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INTERNAL TECHNICAL REPORT

Title: STRESS ANALYSIS OF THE
MODIFIED PULSED NEUTRON ACTIVATION
SYSTEM DOWNSTREAM SHIELD
SUPPORT STRUCTURE

Organization: Applied Mechanics Branch

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ABSTRACT

The modified LOFT Pulsed Neutron Activation (PNA) System downstream shielding support structure was stress analyzed for deadweight and worst-case LOCE loads. No deficiencies were found in the structure. This stress analysis was performed for the PNA Shielding Configuration that has been used on Test L3-2 and that is to be used on Test L3-7.

DISPOSITION OF RECOMMENDATIONS

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1. INTRODUCTION

The purpose of this investigation was to determine the adequacy of the modified Pulsed Neutron Activation system structure to support the PNA sources, detectors, and lead shielding during the most severe design loading. The loading consisted of deadweight plus acceleration due to an 8-inch, hot-leg, 0.001 second opening time LOCE. Stresses in the modified downstream detector shielding support structure and the most highly stressed portions of the existing PNA structure were calculated and compared to AISC¹ and ASME² Code allowables. This stress analysis was performed for the PNA shielding configuration that has been used on Test L3-2 and that is to be used on Test L3-7.

2. METHOD OF ANALYSIS

Affected portions of the existing PNA structure along with the modified downstream shielding support structure³ were modelled using the SAP IV finite element computer program.⁴

Deadweight and three response spectrum runs (one for each of x, y, and z directions) were made. The response spectra were obtained from a computer analysis of the MTA.⁵ Ten percent damping was used in generating the response spectra to account for the damping effects of the lead brick shielding.

Beam element and plate element stresses from the SAP IV runs were calculated and combined, using the absolute sum of all force components, and compared to AISC and ASME Code allowables, respectively.

Some portions of the existing PNA structure were analyzed by multiplying the results of the previous PNA stress analysis⁶ by the ratio of the present shielding mass to the original shielding mass, while other parts were analyzed using the static-equivalent load method.⁷

The SAP IV computer output is not included in this report, but is available for inspection at the Applied Mechanics branch.

A listing of the SAP IV version used is included in Appendix B.

3. RESULTS

All components of the PNA shielding support structure analyzed in this investigation were found to be adequate.

Components not analyzed in this report include the actual methods of attachment of the lead shielding to the PNA source support structure, as mentioned in the previous PNA stress analysis.

4. REFERENCES

1. Manual of Steel Construction, American Institute of Steel Construction, 7th edition, 1970.
2. "Nuclear Power Plant Components," ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, Section III, Division 1, 1977.
3. EG&G Idaho, Inc., "LOFT Pulse Neutron Activation System," Drawing No. 210358, August 24, 1979.
4. R. C. Guenzler, IBM 360/75 and CDC7600 Versions of SAP IV, a Structural Analysis Program for Static and Dynamic Analysis of Linear Systems, TR-775, January 1976.
5. R. G. Rahl, "Stress Analysis of the LOFT Mobile Test Assembly," LTR 1110-20, February 20, 1974.
6. W. R. Mosby, "Stress Analysis of the Pulsed Neutron Activation System Support Structure," LTR LO-87-79-127, to be published.
7. RDT Standard F9-2T, Division of Reactor Research and Development, United States Atomic Energy Commission, January 1974.

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APPENDIX A

PNA DOWNSTREAM SHIELDING SUPPORT STRESS ANALYSIS

CALCULATION WORK SHEET

Subject PNA Downstream Shielding Support An. Page A-1 of _____ Pages
 Prepared By W.R. Mosby Checked _____ Work Request _____

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I. Materials

A. Beams, channels, plate

material - A-36 steel

$$S_y = 36,000 \text{ psi} = \text{yield stress}$$

$$S_u = 58,000 \text{ psi} = \text{ultimate stress}$$

$$\rho = .286 \text{ lb/in}^3$$

AISC code (Ref. 1) allowable stresses were used for all structural members except plates. For plates, the stress intensities for membrane stress alone and for membrane plus bending were compared to ASME (Ref. 2) allowable stress intensities of $\frac{2}{3} S_y$ and S_y , respectively.

For structural members other than plate, the following allowable stresses were used:

$$F_t = \text{allowable axial stress in tension} = .6 S_y$$

$$F_b = \text{allowable normal stress in bending} = .6 S_y$$

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$$F_v = \text{allowable shear stress} = .4 S_y$$

$$F_t = F_b = 21,600 \text{ psi}$$

$$F_v = 14,400 \text{ psi}$$

B. Welds

Weld metal : E7018 electrode

$$S_y = 60,000 \text{ psi}$$

$$S_u = 72,000 \text{ psi}$$

Allowable stress on effective area is the least of

$$.3(72,000) \text{ or } .4(36,000) = \underline{14,400 \text{ psi}}$$

where the weld stress is computed as

$$\sigma_w = \frac{\text{total (vector) force on weld}}{(\text{weld length})(\text{weld throat})}$$

C. Bolts ($\frac{1}{2}$ -13 UNC, A307 steel)

$F_t =$ allowable tensile stress based on area of .1419 in²

$$F_t = 20,000 \text{ psi}$$

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II. Arrangement of structure

Figures 1 and 2 show the physical arrangement of the structure considered in this analysis.

Figures 3, 4, and 5 show the SAP IV model of the structure used in this analysis.

III. Loading considered

The same loading used in the original PNA LOCE analysis (Ref. 6) was used in this analysis.

A plot of the spectra was shown in ref. 6 and will not be repeated here.

Static equivalent loads the same as in ref. 6 were used here:

$$A_x = \text{Acceleration in } x\text{-direction} = 1.5 (\text{spectrum peak}) = 4.46g$$

$$A_y = 2.81g$$

$$A_z = +1.46g, -3.46g$$

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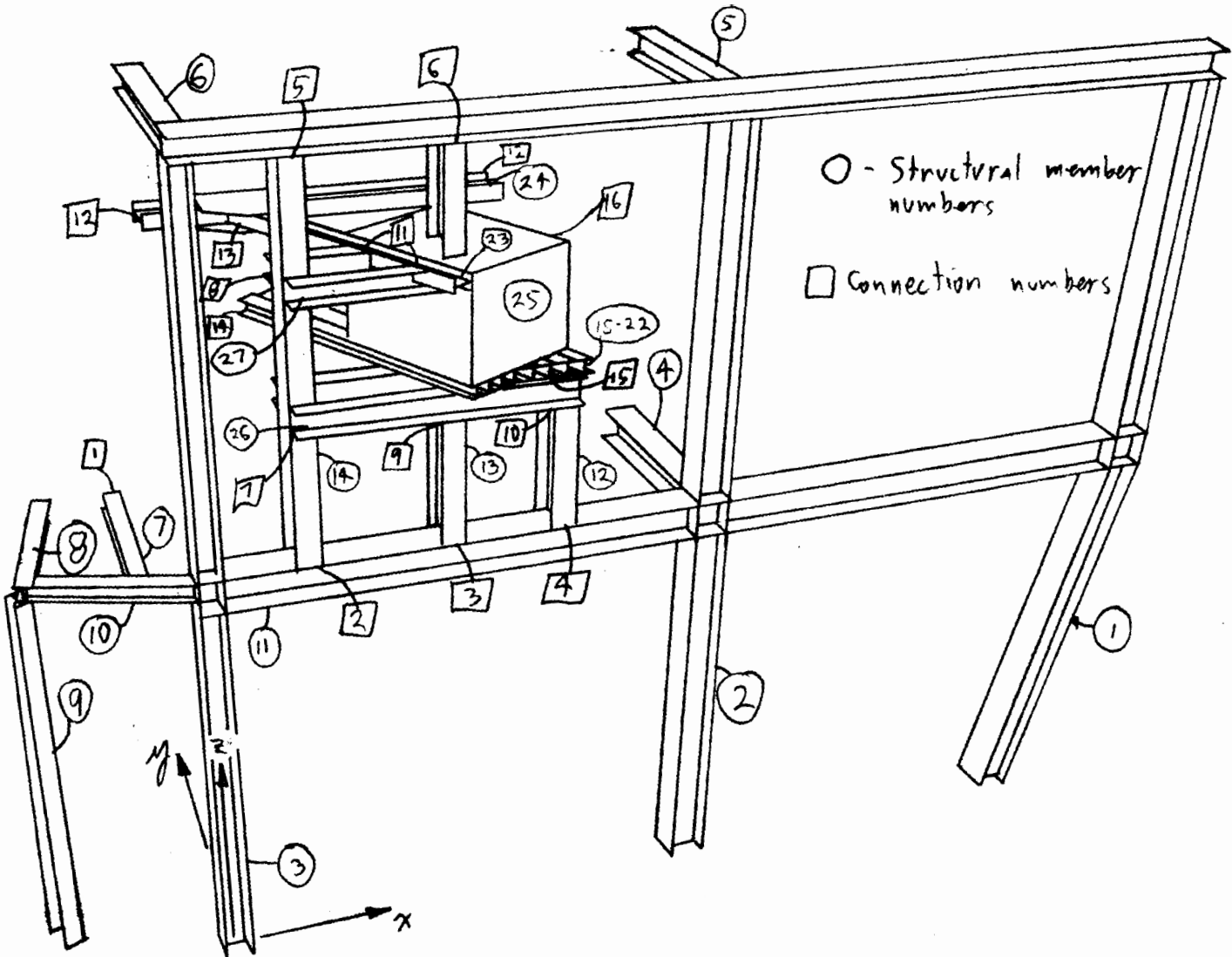


Figure 1: Overall view of shielding Support Structure looking toward MTA

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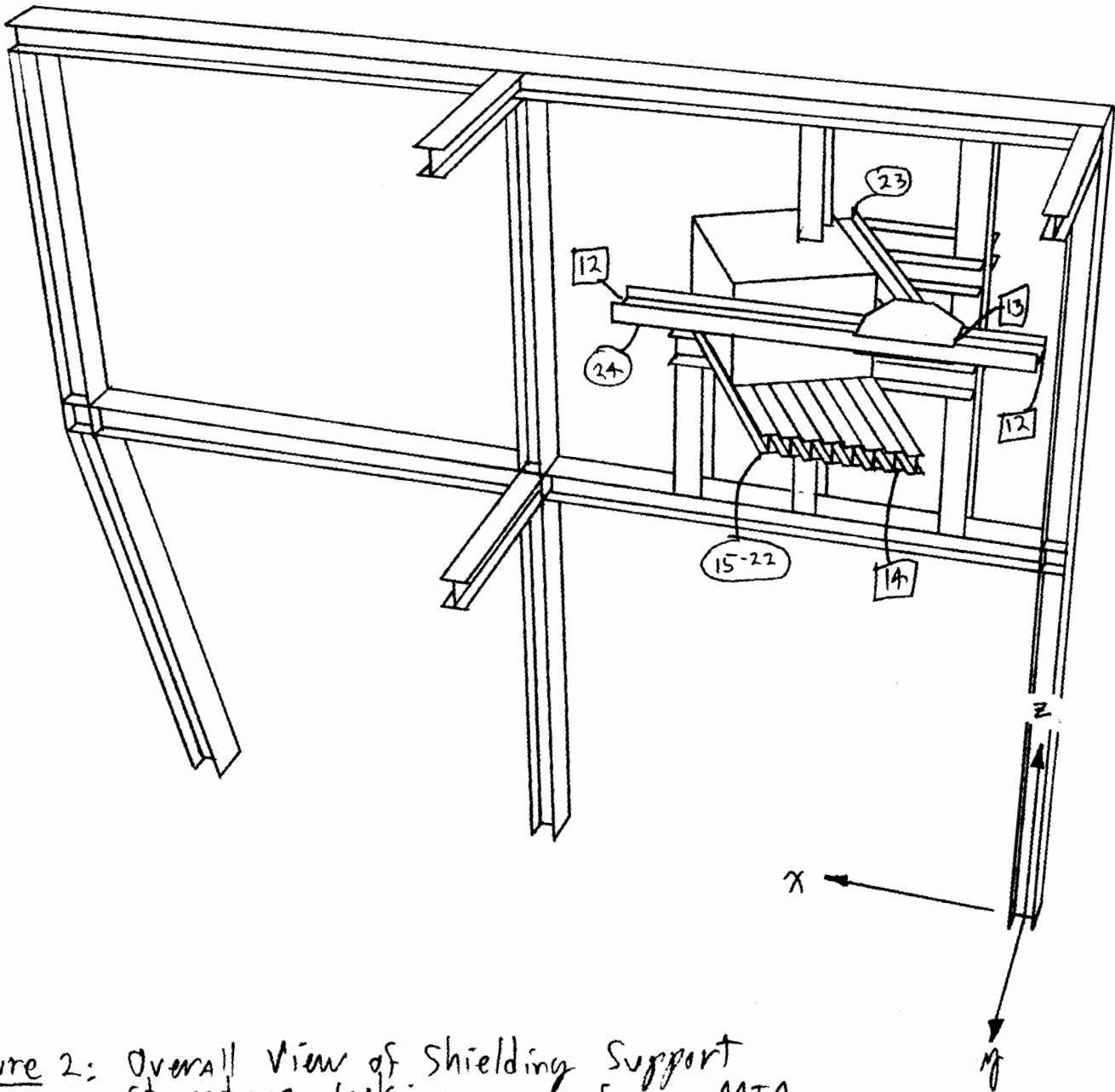


Figure 2: Overall View of Shielding Support Structure, looking away from MTA

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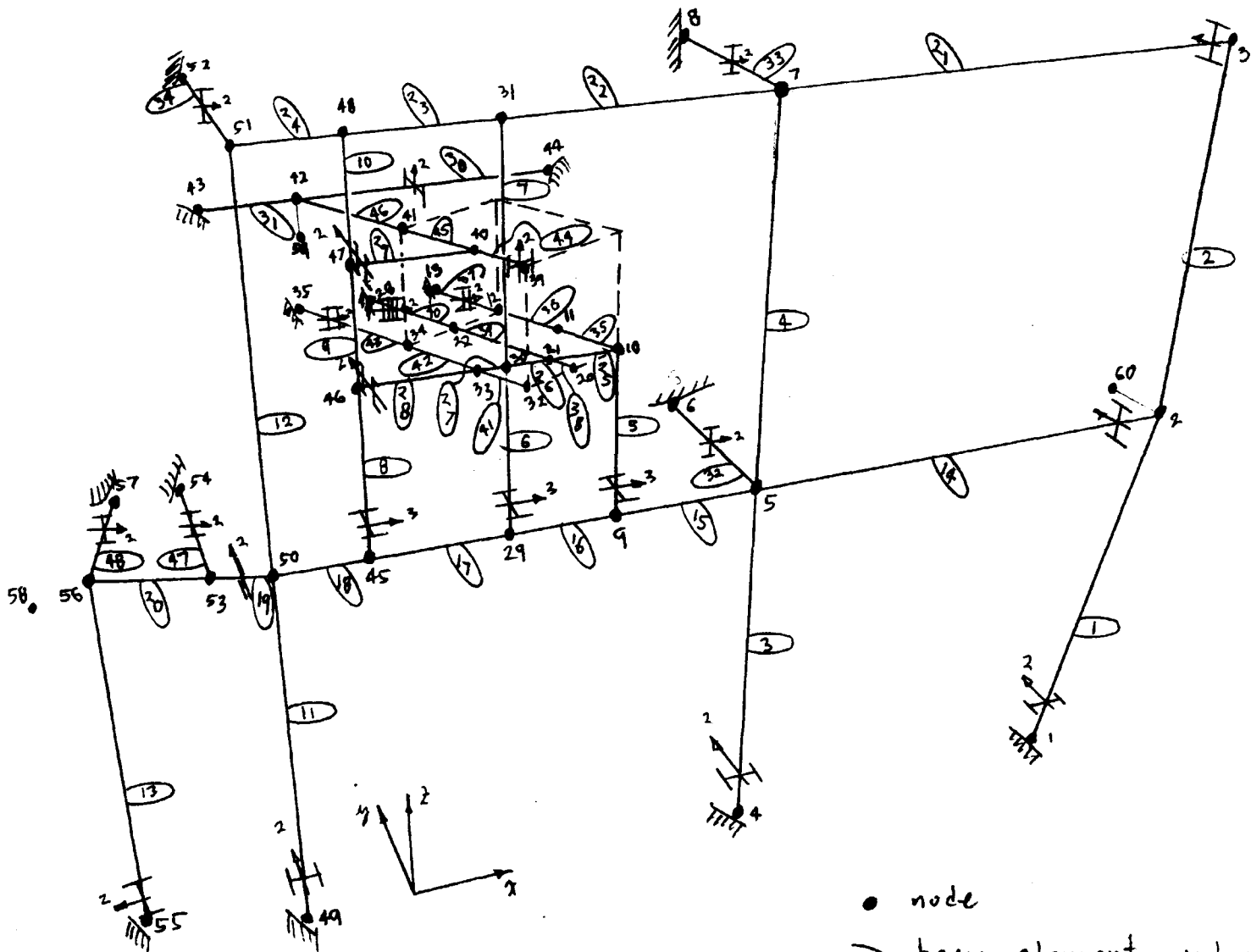


Figure 3 : SAP IV Model of Shielding Support structure

- node
- beam element number
- I section schematic and orientation
- ▨ built-in beam end



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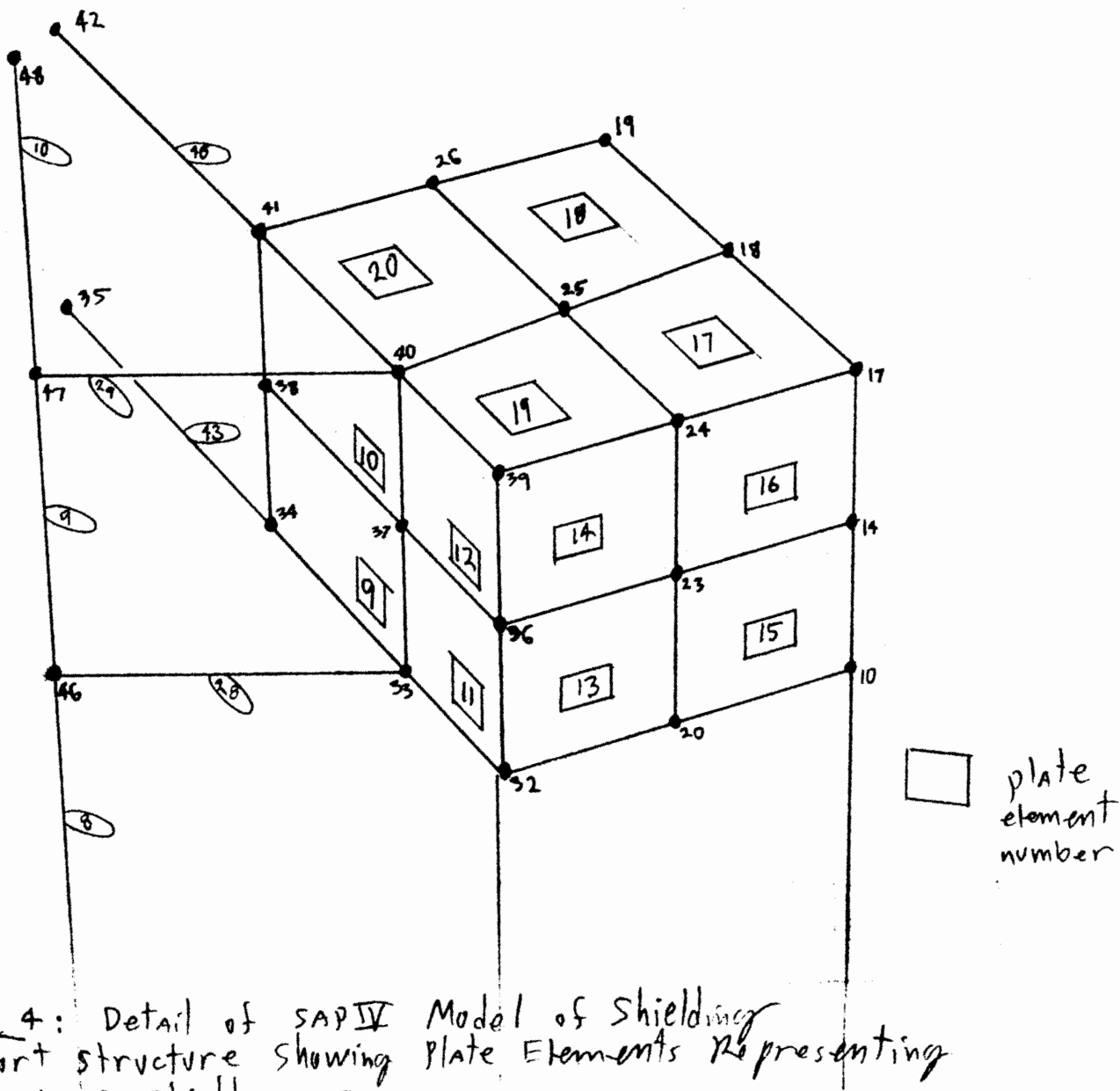


Figure 4: Detail of SAP IV Model of Shielding support structure showing Plate Elements representing Front of Shielding Box



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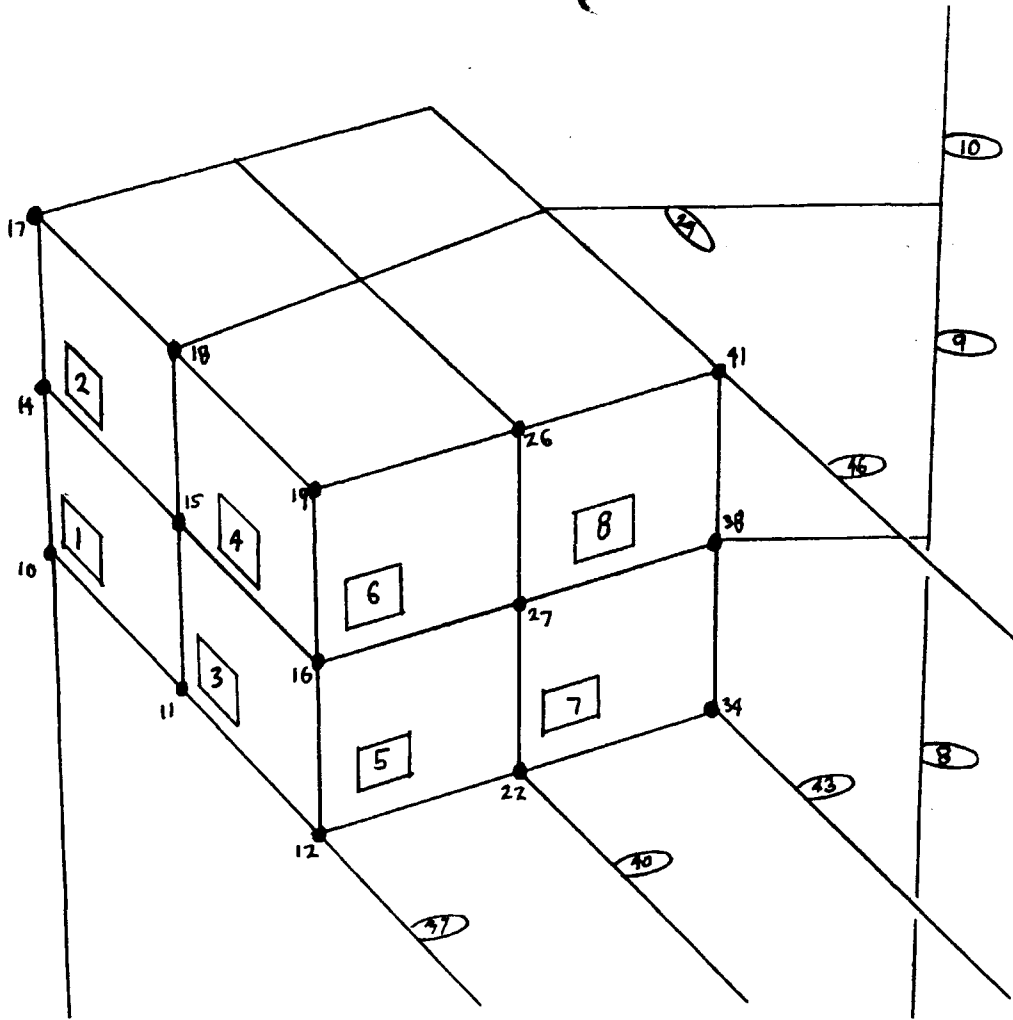


Figure 5: Detail of SAPIV Model of Shielding Support Structure showing Plate Elements Representing Rear of Shielding Box

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IV. Existing structure affected by downstream shielding modifications

A. Structural members 1-10 (fig. 1)

These members were analyzed previously (Ref. 6).

The results of this analysis are in the form of

$$R = \frac{\text{combined stress}}{\text{allowable stress}} \quad ?$$

From Ref. 1, part 5, section 1.6, equations 1.6-1a, 1.6-1b, and 1.6-2 as applicable. These members will be more severely stressed in the present case due to An (next page)

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increased shielding weight. Therefore new values of R can be conservatively calculated by multiplying R by

$$\frac{\text{weight of new downstream} + \text{source shielding}}{\text{weight of source shielding}}$$

This is conservative because it neglects the weight of the old downstream shielding which would appear in the denominator.

Weight of new downstream shielding

$$= .42 \frac{\text{lb}}{\text{in}^3} \times 28 \text{ in} \times 24 \text{ in} \times 34.75 \text{ in} = 9807 \text{ lb}$$

weight of source shielding (ref. E) = 7903

$$R' = R \left(\frac{9807 + 7903}{7903} \right) = \underline{\underline{2.24 R}}$$

Table I shows the results of this procedure.

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B. Existing W6x25 beam, member 11 (Fig. 1)

Almost all the loading on this beam is due to deadweight and LOCE z-accelerations. (fig 6).

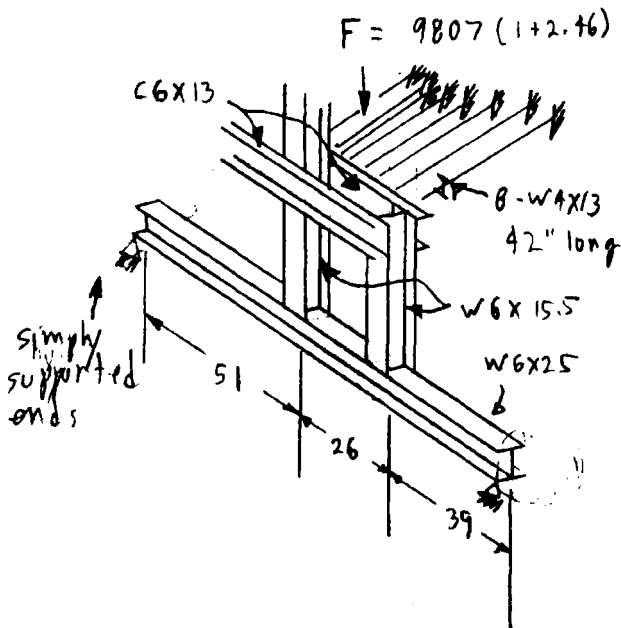


Figure 6: Existing W6x25 beam: arrangement

The total force acts on both the W6x25 beam and on 8-W4x13 beams of average length 42 inches.

The stiffness of the 8 W4x13's together is

$$K_1 = \frac{2EI}{l^3} = \frac{2(29 \times 10^6)(11.3)}{42^3}$$

$$K_1 = \underline{\underline{7.077 \times 10^9 \text{ lb/in}}}$$

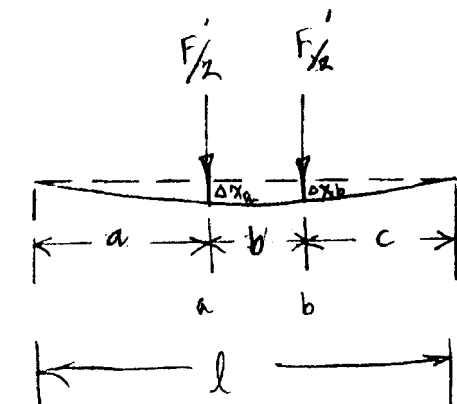
The stiffness of the W6x25 beam will be calculated by assuming that half the load is applied by each vertical W6x15.5 and using the average

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of the deflections calculated at both points (Fig. 7)

From Ref. 1,



$$\Delta x_a = \text{deflection at } a$$

$$= \frac{F a}{12 E I l} \left[(l^2 - a^2)(b + 2c) - (b + c)^3 + c^3 \right]$$

$$\Delta x_b = \frac{F c}{12 E I l} \left[(l^2 - c^2)(b + 2a) - (a + b)^3 + a^3 \right]$$

Figure 7: W6x25 beam (#11, Fig. 1)

With $l = 116$
 $a = 51$
 $b = 26$

$c = 39$
 $E = 29 \times 10^6$
 $I = 53.3$

$$\Delta x = \frac{1}{2} (\Delta x_a + \Delta x_b) = 1.793 \times 10^{-5} F'$$

$$K = K_2 = \frac{F'}{\Delta x} = \underline{\underline{5.578 \times 10^9 \text{ lb/in}}}$$

The total force applied to the W6x25 beam is

$$F' = \frac{5.578 \times 10^9}{7.077 \times 10^9 + 5.578 \times 10^9} (9807)(3.76) = \underline{\underline{14,956 \text{ lb}}}$$

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Bending moment at a & b:

$$M_a = \frac{1}{2} F' \left\{ \frac{(b+c)(a)}{l} + \frac{(c)(a)}{l} \right\} = 22.86 F'$$

$$M_b = \frac{1}{2} F' \left\{ \frac{cb + 2ca}{l} \right\} = 21.52 F'$$

MAX moment = $M_a = 341,894$ in-lb

$S = 16.7$ for W6X25, so

$$f_b = \frac{341,894}{16.7} = 20,473 \text{ psi} < 0.6 \text{ yield} = 21,600 \text{ psi}$$

C. W6X15.5 beams, members 12-14, Fig. 1

Loads (maximum)

$$R_1 = 8108 \text{ lb}$$

$$T_1 = 95 \text{ in-lb}$$

$$V_2 = 2606 \text{ lb}$$

$$M_2 = 17,410 \text{ in-lb}$$

$$V_3 = 461 \text{ lb}$$

$$M_3 = 58,504 \text{ in-lb}$$

$$f_a = \frac{8,108}{4.57} = 1,774 \text{ psi}$$

$$f_{b_2} = \frac{17,410}{10} = 1,741 \text{ psi}$$

$$f_v \leq \frac{2,606}{3.23} + \frac{461}{1.41} + \frac{95(1.235)}{.111} \quad f_{b_3} = \frac{58,504}{3.23} = 18,113 \text{ psi}$$

$$= 1335 \text{ psi}$$

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shear

$$\frac{f_r}{F_r} = \frac{1,335}{14,400} = .09 < 1$$

combined

$$\frac{Kl}{r} \leq \frac{(1)(92)}{1.46} = 63 < C_c$$

$$C_c = 126.1, \quad \frac{Kl/r}{C_c} = .5$$

$$F_a = \frac{[1 - \frac{1}{2}(.5)^2] 36,000}{\frac{5}{8} + \frac{3}{8}(.5) - \frac{1}{8}(.5)^2} = 17,133 \text{ psi}$$

$$F_e' \leq \frac{12(\pi^2)(29 \times 10^3)}{23(63)^2} = 37,624$$

$$C_m = .85, \quad F_b = .6(36,000) = 21,600; \quad \text{eqns. 1.6-1a + -1b}$$

are then:

$$1.6-1a \quad \frac{1774}{17133} + \frac{.85(1741)}{(1 - \frac{1774}{37624})21,600} + \frac{.85(18,133)}{(1 - \frac{1774}{37,624})21,600} = \underline{\underline{.92 < 1}}$$

$$1.6-1b \quad \frac{1774}{21,600} + \frac{1741 + 18133}{21,600} = \underline{\underline{1.00}}, \text{ so ok.}$$

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V. New downstream shield structure
 A. W4 x13 beams, members 15-24

Loads (MAXimum) -

$$R_1 = 3271 \text{ lbs}$$

$$T_1 = 935 \text{ lbs}$$

$$V_2 = 1243 \text{ lbs}$$

$$M_2 = 45190 \text{ in-lbs}$$

$$V_3 = 3235 \text{ lbs}$$

$$M_3 = 19,776 \text{ in-lbs}$$

stresses -

$$f_a = \frac{3271}{3.82} = 856 \text{ psi}$$

$$f_{b_2} = \frac{45,190}{5.45} = 8292 \text{ psi}$$

$$f_w \leq \frac{1243}{2.8} + \frac{3235}{1.17} + \frac{935(.20)}{.154}$$

$$f_{b_3} = \frac{19,776}{1.85} = 10,690 \text{ psi}$$

$$= 4909 \text{ psi}$$

Allowable stresses (ref. 1)

$$C_c = 106.1, \quad \frac{K \cdot l}{r} \approx \frac{1(.80)}{.991} = 80.73, \quad \frac{K \cdot l / r}{C_c} = .64$$

$$F_a = \frac{[1 - \frac{1}{2}(.64)^4](36,000)}{\frac{5}{3} + \frac{3}{8}(.64) - \frac{1}{8}(.64)^3} = 15,277 \text{ psi}$$

$$\frac{f_a}{F_a} = \frac{856}{15,277} = .06, \quad \text{so eqn. 1.6-2 applies}$$

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$$.06 + \frac{8292 + 10,690}{21,600} = \underline{\underline{.94 < 1}}$$

$$\frac{f_v}{F_v} = \frac{4909}{14,400} = \underline{\underline{.34 < 1}}$$

B. C 6 x 13 channels, members 26+27, fig. 1

Loads (max)

$R_1 = 6828$

$T_1 = 882$

$V_2 = 1229$

$M_2 = 57,618$

$V_3 = 4083$

$M_3 = 11,310$

section properties

$A_1 = 7.66 \text{ in}^2$

$J_1 = .482, k_1 = .343$

$r = .525$

$A_2 = 2.959 \text{ in}^2$

$S_2 = 11.6$

$A_3 = 5.299 \text{ in}^2$

$S_3 = 1.28$

Stresses

$f_a = \frac{6828}{7.66} = 891 \text{ psi}$

$f_{b_2} = \frac{57,618}{11.6} = 4967 \text{ psi}$

$f_v = \frac{1229}{2.959} + \frac{4083}{5.299} + \frac{882(.343)}{.482} = 1822 \text{ psi}; f_{b_3} = \frac{11,310}{1.28} = 8836 \text{ psi}$

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bending stresses + membrane stresses

$$\left. \begin{aligned}
 \sigma_x &= 6496 + 742 = 7238 \\
 \sigma_y &= 8270 + 1079 = 9349 \\
 \tau_{xy} &= 12237 + 2296 = 14533
 \end{aligned} \right\} 2\tau_{\max \text{ memb} + \text{ bend}} = 29,371 \text{ psi}$$

Allowable stresses - the ASME code (Ref. 1)
 will be used as a guide here, since the
 AISC code (Ref. 1) does not address plate
 structures -

$$\begin{aligned}
 \text{allowable membrane stress intensity} &= \frac{2}{3}(36,000) = \underline{24,000 \text{ psi}} \\
 \text{allowable memb. + bending stress intens.} &= \underline{36,000}
 \end{aligned}$$

$$\text{so } \frac{2\tau_{\max \text{ memb}}}{24,000} = \underline{\underline{.21 < 1}}$$

$$\frac{2\tau_{\max \text{ memb} + \text{ bend}}}{36,000} = \underline{\underline{.82 < 1}}$$

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VI. Connections

A. Connections in existing structure

The method of **IV. A.** (p. 10) will be used

1. Connection of angled W4X13 beam to MTA built-up beam (fig. 1), connection # 1)

See ref. 6, p. 69: this is the most highly stressed major connection in the source structure, so re-analyze:

$R_1 = 2988$ $T_1 = 123$ (See fig. 3, node 54)

$V_2 = 1953(2.24) = 4375; M_2 = 8031$

$V_3 = 1162$ $M_3 = 16,960(2.24) = 37,990$

at ①

$$\left. \begin{aligned} \tau_{12} &= \frac{2988}{2.683} + \frac{2(37,990)}{2.683(4.06)} = 8,089 \text{ psi} \\ \sigma_2 &= \frac{4375}{2.683} = 1631 \text{ psi} \\ \tau_{32} &= 3699 \text{ psi} \end{aligned} \right\} \sigma_{\max} = \underline{\underline{8946 \text{ psi} < 14,400}}$$

at ②

$$\left. \begin{aligned} \tau_{13} &= 8089 \\ \tau_{23} &= 1631 \\ \sigma_3 &= 3699 \end{aligned} \right\} \sigma_{\max} = \underline{\underline{10,111 \text{ psi} < 14,400 \text{ psi}}}$$

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LOADS

$$R_1 = 6828 \text{ lb}$$

$$T_1 = 882 \text{ in-lb}$$

$$V_2 = 1229 \text{ lb}$$

$$M_2 = 57,618 \text{ in-lb}$$

$$V_3 = 4083 \text{ lb}$$

$$M_3 = 11,310 \text{ in-lb}$$

Forces parallel to weld

due to R_1 : $F'_{R_1} = \frac{6828}{4(6)} = \underline{285 \text{ lb/in}}$

due to M_2 :

$$\frac{1}{4}(57,618) = F'_{m_2}(3)(6) \Rightarrow F'_{m_2} = \underline{800 \text{ lb/in}}$$

Forces perpendicular to weld

due to V_2

$$F'_{V_2} = \frac{1229}{4(6)} = \underline{51 \text{ lb/in}}$$

due to V_3

$$F'_{V_3} = \frac{4083}{4(6)} = \underline{170 \text{ lb/in}}$$

due to T_1 : $F'_{T_1} = \frac{882}{6(2)(6)} = \underline{12 \text{ lb/in}}$

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due to M_3

$$2 \left\{ 2 \left(\frac{1}{2} F'_{m_3} \right) (3) \right\} = \frac{1}{4} (11,310)$$

$$F'_{m_3} = 471.25 \text{ lb/in}$$

$$\begin{aligned} \text{total force/in} &= \sqrt{(285 + 800)^2 + (51 + 12 + 471.25)^2 + 170^2} \\ &= 1221 \text{ lb/in} \end{aligned}$$

$$\sigma_{\text{weld}} = \frac{1221}{(1.707)(.25)} = \underline{\underline{6910 \text{ psi} < 14,400 \text{ psi}}}$$

2. Connections between C 6 X 13 channels and W 4 X 13 beam (fig. 1, # 11)

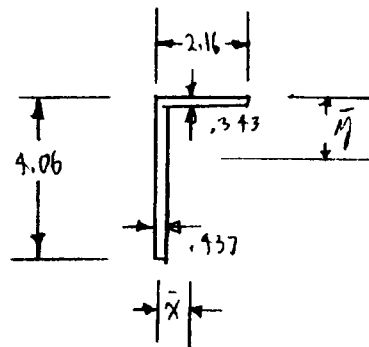
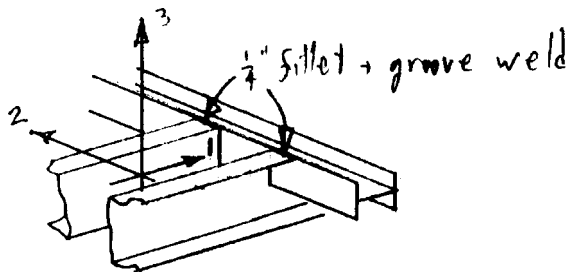


Figure 9: Connections between C 6 X 13 channels and W 4 X 13 beam

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Weld section properties -

$$Area = 2 (.343 (2.16 - .437) + .437 (4.06)) = 4.73 \text{ in}^2$$

$$\bar{x} = \frac{.437 (1.624) + \frac{2.16}{2} (.191)}{1.624 + .741} = .488 \text{ in}$$

$$I_{xx} = \underline{.692 \text{ in}^4}$$

$$\bar{y} = \frac{\frac{4.06}{2} (1.774) + \frac{.343}{2} (.591)}{.591 + 1.774} = 1.566 \text{ in}$$

$$I_{yy} = \underline{3.979 \text{ in}^4}$$

Loads

$$R_1 = 1952 \text{ lb}$$

$$T_1 = 298 \text{ in-lb}$$

$$V_2 = 308 \text{ lb}$$

$$M_2 = 7497 \text{ in-lb}$$

$$V_3 = 1322 \text{ lb}$$

$$M_3 = 7771 \text{ in-lb}$$

forces

parallel to weld

$$\text{due to } V_2 : \frac{308}{4.32} = 71.3 \text{ lb/in.}$$

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$$\text{due to } V_3 : \frac{1322}{8.12} = 163 \text{ lb/in}$$

$$\text{due to } T_1 : \frac{298}{6(4.06)} = 12.2 \text{ lb/in}$$

normal to wall

due to M_2

$$\frac{7497(4.06 - 1.566)}{2(3.974)} (.437) = 1028 \text{ lb/in}$$

due to M_3

$$\frac{7771(2.16 - .988)}{2(.692)} (.343) = 3220 \text{ lb/in}$$

due to R_1

$$\frac{1952}{2(4.06 + 2.16)} = 157 \text{ lb/in}$$

$$\begin{aligned} \text{max force/in} &\leq \sqrt{(3220 + 157)^2 + (163 + 12.2)^2} \\ &= 3382 \text{ lb/in} \end{aligned}$$

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so weld stress = $\frac{3382}{.343} = 9959 \text{ psi} < 19,400$

3. Connection between W4X13 beam and MTA built-up beams (fig. 1, #12; fig. 10)

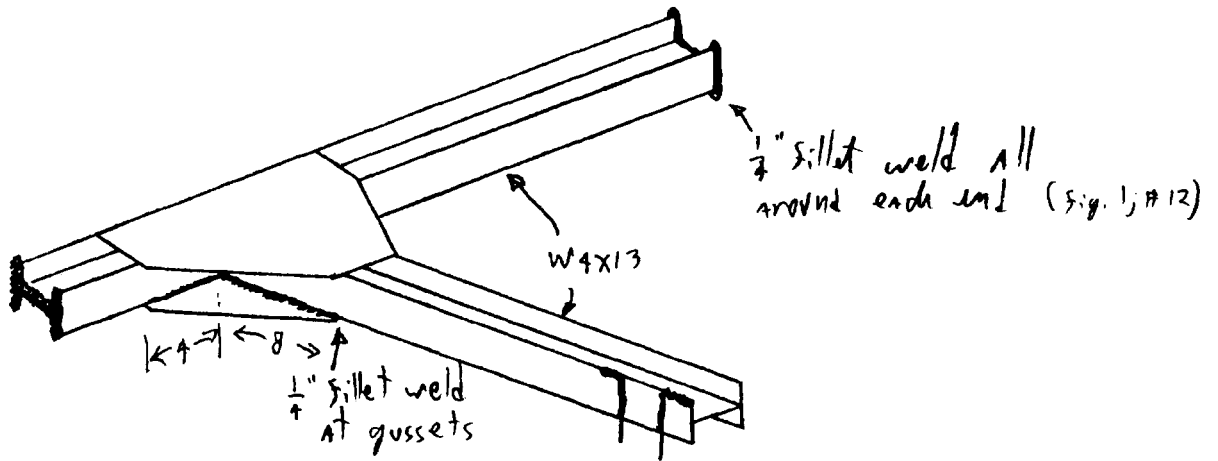
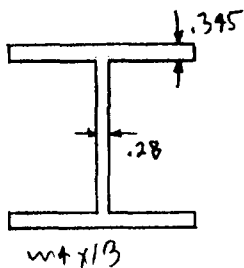


Figure 10: W4X13 beam structure

strength of connection -



Effective weld leg - thicknesses of section are greater than 1/4 inch, so Res. 1, sec. 1.17.6 applies -

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and maximum weld size is $\frac{1}{16}$ inch less than material thickness

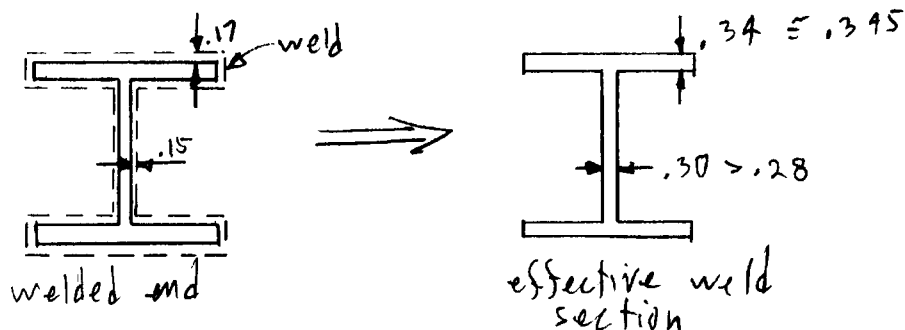
flanges : $.345 - \frac{1}{16} = .2825 \Rightarrow .25$ inch leg, a

web : $.28 - \frac{1}{16} = .2175$ inch leg, a

$a < \frac{3}{8}$ in each case, so the weld throat is equal to the weld leg, .25 and .22 inches, respectively. The weld allowable stress is

19,400 psi vs. 21,600 psi for the base metal.

To allow for this, reduce the effective weld throats by $\frac{19,400}{21,600} = .67$ to .17 in and .15 in, respectively. The weld pattern is then:



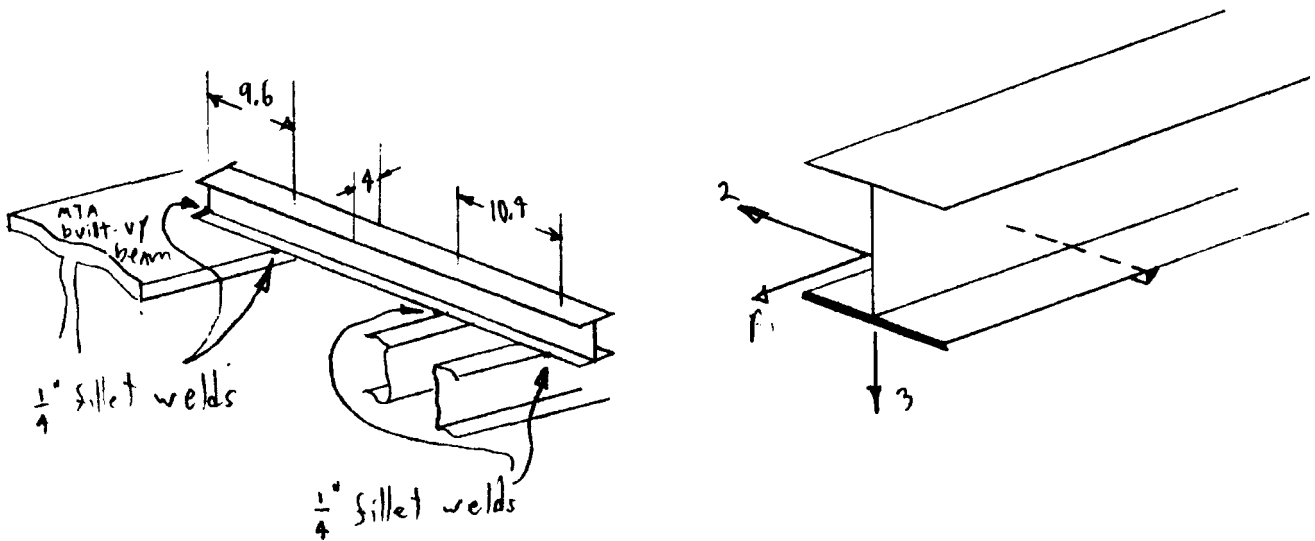
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The effective weld section is as strong as the beam itself, so no further analysis is required.

By inspection, the gusset welds (Fig. 1, # 43; Fig. 10) are stronger than the end welds just considered.

4. Connections between 8 W4X13 beams and MTA built-up beam and C6X13 channels (Fig. 1, # 14915)



The weld at the built-up beam end is the weaker, so analyze it with the worst loads.

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LOADS

$$R_1 = 1297 \text{ lb}$$

$$T_1 = 25 \text{ in-lb} \cong 0$$

$$V_2 = 306 \text{ lb}$$

$$M_2 = 51465 \text{ in-lb}$$

$$V_3 = 777 \text{ lb}$$

$$M_3 = 13,312 \text{ in-lb}$$

Forces parallel to weld

due to V_2

$$F'_{V_2} = \frac{306}{8} = 38.25 \text{ lb/in}$$

due to M_3

$$F'_{M_3} = \frac{13,312}{9.6(4)} = 347 \text{ lb/in}$$

Forces perpendicular to weld

-1 direction

due to R_1

$$F'_{R_1} = \frac{1297}{8} = 162 \text{ lb/in}$$

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in -3 direction

due to M_2

$$F'_{M_2} = \frac{51965}{9.6(4)} = 1340 \text{ lb/in}$$

$$\begin{aligned} \text{Total weld force/in} &= \sqrt{(347 + 38.25)^2 + 162^2 + 1390^2} \\ &= 1404 \text{ lb/in} \end{aligned}$$

$$\text{weld stress} = \frac{1404}{(707)(.25)} = \underline{\underline{7992 \text{ psi} < 19,900 \text{ psi}}}$$

S. Connections between plates in welded box structure

The plates are nearly simply-supported, so the welds are only subject to the membrane stresses in the plates

Loads max normal stress in plate = 3191 psi
 max shear stress in plate = 2296 psi

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weld forces/inch

$$\text{parallel} = 2296 (.25) = 574 \text{ lb/in}$$

$$\text{normal} = 3141 (.25) = 785 \text{ lb/in}$$

$$\text{total} = 973 \text{ lb/in}$$

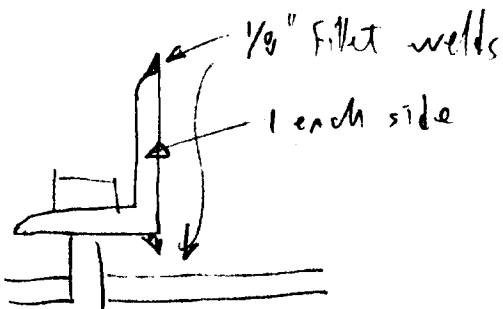
$$\text{weld stress} = \frac{973}{.707(.25)} = \underline{\underline{5505 \text{ psi} < 19,900 \text{ psi}}}$$

6. Bolted connection in shield box structure (fig. 1, #17)

18 bolts, $\frac{1}{2}$ inch - 13 VNC

$$\text{stress} = \frac{9807 \text{ lb} (4.46)}{18 (.1414)} = \underline{\underline{17,127 \text{ psi} < 20,000 \text{ psi}}}$$

the bolts attach the cover plate to the box through a welded angle 20 inches long (See sketch),

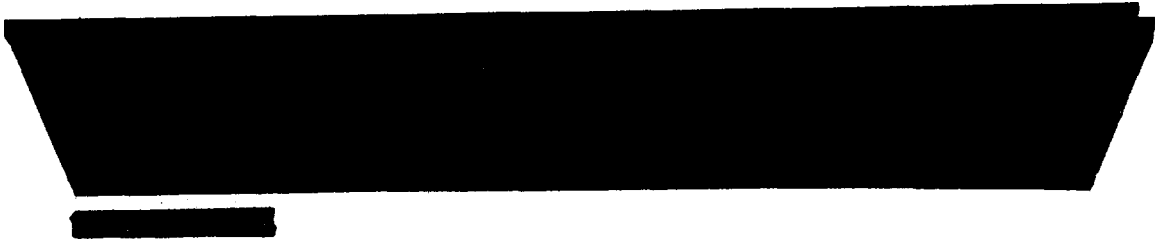


$$\text{weld stress} = \frac{9807 (4.46)}{80 (.125) (.707)} = \underline{\underline{6187 \text{ psi} < 19,900 \text{ psi}}}$$

APPENDIX B
SAP IV SOURCE LISTING

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