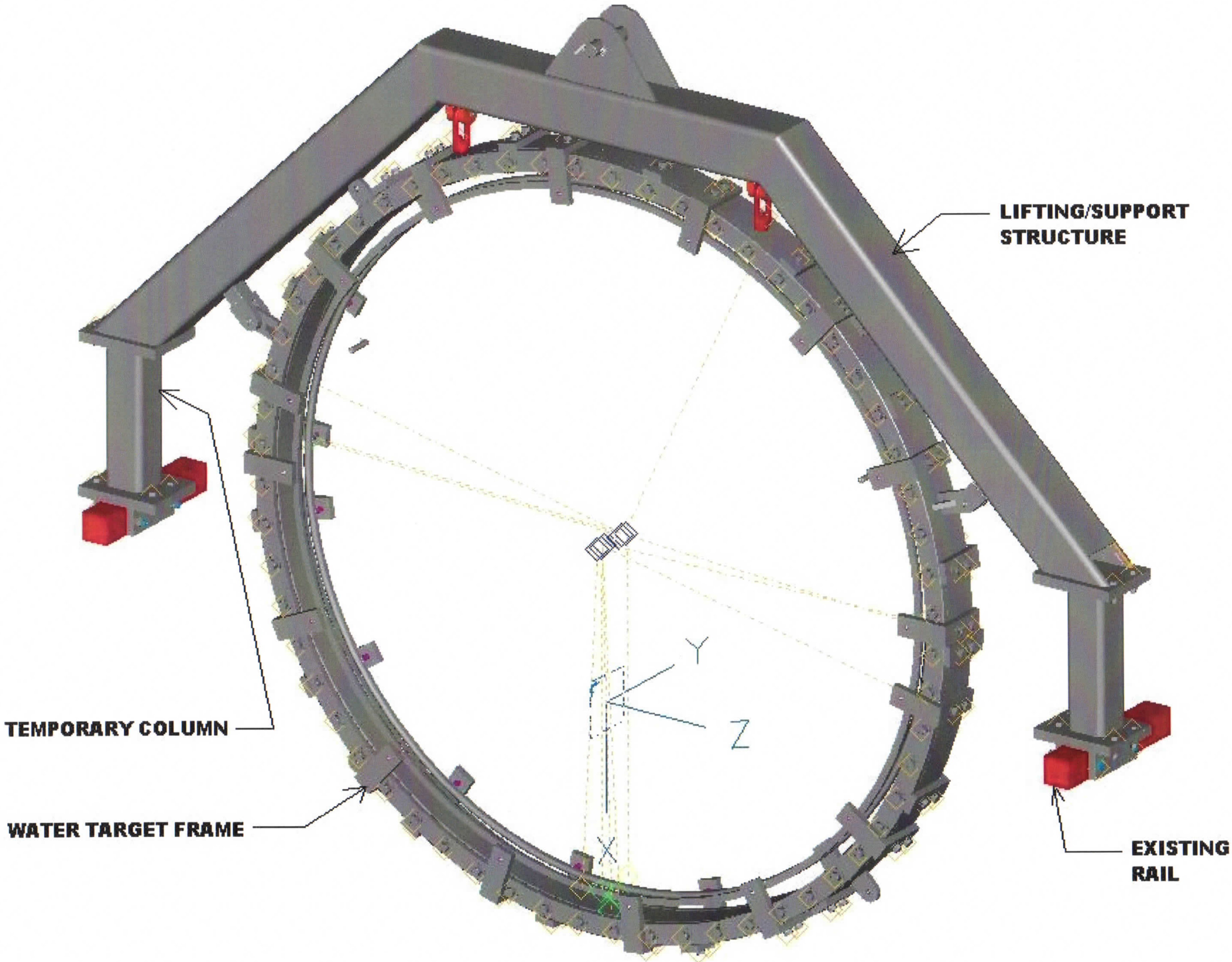
connection3	Fx (lbs)	Fy (lbs)	Fz (lbs)	Mx (lbs-in)	My (lbs-in)	Mz(lbs-in)
Case-1-left side	250	-1544	3152	2570	4131	-4418
Case-1-right side	-250	1544	-3152	2572	4132	-4417
Case-2-left side	0	401	-166	-14511	0	0
Case-2-right side	0	-401	166	-14511	0	0

Table 5
Loads at the Connection4 for Case-1

Case -1 connection4	Fx (lbs)	Fy (lbs)	Fz (lbs)
Bolt 1	217	1495	623
Bolt 2	33	828	-176
Bolt 3	33	-828	-177
Bolt 4	217	-149	623

Conclusions

The maximum stress of the Lifting Fixture/Stand is 11ksi. The maximum displacement of the Lifting Fixture/ Stand is 0.047 inches. The results shown above indicates that this proposed design meets both the ASME B30.20-1993 standard for below-the-hook lifting devices for “Case-1”and the AISC Manual of Steel Construction Ninth Edition requirements for Allowable Stress Design for “Case-2”.


LIFTING/SUPPORT STRUCTURE
TEMPORARY COLUMN
WATER TARGET FRAME
EXISTING RAIL
Y
Z
X