Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project: NuMI

Title: Magnet Transport Cart for the NuMI Magnets in the Carrier Tunnel

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Key Words: Magnet Installation

Abstract Summary: Stress and deflection calculations for the structural steel cart components designed to be used for hauling the 3Q120 quad magnets up the 15% slope and then to lift the magnets onto their stands. This cart is designed to fit within the tight spaces of the carrier tunnel.

Applicable Codes: AISC 9th edition used to define allowable stresses.

Assembly Drawing 8875.119-ME-427382

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SUBJECT	NAME	
Carrier Tunnel Magnet Installation Cart - Modification	Mayling Wong	
	DATE	REVISION DATE 17 Nov 2003

This is a modification of the NuMI Carrier Tunnel Magnet Installation Cart (Engineering Note MD-ENG/03-002). A lug is added between the existing lugs. The wire rope from the winch will attach at the new lug. All modifications are shown in the drawing for the cart (8875.119-ME-427421).

Figure 1 shows the lug.

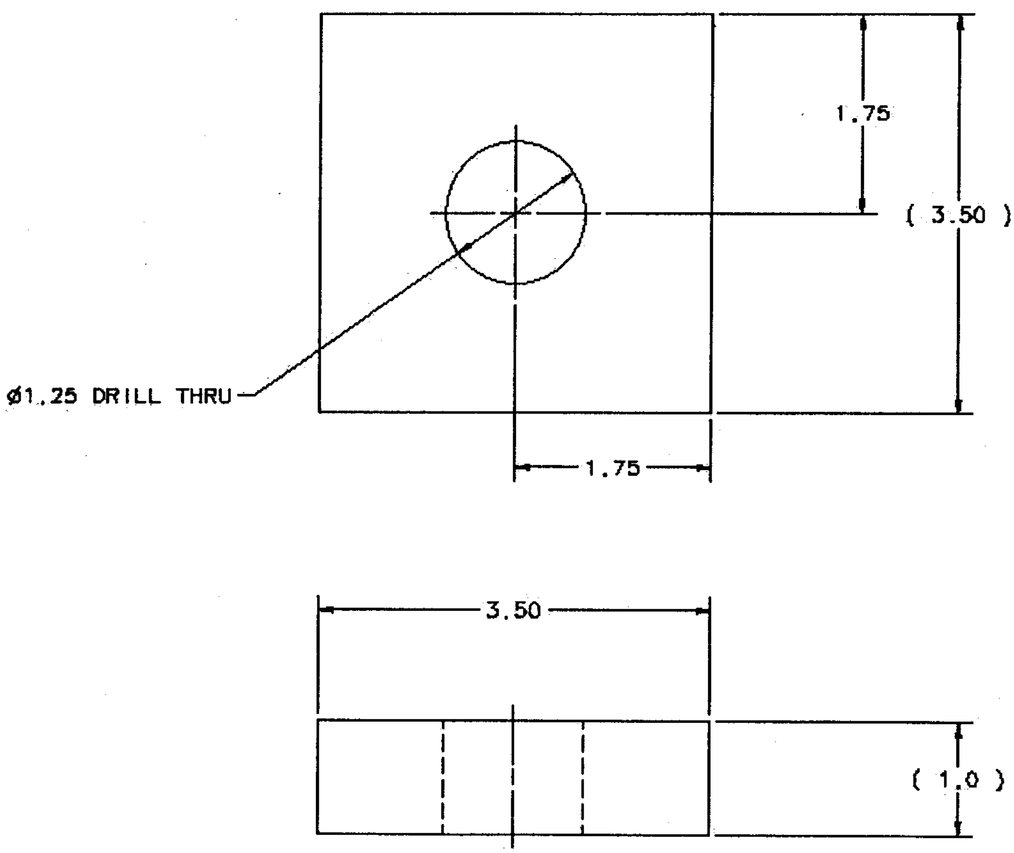


Figure 1 – Dimensions of Center Lug

Let the force pulling on the lug be F = 3000-pounds. (In comparison, a 10,000-pound load pulled along a 9° slope results in a force on the lug of 1564 pounds.) For a plate in tension that has a central circular hole in it, the maximum stress that the plate sees is

$t := 0.5$ plate thickness (inch)

$D := 3.5$ plate width (inch)

$r := 0.625$ plate hole radius (inch)

$P := 3000$ force (pound)

$$k := 3 - 3.13 \cdot \left(\frac{2 \cdot r}{D}\right) + 3.66 \cdot \left(\frac{2 \cdot r}{D}\right)^2 - 1.53 \cdot \left(\frac{2 \cdot r}{D}\right)^3$$

$k = 2.279$ constant

$$nom\_stress := \frac{P}{t \cdot (D - 2 \cdot r)}$$

$nom\_stress = 2.667 \times 10^3$ nominal stress (psi)

$max\_stress := k \cdot nom\_stress$

$max\_stress = 6.078 \times 10^3$ maximum stress (psi)

According to the ASD Section D1, the allowable stress shall Ft shall not exceed 0.60Fy, where Fy is the material's yield stress. For carbon steel, the yield stress is 36,000 psi, so the allowable stress is 21,600 psi. The maximum stress of 6078 psi is less than the allowable stress, so the lug design is good.

ENGINEERING NOTE FOR THE CARRIER TUNNEL INSTALLATION CART.

DESIGNED BY JOHN RAUCH, CALCULATIONS BY D. PUSHKA

CONTENTS

CALCULATIONS FOR THE NUMI LOW PROFILE MAGNET INSTALLATION CART. CART IS TO BE USED FOR INSTALLING 3Q 120 MAGNETS IN THE DRILL & BLAST PORTION OF THE NUMI CARRIER TUNNEL. FLOOR SLOPE IS ABOUT 15%.

INTENT IS TO PLACE A QUAD ON THE CART UNDER THE DROP HATCH, & TOW THE CART UPHILL (WITH THE MAGNET RESTING ON THE HORIZONTAL 8"x8" ⌀ TUBES).

ONCE IN THE CORRECT 'Z' POSITION, THE MAGNET CART WILL BE BLOCKED IN PLACE W/ A TEMPORARY & BOLTED TO THE FLOOR, THE HILMAN ROLLERS TURNED 90° TO THE SLOPE, THE MAGNET RAISED WITH THE HYDRAULIC ARMS, AND THE CART MOVED ACROSS THE FLOOR TO POSITION THE MAGNET ON THE PRE-INSTALLED MAGNET STANDS. ONCE LOAD IS TRANSFERED TO THE STANDS, THE LIFTING FIXTURE IS TO BE UN-BOLTED FROM THE MAGNET, CART MOVED BACK TO THE AISLE, ROLLARS TURNED TO POINT DOWN HILL, & REMOVED, AND CART ALLOWED TO MOVE BACK DOWN HILL.

WEIGHT:

8" ⌀ @ 48.85 #/FT

L = (2)(32") + 25.25 + (2)(36") + 104

= 22.1 FEET

SUBTOTAL

$W_{8"⌀}$ = 1079.8 # 1079.8

6" ⌀ @ 29.37 #/FT

L = 104" = 8.$\overline{6}$ FT

$W_{6"⌀}$ = 254.5 # 1334.32

HILMAN'S ROLLARS

(4)(22+15) = 148 # 1482.32

ARMS:

(4)·(16" × 3½" × 1") × 0.28 #/IN^3 = 63.5 1545.8 ~~63.5~~

Cylinders:

(2) @ 35 # EA = 70 # 1615 #

2" × 4" BOX × 22" LG @ 8.81 #/FT = 16.15 # 1632 #

ESTIMATED WEIGHT = ~~1700~~ #

SEE NEXT PAGE

8" ø @ 75 #/FT

$(2)(8")\left(\frac{1\,FT}{12\,IN}\right)(75\ \#/FT = 100\ \#$ 1732 #

ESTIMATED CART Wt ≐ 1750#

∴ MAGNET Wt = 8200 #

ASSUME ASSEMBLY WEIGHS 10,000 #

EST. C.G. OF CART - HORIZONTAL

IN THE WORST CASE, CONSIDER CART w/ MAG LIFTED SUCH THAT ARM IS HORIZONTAL.

MAGNET WT = 8200 #

OFFSET (FROM HORZ) FROM DATUM = 21.61 - 1.19 = 20.42"

CART COMPONENTS -

	WT	OFFSET	WT * OFFSET
6" ⌀	254.5 #	0	0
VERT 8" ⌀	786.6 # ~~363.3 #~~	0	0
HORZ 8" ⌀	293 #	11.5"	3369
HILMAN ROLLERS	148 #	11.5"	1702
ARMS	63.5	~ 10"	635
CYL	70 #	~ 5"	350
2" × 4"	16 #	7"	112
8" ⌀	100 #	0"	0
	1731.6 #		6168

$$d_{HORIZONTAL} = \frac{\Sigma(wt * offsets)}{\Sigma wt} = \frac{6168}{1731.6} = 3.56''$$

EST. C.G. OF MAGNET CART - VERTICAL

CART COMPONENTS	WT.	OFFSET	WT * OFFSET
6" ø	254.5#	≈ 44½	11,325
2 * 36" VERT 8" ø	293.1#	≈ 31½ ~~≈ 44½~~	9232.6
25.25" VERT 8" ø	102.7#	≈ 31	3183.7
104" HORZ 8" ø	423.3#	≈ 18½	7831.0
2 * 32" HORZ 8" ø	260#	≈ 9½	2470
HILMANS	148#	≈ 3"	444
ARMS	63.5#	≈ 44½	2825.7
CYL	70#	≈ 32"	2240
2" * 4" ø	16#	≈ 50"	800
8" ø	100#	≈ 44½	4450
	1731.1		44,802.4

$$d_{VERT} = \frac{\Sigma(\text{WT} * \text{OFFSETS})}{\Sigma(\text{WT})} = \frac{44{,}802.4}{1731.1} = 25.88''$$

MAGNET VERTICAL

BEAM HT ≈ 32" ∴ D ≐ 32"

C.G. OF ASSEMBLY w/ MAGNET LIFTED:

VERTICAL:

$$D'_{VERT} = \frac{\Sigma(W * d)}{\Sigma W} = \frac{(1731 * 25.88) + (8200)(32)}{1731 + 8200}$$

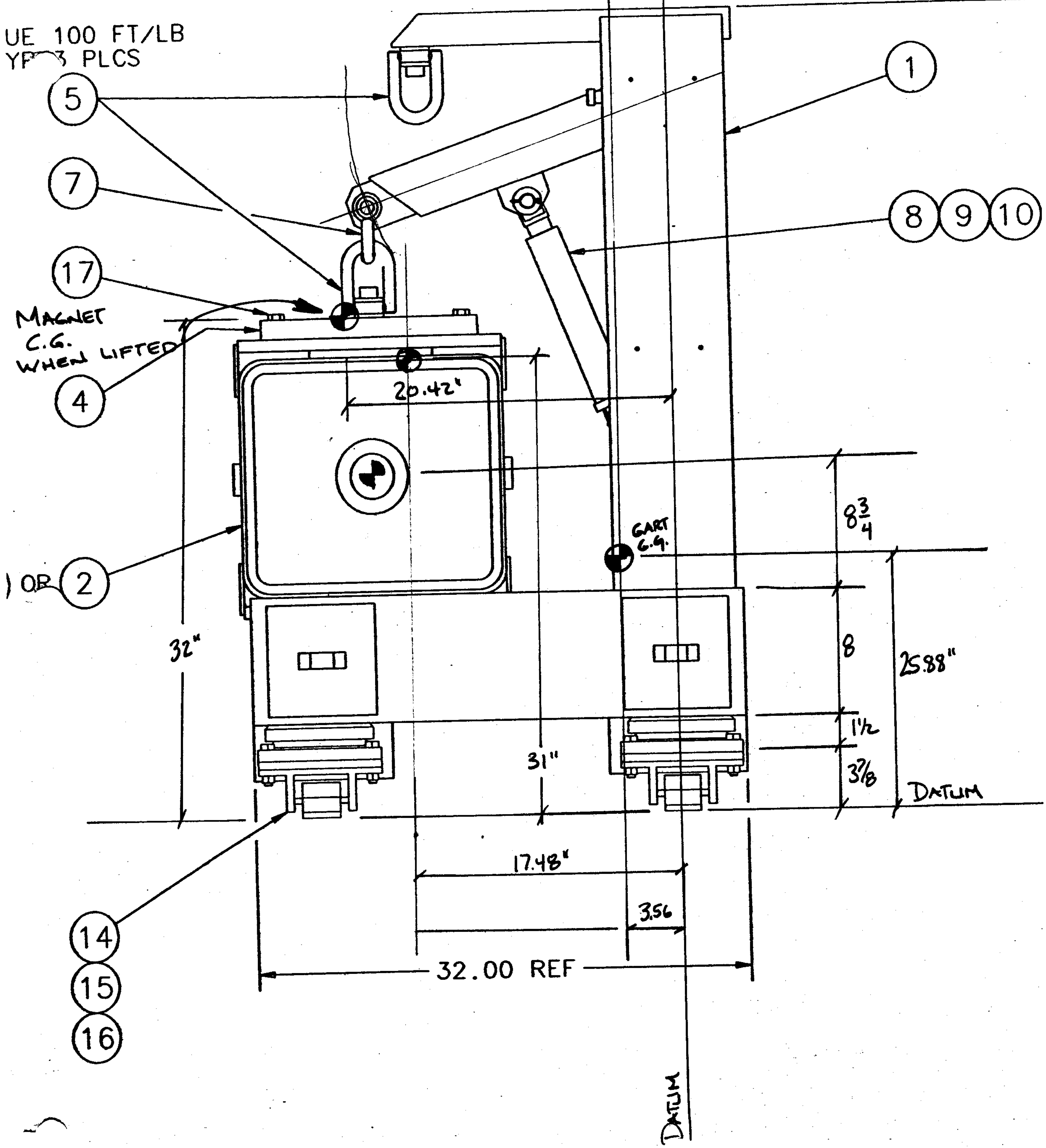
$$= 30.93''$$

HORZ:

$$D'_{HORZ} = \frac{(1731 * 3.56) + (8200 * 20.42)}{1731 + 8200}$$

$$= 17.48''$$

UE 100 FT/LB
YP 3 PLCS



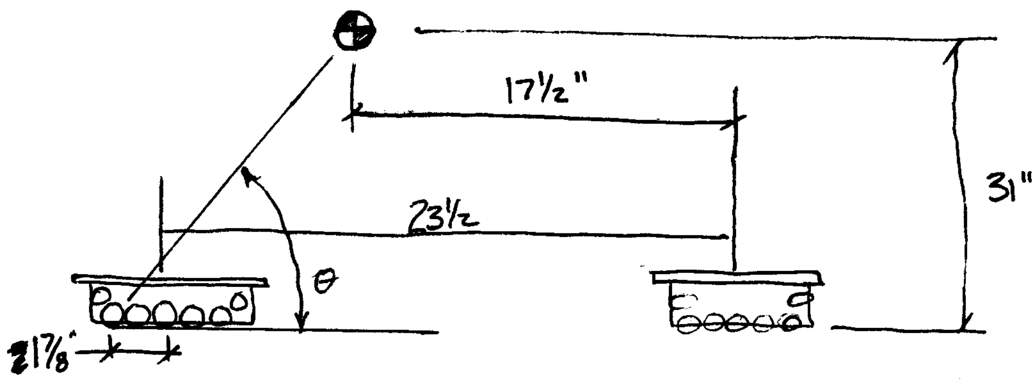
STABILITY –

CONSIDER STABILITY OF CART WHEN BEING MOVED LATERALLY (⊥ TO BEAM).

HILMAN ROLLERS WILL BE TURNED 90° TO ORIENTATION SHOWN ON DWGS.

HILMANS ARE 23.5" C-C

WITH HILMAN ROTATED 90°, EDGE OF 1 ROLLER IS AN ADDITIONAL $2 \times 15/16" = 1\,7/8"$ TO THE SIDE



RISE = 31", RUN = $23\tfrac{1}{2}" + 1\tfrac{7}{8}" - 17\tfrac{1}{2}" = 7.875"$

$\tan\theta = \frac{\text{RISE}}{\text{RUN}} = \frac{31"}{7.875} \Rightarrow \theta = 75.7°$

hypotunse length, $L = (31^2 + 7.875^2)^{1/2} = 32"$

DETERMINE HORIZONTAL VELOCITY REQUIRED TO GET CART TO TIP ABOUT FRONT ROLLER IF IT HITS A STOP:

K.E. = P.E. K.E. = $\frac{1}{2}mv^2$, P.E. = mgh $\Rightarrow$ $\frac{1}{2}\cancel{m}v^2 = \cancel{m}gh$

h = 32" - 31" = 1"

g = 32.2 FT/SEC

$v^2 = 2gh \Rightarrow v = \sqrt{2gh}$

$= \sqrt{2 \cdot 32.2\ FT/s^2 * 1/12\ FT}$

$= 2.3$ FT/SEC

CONCLUSION; 2.3 FT/SEC IS VERY VERY FAST FOR EQUIPMENT ON ROLLARS – A REASONABLE VELOCITY WOULD BE PERHAPS 1" PER SECOND – TIPPING SHOULD NOT BE A PROBLEM.

MATERIAL ALLOWABLE STRESSES.

MATERIALS INCLUDE

A36 CARBON STEEL F_y = 36 KSI MIN.
(ACTUALLY MOST NOW ALSO MEET ASTM A572 gr 50 WHICH HAS A 50 KSI YIELD, BUT WILL USE 36KSI YIELD HERE-IN)

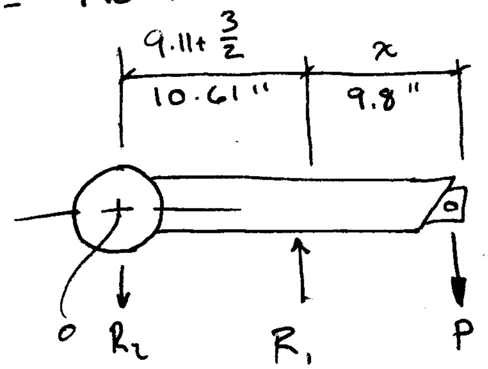
A500 BOX SECTION, F_y = 46 KSI

ALLOWABLE:		TENSION,	COMPRESSION	BENDING.
A36	36KSI	$0.6F_y$ 21.6 KSI	$0.6F_y$ 21.6 KSI	$0.6F_y$ 21.6KSI
1026	47KSI	28.2 KSI	28.2KSI	28.2KSI
A500	46KSI	27.6 KSI	27.6 KSI	27.6 KSI

UNLESS OTHERWISE CALCULATED HERE-IN FOR SLENDER SECTION, PIN CONNECTED MEMBERS, ETC.

THIS DEVICE IS NOT CONSIDERED A 'BELOW THE HOOK' LIFTING DEVICE

ARM - MC-427389 & MC-427393



$x = 21.61 - 1.19 - 10.61$

$x = 9.8''$

FOR A 3Q-120 w/ LIFTING FIXTURE, USE A DESIGN LOAD ON EACH ARM OF 5000 #.

$$\Sigma M_o = 0 = (10.61 R_1) - (10.61 + 9.8) P$$

$$R_1 = \frac{(10.61 + 9.8)\, 5000\#}{10.61} = 9623\ \#$$

$$\Sigma F_v = 0 = R_1 - R_2 - P \Rightarrow R_2 = -P + R_1 = -5000 + 9623$$

$$R_2 = 4623\ \#$$

$$M_{MAX} = \frac{Pab}{\ell} = \frac{R_1 a b}{\ell} = \frac{(9623\#)(10.61)(9.8)}{(10.61 + 9.8)} = 49{,}024 \text{ IN-LBS}$$

ARM IS M/F (2) 1" THK × 3½" TALL BARS

$$I = (2)\,\frac{1}{12} \cdot 1 \times (3\tfrac{1}{2})^3 = 7.14\ \text{in}^4, \quad y = 1.75 \text{ in}$$

$$\sigma_B = \frac{My}{I} = \frac{(49{,}024 \text{ in-lbs})(1.75 \text{ in})}{7.14 \text{ in}^4} = 12{,}005 \text{ psi}$$

$$12 \text{ ksi} < 0.6 F_y = 21.6 \text{ ksi} \quad \therefore \text{OK}$$

ARM - CHECK COMBINED STRESSES -

$\sigma_B = 12{,}005$ PSI

$A_{AXIAL} = (2)(3\tfrac{1}{2}")(1") = 7\ in^2$

AXIAL LOAD = $P_{CYLINDER} \cos 66.7°$ (SEE Pg 14)

$= 4143.8\#$

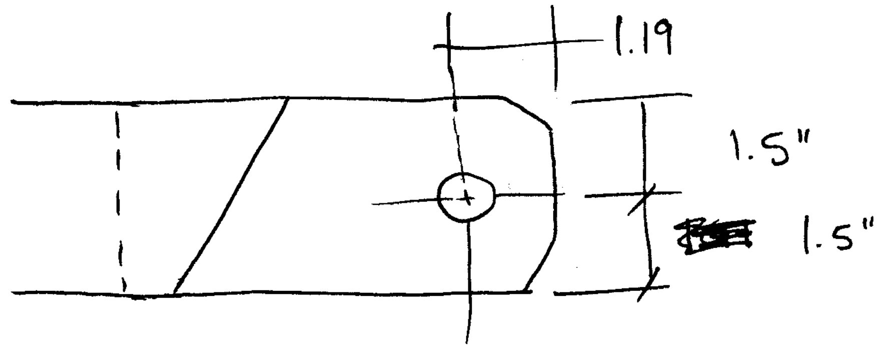
$\sigma_{AXIAL} = \dfrac{4143.8\#}{7\ in^2} = 591.9$ psi

THIS RESULTS IN TENSION IN ARM, ADDS TO TENSILE SIDE OF BENDING STRESS.

$\therefore\ \sigma_{TENSILE + BENDING} = 12{,}005$ psi $+ 591.9$ psi $= 12{,}597$ psi

$\sigma_{COMBINED} < 0.6\ F_y \ \therefore$ OK

ARM END — SEE MB- 427391



HOLE: TENSION: $AREA \approx (1\tfrac{1}{8}")(1.19 - \frac{.875}{2})(2)$

$= 1.69 \text{ in}^2$

$\sigma = \frac{P}{A} = \frac{5000\#}{1.69 \text{ in}} = 2953 \text{ psi} \therefore OK$

SHEAR: $AREA = (2)(1.5)(1.125) = 3.375 \text{ in}^2$

$\tau = \frac{P}{A} = \frac{5000\#}{3.375 \text{ in}^2} = 1481 \text{ psi} \therefore OK$

WELD TO ARM — SHEAR = 5000#

WELD CAPACITY, $= 0.707w \times l \times 0.30 \times 70 \text{ ksi}$

ASSUME $1/4" = w$, $l = 3\tfrac{1}{2}" \times 2$

WELD SHEAR CAPACITY $= .707 \times 1/4" \times 7" \times .3 \times 70 \text{ksi}$

$= 25{,}982\# \gg 5000\# \therefore OK$

(SEE MC-427393)

ARM END - SEE MC-427393

WELD TO ARM - BENDING MOMENT

$$\text{MOMENT} = Pa = (5000\#)(5\text{ in}) = 25{,}000 \text{ IN-LBS}$$

ASSUME 1/4" FILLET WELDS @ TOP & BOTTOM, EACH

ACTING IN SHEAR TO RESIST THE COUPLE.

DISTANCE BETWEEN WELDS (VERTICAL) = 3"

$$\frac{M}{d} = \frac{25{,}000\ \#\text{-in}}{3\text{ in}} = 8300\ \#\ \text{SHEAR}$$

$$8300^{\#} = .707\, w\, l \times 0.3 \times 70{,}000\ psi$$

$$w = 1/4''$$

$$\therefore l_{MIN} = 2.25''$$

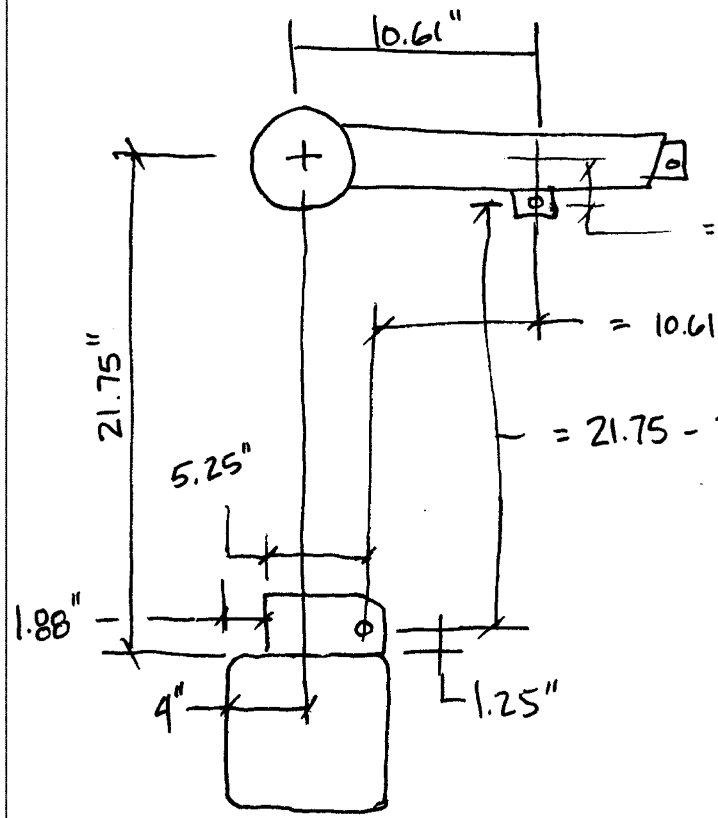
ACTUAL WELD LENGTH = (2 SIDES)(~3 IN/SIDE) = 6"

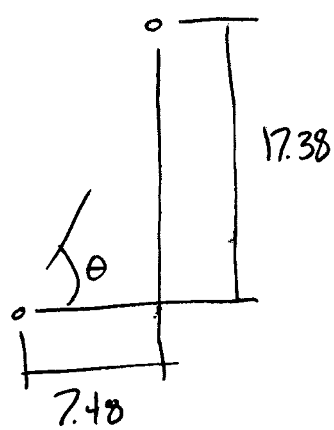
$$6'' > 2.25'' \quad \therefore \text{OK}$$

HYDRAULIC CYLINDER LOADS –

FROM THE ARM CALCULATIONS, THE VERTICAL COMPONENT OF THE CYLINDER FORCE IS R_1 AND IS EQUAL TO 9623 #.

CYLINDER IS NOT NORMAL TO THE ARM –





∴ HORIZONTAL COMPONENT

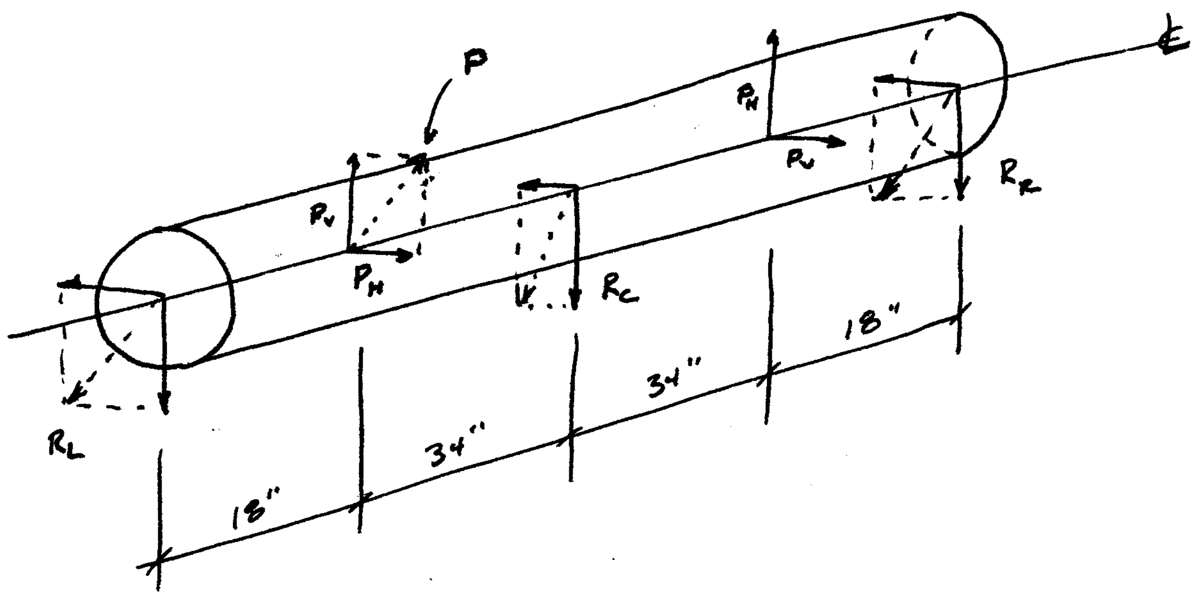
= 10,476# cos 66 = 4143.8 #

$\theta = 66.7°$

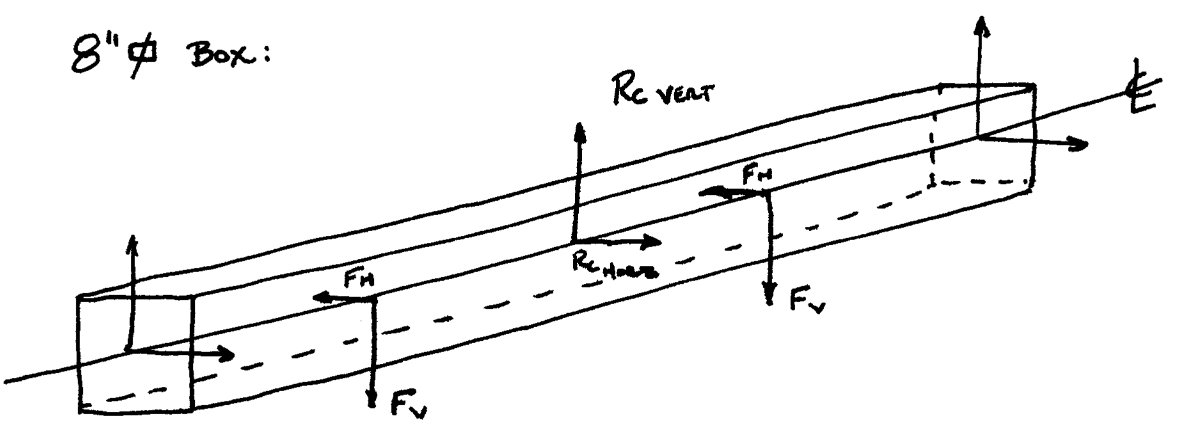
∴ Cylinder LOAD = $\frac{9623\#}{\sin 66.7}$ = 10,476 #

HORIZONTAL MEMBERS - FBD'S

6" ∅ TUBE:



8" ∅ BOX:



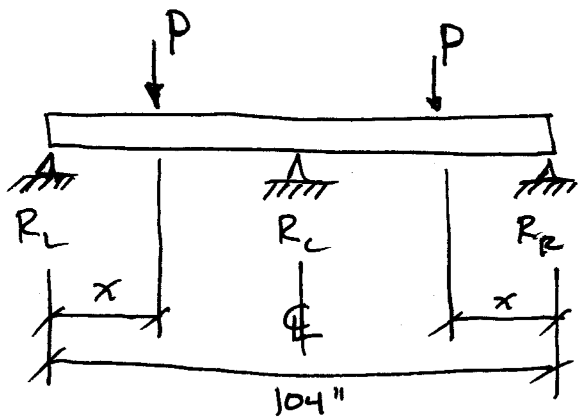
ARM PULLS 6"Ø MEMBER UP AND OUT

6"Ø MEMBER PULLED DOWN BY VERTICAL
8"Ø

8"Ø PULLED UP AT ENDS BY 8"Ø VERTICALS
AND PUSHED DOWN AND BACK BY HYD. CYL.
AND PULLED UP AT CENTER BY 8"Ø BOX

6" Ø ROUND HORIZONTAL TUBE - MC-427386

CONSIDER BENDING -



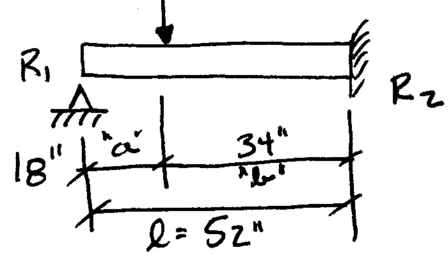
$x = 13.58 + \frac{8.81}{2} = 17.98" \rightarrow$ USE 18"

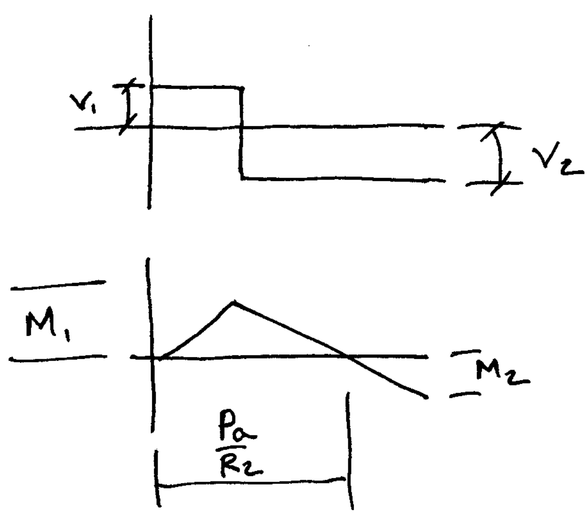
LOAD, $P = R_2$ FROM ARM CALCULATIONS pg 11.

$= 4626\# + 4143\#_{HORIZ}$ (pg 14)

$P = (4626^2 + 4143^2)^{1/2} = 6210\#$

TREAT BEAM AS





$M_1 = R_1 a \Rightarrow$

$$R_1 = V_1 = \frac{Pb^2}{2l^3}(a+2l) = \frac{6210\# \cdot 34^2}{2 \cdot 52^3}(18 + 2 \cdot 52) = 3114\ \#$$

$$R_2 = V_2 = \frac{Pa}{2l^3}(3l^2 - a^2) = \frac{6210 \cdot 18}{2 \cdot 52^3}(3 \cdot 52^2 - 18^2) = 3095\ \#$$

$$M_1 = (3114\ \#)(18'') = 56{,}052 \text{ IN-LBS}$$

$$M_2 = \frac{Pab}{2l^2}(a+l) = \frac{6210 \cdot 18 \cdot 34}{2 \cdot 52^2}(18 + 52) = 49{,}193 \text{ IN-LBS}$$

$$\delta_{\text{@POINT OF LOAD}} = \frac{Pa^2 b^3}{12EI\, l^3}(3l + a)$$

$$= \frac{6210 \cdot 18^2 \cdot 34^3 \cdot (3 \cdot 52 + 18)}{12 \times 29 \times 10^6 \times \frac{\pi}{64}(6^4 - 5^4) \times 52^3}$$

$$= 0.00854 \text{ IN}$$

I.D. OF 8" O.D. × 6" I.D. TUBE IS $\varnothing 6.030^{+0.030}_{-0.000}$.

∴ BINDING DUE TO THIS 8.5 MIL DEFLECTION SEEMS UN-LIKELY.

$$M_{MAX} = 56{,}052 \text{ IN-LBS}$$

$$\sigma_B = \frac{My}{I} = \frac{(56{,}052 \text{ IN-LBS})(4 \text{ IN})}{\frac{\pi}{64}(6^4 - 5^4)} = 6807 \text{ psi}$$

$$\sigma_{ALL} = 0.6 F_y = 0.6(46 \text{ ksi}) = 27.6 \text{ ksi}$$

$$\sigma_B < \sigma_{ALLOW} \quad \therefore \text{ OK}$$

$M_1 = R_1 a = 2319\# \cdot 18 = 41{,}759$ IN-LBS

$M_2 = \dfrac{Pab}{2l^2}(a + l) =$ ~~489,682 IN-LBS~~ 36,645 IN-LBS

$R_1 = V_1 = \dfrac{Pb^2}{2l^3}(a + 2l) = \dfrac{4626 \cdot 34^2}{2 \cdot 52^3}(18 + 2 \cdot 52) = 2319\#$

$R_2 = V_2 = \dfrac{Pa}{2l^3}(3l^2 - a^2) = \dfrac{4628 \cdot 18}{2 \cdot 52^3}(3 \cdot 52^2 - 18^2) = 2309\#$

$\delta_{\text{@ POINT OF LOAD}} = \dfrac{Pa^2 b^3}{12EI\, l^3}(3l + a)$

$= \dfrac{4626 \cdot 18^2 \cdot 34^3 \cdot (3 \cdot 52 + 18)}{12 \cdot 29 \cdot 10^6 \cdot \frac{\pi}{64}(6^4 - 5^4) \cdot 52^3}$

$= 0.006''$

I.D. OF 8" O.D. × 6" I.D. TUBE IS $\varnothing 6.030^{+.030}_{-.000}$

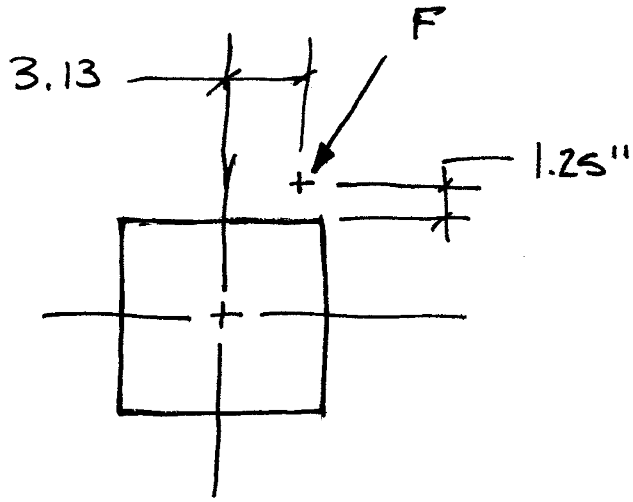
SO BINDING DUE TO THE 6 MIL DEFLECTION SEEMS UN-LIKELY.

$M_{MAX} = 41{,}759$ IN-LBS

$\sigma = \dfrac{My}{I} = \dfrac{(41{,}759)(4)}{\frac{\pi}{64}(6^4 - 5^4)} = 5071$ psi < ALLOWABLE

∴ OK

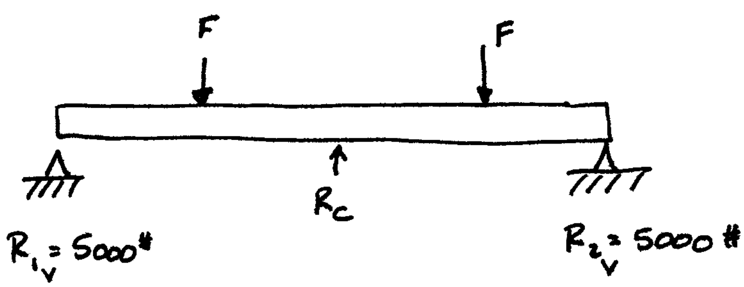
8" ☐ HORIZONTAL BOX BEAM



$F = 10{,}476\ \#$ (LOAD EXERTED BY HYD. CYL)

$F_H = 4143.8\ \#$

$F_V = 9623\ \#$ (COMPONENT NEEDED ON ARM)



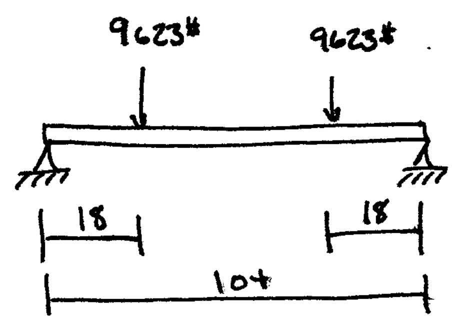
$\Sigma F_H = 0 = (2)(4143) - R_{c_{HORZ}} \therefore R_{c_{HORZ}} = 8286\#$

$\Sigma F_V = 0 = 9623 + 9623 - 5000 - 5000 + (-R_{c_{VERT}})$

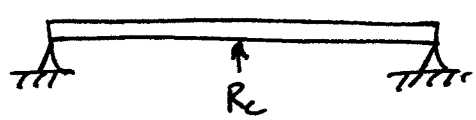
$R_{c_{VERT}} = 9246\ \#$

8" ⌀ LOWE HORZ. BOX BEAM. (ME-427383)

SINCE BOX IS SQUARE CONSIDER VERTICAL LOAD & BENDING ABOUT ~~the~~ HORZ N.AXIS.



① $M'_{MAX} = Pa = (9623\#)(18_{in}) = 173,214$ IN-LBS



② $M^{2}_{MAX} = -\frac{Pl}{4} = \frac{-9246(104)}{4} = -240,396$ IN-LBS

USING SUPERPOSITION:

$\Sigma M = M'_{MAX} + M^{2}_{MAX} = 173,214 - 240,396$ IN-LBS

$= -67,182$ IN-LBS

$I = 131_{in}^{4}$ $y = 4"$

→ $\sigma = \frac{MY}{I} = \frac{(67,182 \text{ IN-LBS})(4)}{131} = 2051$ psi

∴ OK

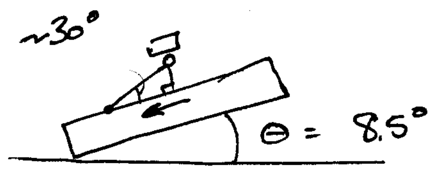
STATIONARY CENTER 2" × 4" BOX (SEE MC-427387)
ARM ANALYSIS – CONSIDER LOADING DUE TO SLOPE

ASSUME DESIGN CAPACITY OF 10,000 #
15% SLOPE

$\theta = \tan^{-1}(.15) = 8.5°$

$\sin 8.5° = 0.148$

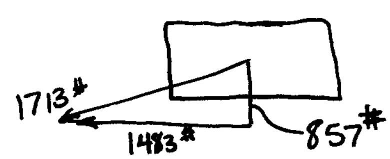
SIDE LOAD = $(10{,}000\#)(\sin 8.5°) = 1483\#$



TENSION IN COME ALONG = T

$T = \dfrac{\text{SIDE LOAD}}{\cos 30°} = \dfrac{1483}{\cos 30} = 1713\#$

FORCES ON CENTER ARM:



CENTER ARM IS A 2" × 4" × 1/4" BOX

$I_{xx} = 4.69\ in^4 \rightarrow l = 20.5"$, $F = 1483\#$, $M = 30{,}401$ IN-LBS
$I_{yy} = 1.54\ in^4 \rightarrow l = 20.5"$, $F = 857\#$, $M = 17{,}571$ IN-LBS

$\sigma_{xx} = \dfrac{My}{I_{xx}} = \dfrac{(30{,}401)2}{4.69} = 12{,}964$ Ksi

$\sigma_{yy} = \dfrac{My}{I_{yy}} = \dfrac{(17571)(1)}{1.54 \ \text{~~857\#~~}} = 11.4$ Ksi

} BOTH LESS THAN 60% OF F_y ∴ OK

COMBINED STRESSES ON STATIONARY 2" x 4" BOX (MC-427387)

σ_{xx} = 12.96 ksi

σ_{yy} = 11.4 ksi

~~$\sigma_{combined} = \sqrt{\sigma_{xx}^2 + \sigma_{yy}^2} = (12.96^2 + 11.4^2)^{1/2} = 17.26$ ksi~~

N.G. ADD DIRECTLY, NOT IN QUADRATURE

$\sigma_{allowable} = 0.60 F_y = (0.60)(46 \text{ ksi}) = 27.6$ ksi

$\sigma_{combined} < \sigma_{allowable}$ ∴ OK

ADD TENSILE COMPONENTS, NOT IN QUADRATURE

$\sigma_{xx\ tensile}$ = 12.96

$\sigma_{yy\ tensile}$ = 11.4 ksi

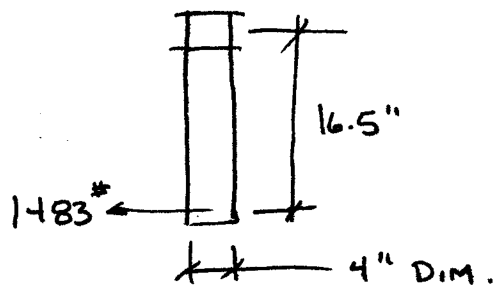
$\sigma_{sum\ tensile}$ = 12.96 ksi + 11.4 ksi = 22.36 ksi

$\sigma_{sum\ tensile}$ = 22.36 ksi < 27.6 ksi = $\sigma_{allowable}$

∴ OK

STATIONARY CENTER 2 x 4" BOX - BENDING.
(SEE MC-427387)

IN HORZ PLANE:
(STRONG DIR)



$M = (1483)(16.5") = 24,469$ in-LBS

$\sigma = \frac{My}{I} = \frac{(24,469 \text{ in-LBS})(2 \text{ in})}{~~1.54~~\ 4.69 \text{ in}^4}$ = ~~31,778~~ psi

= 10,434 psi ∴ OK

IN VERT PLANE
(WEAK DIR)

$M = (857\#)(16.5") = 14,140$ in-LBS

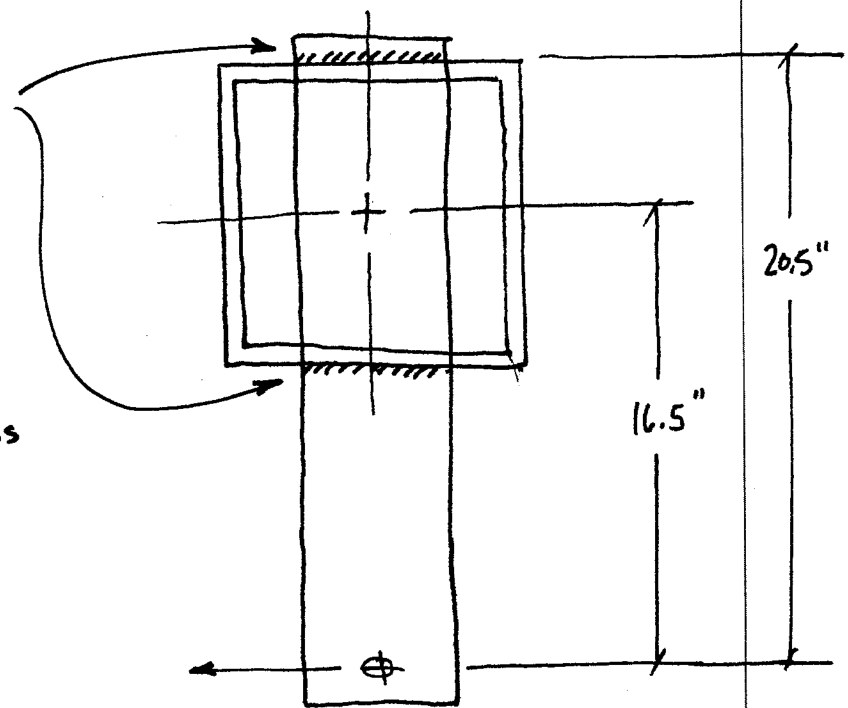
$\sigma_{\text{BENDING HORIZONTAL}} = \frac{My}{I} = \frac{(14,140 \text{ in-LBS})(1")}{1.54 \text{ in}^4} = 9182$ psi ∴ OK

$\delta_H = \frac{Pl^3}{3EI} = \frac{(1483)(16.5^3 \text{ in}^3)}{3 \cdot 29 \cdot 10^6 \cdot 4.69 \text{ in}^4} = 0.016"$ ∴ OK

$\delta_V = \frac{Pl}{3EI} = \frac{(857)(16.5 \text{ in})^3}{3 \cdot 29 \cdot 10^6 \text{ psi} \cdot 1.54 \text{ in}^4} = 0.028"$ ∴ OK

$\delta_{TOTAL} = (\delta_H^2 + \delta_V^2)^{1/2} = 0.033$ in $< 0.050"$ ∴ OK

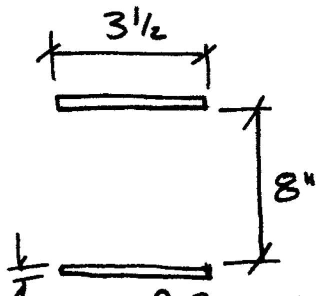
CHECK WELD BETWEEN 2"x 4" BOX & 8"Ø VERT
(SEE ME-427382)



M_{HORZ} = 24,469 IN-LBS

M_{VERT} = 14,140 IN-LBS

MOMENT OF INERTIA OF SECTION:



$I = \frac{1}{12} \cdot 3\frac{1}{2} \cdot (8.5^3 - 8^3)$

$= 29.78 \text{ in}^4$

$y = 4.125$

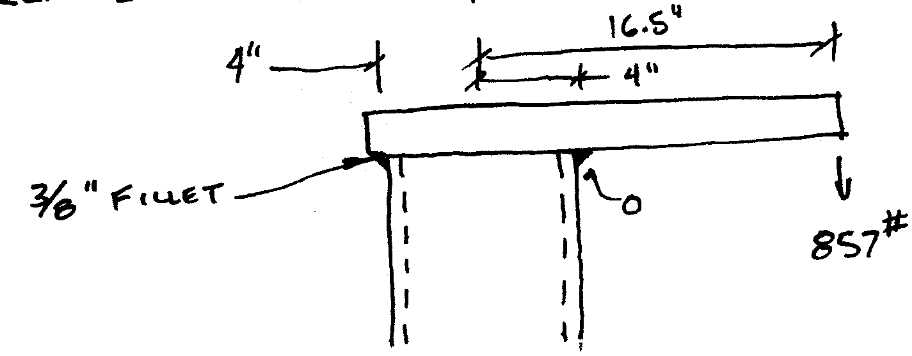
$\sigma_H = \frac{M_H\, y}{I} = \frac{(24{,}469 \text{ in-lbs})(4.125 \text{ in})}{29.78 \text{ in}^4} = 3388 \text{ psi}$

$\sigma_V = \frac{(14{,}140 \text{ in-lbs})(4.125)}{29.78} = 1958 \text{ psi}$

$\sigma_{MAX} = (\sigma_H^2 + \sigma_V^2)^{1/2} = 3913 \text{ psi} \ll 0.3 \times 70 \text{ ksi}$

∴ OK

WELDS BETWEEN 2" × 4" BOX & 8" ⌀ VERTICAL MEMBER



$\Sigma M_O = 0 \quad (-857)(12.5") + R_L(8") \Rightarrow R_L = 1339\#$

WELD AREA : $l = 3\frac{1}{2}"$

$w = 0.375"$

$A_{WELD} = 3\frac{1}{2} \times 0.375 \times .707 = .928 \text{ in}^2$

TENSILE STRESS ON WELD (3/8" FILLET) $= \dfrac{1339\#}{.928 \text{ in}^2} = 1443 \text{ psi}$

ASSUME E70XX (70 KSI ULT WELD STRENGTH) ∴ $\sigma_{ALL} = (0.3)(70{,}000) \text{ psi}$

$= 21{,}000 \text{ psi}$

$= 21 \text{ ksi}$

$\sigma_{TENSILE} < \sigma_{ALLOWABLE}$

$1443 \text{ psi} < 21{,}000 \text{ psi}$ ∴ OK

CHECK COMBINED WELD STRESS —

$\sigma_{MAX\,BENDING} = 3913 \text{ psi}$

$\sigma_{TENSILE} = 1443 \text{ psi}$

$\sigma_{COMBINED} = (\sigma_B^2 + \sigma_T^2)^{1/2}$

$= ((3913^2 \text{ psi}) + 1443^2 \text{ psi})^{1/2}$

$= 4170 \text{ psi}$

$4170 \text{ psi} < 21{,}000 \text{ psi}$ ∴ OK

Consider Torsion on Center 8" ⌀ due to 2 × 4" Box

Tension in cable is 1713 # cos 30 = 1483 #

Lever arm is (22 - 1.5 - 4) = 16.5"

$M = P_a = (1483\#)(16.5") = 24{,}469$ in-lbs

Torsional Stress = $\tau = \frac{Tr}{J} = \frac{24{,}469 \text{ in-lbs } (3.03) \text{in}}{217 \text{ in}^4}$

$= 341$ psi

Check Bending on Center 8" ⌀ due to 2" × 4" Box

Vertical = 1713 sin 30 = 857 #

$a = 16.5"$

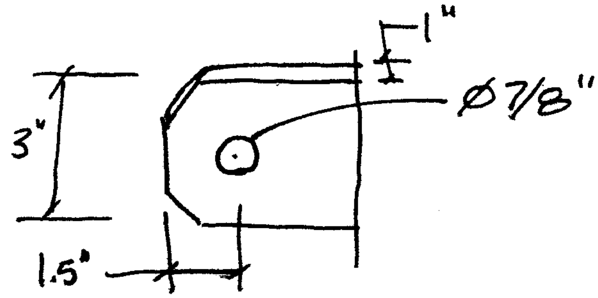
$M = Pa = (857\#)(16.5 \text{ in}) = 14{,}140$ in-lbs

$\sigma = \frac{My}{I} = \frac{(14{,}140)(4)}{131} = 431$ psi

Conclusion - Loads on steel 8" ⌀ from the 2" × 4" Box result in very low stresses. Ignore δ calculations.

TOW LUGS - SEE MB-406916

ASSUME 1 LUG SEES 10,000 # LOAD
(MAGNET wt + CART EST. wt)



TENSILE AREA

$A = (1'')(3 - 7/8) = 2.125 \, in^2$

$P = 10{,}000 \, \#$

$\sigma_T = \frac{P}{A} = \frac{10{,}000}{2.125} = 4705 \, psi \; \therefore OK$

SHEAR:

$A = (2)(1.5 \, in)(1 \, in) = 3 \, in^2$

$P = 10{,}000 \, psi$

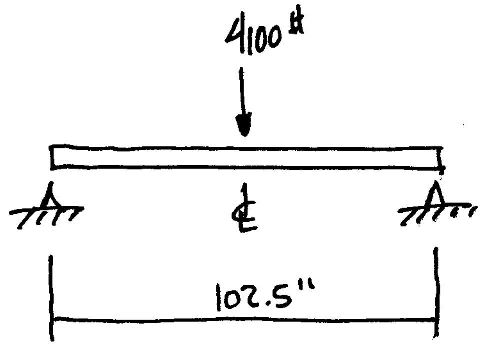
$\tau = \frac{10{,}000}{3} = 3{,}333 \, psi \; \therefore OK$

8.950

3Q60 SUPPORT SPREADER - SEE MC-427338

(2) 2" × 6" × 3/16" A500 STRUCTURAL STEEL

LOAD = 3350# PER THE TEV II FACILITIES HANDBOOK (WT FOR A 3Q120 = 8200#) ∴ USE 4100# AS THE DESIGN LOAD



$M_{MAX} = \frac{PL}{4} = \frac{(4100\#)(102.5")}{4} = 105{,}062.5$ in-LBS

$\sigma_B = \frac{My}{I}$ $I_{6" \times 2" \times 3/16} = 11.1 \text{ in}^4$, $y = 3"$

2 MEMBERS ARE USED ∴ $I_{TOTAL} = 22.2 \text{ in}^4$

$\sigma_B = \frac{(105{,}062 \text{ in-LBS})(3 \text{ in})}{22.2 \text{ in}^4} = 14{,}197$ psi

$F_y = 46$ ksi $F_{ALLOW} = 0.6 F_y = 27{,}600$ psi

$\sigma_B < F_{ALLOW}$ ∴ OK

Check Beam Deflection –

$$\delta_{MAX} = \frac{P\ell^3}{48EI} = \frac{(4100\#)(102.5\ in)^3}{48 * 29*10^6 psi * 22.4\ in^4}$$

$$= 0.142''$$

This is okay as it will not cause interferences.

3Q60 Support – MC-427338

Check Welds –

$P = A * F_v = 0.707\ w * l * F_v$

$F_v = 0.3 * 70{,}000$

$P = 0.707 * 0.25 * (2 * 4'') * 0.3 * 70{,}000$ psi

$= 29{,}694$ #

So, the shear on the welds @ each end has a capacity of 29,694#.

Shear load on each end is $\frac{4100\ \#}{4} = 1000\ \#$

∴ Welds are sufficient.

Fermi National Accelerator Laboratory
PPD / Mechanical Support / Engineering Analysis

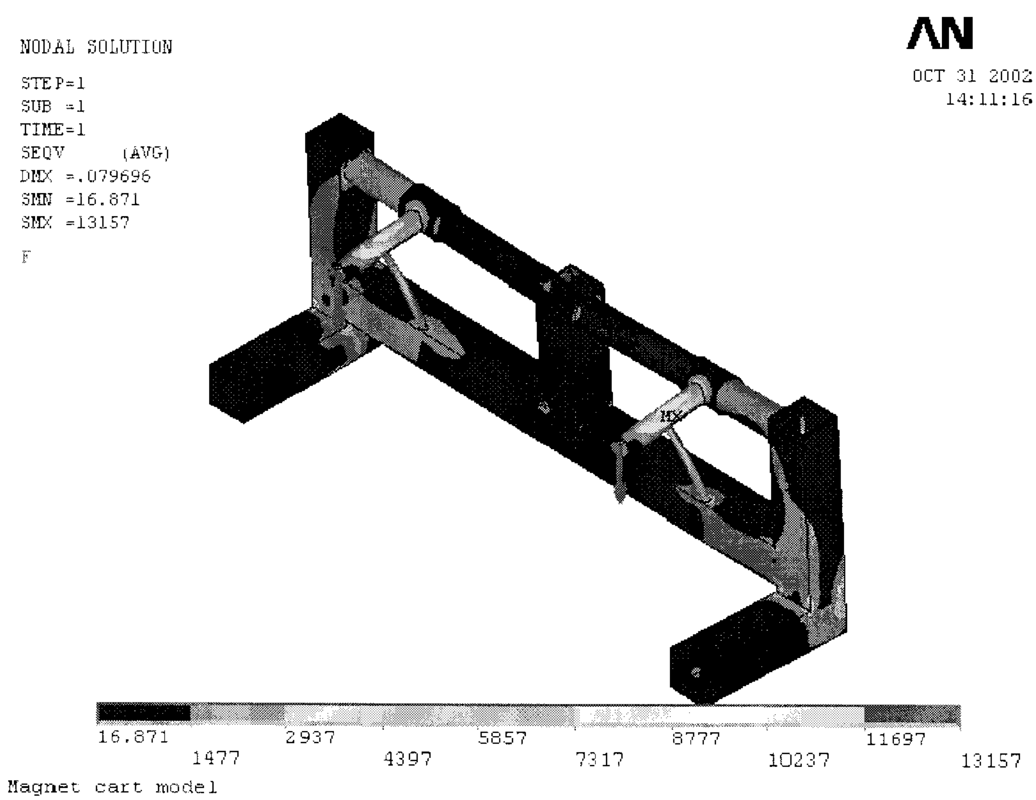
Analysis of the Numi Magnet Cart

Zhijing Tang
October 31, 2002

A steel cart is designed to facilitate the installation of the magnet. This analysis is to make sure that the design is structurally sound.

A finite element model is built using solid element, assuming all the material used in the cart is steel. The weight of the magnet is 8050 lb, and we apply 8400 lb as the load. The weight of the cart is about 1484 lb. The cart is tilted 9 degree.

The result shows maximum stress of 13157 psi and maximum displacement of 0.08 inch.



For the convenience of manufacturing, the pivot design is changed from tube to blocks. The blocks are made of 1 inch thick steel plate, and the height of the blocks is 3.5 inch, as shown in the Figure. The maximum stress in the new pivot is 13297 psi. So this design is also OK.