Fermilab

Revision 1.0

1/21/1999

Particle Physics Division

Engineering and Technical Teams

Mechanical Support Engineering Note

Number: MD – ENG - 122 Date: April 5, 2007

Project: Minerva Project Internal Reference:

Title: Engineering note for Minos Cart Modifications

Author(s): J. Kilmer

Reviewer(s):

Key Words:

Abstract/Summary:
This note describes the modifications required to make on the Minos cart to allow it to be used to transport Minerva strongbacks and frames.

Applicable Codes:

AISC Manual of Steel Construction, 9th Edition.

USS Steel Design Manual, Brockenbrough and Johnston, 1968.

Structural Calculations for Minos Cart Modifications for use in Minerva

James Kilmer

March 23, 2007

In this document the stresses are calculated for the modifications to the Minos Cart so it can be used in the installation of the Minerva dector. The only structural calculations that are affected are the one for the attachment point on the cart top rail that supports the weight of the strongback and a Minerva frame. For this purpose use the heaviest of the Minerva frame loads or 5200 lbs. The weight of the strongback is approximately 4200 lbs or a total weight on the cart of 9400 lbs. Note that for the Minos project the cart had to carry a load of 8000lb per plane and 1600 lb of strongback or 9600lbs. Framing in the base of the cart that keeps the base square has to be rearranged, but does not affect the strength of the cart to support weight at all. Because of the similarity of use between the Minos work and Minerva most of the original engineering note data applies.

The Minerva strongback is secured to the cart by a hanging structure that supports the strongback on the face of the cart truss structure as in the attached drawing, 3938.330-MD-435763. This puts a torque on the top rail as follows.For this calculation we assume that the lower rail and the truss members do not aid in resisting this torque on the upper member. It should be noted however that though the upper support may rotate that the lower member will keep the strongback and frame combination from falling forward off the cart. Additionally the strongback is held by bolts to the cart structure.

$Wt := 9400 \cdot lb$ Weight of the strongback and frame combination

The eccentric distance of the load from the center of the upper support rail is the sum of the distance from the center of the rail to it's outer fibers plus the distance from the back of the strongback to its center of mass.

$db := 4.5 \cdot in$ distance from center to edge of rail beam

$dcm := 9.56 \cdot in$ distance from edge of strongback to center of mass location

$d := db + dcm$

$d = 14.06\,in$

$T := Wt \cdot d$

$T = 1.322 \times 10^{5}\,lb \cdot in$

For a TS9"by 5" by 3/8" structural tube use the data for torsional properties from the AISC Manual of Steel Construction. page 1-100.

$J := 92.2 \cdot in^{4}$

Find the angular displacement of this beam and the stress. For this use the equations from the USS Steel Design Manual,Brockenbrough and Johnson, U S Steel Corp, 1968. This is from Chapter 7, "Torsion" pages 156-169.

$G := \left(11.2 \cdot 10^{6}\right) \cdot \frac{lb}{in^{2}}$ Steel Shear Modulus of elasticity

$E := \left(29 \cdot 10^6\right) \cdot \frac{lb}{in^2}$ Steel Modulus of elasticity

For the tube sitting on its side the moment of inertia we need for the equation is Ix

$Ix := 97.8 \cdot in^4$

$ds := 5 \cdot in$ ds is the length of the affected side of the tube

$a := \left(\frac{ds}{2}\right) \cdot \sqrt{\frac{E \cdot Ix}{J \cdot G}}$

$a = 4.143\,in$

The case for the rotation angle we use is on page 164, a sinple span with a rotating load in the center.

$L := 267.5 \cdot in$ Length of the span on the beam.

$\Theta T := \frac{Wt \cdot d \cdot a}{J \cdot G} \cdot \left[\left(\frac{L}{2 \cdot a}\right) - \tanh\left(\frac{L}{2 \cdot a}\right)\right]$

$\Theta T = 0.017$ Twist angle of beam in radians

$Thetatwist := \Theta T \cdot 57.3$

$Thetatwist = 0.95$ Twist angle of beam in degrees

This less than 1 degree rotation is minimal and will not affect the function of the cart.

Next find the shear stress from torsion using formula 7.14 from page 159 of the USS book. First find b/t.

$b := 5.0 \cdot in$ $t := 0.375 \cdot in$ Properties of the tube

$\frac{b}{t} = 13.333$

Therefore we can use formula 7.14.

$fs := \frac{T \cdot t}{J}$

$fs = 537.543 \frac{lb}{in^2}$

Note that the normal shear allowable stress is 40% of the nominal Fy of the material. Assume that the tube is A500 Grade B with an Fy = 46ksi. Then Fs = 18.4ksi.

Since Fs > fs the shear stress in the upper rail is OK for this design.

The actual weight of the strongback is carried by the 6" by 3" by 0.187" rectangular structural tubing that is welded to the cart truss. Look at the small tubes, part number 4 on drawing 444104. Each tube must carry half of the weight of the strongback and frame. Each tube is welded to the heavy frame by four 0.3125" welds five inches long. First compression on the tubes.

$P := Wt$

$Atube := 3.14 \cdot in^2$

$\sigma tube := \frac{P}{Atube}$ $\quad \sigma tube = 2.994 \times 10^3 \frac{lb}{in^2}$

This very low compressive stress is fine for these tubes. Now check on the weld stress in shear.

eight welds five inches long by 5/16"

$Aw := 8 \cdot 5 \cdot in \cdot .3125 \cdot \frac{in}{1.414}$

$Aw = 8.84\, in^2$

$\sigma weldshear := \frac{P}{Aw}$

$\sigma weldshear = 1.063 \times 10^3 \frac{lb}{in^2}$

The welds will take this load in shear. All welds on the cart are in E70XX rod with a yield strength of 70KSI. In shear these welds would have a maximum shear stress allowed of:

70KSI X 0.30 = 21.0 KSI

per Table J2.5 on page 5-70 of the AISC code. Notice however that in addition to these welds part number 5 supports each of the vertical tubes.

Part 5 can be modelled as a cantilevered beam with a uniform load as in Case 19 page 2-302 of the AISC code. This assumes that all of the load is carried by the cantilever and none is carried by the welds in shear as calculated just above. Because part 1 is welded completely on the end to part 5 case 20 might be more appropriate, but use case 19 because it yields a higher moment and stress.

$l := 6 \cdot in$ length of cantilever

$w := \frac{P}{2 \cdot l}$ load per inch

$$Mmax := w \cdot \frac{l^2}{2}$$

$$Mmax = 1.41 \times 10^4 \, in \cdot lb$$

$S_x := 4.76 \cdot in^3$ Section modulus for 6" by 3" by 3/16" wall tubing

$$\sigma bend := \frac{Mmax}{S_x}$$

$$\sigma bend = 2.962 \times 10^3 \, \frac{lb}{in^2}$$

In bending structural tubing Fb=Fy*0.66 or Fb=30.3 KSI which is much greater than 3000 psi. Hence part 5 in this cantilever is OK.

Now lok at the weld from parts 5 to the lower horizontal beam. The two cantilever beams are welded with a 5/16" fillet weld. First calculate the total moment these two beams have to support.

$M := 9400 \cdot lb \cdot 15 \cdot in$

$M = 1.41 \times 10^5 \, lb \cdot in$

Now calculate the total moment resistance provided by the welds on both sides of these two beams. Basically it is the integrated moment of the weld yield stress multiplied by the area of the weld at any part of the weld

$\sigma_{wyield} := 70000 \cdot \frac{lb}{in^2}$ Using E70XX rod

$l_w := 9 \cdot in$

$t_w := \left(\frac{5}{8}\right) \cdot \left(\frac{5}{16} \cdot in\right)$ Weld throat distance given on page 4-173 of the AISC code for this style of weld

$t_w = 0.195 \, in$

$$M_w := \int_0^l \sigma_{wyield} \cdot t_w \cdot l \, dl$$

$M_w = 5.537 \times 10^5 \, lb \cdot in$

Now check the safety factor of the weld moment support capability with the required moment.

$$\frac{M_w}{M} = 3.927$$

This safety factor is more than sufficient to support the load of the strongback and frame being carried.

In order to resist the moment trying to pull the strongback off the cart two threaded fasteners are provided. The welding fixture has two holes drilled through the columns that match threaded holes in the back of the strongback. First calculate the stress the bolts might see. The total moment is the same as calculated above for bending on the columns. The distance the force is supplied at for the moment resistance is from the bottom of the strongback where the rail hits the columns to the holes where the threaded rods are.

$M := 9400 \cdot lb \cdot 14.9in$ Moment of strongback to middle of support rail

$lm := 62.5 \cdot in$ Distance from bottom of lower rail to threaded hole

$Fbolt := \frac{M}{2 \cdot lm}$ Each bolt supports half the moment

$Fbolt = 1.12 \times 10^{3}\ lb$

$pi := 3.4145$

$Abolt := \frac{pi}{4} \cdot (.75 \cdot in)^{2}$

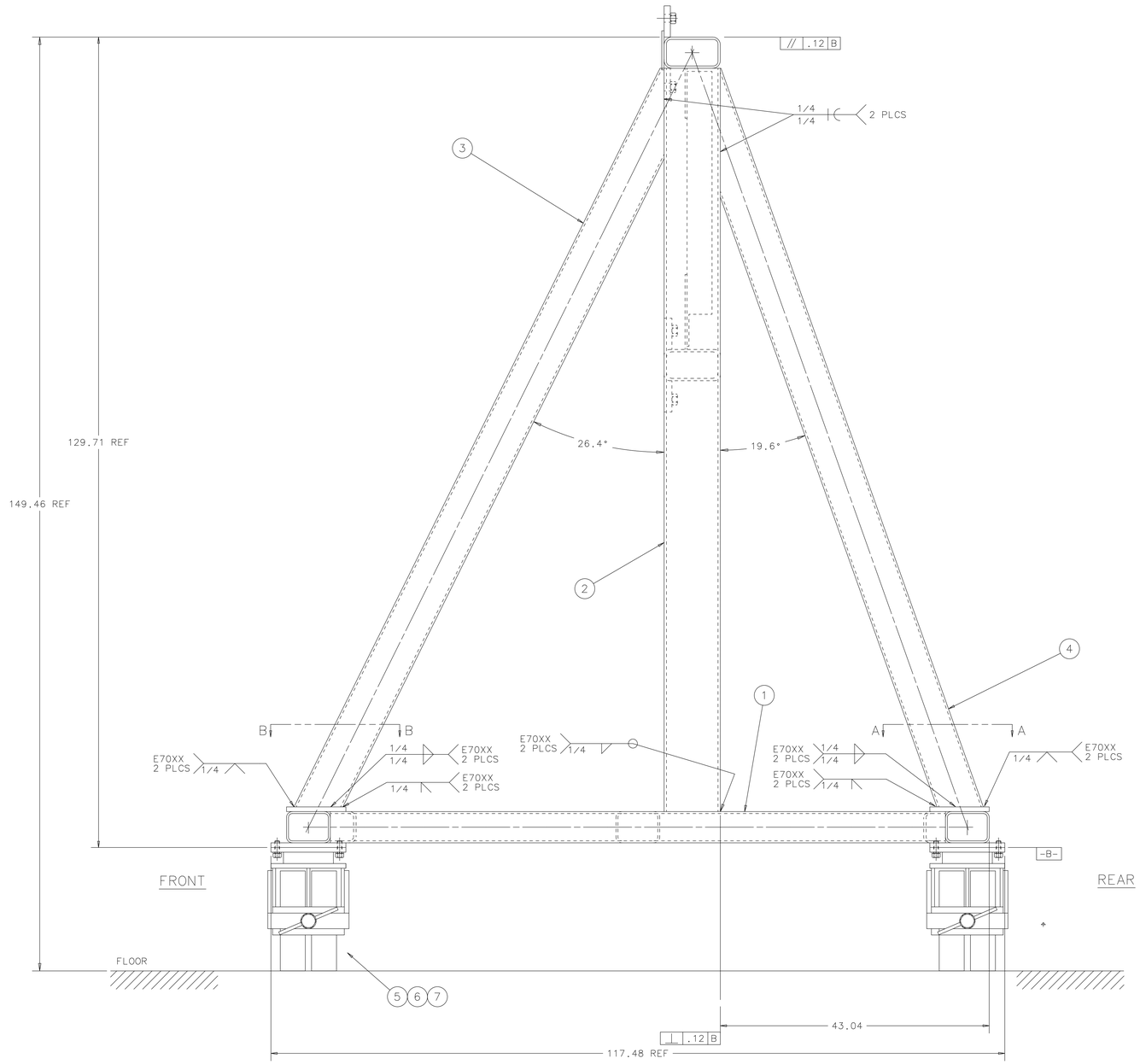
$Abolt = 0.48\ in^{2}$

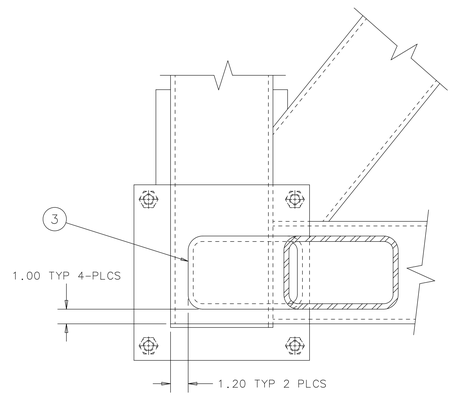
$\sigma bolt := \frac{Fbolt}{Abolt}$

$\sigma bolt = 2.334 \times 10^{3}\ \frac{lb}{in^{2}}$

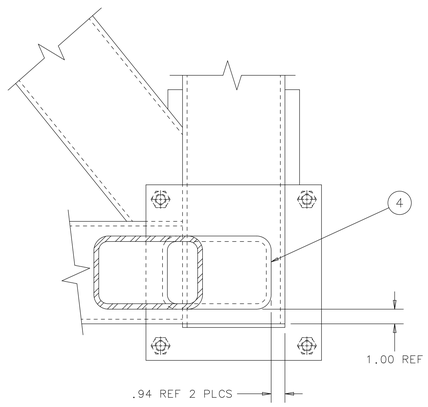
These bolts are 3/4"-10 and any grade will easily support a tensile load of 1100 pounds force with a tensile stress of 2334 psi.

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE





SECTION B-B
SCALE: 1/4"=1"



SECTION A-A
SCALE: 1/4"=1"

NOTES:

1. ALL STRUCTURAL STEEL SHALL BE PAINTED AS FOLLOWS:
   EXCEPT FOR LABEL AND SURFACES WITHIN 2 INCHES OF ANY WELD, OPERATING PARTS, FINISHED SURFACES AND ALL OTHER NOT CONCEALED STEEL PARTS SHALL BE:
   THOROUGHLY CLEANED OF ALL SCALE, RUST AND DIRT PER SPECIFICATIONS OF THE STEEL STRUCTURE PAINTING COUNCIL (SSPC) "SURFACE PREPARATION SPECIFICATION NO. 3.(SP-3) POWER TOOL CLEANING";
   PRIMED WITH SYNTHETIC, QUICK DRYING, RUST-INHIBITING FERROUS METAL PRIMER GLIDDEN 5205 GLID-GUARD TANK AND STRUCTURAL PRIMER; PAINTED WITH TWO COATS OF INTERIOR, SEMI-GLOSS, ODORLESS, ALKYD ENAMEL GLIDDEN 4200 SPREAD ULTRA SEMI-GLOSS ENAMEL. COLOR SHALL BE "MASSEY FERGUSON RED".
   INCLUDE 1 GALLON OF FINAL PAINT WITH SHIPMENT (FOR TOUCH-UP).
2. WELDING SHALL BE DONE USING THE ELECTRIC ARC PROCESSBY WELDERS HOLDING CURRENT WELDING CERTIFICATES FOR EACH REQUIRED PROCEDURE.
3. FABRICATION, ASSEMBLY SHALL BE IN ACCORDANCE WITH AISC STANDARD PRACTICE. SPECIAL TOLERANCES SHOWN ON DRAWING SHALL BE FOLLOWED.
4. IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR AND/OR SUBCONTRACTOR TO VERIFY ALL PART DIMENSIONS TO INSURE THE EXACT OVERALL DIMENSIONS AND TOLERANCES OF THE FINAL ASSEMBLY AS SHOWN ON THE DRAWING.
5. TORQUE ALL 3/4" BOLTS ON CASTERS TO 200 FT-LBS.
6. THE APPROXIMATE WEIGHT OF THE TRANSPORT CART WITHOUT THE CASTERS IS 7500 LBS.
7. THE APPROXIMATE WEIGHT OF THE TRANSPORT CART WITH THE CASTERS IS 9000 LBS.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
7	COML	LOCKWASHER FOR 3/4 BOLT HI-STRENGTH ALLOY SPRING MCMASTER-CARR #91104A036	24
6	COML	BOLT, 3/4-10UNC X 2 LG. HX HD ASTM A325 TYPE 1	24
5	COML	ALBION 850 SERIES DUAL WHEEL SWIVEL CASTER WITH POLYURETHANE/IRON CORE, 16x5 SWIVEL LOCK & FACE CONTACT WHEEL BRACE #850PY16801S-SL-FCB	6
4	MC-397446	TUBE, SIDE REAR	2
3	MC-397442	TUBE, SIDE FRONT	2
2	ME-397462	TRUSS FRAME WELDMENT	1
1	ME-397463	BASE FRAME WELDMENT	1

PARTS LIST

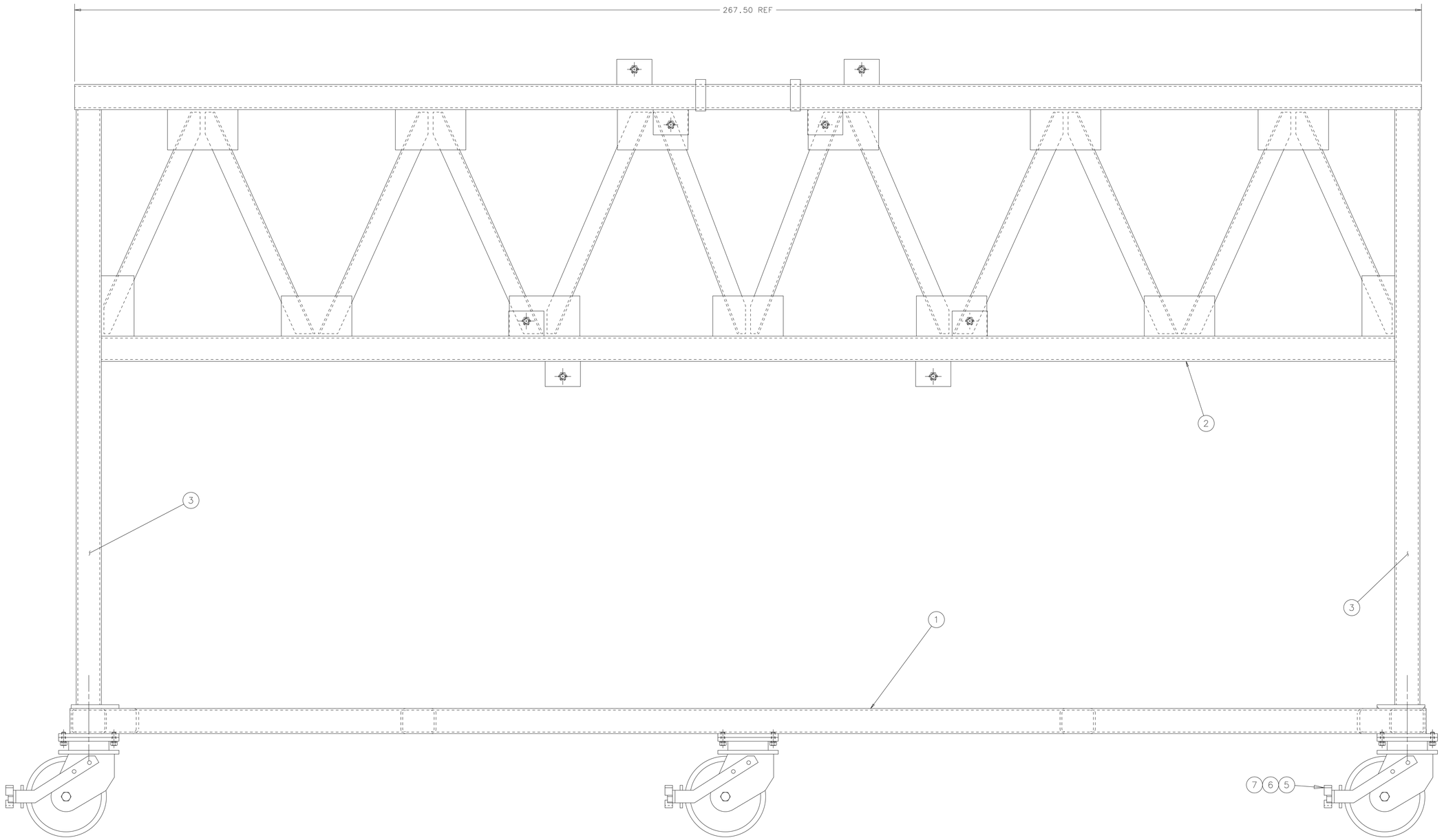
UNLESS OTHERWISE SPECIFIED			ORIGINATOR	I.FANG	22-JAN-2001
.XX	.XXX	ANGLES	DRAWN	V.MAJDANSKI	22-JAN-2001
± .03	± --	±.05°	CHECKED	----	17-APR-2008
1. BREAK ALL SHARP EDGES .015 MAX.			APPROVED	----	17-APR-2008
2. DO NOT SCALE DRAWING.			USED ON	ME-397467	
3. DIMENSIONS BASED UPON ASME Y14.5M-1994					
4. MAX. ALL MACH. SURFACES 125			MATERIAL	SEE PARTS LIST ABOVE	
5. DRAWING UNITS: U.S. INCH					

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

PPD/MECHANICAL SUPPORT
MINOS NEAR DETECTOR
TRANSPORT CART WELDMT. SIDE VIEW

SCALE	DRAWING NUMBER	SHEET	REV
1:8	9213.300-ME-397430	1 OF 3	
CREATED WITH : Ideas12NXSeries		GROUP: PPD/MECHANICAL DEPARTMENT	

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE



FRONT ELEVATION

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	I.FANG	22-JAN-2001
.XX	.XXX	ANGLES	DRAWN	V.MAJDANSKI	22-JAN-2001
± .03	± --	± .5°	CHECKED	----	17-APR-2008
1. BREAK ALL SHARP EDGES .015 MAX.			APPROVED	----	17-APR-2008
2. DO NOT SCALE DRAWING.			USED ON		
3. DIMENSIONS BASED UPON ASME Y14.5M-1994					
4. MAX. ALL MACH. SURFACES 125			MATERIAL	SEE PARTS LIST ON SHT 1	
5. DRAWING UNITS: U.S. INCH					

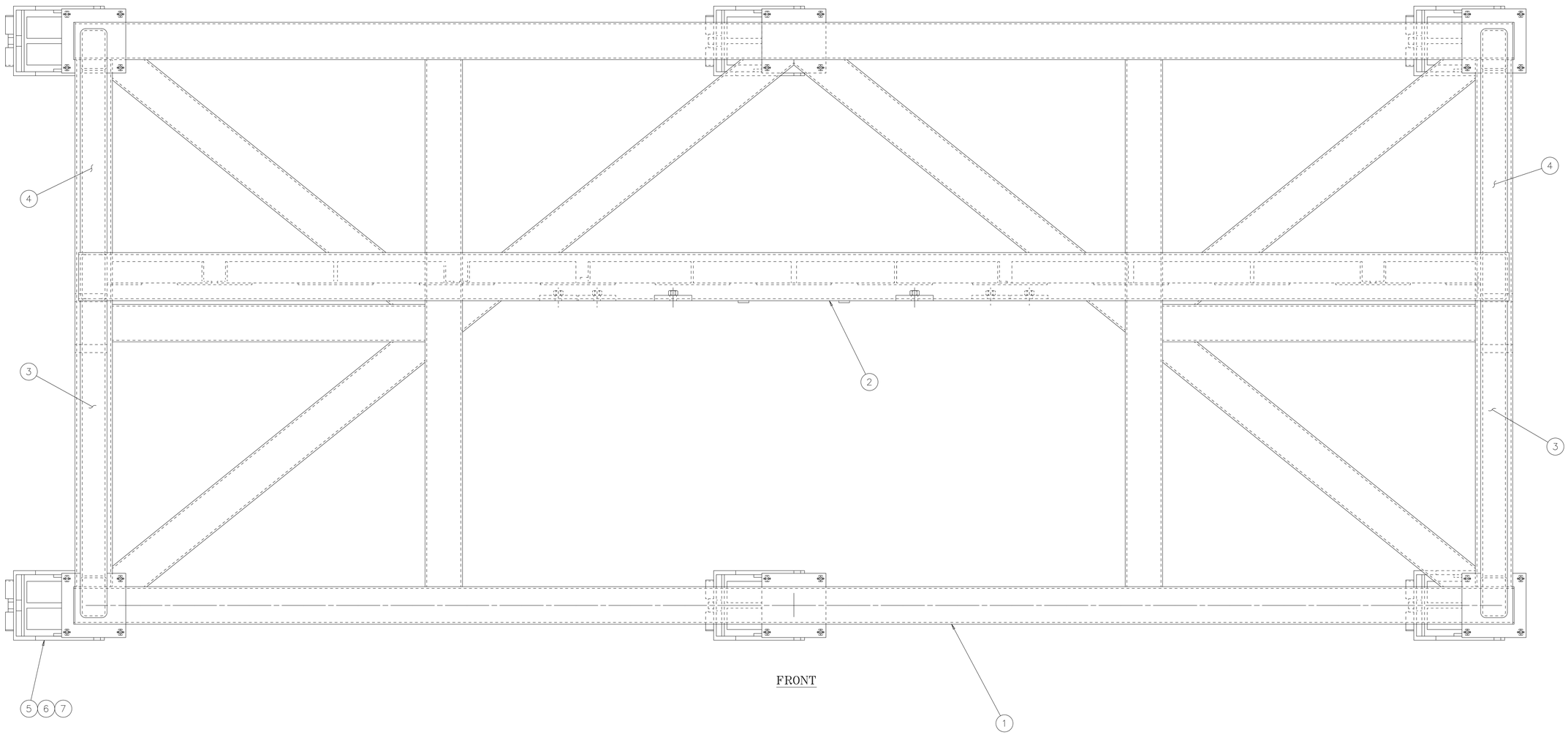
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

PPD/MECHANICAL SUPPORT
MINOS NEAR DETECTOR
TRANSPORT CART WELDMT FRONT ELEV

SCALE	DRAWING NUMBER	SHEET	REV
1:8	9213.300-ME-397430	2 OF 3	
CREATED WITH : Ideas12NXSeries		GROUP: PPD/MECHANICAL DEPARTMENT	

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE

REAR



FRONT

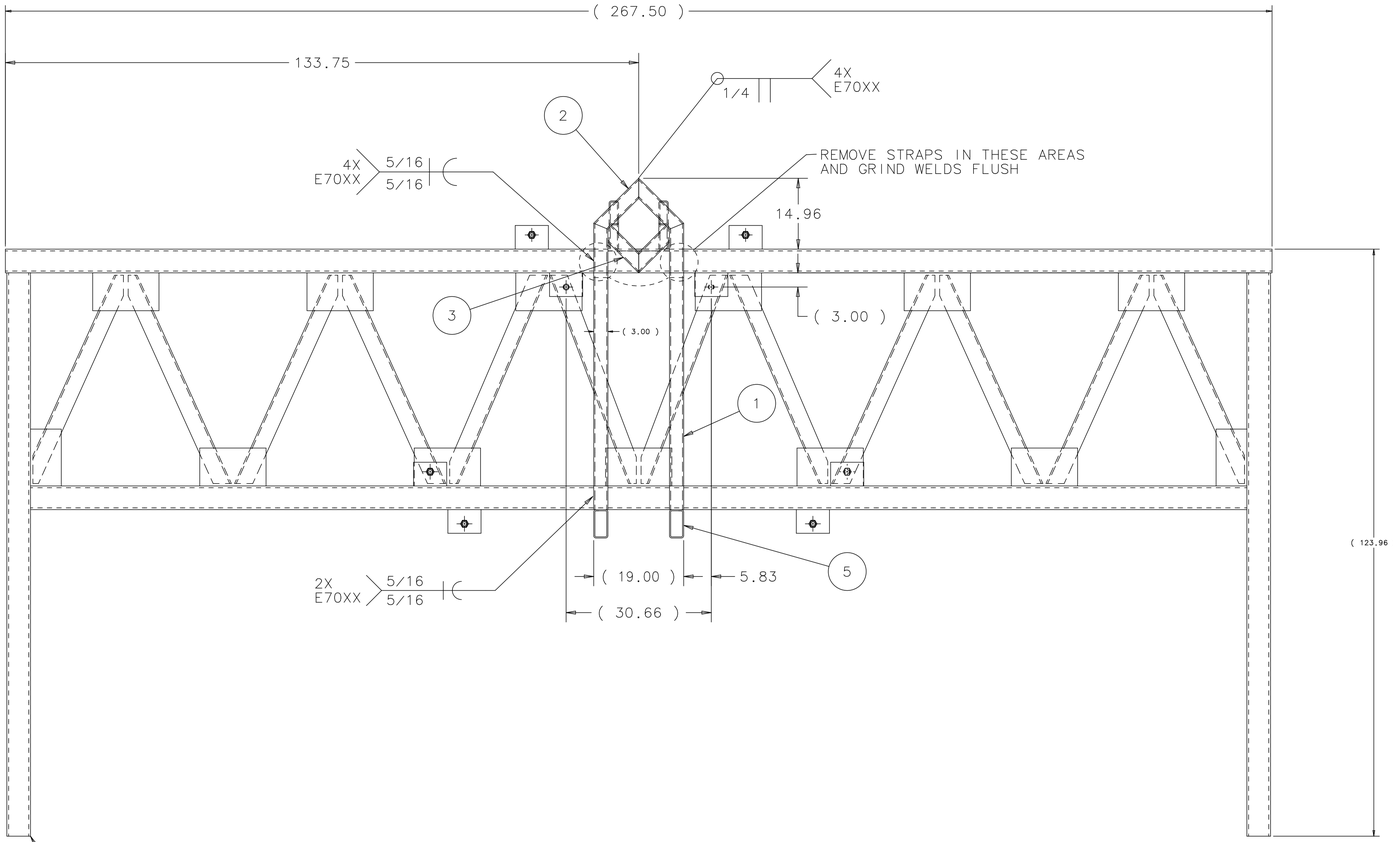
UNLESS OTHERWISE SPECIFIED			ORIGINATOR	I.FANG	22-JAN-2001
.XX	.XXX	ANGLES	DRAWN	V.MAJDANSKI	22-JAN-2001
± .03	± ---	± .05°	CHECKED	----	17-APR-2008
1. BREAK ALL SHARP EDGES .015 MAX.			APPROVED	----	17-APR-2008
2. DO NOT SCALE DRAWING.			USED ON		
3. DIMENSIONS BASED UPON ASME Y14.5M-1994					
4. MAX. ALL MACH. SURFACES 125			MATERIAL	SEE PARTS LIST ON SHT 1	
5. DRAWING UNITS: U.S. INCH					

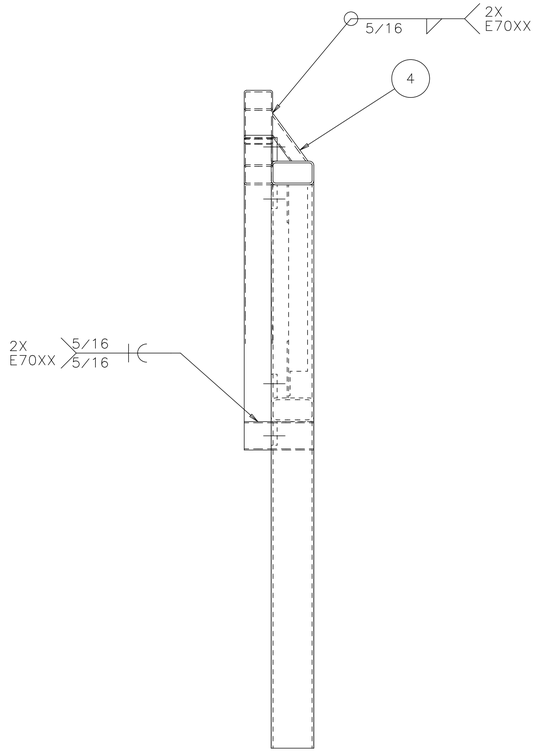
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

PPD/MECHANICAL SUPPORT
MINOS NEAR DETECTOR
TRANSPORT CART WELDMT. TOP VIEW

SCALE	DRAWING NUMBER	SHEET	REV
1:8	9213.300-ME-397430	3 OF 3	
CREATED WITH : Ideas12NXSeries		GROUP: PPD/MECHANICAL DEPARTMENT	

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE





5	COML	RECTANGLAR TUBING, 6 X 3 X .188 WALL X 14.00 LG-CARBON STEEL ASTM A500 GR.B	2
4	MD-444105-07	ANGLE BRACE (BACK)	2
3	MD-444105-06	ANGLE BRACE (LOWER)	2
2	MD-444105-05	ANGLE BRACE (UPPER)	2
1	MD-444105-10	VERTICAL BEAM (MEDIUM)	2
ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	J.KILMER	15-MAR-2006
.XX	.XXX	ANGLES	DRAWN	W.CYKO	15-MAR-2006
± .06	± ---	± 1°	CHECKED	W.CYKO	26-MAR-2007
			APPROVED	J.KILMER	26-MAR-2007

1. BREAK ALL SHARP EDGES .015 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ASME Y14.5M 1994
4. MAX. ALL MACH. SURFACES 250
5. DRAWING UNITS: INCHES

USED ON

MATERIAL
SEE PARTS LIST ABOVE

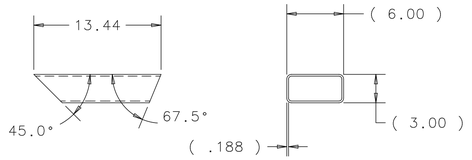
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

MINERVA-MECHANICAL DETECTOR TRANS CART TRUSS FRAME MOD

SCALE	DRAWING NUMBER	SHEET	REV
1/16	3938.330-MD-435763	1 OF 1	

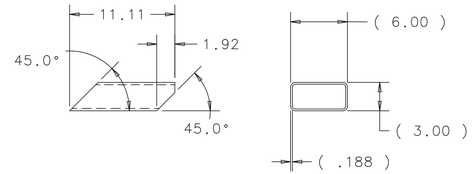
CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE
A	ITEMS 4,5,6 & 7 WERE 6 X 2 X .38 WALL NOW 6 X 3 X .188 WALL	G SMITH	19-JAN-2007
		J JILMER	19-JAN-2007
B	ITEM MD-444105-10 ADDED	G SMITH	26-MAR-2007
		G SMITH	26-MAR-2007



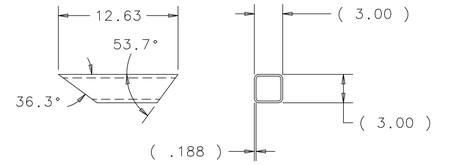
MD-444105-05 - ANGLE BRACE (UPPER)

A MAT'L.: 6 X 3 X .188 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B



MD-444105-06 - ANGLE BRACE(LOWER)

A MAT'L.: 6 X 3 X .188 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B

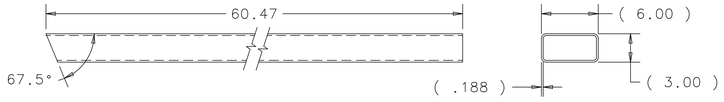


MD-444105-07 - ANGLE BRACE (BACK)

A MAT'L.: 6 X 3 X .188 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B

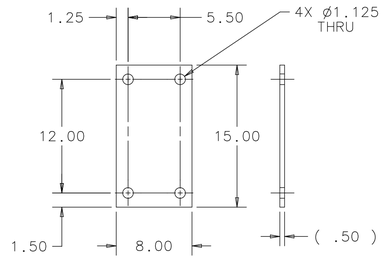
MD-444105-04 - VERTICAL BEAM SHORT

A MAT'L.: 6 X 3 X .188 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B



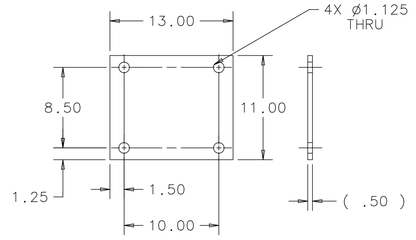
MD-444105-10 - VERTICAL BEAM MEDIUM

B MAT'L.: 6 X 3 X .188 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B



MD-444105-08 - SIDE FOOT

MAT'L.: 1/2" THICK PLATE
CARBON STEEL ASTM A36

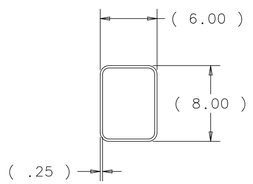


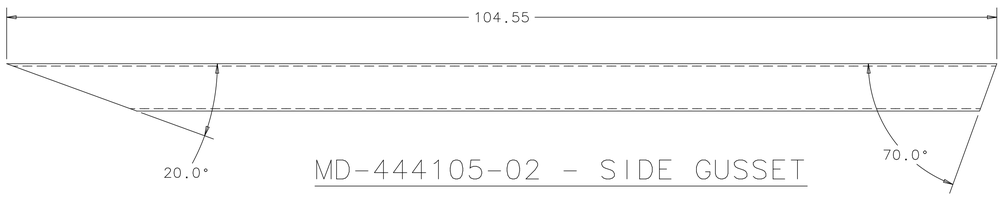
MD-444105-09 - BACK FOOT

MAT'L.: 1/2" THICK PLATE
CARBON STEEL ASTM A36

MD-444105-3 - BACK GUSSET

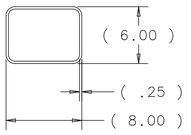
MAT'L.: 8 X 6 X .250 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B





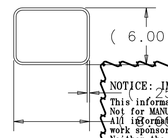
MD-444105-02 - SIDE GUSSET

MAT'L.: 8 X 6 X .250 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B



MD-444105-01 - VERTICAL BEAM (LONG)

MAT'L.: 8 X 6 X .250 WALL STRUCTURAL TUBING
CARBON STEEL ASTM A500 GR. B



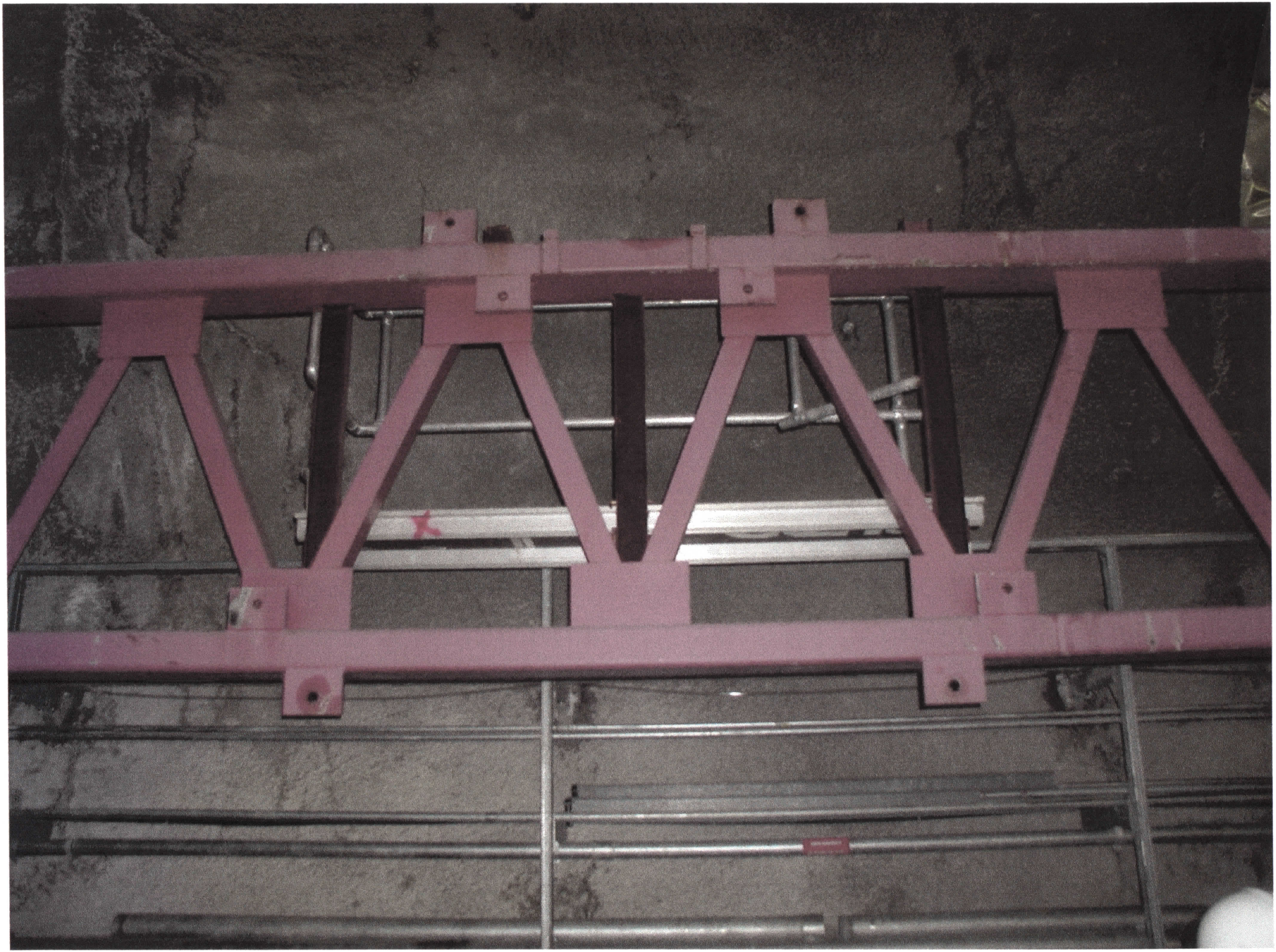
UNLESS OTHERWISE SPECIFIED			ORIGINATOR	J.KILMER	21-SEP-2006
.XX	.XXX	ANGLES	DRAWN	G.SMITH	21-SEP-2006
± .03	± ---	±1.0°	CHECKED	D.FRIEND	19-OCT-2006
1. BREAK ALL SHARP EDGES .015 MAX. 2. DO NOT SCALE DRAWING. 3. DIMENSIONS BASED UPON ASME Y14.5M-1994 4. MAX. ALL MACH. SURFACES 125 5. DRAWING UNITS: U.S.INCH			APPROVED	J.KILMER	19-OCT-2006
			USED ON	ME-444104	
			MATERIAL	AS LISTED IN DWG. DETAILS	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

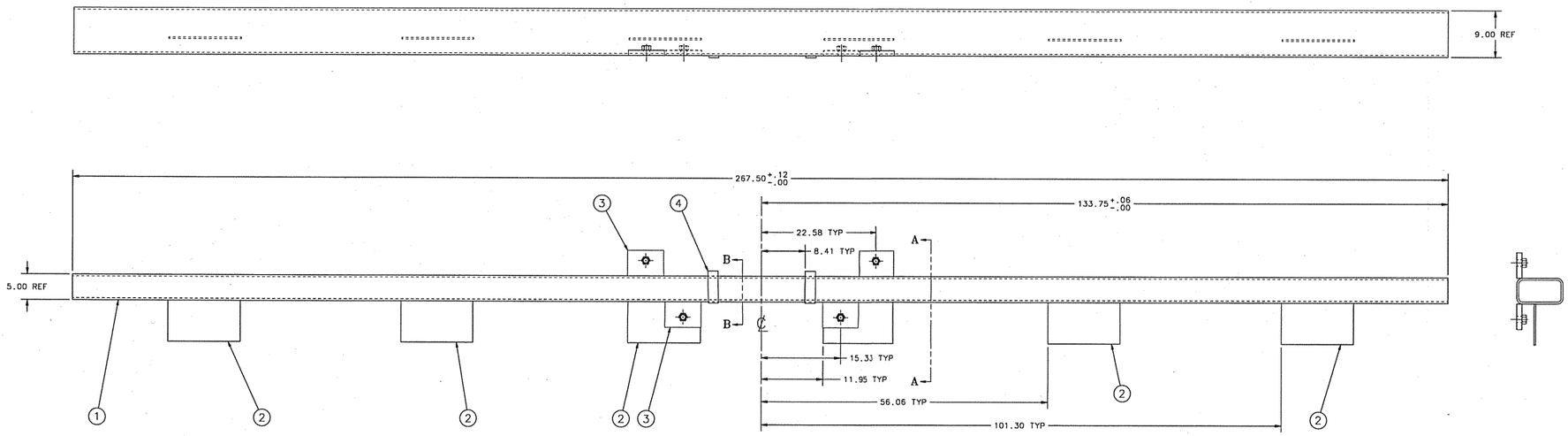
MINERVA - MECHANICAL DETECTORS STRONGBACK FLOOR SUPPORT PARTS

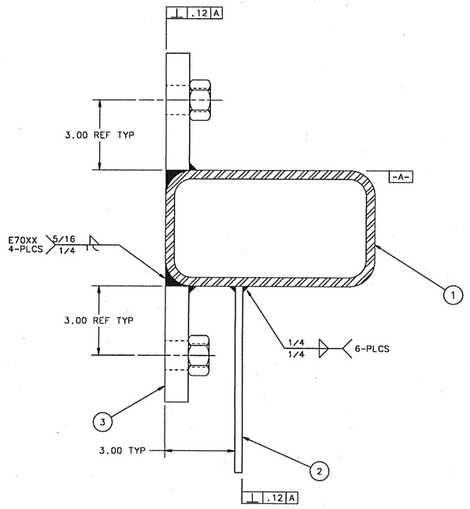
SCALE	DRAWING NUMBER	SHEET	REV
1:8	3938.330-MD-444105	1 OF 1	B

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

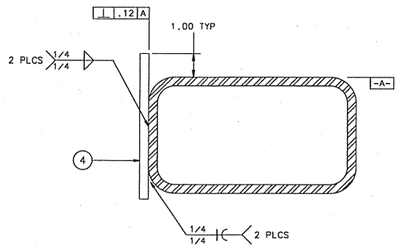


REV.	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE





SECTION A-A
SCALE: HALF



SECTION B-B
SCALE: HALF

NOTES:

1. ALL WELDING SHALL BE DONE USING THE ELECTRIC ARC PROCESS BY WELDERS HOLDING CURRENT WELDING CERTIFICATES FOR EACH REQUIRED PROCEDURE.
2. FABRICATION & ASSEMBLY SHALL BE IN ACCORDANCE WITH AISC STANDARD PRACTICE. SPECIAL TOLERANCES SHOWN ON DRAWING SHALL BE FOLLOWED.
3. IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR AND/OR SUBCONTRACTOR TO VERIFY ALL PART DIMENSIONS TO INSURE THE EXACT OVERALL DIMENSIONS AND TOLERANCES OF THE FINAL ASSEMBLY AS SHOWN ON THE DRAWING.

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
4	COML	PLATE, 2.00 x 6.25 x 3/8 THK A36 STEEL	2
3	MB-397432	PLATE, CONNECTING	4
2	COML	PLATE, 14.00 x 8.00 x 5/16 THK A36 STEEL	6
1	COML	TUBING, A500 STEEL GRADE B RECTANGULAR 9 x 5 x 3/8 WALL	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	I. FANG	JAN01
.XX	.XXX	ANGLES	DRAWN	VIC MAJDANSKI	22JAN01
± .03	± ——	± .5°	CHECKED		
			APPROVED		

1. BREAK ALL SHARP EDGES 015 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5M-1982
4. ALL DIMENSIONS ARE IN INCHES.

USED ON ME-397462

125 MAX. ALL MACHINED SURFACES

MATERIAL SEE PARTS LIST

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

PPD/MECHANICAL SUPPORT MINOS-NEAR DETECTOR TRANSPORT CART TUBE WELDMENT, TOP

SCALE	DRAWING NUMBER	SHEET NO.	REV.
1/8"=1'	9213.300-ME-397431	1 OF 1	