85015473 EGG

LOFT TECHNICAL REPORT LTR 1310-31

RE&C INTERNAL REPORT RE-A-78-133

MARCH 26, 1979

EGG/LTR--1310-31

DE85 015473

LOFT 3C CABLE TRAY
AND LADDER SEISMIC ANALYSIS

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IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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LOFT 3C CABLE TRAY

AND LADDER SEISMIC ANALYSIS

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LOFT TECHNICAL REPORT
LOFT PROGRAM

FORM EG&G-229
(Rev. 12-76)

TITLE LOFT 3C CABLE TRAY AND LADDER SEISMIC ANALYSIS		REPORT NO. LTR 1310-31
		RE-A-78-133
AUTHOR W. R. Mosby	GWA. NO.	
PERFORMING ORGANIZATION Applied Mechanics <i>Ed Moore 6-14-78</i>	DATE	
LOFT APPROVAL <i>[Signatures]</i>	March 26, 1979	
PSE Seismic P&CSB Review Mgr.	PSB Mgr. RSB Mgr.	

ABSTRACT

The LOFT 3C cable tray and ladder were analyzed for LOCE and Safe Shutdown Earthquake (SSE) seismic loads by using equivalent static loads. Design changes were recommended to alleviate overstress conditions.

DISPOSITION OF RECOMMENDATIONS

The necessary changes and additions will be accomplished during FY'79 in a task identified as 521867F00 and SWR 52218.

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LOFT 3C CABLE TRAY AND LADDER SEISMIC ANALYSIS

I. INTRODUCTION

The LOFT 3C cable tray and ladder were analyzed for LOCE and Safe Shut-down Earthquake (SSE) seismic loads by using equivalent static loads. Design changes were recommended to alleviate overstress conditions.

II. METHOD OF ANALYSIS

The cable tray and ladder were each treated as rigid bodies subjected to static forces acting on their centers of gravity. These equivalent static loads were calculated using acceleration data from References 3, 4, and 5 and weight data from private communication with N. Pyke (May 22, 1978).

Using simplifying assumptions, forces and stresses were calculated in the cable tray support welds and bolts and in the ladder support welds, bolts, and studs from static equilibrium considerations.

Material properties were used from References 2 and 7. Allowable stresses from Reference 1 were used while section properties and stress formulas from References 6 and 8 were used.

III. RESULTS AND RECOMMENDATIONS

Due to the high predicted seismic accelerations acting on the cable tray and ladder, strengthening of these structures is required as follows:

1. The fillet welds attaching the cable tray supports (2 x 2 x 1/4" angle) to the mounting plates (3 x 3 x 5/8") should be modified so that

$$\frac{I_{xx}}{C} \geq .771 \text{ in.}^3$$

(see Figure 5, on page 9 of the Appendix).

2. Use three 5/16"-18 UNC bolts to attach each cable tray to each of its four supports.
 3. Replace the ladder mounting bolts and studs as shown in Table I, below.
- The bolt numbering system is shown in Figure 15 on page 23 of the Appendix.

TABLE I

LADDER MOUNTING BOLT AND STUD REPLACEMENT

<u>Bolt or Stud Number</u>	<u>Original Size</u>	<u>Replacement</u>	<u>Note</u>
1	1/2"-13 UNC	5/8"-11 UNC	
2	1/2"-13 UNC	5/8"-11 UNC	
3	1/2"-13 UNC	No Change	
4	1/2"-13 UNC	No Change	
5	1/2"-13 UNC	1"-8 UNC	
6	1/2"-13 UNC	1"-8 UNC	
7	1/2"-13 UNC	5/8"-11 UNC	
8	1/2"-13 UNC	5/8"-11 UNC	
9	1/2"-13 UNC	5/8"-11 UNC	
10	1/2"-13 UNC	5/8"-11 UNC	
11	1/2"-13 UNC	3/4"-10 UNC	(1)
12	1/2"-13 UNC	3/4"-10 UNC	(1)
13	1/2"-13 UNC	3/4"-10 UNC	(2)
14	1/2"-13 UNC	3/4"-10 UNC	(2)
15	1/2"-13 UNC	5/8"-11 UNC	
16	1/2"-13 UNC	5/8"-11 UNC	
17	3/8"-16 UNC	No Change	
18	3/8"-16 UNC	No Change	
19	3/8"-16 UNC	No Change	
20	3/8"-16 UNC	No Change	
21	3/8"-16 UNC	No Change	
22	3/8"-16 UNC	No Change	
23	3/8"-16 UNC	No Change	
24	3/8"-16 UNC	No Change	
25	3/8"-16 UNC	1/2"-13 UNC	
26	3/8"-16 UNC	7/8"-9 UNC	
27	3/8"-16 UNC	5/8"-11 UNC	
28	3/8"-16 UNC	7/8"-9 UNC	

Notes:

- (1) Use two replacement bolts per original bolt as shown in Figure 16, page 29 of the Appendix.
- (2) Use two replacement bolts per original bolt as shown in Figure 17, page 29 of the Appendix.

IV. REFERENCES

1. American Institute of Steel Construction, Steel Construction Manual, Seventh Edition, 1970.
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6. O. W. Blodgett, "Design of Welded Structures", James F. Lincoln Arc Welding Foundation, 1966.
7. American Society for Testing and Materials, Annual Book of ASTM Standards, 1977.
8. R. J. Roark and W. C. Young, Formulas for Stress and Strain, 5th Edition, McGraw-Hill, 1975.

APPENDIX
CABLE TRAY AND LADDER SEISMIC ANALYSIS

CALCULATION WORK SHEET

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I. Cable tray support and cable ladder geometry

A. Cable tray supports

Figure 1 shows the cable tray and its supports. The trays are bolted to the supports which are welded to terminal boxes on the LOFT MTA.

Figure 1: Cable trays and Supports

The total weight of trays and supports is 704 lbs, made up of the trays (15.83 ft @ 35 lb/ft total for both trays + 3 ft. of cable projecting at each end @ 15 lb/ft total) and the four supports (3 @ 16.5 lb, 1 @ 10.25 lb.).

Section A-A in Figure 1 is shown in Figure 2

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Figure 2: Support Details

B. Cable ladder

Figure 3 shows the cable ladder and its supporting structure.

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Figure 3: Cable Ladder

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II. Materials

A. Bolts - carbon steel

Assume carbon steel nuts and bolts to be A307 steel.
Reference 1, section 1.6-3, gives

$$F_T = \text{Allowable tensile stress} = 28000 \text{ psi} - 1.6 F_v \leq 20,000 \text{ psi}$$

$$F_v = \text{Allowable shear stress} = 10,000 \text{ psi}$$

S_v = computed shear stress

$$A_T = \text{tensile (a shear) stress area} = .7854 \left(D - \frac{.9743}{n} \right)^2$$

D = nominal bolt diameter

n = # threads per inch

$$A_s = \text{thread shear area} = \frac{\pi E L_e}{2} \quad (\text{ref. B})$$

$$E = D - \frac{.64952}{n}$$

L_e = engagement distance = nut thickness

B. Studs (304 s.s., ASTM A-276) and nuts

Reference 7 gives

$$F_y = 45,000 \text{ psi for bar of diameter} \leq \frac{1}{2}''$$

$$= 30,000 \text{ psi for bar of diameter} > \frac{1}{2}''$$

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Allowable tensile and shear stresses for studs made of this material are calculated by analogy with Reference 1. For A307 steel,

$$F_y = 36,000 \text{ psi}$$

$$F_T = 28,000 - 1.6 F_v \leq 20,000 \text{ psi}$$

or

$$F_T = .78 F_y - 1.6 F_v \leq .56 F_y$$

$$F_v = 10,000 \text{ psi} \approx .3 F_y$$

so for 304 ss, A-276,

1) Diameter $\leq \frac{1}{2}"$

$$F_T = 31,500 \text{ psi} - 1.6 F_v \leq 25,200 \text{ psi}$$

$$F_v = 13,500 \text{ psi}$$

2) Diameter $> \frac{1}{2}"$

$$F_T = 23,400 \text{ psi} - 1.6 F_v \leq 16,800 \text{ psi}$$

$$F_v = 9,000 \text{ psi}$$

C. Ladder Braces (3"-40, ASTM A53 pipe)

$$E = 29 \times 10^6 \text{ psi}$$

$$F_y = 35,000 \text{ psi}$$

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

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D. $\frac{3}{8}$ inch plate (misc. support pieces)

ASTM A-36 steel

$F_y = 36,000$ psi = yield strength

$F_u = 58,000$ psi = ultimate strength

E. Welds

1. to A-36 steel

F_w = allowable stress = $.3 F_u$ or $.4 F_y$, whichever is less.

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

2. 304 s.s. studs to containment

$F_y = 38,000$ psi for containment (SA-516 Gr. 70)
(ref. 2)

so for stud. diameter $\leq \frac{1}{2}$ ", $F_w = .4(38,000)$,

$$F_w = 15,200 \text{ psi}$$

For stud diam $\geq \frac{1}{2}$ ", $F_w = .4(30000) = 12,000 \text{ psi}$

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III. Seismic and LOCE Accelerations**A. Seismic Accelerations (2% damping)**

Using the LOFT MTA model (ref. 3) the following SSE accelerations were found to apply to the cable trays, after multiplying by 1.5 (ref. 5):

$$\ddot{x} = 13.25 g, \ddot{y} = 11.03 g, \ddot{z} = 1.88 g$$

The ground response spectrum (ref. 4) accelerations multiplied by 8 (ref. 5) apply to the ladder:

$$\ddot{x} = 6.2 g, \ddot{y} = 6.2 g, \ddot{z} = 4.13 g$$

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B. LOCE Accelerations (2% damping)

The LOCE accelerations are zero for the ladder. The LOFT MTA model shows

$$\ddot{x} = 2.74 g$$

$$\ddot{y} = 1.19 g$$

$$\ddot{z} = 2.59 g$$

The z-direction acceleration causes only small stresses in the cable tray assembly and the x- and y-direction accelerations are much higher for the SSE than for the LOCE.

Only SSE accelerations will be used in the analysis.

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IV. Cable Tray And Support Stresses

A. X-direction accelerations

1. Forces & moments

X-direction accelerations cause bending-type stresses in the support base welds
As shown in fig. 4. On each support,

$$V = \frac{F_x}{4} = \frac{13.25(704)}{4}$$

$$V = \underline{\underline{2332 \text{ lb}}}$$

Figure 4: x-force system on cable tray assembly

$$M = \frac{9 F_x}{4} = \underline{\underline{20,988 \text{ in-lb}}}$$

2. Stresses

a. Mounting plate fillet welds (see fig. 2)

$$\sigma = \frac{M c}{I} ; I = 4 \int_{.5}^{1.5} (.707)(.25) y^2 dy + 4(1)(.707)(.25)(1.5)^2$$

$$I = \frac{4(.707)(.25)}{3} [1.5^3 - .5^3] + 4(.707)(.25)(1.5)^2$$

$$I = 2.36 \text{ in}^4$$

$$c = 1.5 \text{ in}$$

$$M = \frac{20,988}{2} = 10,494 \text{ in-lb}$$

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$$\sigma = \frac{(10,494)(1.5)}{2.36} = \underline{\underline{6670 \text{ psi}}}$$

$$f_v = \tau = \frac{V}{A}, \quad V = \frac{2332}{2} = 1166 \text{ lb}$$

$$A = .707(1.25)(8) = 1.41 \text{ in}^2$$

$$f_v = \frac{1166}{1.41} = \underline{\underline{827 \text{ psi}}}$$

b. Angle-to-mounting plate fillet welds

Figure 5 shows a plan view of this weld. From reference 6,

Figure 5: Angle-to-mounting plate weld

$$I_{xx} \approx \frac{(d^3)(4b+d)}{12(b+d)}$$

$$I_{xx} \approx 2(.1768) \frac{(2^3)(4(2)+2)}{12(2+2)} = \underline{\underline{.590 \text{ in}^4}}$$

$$I_{yy} = h_w^2 A_w + I_{xx} \Rightarrow h = \sqrt{\frac{I_{yy} - I_{xx}}{A_w}}$$

$$A_w \approx 4(2(.1768)) = \underline{\underline{1.41 \text{ in}^2}}$$

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$$I_{yy} = \frac{2(2(1.768))^3}{12} + \frac{1}{2} \frac{(2(1.768))(4)^3}{12} = .950 \text{ in}^4$$

$$h = \sqrt{\frac{.950 - .590}{1.41}} = .5$$

$$c = 2 - .5 = 1.5 \text{ in}$$

$$\sigma = \frac{(10,444)(1.5)}{.590} = \underline{\underline{26,680 \text{ psi}}}$$

$$s_v = \tau = \frac{1166}{1.41} = \underline{\underline{827 \text{ psi}}}$$

c. $\frac{5}{16}$ - 18 UNC bolts

Negligible tensile stresses are produced in these bolts by x-direction accelerations.

$$s_v = \tau = \frac{V/4}{A_T} ; \quad \frac{V}{4} = 583 \text{ lb}$$

$$A_T = .7854 \left(\frac{5}{16} - \frac{.9743}{18} \right)^2 = .0524 \text{ in}^2$$

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$$f_v = \frac{583}{.0524} = \underline{\underline{11,126 \text{ psi}}}$$

d. Cross-member fillet welds

$$f_v = \tau = \frac{V/2}{A_w} ; V/2 = 1166 \text{ lb}$$

$$A_w = (.1768)(2) = .3536 \text{ in}^2$$

$$f_v = \underline{\underline{3298 \text{ psi}}}$$

B. Y+Z-direction accelerations

1. Forces on supports

The tray-support assembly can be considered a rigid body for y+z-direction accelerations. See figure 6.

Figure 6: y+z force system

$$\Sigma M_0 = 0$$

$$F_2(21) + F_y(11) + F_z(11.5) = 0$$

$$F_y = 11.03 \left(\frac{704}{4} \right) = \frac{7765}{4} \text{ lb}$$

$$F_z = (1.88 - 1) \left(\frac{704}{4} \right) = \frac{620}{4} \text{ lb}$$

$$4(F_2) = \frac{-7765(11) - 620(11.5)}{21}$$

$$F_2 = -4407 \text{ lb/4} = \underline{\underline{-1102 \text{ lb}}}$$

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$$\sum F_z = 0$$

$$F_z + F_1 + F_2 = 0$$

$$F_1 = \frac{-620 - (-4407)}{4} = 3787 \text{ lb/4} = \underline{\underline{947 \text{ lb}}}$$

$$\sum F_y = 0$$

$$-2V_1 + F_y = 0$$

$$V_1 = \frac{F_y}{2} = \frac{7765}{2} = 3883 \text{ lb/4} = \underline{\underline{971 \text{ lb}}}$$

2. Forces on $\frac{5}{16}$ " - 18 UNC bolts

See Figure 7.

$$\sum M_0 = 0$$

$$F_4 (4) + F_2 (2) + F_y (2) = 0$$

$$F_y = \frac{11.03(352)}{4} = 971 \text{ lb}$$

$$F_2 = \frac{(1.88-1)(352)}{4} = 77 \text{ lb}$$

Figure 7: Max force system on cable tray

$$F_4 = \frac{-971(2) - 77(2)}{4} = \underline{\underline{-131 \text{ lb}}}$$

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$$\sum F_y = 0$$

$$V_1 = \frac{F_y}{2} = \underline{\underline{486 \text{ lb}}}$$

$$\sum F_z = 0$$

$$F_3 + F_4 + F_2 = 0$$

$$F_3 = -F_4 - F_2 = 131 - 77 = \underline{\underline{54 \text{ lb.}}}$$

3. Stresses

a. Mounting plate fillet welds

$$\sigma = \frac{F_2}{A_w} = \frac{1102}{1.41} = \underline{\underline{782 \text{ psi}}}$$

$$f_v = \frac{V_1}{A_w} = \frac{971}{1.41} = \underline{\underline{689 \text{ psi}}}$$

b. Angle-to-mounting plate fillet welds

$$\sigma = \frac{1102}{1.41} = \underline{\underline{782 \text{ psi}}}$$

$$f_v = \frac{971}{1.41} = \underline{\underline{689 \text{ psi}}}$$

c. $\frac{5}{16}$ " - 18 bolts

$$\sigma = \frac{F_4}{A_T} = \frac{131}{.0524} = \underline{\underline{2500 \text{ psi}}}$$

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$$f_v = \frac{V_2}{A_T} = \frac{486}{.0524} = \underline{\underline{9275 \text{ psi}}}$$

C. Combined stresses and Allowable stresses

The forces mentioned above all act simultaneously. The worst-case load direction combinations are assumed below.

1. Mounting plate fillet welds

$$V_t = \text{total shear force} = \sqrt{(V_2)^2 + V_1^2} = 1517 \text{ lb}$$

$$f_{v_t} = \frac{V_t}{1.41} = \underline{\underline{1076 \text{ psi}}} < \underline{\underline{14,400 \text{ psi}}} = \text{allowable fillet weld stress}$$

$$\sigma_t = 6,670 \text{ psi} + 782 \text{ psi} = \underline{\underline{7452 \text{ psi}}} < \underline{\underline{14,400 \text{ psi}}}$$

2. Angle-to-mounting plate welds

$$V_t = 1517 \text{ lb}$$

$$f_{v_t} = \frac{V_t}{1.41} = \underline{\underline{1076 \text{ psi}}} < \underline{\underline{14,400 \text{ psi}}}$$

$$\sigma_t = 26,680 \text{ psi} + 782 \text{ psi} = \underline{\underline{27,462 \text{ psi}}} > \underline{\underline{14,400 \text{ psi}}}$$

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3. $\frac{5}{16}$ " - 18 UNC bolts

$$V_t = \sqrt{583^2 + 486^2} = 759 \text{ lb}$$

$$S_{V_t} = \frac{759}{.0524} = \underline{14,485 \text{ psi}} > \underline{10,000 \text{ psi}} = \text{allowable bolt shear stress}$$

$$F_t = 28,000 - 1.6(14,485) = 4824 \text{ psi}$$

$$\sigma = \underline{2500 \text{ psi}} < \underline{4824 \text{ psi}}$$

4. Cross-member fillet welds

$$S_v = \underline{3298 \text{ psi}} < \underline{14,400 \text{ psi}}$$

This neglects a very small vertical acceleration component.

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V. Ladder Support And Bolt Stresses

A. Ladder support bolts

Figure 8: Ladder Force system

1. Forces due to F_y and F_z

The complete system of forces acting on the ladder support bolts is shown in Figure 8. Forces F_5 , F_6 , F_7 , and F_8 actually act on the ladder support brackets. Figure 9 shows a two-dimensional representation of the ladder which will be used to calculate the y-z plane forces.

From Figure 9,

Figure 9: Simplified Ladder Force system

$$F_A = F_F \cos \theta = .74 F_F$$

$$F_C = -F_F \sin \theta = -.67 F_F$$

This Assumes that the angled pipe supporting the outer end of the ladder acts as a truss and transmits only small

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Forces perpendicular to its centerline.

Moment and force equilibrium give, with $\theta = 42^\circ$,

$$\sum M_0 = 0$$

$$F_B(65.3) + F_D(-6.8) + F_F(0) = F_Y(-14.14) + F_Z(-27.6)$$

$$\sum F_Y = 0$$

$$F_B(0) + F_D(-1) + F_F(.67) = -F_Y$$

$$\sum F_Z = 0$$

$$F_B(1) + F_D(0) + F_F(.74) = -F_Z$$

Or

$$F_A = (.1)F_Y - .5 F_Z, \quad F_B = -.103 F_Y - .47 F_Z,$$

$$F_C = -.09 F_Y + .48 F_Z, \quad F_D = 1.09 F_Y - .48 F_Z$$

$$F_F = .14 F_Y - .71 F_Z$$

2. Forces due to F_x

Assume $F_1 = F_4 = F_9 = F_{12} = F_5 = F_8 = 0$ with only F_x acting. This is equivalent to assuming that the inner support structure is much stiffer than the outer (pipe) supports for this loading direction. Also Assume

$$F_{6x} = F_{7x} = \underline{F_x/2}$$

Forces due to F_x alone will be written

$F_{1x}, F_{2x}, \text{etc.}$

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Using the point of application of F_2 as origin,

$$\Sigma M_y = 0$$

$$F_{3x} = \frac{F_x (7.6)}{24} = \underline{\underline{.32 F_x}}$$

$$\Sigma F_z = 0$$

$$F_{2x} = -F_{3x} = \underline{\underline{-.32 F_x}}$$

$$\Sigma M_z = 0$$

$$F_{11x} = - \frac{F_x (37.7)}{24} = \underline{\underline{-1.57 F_x}}$$

$$\Sigma F_y = 0$$

$$F_{10x} = -F_{11x} = \underline{\underline{1.57 F_x}}$$

B. Ladder outer supports (pipes)

Equilibrium along each pipe requires

$$F_g = F_f - F_{yp} \sin \theta - F_{zp} \cos \theta$$

$$F_g = .14 F_y - .71 F_z - .67 F_{yp} - .74 F_{zp}$$

The maximum lateral inertial load on the pipe is

$$F_{LAT} = \sqrt{(F_{yp} \cos \theta + F_{zp} \sin \theta)^2 + F_{xp}^2}$$

$$F_{LAT} = \sqrt{(.74 F_{yp} + .67 F_{zp})^2 + F_{xp}^2}$$

Figure 10: Ladder outer Support Force system

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Figure 12: Ladder support Bracket Forces

E. Ladder bracket bolt forces

Figure 13 shows the left ladder bracket along with the force systems for both brackets.

1. Left bracket forces

$$\sum M_x = 0$$

$$F_{41} = 1.02 F_{10}$$

$$\sum M_y = 0$$

$$F_{40} = -3 F_6$$

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$$\sum M_z = 0$$

$$\sum F_x = 0$$

$$F_{38} = 4 F_6$$

Figure 13: Ladder Bracket

$$\sum F_y = 0$$

$$F_{47} = -.02 F_{10}$$

$$\sum F_z = 0$$

$$F_{43} = -F_2 - .65 F_{10}$$

2. Right bracket forces

$$F_{42} = 1.02 F_{11}, \quad F_{50} = -3 F_7$$

$$F_{51} = 4 F_7, \quad F_{48} = -.02 F_{11}$$

$$F_{44} = -F_3 - .65 F_{11}$$

F. Combined forces and bolt stresses

Table II gives the tension and shear forces and stresses in the ladder assembly bolts ($1/2$ "-13UNC) and studs ($3/8$ "-16UNC), along with the respective thread shear stresses and the stud-to-containment weld stresses. See Figure 15 for bolt locations.

These quantities are calculated as follows:

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1. Bolt tensile, shear, and thread shear stress

$$\sigma = \frac{\text{maximum resultant tension}}{A_T}$$

$$\tau_v = \tau = \frac{\text{maximum resultant shear}}{A_T}$$

$$\tau_{vT} = \tau_T = \frac{\text{maximum resultant tension}}{A_s} = \text{thread shear stress}$$

2. Stud-to-containment weld tensile and shear stress

$$\sigma_w = \frac{\text{maximum resultant stud tension}}{A_w}$$

$$\tau_w = \frac{\text{maximum resultant stud shear}}{A_w}$$

$$A_w = \pi D \left(\frac{1}{8} + \frac{1}{8} \sqrt{\frac{2}{2}} \right) \quad (\text{see Fig. 14})$$

Figure 14: Stud-to-containment weld area

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3. Tensile, thread shear, and weld areas

TABLE I
Tensile, Thread shear, and Weld Areas

Bolt Size, in.	A_T, in^2	A_s, in^2	A_w, in^2
3/8 - 16 UNC	.077	.164	.251
1/2 - 13 UNC	.142	.309	.335
5/8 - 11 UNC	.226	.500	.419
3/4 - 10 UNC	.334	.740	.503
7/8 - 9 UNC	.462	.946	.586
1 - 8 UNC	.606	1.263	.670
1 1/8 - 7 UNC	.763	1.621	.754

4. Seismic forces

The forces $F_1 - F_{11}$ calculated in D.A. through V.E. above, are given in terms of F_x , F_y , and F_z of Figure 8 and F_{xp} and F_{zp} of Figure 10.

$$\begin{aligned} F_x &= \pm 320 (6.2) = \pm 1984 \text{ lb} \\ F_y &= \pm 320 (6.2) = \pm 1984 \text{ lb} \\ F_z &= \pm 320 (5.13) = \pm 1642 \text{ lb} \\ F_{xp} &= \pm 76 (6.2) = \pm 471 \text{ lb} \\ F_{yp} &= \pm 76 (6.2) = \pm 471 \text{ lb} \\ F_{zp} &= \pm 76 (5.13) = \pm 390 \text{ lb} \end{aligned}$$

In calculating the maximum resultant force at a point the above signs will be taken so as

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to produce the maximum force.

Figure 15 : Ladder Support Bolt
and Stud Numbering System

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TABLE II

Original Ladder Support Bolt and Stud Forces and Stresses

Bolt #	Bolt Size	Forces (lb.)		Stresses and Allowables (p.s.i.)								
		Tension	Shear	σ	F_T	f_v	f_{vT}	F_v	σ_w	τ_w	F_w	
1	$\frac{1}{2}$ "-13	0	2,048	0	4,924	14,423	0	10,000	—	—	—	
2	$\frac{1}{2}$ "-13	0	2,048	0	4,924	14,423	0	10,000	—	—	—	
3	$\frac{1}{2}$ "-13	0	702	0	20,000	4,944	0	10,000	—	—	—	
4	$\frac{1}{2}$ "-13	0	702	0	20,000	4,944	0	10,000	—	—	—	
5	$\frac{1}{2}$ "-13	992	4,736	6,986	-0-	33,352	3,210	10,000	—	—	—	
6	$\frac{1}{2}$ "-13	992	4,736	6,986	-0-	33,352	3,210	10,000	—	—	—	
7	$\frac{1}{2}$ "-13	3,968	1,222	27,944	14,230	8,606	12,841	10,000	—	—	—	
8	$\frac{1}{2}$ "-13	3,968	1,222	27,944	14,230	8,606	12,841	10,000	—	—	—	
9	$\frac{1}{2}$ "-13	2,976	1,222	20,958	14,230	8,606	9,631	10,000	—	—	—	
10	$\frac{1}{2}$ "-13	2,976	1,222	20,958	14,230	8,606	9,631	10,000	—	—	—	
11	$\frac{1}{2}$ "-13	0	4,692	0	-0-	33,042	0	10,000	—	—	—	
12	$\frac{1}{2}$ "-13	0	4,692	0	-0-	33,042	0	10,000	—	—	—	
13	$\frac{1}{2}$ "-13	0	6,163	0	-0-	43,401	0	10,000	—	—	—	
14	$\frac{1}{2}$ "-13	1,984	6,163	13,972	-0-	43,401	6,421	10,000	—	—	—	
15	$\frac{1}{2}$ "-13	0	2,256	0	2,580	15,887	0	10,000	—	—	—	
16	$\frac{1}{2}$ "-13	0	2,256	0	2,580	15,887	0	10,000	—	—	—	
17	$\frac{3}{8}$ "-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200	
18	$\frac{3}{8}$ "-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200	
19	$\frac{3}{8}$ "-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200	
20	$\frac{3}{8}$ "-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200	
21	$\frac{3}{8}$ "-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200	
22	$\frac{3}{8}$ "-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200	
23	$\frac{3}{8}$ "-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200	
24	$\frac{3}{8}$ "-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200	
25	$\frac{3}{8}$ "-16	3,082	0	40,026	25,200	0	18,793	13,500	12,279	0	15,200	
26	$\frac{3}{8}$ "-16	6,236	0	80,927	25,200	0	38,024	13,500	24,845	0	15,200	
27	$\frac{3}{8}$ "-16	3,082	0	40,026	25,200	0	18,793	13,500	12,279	0	15,200	
28	$\frac{3}{8}$ "-16	6,236	0	80,927	25,200	0	38,024	13,500	24,845	0	15,200	

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G. Ladder Brace Stability

For 3" 40 pipe, $I = \frac{\pi}{4} \left(\left(\frac{3.5}{2} \right)^4 - \left(\frac{3.068}{2} \right)^4 \right) = 3.0107 \text{ in}^4$

$A = \pi \left(\left(\frac{3.5}{2} \right)^2 - \left(\frac{3.068}{2} \right)^2 \right) = 2.23 \text{ in}^2$

$r = \sqrt{\frac{I}{A}} = 1.16 \text{ in.}$

From ref. 1, sec. 1.5.1.3:

$\frac{Kl}{r} = (1) \frac{(124.75)}{1.16} = 107.54$ (K from ref. 1, table C1.8.1)

$C_c = \sqrt{\frac{2\pi^2(29 \times 10^6)}{35,000}} = 127.89$; $\frac{Kl}{r} < C_c$, so formula 1.5-1

applies, and

$F_a = \frac{\left[1 - \frac{1}{2} \left(\frac{107.54}{127.89} \right)^2 \right] (35,000)}{\frac{5}{3} + \frac{3}{8} \left(\frac{107.54}{127.89} \right) - \frac{1}{8} \left(\frac{107.54}{127.89} \right)^3} = \underline{11,861} \text{ psi}$

$F_b = .6 F_y = \underline{21,000} \text{ psi}$ (using the lowest found in ref. 1, sec. 1.5.1.4)

$f_a = \frac{F_g \text{ MAX}}{2.21 \text{ in}^2} = \frac{2048}{2.21} = 918.39 \text{ psi}$

$\frac{f_a}{F_a} = \frac{918.39}{11,861} = .0774 < .15$, so formula 1.6-2 applies

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$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 ; \quad \text{this is a round section,}$$

$$\text{USE } f_{bx} = f_b, \quad f_{by} = 0$$

then

$$\frac{918.39}{11,861} + \frac{Mc/I}{21,000} = .0774 + \frac{(29,804)(1.75)/3,0107}{21,000} = .76 < 1$$

and the brace stresses are lower than allowed.

M was calculated from ref. 8:

$$M = \frac{w}{2R} \tan \frac{\theta l}{2}, \quad \text{with}$$

$$w = \sqrt{(.74 F_{yp} + .67 F_{2p})^2 + F_{xp}^2} = 771 \text{ lb}$$

$$R = \sqrt{\frac{2048}{(29 \times 10^6)(3.0107)}} = 4.84 \times 10^{-3}$$

$$M = \frac{771}{2(.00484)} \tan \left(\frac{(.00484)(124.75)}{2} \right) = 24,804 \text{ in-lb.}$$

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VI. Recommendations

A. Angle - to - mounting plate fillet welds.

Increase $\frac{I}{C}$ so

$$\sigma = \frac{(10,494)}{\left(\frac{I}{C}\right)} + 782 \text{ psi} < 14,400 \text{ psi}$$

$$\therefore \frac{I}{C} > \underline{\underline{7.771}} \text{ in}^3 \quad (\text{see figure 5, p. 9})$$

B. $\frac{5}{16}$ " - 18 UNC Bolts.

Use 3 bolts instead of 2 per support; then

$$\begin{aligned} \tau_{v_t} &= \text{bolt shear stress} = 14,485 \left(\frac{2}{3} \right) = 9657 \text{ psi} \\ &= \underline{\underline{9657}} \text{ psi} < 10,000 \text{ psi} \end{aligned}$$

C. Ladder mounting bolts ($\frac{1}{2}$ " - 13 UNC) and studs ($\frac{3}{8}$ " - 16 UNC).

Replace originally specified bolts and studs with those shown in table III (on larger diameter UNC.)

See notes, p. 29

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TABLE III

Recommended Ladder Support Bolt and Stud Forces and Stresses

Bolt #	Bolt Size	Forces (lb)		Stresses and Allowables (p.s.i)							
		Tension	Shear	σ	F_t	S_v	S_{vt}	F_v	σ_w	τ_w	F_w
1	1/2"-11	0	2,048	0	13,507	9,062	0	10,000	—	—	—
2	1/2"-11	0	2,048	0	13,507	9,062	0	10,000	—	—	—
3	1/2"-13	0	702	0	20,000	4,944	0	10,000	—	—	—
4	1/2"-13	0	702	0	20,000	4,944	0	10,000	—	—	—
5	1"-8	992	4,736	1,637	15,496	7,815	785	10,000	—	—	—
6	1"-8	992	4,736	1,637	15,496	7,815	785	10,000	—	—	—
7	5/16"-11	3,698	1,222	16,363	19,349	5,407	7,396	10,000	—	—	—
8	5/16"-11	3,698	1,222	16,363	19,349	5,407	7,396	10,000	—	—	—
9	5/16"-11	2,976	1,222	13,168	19,349	5,407	5,952	10,000	—	—	—
10	5/16"-11	2,976	1,222	13,168	19,349	5,407	5,952	10,000	—	—	—
11 (1)	3/4"-10	0	2,346	0	16,672	7,024	0	10,000	—	—	—
12 (1)	3/4"-10	0	2,346	0	16,672	7,024	0	10,000	—	—	—
13 (2)	1/2"-10	0	3,082	0	13,238	9,226	0	10,000	—	—	—
14 (2)	1/2"-10	992	3,082	2,970	13,238	9,226	1,341	10,000	—	—	—
15	1/2"-11	0	2,256	0	12,028	9,982	0	10,000	—	—	—
16	1/2"-11	0	2,256	0	12,028	9,982	0	10,000	—	—	—
17	3/4"-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200
18	3/4"-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200
19	3/4"-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200
20	3/4"-16	686	758	8,909	15,749	9,844	4,183	13,500	2,733	3,020	15,200
21	3/4"-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200
22	3/4"-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200
23	3/4"-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200
24	3/4"-16	981	564	12,740	19,781	7,325	5,982	13,500	3,908	2,247	15,200
25	1/2"-13	3,082	0	21,704	25,200	0	9,974	13,500	9,200	0	15,200
26	7/8"-9	6,236	0	13,498	16,800	0	6,592	9,000	10,642	0	12,000
27	5/8"-11	3,082	0	13,637	16,800	0	6,164	9,000	7,356	0	12,000
28	7/8"-9	6,236	0	13,498	16,800	0	6,592	9,000	10,642	0	12,000

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C. Ladder inner support structure

$$F_{23} = F_m \cos \theta_b = .87 F_m$$

$$F_{24} = F_L \cos \theta_b = .87 F_L$$

$$F_{27} = -F_m \sin \theta_b = -.5 F_m$$

$$F_{28} = -F_L \sin \theta_b = -.5 F_L$$

(See Fig. 11)

Figure 11: Ladder inner support force system

Solving the equilibrium equations,

$$F_{17} = F_6 + F_7$$

$$F_{21} = F_{11} + 1.73 F_3 - 1.08 (F_6 + F_7)$$

$$F_{22} = 1.08 (F_6 + F_7) + F_{10} + 1.73 F_2$$

$$F_L = -2 F_3$$

$$F_m = -2 F_2$$

D. Ladder support bracket forces

See Figure 12. The studs holding these six brackets to the containment shell are subjected to forces F_{29} through F_{37} as shown.

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Notes to Table III

1. Bolts 11 and 12: Install an additional bolt below the original as shown in figure 16.

Figure 16: Bolt 11+12
Replacement with
two Bolts Each

2. Bolts 13 and 14: Lengthen mounting bracket and use two bolts in place of each original bolt as shown in figure 17.

Figure 17: Bolt 13 & 14
Replacement with
Two Bolts Each