OH MODULE
ASSEMBLY STAND

Patrick J. Bolan

10 / 16 / 90

D-Zero Engineering Note

#3740.225-EN-262

Approved by:

Keith Primdahl
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There is an OH module assembly stand in use at IB4. This design has been approved by safety, as presented by Mike Foley, and has been successfully used. Another one is needed at the D-zero assembly building, but some modifications need to be made. This report will show that the new modified design is at least as strong, if not stronger, than the older IB4 design in every aspect.

Since the weight distribution of the OH modules on the sling is indeterminate, this report compares three cases of support for the entire assembly: the lowest two beams only, the lowest four beams only, and all six beams. In each of these cases, the new design is stronger than the old design in maximum allowable weight.

The ability of the the cradle to support the weight is also shown. For all of the failure conditions except for two, the cradle is stronger than the beams that it supports. In the two excepted situations, the calculated limit of the cradle is less than the beams it supports. This is because no credit is taken for the sling and strongback, which in reality will relieve much of the horizontal load. See page seven in appendix A.

Referenced is the AISC "Manual of Steel Construction", eighth edition, as well as the old design calculations by Mike Foley (apdx. B).

Table 1
Comparison of DAB strap beams to IB4 design

Supporting Case	#of beams DAB (IB4)	Limiting Condition	AISC Max Allow, lbs IB4 Design	AISC Max Allow, lbs DAB Design	Actual Force	Apx A Page
Case 1:	2 (1)	Shear	148,000	500,200	ind.**	4,5
		Bending	25,400	36,500	ind.**	4,5
		Cradle limit*	-	263,000	ind.**	12
Case 2:	4 (3)	Shear	421,300	1,442,500	ind.**	4,5
		Bending	72,500	105,300	ind.**	4,5
		Cradle limit*	-	136,300	ind.**	12
Case 3:	6 (5)	Shear	630,600	1,923,400	73,200	4,5
		Bending	108,400	140,400	73,200	4,5
		Cradle limit*	-	158,200	73,200	12

*Assumes Coefficient of friction of >= 0.25
**Indeterminate, but less than 73,000 lbs

Table 2
Comparison of Cradle strength to strap beam strength

Weight Component	Limiting Condition	Max Radial Weight (lbs) AISC allow.	Beam limit	Page
Inside (W1)	Column stability	134,000	18,600	6
	Lateral support	No limit, friction is adequate		8
Middle (W2)	Column stability	161,800	37,200	6
	Lateral Weld Shear	279,400	37,200	9
	Lateral Weld Bending	41,400	37,200	9
Outside (W3)	Column stability	172,700	24,800	6
	Column Bending	*17,220	24,800	10
	Lateral Weld Shear	97,700	24,800	9
	Lateral Weld Bending	*14,490	24,800	9
	Skip weld shear	323,300	24,800	11

* Though credit is not taken for the sling and strongback in any calculations in this report, it will significantly relieve the horizontal force for these two conditions. See page 7, apx A.

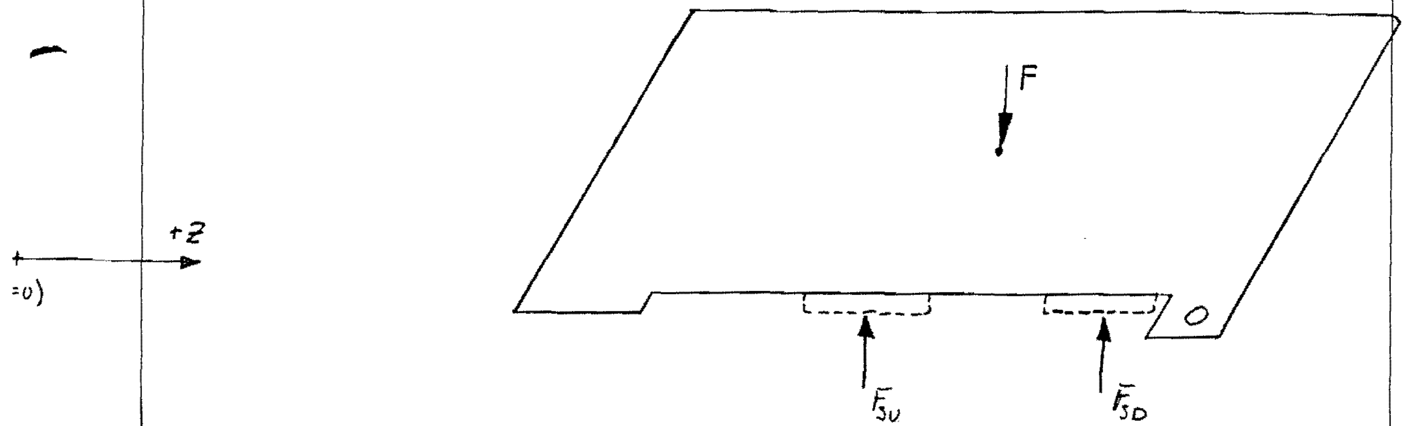
Appendix A

New Design Calculations

Note #3740.225-EN-262

Patrick J. Bolan

OH Weight distribution



F is the radial force exerted on the OH centroid

F_{SU}, F_{SD} are the strap reaction forces at the upstream and downstream ends

Force	Z position
F	100.790"
F_{SU}	75.604"
F_{SD}	113.728"

$\Sigma F_{rad} = 0 : \quad F = F_{SU} + F_{SD}$

$\Sigma M_{z=0} = 0 : \quad F(100.79) = F_{SU}(75.604) + F_{SD}(113.728)$

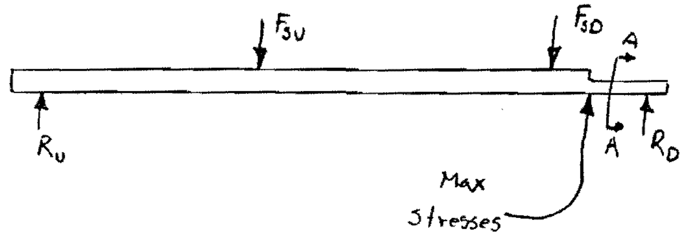
$F_{SU} + F_{SD} = F_{SU}(.750) + F_{SD}(1.128)$

$F_{SU} = F_{SD}\frac{.128}{.250} = .5137 F_{SD}$

$F_{SD} + (.5137)F_{SD} = F$

$F_{SD} = .661 \cdot F$

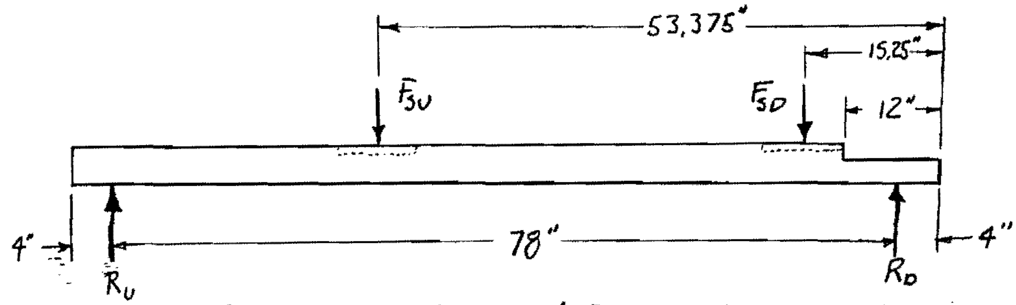
$F_{SU} = .339 \cdot F$



Cross Section A-A of:

	4x4 beam	4x6 Beam	4x3 Beam
Height	2.125"	2.125"	2.125"
Width	4.000"	6.000"	3.000"
$y_{max} = c$ (Neutral axis → edge)	1.063"	1.063"	1.063"
$I_z = \frac{1}{12} wh^3$	3.199 in^4	4.798 in^4	2.399 in^4
Area	8.5 in^2	12.75 in^2	6.375 in^2

STRAP BEAM STRENGTH



Geometry for 4x3, 4x4, + 4x6 beams

$\Sigma F_{radial} = 0 \Rightarrow \quad F_{SU} + F_{SD} = R_U + R_D = F$

$\Sigma M_{R_D} = 0 \Rightarrow \quad F_{SU} \cdot 49.375 + F_{SD} \cdot 11.25 = R_U \cdot 78$

$$F(.339 \cdot 49.375 + .661 \cdot 11.25) = (F - R_D)(78)$$

$$F \cdot 53.83 = 78\, R_D$$

$$R_D = .690 \cdot F$$

$$R_U = .310 \cdot F$$

SHEAR

Maximum shear occurs 12" from the downstream end.

shear force = $V = R_D$

shear = $\sigma = V/A$

for 4150 steel, $\sigma_y = 69{,}000$ psi

AISC max allow shear = $.4\sigma_y = 27{,}600$

4x3 Beam	4x4 Beam	4x6 Beam
$27{,}600 = \frac{R_D}{6.375}$	$27{,}600 = \frac{R_D}{8.5}$	$27{,}600 = \frac{R_D}{12.75}$
$0.690 \cdot F = 175{,}950$	$0.690 \cdot F = 234{,}600$	$0.690 \cdot F = 351{,}900$
$F_{max} = 255$ Kip	$F_{max} = 340$ Kip	$F_{max} = 510$ Kip

BENDING

Maximum bending stress occurs 12" from the downstream end.

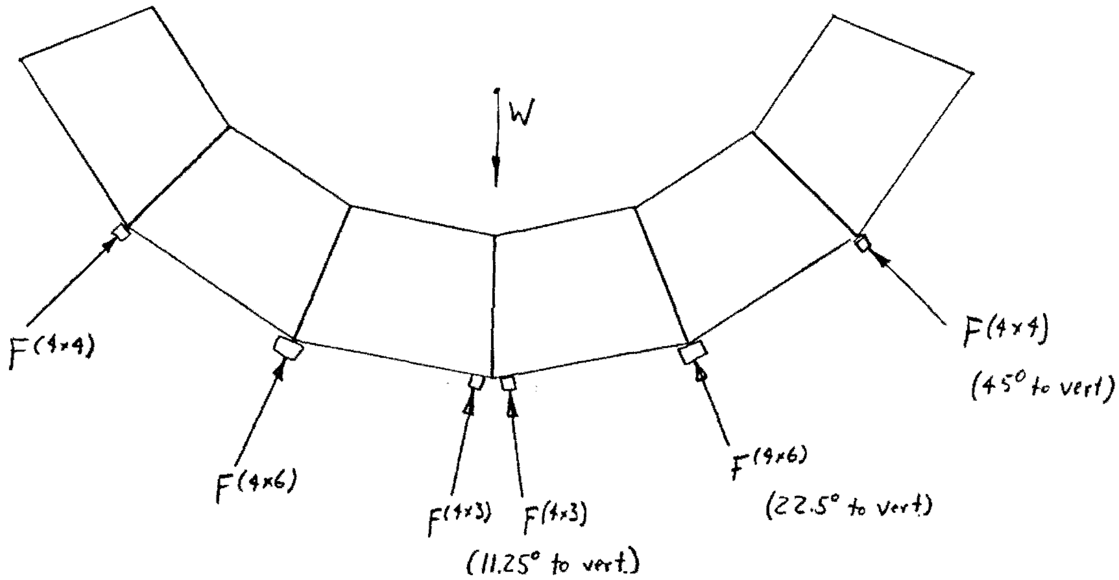
Bending Moment = $M = R_D \cdot 8"$

Bending Stress = $\sigma = \frac{Mc}{I}$

AISC max allow bending = $.66\sigma_y = 45{,}540$ psi

$$8 \cdot R_D \cdot \frac{c}{I_z} = 45{,}540 \text{ psi}$$

4x3 Beam	4x4 Beam	4x6 Beam
$8 \cdot R_D \cdot \frac{1.063}{2.399} = 45{,}540$	$8 \cdot R_D \frac{1.063}{3.199} = 45{,}540$	$8 \cdot R_D \frac{1.063}{4.798} = 45{,}540$
$2.44\,F = 45{,}540$	$1.83\,F = 45{,}540$	$1.22\,F = 45{,}540$
$F_{max} = 18{,}619$ lb	$F_{max} = 24{,}827$ lb	$F_{max} = 37{,}237$ lb



This shows positioning of the strap beams on the OH assembly

Case #1: Lowest two beams only

$\Sigma F_y = 0$: $W_{max} = 2 F_{max}^{(4\times3)} \cos 11.25°$

For shear: $W_{max} =$ 500,200 lb
bending: $W_{max} =$ 36,520 lb

Case #2: Lowest four beams only

$\Sigma F_y = 0$: $W_{max} = 2 \left[F_{max}^{(4\times3)} \cos 11.25° + F_{max}^{(4\times6)} \cos 22.5° \right]$

For shear: $W_{max} =$ 1,442,560 lb
bending: $W_{max} =$ 105,330 lb

Case #3: ALL Beams at yeild point

$\Sigma F_y = 0$: $W_{max} = 2 \left[F_{max}^{(4\times3)} \cos 11.25 + F_{max}^{(4\times6)} \cos 22.5° + F_{max}^{(4\times4)} \cos 45° \right]$

For shear: $W_{max} =$ 1,923,390 lb
bending: $W_{max} =$ 140,440 lb

The OLD design (in use at IB4) has different dimensions and material, which affects the strength.

From Mike Foley's notes:

$R_B = R_D = .73 \cdot F$

$R_A = R_V = .27\ F$

$S = \sigma_{max} = .934 \cdot F$ (for max bending stress)

For Bending: (For A-36 stainless)

σ_{max} (by AISC) $= .66 \cdot \sigma_y = .66 \cdot 36{,}00$ psi

$= 23{,}760$ psi

$.934 F_{max} = 23{,}760$ psi

$F_{max} = 25{,}440$ lb

Note: same beam design for all five locations.

For Shear:

$\sigma_{max} = .4\ \sigma_y = 14{,}400$ psi

$\sigma = \frac{R_B}{A}$ $A = 4 \cdot 1\frac{7}{8} = 7.5 in^2$

$.73 \cdot F / 7.5 = 14{,}400$

$F_{max} = 147{,}950$ lb

Case #1: 1 beam only

$W_{max} = F_{max}$ Bending → $W_{max} = 25{,}440$ lb
shear → $W_{max} = 147{,}950$ lb

Case #2: Bottom 3 beams

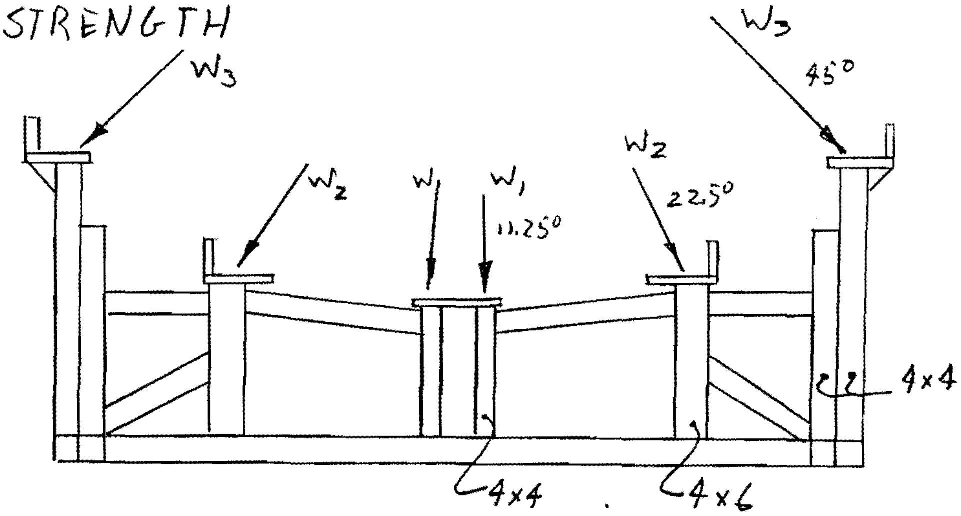
$W_{max} = F_{max} (1 + 2 \cos 22.5°)$ Bending → $W_{max} = 72{,}450$ lb
shear → $W_{max} = 421{,}330$ lb

Case #3: All 5 beams

$W_{max} = F_{max} (1 + 2 \cos 22.5° + 2 \cos 45°)$

Bending → $W_{max} = 108{,}420$ lb
shear → $W_{max} = 630{,}558$ lb

CRADLE STRENGTH



OH Weight is distributed from the strap beams to the stand:

$$W_{max} = 2(W_1 + W_2 + W_3)$$

The maximum for each W_n is determined by column stability and lateral support of the weight.

Column Stability

In Section 3 of the AISC steel construction code, allowable concentric loads are tabulated for standard structural tubing of various effective lengths, K·L. "K" for the end constraints here (approx. fixed-pinned) is 0.8, from Table C1.8.1. The stresses are also reduced for steel of $\sigma_y = 36$ksi, down from 46 ksi.

- Short 4x4 Column, $L = 22.5''$, $KL = 18''$

Using ½" thk, $\sigma_y = 36$ksi, $KL = 24''$, $W_{1y\,max} = 168{,}000 \cdot \frac{36}{46} = 132$ kip

$$W_{1max} = \frac{132{,}000}{\cos 11.25°} = 134{,}000\text{ lb}$$

- 4x6 column, $L = 26.5$ in, $KL = 21.2''$

Using $KL = 6'$ (smallest available), $W_{2y\,max} = 191{,}000 \cdot \frac{36}{46} = 149{,}500$ lb

$$W_{2max} = \frac{149{,}500}{\cos 27.5°} = 161{,}800\text{ lb}$$

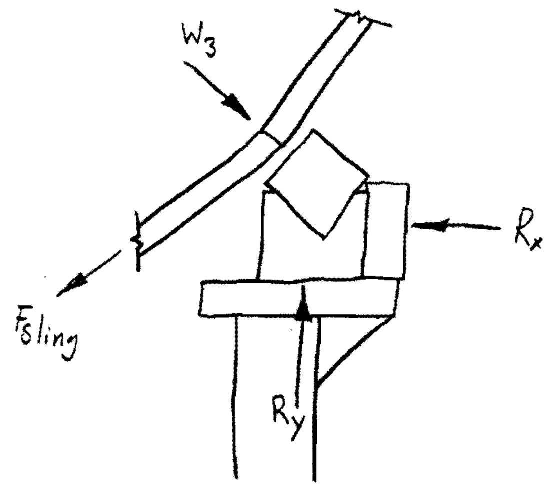
- Long 4x6 column, $L = 46.5''$, $KL = 37.2''$

Using $KL = 48''$, $W_{3y\,max} = 156{,}000 \cdot \frac{36}{46} = 122{,}000$ lb

$$W_{3max} = \frac{122{,}000}{\cos 45°} = 172{,}200\text{ lb}$$

NOTE:

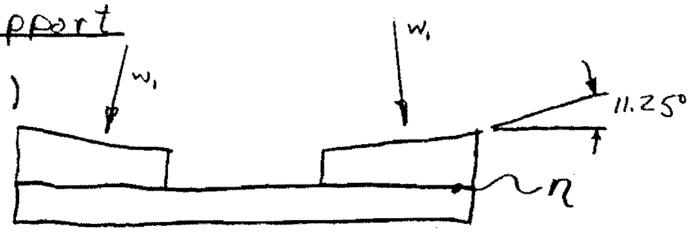
The horizontal components of the weights W_2 and W_3 actually much less than indicated in these calculations, due to the forces also exerted by the sling and strongback.



The force F_{sling} is neglected completely, making the estimate of R_x (W_{nxmax}) used on the next several pages very conservative.

Lateral Weight Support

- For Inner weight (W_1)

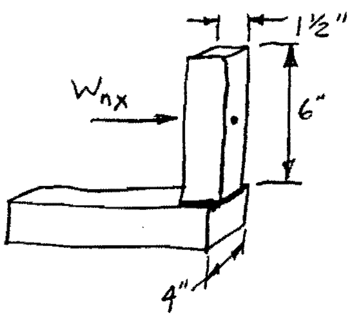


The only support holding the blocks (horizontally) is friction.

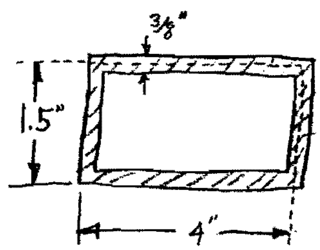
$$\eta \geq \frac{W_1 \sin 11.25}{W_1 \cos 11.25} = \tan 11.25° = .199$$

We will assume that $\eta \geq .25$ and the blocks will be adequetely supported.

- For Middle and Outer Weights ($W_2 + W_3$)



$\frac{3}{8}$" Fillet with Weld Prep Around



$$Area = \left(1.5 + \tfrac{3}{16}\right)\left(4 + \tfrac{3}{16}\right) - \left(4 - \tfrac{9}{16}\right)\left(1.5 - \tfrac{9}{16}\right) = 3.84\ in^2$$

$$I = \frac{1}{12}\left[\left(4 + \tfrac{3}{16}\right)\left(1.5 + \tfrac{3}{16}\right)^3 - \left(4 - \tfrac{9}{16}\right)\left(1.5 - \tfrac{9}{16}\right)^3\right] = 1.44\ in^4$$

$$c = 1.5 + \tfrac{3}{16} / 2 = .844$$

$M = W_{nx} \cdot 3"$

$\sigma_y = 36$ ksi

AISC max allow shear $= .4\ \sigma_y = 14,400$ psi

Bending

$$14,400 = \frac{W_{nx} \cdot 3 \cdot .844}{1.44}$$

$W_{nx(max)} = 8197$ lb

Shear

$$14,400 = \frac{W_{nx}}{3.84}$$

$W_{nx(max)} = 55,296$ lb

- For Middle and Outer Weights (cont.)

taking credit for friction

$W_{nx(max)} = W_{nx} - W_{ny}\,\eta = W_n(\sin\theta - \eta\cos\theta)$

Middle, W_2, $\eta = .25$

Bending

$W_{2\,max} = \dfrac{8197}{\sin 22.5 - .25\cos 22.5}$

$= 54{,}000\text{ lb}$

Shear

$W_{2\,max} = \dfrac{55{,}296}{\sin 22.5 - .25\cos 22.5}$

$= 364{,}500\text{ lb}$

Outer, W_3, $\eta = .25$

Bending

$W_{3\,max} = \dfrac{8197}{\sin 45^\circ - .25\cos 45^\circ}$

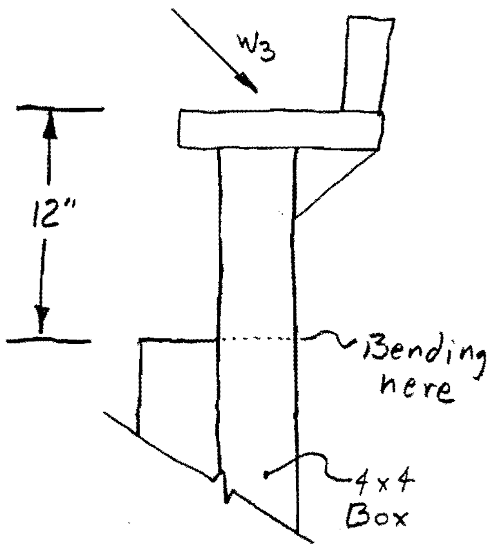
$= 15{,}500\text{ lb}$

Shear

$W_{3\,max} = \dfrac{55{,}296}{\sin 45^\circ - .2\cos 45^\circ}$

$= 104{,}300\text{ lb}$

Outer Column Bending



$\sigma_y = 36{,}000\,psi$

AISC max allow bending $= .66\,\sigma_y = 23{,}760\,psi$

$M = W_3 \sin 45° \cdot 12''$

$I = 12.3\,in^4$ (From AISC)

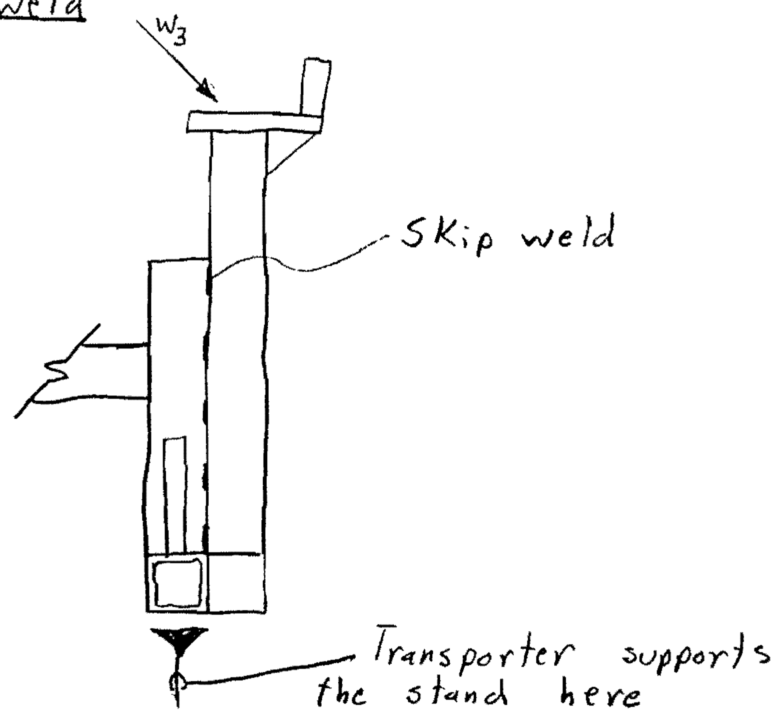
$c = 2''$

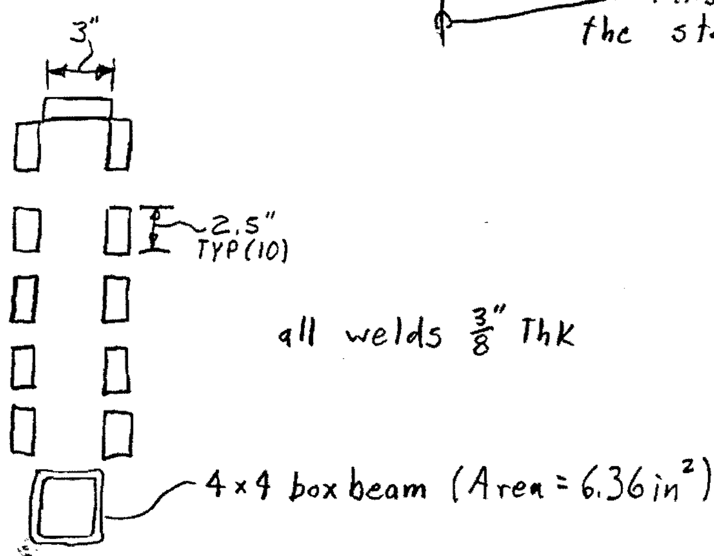
$$\sigma_{max} = \frac{M_{max}\,c}{I}$$

$$W_{3\,max} = \frac{23{,}760 \; 12.3\,in^4}{2'' \cdot 12'' \cdot \sin 45°}$$

$$= 17{,}220\,lb$$

Shear on skip weld





Shear Area

$$Area = ((10)(2.5) + 3) \cdot \frac{3}{8} + 6.36$$
$$= 16.86 \text{ in}^2$$

$\sigma_y = 36{,}000$

AISC max allow shear $= .4\,\sigma_y = 14{,}400$ psi

$$\frac{W_3\, y_{max}}{16.86 \text{ in}^2} = 14{,}400 \text{ psi}$$

$$W_{3\,max} = 14{,}400 \frac{16.86}{\cos 45^\circ} = 343{,}350 \text{ lb}$$

Cradle Strength Summary

In case 1, the only factor limiting the cradle is the column stability:

$$W_{max} = 2\,W_{1max} \cos 11.25^{\circ}$$

$$= 263,000\,lb \quad \text{(stronger than beams)}$$

In case 2, the limiting factor will be the weld bending stress.

- The weight distribution is indeterminate, so we will assume that the two center beams are loaded to their yeild point ($W_{max} = 36,500\,lb$), and then the weld bending limits the maximum weight.

$$W_{2max} = 54,000\,lb \quad \text{(weld bending, pg 9)}$$

$$W_{max} = 36,500 + 2\,W_{2max} \cos 22.5^{\circ}$$

$$= 136,300\,lb$$

In case 3, the limiting factor will again be the weld bending stress.

- We will again assume that the center beams are loaded to their limit, and the weld bending of the middle (W_2) columns is also at its maximum.

$$W_{max} = 136,300\,lb + 2\,W_{3max} \cos 45^{\circ}$$

$$= 136,300 + 15,500 \cdot 2 \cdot \cos 45^{\circ}$$

$$= 158,200\,lb$$

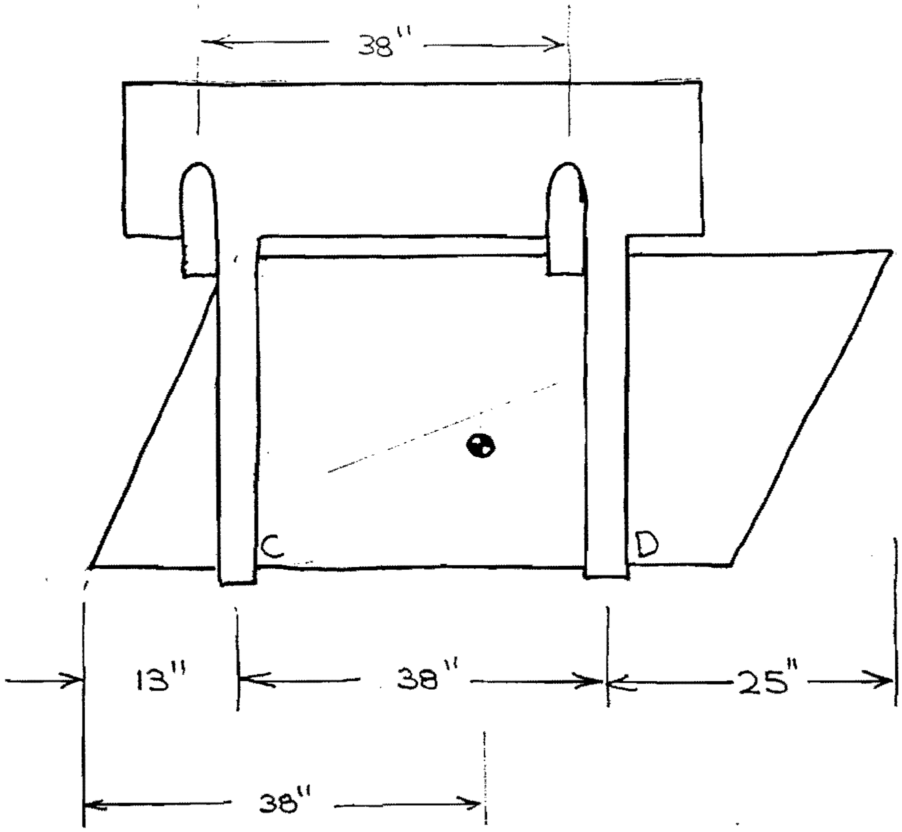
Appendix B

IB4 Design Calculations

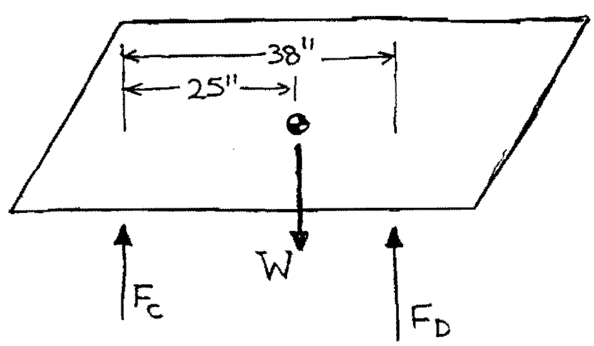
Mike Foley

Note #3740.225-EN-262

1. DETERMINATION OF REACTION FORCES F_C AND F_D AT POINTS OF SUPPORT FOR THE OH SLING ON CRADLE BARS



NOTE. All measurements above are approximate.



$$+\circlearrowright \sum M_C = 25W - 38F_D = 0$$

$$+\uparrow \sum F_y = F_C + F_D - W = 0$$

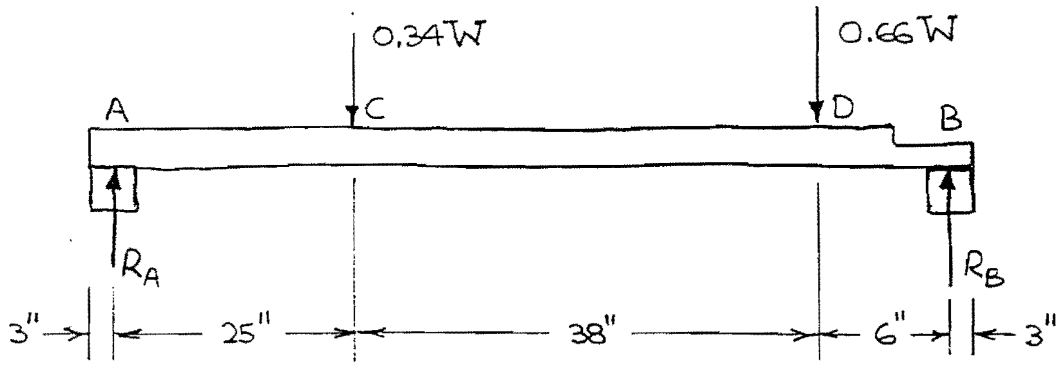
$$F_C + F_D = W$$

$$F_D = \frac{25}{38} W \cong 0.66W$$

$$F_C = \frac{13}{38} W \cong 0.34W$$

where $W \triangleq$ weight of OH modules (neglect weight of sling).

2. DETERMINATION OF REACTION FORCES R_A AND R_B AT POINTS OF SUPPORT FOR OH TEST RING CRADLE BARS ON CRADLE.



Neglect weight of cradle bar(s).

$$+\circlearrowleft \sum M_A = 0.34W(25) + 0.66W(63) - R_B(69) = 0$$

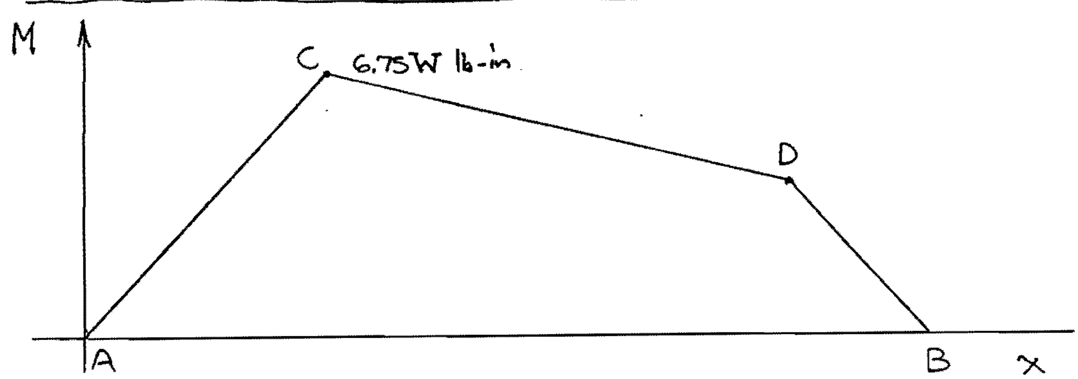
$$\boxed{R_B = 0.73W}$$

$$+\uparrow \sum F_y = R_A + R_B - W = 0$$

$$R_A + R_B = W$$

$$\boxed{R_A = 0.27W}$$

3. DETERMINATION OF MAXIMUM BENDING STRESS IN CRADLE BAR

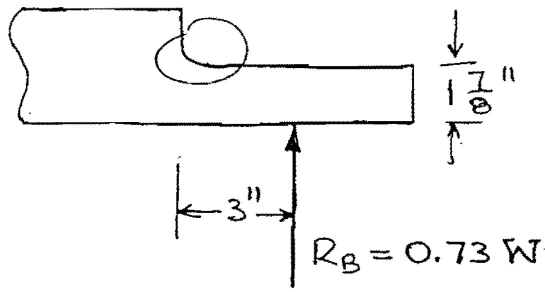


Maximum bending moment occurs at point C:

$$M_{max} \cong 6.75W \text{ lb-in}$$

Resulting compressive stress at point C is:

$$s = \frac{M_{max}c}{I} = \frac{6.75W(2)}{\frac{1}{12}(4)(4)^3} \cong 0.63W$$



At notch at downstream end of cradle bar:

$$M = R_b(3) \cong 0.73\,W\,(3) = 2.19\,W$$

$$S = \frac{Mc}{I} = \frac{(2.19\,W)(0.9375)}{\frac{1}{12}(4)(1.875)^3} \cong 0.934\,W$$

This is the point of maximum bending stress for the cradle bar.

4. CONCLUSIONS

That percentage of the total load (due to six OH modules) carried by the central cradle bar is indeterminate.

Weight of six OH modules equals

$$6 \times 12,200 \text{ lbs} = 73,200 \text{ lbs}$$

If the central cradle bar carries 80% of the total load, then

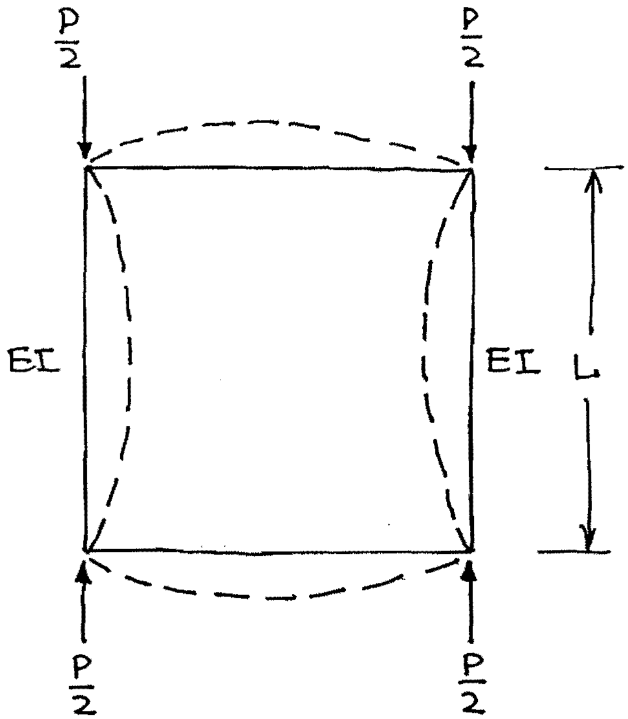
$$W = (0.8)(73,200) \cong 58,600 \text{ lbs}$$

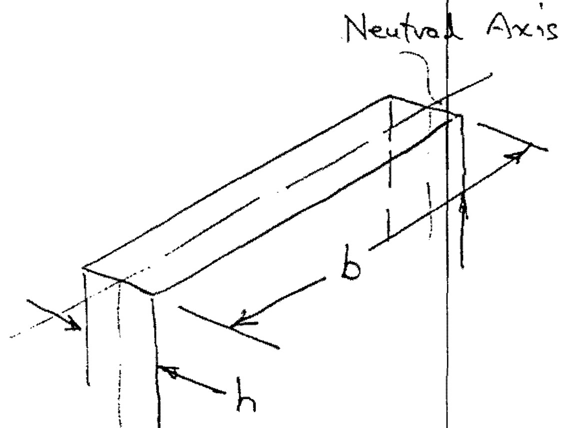
Bending stress at notch is approximately

$$S \cong 54,700 \text{ psi}$$

→ This is possible point of failure.

BUCKLING – 4x4 BOX BEAM FOR CRADLE





$$P_{CR} = \frac{2\pi^2 EI}{(.774L)^2}$$

$I = \frac{1}{2} b h^3$

$E = 30 \cdot 10^6$

$b = 4''$

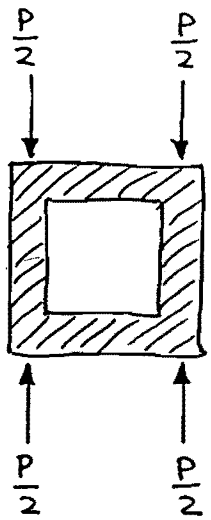
$h = \frac{3}{8}''$

$L = 4''$

$$P_{CR} = \frac{2\pi^2 (30 \cdot 10^6)(4)(3)^3}{12\,(.774)^2 (4)^2 (8)^3} \cong 1.09 \cdot 10^6 \text{ lbs}$$

Ref. TIMOSHENKO, S, STRENGTH OF MATERIALS, II, pp. 157–158

COMPRESSION



$$A = bh$$

$$S_c = \frac{\frac{P}{2}}{bh} = \frac{P}{2bh} = \frac{P}{2(4)\left(\frac{3}{8}\right)} = \frac{P}{3}$$

$$S_c = \frac{P}{3}$$

LOAD ON REAR BOX BEAM $P \cong 0.73W$

Assuming total load $W = 73{,}200$ lbs

$P \cong 0.73\,W \cong 53{,}400$ lbs

$S_c \cong 17{,}800$ psi

ADDENDUM B

D-Zero Engineering Note

#3740.225-EN-262

Keith Primdahl

Revised: 11 / 9 / 90

The EC cryostat has been found to be undersize [in radius] in the region where OH module 2 and OH module 3 are joined. Furthermore the location of the support feet on the beam (aka strongback), which is driven by the socket location on the cryostat, was moved outboard slightly. This change inadvertently lowered the beam and strap (aka strongback and sling) relative to the cryostat. These changes have resulted in interferences which prevent the use of the 4" x 4" solid cradle beams in this location.

Recall that in designing the cradle for D-Zero Assembly Building, DAB our primary criteria was to make it as strong, or stronger, than the cradle previously used at Industrial Building 4, IB4. Since the distribution of loads seemed indeterminate, the solid cradle beams were designed so that the bottom four (two 4" x 3" and two 4" x 6" solid beams of 4150 steel) could support far more than the entire load. Referring to page 2 of the original note, these four solid cradle beams alone are code allowable for 105,300 lb while six OH modules weigh in at 73,200 lb.

Furthermore, a more careful analysis of the structure revealed that certain forces, previously considered to be indeterminate, can actually be resolved. For the configuration where the two 4" x 4" solid cradle beams are not installed, this Addendum considers two cases:

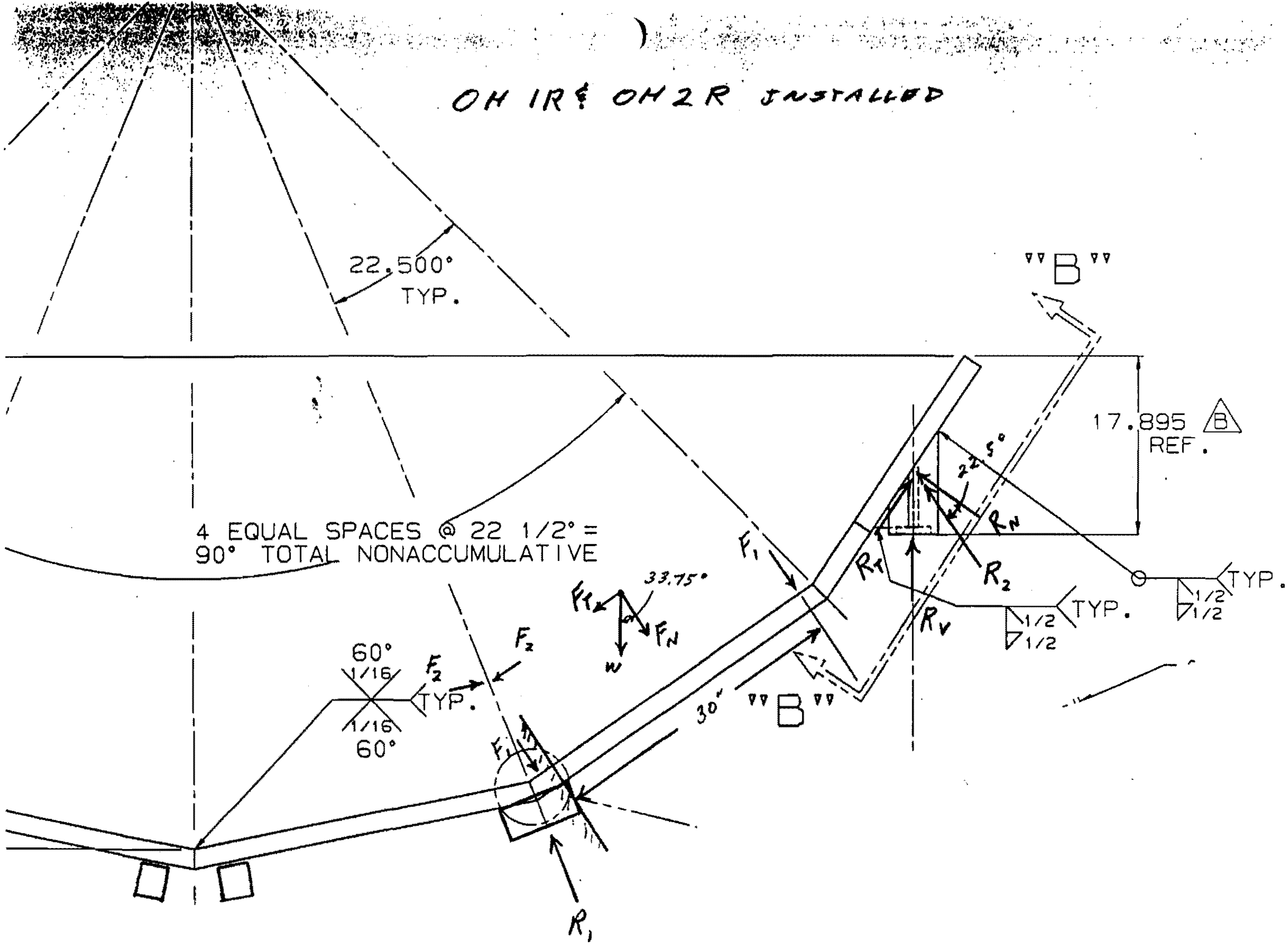
Case A) Four OH modules installed
Case B) Six OH modules installed

The case where only the first two modules are installed is considered trivial since the load will clearly be taken by the bottom four solid cradle beams. Results, summarized in table B-1, indicate that the four solid cradle beam configuration is acceptable.

Table B-1
Comparison of Strap Strength to Allowable

Configuration	Limiting Condition	Stress (psi) AISC allow.	Stress (psi) Actual	Page
Case A	Tension +Bending	18,000	7100	B3
	Shear	12,000	150	B3
Case B	Tension +Bending	18,000	16,000	B12
	Shear	12,000	350	B11

OH 1R & OH 2R INSTALLED



MODULE WEIGHT = 12,200 LB

CENTERLINE OF FRONT SLING Z = 75.604

CENTERLINE OF BACK SLING Z = 113.728

CG OF OH MODULE Z = 100.790

MODULE WEIGHT ON BACK SLING

$$W = \frac{12{,}200\,LB}{(113.728'' - 75.604'')}(100.790'' - 75.604'') = 8060\,LB$$

COMPONENT OF W, NORMAL TO SLING

$$F_N = (8060\,LB)(\cos 33.75^\circ) = 6702\,LB$$

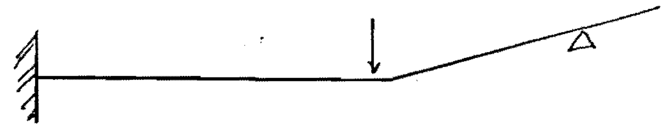
COMPONENT OF W, TANGENT TO SLING

$$F_T = (8060\,LB)(\sin 33.75^\circ) = 4478\,LB$$

FORCE ON SLING SHIM

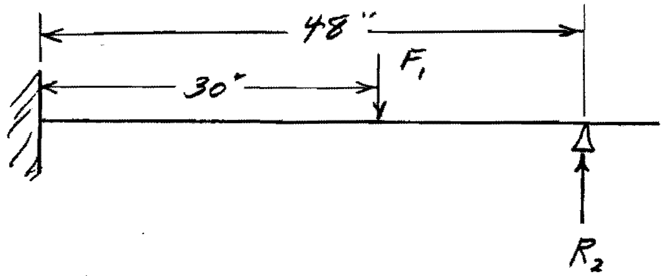
$$F_1 = F_N/2 = 6702\,LB/2 = 3351\,LB$$

I POSTULATE THAT THIS BEAM IS SIMILAR



$$I = \frac{(6)(2)^3}{12} = 4$$

TO THIS BEAM



R_2 (FROM ROARK SPREADSHEET) = 1554 LB

σ (" " ") = 6995 psi

$R_N = (1554\ LB)(\cos 22.5°)$ = 1436 LB

$R_T = (1554\ LB)(\sin 22.5°)$ = 595 LB

$R_V = \frac{1554\ LB}{\cos(33.75)}$ = 1869 LB

R_T INDUCES A MOMENT ON THE SLING THAT IS OPPOSITE TO THE MOMENT FROM R_2. I'LL IGNORE THIS EFFECT (TAKE NO CREDIT)

τ_{MAX} OCCURS AT FIXED END $\frac{1797\ LB}{12\ in^2} = 150\ psi$

R_T ALSO INDUCES A TENSILE STRESS R_T/A

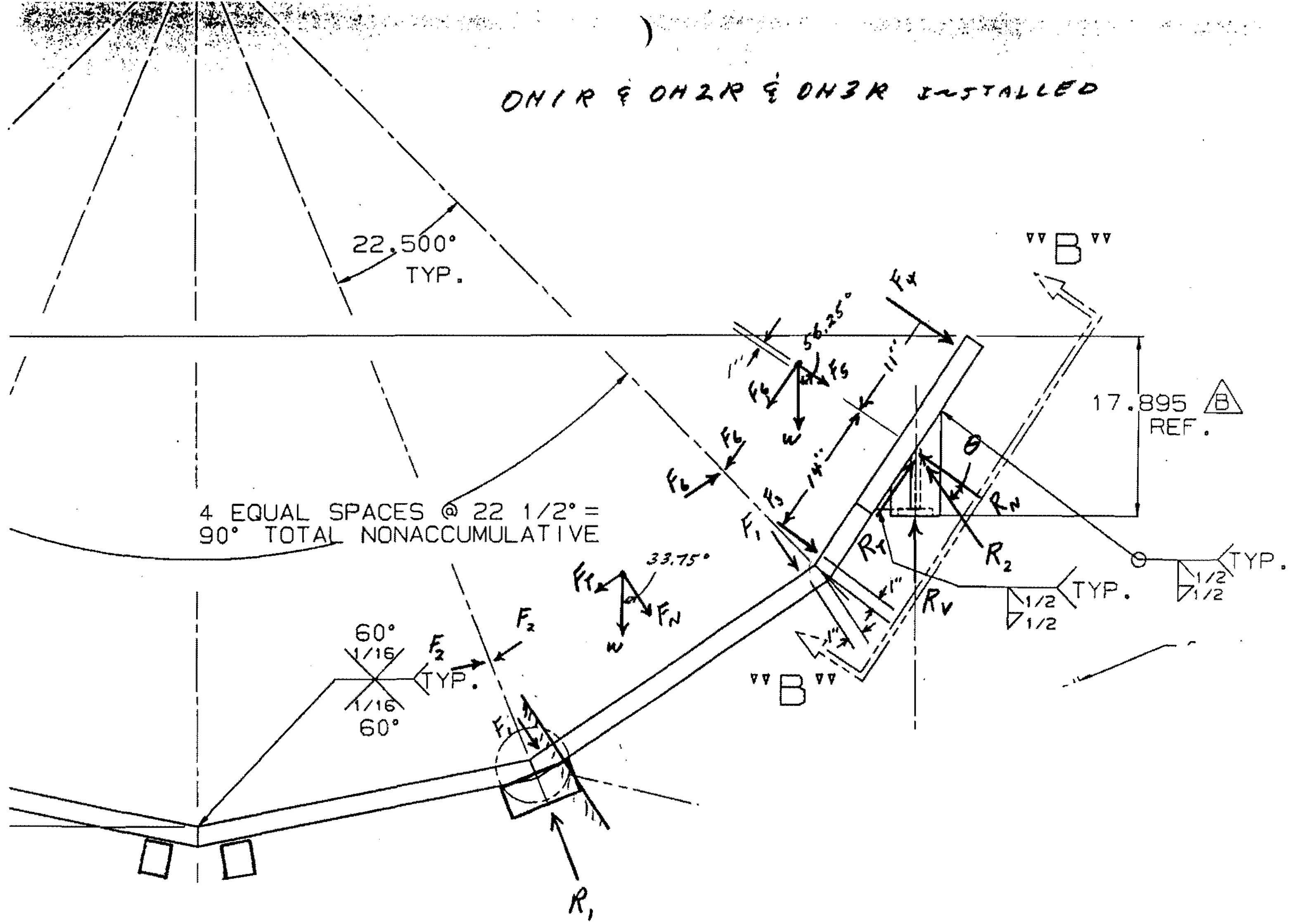
$$\sigma_{MAX} = 6995\ psi + \frac{595\ LB}{12\ in^2} = 7100\ psi$$

↑ COMBINED TENSION & BENDING

OH1 & OH2 ONLY

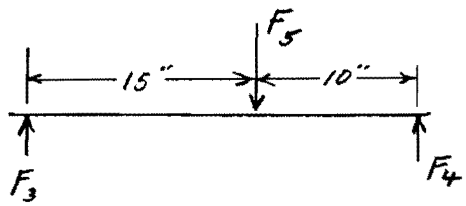
St	Input	Name	Output	Unit	Comment
					Left simple support, right fixed
					Table 3 Case 1 - Roark & Young (6 ed)
					Concentrated Intermediate Load
					Page 100
		case	'CASE_1c		End Restraints Reference Number
	17	matl#			Material Number (See Material Table)
		matl	'Steel_AS		
		plot			Generate plots ? 'y=yes (Default=no)
		table			Generate a table? 'y=yes (Default=no)
	48	L		in	Length of beam
	18	a		in	Load distance from left end
F1 =	3351	W		lb	Load
		E	2.9E7	psi	Young's Modulus
	4	I		in^4	Area moment of inertia
	1	z		in	Neutral axis to stress point
					AT SECTION:
	18	x		in	Distance from left end
		V	1554.419	lb	Transverse shear
		M	27979.541	in-lb	Bending moment
		theta	-.0002666	rad	Slope
		y	-.0308486	in	Deflection
		st	6994.885	psi	Fiber stress at stress point
		sty	'_	psi	Max Fiber stress at extremity y
					AT LEFT END:
		RA	1554.419	lb	Vertical reaction
		MA	0	in-lb	Bending moment
		thetaA	-.0024374	rad	Slope
		yA	0	in	Deflection
					AT RIGHT END:
		RB	1796.581	lb	Vertical reaction
		MB	-25917.89	in-lb	Bending moment
		thetaB	0	rad	Slope
		yB	0	in	Deflection

ON1R & ON2R & ON3R INSTALLED



8-5

W = MODULE WEIGHT ON BACK SLING = 8060 LB



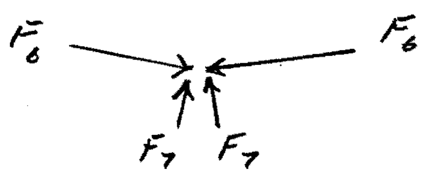
$F_5 = (8060\,LB)(\cos 56.25^\circ) = 4478\,LB$

$F_6 = (8060\,LB)(\sin 56.25^\circ) = 6702\,LB$

$F_3 = (4478\,LB)\left(\frac{10''}{25''}\right) = 1791\,LB$

$F_4 = (4478\,LB)\left(\frac{15''}{25''}\right) = 2687\,LB$

F_6 MUST DEVELOP REACTION FORCES:

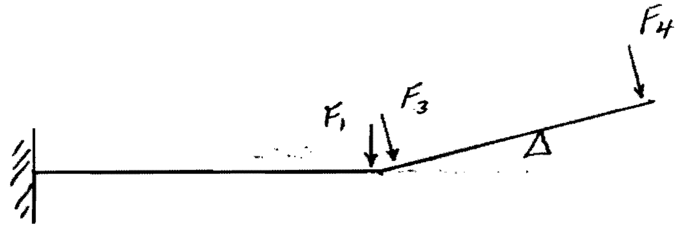


$F_7 = F_6 \frac{\sin 22.5^\circ}{\cos 11.25^\circ} = (6702\,LB)\left(\frac{\sin 22.5^\circ}{\cos 11.25^\circ}\right) = 2615\,LB$

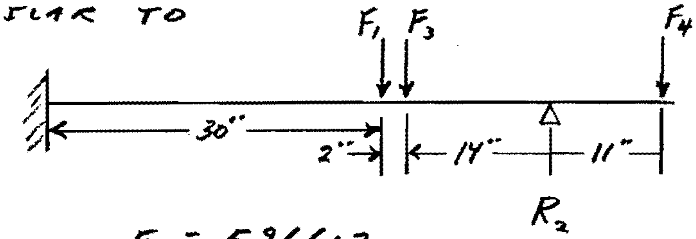
SO, FOR THIS CASE F_1 BECOMES

$F_1 = 3351\,LB + 2615\,LB = 5966\,LB$

↑ FROM PAGE B-2



IS SIMILAR TO



WHERE $F_1 = 5966$ LB

$F_3 = 1791$ LB

$F_4 = 2687$ LB

I'LL SOLVE THESE INDIVIDUALLY USING ROARKS, THEN SUPERIMPOSE THE RESULTS. I'LL ASSUME $I = 12 in^4$ ALONG ENTIRE BEAM. STRESS IS TABULATED FOR THE POINT BELOW F_1

FROM F_1	$R_2 = 3093$ LB	$\sigma = 10938$ psi
FROM F_3	$R_2 = 1030$ LB	$\sigma = 2843$ psi
FROM F_4	$R_2 = 3595$ LB	$\sigma = -3305$ psi *
	$R_2 = 7718$ LB	$\sigma = 10476$ psi

* NEGATIVE BECAUSE MOMENT IS IN OPPOSITE DIRECTION

St	Input	Name	Output	Unit	Comment
					Left simple support, right fixed
					Table 3 Case 1 - Roark & Young (6 ed)
					Concentrated Intermediate Load
					Page 100
		case	'CASE_1c		End Restraints Reference Number
	17	matl#			Material Number (See Material Table)
		matl	'Steel_AS		
		plot			Generate plots ? 'y=yes (Default=no)
		table			Generate a table? 'y=yes (Default=no)
	48	L		in	Length of beam
	16	a		in	Load distance from left end
F₁ =	5966	W		lb	Load
		E	2.9E7	psi	Young's Modulus
	4	I		in^4	Area moment of inertia
	1	z		in	Neutral axis to stress point
					AT SECTION:
	18	x		in	Distance from left end
		V	-2872.519	lb	Transverse shear
		M	43750.667	in-lb	Bending moment
		theta	-.0001714	rad	Slope
		y	-.0531454	in	Deflection
		st	10937.667	psi	Fiber stress at stress point
		sty	'_	psi	Max Fiber stress at extremity y
					AT LEFT END:
		RA	3093.481	lb	Vertical reaction
		MA	0	in-lb	Bending moment
		thetaA	-.0043888	rad	Slope
		yA	0	in	Deflection
					AT RIGHT END:
		RB	2872.519	lb	Vertical reaction
		MB	-42424.89	in-lb	Bending moment
		thetaB	0	rad	Slope
		yB	0	in	Deflection

o P. B-7

TO P. B-12

St	Input	Name	Output	Unit	Comment
					Left simple support, right fixed
					Table 3 Case 1 - Roark & Young (6 ed)
					Concentrated Intermediate Load
					Page 100
		case	'CASE_1c		End Restraints Reference Number
	17	matl#			Material Number (See Material Table)
		matl	'Steel_AS		
		plot			Generate plots ? 'y=yes (Default=no)
		table			Generate a table? 'y=yes (Default=no)
	48	L		in	Length of beam
	14	a		in	Load distance from left end
	F_3 = 1791	W		lb	Load
		E	2.9E7	psi	Young's Modulus
	4	I		in^4	Area moment of inertia
	1	z		in	Neutral axis to stress point
					AT SECTION:
	18	x		in	Distance from left end
		V	-761.343	lb	Transverse shear
		M	11369.818	in-lb	Bending moment
		theta	.000013	rad	Slope
		y	-.0149627	in	Deflection
		st	2842.455	psi	Fiber stress at stress point
		sty	'_	psi	Max Fiber stress at extremity y
					AT LEFT END:
		RA	1029.657	lb	Vertical reaction
		MA	0	in-lb	Bending moment
		thetaA	-.0013014	rad	Slope
		yA	0	in	Deflection
					AT RIGHT END:
		RB	761.343	lb	Vertical reaction
		MB	-11470.48	in-lb	Bending moment
		thetaB	0	rad	Slope
		yB	0	in	Deflection

TO P. 8-7

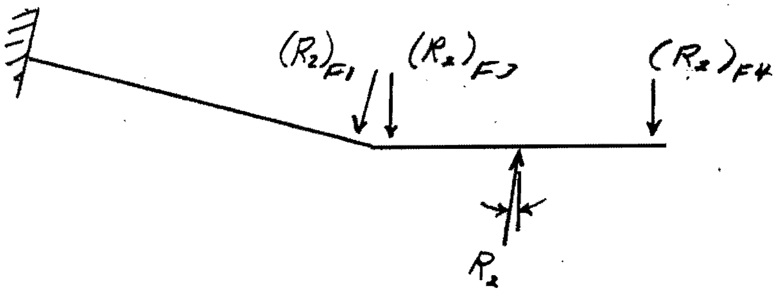
TO P. 8-12

St	Input	Name	Output	Unit	Comment
					Left simple support, right fixed
					Table 3 Case 1 - Roark & Young (6 ed)
					Concentrated Intermediate Load
					Page 100
		case	'CASE_1c		End Restraints Reference Number
	17	matl#			Material Number (See Material Table)
		matl	'Steel_AS		
		plot			Generate plots ? 'y=yes (Default=no)
		table			Generate a table? 'y=yes (Default=no)
	48	L		in	Length of beam
	-11	a		in	Load distance from left end
F_4 =	2687	W		lb	Load
		E	2.9E7	psi	Young's Modulus
	4	I		in^4	Area moment of inertia
	1	z		in	Neutral axis to stress point
					AT SECTION:
	18	x		in	Distance from left end
		V	907.487	lb	Transverse shear
		M	-13222.24	in-lb	Bending moment
		theta	-.0001009	rad	Slope
		y	.0191153	in	Deflection
		st	-3305.559	psi	Fiber stress at stress point
		sty	'_	psi	Max Fiber stress at extremity y
					AT LEFT END:
		RA	3594.487	lb	Vertical reaction
		MA	0	in-lb	Bending moment
		thetaA	.0046196	rad	Slope
		yA	0	in	Deflection
					AT RIGHT END:
		RB	-907.487	lb	Vertical reaction
		MB	14002.372	in-lb	Bending moment
		thetaB	0	rad	Slope
		yB	0	in	Deflection

TO P. B-7

TO P. B-12

FIND θ, DIRECTION OF REACTION VECTOR



$$\Sigma F_Y = (R_2)_{F3} + (R_2)_{F4} + (R_2)_{F1}(\cos 22.5°) - R_2 (\cos \theta) = 0$$

$$\frac{1030\text{LB} + 3595\text{LB} + (3093\text{ LB})(\cos 22.5°)}{(7718\text{LB})} = \cos \theta$$

$$\theta = 14.2°$$

$$R_N = (7718\text{LB})(\cos 14.2°) = 7482\text{LB}$$

$$R_T = (7718\text{LB})(\sin 14.2°) = 1893\text{LB}$$

$$R_V = \frac{7718\text{LB}}{\cos 14.2°} = 7961\text{LB}$$

τ_{MAX} OCCURS BETWEEN F_3 AND R_2

$$\tau_{MAX} = \frac{3093\text{LB} + 1030\text{LB}}{12\text{ in}^2} = 350\text{psi}$$

R_T INDUCES A MOMENT ON THE SLING THAT IS OPPOSITE TO THE MOMENT FROM R_2.
I'LL IGNORE THIS EFFECT (TAKE NO CREDIT)

R_T ALSO INDUCES A TENSILE STRESS R_T/A

$$\sigma_{max} = 10476\,psi + \frac{1893\,LB}{12\,in^2} = 10700\,psi$$

↑ COMBINED TENSION & BENDING

FIND STRESS AT VERTEX WHERE OH1 AND OH2 JOIN IN THIS CASE THE MOMENT INDUCED BY R_T IS IN THE SAME DIRECTION AS THOSE FROM F_1, F_3, & F_4

$$M_{R_T} = (1893\,LB)(32\,in)(\sin 22.5°) = 23181\,in\,LB$$

TOTAL BENDING MOMENT:

$$M = -42425\,in\,LB - 11470\,in\,LB + 14002\,in\,LB - 23181\,in\,LB = 63074\,in\,LB$$

BENDING STRESS:

$$\sigma = \frac{(63074\,in\,LB)(1\,in)}{4\,in^4} = 15768\,psi$$

$$\sigma_{MAX} = 15768\,psi + \frac{1893}{12\,in^2} = 16,000\,psi$$

↑ COMBINED TENSION & BENDING

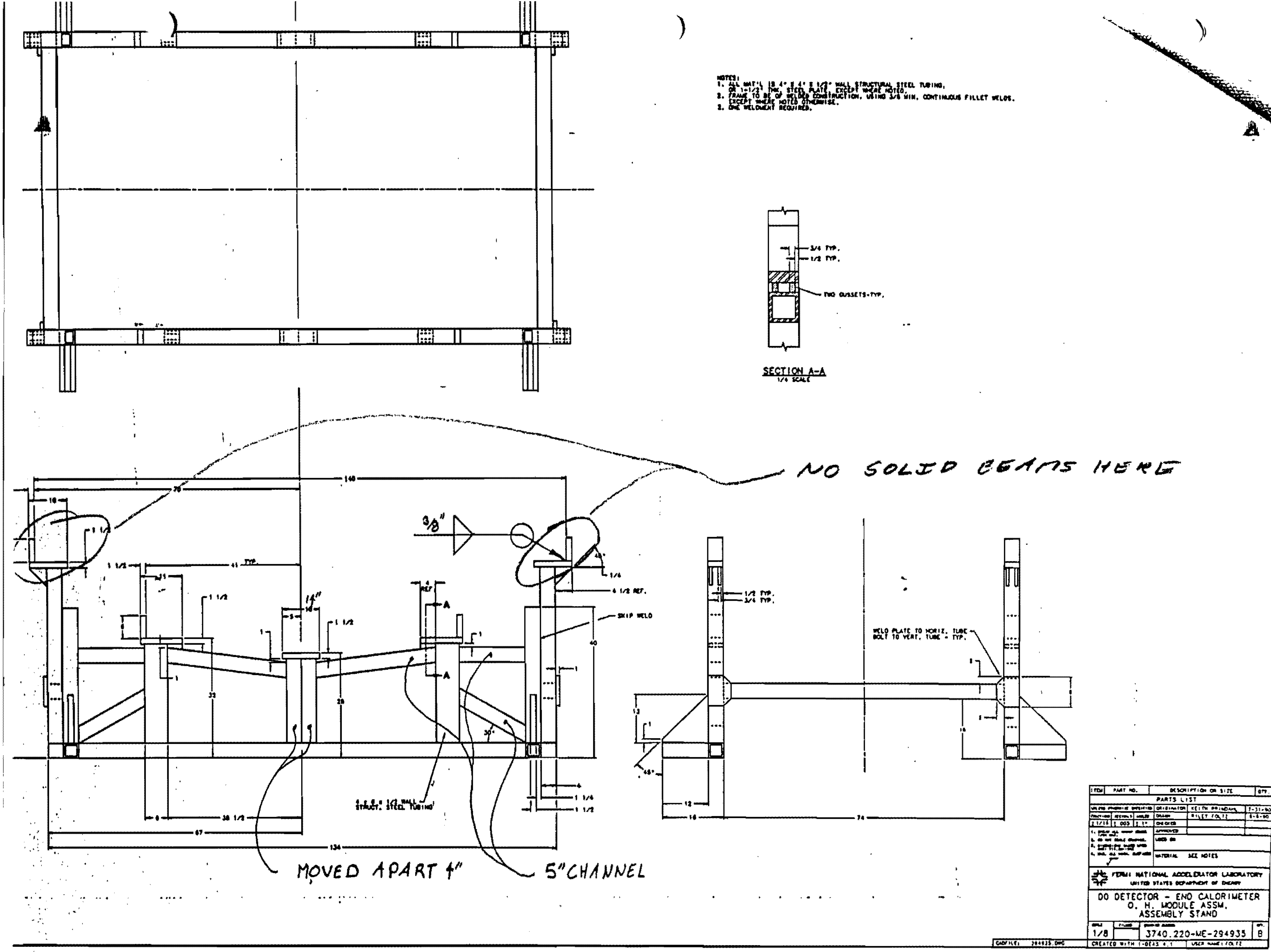
FOR ALLOWABLES, I'LL USE:

TENSION + BENDING:

$\sigma_{ALL} = (.6)(30{,}000\,psi) = 18{,}000\,psi$

SHEAR:

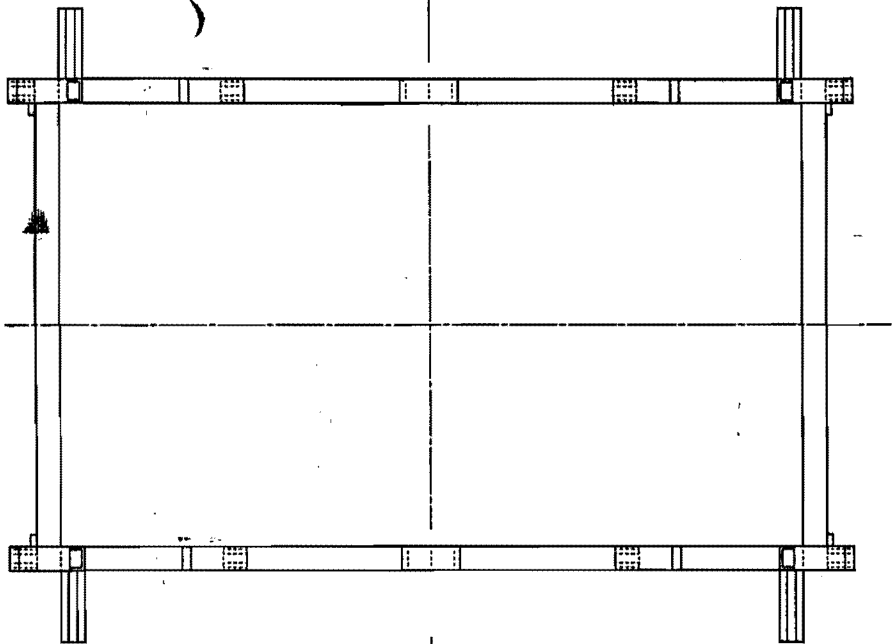
$\tau_{ALL} = (.4)(30{,}000\,psi) = 12{,}000\,psi$


NOTES:
1. ALL MAT'L IS 4" X 4" X 1/2" WALL STRUCTURAL STEEL TUBING, OR 1-1/2" THK. STEEL PLATE, EXCEPT WHERE NOTED.
2. FRAME TO BE OF WELDED CONSTRUCTION, USING 3/8 MIN. CONTINUOUS FILLET WELDS, EXCEPT WHERE NOTED OTHERWISE.
3. ONE WELDMENT REQUIRED.
3/4 TYP.
1/2 TYP.
TWO GUSSETS-TYP.
SECTION A-A
1/4 SCALE
NO SOLID BEAMS HERE
3/8"
1/4"
SKIP WELD
6 1/2 REF.
WELD PLATE TO HORIZ. TUBE BOLT TO VERT. TUBE - TYP.
4 X 6 X 1/2 WALL STRUCT. STEEL TUBING
MOVED APART 4"
5"CHANNEL
PARTS LIST
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
D0 DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND
1/8
3740.220-ME-294935
B

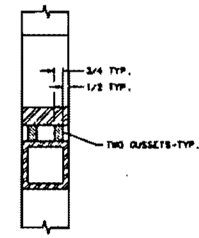
Appendix C

Drawings

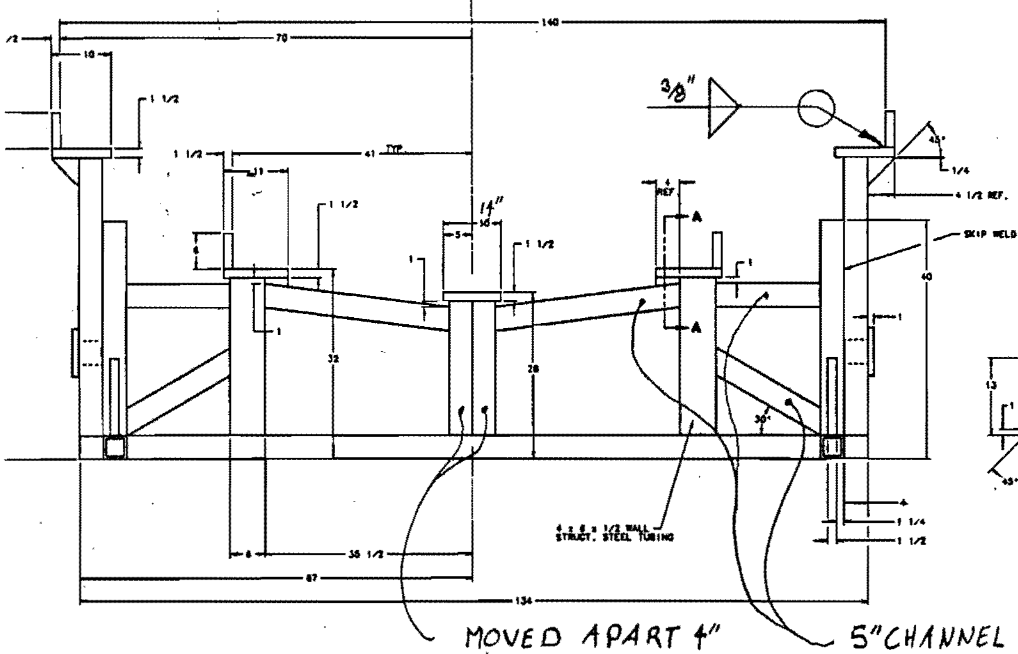
Note #3740.225-EN-262

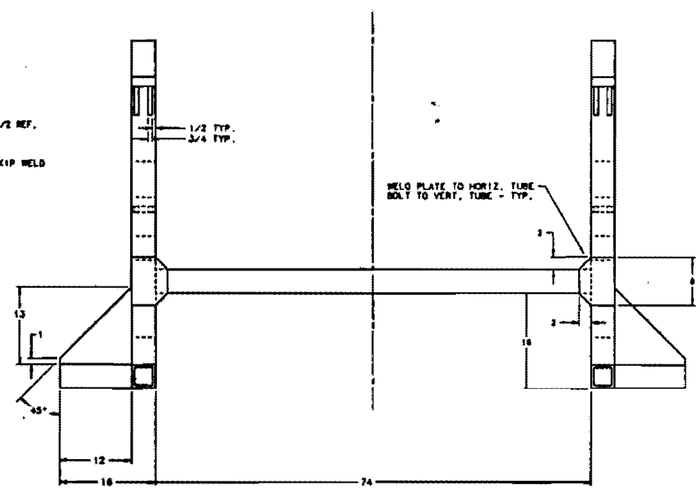


NOTES:
1. ALL MAT'L IS 4" X 4" X 1/2" WALL STRUCTURAL STEEL TUBING, OR 1-1/2" THK. STEEL PLATE, EXCEPT WHERE NOTED.
2. FRAME TO BE OF WELDED CONSTRUCTION, USING 3/8 MIN. CONTINUOUS FILLET WELDS, EXCEPT WHERE NOTED OTHERWISE.
3. ONE WELDMENT REQUIRED.



SECTION A-A
1/4 SCALE





ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
PARTS LIST			

ORIGINATOR	KEITH PRIMDAHL	7-31-90
DRAWN	RILEY FOLTZ	8-6-90
CHECKED		
APPROVED		
USED ON		
MATERIAL	SEE NOTES	

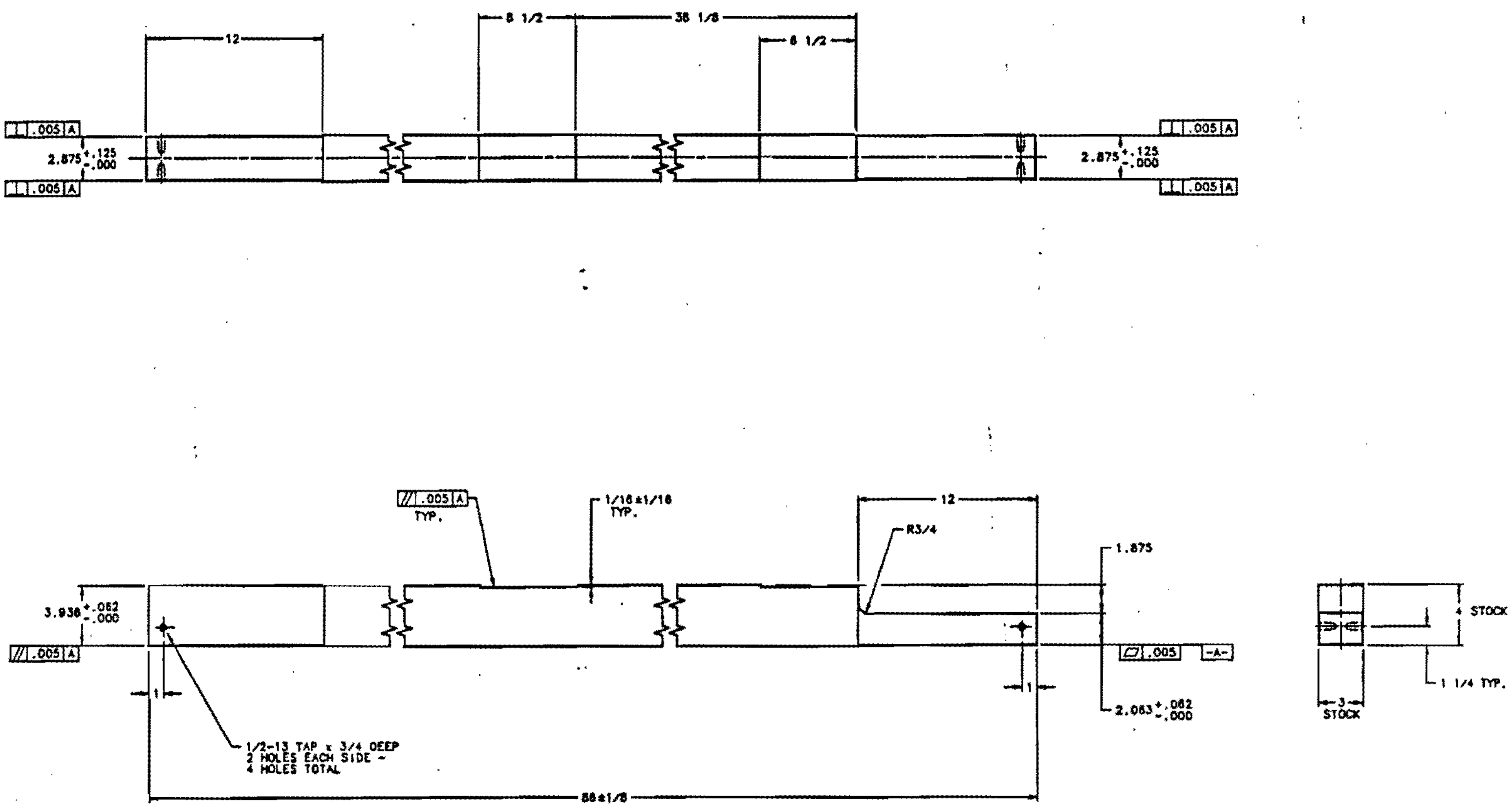
± 1/16 | ± .005 | ± 1°

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND

SCALE		DRAWING NUMBER	REV.
1/8		3740.220-ME-294935	B

CADFILE: 294935.DWG | CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ



NOTE - TWO REQ'D

REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTION	DECIMAL	ANGLES	ORIGINATOR	KEITH PRIMDAHL	9-12-90
±1/16	±.005	± 1°	DRAWN	RILEY FOLTZ	9-13-90
			CHECKED	[signature]	9-13-90
			APPROVED		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES

USED ON

MATERIAL 4150 STEEL, RE-SULPHERIZED 3x4"-MODIFIED, ANNEALED, HOT ROLLED

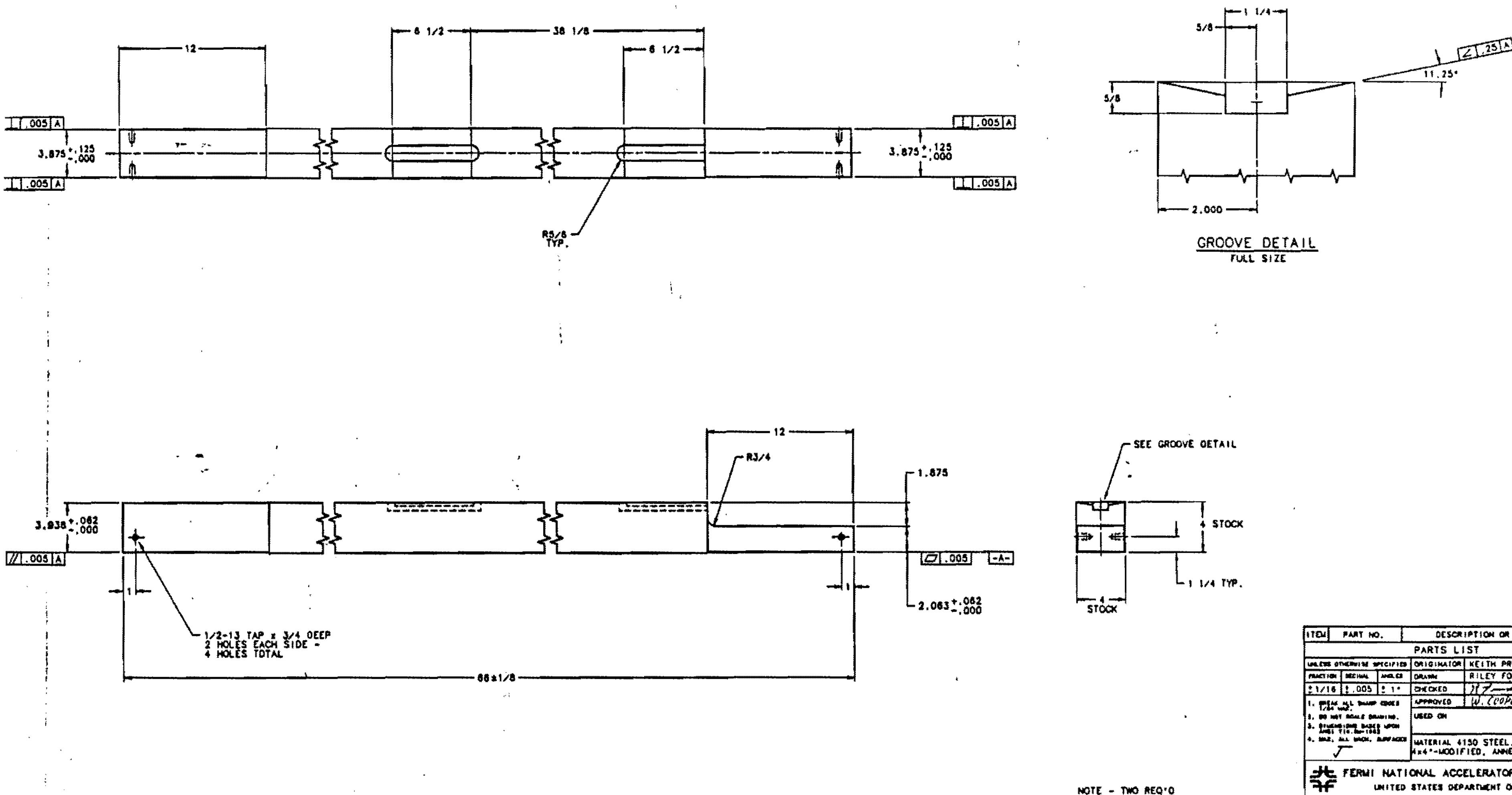
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND - HORIZONTAL BAR

SCALE	FILMED	DRAWING NUMBER	REV.
1/4		3740.220-MD-295017	

CADFILE: 295017.DWG

CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ



ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTION	DECIMAL	ANGLES	ORIGINATOR	KEITH PRIMDAHL	8-1-90
±1/16	±.005	±1°	DRAWN	RILEY FOLTZ	8-1-90
			CHECKED	[signature]	8-3-90
			APPROVED	W. COOPER	8/15/90

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONING BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES

USED ON

MATERIAL 4130 STEEL, RE-SULPHERIZED 4x4"-MODIFIED, ANNEALED, HOT ROLLED

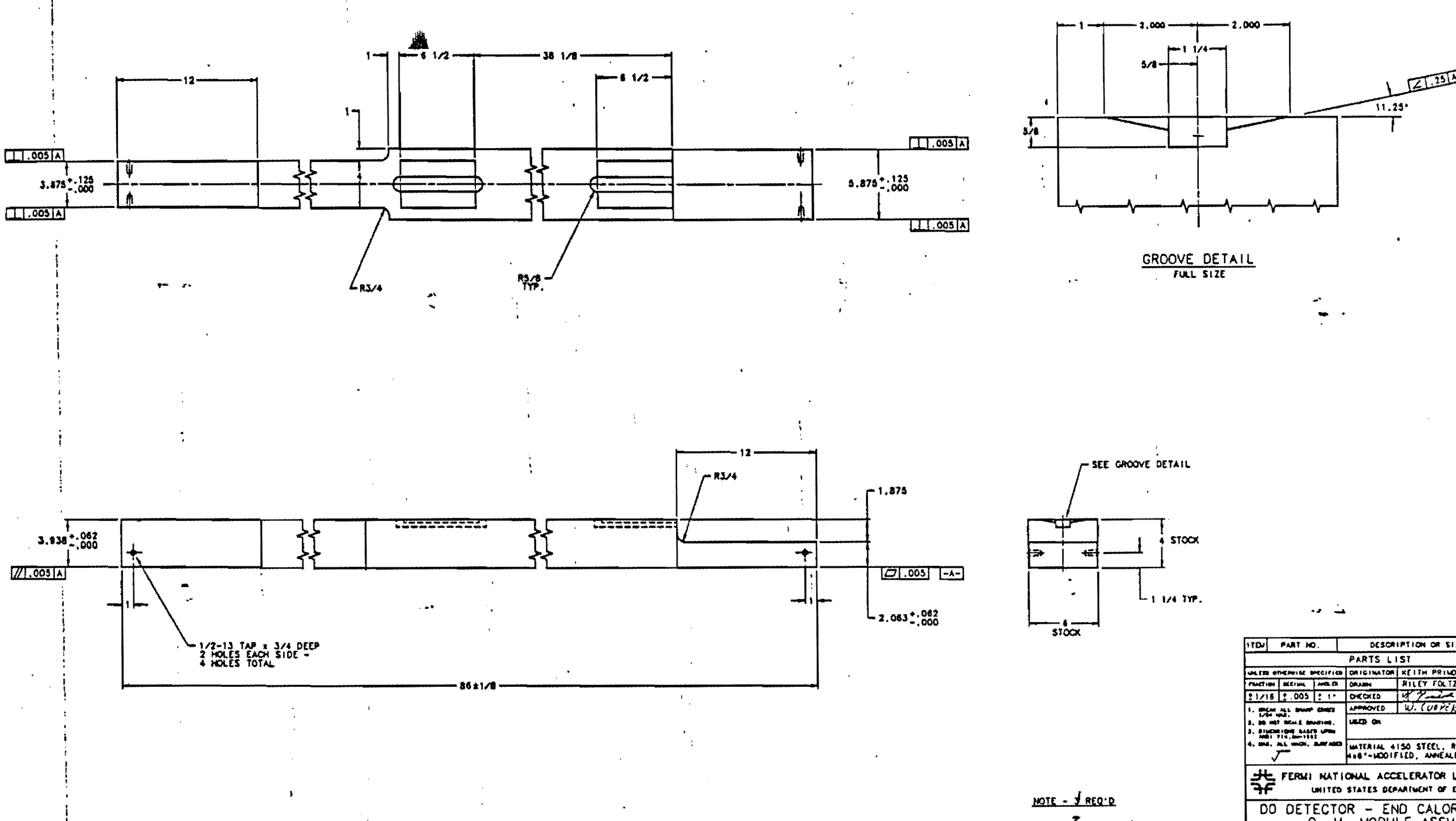
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D0 DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND - HORIZONTAL BAR

SCALE	FILMED	DRAWING NUMBER	REV.
1/4		3740.220-MD-294936	

CADFILE: 294936.DWG | CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ

REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE



REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	KEITH PRIMDAHL	8-1-90
FRACTION	DECIMAL	ANGLES	DRAWN	RILEY FOLTZ	8-3-90
±1/16	±.005	±1°	CHECKED	[signature]	8-3-90
			APPROVED	W. COOPER	8/15/90

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES √

USED ON

MATERIAL 4150 STEEL, RE-SULPHERIZED 4x6"-MODIFIED, ANNEALED, HOT ROLLED

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND - HORIZONTAL BAR

SCALE	FILMED	DRAWING NUMBER	REV.
1/4		3740.220-MD-294937	

CADFILE: 294937.DWG

CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ

FERMILAB
ENGINEERING NOTE

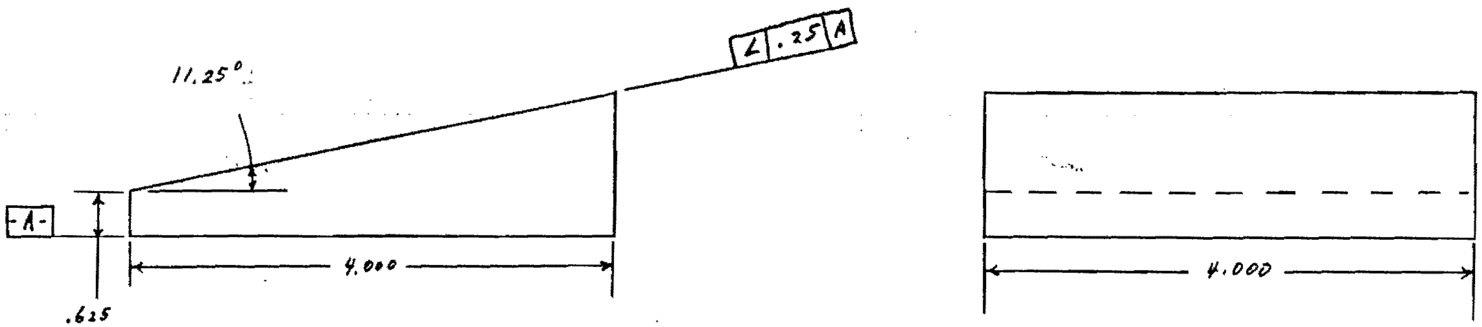
SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: ON CRADLE ANGLE BLOCK

NAME: K. PRIMDAHL

DATE: 9-18-90

REVISION DATE:

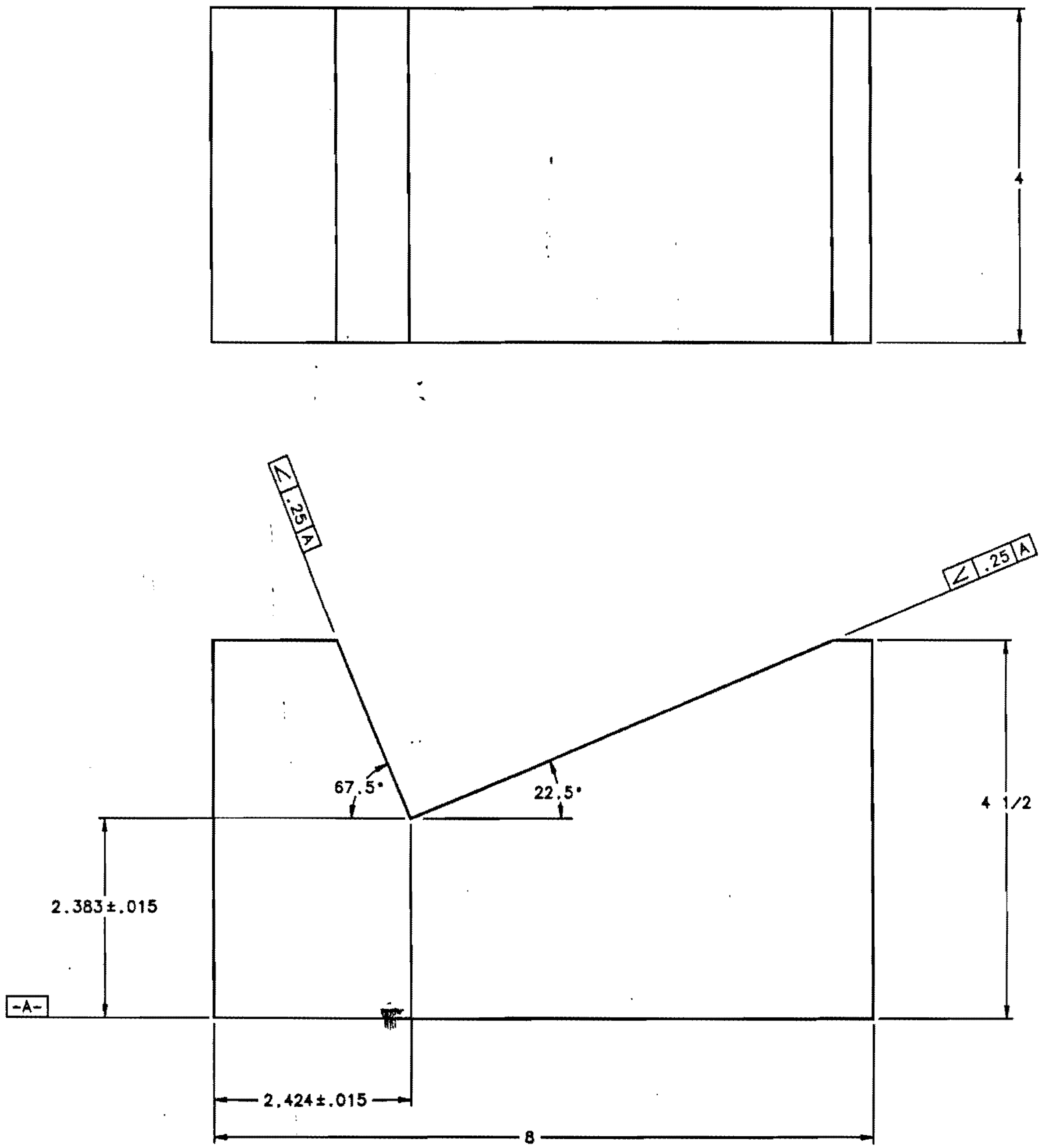


4 REQUIRED

A36 STEEL

±.062 UNLESS NOTED

REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	67.5° WAS 60°, 22.5° WAS 30° 2.383 WAS 2.500, 2.424 WAS 3.116 4-1/2 WAS 5	R. FOLTZ	8-13-90



NOTE - TWO REQ'D

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTION	DECIMAL	ANGLES	ORIGINATOR	KEITH PRIMDAHL	8-2-90
±1/64	±.005	± 1°	DRAWN	RILEY FOLTZ	8-6-90
			CHECKED	R. Rimdahl	8-6-90
			APPROVED	W. COOPER	8/15/90

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES √

USED ON

MATERIAL A-36 STEEL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

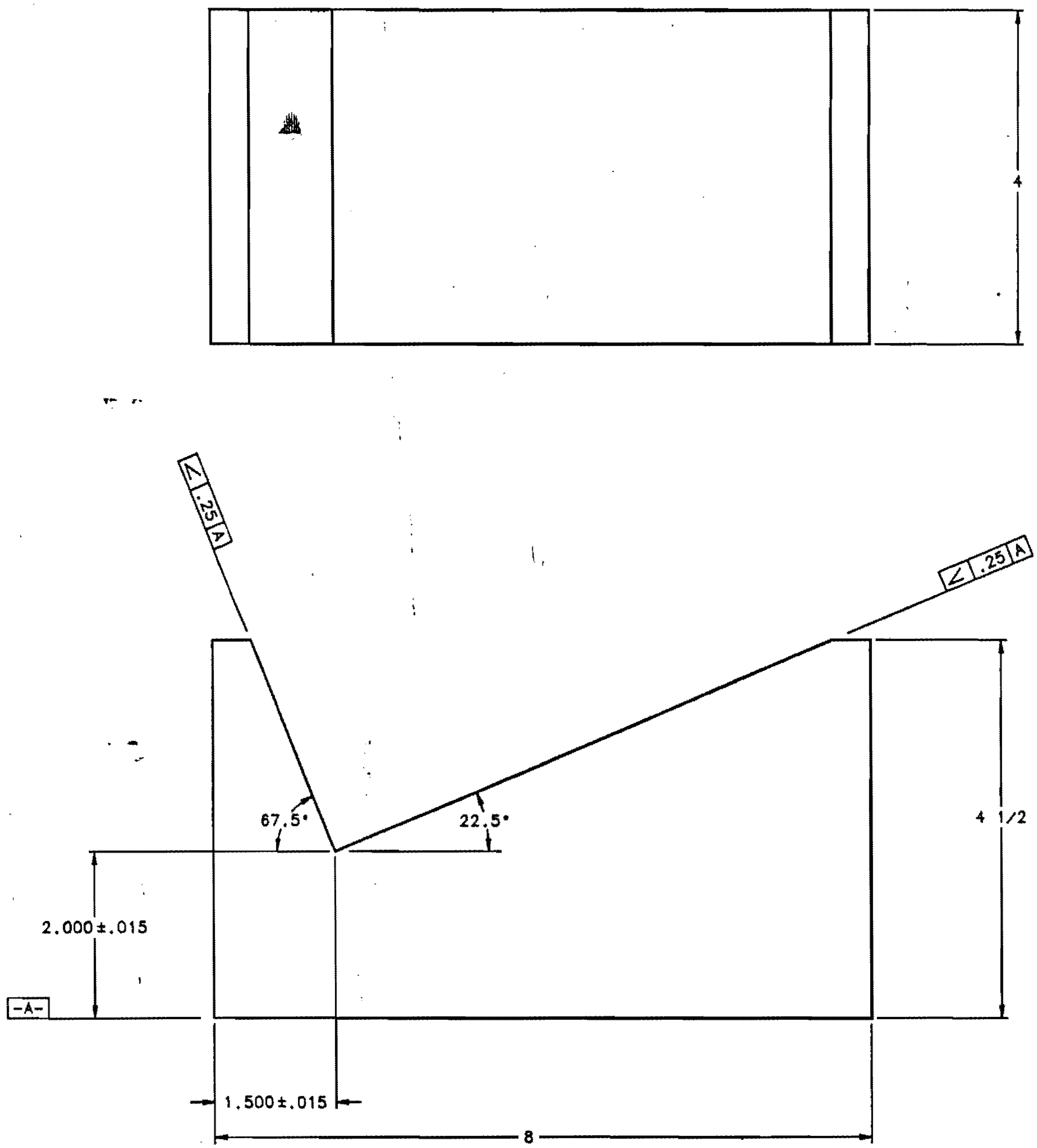
DO DETECTOR - END CALORIMETER O. H. MODULE ASSM. ASSEMBLY STAND - V-BLOCK

SCALE	FILMED	DRAWING NUMBER	REV.
1:1		3740.220-MC-294950	

CADFILE: 294950.DWG

CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ

REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	67.5° WAS 60°, 22.5° WAS 30°, 1.500 WAS 2.250, 4-1/2 WAS 5	R. FOLTZ	8-13-90
		K. Primdahl	8-13-90



NOTE - TWO REQ'D

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
		PARTS LIST	

UNLESS OTHERWISE SPECIFIED: FRACTION ±1/64, DECIMAL ±.005, ANGLES ±1°

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES √

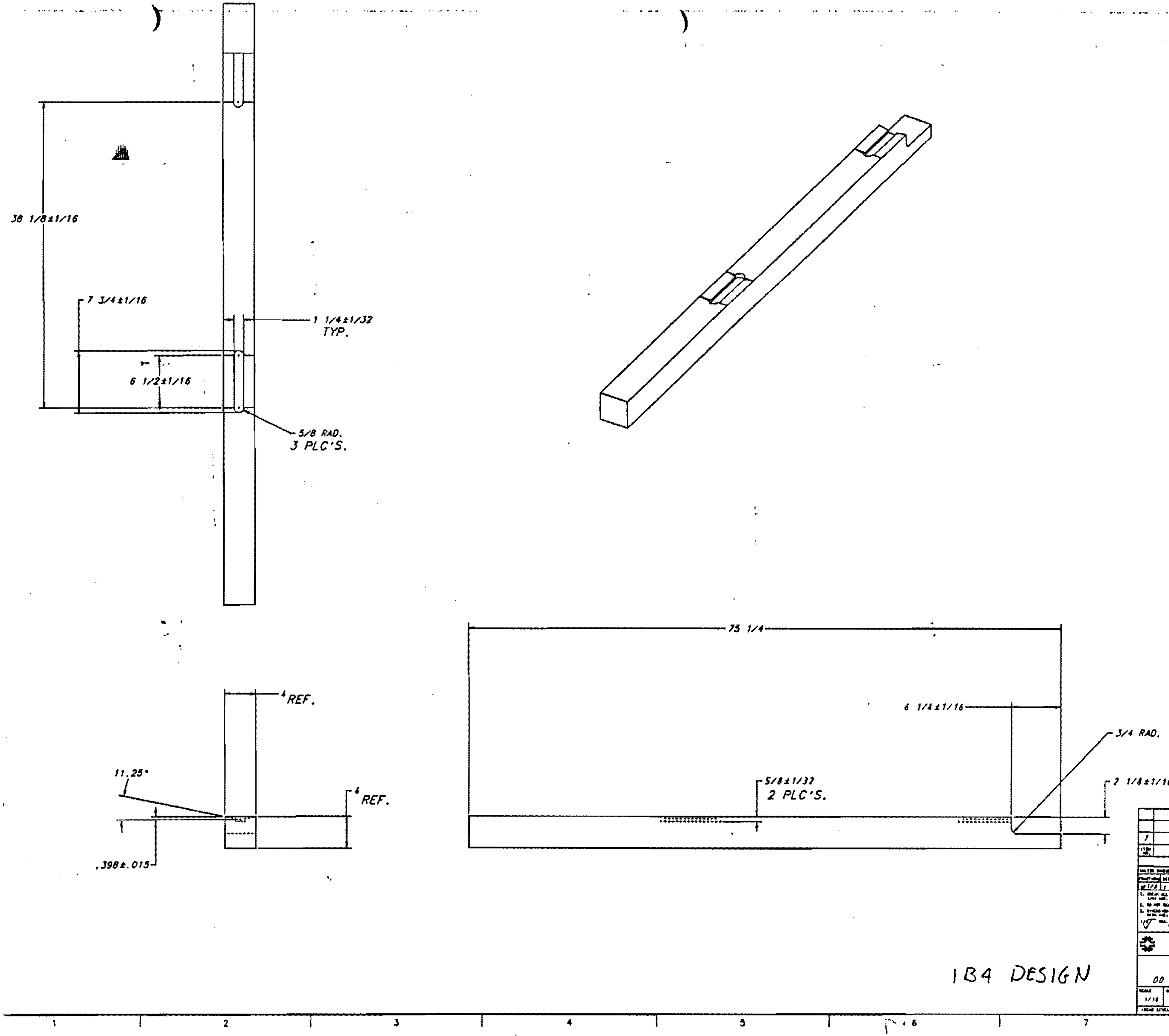
ORIGINATOR	KEITH PRIMDAHL	8-2-90
DRAWN	RILEY FOLTZ	8-6-90
CHECKED	K. Primdahl	8-13-90
APPROVED	W. COOPER	8/15/90
USED ON		
MATERIAL	A-36 STEEL	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND - V-BLOCK

SCALE	FILMED	DRAWING NUMBER	REV.
1:1		3740.220-MC-294949	

CADFILE: 294949.DWG | CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ



1			
ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.

PARTS LIST

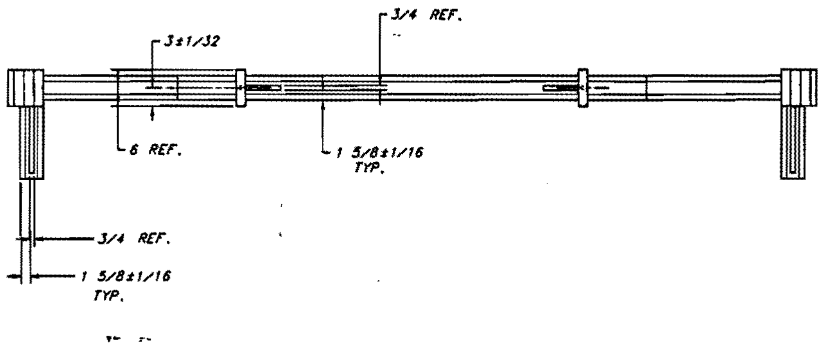
ORIGINATOR: J. SAUER
DRAWN: V. L. JACOBSEN 5/22/89
USED ON
MATERIAL - CR STL. BAR

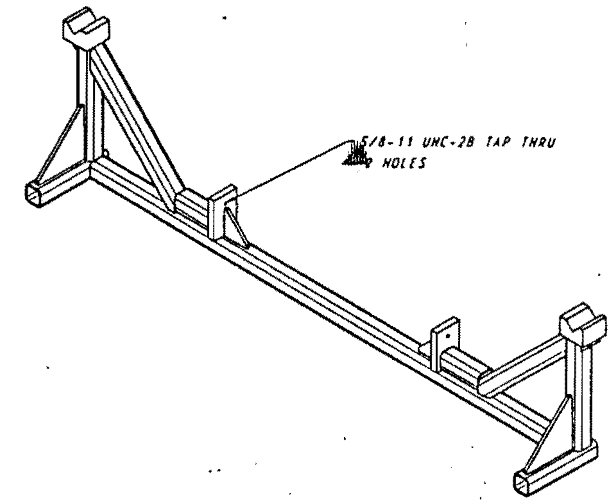
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

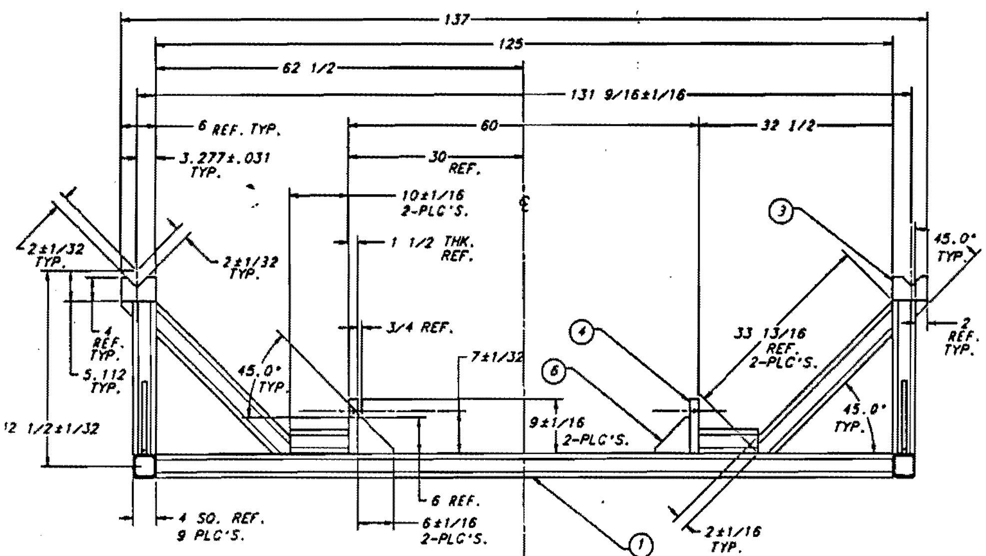
BAR
O.H. MODULES
D0 DETECTOR-END CALORIMETER

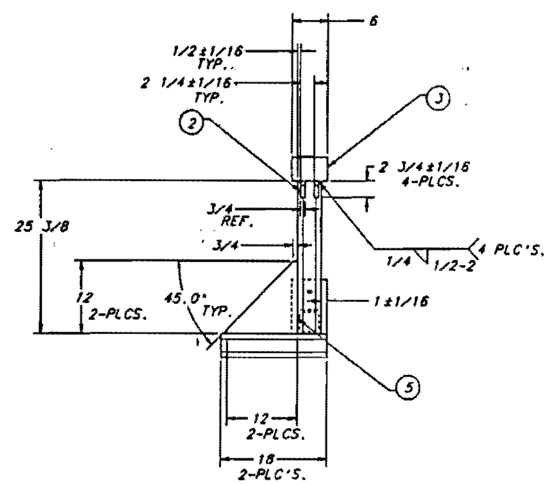
SCALE: 1/16 | SIZE: E | DRAWING NUMBER: 3740.220-ME-278705

JACOBSEN









NOTES:
1) ALL WELDS SHALL BE 3/8 FILLET 1-4 UNLESS OTHERWISE NOTED.

IB4 DESIGN

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
6		3/4x6 HR. STL. FLAT-M1020	AS REQ'D
5		3/4 HR. STL. PLATE-M1020	AS REQ'D
4		1-1/2x6 HR. STL. FLAT-M1020	AS REQ'D
3		4x6 HR. STL. FLAT-M1020	AS REQ'D
2		3/4x2 HR. STL. FLAT-M1020	AS REQ'D
1		4x4x.375 SQ. STRUCT. STL. TUBE-ASTM A-500	AS REQ'D

PARTS LIST

ORIGINATOR: L. SAUER 6/88
DRAWN: V. L. JACOBSEN 4/20/89
CHECKED
APPROVED
USED ON
MATERIAL: SEE DESCRIPTION

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

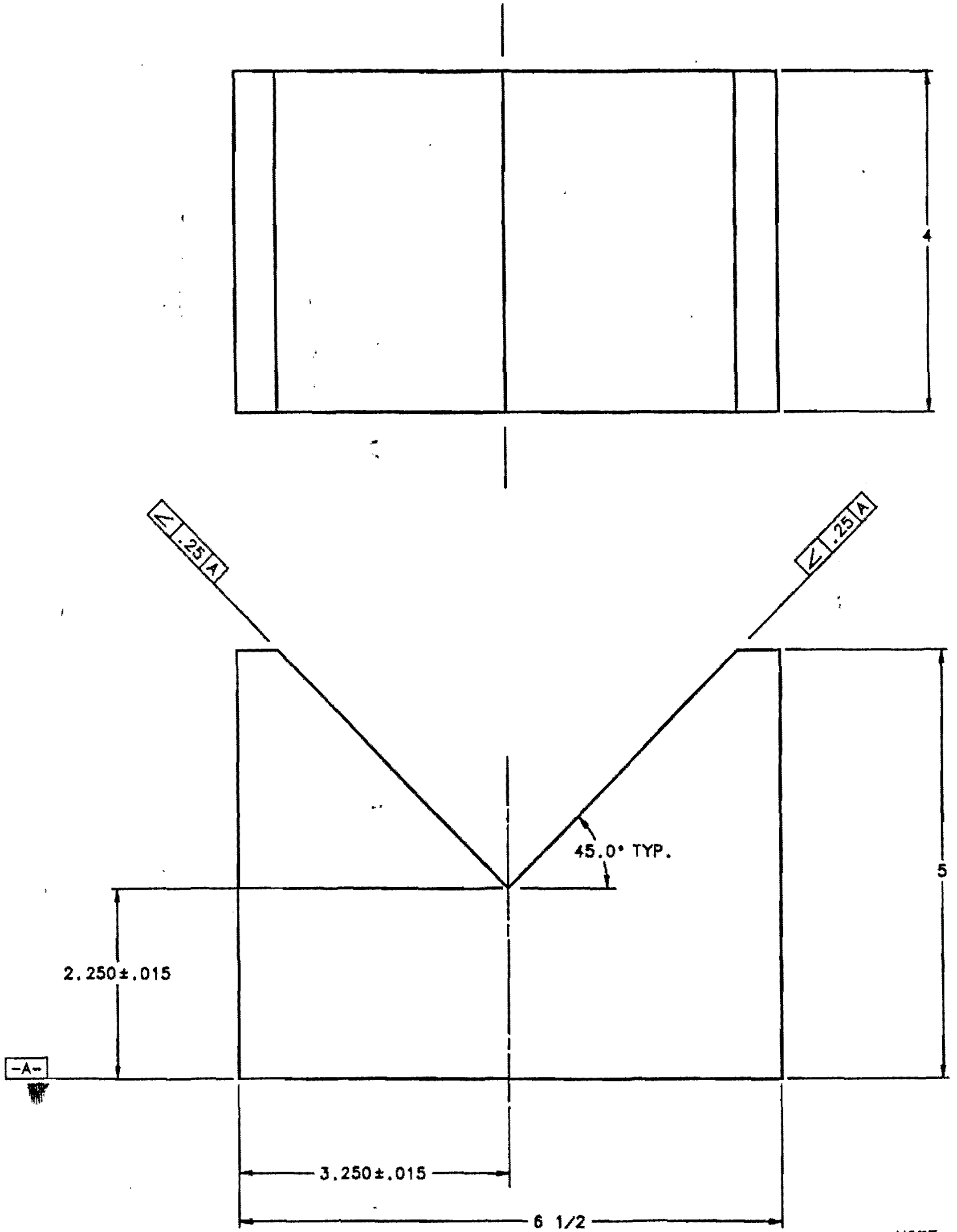
FIXTURE WELDMENT
OHMODULE CRADLE ASS'Y.
RD/MECH. DEPT.

SCALE 1/8 | SIZE E | DRAWING NUMBER 3740.220-ME-278704

JACOBSEN

1 2 3 4 5 6 7 8

REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE



NOTE - 4 REQ'D

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTION ±1/64	DECIMAL ±.005	ANGLES ± 1°	ORIGINATOR	KEITH PRIMDAHL	8-2-90
			DRAWN	RILEY FOLTZ	8-6-90
			CHECKED	[signature]	8-7-90
			APPROVED	W. COOPER	8/15/90

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES √

USED ON

MATERIAL A-36 STEEL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

DO DETECTOR - END CALORIMETER
O. H. MODULE ASSM.
ASSEMBLY STAND - V-BLOCK

SCALE	FILMED	DRAWING NUMBER	REV.
1:1		3740.220-MC-294951	

CADFILE: 294951.DWG | CREATED WITH I-DEAS 4.1 | USER NAME: FOLTZ

ADDENDUM TO

D-Zero Engineering Note

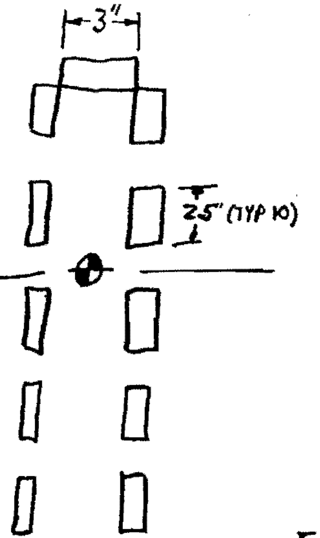
#3740.225-EN-262

Patrick J. Bolan

Revised: 10 / 30 / 90

Approved by:

Kurt D. Rumbaugh



Modifications to page 11 of appendix A.

Shear area $= [(10 \cdot 2.5) + 3] \cdot \frac{3}{8} \cdot \underline{.707}$

$= 7.425 \text{ in}^2$

$\sigma_y = 36$ Ksi

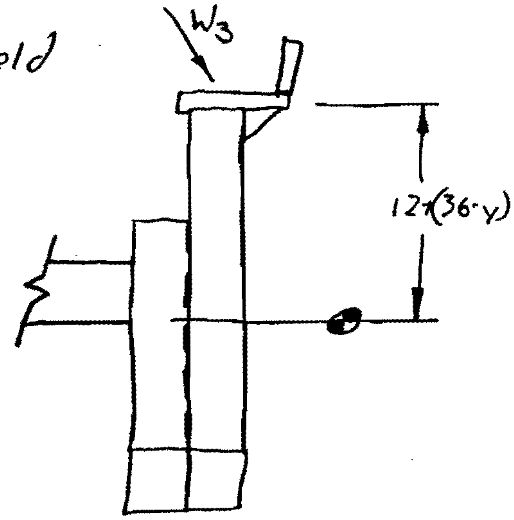
AISC max allow shear $= .4 \cdot \sigma_y = 14,400$ psi

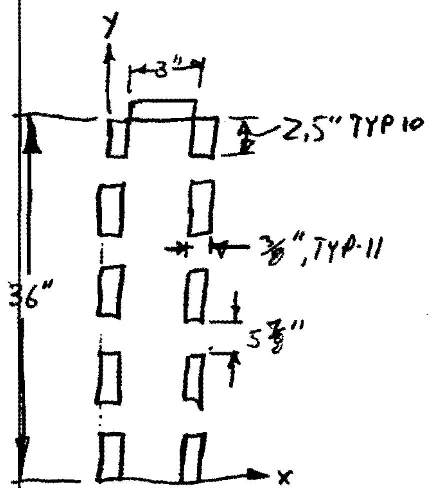
$$\frac{W_3 y_{max}}{7.425 \text{ in}^2} = 14,400 \text{ psi}$$

$$W_{3max} = 14,400 \frac{7.425}{\cos 45^\circ} = \underline{\underline{75,600 \text{ lb}}}$$

-The outer column bending is still a more critical factor. See page 10, appendix 'A'.

Bending of the Skip weld





$\bar{x}$, by symmetry = 1875

$$\bar{y} = \frac{(\frac{3}{8}\cdot 2.5\cdot 2)(1.25+9.625+18.0+26.375+34.75)+3\cdot\frac{3}{8}\cdot 36\frac{3}{16}}{(3/8\cdot 2.5\cdot 2\cdot 5)+3\cdot\frac{3}{8}}$$

$= 19.95 in$

Moment of inertia about Neutral axis ($y=19.95$)

Using the parallel axis theorem, $I_{xx} = I_{x'x'} + Ad^2_{x\to x'}$

$$I = \sum_{n=1}^{5} 2\cdot b\cdot h^3\cdot\frac{1}{12} + \sum_{n=1}^{5} Ad_n^2 + 3\cdot\frac{3}{8}^3 + 3\cdot\frac{3}{8}\cdot(36\tfrac{3}{16}-19.95)^2$$

$$= 5\cdot 2\cdot\frac{3}{8}\cdot\frac{1}{12}\cdot 2.5^3 + 2.5\cdot\frac{3}{8}\left[(19.95-1.25)^2+(19.95-9.625)^2+(19.95-18)^2+(26.375-19.95)^2 + (34.75-19.95)^2\right] + 3\cdot\frac{3}{8}^3 + 3\cdot\frac{3}{8}\cdot(36\tfrac{3}{16}-19.95)^2$$

$= 4.88\, in^4 + 675.4\, in^4 + .16\, in^4 + 297\, in^4$

$= 977\, in^4$

$\sigma_y = 36{,}000\, psi$ AISC max allow $= .66\cdot\sigma_y = 23{,}760\, psi$

$M = W_3 \sin 45°\,(12+36-19.95)$

$I = 977 in^4$

$c = y = 19.95$

$$\sigma_{max} = \frac{M_{max}\, c}{I}$$

$$W_{3\,max} = \frac{23700_{psi} \cdot 977 in^4}{19.95 in \cdot 28.05 \sin 45^\circ}$$

$$= \underline{\underline{58,500\ lb}}$$

- outer column bending is still a more critical factor. See page 10, appendix A