# BELOW-THE-HOOK LIFTING DEVICE
## Engineering Note Cover Page

Lifting Device Numbers:

FNAL Site No.:_______ (if applicable) Div. Specific No.: 105 (if applicable) Asset No. _______ (if applicable)

ASME B30.20 Group: (check one)
- ✓ Group I Structural and Mechanical Lifting Devices
- ˇ Group II Vacuum Lifting Devices
- ˇ Group III Magnets, Close Proximity Operated
- ˇ Group IV Magnets, Remote Operated

Device Name or Description: CTC / COT LIFTING FIXTURE

Device was: (check all applicable)
- ˇ Purchased from a Commercial Lifting Device Manufacturer
  mfg. name: ______
- ✓ Designed and Built at Fermilab
- ˇ Designed by Fermilab and Built by a Vendor
  Assy drawing number: ______
- ˇ Provided by a User or Other Laboratory
- ˇ Other. Describe:______

Engineering Note Prepared by: RICH STANEK Date : 5/27/99

Engineering Note Reviewed by: James R. Kilmer Date: 5/27/99

Lifting Device Data:

Capacity: 5 TON

Fixture Weight: ______

Service: ✓ normal ˇ heavy ˇ severe (refer to B30.20 for definitions)

Duty Cycle: ______ 8, 16 or 24 hour rating (applicable to groups III, and IV)

Inspections Frequency: ______

Rated Load Test by FNAL (if applicable): Date : 5/27/99 Load: 12,500 #

ˇ Check if Load Test was by Vendor and attach the certificate.

Satisfactory Load Test Witnessed by: Rich Stanek, Dick Worland, John Voirin

Signature (of Load Test Witness): Richard P Stanek,

Notes or Special Information:

# CTC/COT Lifting Fixture #105

R. Stanek 5/26/99

## History of the CTC Lifting Fixture

This lifting fixture was used to lift the Central Tracking Chamber (CTC), back in 1986. However, there is no documentation, currently available from that period of operation, which sets the rated load of the fixture. It was used in conjunction with another lifting device (H Frame) which attached directly to the chamber. The fixture was then stored at the Railhead for the last 12 years along with the siege cart and extraction rails. Earlier this year, the lifting fixture was cleaned, visually inspected and repainted. The visual inspection of the members and welds revealed no apparent problems. The fixture has been recently load tested to 125% of its rated capacity (5 Ton) in accordance with the Below the Hook Lifting Devices Standard. This rating is well beyond the needs of the loads incurred during the lifting of the old CTC or the new Central Outer Tracker (COT). After the CTC is extracted from the tracking volume, this fixture will be reused to install the COT sometime in October of this year.

## Description

The CTC lifting fixture is made of carbon steel members welded together to provide the required strength and moment of inertia. The main beam members are four C12X25 channels stitch welded together, both top and bottom, for reinforcement to form two rectangular box beams separated by six inches. The box beams (double C channels) are tied together at the ends by a welded steel plate and at the center by the center lifting pin, thus helping to prevent web buckling. Lifting lugs (1.25" diameter hole drilled through a 3"x4.5"x1.5" block of steel) are provided at 143" spacing and are attached to the beams using a 1" thick plate (12"x17"). The center pick point is a slightly tapered pin with a minimum throat diameter of two inches. The ends of the pin are turned down (to 1.75" diameter), inserted through the inner C channel web and welded for additional strength. The welds are all continuous 1/4" fillet welds except for the skip welding done on the flanges to tie the C channels together.

## Note

This lifting fixture is quite capable of being rated for a higher load. The stresses and deflections for a 5 Ton rating are small and well within standard practices. However, at this time and for this project, a 5 Ton rating is more than sufficient.

LOAD TEST -

A LOAD TEST WAS PERFORMED ON WEDNESDAY, MAY 26, 1999 ACROSS FROM MAB BUILDING. IT WAS WITNESSED BY RICH STANEK, DICK WORLAND, JOHN VOIRIN AND WAYNE SHADDIX. THE TEST WAS SUCCESSFUL.

Richard P. Stanek
5/26/99

LOAD = 1 H BLOCK (12,150#)
+ 7 LEAD/CONCRETE BLOCKS (50# EACH)

TOTAL TEST WEIGHT = 12,500# (125% of 5 TON RATING

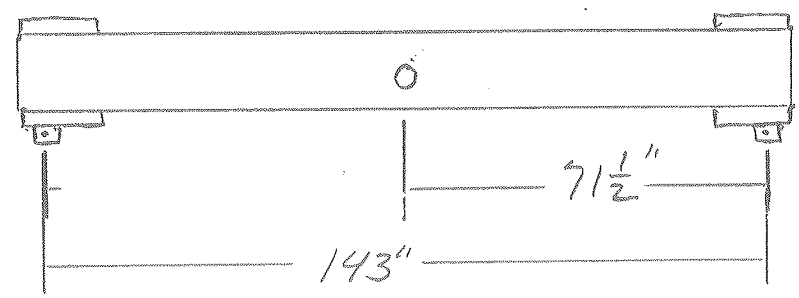
THE TEST LOADED THE LIFTING FIXTURE IN THE EXACT WAY IT WOULD BE LOADED DURING OPERATION.

COMPONENTS OF THE LIFTING FIXTURE - ALL CARBON STEEL MATERIAL

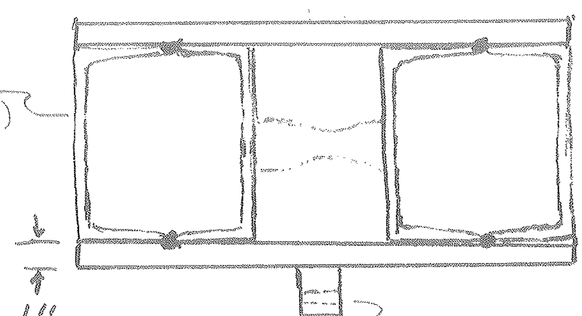
- 4 C CHANNELS (C12 x 25) => MAIN BEAM MEMBERS
- 1 TAPERED CENTER PIN => CRANE HOOK-UP
- 2 LIFTING LUGS (SPACED AT 143") => ATTACH CLEVIS & SLING.
- 4 ATTACHMENT PLATES (12" x 17" x 1") => ONE ON EACH END.
- 2 SPACER PLATES (~ 1/4" THICK) => TIES BOX BEAMS TOGETHER.

SKETCH

SPAN




X SECTION:




CONCLUSION:

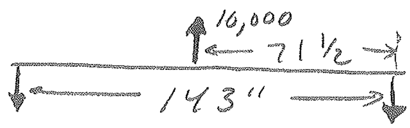
STRESSES & DEFLECTIONS ARE LOW AND HAVE A SAFETY FACTOR OF MUCH MORE THAN 3 WHEN COMPARED TO STANDARD CARBON STEEL YIELD STRENGTH. ($\sigma_y \sim 36$ ksi)

MAIN BEAM MEMBERS

4 C Channels C12 x 25 ⇒ WELDED INTO TWO BOX BEAMS

PROPERTIES OF EACH CHANNEL

$A = 7.35\ in^2$ $\quad I = 144\ in^4$ $\quad S = 24.1\ in^3$




THE COMBINED MOMENT OF INERTIA FOR ALL 4 C CHANNELS IS EQUAL TO $4 \times I_{EACH} = 4 \times 144 = 576\ in^4$

$$M_{MAX} = \frac{PL}{4} = \frac{10{,}000(143)}{4} = 357{,}500\ in\#$$

$$\sigma = \frac{Mc}{I} = \frac{357{,}500(6)}{576} = 3{,}724\ psi$$

$$MAX\ \Delta = \frac{PL^3}{48EI} = \frac{10{,}000\,(143)^3}{48\,(29 \times 10^6)(576)} = .036''$$

WELD STRENGTH

C CHANELS ARE CONNECTED AT THE WEB BY 22 (11 PER SIDE) 3" LONG × 1/4" WELDS

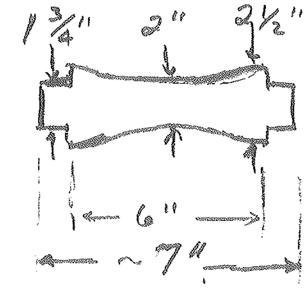
LENGTH OF WELD = 66"

LOAD (WORST CASE) = 10,000 #

$$STRESS\ IN\ WELD = \frac{10{,}000\#}{1/4 \times 66} = 606\ psi$$

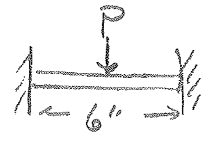
THIS IS VERY CONSERVATIVE SINCE IT NEGLECTS THE EFFECTS OF ATTACHMENT PLATES WELDED TO THE ENDS OF THE BEAMS.

CENTER TAPERED PIN:
(USED TO CONNECT TO CRANE)




SOLID CARBON STEEL PIN

MINIMUM DIAMETER = 1 3/4"




P = 10,000 #

X SECTIONAL AREA = 2.4 sq in.

REACTION FORCE = 10,000# / 2 = 5000# at each end

SHEAR STRESS = $\frac{5000}{2.4}$ = 2083.3 psi

$M_{MAX} = \frac{PL}{8} = \frac{10000(6)}{8} = 7500$ in-# at center & ends

NOTE: ENDS ARE CAPTURED INSIDE WEB ⇒ NOT CAPABLE OF ROTATING

STRESS @ ENDS = $\frac{M}{S} = \frac{7500}{.526}$ = 14,254 psi (for the smallest end diameter)

$S = \frac{\pi d^3}{32} = \frac{\pi(1.75)^3}{32} = .526 \text{ in}^3$

At the throat of the pin, $\phi$ = 2"
BENDING STRESS = 9,549 psi
(FOR 2" $\phi$)

$\Delta_{MAX} = \frac{PL^3}{192 EI}$ use 2" diameter for pin., $I = .785 \text{ in}^4$

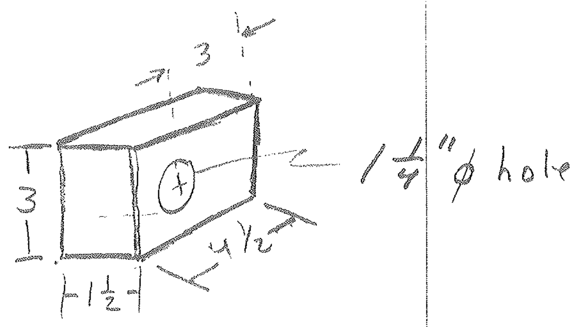
$= \frac{10,000(6)^3}{192(29\times10^6)(.785)} = .0005$ in.

BEARING STRESS = $\frac{5000}{\frac{1}{2} \text{ of circumference}} = \frac{5000}{\frac{1}{2}(\pi \times 1.75)}$ = 1819 psi

CENTER PIN IS FULLY WELDED TO INNER C CHANNEL WEB FOR STABILITY REASONS ONLY, NOT NEEDED FOR STRENGTH.

LIFTING LUGS

- USE STANDARD INDUSTRIAL SHACKLES OF APPRORIATE LOAD RATING.




LOAD / LUG = 5000#

MINIMUM X SECTIONAL AREA = $(4.5 - 1.25) \times 1.5 = 4.875$ sq in

$$\text{TENSILE STRESS} = \frac{5000\#}{4.875 \text{ sq in}} = 1{,}025.6 \text{ psi}$$

$$\text{"TEAR-OUT" STRESS} = \frac{5000}{A_{thinnest}} = \frac{5000\#}{1.3125 \text{ sq in}} = 3{,}809.5 \text{ psi.}$$

where $A_{Thinnest} = \frac{(3 - 1.25)}{2} \times 1.5 = 1.3125$ sq in.

WELD STRENGTH:

LIFTING LUG ATTACHED BY 12" of CONTINUOUS $\frac{1}{4}$" FILLET

THROAT LENGTH = $.25(\sin 45°) = .177$"

"AREA" OF THE WELD = $(.177)(12) = 2.12$ sq in.

LOAD = 5000#

$$\text{STRESS} = \frac{5000\#}{2.12 \text{ sq in}} = 2{,}357 \text{ psi}$$

ATTACHMENT PLATES -

4 PLATES - 12" x 17" x 1" THICK

ONE AT EACH END TOP & BOTTOM

THE STRESSES & DEFLECTIONS IN THE 1" THICK PLATE ARE QUITE SMALL. AS AN APPROXIMATION USE Roark & Young Table 26 Case 8b.

RECTANGULAR PLATE, ALL EDGES FIXED
- UNIFORM LOAD OVER SMALL CONCENTRIC CIRCLE.
(Approximated By LENGTH OF WELD OF LIFTING LUG TO 1" PLATE ~ 12" of 1/4" FILLET)

LOAD = 5000#

LOAD/INCH = $\frac{5000}{12} = 416.7$ #/in $= W$

$t = 1''$, $a = 17''$, $b = 12''$

$\beta_1 = .011$, $\beta_2 = .9624$, $\alpha = .0754$

$r_0'$ approximately $\approx 1.5''$ (USING EQUIVALENT AREAS)

(At CENTER) $\sigma_b = \frac{3W}{2\pi t^2}\left[(1+\nu)\left(\ln\frac{2b}{\pi r_0'}\right) + \beta_1\right]$

$= \frac{3(416.7)}{2\pi(1)^2}\left[(1.33)(\ln 5.09) + .011\right]$

$= \underline{432.9}$ psi

MAX $\Delta = \frac{\alpha W b^2}{E t^3} = \frac{.0754(416.7)(12)^2}{29\times10^6\,(1)^3} = .00016''$

WELD STRENGTH

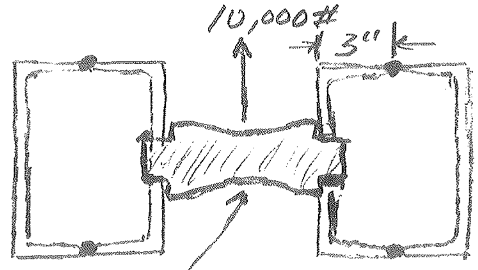
ATTACHMENT PLATES ARE CONNECTED TO BEAMS BY APPROXIMATELY 70" of 1/4" FILLET WELDS.

THROAT LENGTH = .25(SIN 45°) = .177"

"AREA" OF WELD = .177 (70) = 12.37 sqin

STRESS = $\frac{5000\#}{12.37\text{ sqin}} = \underline{404}$ psi

During the course of the note review, a question arose as to the torsional resistance of the main beam members, due to the center pin loading the members in an eccentric manner. Recall the configuration at the pin.



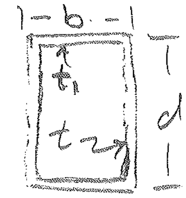

The concern is that the eccentric loading (3" offset) on the double C Channel box beam imparts a torsional moment on the beam which leads to a combination of stresses: (1) pure torsional shear stress (2) warping shear stress (3) warping normal stress. A review of the literature on this topic reveals a methodology to examine the magnitude of the problem.

The phenomena of warping, i.e. the rotation of a cross section of a beam due to eccentric loading is much more pronounced in "open" beam cross sections. In fact, the use of a closed section such as a tubular or closed rectangular tubular section distributes the shear stresses more uniformly around the circumference of the member and helps to minimize the problem.

Torsional Resistance (R) is a stiffness factor which has been established for various standard sections

For a closed rectangular tubular section:

$$R = \frac{2tt_1(b-t)^2(d-t_1)^2}{bt + dt_1 - t^2 - t_1^2}$$ where:



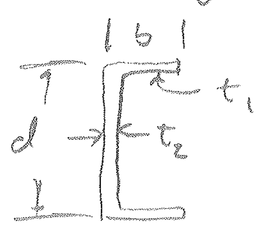

for the double C12x25 section:

$b = 6''$ $t_1 = .5''$ $d = 12''$ $t = .375''$

so: $$R = \frac{2(.375)(.5)(6-.375)^2(12-.5)^2}{(6\times.375)(12\times.5)-(.5)^2-(.375)^2} = \underline{199.7} \text{ in}^4$$

In contrast, an open section, such as a singular C channel has a resistance of

$$R = \frac{2bt_1^3 + dt_2^3}{3}$$




$b = 3''$ $t_1 = .5''$ $d = 12''$ $t_2 = .375''$

so $$R = \frac{2(3)(.5)^3 + 12(.375)^3}{3} = \underline{.46} \text{ in}^4$$

the use of average thickness for the flanges induces a slight error into this calculation. Tables of torsional properties for standard C shapes list the torsional constant for C12x25 as equal to .54 in$^4$.

Therefore, the relative torsional resistance of a box beam versus an open C channel is

$$\frac{R_{box}}{R_C} = \frac{199.7}{.54} = \underline{369.8}$$

Clearly, closed sections should be used whenever it is possible.

For the rectangular closed tube section:
The torsional shear stress is given by:

$$\tau = \frac{T}{2t_1(b-t)(d-t_1)}$$

where T = 5000# · (3") = 15,000 in-#

again, $t_1$ = .5"
b = 6"
t = .375"
d = 12"

so $\tau = \frac{15,000}{2(.375)(6-.375)(12-.5)} = \underline{309}$ psi

the angular twist is given by:

$$\phi = \frac{TL}{E_s R}$$

where, $E_s$ = 11,200,000 psi modulus of elasticity in shear
L = 122"

so: $\phi = \frac{15,000(122)}{(11.2 \times 10^6)(199.7)} = .00082$ Radians = .047°
(assumes ends are free ⇒ worst case)

It appears that for the closed rectangular tube section under an eccentric load of 15,000 in·# torsional torque, the stresses and angular twist are minimal.

(another way to look at the problem)

Following the analysis of AISC publication, "Torsional Analyses of Steel Members" —

NOTE! This methodology (cases, tables, graphs, etc) deals only with OPEN SECTIONS. Therefore, I will run through the analysis for a single C Channel section (OPEN) then substitute the higher Torsional Resistance Constant of the closed rectangular tubing to scale to the real conditions.

TORSIONAL PROPERTIES FOR C12x25 SINGLE "OPEN" CHANNEL

$J = R = .54\ in^4$ [NOTE: For the RECTANGULAR TUBE $R = 199.7$]

$S_{w1} = 5.28\ in^4$ $\quad S_{w2} = 4.01$ $\quad S_{w3} = 2.00$

$Q_f = 7.83\ in^3$

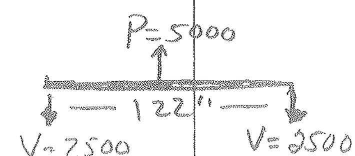
$a = 24.9\ in$ $\quad [a = (EC_w/GJ)^{1/2}]$

$C_w = 130\ in^6$

$Q_w = 14.8\ in^3$

$W_{n0} = 11.0\ in^2$ $\quad W_{n2} = 5.40$

Plane Bending




Bending Stress:

$M = \frac{PL}{4} = \frac{5000(122)}{4} = 152,500$ in #

L = length between attachment plates which tie the box beams together top & bottom.

$\sigma_b = \frac{M}{S}$ $\quad$ for single C Channel $S = 24\ in^3$; for double Rect. Tube $S = 48\ in^3$

$\sigma_b|_c = 6354$ psi $\quad$ Compared to: $\sigma_b|_\square = 3,177$ psi

Web Shear Stress:

$\tau_b|_c = \frac{V Q_w}{I t} = \frac{2500(14.8)}{144(.375)} = 685$ psi

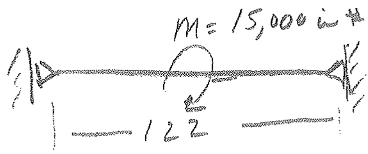
$\tau_b|_\square = \frac{2500(14.8)}{288(.375)} = 342.5$ psi

Flange Shear Stresses

$$\tau_b|_c = \frac{VQ_f}{I_c t} = \frac{2500\,(7.83)}{144\,(.5)} = \underline{272}\ \text{psi}$$

$$\tau_b|_{\square} = \frac{VQ_f}{I_{\square} t} = \frac{2500\,(7.83)}{288\,(.5)} = \underline{136}\ \text{psi}$$

TORSIONAL LOADING




assume ends can translate up/down but not twist or warp due to attachment plate.

Use Case 3 with $\alpha = .5$

$$a = \sqrt{\frac{E C_w}{G J}}$$

C Channel
$a = 24.9$
$L/a = 4.9$

At midspan ($z/L = 0.5$):

C Channel

$\phi \times \frac{GJ}{m} \times \frac{1}{L} = .15$ $\quad$ $\phi = 4.58 \times 10^{-2}$

$\phi'' \times \frac{GJ}{m} \times a = -.48$ $\quad$ $\phi'' = -4.82 \times 10^{-5}$

$\phi' \times \frac{GJ}{m} = 0$ $\quad$ $\phi' = 0$

$\phi''' \times \frac{GJ}{m} \times a^2 = -.5$ $\quad$ $\phi''' = -2.02 \times 10^{-6}$

At the ends ($z/L = 0$):

$\phi \times \frac{GJ}{m} \times \frac{1}{L} = 0$ $\quad$ $\phi = 0$

$\phi'' \times \frac{GJ}{m} \times a = 0$ $\quad$ $\phi'' = 0$

$\phi' \times \frac{GJ}{m} = .42$ $\quad$ $\phi' = 1.05 \times 10^{-3}$

$\phi''' \times \frac{GJ}{m} \times a^2 = -.08$ $\quad$ $\phi''' = -3.23 \times 10^{-7}$

where $\frac{M}{GJ}\Big|_c = \frac{15{,}000}{(11.2 \times 10^6)(.54)} = .0025$, $L = 122''$, $a = 24.9$, Torsional Stresses:

(1) Pure torsional shear stress: $\tau_t = G t \phi'$

at ends

Web: $\tau_t = (11.2\times10^6)(.375)(1.05\times10^{-3}) = 4410\,psi$

Flange: $\tau_t = (11.2\times10^6)(.5)(1.05\times10^{-3}) = 5880\,psi$

at midspan $\phi' = 0 \Rightarrow \tau_t = 0$

(2) Warping normal stresses in flanges: $\sigma_w = E W_{no} \phi''$

at ends $\phi'' = 0 \Rightarrow \sigma_w = 0$

at midspan $\sigma_w = (29\times10^6)(11.0)(-4.82\times10^{-5}) = -15{,}376\,psi$

(3) Warping shear stresses in flanges. $\tau_w = \frac{E S_w}{t}\phi'''$

at ends $\tau_w = \frac{(29\times10^6)\,5.28}{.375}(3.23\times10^{-7}) = 132\,psi$

at midspan $\tau_w = \frac{(29\times10^6)\,5.28}{.375}(-2.02\times10^{-6}) = 825\,psi$

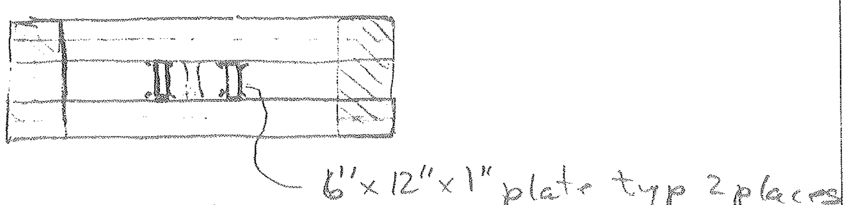
Most of the shear stresses are low and present no problem for the C Channel X section. However, the normal stresses $[\sigma_b + \sigma_w]$ add to 21,730 psi which is within a factor of 2 of the yield strength. Therefore, a single C channel would be marginal.

If the section is closed, such as what we have when we weld the 2 C channels together to form a rectangular box beam, the warping stresses are reduced dramatically. $\phi''$ scales by $1/\sqrt{R}$ so when R increases from .54 in$^4$ to 199.7 in$^4$ $\phi''$ drops to ~ 800 psi. and the combined normal stresses $[\sigma_b + \sigma_w]$ drop to ~ 3977 psi, which is good.

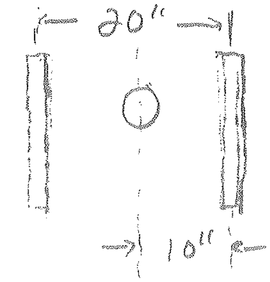
PHYSICAL MODIFICATION OF LIFTING FIXTURE

Given the concerns and the ease of modification, the fixture was modified to enhance its stiffness by adding 2 (1" thick) steel plates close to the center pin. The dimensions are ~6" x 12" x 1". This additional bracing eliminates any twist of the main beam members.

Top View.




SIDE VIEW




Bracing is placed 20" on center, and 10" from the center pin on either side. Plate is welded with a continuous fillet weld (5/16") on both sides.

Shear stress on the welds:

P = 5000# (worst case)     $l$ = length of weld = 24"

throat length = (.3125) sin 45° = .220"

$$\text{STRESS} = \frac{5000}{.220(24)} = \underline{947}\ psi$$

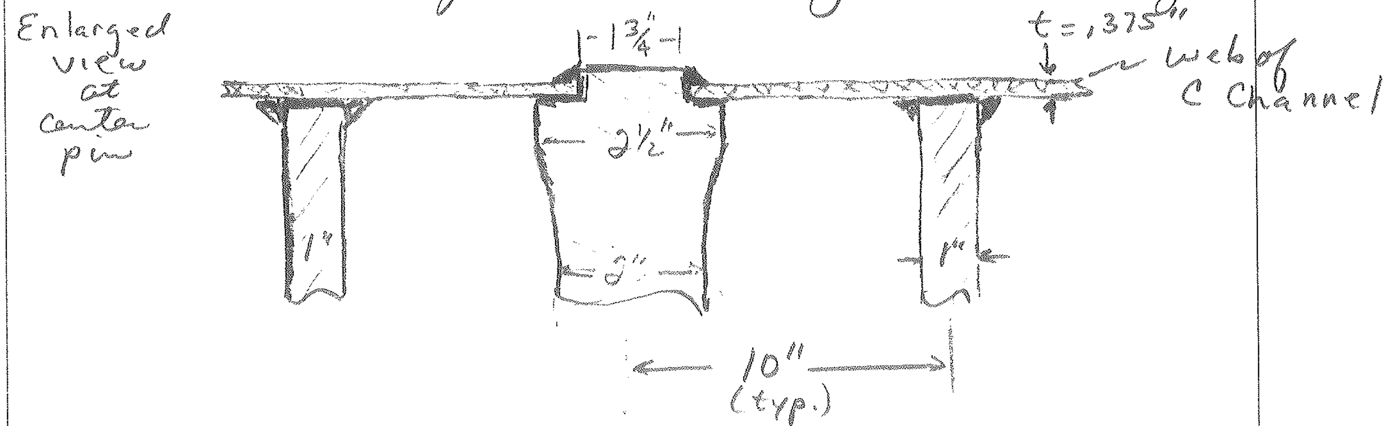
Bending stress in the plate:

$$M_{AX} = \frac{PL}{4} = \frac{5000(3)}{4} = 3750\ in\#$$

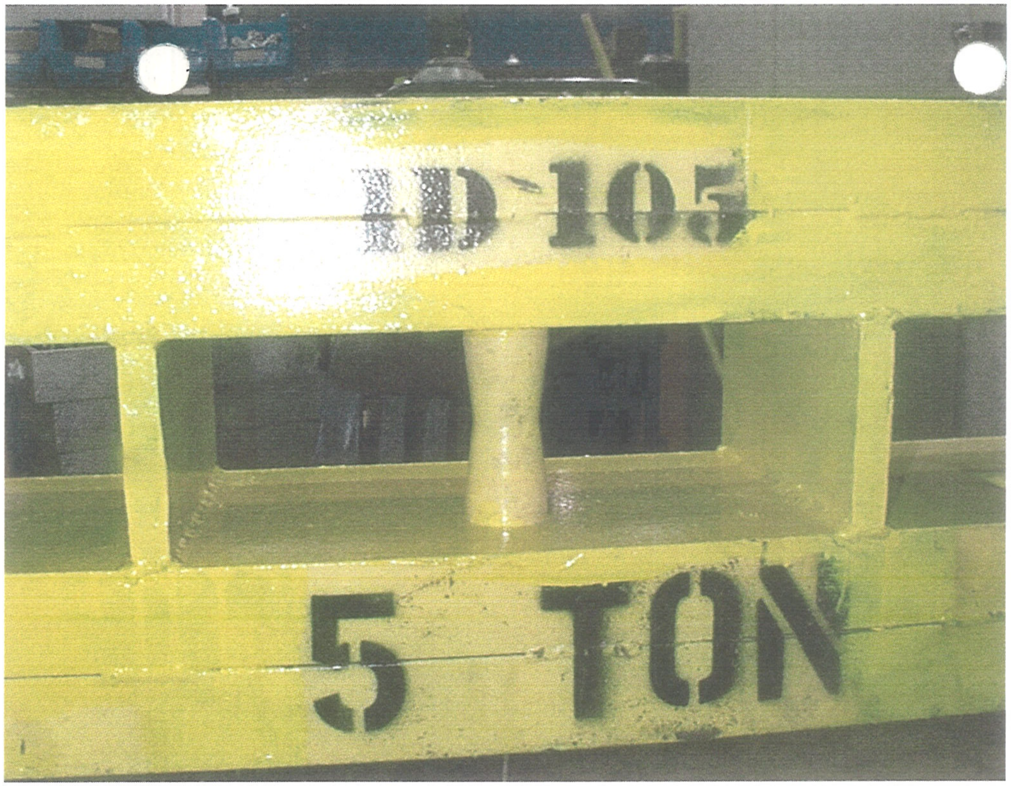
$$I = \frac{bh^3}{12} = \frac{(1)(12)^3}{12} = 144\ in^4$$

$$\sigma_B = \frac{MC}{I} = \frac{3750(6)}{144} = \underline{156\,psi}$$

The combination of the 2 (1" thick) plates and the way the center pin is "seated" and welded in the web of the C channel provides a "fixed" end condition for the bracing beam analysis




The bracing prevents the web of the C channel from rotating due to the torsional torque of the eccentric load.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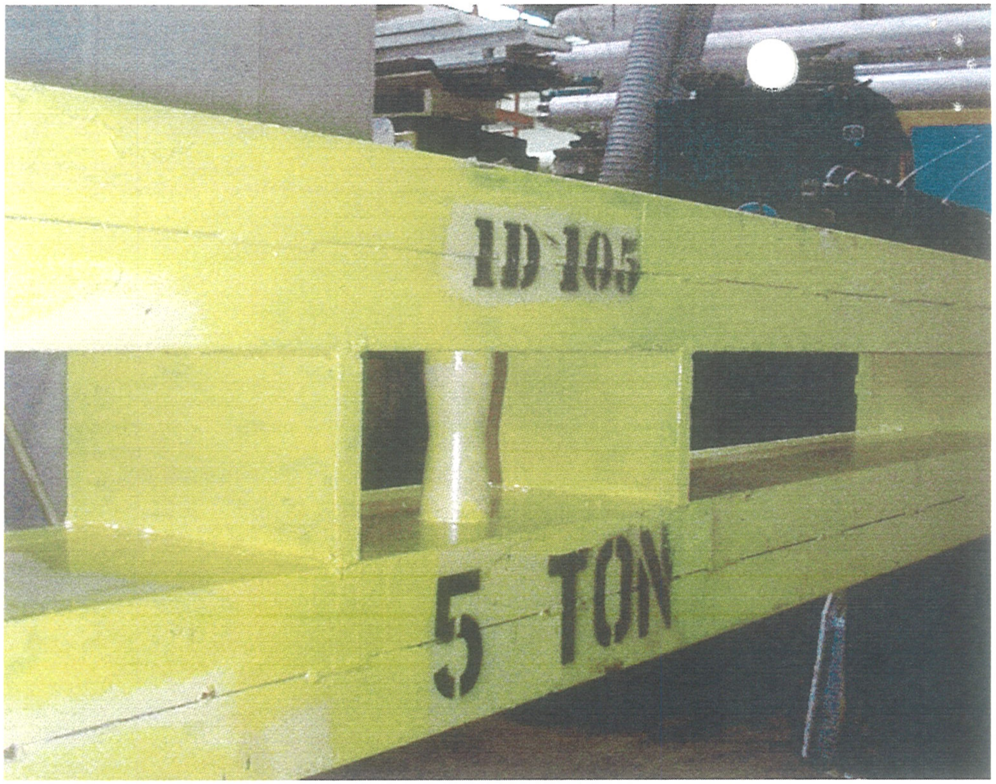
5 TON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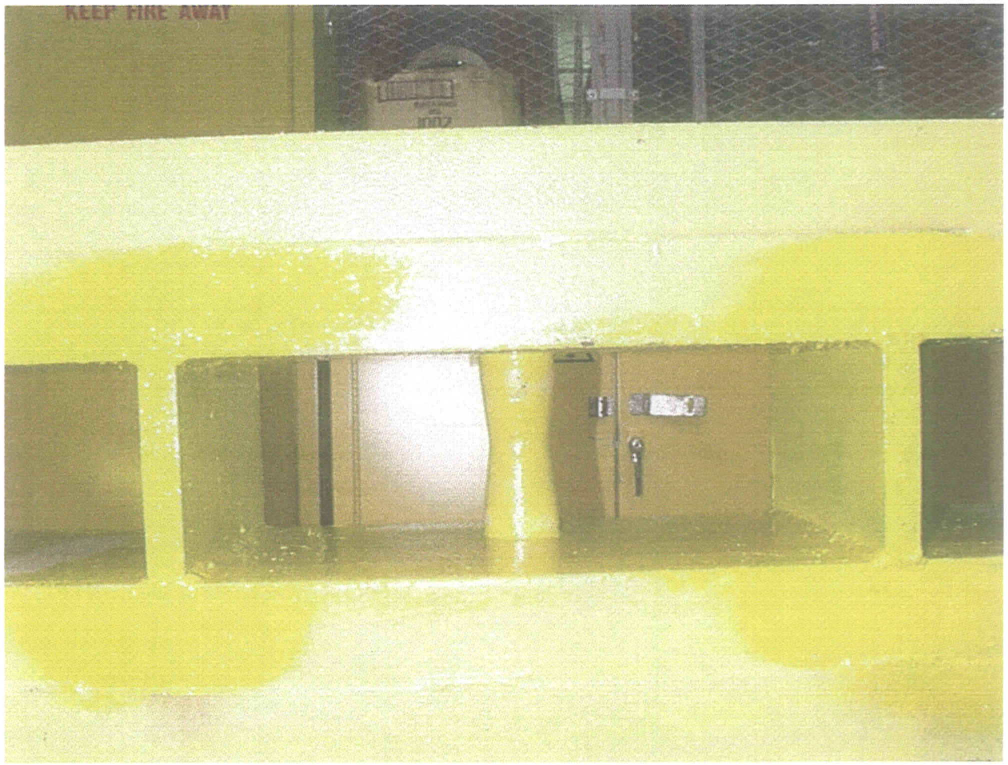
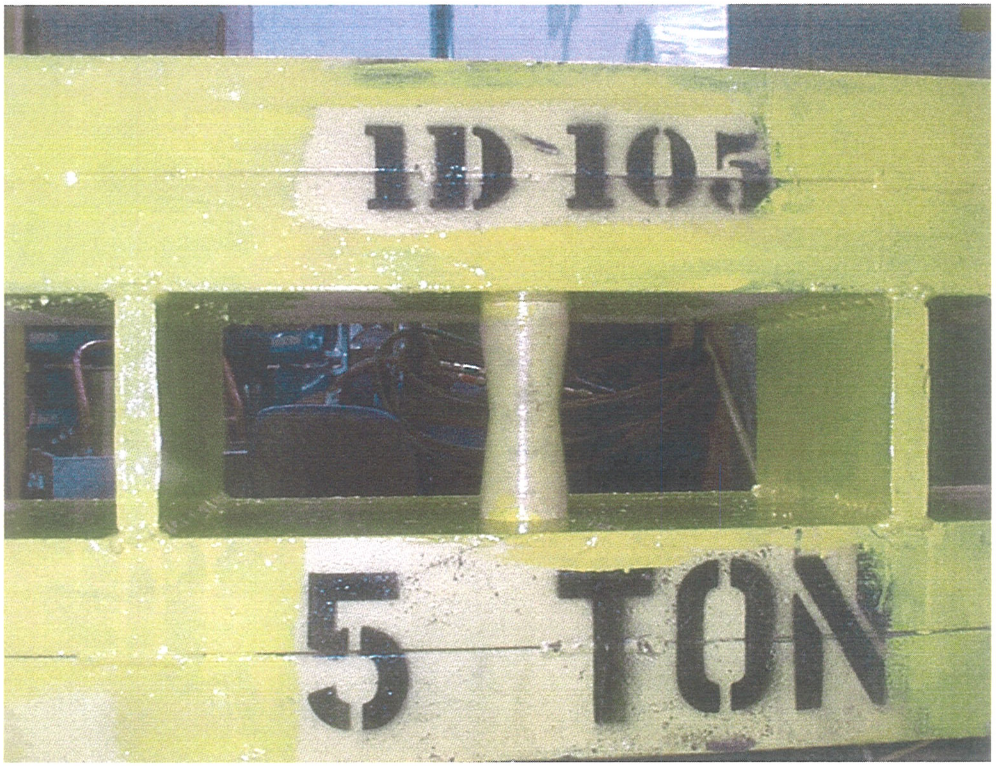
5 TON


KEEP FIRE AWAY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5 TON