Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project Internal Reference:

Project: SciBooNE

Title: The Brief Structural Analysis for the Main Frame of the Scibar & EC Detector

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Reviewer(s): Arghee

Key Words: Frame, Structure, Tubing, Allowable Stress, Von Mises Stress, Welds, Shear and Bending Stress.

Abstract Summary: The main frame is specially designed for supporting the 35 ton force which is composed of the 64 scibar module layers, 64 Electron Catcher modules and numerous accessorial components of the detector. The several working stresses of the main frame were calculated by the simulated Finite Element Model, so as to calculate the deflection of the frame under the applying load. The allowable stresses, welds have been extensively discussed and calculated per the related applicable specifications and codes.

Applicable Codes:

"Allowable Stress Design", AISC, 9th edition
"Structural Welding Code-Steel", AWS D1.1-90
"Design of Weldments", By Omer W. Blodgett

1. *Overview*

As showing in Figure 1.1, the support frame is for housing the Scibar, Electron Catcher (EC) detectors, and other numerous accessorial devices and instruments, and the total weight of the system (live and dead) is about 35 tons (70,000 lbs).

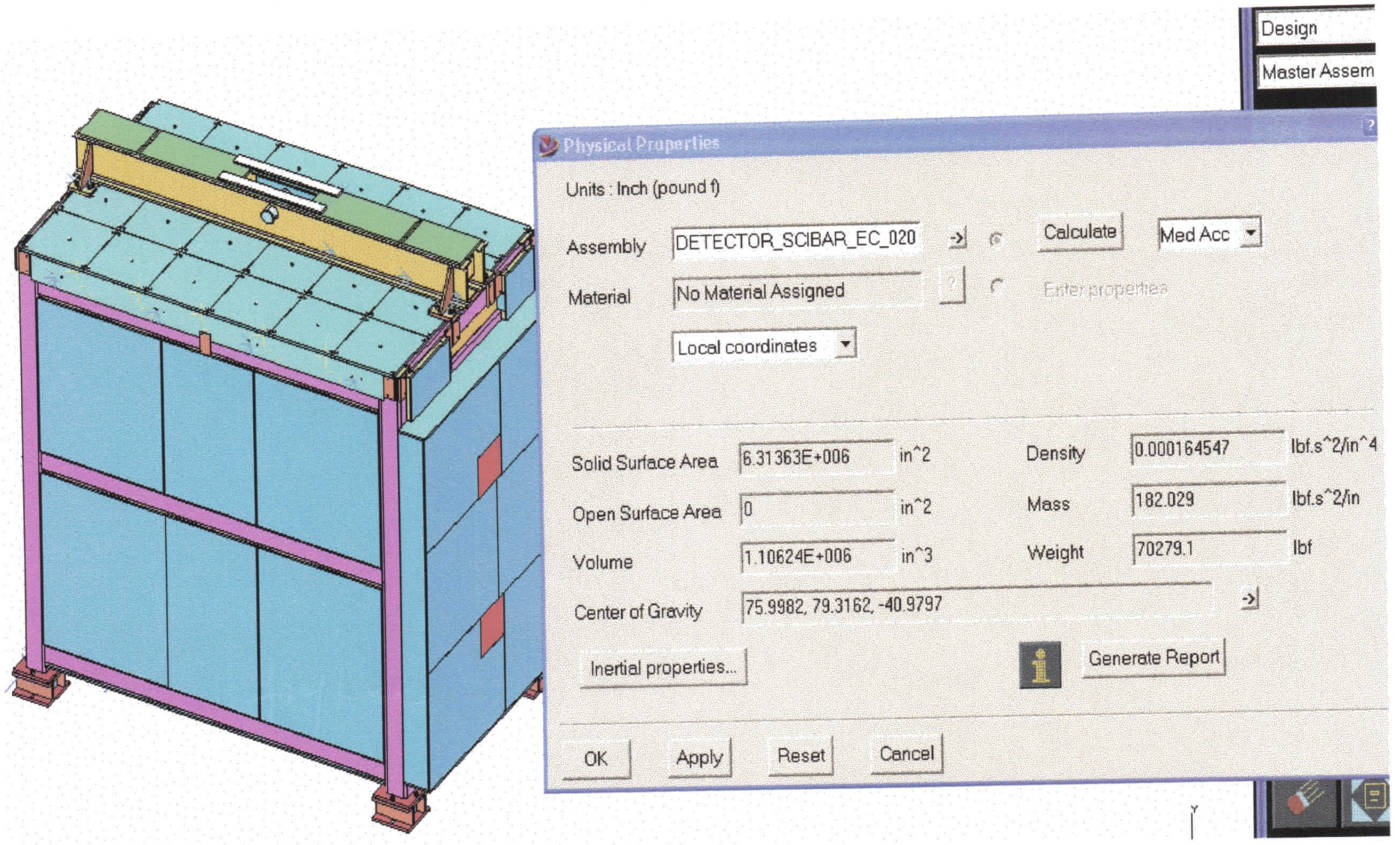


Fig. 1.1, The Isometric View of the Scibar and EC Detector of the SciBoone

For the simplicity, it is reasonable to assume that the structure of the main frame has to be designed to support the 35 tons applying load. The following page has more descriptions about the details of the applying load and the distributions.

The most critical load case for the main frame is that the main frame is lifted up for moving through four lifting pads at the top of the frame while all the components of the detector are installed in place. There is an extensive discussion regarding such loading case in section 3.

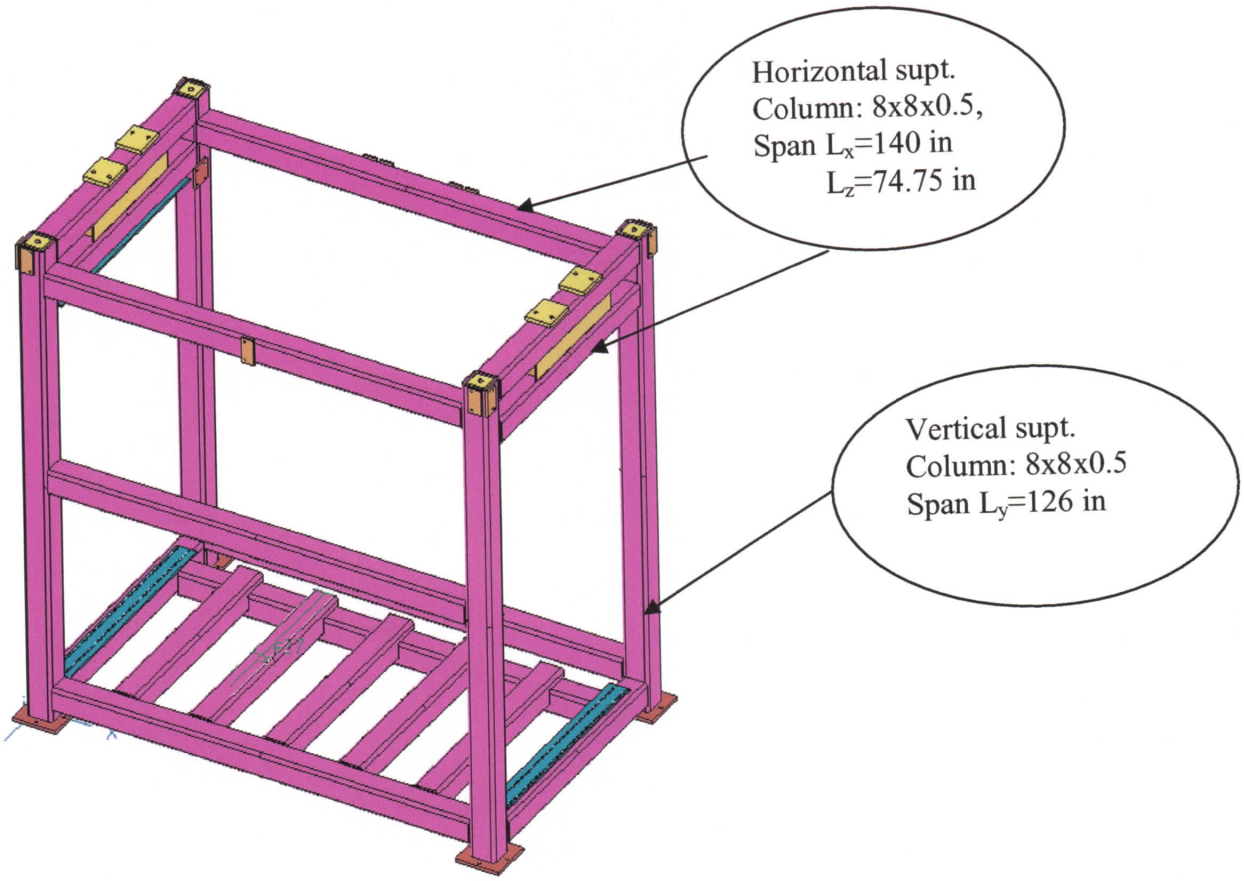


Fig. 1.2, The Support Frame of Scibar & EC Detectors.
(2D drawing: ME-435903)

The Figure 1.2 is an iso. View of the frame and the mechanical drawing ME-435903 has detail specifications for the construction of the frame.

The 64 Scibar module layers are support by frame through 64 mounting brackets, the horizontal EC (with 32 modules) and the vertical EC (w/32 modules) are installed in the downstream of the support frame, figure 1.3 is showing the inside iso installation view of the support system without the dark room around.

The support frame is designed to be built by the steel structural tubing, the specifications of the steel tubing are:

8" x 8" x ½" structural steel tubing,
ASTM A500, Grade B
F_y = 46 ksi
A = 14.4 in^2,
$I_{xx} = I_{yy}$ = 131 in^4
$S_{xx} = S_{yy}$ = 32.9 in^3
Γ = 3.03 in

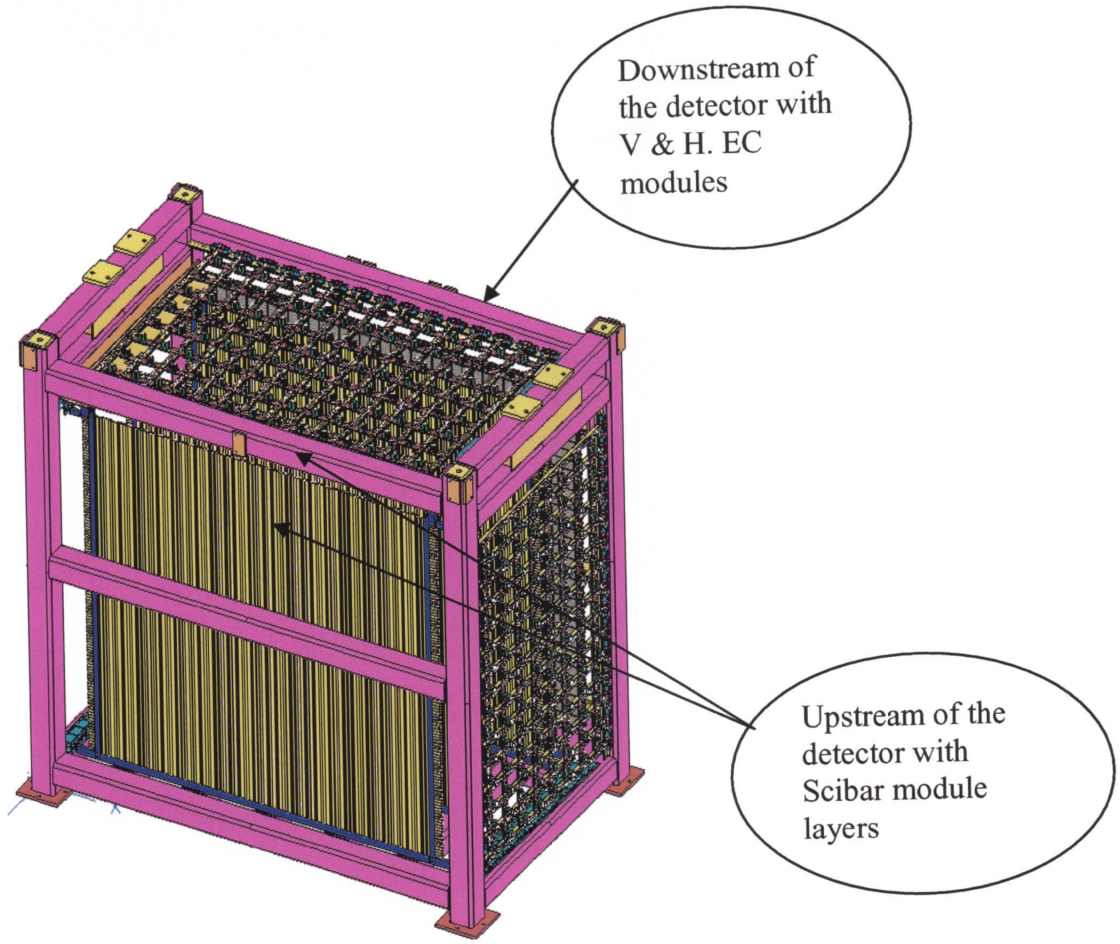


Fig. 1.3, Inside installation iso. view of the Scibar & EC detectors w/support frame

2. *Discussions and Calculations of the Allowable Stresses*

Considering the complex of the force distribution of the support frame, I built a FEA model to simulate the work load case of the support frame to calculate the working stress and displacement under different boundary conditions. However, it is still necessary to find out the allowable working stresses F_a, F_b & F_v under the current working boundary condition.

Assuming the square tube L_x=140 in (from fig. 1.2) under the loading case of "simple beam with uniformly distributed load" (#1 case of page 2-296, ASD 9th edition):

Per section B5.1d of ASD 9th edition,
b = 8" – 3x0.5"= 6.50 in
d = 8"
t_f = 0.5" = t_w
Per table B5.1 of section B5:
$190/(F_y)^{1/2} = 28$
$238/(F_y)^{1/2} = 35$
$b/t = 6.50/0.5 = 13 < 190/(F_y)^{1/2} = 28 < 238/(F_y)^{1/2} = 35$

Per equation F1-2 of Sections F1.1 and eq. F1-5 of section F1.2:
$L_c = (76b_f)/(F_y)^{1/2}$

$= (76 \times 8 \text{ in}) / (46\text{ksi})^{1/2}$
$= 89 \text{ in} < L_x = 140 \text{ in}$

So:

$F_b = 0.6\ F_y$
$= \underline{27.6 \text{ ksi}}$

Per section F4 of ASD 9th edition:

$380 / /(F_y)^{1/2} = 56$

$h = 8" - 2 \times 0.5"$
$= 7.0 \text{ in}$

$h/t_w = 7 \text{ in}/0.5 \text{ in}$
$= 14 < 380/(F_y)^{1/2} = 56$

Per eq F4-1 of section F4 of ASD 9th edition:

$F_v = 0.40\ F_y$
$= \underline{18.4 \text{ ksi}}$

The allowable stress for the vertical square column tube L_y=126 in:
Per section E2 of ASD 9th edition:
Assuming K = 1.0 for the loading case of the support frame, then:

$C_c = (2\pi^2 E / F_y)^{1/2}$
$= 111$

$KL / r = 1.0 \times 126 \text{ in} / 3.03 \text{ in}$
$= 41.58 < C_c = 111$

The allowable stress is:

$F_a = [1 - (KL/r)^2 / 2\ C_c^2]F_y \div [5/3 + 3\ (KL/r)/8C_c - (KL/r)^3/8C_c^3]$
$= [1 - (41.58)^2 / 2x111^2]x\ 46 \text{ ksi} \div [5/3 + 3x\ 41.58/8x111 - (41.58)^3/8x\ 111^3$
$= 42.77 \text{ ksi} \div (1.667 + 0.14 - 0.00657)$
$= \underline{23.75 \text{ ksi}}$

3. *Discussios and Analysis of the FEM results:*

As mentioned in section 2, several FEA models were built to simulating the main frame force loading conditions, and calculate the working stresses and displacements of the support frame under simulating boundary conditions of the frame. Fig. 3.1 is showing the model simulating the boundary conditions:

Due to the capacity of the computer, the model is assumed the boundary condition is symmetrical about the YZ plane @ where x=0.0, so it was use half of the frame.

The mass weight of the frame W_f = 10,500 lbs (50% of it) is distributed through the frame model.

The forces from EC vertical modules, EC horizontal modules, 64 Scibar module layers, vertical and top horizontal PMT assemblies, dark-house (6 sides with top side also acting as rated

service floor as shown in fig. 1) and other accessorial devices are distributed stimulatingly per the design and application of the whole detector support system.

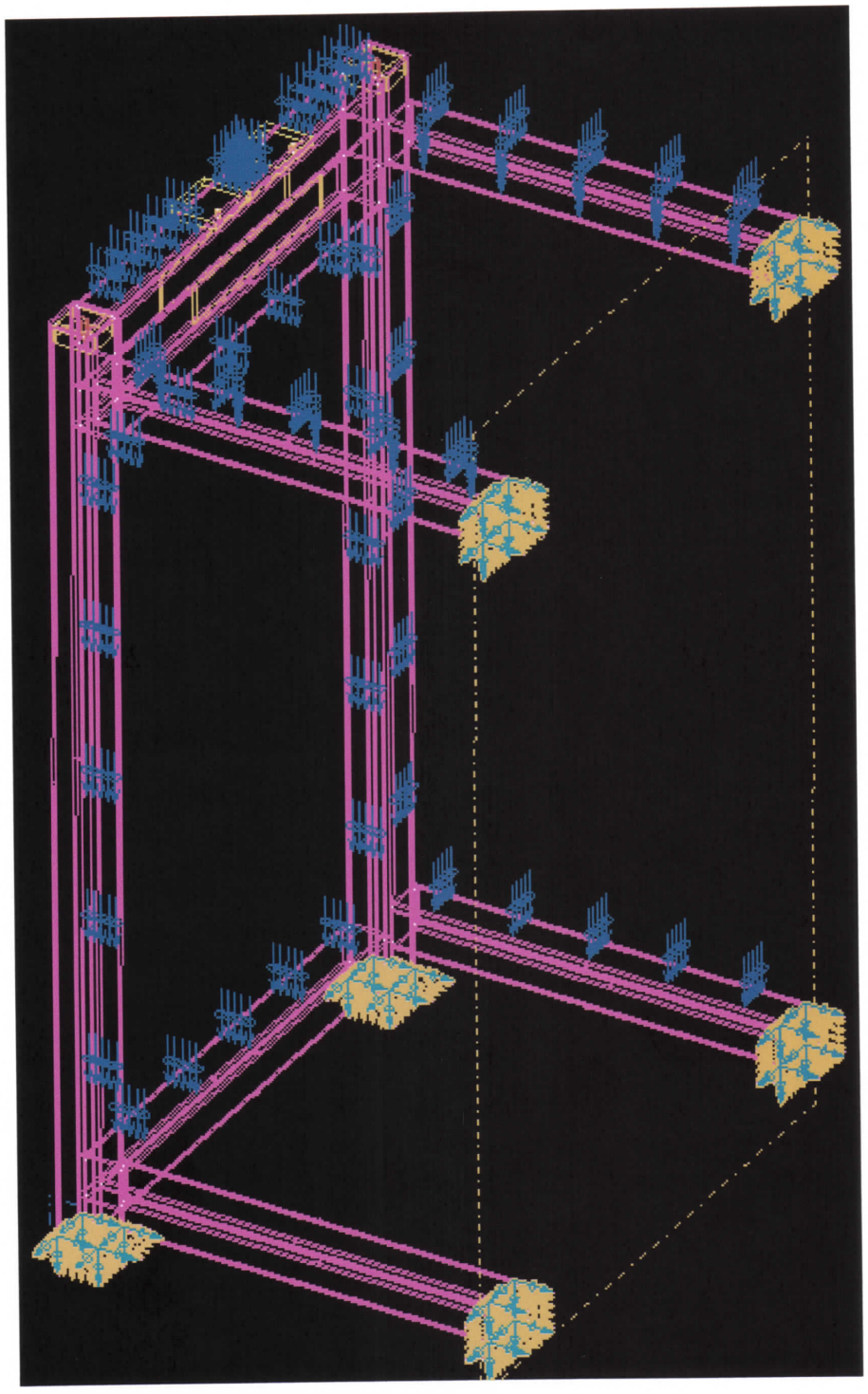


Figure 3.1, The Boundary Conditions for the Subjected FEA Model
(The main frame is lifted with the full detector components are loaded)

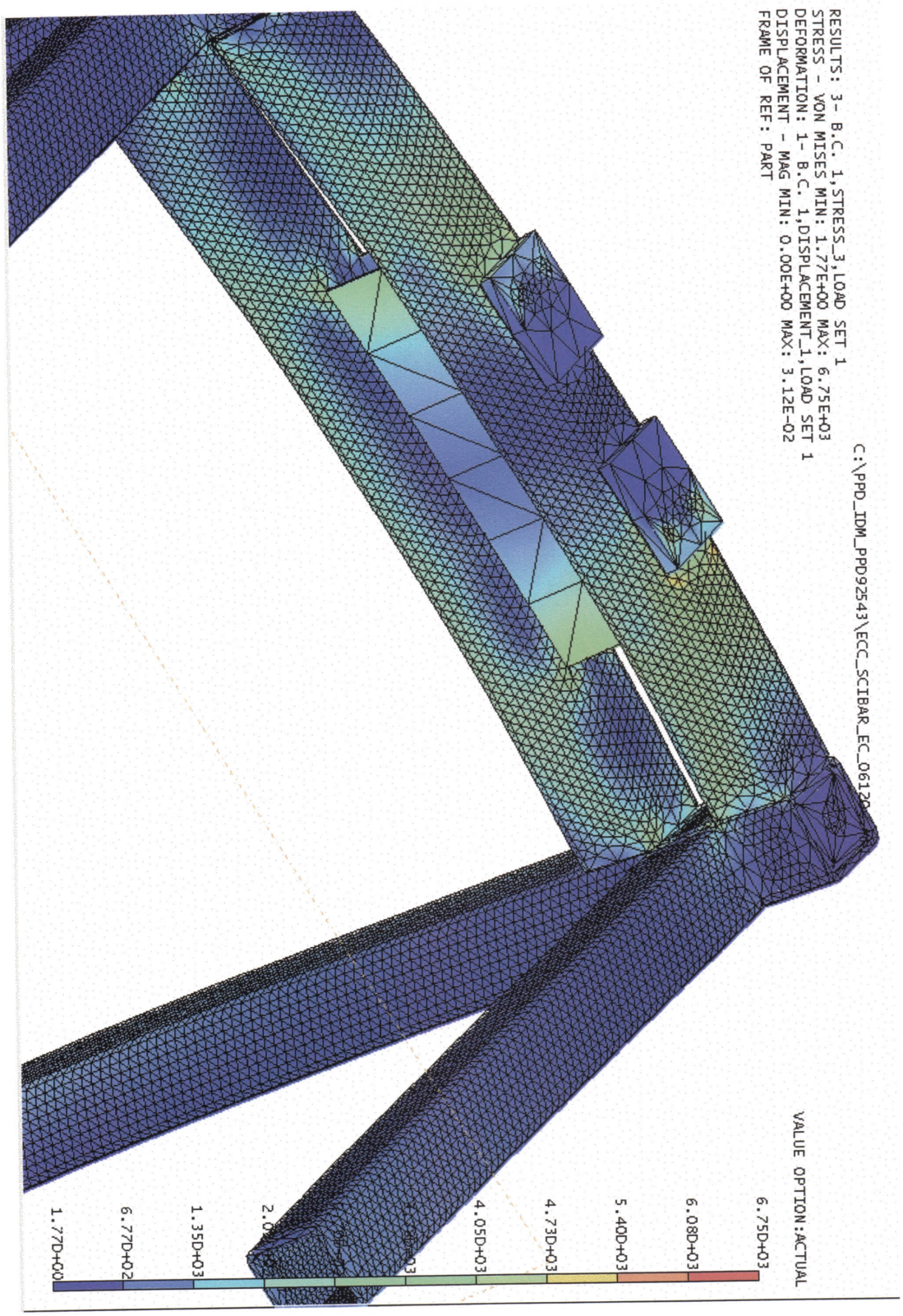


Figure 3.2, The Calculated Stress Distribution When the Detector is Lifted

I-DEAS 12 NX Series m1: Simulation 16-Jun-06 16:15:07
C:\PPD_IDM_PPD92543\ECC_SCIBAR_EC_061206.mf1

Group ID : None
Result Set : 2 - B.C. 1,REACTION FORCE_2,LOAD SET 1
Report Type : Contour Units : IN
Result Type : REACTION FORCE
Frame of Reference: Part Data Component: Magnitude

	Reacti-X	Reacti-Y	Reacti-Z	Reacti-RX	Reacti-RY	Reacti-RZ
Total	-4.272E-04	-2.441E-04	-3.745E+04	0.000E+00	0.000E+00	0.000E+00
Maximum	15495 1.137E+03	2753 1.612E+03	7188 1.329E+03	17 0.000E+00	17 0.000E+00	17 0.000E+00
Minimum	15630 -1.099E+03	3598 -1.551E+03	2753 -3.765E+03	17 0.000E+00	17 0.000E+00	17 0.000E+00
Average	-2.225E-06	-1.272E-06	-1.950E+02	0.000E+00	0.000E+00	0.000E+00

Table 3.1, The Summary of the reaction force for the FEA model .

I-DEAS 12 NX Series m1: Simulation 23-Mar-07 15:27:46
C:\PPD_IDM_PPD92543\ECC_SCIBAR_EC_061206.mf1

Group ID : None
Result Set : 3 - B.C. 1,STRESS_3,LOAD SET 1
Report Type : Contour Units : IN
Result Type : STRESS
Frame of Reference: Part Data Component: X-Component

	Stress-XX	Stress-XY	Stress-YY	Stress-XZ	Stress-YZ	Stress-ZZ
Maximum	11469 2.119E+03	31554 1.761E+03	1367 6.008E+03	52649 3.195E+03	52380 2.406E+03	52374 6.604E+03
Minimum	30594 -2.542E+03	15772 -1.762E+03	10516 -4.762E+03	4861 -2.384E+03	52374 -2.679E+03	176 -3.326E+03
Average	2.063E+00	6.272E-01	-3.826E+01	2.133E+01	-8.256E-01	2.373E+02

Table 3.2, The Summary of the calculated stresses for the FEA model

It is found from Figure 3.2 that the max. Von Mises stress $\mathbf{F_{vm} = 7.75\ ksi}$ which is less than the allowable stress $\mathbf{F_a = 23.75\ ksi}$. (see section2, page 5).

Table 3.2 summarized all max. & min. stresses in different directions from the simulated model. As you can see, all the values of the stress are less than the allowable stresses F_v and F_b respectively.

The deflections:
The SciBooNE Experiment set the criteria of the deflection in Y direction (the direction of the gravitation) is +/- 0.059" (+/- 1.5 mm).
From the Figure 3.2, it is found that the maximum deflection of the frame is about 0.0312", which is less than the experimental defined value of 0.059".

4. *The discussions of the welds:*

All welding metals are E70, where $F_u = 70$ ksi
Then, the allowable stress of the welding metal: $F_{wv} = 0.30 \times 70\ ksi = 21 ksi$
(per Table J2.5, Chapter J, ASM, 9th edition)

The actual loading case for the tubing sections of the frame (ref. to fig. 1.2 of page 3, fig.1.3 of page 4 and fig. 3 of page 6) is between the "simple beam to the fixed beam at both ends, force uniformly distributed." (See cases #1 & #15 of section 2, ASD, 9th edition).

For the simple and conservative sake, we chose the beam (tube) connected as: **fixed at both ends with uniformly distributed loads w**. We also picked the longest beam support span L = 140" as the case we'll discuss (see fig. 1.2 in page 3). See fig. 4.1 for the force distribution.

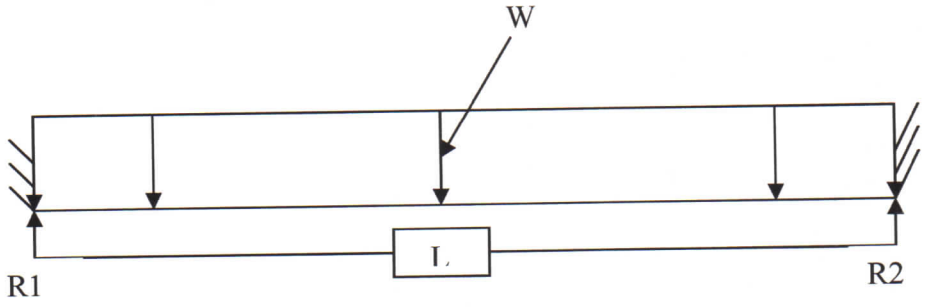


Fig. 4.1, Force distribution of the frame tubing beam.

Conservatively assuming P = 17.5 tons = 35,000 lbs applying to the subjected beam along,
Where:

L = 140.0",
w = P/L = 35,000 lbs / 140" = 250 lbs/in
$R_1 = R_2 = P/2 = 17{,}500$ lbs.

$M_{max} = wL^2 / 12 = (250 \times 140^2) / 12 = 408{,}334$ lbs-in

Figures 4.2 is partial view from the engineering drawing and figure 4.3 is the configuration of the tubing welds in cross view.

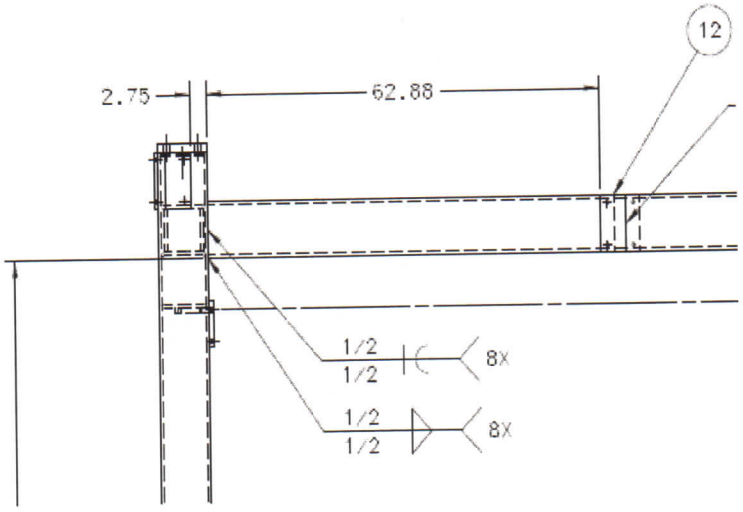


Fig. 4.2, The partial view of the main frame drawing ME-435903 (related to the tubing Weld in discussed area)

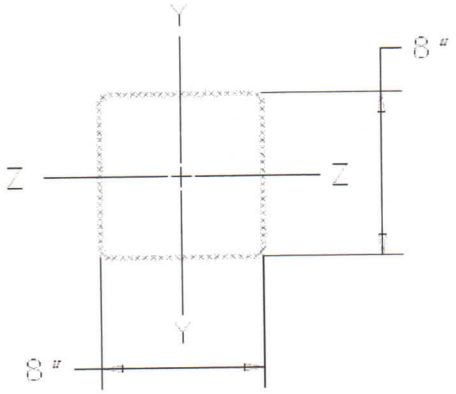


Figure 4.2. The weld configuration of the connect tubing beam to treat as lines

Find the geometric properties of the welds (treated as lines):

From figure 4,2, it is found that:
Length L = 2 (b+d) = 32 in where b = 8 in = d
$I_z = I_y = d^2 (3b + d) \div 6$

$= 341.33\ in^3$

$S_z = Sy = d\,(3b + d) \div 3$

$= 85.33\ in^2$

Compute the components of the force in the welds:

The primary shear stress due to direct load f_v

$f_v = R1 \div$ weld length

$= 17{,}500$ lbs $\div$ 32.0 in

$= 547$ lbs/in $\downarrow$

The bending stress f_b about the Z axis:

$f_b = M_{max} / I_z$

$= (408{,}334 \div 85.33)$ lbs/in

$= 4{,}786$ lbs/in

The resultant force f_t

$f_t = (f_v^2 + f_b^2)^{1/2}$

$= (547^2 + 4{,}786^2)^{1/2}$ lbs/in

$= 4{,}817$ lbs/in

Find the fillet weld size C, per drawing; all are fillet welds with E70 weld metal:
Allowable stress of the weld metal F_{wv}:

$F_{wv} = 0.30 \times 70$ ksi $= 21$ksi, for E70 weld metal

$C = f_t / (0.707 \times F_{wv})$

$= 4{,}817$ lbs/in $\div (0.707 \times 21{,}000)$ lbs/in^2

$= 0.3245$ in

Per drawing ME-435903 (also see fig. 4.2), it was found that the weld sizes are 0.50", so the design is satisfactory.

5. *The conclusions:*

The calculated working stresses are less that the allowable stress of the support frame; the calculated deflection values are less that the experimental designated deflection values; the designed welding sizes are much larger than the calculated required sizes. Up to those ends, the design of the main frame is satisfactory to the applying force distributions of the Scibar and Electron Catcher detector.

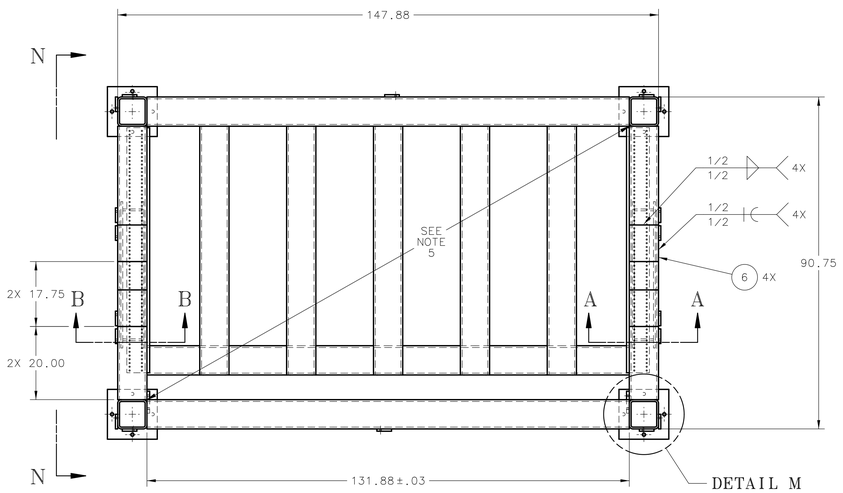
6. *Some direct related reference drawings:*

ME – 435903 -1
ME – 435903 -2
ME – 444071 -1
ME – 444071 -2

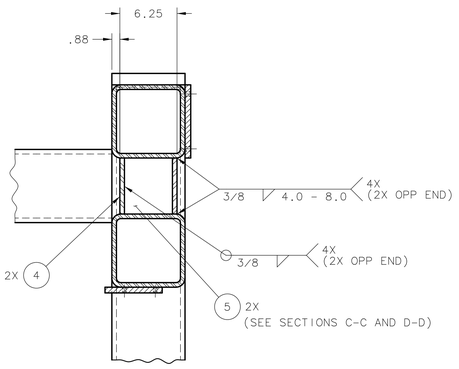
In order to view more details of the drawings, please go to the link:
http://home.fnal.gov/~edchi/SciBoone/EC_Scibar/drawings/

The site contains the master drawing list and the pdf format type of 2d drawings

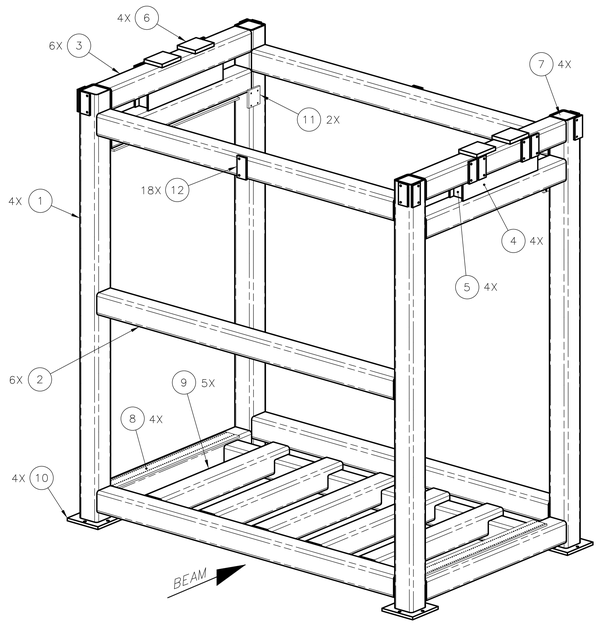
REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE



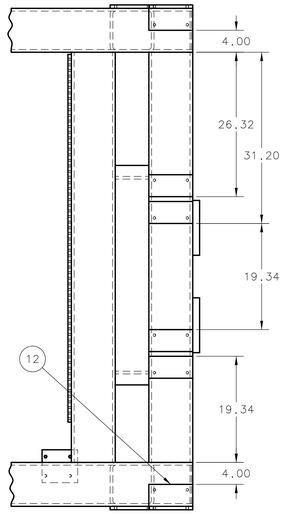
TOP VIEW



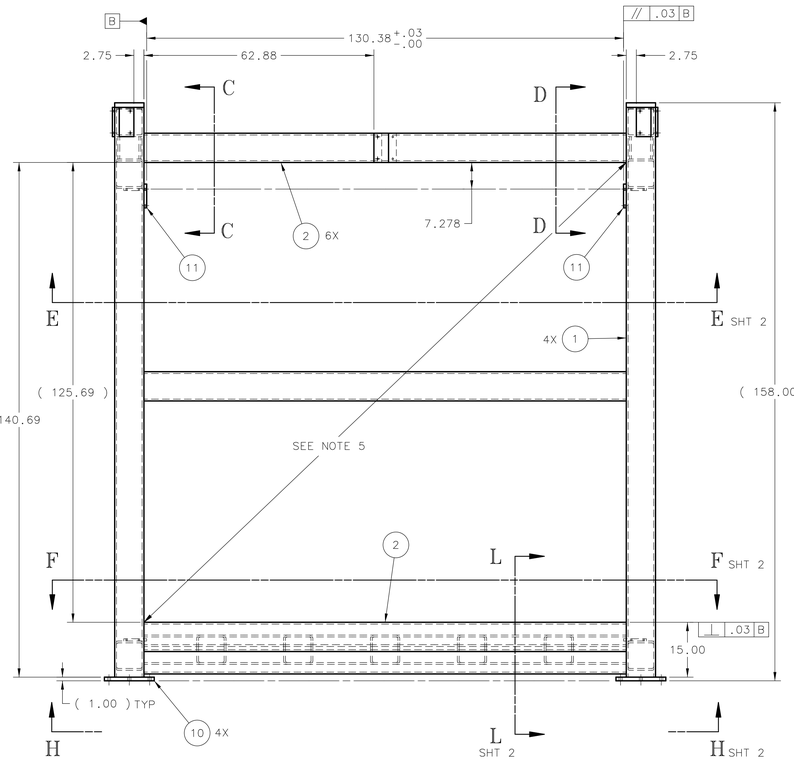
SECTION A–A (SHOWN)
SECTION B–B (MIRROR IMAGE)
SCALE 5/32

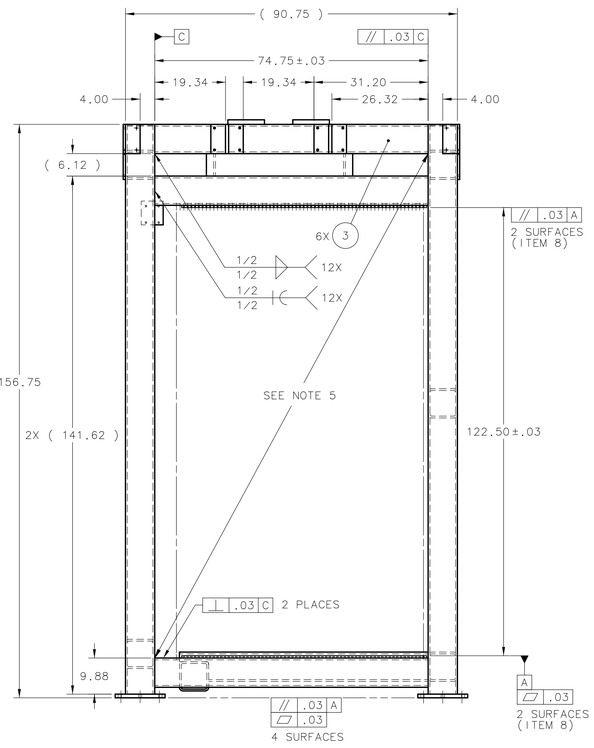


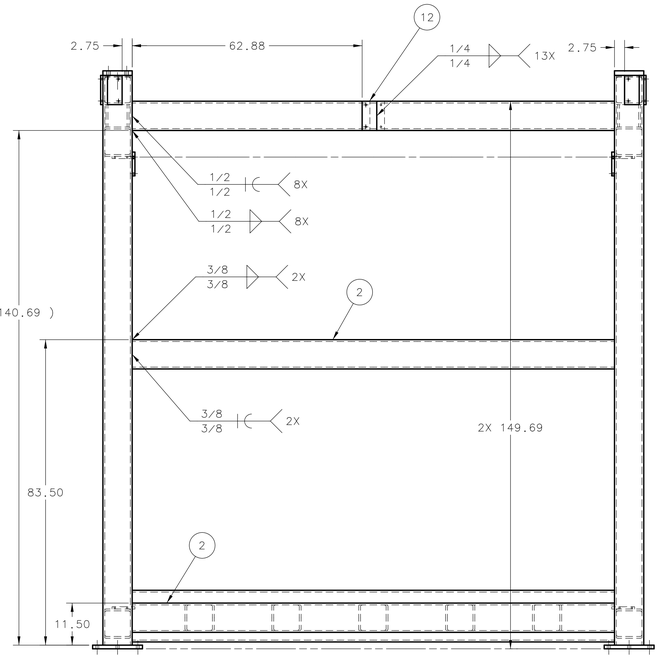
ISOMETRIC VIEW
SCALE .05 = 1.0

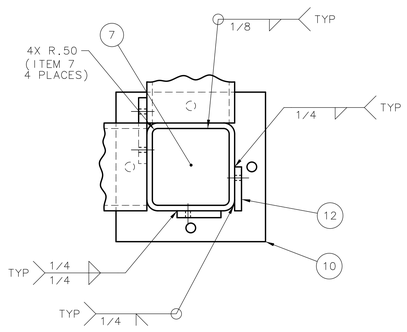


VIEW N–N
SCALE 3/32

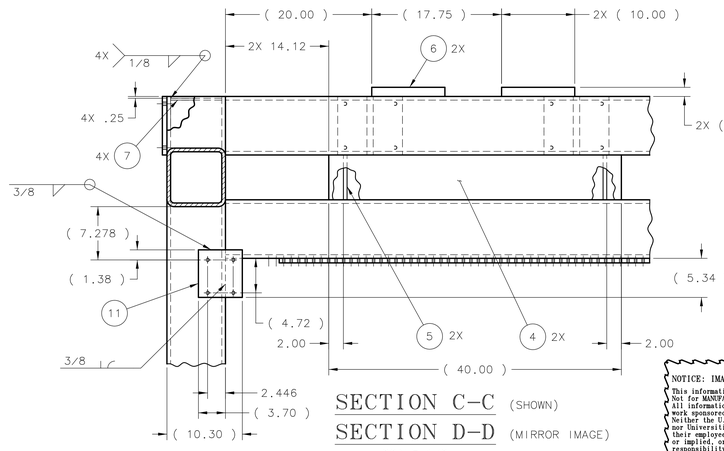








DETAIL M
TYP 4 CORNERS
SCALE 3/16



SECTION C–C (SHOWN)
SECTION D–D (MIRROR IMAGE)
SCALE 1/8

NOTES:

1. ALL WELDMENTS MUST BE IN ACCORDANCE WITH STRUCTURAL WELDING CODE - AWS D1.1.
2. ALL WELD FILLER METALS ARE E70XX UNLESS OTHERWISE SPECIFIED.
3. APPROXIMATE WEIGHT: 9,700 LBS.
4. PAINT WITH RED OXIDE DAMP-PROOF RUST-OLEUM PRIMER OR EQUIVALENT, EXCEPT FOR ALL HOLES AND ENTIRE MOUNTING SURFACES OF ITEM 8 (4 PLACES).
5. DURING AND AFTER WELDING CHECK FOR SQUARENESS. SQUARENESS MUST BE WITHIN ±.06.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
12	MB-435904	PLATE MTG RAILING	18
11	MB-435876	PLATE MTG VT TOP END	2
10	MC-435878	PLATE BOTTOM FRAME	4
9	MD-435877	TUBE Z SQUARE FRAME	5
8	MD-435879	PLATE MTG BRKT MODULE	4
7	COML	STEEL PLATE, 7.00 x 7.00 x 1/4 THK, ASTM A36	4
6	COML	PLATE, HOT ROLLED CARBON STEEL, ASTM A36, 8.00 x 10.00 x 1-1/4 THK	4
5	COML	PLATE, HOT ROLLED CARBON STEEL, ASTM A36, 6.12 x 5.25 x 1/2 THK	4
4	COML	PLATE, HOT ROLLED CARBON STEEL, ASTM A36, 6.12 x 40.00 x 1/2 THK	4
3	COML	SQUARE TUBING, CARBON STEEL, ASTM A500 GRADE B, 8 x 8 x 1/2 WALL x 74.75 LG	6
2	COML	SQUARE TUBING, CARBON STEEL, ASTM A500 GRADE B, 8 x 8 x 1/2 WALL x 131.88 LG	6
1	COML	SQUARE TUBING, CARBON STEEL, ASTM A500 GRADE B, 8 x 8 x 1/2 WALL x 155.75 LG	4

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	E.CHI	07-JUN-2006
.XX	.XXX	ANGLES	DRAWN	T.SPERRY	07-JUL-2006
± .04	± .020	± - -	CHECKED	J.RAUCH	11-AUG-2006
1. BREAK ALL SHARP EDGES MAX.			APPROVED	E.CHI	11-AUG-2006
2. DO NOT SCALE DRAWING. 3. DIMENSIONS BASED UPON ASME Y14.5M-1994 4. MAX. ALL MACH. SURFACES			USED ON		
5. DRAWING UNITS: U.S. INCH			MATERIAL	SEE PARTS LIST ABOVE	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCIBOONE - MECHANICAL
DETECTORS
FRAME SCIBAR EC ASSY

SCALE	DRAWING NUMBER	SHEET	REV
3/32 & AS NOTED	3954.330-ME-435903	1 OF 2	

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

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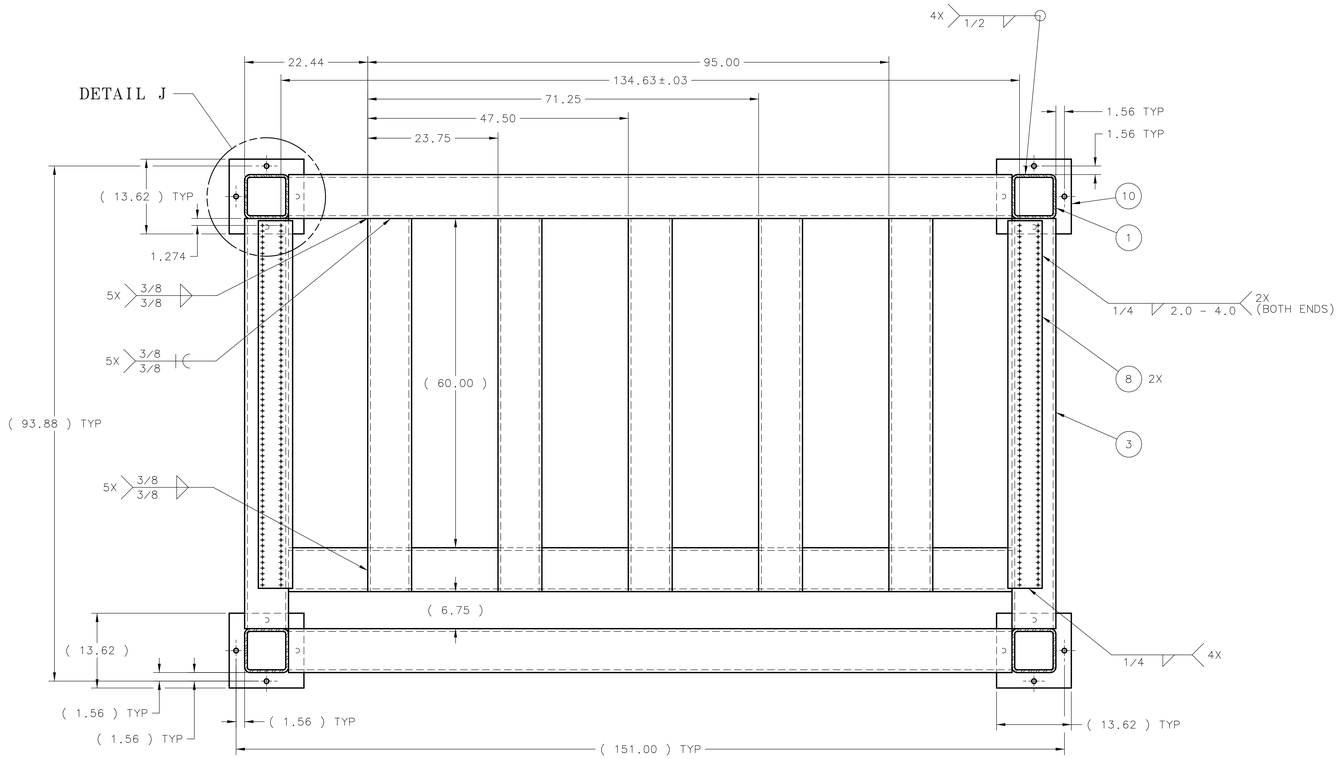
		APPROVED	DATE



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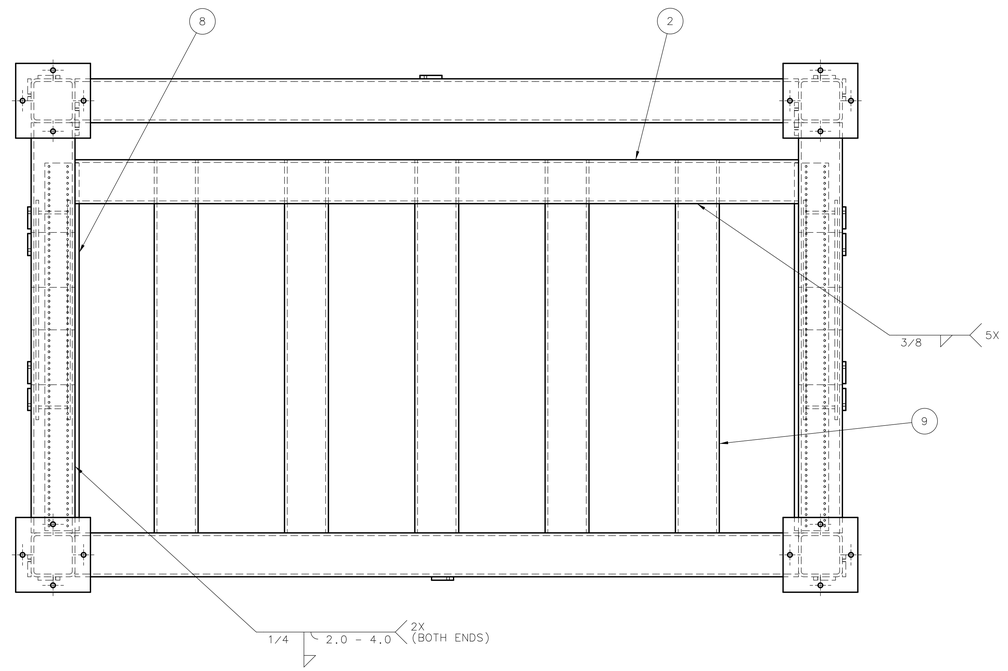
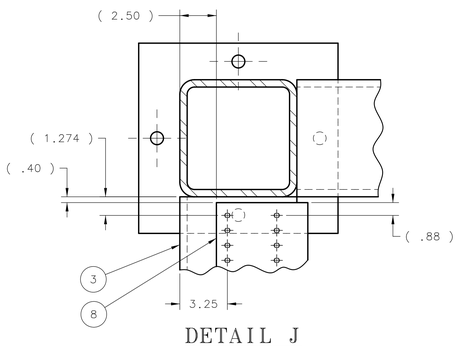


VIEW H–H
SCALE 3/32



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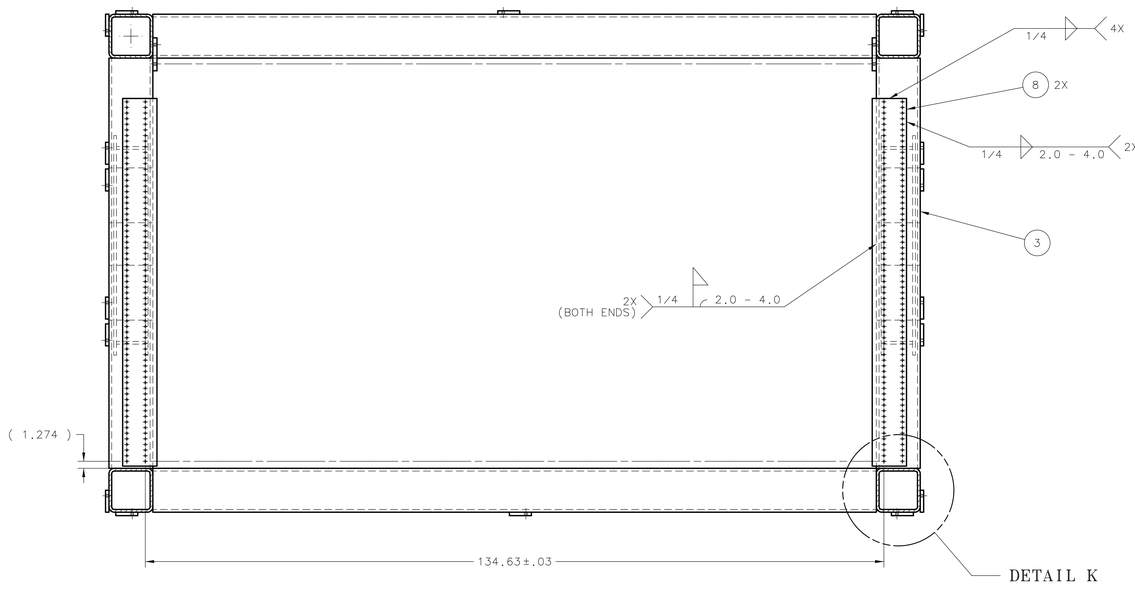
TYP 2X
SCALE 1/4



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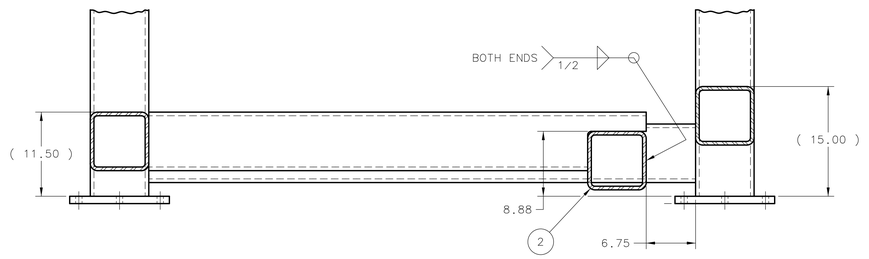

SECTION L–L
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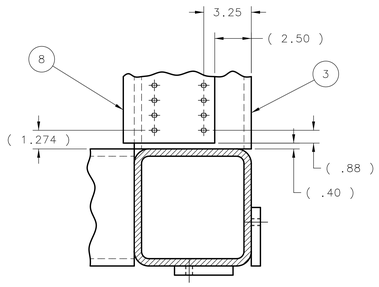

DETAIL K
TYP 2X
SCALE 1/4

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	E.CHI	07-JUN-2006
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± .04	± .020	± - -	CHECKED	J.RAUCH	11-AUG-2006
1. BREAK ALL SHARP EDGES MAX.			APPROVED	E.CHI	11-AUG-2006
2. DO NOT SCALE DRAWING.			USED ON		
3. DIMENSIONS BASED UPON ASME Y14.5M-1994					
4. MAX. ALL MACH. SURFACES			MATERIAL	SEE PARTS LIST	
5. DRAWING UNITS: U.S. INCH					

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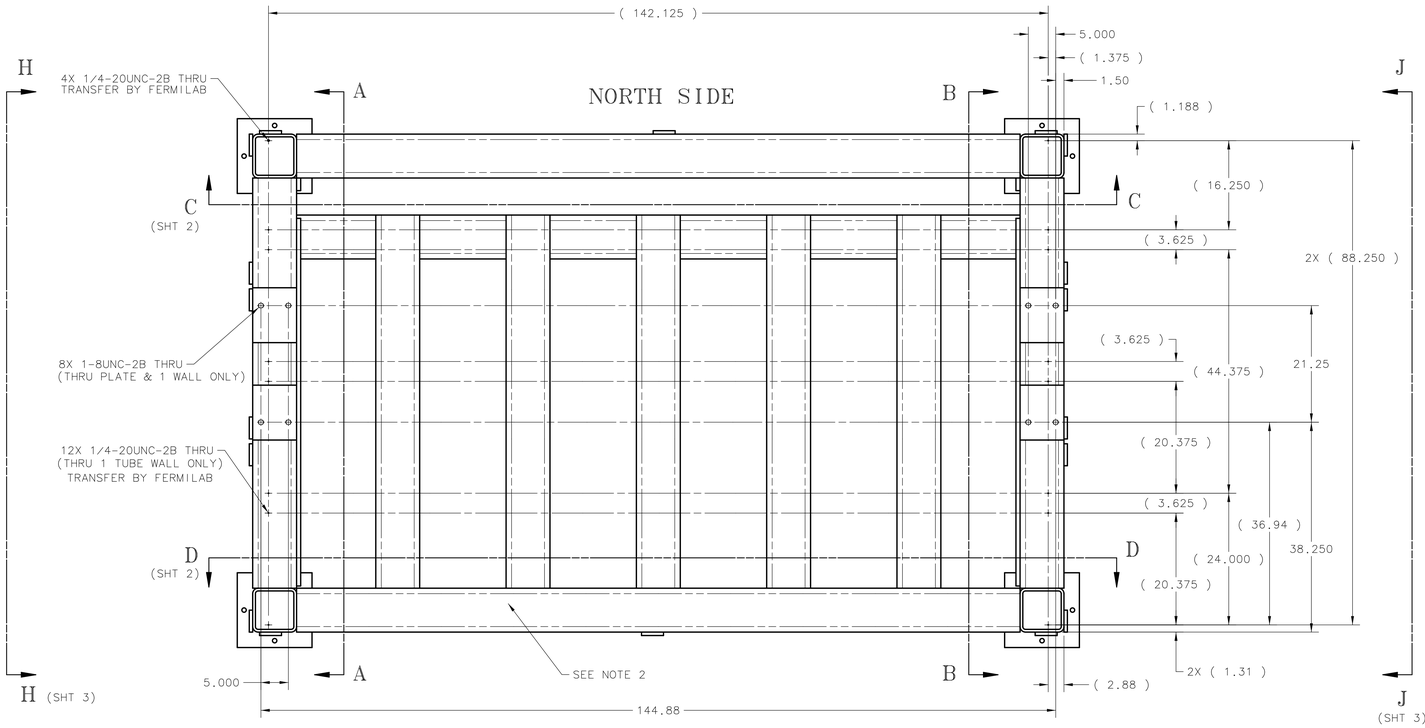
UNITED STATES DEPARTMENT OF ENERGY

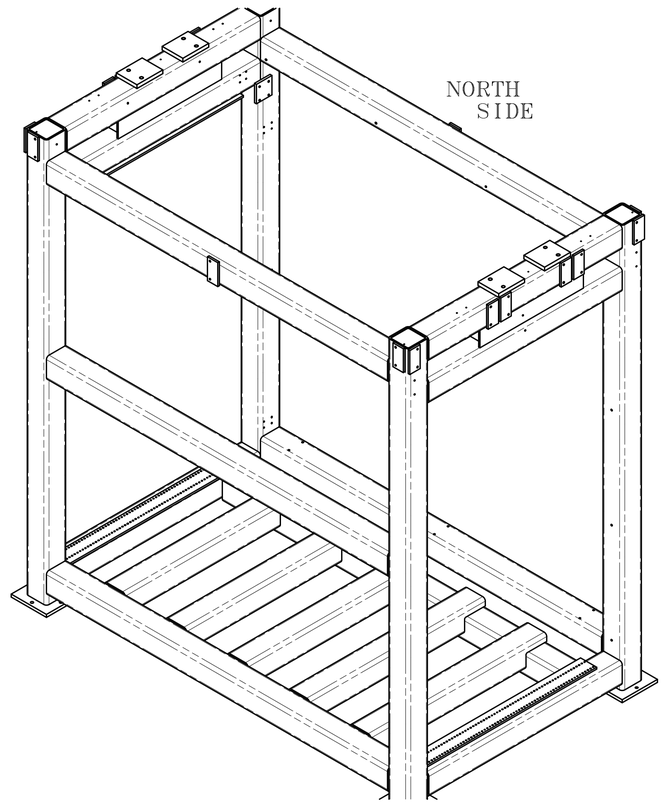
SCIBOONE – MECHANICAL
DETECTORS
FRAME SCIBAR EC ASSY

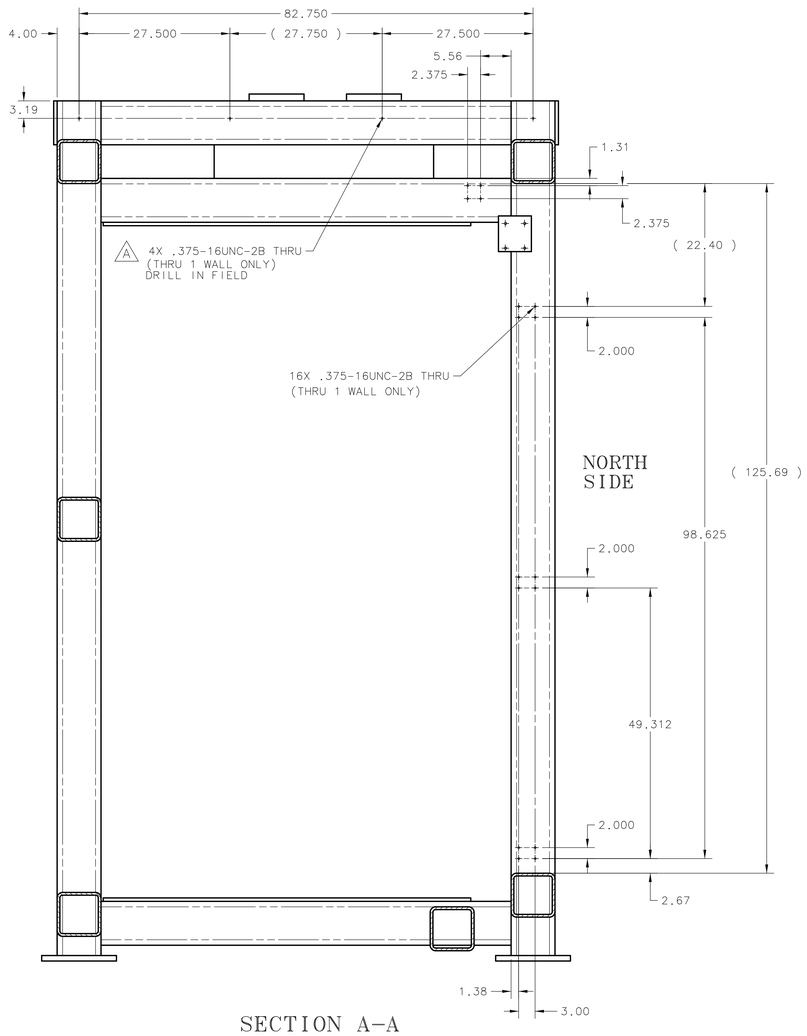
SCALE	DRAWING NUMBER	SHEET	REV
3/32 & AS NOTED	3954.330-ME-435903	2 OF 2	
CREATED WITH : Ideas12NXSeries		GROUP: PPD/MECHANICAL DEPARTMENT	

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE
A	ADDED (12) 3/8-16UNC-2B HOLES SEE SECTIONS A-A, B-B AND F-F	T.SPERRY	16-OCT-2006
		E.CHI	16-OCT-2006
B	ADDED SHT 3 - ADDED (6) 1/2-13 HOLES (VIEW H-H). ADDED (6) 3/8-16 HOLES (VIEW J-J). - ADDED (8) 1/4-20 HOLES (SEE SECTION B-B)	T.SPERRY	04-APR-2007
		E.CHI	04-APR-2007



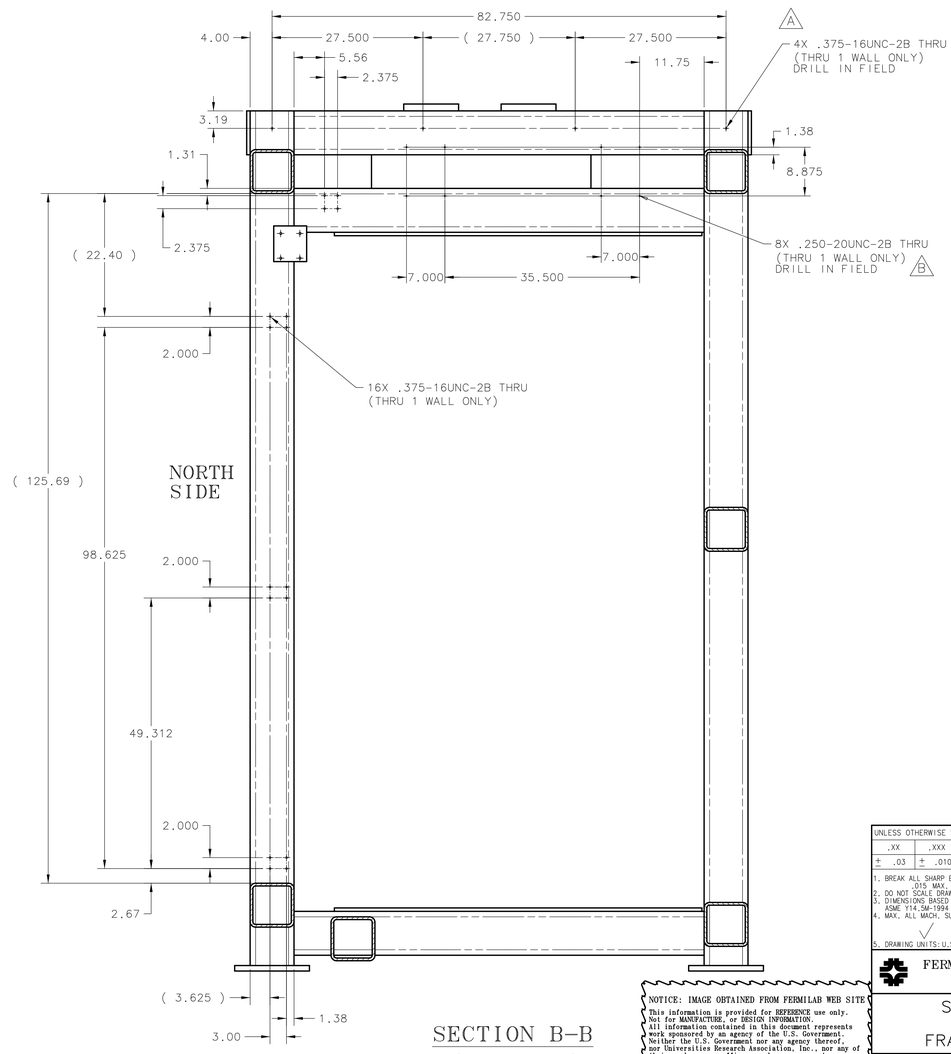
PLAN VIEW





SECTION A-A

(ROTATED 90° CW)



SECTION B-B

(ROTATED 90° CCW)

NOTES:

1. THIS IS THE DRILLING AND MACHINING DRAWING FOR FRAME DWG ME-435903.

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	E.CHI	07-JUN-2006
.XX	.XXX	ANGLES	DRAWN	T.SPERRY	07-SEP-2006
± .03	± .010	± - -	CHECKED	J.RAUCH	12-SEP-2006
			APPROVED	E.CHI	14-SEP-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
5. DRAWING UNITS: U.S. INCH

USED ON

MATERIAL: ME-435903

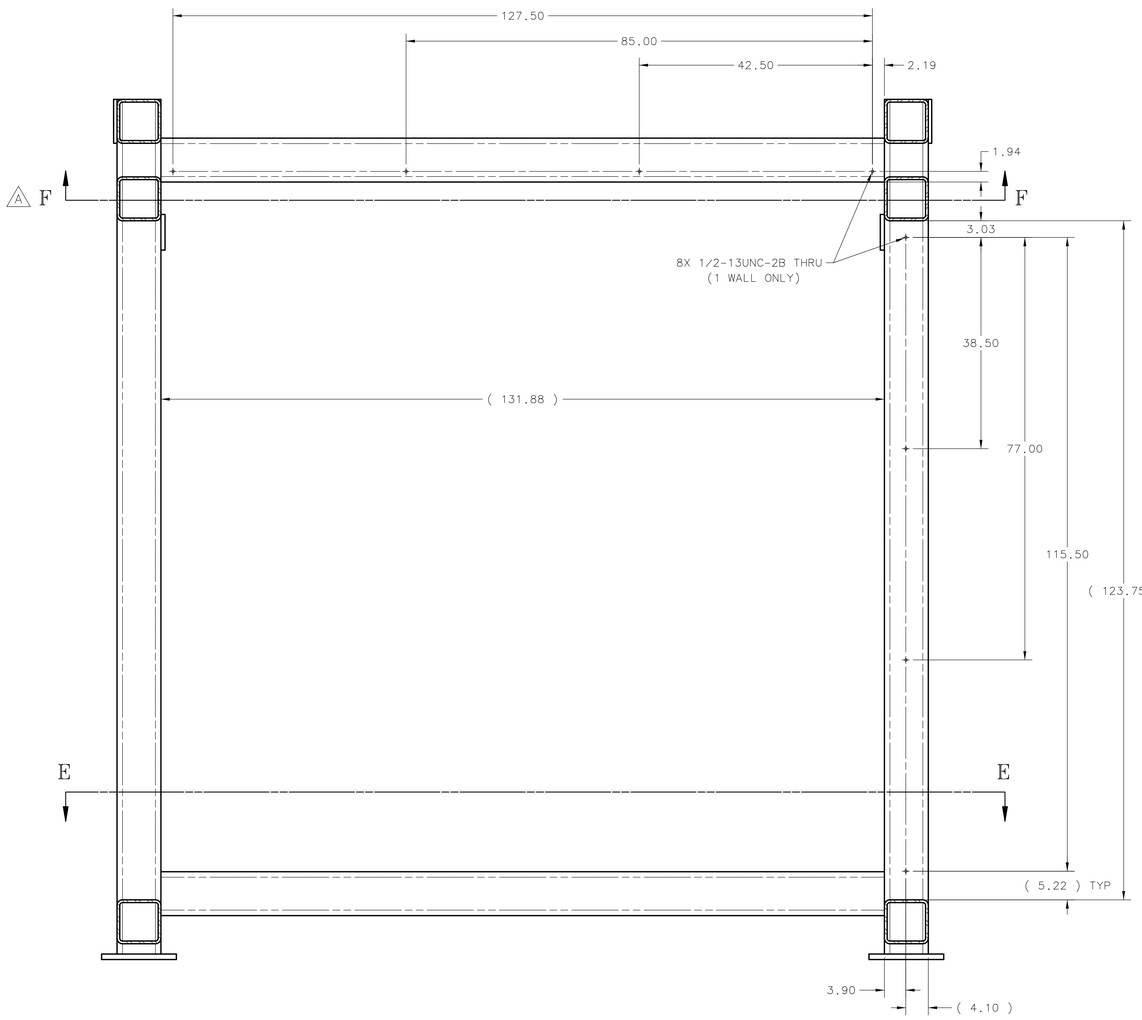
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCIBOONE - MECHANICAL DETECTORS FRAME SCIBAR EC MODIFIED

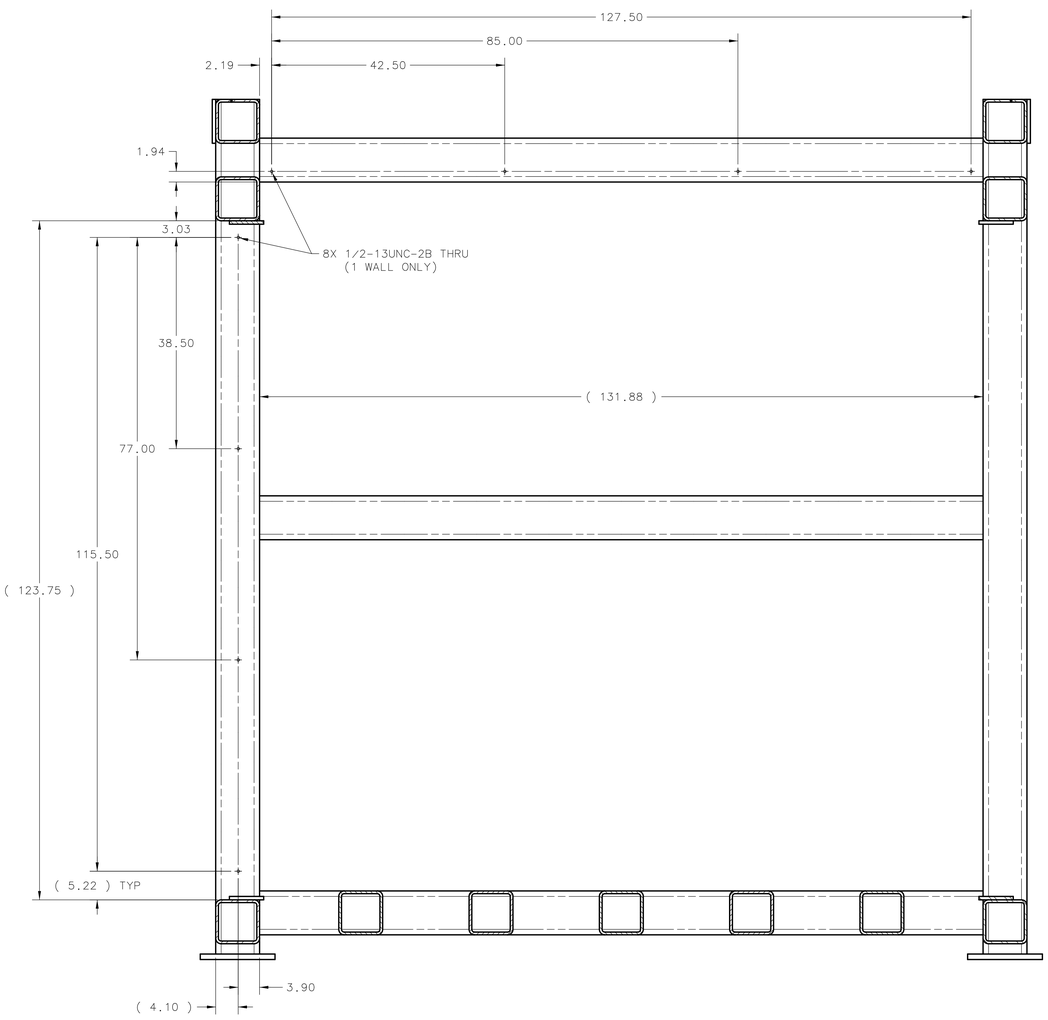
SCALE	DRAWING NUMBER	SHEET	REV
3/32	3954.330-ME-444071	1 OF 3	B

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

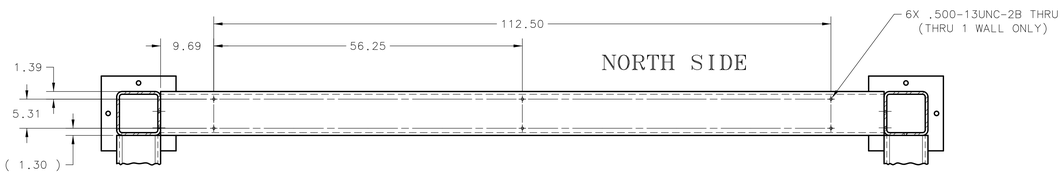
REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE



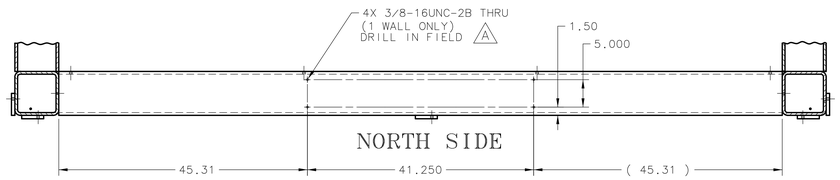
SECTION C-C



SECTION D-D
(ROTATED 180°)



SECTION E-E



A SECTION F-F

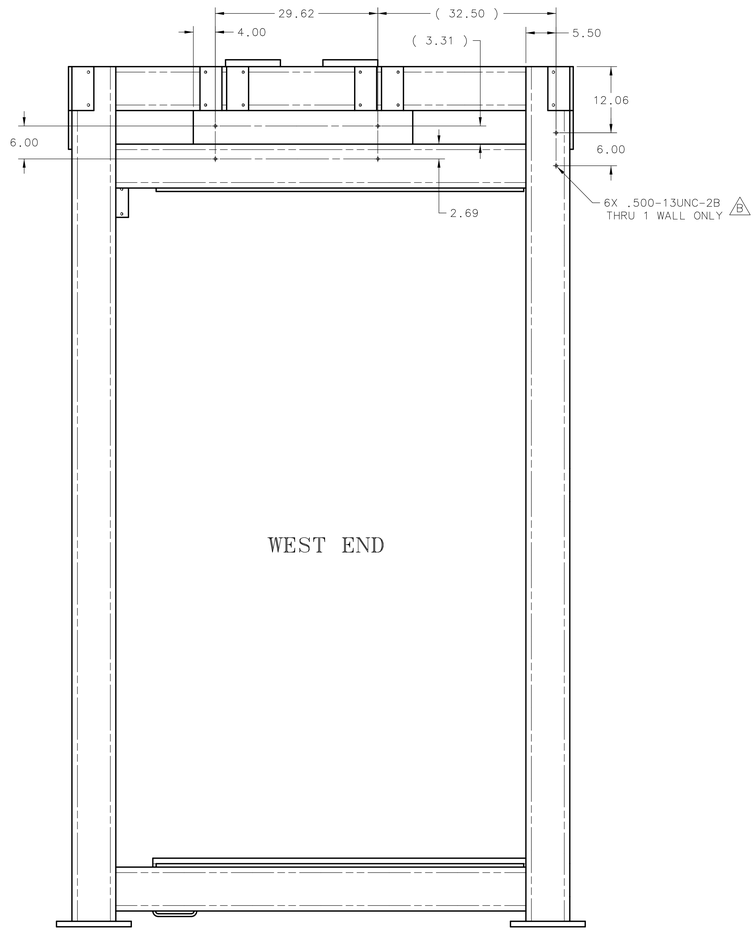
UNLESS OTHERWISE SPECIFIED			ORIGINATOR	E.CHI	07-JUN-2006
.XX	.XXX	ANGLES	DRAWN	T.SPERRY	07-SEP-2006
± .03	± .010	± - -	CHECKED	J.RAUCH	14-SEP-2006
1. BREAK ALL SHARP EDGES .015 MAX.			APPROVED	E.CHI	14-SEP-2006
2. DO NOT SCALE DRAWING.			USED ON		
3. DIMENSIONS BASED UPON ASME Y14.5M-1994.					
4. MAX. ALL MACH. SURFACES			MATERIAL		
5. DRAWING UNITS: U.S. INCH					

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

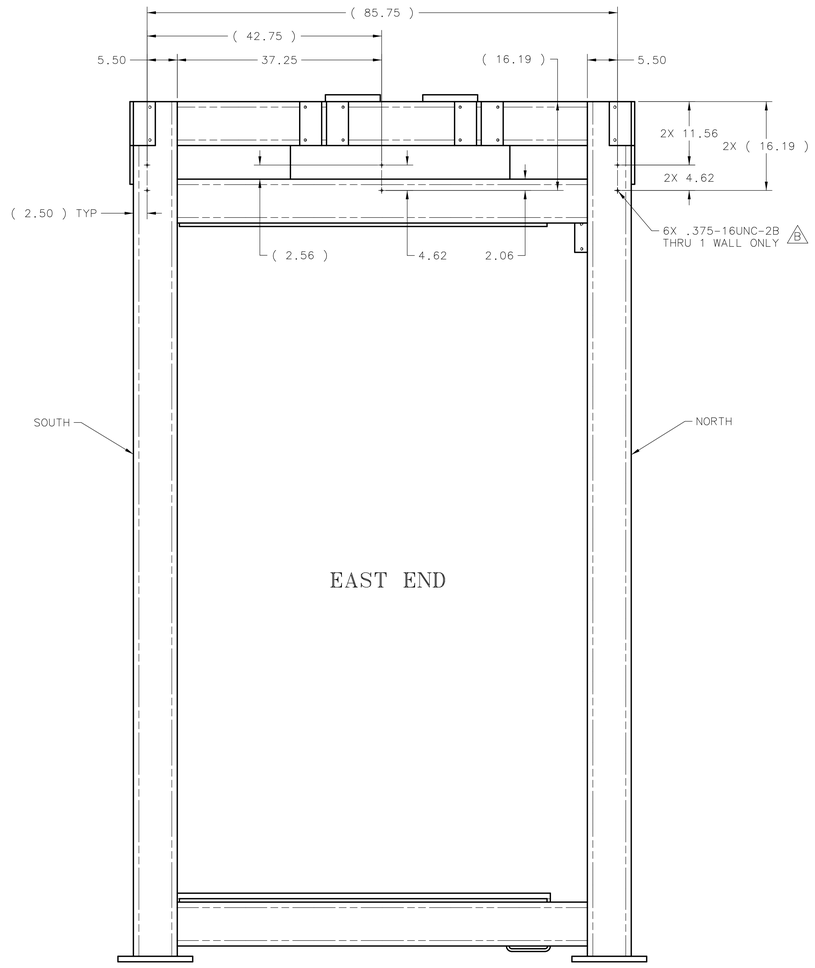
SCIBOONE - MECHANICAL DETECTORS FRAME SCIBAR EC MODIFIED

SCALE	DRAWING NUMBER	SHEET	REV
3/32	3954.330-ME-444071	2 OF 3	B
CREATED WITH : Ideas12NXSeries		GROUP: PPD/MECHANICAL DEPARTMENT	

REV	DESCRIPTION	DRAWN	DATE
		APPROVED	DATE



WEST END



EAST END

B VIEW H–H
ROTATED 90° CCW
SCALE: 3/32

B VIEW J–J
ROTATED 90° CW
SCALE: 3/32

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	E.CHI	07-JUN-2006
.XX	.XXX	ANGLES	DRAWN	T.SPERRY	07-SEP-2006
± .03	± .010	± - -	CHECKED	J.RAUCH	14-SEP-2006
1. BREAK ALL SHARP EDGES .015 MAX.			APPROVED	E.CHI	14-SEP-2006
2. DO NOT SCALE DRAWING.			USED ON		
3. DIMENSIONS BASED UPON ASME Y14.5M-1994					
4. MAX. ALL MACH. SURFACES			MATERIAL		
5. DRAWING UNITS: U.S.INCH					

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SCIBOONE - MECHANICAL DETECTORS FRAME SCIBAR EC MODIFIED

SCALE	DRAWING NUMBER	SHEET	REV
3/32	3954.330-ME-444071	3 OF 3	B

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT