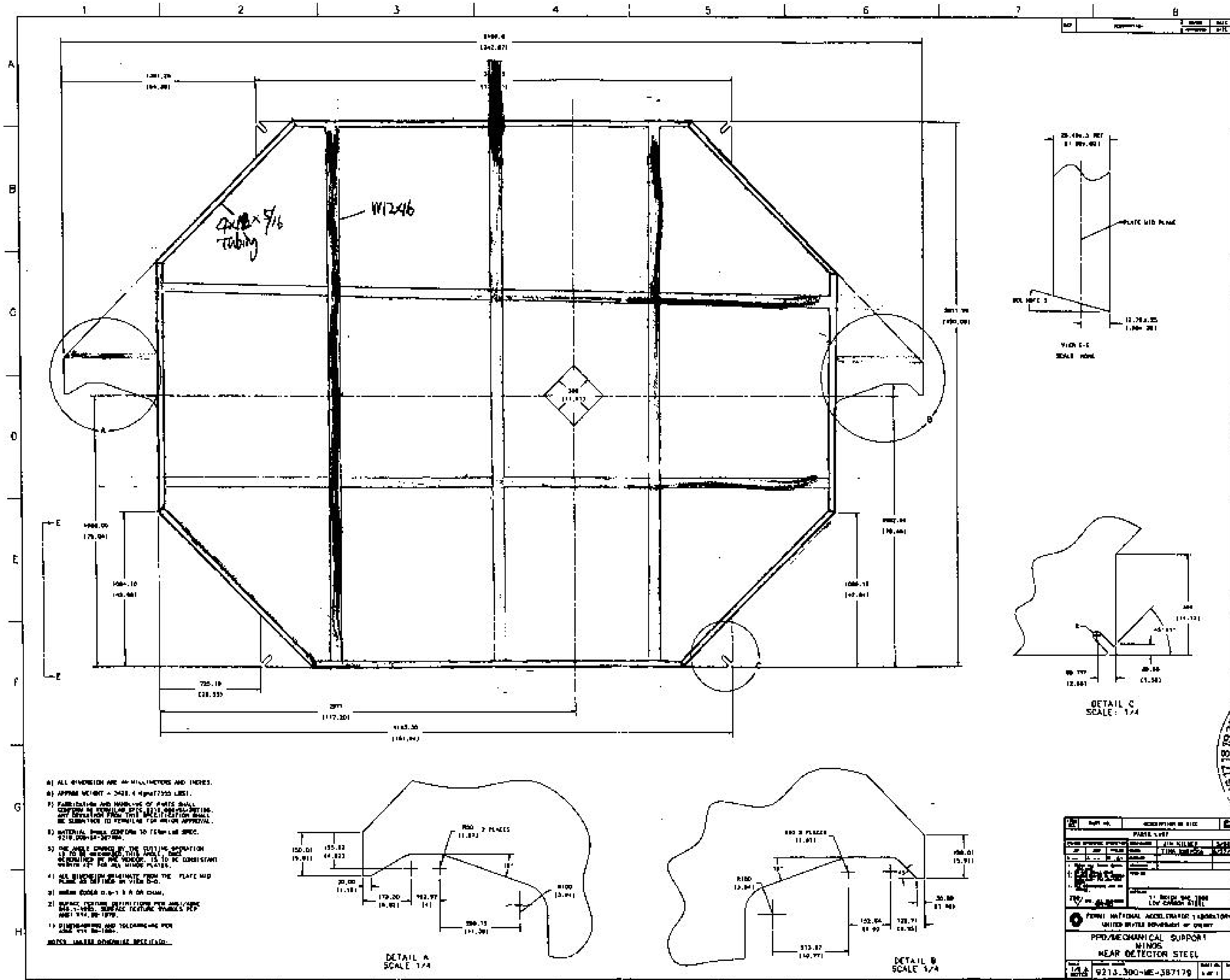

W12x46
DETAIL A
SCALE 1/4
DETAIL B
SCALE 1/4
DETAIL C
SCALE: 1/4
VIEW E-E
SCALE NONE
ALL DIMENSION ARE IN MILLIMETERS AND INCHES.
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
PPD/MECHANICAL SUPPORT
NUMI NOS
NEAR DETECTOR STEEL
9213.300-ME-387179

— CHECK THE SIZE OF THE STRUCTURES :

[redacted]

From the ansys results, the worst load combination exclude Element 137 in weak axis bending and Element 141~151, 203~213 in torsion are:

Element 140-0° $F_x = 10621$ lb (Tension) or (Compression)

Element 137-0° $F_y = 892.87$ lb (shear in y-direction)

Element 140-90° $F_z = 4790.2$ lb (shear in z-direction)

Element ~~244~~-90° $M_x = 3090.8$ lb-in (Torsion)

Element 137-90° $M_y = 86115$ lb-in (strong axis bending)

Element 262-0° $M_z = 3882$ lb-in (weak axis bending)

— FIND THE ALLOWABLE TENSILE STRESS F_t (ksi)

According to D1, AISC, ASD, page 5-40.

The allowable stress $F_t = 0.60 F_y$

where $F_y = 36$ksi for A36

$F_t = 0.60 \times 36 = 21.6$ ksi

According to ANSI/ASME B30.20-1985, Below the Hook Lifting Devices

$F_t = \frac{1}{3} F_y$ where $F_y = 36$ ksi for A36

$F_t = \frac{1}{3} \times 36 = 12$ ksi — governs

- FIND THE ALLOWABLE BENDING STRESS IN STRONG AIXS F_{bx} (ksi)

According to Table B5.1, AISC, ASD, page 5-36

$$\frac{b_f}{2t_f} = \frac{4}{2\times 0.265} = 7.547$$

$$\frac{65}{\sqrt{F_y}} = \frac{65}{\sqrt{36}} = 10.83 \quad \text{where } F_y = 36\text{ ksi for A36}$$

$$\frac{b_f}{2t_f} < \frac{65}{\sqrt{F_y}}$$

therefore, the section is compact.

According to TABLE, AISC, ASD, page 2-68

for W12x16 → $L_c = 4.10\text{ ft} = 49.2\text{ in}$

$L_u = 4.30\text{ ft} = 51.6\text{ in}$

knowing $L_b = 52.82\text{ in} > L_c$

According to F1.1, AISC, ASD, page 5-46, the allowable bending stress in compression is determined as the larger value from EQ (F1-6), EQ (F1-7) and EQ (F1-8)

USE EQ (F1-8).

$$F_{bx} = \frac{12\times10^3 C_b}{ld/A_f} \le 0.60 F_y$$

where $C_b = 1.75 + 1.05\left(\frac{M_1}{M_2}\right) + 0.3\left(\frac{M_1}{M_2}\right)^2$

A_f = area of the compression flange, in^2

l = distance between cross section braced against twist or lateral displacement of the compression flange, in

d = Depth of the beam

Therefore,

$C_b = 1.75$ when $M_1 << M_2$

$\frac{d}{A_f} = 11.3$ from page 1-28, AISC, ASD

$l = 52.82$ in

$$F_{bx} = \frac{12\times10^3\times1.75}{52.82\times11.3} = 35.18 \text{ (ksi)}$$

$F_{bx} = 0.60 F_y$ where $F_y = 36$ ksi for A36

$F_{bx} = 0.60\times36 = 21.6$ (ksi)

Since $F_{bx} \le 0.60 F_y$, use $F_{bx} = 21.6$ (ksi)

According to ANSI/ASME B30.20-1985 Below the Hook Lifting Device

$F_{bx} = \frac{1}{3} F_y$ where $F_y = 36$ ksi for A36

$F_{bx} = \frac{1}{3} \times 36 = 12$ ksi — governs

— FIND THE ALLOWABLE BENDING STRESS IN WEAK AIXS F_{by} (ksi)

According to F2.2, AISC, ASD, Page 5-48

$$F_{by} = F_y \left[1.075 - 0.005 \left(\frac{b_f}{2t_f}\right)\sqrt{F_y}\right]$$

where $F_y = 36$ ksi for A36

$\frac{b_f}{2t_f} = 7.5$ — page 1-28

$$F_{by} = 36\left[1.075 - 0.005 \times 7.5 \times \sqrt{36}\right] = 30.6 \text{ ksi}$$

According to ANSI/ASME B30.20-1985 Below the Hook Lifting Device

$F_{by} = \frac{1}{3} F_y$ where $F_y = 36$ for A36

$F_{by} = \frac{1}{3} \times 36 = 12$ ksi — governs

— FIND THE COMPUTED TENSILE STRESS f_a (ksi)

$$f_a = \frac{P}{A}$$

where $P = 10621$ lb

$A = 4.71$ in^2 — page 1-28, AISC, ASD

$$f_a = \frac{10621}{4.71} = 2.2 \text{ ksi}$$

- FIND THE COMPUTED BENDING STRESS IN STRONG AXIS

f_{bx} (Ksi)

$$f_{bx} = \frac{M_y}{S_x}$$ where $M_y = 86115$ lb-in

$S_x = 17.1\ in^3$ from page 1-28, AISC ASD

$$f_{bx} = \frac{86115}{17.1} = 5.04\ Ksi$$

- FIND THE COMPUTED ENDING STRESS IN WEAK AXIS

f_{by} (Ksi)

$$f_{by} = \frac{M_z}{S_x}$$ where $M_z = 3882$ lb-in

$S_x = 1.41\ in^3$ from page 1-28, AISC, ASD

$$f_{by} = \frac{3882}{1.41} = 2.75\ Ksi$$

- FIND THE COMBINED STRESSES

According to H2, AISC, ASD, page 5-55, EQ (H2-1) permits

$$\frac{f_a}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{bx}}{F_{by}} \leq 1.0$$

Where $f_a = 2.2$ Ksi $\quad F_{bx} = 12$ Ksi

$F_t = 12$ Ksi $\quad F_{by} = 12$ Ksi

$f_{bx} = 5.04$ Ksi

$f_{by} = 2.75$ Ksi

$$\frac{2.2}{12} + \frac{5.04}{12} + \frac{2.75}{12} = 0.83 < 1.0 \quad \underline{OK}$$

$$SF = \frac{1.0}{0.83} = 1.2$$

- FIND THE ALLOWABLE COMPRESSIVE STRESS F_a (ksi)

From previous study, knowing $\frac{b_f}{2t_f} < 65/\sqrt{F_y}$.

According to AISC, ASD, Table B5.1, page 5-36, for webs in combined flexural and axial compression.

$$\frac{d}{t_w} = \frac{11.99}{0.22} = 54.5$$

for $\frac{f_a}{F_y} = \frac{2.2}{36} = 0.06 \le 0.16 \rightarrow \frac{640}{\sqrt{F_y}}\left(1-3.74\frac{f_a}{F_y}\right)$

$$= \frac{640}{\sqrt{36}}(1-3.74 \times 0.06)$$

$$= 82.73$$

therefore

$$\frac{d}{t_w} < \frac{640}{\sqrt{F_y}}\left(1-3.74\frac{f_a}{F_y}\right) \Rightarrow \text{section is compact.}$$

According to E2, AISC, ASD, page 5-42

$\frac{Kl}{r}$ where K – effective length factor

l – length

r – radius of gyration

when $K = 2$, $l = 52.82$ in, $r = 0.773$ in

$$\frac{Kl}{r} = \frac{2 \times 52.82}{0.773} = 136.66$$

According to AISC, ASD, page 5-120, the column slenderness ratio for A36 is $C_c = 126.1$

therefore, $\frac{Kl}{r} > C_c$

The allowable stress is permitted under EQ (E2.2)

The allowable stress is permitted under the EQ (E2.2), AISC, ASD, page 5-42.

$$F_a = \frac{12\pi^2 E}{23\left(\frac{Kl}{r}\right)^2} \quad \text{EQ (E2-2)}$$

where $E = 29 \times 10^6$

$\frac{Kl}{r} = 136.66$

$$F_a = \frac{12 \times \pi^2 \times 29 \times 10^6}{23 \times (136.66)^2} = 7.99 \text{ ksi} \text{ - governs}$$

According to ANSI/ASME, B30.20-1985 Below the Hook Lifting Device

$F_a = \frac{1}{3} F_y$ where $F_y = 36$ ksi for A36

$F_a = \frac{1}{3} \times 36 = 12$ ksi

– FIND THE COMBINED STRESSES

According to H1, AISC, ASD, page 5-54, knowing when $\frac{f_a}{F_a} = \frac{2.2}{7.99} = 0.27 \nleq 0.15$, EQ (H1-1) & EQ (H1-2) are permitted.

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F_{ey}}\right) F_{by}} \leq 1.0 \quad \text{(H1-1)}$$

where $f_a = 2.2$ ksi

$F_a = 7.99$ ksi

$C_{mx} = 1$

$C_{my} = 1$

$f_{bx} = 5.04$ ksi

$f_{by} = 2.75$ ksi

$F_{bx} = 12$ ksi

$F_{by} = 12$ ksi

$$F'_{ex} = \frac{12\pi^2 E}{23(Kl/r_x)^2} = \frac{12 \times \pi^2 \times 29 \times 10^6}{23 \times \left(\frac{2 \times 52.82}{4.67}\right)^2} = 291.8 \text{ ksi}$$

$$F'_{ex} = \frac{12\pi^2 E}{23(Kl/r_y)^2} = 7.99 \text{ ksi}$$

then

$$\frac{2.2}{7.99} + \frac{(1) \times (5.04)}{\left(1 - \frac{2.2}{291.8}\right) \times 12} + \frac{(1) \times (2.75)}{\left(1 - \frac{2.2}{7.99}\right) \times 12} = 1.00 \le 1.0$$

OK

CHECK:

$$\frac{f_a}{0.60F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0 \qquad \text{EQ (H1-2)}$$

where $f_a = 2.2$ ksi

$0.60F_y = 12$ ksi

$f_{bx} = 5.04$ ksi

$f_{by} = 2.75$ ksi

$F_{bx} = 12$ ksi

$F_{by} = 12$ ksi

$$\frac{2.2}{12} + \frac{5.04}{12} + \frac{2.75}{12} = 0.83 \leq 1.0$$

<u>ok</u>

$$SF = \frac{1.0}{0.83} = 1.2$$

– FIND THE ALLOWABLE SHEAR STRESS F_v (ksi)

According to F4, AISC, ASD, page 5-49

when $\frac{h}{t_w} = 54.5$ for W12x16, page 1-29, AISC, ASD

$$\frac{380}{\sqrt{F_y}} = \frac{380}{\sqrt{36}} = 63.3$$

$$\frac{h}{t_w} < \frac{380}{\sqrt{F_y}}$$

Therefore, the allowable shear stress is

$F_v = 0.40 F_y$ where $F_y = 36$ ksi for A36

$F_v = 0.40 \times 36 = 14.4$ ksi

According to ANSI/ASME, B30.20-1985 Below the Hook Lifting Devices

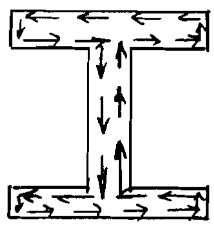
$F_v = \frac{1}{3} F_y$ where $F_y = 36$ ksi for A36

$F_v = \frac{1}{3} \times 36 = 12$ ksi

— governs

– FIND THE COMPUTED SHEAR STRESSES f_v (KSi)

0 St venant torsion :



According to "STRUCTURAL STEEL DESIGN" Chapter 7.5, Torsion, page 190

The maximum torsional shear stress in the wide-flange occurs at the center of the outer edge of the flange.

The maximum torsional shear stress can be calculated from

flange $f_{vs} = \frac{T \times t_f}{J}$ (EQ 7.16)

web $f_{vs} = \frac{T \times t_w}{J}$ (EQ 7.16)

where T — Torsional moment
t — thickness of web or flange
J — torsional constant for the entire cross section.

where $T = 3090.8$ lb-in
$t_w = 0.22$ in
$t_f = 0.265$ in
$J = 0.10$ in^4

flange: $f_{vs} = \frac{3090.8 \times 0.265}{0.10} = 8.19$ ksi

web: $f_{vs} = \frac{3090.8 \times 0.22}{0.10} = 6.799$ ksi

o Shear stress in Y-direction (flange)

$f_{vy} = \frac{V_y}{A}$

where $V_y = 892.87$ lb

$A = 4.71$ in^2

$f_{vy} = \frac{892.87}{4.71} = 0.189$ ksi

o Shear stress in Z-direction (web)

$f_{vz} = \frac{V_z}{A}$

where $V_z = 4790.2$ lb

$A = 4.71$ in

$f_{vz} = \frac{4790.2}{4.71} = 1.017$ ksi

o Combined shear stress in Y-direction (flange)

$f'_{vy} = f_{vs} + f_{vy}$

where $f_{vs} = 8.19$ ksi $f_{vy} = 0.189$ ksi

$f'_{vy} = 8.19 + 0.819 = 9.009$ ksi

o Combined shear stress in Z-direction (web)

$f'_{vz} = f_{vs} + f_{vz}$

where $f_{rs} = 6.799$ ksi $f_{vz} = 1.017$ ksi

$f'_{vz} = 6.799 + 1.017 = 7.816$ ksi

o FIND THE COMPUTED RESULTANT SHEAR STRESSES f_v (ksi)

$f_v = \sqrt{f'^2_{vz} + f'^2_{vy}}$ where $f'_{vz} = 7.816$, $f'_{vy} = 9.009$

$= \sqrt{(7.816)^2 + (9.009)^2}$

$= 11.92$ ksi

o FIND THE SAFETY FACTOR ON SHEAR STRESS :

$f_v = 11.92$ ksi

$F_v = 12$ ksi

$SF = \frac{12}{11.92} = 1$

In Conclusion, the Cross member is adequate for the load requirement except for Element 137 in member axis bending and the torsional shear for element 141~151 and 203-213. see detail design on page 12(1) ~ 12(13)

[redacted]

From the ansys results, knowing those elements suffer the maximum torsional shear stress.

$M_x = 5569$ lb-in

— FIND THE COMPUTED SHEAR STRESS DUE TO TORSION. f_v (ksi)

According to "STRUCTURAL STEEL DESIGN" Chapter 7.5 page 190, St venant torsion for wide-flange beam

flange: $f_{vs} = \frac{T \times t_f}{J}$ (EQ 7.16)

web: $f_{vs} = \frac{T \times t_w}{J}$ (EQ 7.16)

where: T — Torsional moment

t — thickness of web / flange

J — torsional constant for the entire cross section.

when $T = 5569$ lb-in

$t_f = 0.265$ in

$t_w = 0.22$ in

$J = 0.10$ in^4

flange: $f_{vs} = \frac{5569 \times 0.265}{0.10} = 14.757$ ksi

web: $f_{vs} = \frac{5569 \times 0.22}{0.10} = 12.251$ ksi

From previous study, knowing $f_{vy} = 0.189$ ksi (flange)

$f_{vz} = 1.017$ ksi (web

the resultant the shear stress f_v

$$f_v = \sqrt{(f_{vs})^2_{flange} + (f_{vs})^2_{web}}$$

where $(f_{vs})_{flange} = 14.757 \text{ ksi} + 0.189 \text{ ksi} = 14.946 \text{ ksi}$

$(f_{vs})_{web} = 12.251 \text{ ksi} + 1.017 \text{ ksi} = 13.268 \text{ ksi}$

$$f_v = \sqrt{14.946^2 + 13.268^2} = 19.98 \text{ ksi} > F_v = 12 \text{ ksi}$$

N.G.

— DESIGN THE WELD FOR TORSION PLATES

propose to weld two plates on both side of W12x16. to take the larger shear stress.

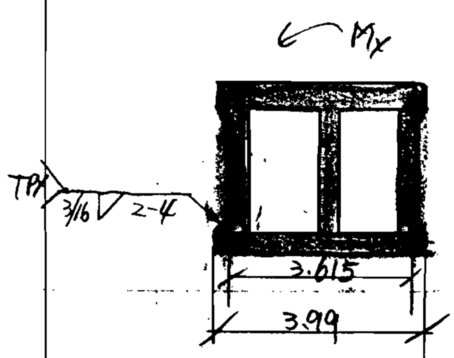


Plate: 1/4" x 11 7/16" x 65"

o FIND THE COMPUTED SHEAR STRESS f_v (ksi)

According to "STEEL DESIGN MANUAL" chapter 7, Torsional shear stress, page 159. for rectangular beam.

$$f_s = \frac{T}{2bht}$$

where T — Torsional moment

b — width of the tubing

h — height of the tubing

t — thickness of the tubing

when $T = 5569\ lb\text{-}in$

$b = 3.99\ in$

$h = 11.99\ in$

$t = 0.25\ in$

$$f_s = \frac{5569}{2 \times 3.99 \times 11.99 \times 0.25} = 0.232\ ksi$$

The resultant shear stress is

$$f_r = \sqrt{(f_s + f_{vy})^2 + (f_s + f_{vz})^2}$$

Where $f_{vy} = 0.189\ ksi$ $\quad f_s = 0.232\ ksi$

$f_{vz} = 1.017\ ksi$

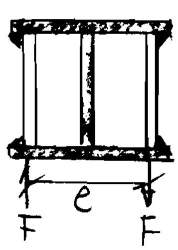
$$f_r = \sqrt{(0.232 + 0.189)^2 + (0.232 + 1.017)^2} = 1.318 \leq 12ksi$$

OK

$$SF = \frac{12}{1.318} = 9.$$

therefore, the reinforce member is adequate to carry the shear stress due to the torsion.

O FIND THE SHEAR STRESS ON THE WELDS.



Knowing: $M_x = F \times e$

Where $M_x = 5569\ lb\text{-}in$

$e = 3.615\ in$

$$F = \frac{M_x}{e} = \frac{5569}{3.615} = 1540.5\ lb$$

For each weld:

$$F' = \frac{1}{2}F = \frac{1}{2} \times 1540.5 = 770.26\ lb$$

According to AISC, ASD. J2.2, page 5-67.

the maximum size of fillet welds is 3/16".

use E70XX

According to AISC, ASD. Table J2.5, page 5-70.

knowing, the allowable stress on welds for the fillet weld on shear is

$0.30 \times F_u$ where $F_u = 70$ ksi for E70XX

$0.30 \times 70 = 21$ ksi

therefore, the allowable loads in kips is

$21 \times 0.707 \times 3/16 = 2.78$ kip/in.

o FIND THE WELD LENGTH

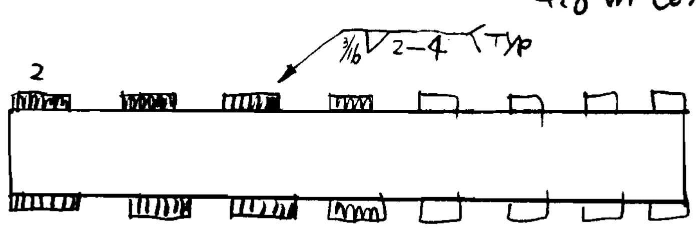
knowing: $F' = 770.26 = 0.770$ kips

welds: 2.78 kip/in

the required weld length: $\frac{0.770}{2.78} = 0.28$ in

$SF = \frac{2}{0.25} = 8$

use 2 in on every element length. which equals to 4.8 in long.



[redacted] ~~WEB REINFORCEMENT PLATE FOR ELEMENT 137~~
[redacted]

From the ansys results, those elements suffer the maximum Bending stress in weak axis.

	Fx	Fy	Fz	Mx	My	Mz
ELEMENT 137-0°	3374 lb	892 lb	3374 lb	0	60892	16072 lb-in
ELEMENT 137-45°	3374 lb	0	0	0	45698	12054 lb-in
ELEMENT 137-90°	0	892.87 lb	4772 lb	0	86115	16072 lb-in

○ FIND THE COMPUTED AXIAL STRESS f_a (ksi)

$$f_a = \frac{P}{A}$$

Where $P = 3374$ lb

$A = 4.71\ in^2$ from AISC, ASD, page 1-28

$$f_a = \frac{3374}{4.71} = 0.716 \text{ ksi}$$

○ FIND THE COMPUTED BENDING STRESS IN STRONG AXIS f_{bx} (ksi)

ELEMENT 137-0°: $f_{bx} = \frac{M_x}{S_x} = \frac{60892}{17.1} = 3.56$ ksi

ELEMENT 137-45°: $f_{bx} = \frac{M_x}{S_x} = \frac{45698}{17.1} = 2.67$ ksi

ELEMENT 137-90°: $f_{bx} = \frac{M_x}{S_x} = \frac{86115}{17.1} = 5.04$ ksi o FIND THE COMPUTED BENDING STRESS IN WEAK AXIS f_{by} (ksi)

ELEMENT 137-0° $f_{by} = \frac{M_z}{S_y} = \frac{16072}{1.41} = 11.398$ ksi

ELEMENT 137-45° $f_{by} = \frac{M_z}{S_y} = \frac{12054}{1.41} = 8.548$ ksi

ELEMENT 137-90° $f_{by} = \frac{M_z}{S_y} = \frac{16072}{1.41} = 11.398$ ksi

o FIND THE COMBINED STRESSES

From previous study, knowing: $F_a = 7.99$ ksi

$$\frac{f_a}{F_a} = \frac{0.716}{7.99} = 0.089 \le 0.15.$$

According to AISC, ASD, H1, page 5-54

Equation (H1-3) is permitted

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0.$$

For Element 137-0°:

when, $f_a = 0.76$ ksi, $F_a = 7.99$ ksi $F_{bx} = 12$ ksi, $F_{by} = 12$ ksi

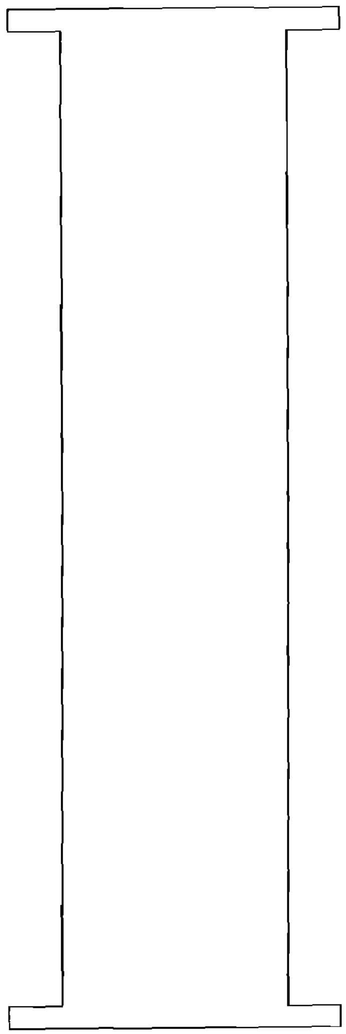
$f_{bx} = 3.56$ ksi $f_{by} = 11.398$ ksi

$$\frac{0.76}{7.99} + \frac{3.56}{12} + \frac{11.398}{12} = 1.34 \not\le 1.0.$$

For Element 137-45°:

when: $f_a = 0.76$ ksi, $F_a = 7.99$ ksi $F_{bx} = 12$ ksi

$F_{by} = 12$ ksi, $f_{bx} = 2.67$ ksi $f_{by} = 8.548$ ksi



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Xcg=-1.30596e+01
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Kycg=8.11394e-01
Kxor=4.74207e+00
Kyor=1.30848e+01
Ixprin=2.19139e+01
Iyprin=4.14098e+02
Ipolar=4.36012e+02

$$\frac{0.76}{7.99} + \frac{2.67}{12} + \frac{8.548}{12} = 1.029 \not< 1.0 .$$

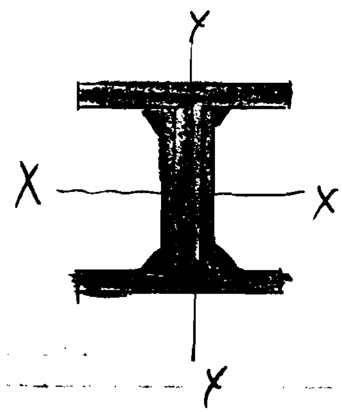
For Element 137-90°

When, $f_a = 0$, $F_a = 7.99$ ksi, $F_{bx} = 12$ ksi
$F_{by} = 12$ ksi $f_{bx} = 5.04$ ksi $f_{by} = 11.398$ ksi

$$\frac{0}{7.99} + \frac{5.04}{12} + \frac{11.398}{12} = 1.37 \not< 1.0 .$$

– DESIGN THE REINFORMENT PLATES ON WEB

propose to weld two plates on both side of the web to take the large bi-axial bending stress.



From the ideas results. knowing

$I_x = 414 \text{ in}^4$

$I_y = 21.9 \text{ in}^4$

then,

Plate: 1¼" x 11⅞" x 30" LONG

weld: 5/16 3-4.5 / 5/16 3-4.5 TYP

$$S_x = \frac{I_x}{Y} = \frac{414}{\left(\frac{11.99}{2}\right)} = 69.06 \text{ in}^3$$

$$S_y = \frac{I_y}{X} = \frac{21.9}{\left(\frac{3.99}{2}\right)} = 10.97 \text{ in}^3$$

O FIND THE COMPUTED BENDING STRESS IN STRONG AXIS f_{bx} (ksi)

ELEMENT 137-0° $f_{bx} = \frac{M_x}{S_x} = \frac{60892}{69.06} = 0.882$ Ksi

ELEMENT 137-45° $f_{bx} = \frac{M_x}{S_x} = \frac{45698}{69.06} = 0.662$ Ksi

ELEMENT 137-90° $f_{bx} = \frac{M_x}{S_x} = \frac{86115}{69.06} = 1.247$ Ksi

O FIND THE COMPUTED BENDING STRESS IN WEAK AXIS f_{by}(Ksi)

ELEMENT 137-0° $f_{by} = \frac{M_z}{S_y} = \frac{16072}{10.97} = 1.465$ Ksi

ELEMENT 137-45° $f_{by} = \frac{M_z}{S_y} = \frac{12054}{10.97} = 1.099$ Ksi

ELEMENT 137-90° $f_{by} = \frac{M_z}{S_y} = \frac{16072}{10.97} = 1.465$ Ksi

O FIND THE COMPUTED COMPRESSIVE STRESS f_a (Ksi)

$f_a = \frac{P}{A}$ where $P = 3374$ lb

$A = 33.3$ in² from ideas results

$f_a = \frac{3374}{33.3} = 0.101$ Ksi

O FIND THE ALLOWABLE COMPRESSIVE STRESS F_a (Ksi)

According to AISC, ASD, Table B5.1, page 5-36, knowing, for welded beam in flexure.

$$\frac{b}{t} = \frac{3.99}{2(0.22+1.25+1.25)} = 0.73$$

$$\frac{65}{\sqrt{F_y}} = \frac{65}{\sqrt{36}} = 10.83$$

$$\frac{b}{t} < \frac{65}{\sqrt{F_y}}.$$

for web in combined flexural and axial compression

$$\frac{d}{t_w} = \frac{11.99}{(0.22+1.25+1.25)} = 4.4$$

when $f_a = 0.101$ ksi $F_y = 36$ ksi for A36

$$\frac{f_a}{F_y} = \frac{0.101}{36} = 0.003 \leq 0.16$$

then

$$\frac{640}{\sqrt{F_y}}\left(1-3.74\frac{f_a}{F_y}\right) = \frac{640}{\sqrt{36}}(1-3.74\times 0.003)$$

$$= 105.5$$

therefore,

$$\frac{d}{t_w} < \frac{640}{\sqrt{F_y}}\left(1-3.74\frac{f_a}{F_y}\right)$$

this section meets the provisions of the AISC, ASD for compact.

According to E2, AISC, ASD, page 5-42.

$\frac{Kl}{r}$ where K = effective length factor
l = length
r = radius of gyration

When $K=2$

$l = 52.82$ in

$r = \sqrt{\frac{I}{A}}$ where $I = 21.9\ in^4$ $A = 33.3\ in^2$

$r = \sqrt{\frac{21.9}{33.3}} = 0.81$ in

$$\frac{Kl}{r} = \frac{2 \times 52.82}{0.81} = 130.26$$

From previous study, Knowing $C_c = 126.1$

therefore $\frac{Kl}{r} < C_c$

The allowable stress is permitted in Eq (E2-2)

$$F_a = \frac{12\pi^2 E}{23(Kl/r)^2}$$

where $E = 29 \times 10^6$

$\frac{Kl}{r} = 130.26$

$$F_a = \frac{12 \times \pi^2 \times 29 \times 10^6}{23 \times (130.26)^2} = 8.8 \text{ Ksi} \quad \text{— governs}$$

According to ANSI / ASME. B30.20-1985, Below the Hook Lifting Device, Knowing.

$F_a = \frac{1}{3} F_y$ where $F_y = 36$ Ksi for A36

$F_a = \frac{1}{3} \times 36 = 12$ Ksi

- FIND THE COMBINED STRESSES.

According to H1, AISC, ASD, page 5-54, providing

when $\frac{f_a}{F_a} = \frac{0.101}{8.8} = 8.8 \times 10^{-7} < 0.15$, EQ (H1-3)

is permitted

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \le 1.0 .$$

For Element 137-0°

when $f_a = 0.101$ ksi $F_a = 8.8$ ksi $f_{bx} = 0.882$ ksi

$F_{bx} = 12$ ksi $f_{by} = 1.465$ ksi $F_{by} = 12$ ksi

$$\frac{0.101}{8.8} + \frac{0.882}{12} + \frac{1.465}{12} = 0.21 < 1.0 \quad \underline{\underline{OK}}$$

$$SF = \frac{1.0}{0.21} = 4.8$$

For Element 137-45°

when $f_a = 0.101$ ksi $F_a = 8.8$ ksi $f_{bx} = 0.662$ ksi

$F_{bx} = 12$ ksi $f_{by} = 1.099$ ksi $F_{by} = 12$ ksi

$$\frac{0.101}{8.8} + \frac{0.662}{12} + \frac{1.099}{12} = 0.16 < 1.0 \quad \underline{\underline{OK}}$$

$$SF = 6.3$$

For Element 137-90°

when $f_a = 0$ $F_a = 8.8$ ksi $f_{bx} = 1.247$ ksi

$F_{bx} = 12$ ksi $f_{by} = 1.465$ ksi $F_{by} = 12$ ksi

$$\frac{0}{8.8}+\frac{1.247}{12}+\frac{1.465}{12}=0.23<1.0 \quad \underline{OK}$$

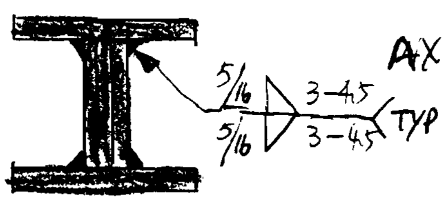
$$SF=\frac{1.0}{0.23}=4.3$$

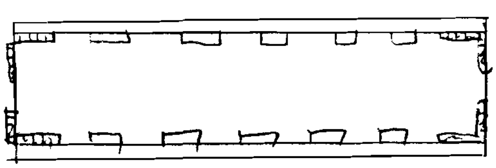
Therefore, the reinforced member is adequate for taking the larger bi-axial bending stress.

— DESIGN THE WELDS FOR BENDING MOMENT ONLY

From the ansys results, knowing the bending moments at the strong axis and weak axis are:

	My	Mz
Elements 137-90°	86115 lb-in	16072 lb-in





o FIND THE BENDING STRESS IN STRONG AXIS AT POINT of WELDS

$$f_{bx}=\frac{MY}{I_x}$$

where $M_y=86115$ lb-in

$y=\frac{11.99}{2}-0.265=5.73$ in

$I_x=414\ in^4$

$$f_{bx}=\frac{86115\times 5.73}{414}=1.192\ ksi$$

o FIND THE BENDING STRESS IN WEAK AXIS AT POINT OF WELDS

$$f_{by}=\frac{M_z X}{I_y}$$

where $M_z=16072$ lb-in

$X=\frac{1}{2}\times(0.22+2\times 1.25)=1.36$ in

$I_y=27.9\ in^4$

$$f_{by} = \frac{16072 \times 1.36}{21.9} = 0.998 \text{ ksi}$$

O FIND THE COMBINED BENDING STRESS AT POINT OF WELD

$$f_{combined} = \frac{1}{2} \times 1.192 + \frac{1}{2} \times 0.998 = 1.095 \text{ ksi}$$

O FIND THE ALLOWABLE STRESS ON THE WELDS

According to AISC, ASD, Table J2.5, Page 5-70, knowing for fillet welds under tension or compression parallel to axis of weld, the allowable stress is the same as the base metal. According to ANSI-ASME, B30.20 -1993, Below the Hook Lifting Device, knowing, the allowable is $\frac{1}{3} F_y$ where $F_y = 36$ ksi for A36

$$\text{Allow.} = \frac{1}{3} \times 36 = 12 \text{ ksi}$$

O FIND THE ALLOWABLE LOAD ON THE WELDS.

According to AISC, ASD, J2.2a, Page 5-67 knowing the size of fillet weld is 5/16", using E70XX weld then, $0.707 \times 5/16 \times 12 = 2.65$ kips/in

O FIND THE REQUIRED LENGTH OF THE WELD.

$$\frac{2.65}{1.095} = 2.4 \text{ in per element } (4.5'' \text{ LONG})$$

$$\text{use } 3'' \rightarrow SF = \frac{3}{2.4} = 1.3$$

In conclusion, the cross member design is accurate to carry the load requirement.

[redacted] TUB[redacted] 4 X 5/16

From the ansys results, the worst load combination will be:

Element 116–0° $F_x = 2646.9$ lb (compression)

Element 62–0° $F_y = 3429.5$ lb (shear in y-direction)

Element 124–90° $F_z = 2457$ lb (shear in z-direction)

Element 116–90° $M_x = 18949$ lb-in (Torsion)

Element 1–45° $M_y = 89099$ lb-in (strong axis bending)

Element 63–0° $M_z = 52055$ lb-in (weak axis bending)

– FIND THE COMPUTED AXIAL STRESS f_a (ksi)

$$f_a = \frac{P}{A}$$

where $P = 2646.9$ lb

$A = 9.36 \text{ in}^2$ from page 1-98, AISC, ASD

$$f_a = \frac{2646.9}{9.36} = 0.283 \text{ ksi}$$

– FIND THE ALLOWABLE COMPRESSIVE STRESS F_a (ksi)

According to Table B5.1, AISC, ASD, page 5-36,

Flanges of rectangular box subject to bending or compression

$$\frac{b}{t}$$

According to AISC, ASD, page 5-120, Cc is the column slenderness ratio, for A500 grade B tubing ($F_y = 46$ ksi)

$C_c = 111.6$

Therefore $\frac{Kl}{r} < C_c$

The allowable stress is permitted under EQ (E2.1)

$$F_a = \frac{\left[1 - \frac{(Kl/r)^2}{2C_c^2}\right] F_y}{\frac{5}{3} + \frac{3(Kl/r)}{8C_c} - \frac{(Kl/r)^3}{8C_c^3}} \quad \text{— (E2.1)}$$

AISC, ASD, page 5-42, E2.1

where $C_c = 111.6$

$\frac{Kl}{r} = 70.43$

$$F_a = \frac{\left[1 - \frac{70.43^2}{2 \times 111.6^2}\right] \times 46}{\frac{5}{3} + \frac{3 \times 70.43}{8 \times 111.6} - \frac{70.43^3}{8 \times 111.6^3}} = 19.68 \text{ ksi}$$

According to ANSI/ASME, B30.20-1985 Below the Hook Lifting Device

$F_a = \frac{1}{3} F_y$ where $F_y = 46$ ksi for A500 grade B tubing

$F_a = \frac{1}{3} \times 46 = 15.33$ ksi — governs

- FIND THE ALLOWABLE BENDING STRESS IN STRONG AXIS F_{bx} (KSi)

According to F3, AISC, ASD, Page 5-48, To be classified as a compact section, in addition to the requirements in section B5, a depth not greater than 6 times the width, a flange thickness not greater than 2 times the web thickness and the laterally unsupported length L_b less than or equal to EQ (F3-2)

$$L_c = \left(1950 + 1200\frac{M_1}{M_2}\right)\frac{b}{F_y}$$

when $d = 12$ in

6 times the width $= 6 \times 4 = 24$ in.

$d \not> 6$ times the width

OK

when $t = 0.3125$ in

2 times the thickness $= 2 \times 0.3125 = 0.625$ in

$t \not> 2$ times the thickness

OK

when $L_b = 59.51$ in

$$L_c = \left(1950 + 1200\frac{M_1}{M_2}\right)\frac{b}{F_y}$$

where $b = 1.0625$ in

$F_y = 46$ ksi for A500 Grade B tubing.

Assume $M_1 << M_2$

Then $L_c = (1950) \times \frac{1.0625}{46} = 45.04$ in

$L_b > L_c$

Therefore, this member is the noncompact section.

According to F3.2, AISC, ASD, page 5-49

the allowable stress is

$F_{bx} = 0.60 F_y$ where $F_y = 46$ Ksi for A 500 gradeB tubing

$F_{bx} = 0.60 \times 46 = 27.6$ Ksi

According to ANSI/ASME B30.20-1985, Below the Hook Lifting device

$F_{bx} = \frac{1}{3} F_y$ where $F_y = 46$ Ksi for A500 grade B tubing

$F_{bx} = \frac{1}{3} \times 46 = 15.33$ Ksi — governs

– FIND THE ALLOWABLE BENDING STRESS IN WEAK AXIS F_{by} (ksi)

According to F3.2, AISC, ASD, page 5-49

$F_{by} = 0.60 F_y$ where $F_y = 46$ ksi for A500 grade B tubing

$F_{by} = 0.60 \times 46 = 27.6$ ksi

According to ANSI/ASME, B30.20-1985 Below the Hook Lifting Devices

$F_{by} = \frac{1}{3} F_y$ where $F_y = 46$ ksi for A500 grade B tubing

$F_{by} = \frac{1}{3} \times 46 = 15.33$ ksi — governs

– FIND THE COMPUTED BENDING STRESS IN STRONG AXIS f_{bx} (ksi)

$f_{bx} = \frac{M}{S_x}$

Where $M = 89099$ lb-in

$S_x = 25.5$ in^3 from page 1-98, AISC, ASD.

$f_{bx} = \frac{89099}{25.5} = 3.49$ Ksi

– FIND THE COMPUTED BENDING STRESS IN WEAK AXIS f_{by} (ksi)

$f_{by} = \frac{M}{S_y}$

Where $M = 52055$ lb-in

$S_y = 13.3$ in^3 from page 1-98, AISC, ASD

$$f_{by} = \frac{52055}{13.3} = 3.913 \text{ ksi}$$

- FIND THE COMBINED STRESSES

According to H1, AISC, ASD, page 5-54, knowing when

$$\frac{f_a}{F_a} = \frac{0.283}{15.33} = 0.018 \leq 0.15$$

EQ (H1-3) is permitted.

Therefore,

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0$$

where $f_a = 0.283$ ksi

$F_a = 15.33$ ksi

$f_{bx} = 3.49$ ksi

$F_{bx} = 15.33$ ksi

$f_{by} = 3.913$ ksi

$F_{by} = 15.33$ ksi

$$\frac{0.283}{15.33} + \frac{3.49}{15.33} + \frac{3.913}{15.33} = 0.50 \leq 1.0$$

OK

$$SF = \frac{1.0}{0.50} = 2$$

– FIND THE ALLOWABLE SHEAR STRESS F_v (ksi)

According to T4. AISC, ASD, page 5-49, when

$$\frac{h}{t_w} = \frac{12}{2\times0.3125} = 19.2$$

$$\frac{380}{\sqrt{F_y}} = \frac{380}{\sqrt{46}} = 56$$

$\frac{h}{t_w} < \frac{380}{\sqrt{F_y}}$, therefore, the allowable shear stress is

$F_v = 0.40 F_y$ where $F_y = 46$ ksi for A500 grade B tubing

$F_v = 0.40\times46 = 18.4$ ksi

According to ANSI / ASME, B30.20-1985, Below the Hook Lifting Devices

$F_v = \frac{1}{3} F_y$ where $F_y = 46$ ksi for A500 grade B tubing

$F_v = \frac{1}{3}\times 46 = 15.33$ ksi — governs

ccording to "STEEL DESIGN MANUAL"
chapter 7, Torsion, page 159

The shear stresses in a closed rectangular section subject to torsion are parallel to the sides of the sections. The shear flow has a uniform value along both sides, and when moments at the corners are summed, the shear stresses along side is

$$f_s = \frac{T}{2bht}$$

where T — Torsional moment
b — width of the tubing
h — height of the tubing
t — thickness of the tubing

= 18949 lb-in
= 4 in
= 12 in
= 0.3125 in

ksi

f_{vx}

page 1-98, AISC, ASD

i

f_{vz}

page 1-98, AISC, ASD

/- direction

0.997 ksi

o Combined shear stresses in z-direction

$f'_{vz} = f_s + f_{vz}$

Where $f_s = 0.631$ ksi

$f_{vz} = 0.262$ ksi

$f'_{vz} = 0.631 + 0.262 = 0.893$ ksi

o The computed resultant shear stresses f_v ksi

$f_v = \sqrt{f'^2_{vy} + f'^2_{vz}}$

Where $f'_{vy} = 0.997$ ksi

$f'_{vz} = 0.893$ ksi

$f_v = \sqrt{0.997^2 + 0.893^2} = 1.338$ ksi

— FIND THE SAFETY FACTOR ON SHEAR STRESS :

$f_v = 1.338$ ksi

$F_v = 15.33$ ksi

$SF = \dfrac{15.33}{1.338} = 11.5$

In conclusion, the frame member is adequate to carry the load requirement.