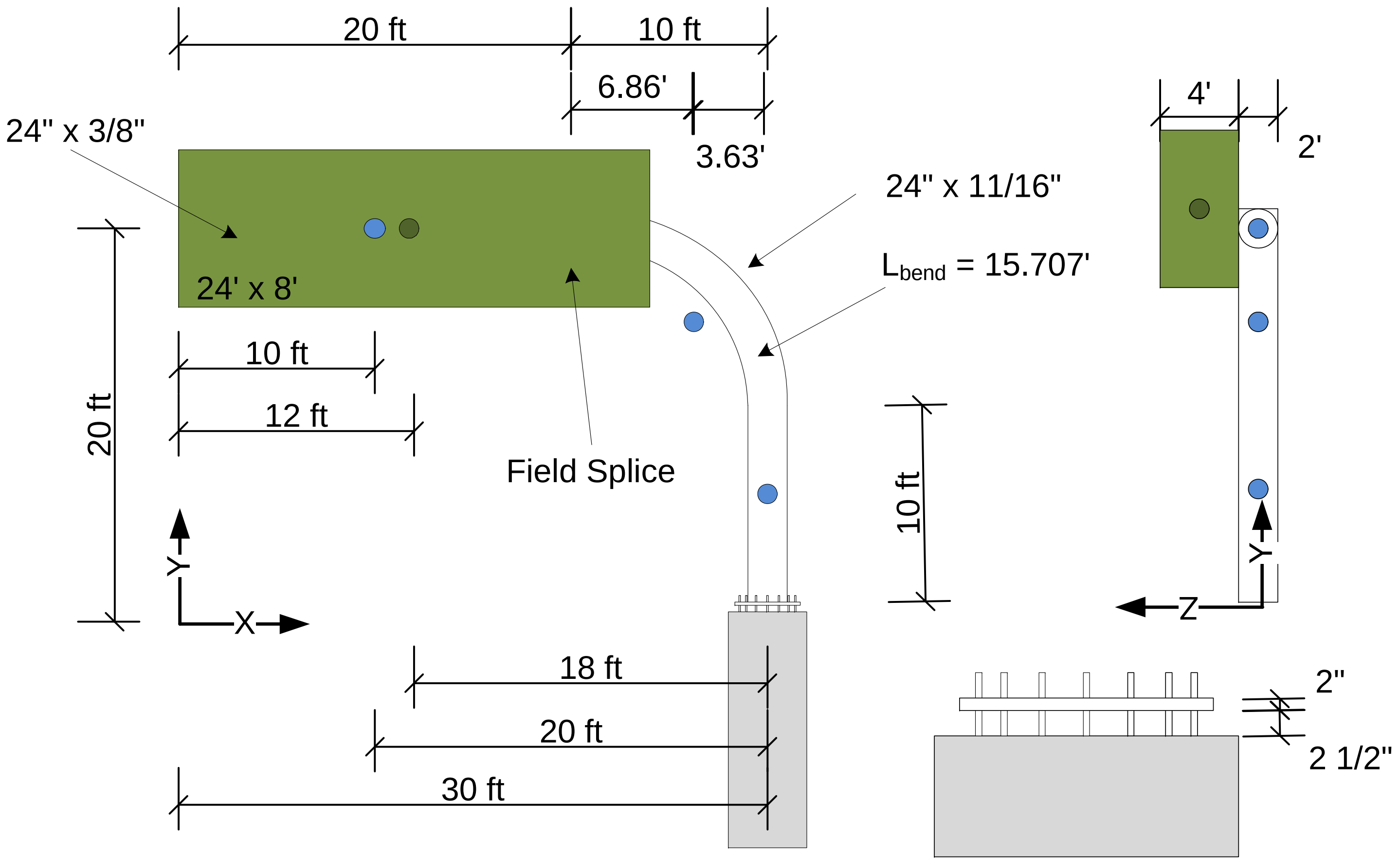
Design Example 9

Cantilevered Monotube Support for a Dynamic Message Sign

Problem Statement:

Design a cantileved monotube structure in Ft. Collins, CO. It will support a dynamic message sign weighing 5,000 pounds. Assume a 24" diameter circular tube fabricated from A36 steel. Bolts are ASTM A 325 bolts. The structure would cross a lifeline travelway on failure.



Overview Monotube Design Example

- Video 1 – Example Introduction & Strength Loads
- Video 2 – Tube Strength Design Checks
- Video 3 – Base Plate Design
- Video 4 – Fatigue Loads
- Video 5 – Fatigue Resistance and Design Checks

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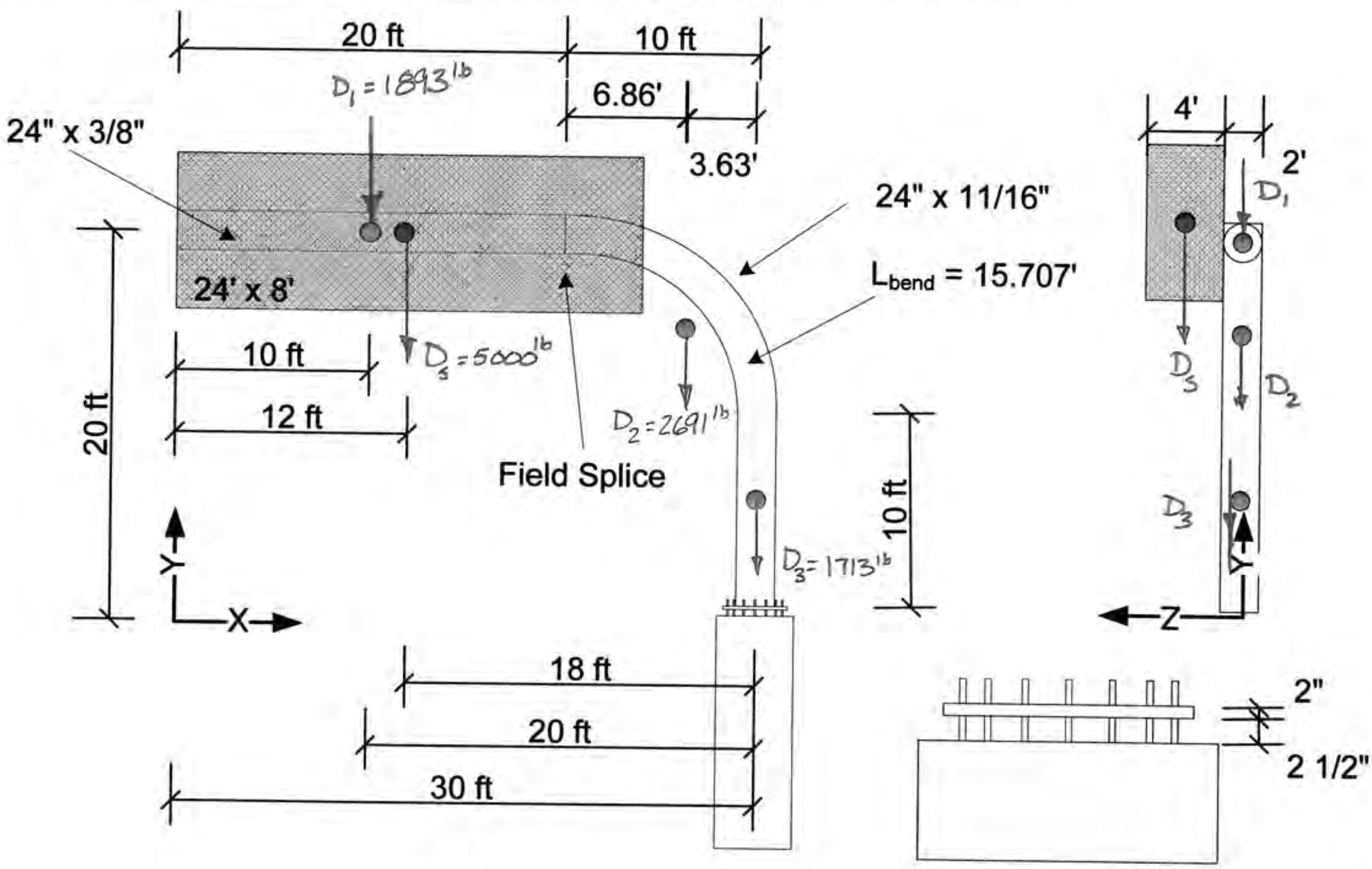

NOMINAL DEAD LOADS SHOWN AT LOAD CENTROIDS

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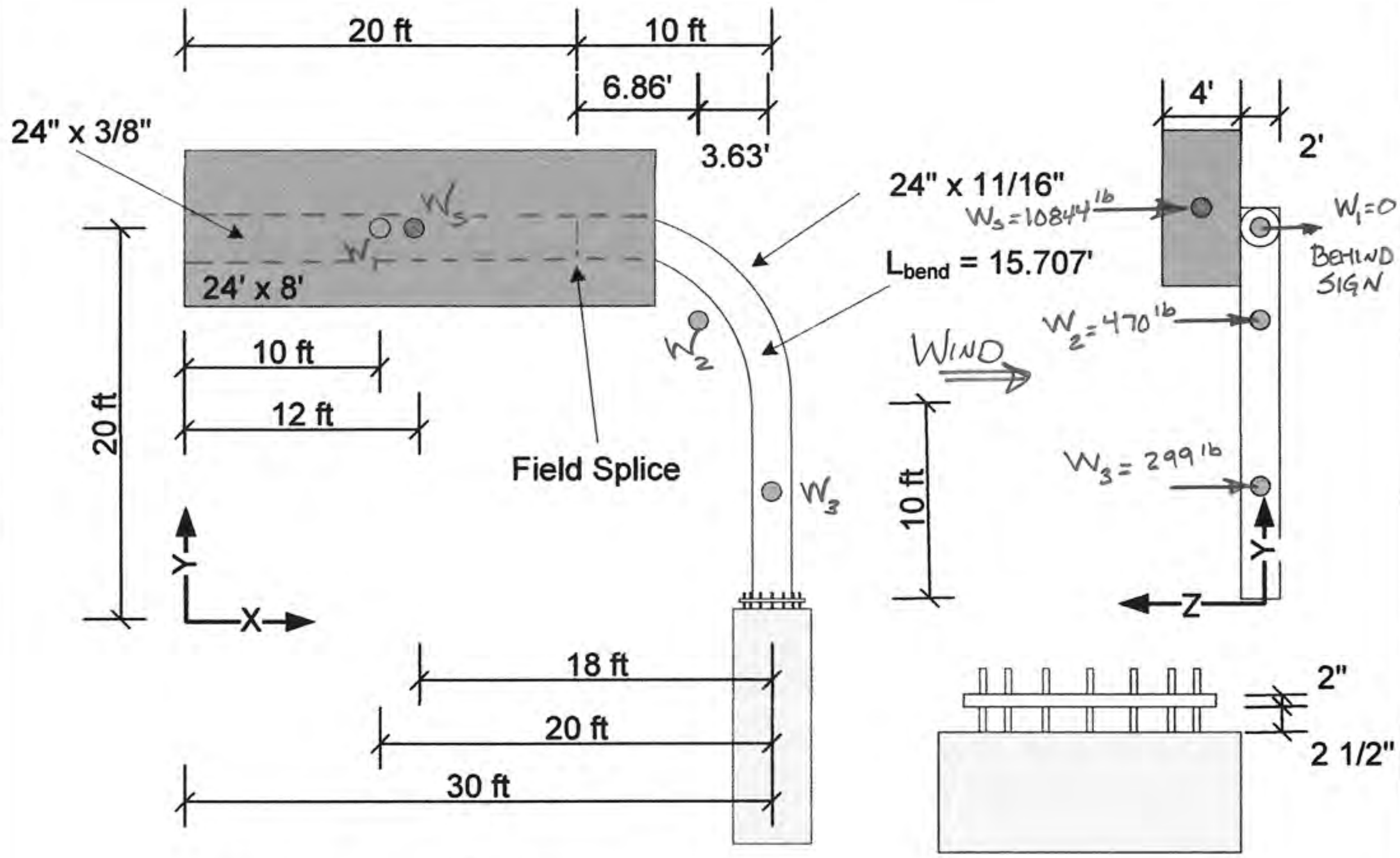
CIVIL AND ARCHITECTURAL ENGINEERING

Name: 2

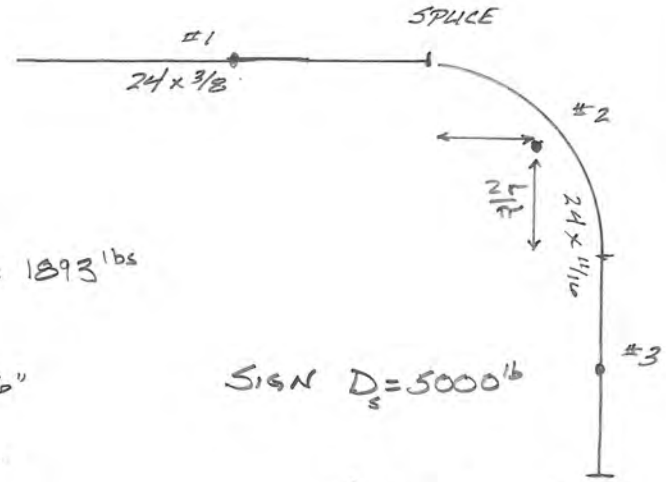
Date: Class: Assignment:



WIND INTO PAGE

NOMINAL WIND LOADS SHOWN AT CENTROIDS

DEAD LOAD SELF WEIGHT



TUBE #1 $A = 6.28Rt$ $R = \frac{24 - 3/8}{2} = 11.81''$
24x3/8
$A = 6.28(11.81)(3/8) = 27.82\,in^2$

$D_1 = \frac{27.82\,in^2\,(490\,lb/ft^3)}{144\,in^2/ft^2}(20ft) = 1893\,lbs$

TUBE #2 $A = 6.28Rt$ $R = \frac{24 - 11/16}{2} = 11.66''$
24x11/16
$A = 6.28(11.66)(11/16) = 50.34\,in^2$

$D_2 = \frac{50.34(490)}{144}\left(\frac{2\pi\,10ft}{4}\right) = 2691\,lb$

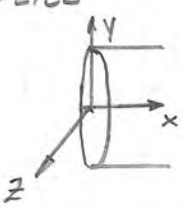
TUBE #3 $A = 50.34\,in^2$
24x11/16
$D_3 = \frac{50.34(490)}{144}(10) = 1713\,lb$

APPENDIX B

Property	Round Tube
Moment of inertia, I	$3.14R^3t$
Section modulus, S	$3.14R^2t$
Area, A	$6.28Rt$
Shape factor, $K_p = Z/S$	1.27
Radius of gyration, r	$0.707R$
Cross-sectional constant, C	3.14
Pictorial representation	
Torsional constant for stress computations,	$6.28R^2t$

NOMINAL DEAD LOAD EFFECTS

AT SPLICE

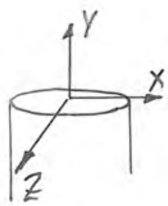


$V_y = 5000 + 1893 = 6.93^k$ (SHEAR)

$M_z = 5000(8) + 1893(10) = 58.93\,ft{\cdot}k$ (BENDING)

$M_x = 5000(3) = 15.0\,ft{\cdot}k$ (TORSION)

AT BASE



$P_y = 5000 + 1893 + 2691 + 1713 = 11.30^k$ (C) (AXIAL)

$M_z = 5000(18) + 1893(20) + 2691(3.63) = 137.6\,ft{\cdot}k$ (BENDING)

$M_x = 5000(3) = 15.0\,ft{\cdot}k$ (BENDING)

WIND LOADS [WIND IN Z DIRECTION CRITICAL]

TUBE #1 BEHIND SIGN - NO WIND AREA

TUBE #2 $A_{w2} = \frac{2\pi(10)}{4} \times 2 = 31.42\ ft^2$ [IGNORE LOSING PORTION BEHIND SIGN]

TUBE #3 $A_{w3} = 10(2) = 20\ ft^2$

WIND PRESSURE $P_z = 0.00256\, K_z K_d G V^2 C_d$

STRUCTURE CROSSES LIFELINE TRAVELWAY TABLE 3.8-1

RISK CATEGORY = HIGH
USE 1700yr MRE WIND
$V = 120\,mph$

3.8.4 $K_z = 2.0\left(\frac{z}{z_g}\right)^{2/\alpha}$ $z_g = 900$ $\alpha = 9.5$
EXP. C

CONSERVATIVELY USE $z = 24\,ft$ FOR ALL HEIGHTS

$$K_z = 2.0\left(\frac{24}{900}\right)^{2/9.5} = 0.93$$

3.8.6 $G = 1.14$

3.8.5 TABLE 3.8.5-1 $K_d = 0.85$ (DYN. MSG SIGN & HORIZ ARM SPTS)

3.8.7 C_d FACTOR TABLE 3.8.7-1

CYLINDRICAL WITH $V \cdot d > 78\,mph$ $C_d = 0.45$

DYNAMIC MESSAGE SIGN $C_d = 1.70$

PRESSURE $P_z = 0.00256(0.93)(0.85)(1.14)(120)^2\, C_d$

$= 33.22\, C_d$

FOR TUBE $P_z = 33.22(0.45) = 14.95\,psf$

FOR SIGN $P_z = 33.22(1.70) = 56.48\,psf$

Date: Class: Assignment:

WIND FORCES

TUBE #1 $W_1 = 0$ (BEHIND SIGN)

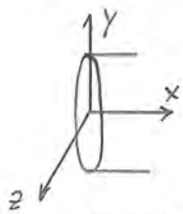
TUBE #2 $W_2 = 31.42\,ft^2(14.95\,psf) = 469.7^{lb}$

TUBE #3 $W_3 = 20\,(14.95) = 299.0^{lb}$

SIGN $W_S = (8\times24)\,56.48 = 10844^{lb}$

NOMINAL WIND LOAD EFFECTS

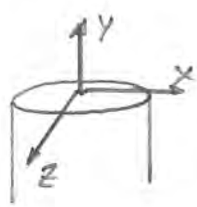
AT SPLICE



$V_Z = 10844^{lb} = 10.84^{k}$ (SHEAR)

$M_Y = 10844(8) = 86.75\,ft{\cdot}k$ (BENDING)

AT BASE



$V_Z = 10844 + 469.7 + 299 = 11.61^{K}$ (SHEAR)

$M_X = 10844(20) + 469.7(16.37) + 299(5) = 226.1\,ft{\cdot}k$ (BENDING)

$M_Y = 10844(18) + 469.7(3.63) = 196.9\,ft{\cdot}k$ (TORSION)

FACTORED LOADING EXTREME I LIMIT STATE

TABLE 3.4-1 $\gamma_D = 1.25$

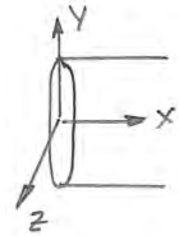
OR

$\gamma_D = 1.10 + \gamma_W = 1.0$ ← WILL CONTROL

$\gamma_D = 0.9$ FOR UPLIFT WILL NOT CONTROL

AT SPLICE

	LOAD	NOMINAL D	W	FACTORED $1.1D + 1.0W$
AXIAL	P_x	0	0	0
SHEAR	V_y	6.93^k	0	7.62^k
SHEAR	V_z	0	10.84^k	10.84^k
TORSION	M_x	15 ft·k	0	16.5 ft·k
BENDING	M_y	0	86.75 ft·k	86.75 ft·k
BENDING	M_z	58.93 ft·k	0	64.82 ft·k



TOTAL BENDING $M = \sqrt{M_y^2 + M_z^2} = 108.3\text{ ft}\cdot\text{k}$

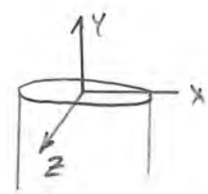
TOTAL SHEAR $V = \sqrt{V_y^2 + V_z^2} = 13.25^k$

DESIGN FACTORED FORCE EFFECTS

AXIAL	$P_u = 0$
SHEAR	$V_u = 13.25^k$
BENDING	$M_u = 108.3\text{ ft}\cdot\text{k}$
TORSION	$T_u = 16.5\text{ ft}\cdot\text{k}$

AT BASE

	NOMINAL LOAD	D	W	FACTORED $1.1D + 1.0W$
SHEAR	V_x	0	0	0
AXIAL	P_y	11.30^k (c)	0	12.43^k
SHEAR	V_z	0	11.61^k	11.61^k
BENDING	M_x	15.0 ft·k	226.1 ft·k	242.6 ft·k
TORSION	M_y	0	196.9 ft·k	196.9 ft·k
BENDING	M_z	137.6 ft·k	0	151.4 ft·k



TOTAL BENDING $M = \sqrt{M_x^2 + M_z^2} = 286.0$ ft·k

TOTAL SHEAR $V = \sqrt{V_x^2 + V_z^2} = 11.61^k$

DESIGN FACTORED FORCE EFFECTS

AXIAL $P_u = 12.43^k$ (c)
SHEAR $V_u = 11.61^k$
BENDING $M_u = 286.0$ ft·k
TORSION $T_u = 196.9$ ft·k

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Design Example 9

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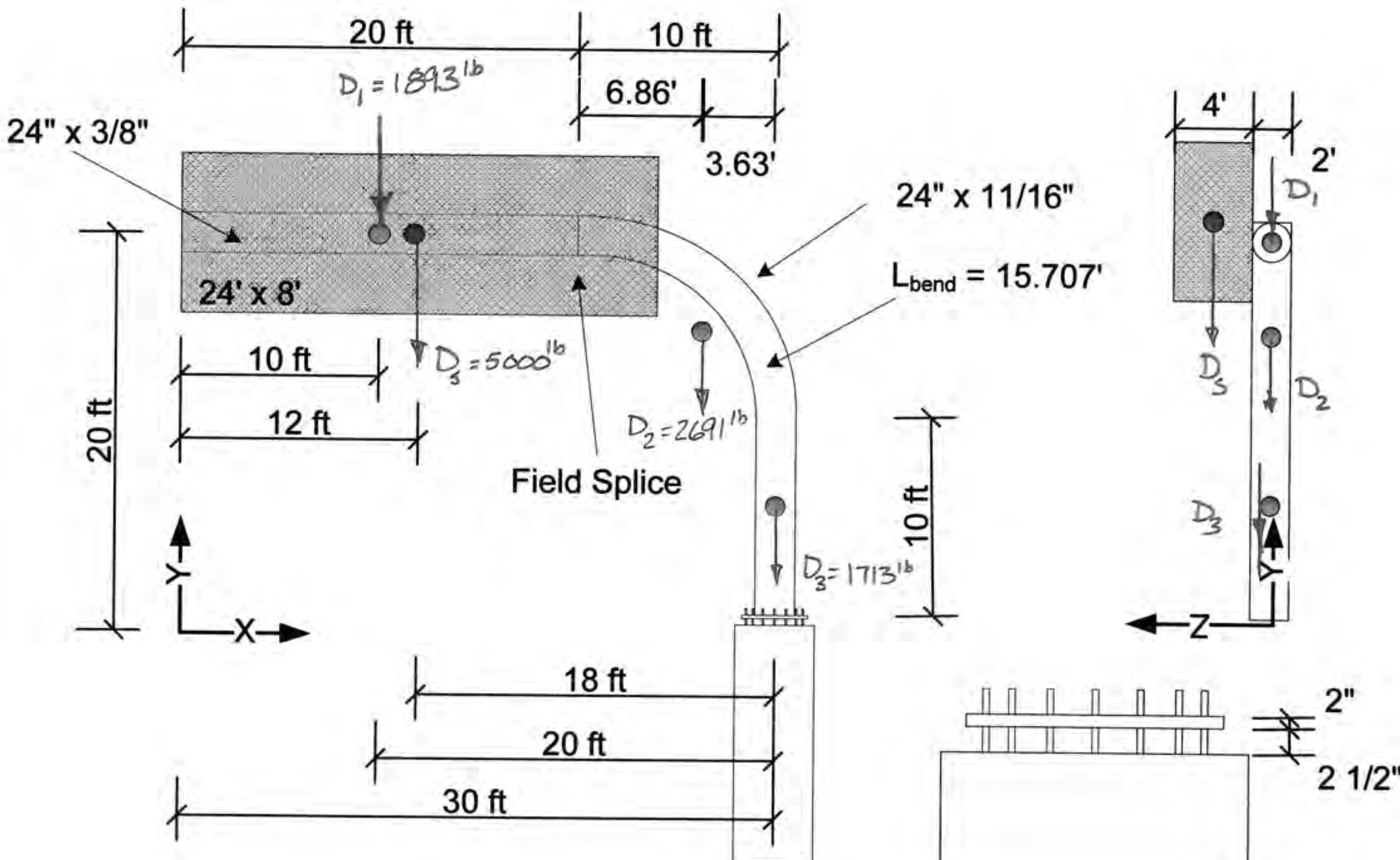
ANCHORS ARE F1554 $F_y = 55 ksi$ $F_u = 75 ksi$



NOMINAL DEAD LOADS SHOWN AT LOAD CENTROIDS

TUBE DESIGN CHECKS

FLEXURE $\phi_f = 0.90$
SHEAR $\phi_v = 0.90$
AXIAL COMP $\phi_c = 0.90$
TORSION $\phi_T = 0.95$

SPLICE $P = 0$ $V_u = 13.25^k$ $M_u = 108.3\,ft\cdot k$ $T_u = 16.5\,ft\cdot k$

$24''\phi \times 3/8$ $R = 11.81''$ $t = 3/8''$

APPENDIX B
$A = 6.28Rt = 27.82\,in^2$
$I = 3.14R^3t = 1940\,in^4$
$SF = 1.27$ SHAPE FACTOR
$S = 3.14R^2t = 164.2\,in^3$
$C_t = 6.28R^2t = 328.5\,in^3$ TORSION CONST

BENDING $D/t = 24/\tfrac{3}{8} = 64 > \lambda_p = 0.07\dfrac{E}{F_y} = 0.07\dfrac{(29000)}{36} = 56$ NOT COMPACT

TABLE 5.7.2-1 $\lambda_r = 0.31\dfrac{E}{F_y} = 250$ $\lambda_p < D/t < \lambda_r$

NON-COMPACT

TABLE 5.8.2-1

$$M_n = M_p\left[0.77 + \frac{0.016(E/F_y)}{D/t}\right] = 0.97\,M_p$$

$$M_p = SF \cdot S\,F_y = 1.27(164.2\,in^3)(36\,ksi)\left(\frac{1\,ft}{12\,in}\right) = 625.6\,ft\cdot k$$

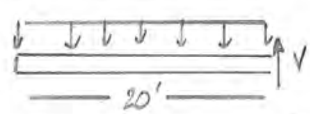
$$M_n = 0.97\,M_p = 606.8\,ft\cdot k$$

$$\underline{M_r = \phi_f M_n = 0.9(606.8) = 546.2\,ft\cdot k}$$

SHEAR $V_n = A_v F_{nv}$ $A_v = \dfrac{A_g}{2} = \dfrac{27.82}{2} = 13.91\,in^2$

$$F_{nv} = \max\left\{\frac{1.60E}{\sqrt{\frac{L_v}{D}}\left(\frac{D}{t}\right)^{5/4}} \text{ AND } \frac{0.78E}{(D/t)^{3/2}}\right\} \text{ BUT LESS THAN OR EQUAL TO } 0.6F_y$$

L_v DISTANCE TO ZERO SHEAR



$L_v = 20\,ft$

$$F_{nv} = \max\left\{\frac{1.6(29000)}{\sqrt{\frac{20\times12}{24}}(64)^{5/4}} = 81\,ksi \text{ AND } \frac{0.78(29000)}{(64)^{3/2}} = 44.2\,ksi\right\} \le 0.6(36) = 21.6\,ksi$$

$F_{nv} = 21.6\,ksi$

$$V_n = 13.91\,in^2(21.6\,ksi) = 300.4^k$$

$$\underline{V_r = \phi_v V_n = 0.9(300.4) = 270.4^k}$$

TORSION $T_n = C_t F_{nt}$ $C_t = 328.5\ in^3$

$$F_{nt} = max\left\{ \frac{1.23E}{\sqrt{\frac{L}{D}}(D/t)^{5/4}} = 62\,ksi \text{ AND } \frac{0.6E}{(D/t)^{3/2}} = 34\,ksi \right\} \le 0.6F_y = 21.6\,ksi$$

$F_{nt} = 21.6\,ksi$

$$T_n = 328.5\,in^3(21.6\,ksi)\left(\frac{1ft}{12in}\right) = 591.3\ ft\cdot k$$

$$T_r = \phi_T T_n = 0.95(591.3) = 561.7\ ft\cdot k$$

COMBINED FORCES INTERACTION EQUATION

$\frac{T_u}{T_r} = \frac{16.5}{561.7} = 0.03 < 0.2$ TORSION & SHEAR CAN BE IGNORED

$\frac{P_u}{T_r} = 0$ $\therefore \frac{P_u}{2P_r} + \frac{B M_u}{M_r} = \frac{108.3}{546.2} = 0.20 < 1$ (0; 1.0 (NO AXIAL))

SPLICE SECTION O.K.

BASE $P_u = 12.43^k (c)$ $V_u = 11.61^k$ $M_u = 286.0\ ft\cdot k$ $T_u = 196.9\ ft\cdot k$

$24''\phi \times {}^{11}/_{16}$ $R = 11.66''$ $t = {}^{11}/_{16}$

APPENDIX B

$A = 6.28Rt = 50.34\,in^2$
$I = 3.14R^3t = 3422.1\,in^4$
$SF = 1.27$ SHAPE FACTOR
$S = 3.14R^2t = 293.5\,in^3$
$C_t = 6.28R^2t = 587.0\,in^3$

BENDING $D/t = 24/{}^{11}/_{16} = 34.9 < \lambda_p = 56$ COMPACT

$$M_n = M_p = SF * SF_y = 1.27(293.5)(36)\left(\tfrac{1}{12}\right) = 1118.2\ ft\cdot k$$

$$M_r = \phi_f M_n = 0.9(1118.2) = 1006.4\ ft\cdot k$$

SHEAR $V_n = A_v F_{nv}$ $A_v = \frac{A_g}{2} = \frac{50.34}{2} = 25.17\ in^2$

$F_{nv} = 0.6F_y = 21.6\ ksi$ ← D/t LOWER THAN 24x3/8 TUBE

$V_n = 25.17(21.6) = 543.7^k$

$V_r = \phi_v V_n = 0.9(543.7) = 489.3^k$

TORSION $T_n = C_t F_{nt}$ $C_t = 587.0\ in^3$ $F_{nt} = 0.6F_y = 21.6\ ksi$

$T_n = 587.0(21.6)(\frac{1}{12}) = 1056.6\ ft\cdot k$

$T_r = \phi_T T_n = 0.95(1056.6) = 1003.8\ ft\cdot k$

AXIAL COMPRESSION $P_{nc} = A_g F_{cr}$ APPENDIX B $r = 0.707R = 8.24''$

$A_g = 50.34\ in^2$ USE $L = 20ft$, $K = 2.1$ $\frac{KL}{r} = \frac{2.1(20\times12)}{8.24} = 61.2$

$\frac{KL}{r} < 4.71\sqrt{\frac{E}{F_y}} = 134$

$\frac{D}{t} = 34.9 < \lambda_r = 0.11\frac{E}{F_y} = 88$

NO LOCAL BUCKLING Q = 1

$F_e = \frac{\pi^2 E}{(KL/r)^2} = 76.4\ ksi$

$F_{cr} = 0.658^{\left(\frac{F_y}{F_e}\right)} F_y = 0.658^{\left(\frac{36}{76.4}\right)}(36) = 29.56\ ksi$

$P_{nc} = 50.34(29.56) = 1487.9^k$

$P_{rc} = \phi_c P_{nc} = 0.9(1487.9) = 1339.0^k$

COMBINED FORCES INTERACTION EQN

$\frac{T_u}{T_r} = \frac{196.9}{1003.9} = 0.197 < 0.20$ TORSION & SHEAR CAN BE IGNORED

$\frac{P_u}{P_r} = \frac{12.43}{1339} = 0.01 < 0.2$

$\therefore \frac{P_u}{2P_r} + \frac{BM_u}{M_r} = \frac{12.43}{2(1339)} + \frac{1.003(286)}{1006.4} = 0.30 < 1$ BASE SECTION OK.

$B = \frac{1}{1-\frac{P_u}{P_e}} = \frac{1}{1-\frac{P_u}{A_g F_e}} = \frac{1}{1-\frac{12.43}{50.34(76.4)}} = 1.003$

EXAMPLE

* IF $\frac{T_u}{T_r} > 0.2$ (ALMOST FOR THIS CASE)

$\left(\frac{P_u}{P_r}\right) + \left(\frac{BM_u}{M_r}\right) + \left(\frac{V_u}{V_r} + \frac{T_u}{T_r}\right)^2$

$= \frac{12.43}{1339} + \frac{1.003(286)}{1006.4} + \left[\left(\frac{11.61}{489.3}\right) + \left(\frac{196.9}{1003.9}\right)\right]^2 = 0.35$

POLE TO BASE PLATE WELD ½" FILLET WELD, E70 ELECTRODES

$P = 12.43^k$ $V = 11.61^k$ $BM_u = 1.003(286) = 286.9$ ft·k ANALYZE PER 1" OF WELD

$T_u = 196.9$ ft·k

AXIAL $g_A = \frac{P}{A} = \frac{12.43}{75.4} = 0.17$ k/in

SHEAR $g_V = \frac{V_u}{A/2} = \frac{11.61}{75.4/2} = 0.31$ k/in

CIRCLE $A_V = \frac{A_g}{2}$

$r = 12"$
$A = 2\pi r = 75.4$ in
$I = \pi r^3 = 5429$ in^3
$S = \pi r^2 = 452.4$ in^2
$J = 2\pi r^3 = 10857$ in^3

BENDING $g_m = \frac{BM_u}{S} = \frac{286.9 \times 12}{452.4} = 7.61$ k/in

TORSION $g_T = \frac{Tr}{J} = \frac{196.9(12)(12)}{10857} = 2.61$ k/in

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COMBINE FORCES ON WELD (VECTORALLY)

$$q = \sqrt{\left(\frac{P}{A} + \frac{B M_u}{S}\right)^2 + \left(\frac{V}{A/2} + \frac{T r}{J}\right)^2} = \sqrt{(0.17+7.61)^2 + (0.31+2.61)^2} = 8.31 \ ^k/_{in}$$

WELD CAPACITY (ASSUME SHEAR ON WELD THROAT)

$\varphi_W = 0.75 \qquad F_{nw} = 0.6 F_{Exx} = 0.6(70) = 42\,ksi$

$\varphi R_n = \varphi_W F_{nw} (0.707\, t_w) = 0.75(42ksi)(0.707 \times 1/2) = 11.14 \ ^k/_{in} > q$

WELD OK.

THRU-THICKNESS CHECK

$\varphi R_n = \varphi t_{TUBE}\, 0.6 F_u = 0.75(11/16)\, 0.6(58ksi) = 17.9 \ ^k/_{in}$ O.K.

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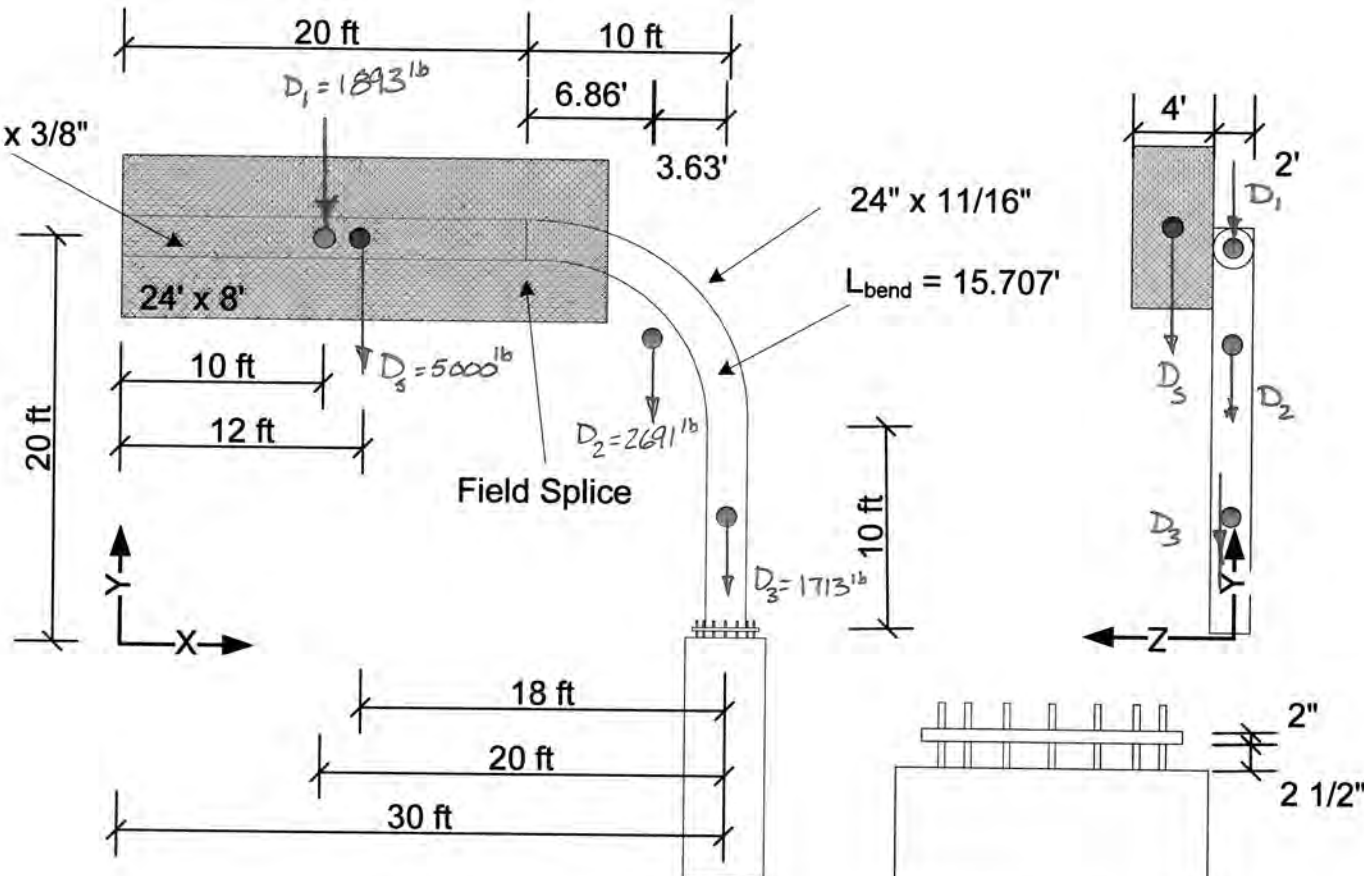


NOMINAL DEAD LOADS SHOWN AT LOAD CENTROIDS

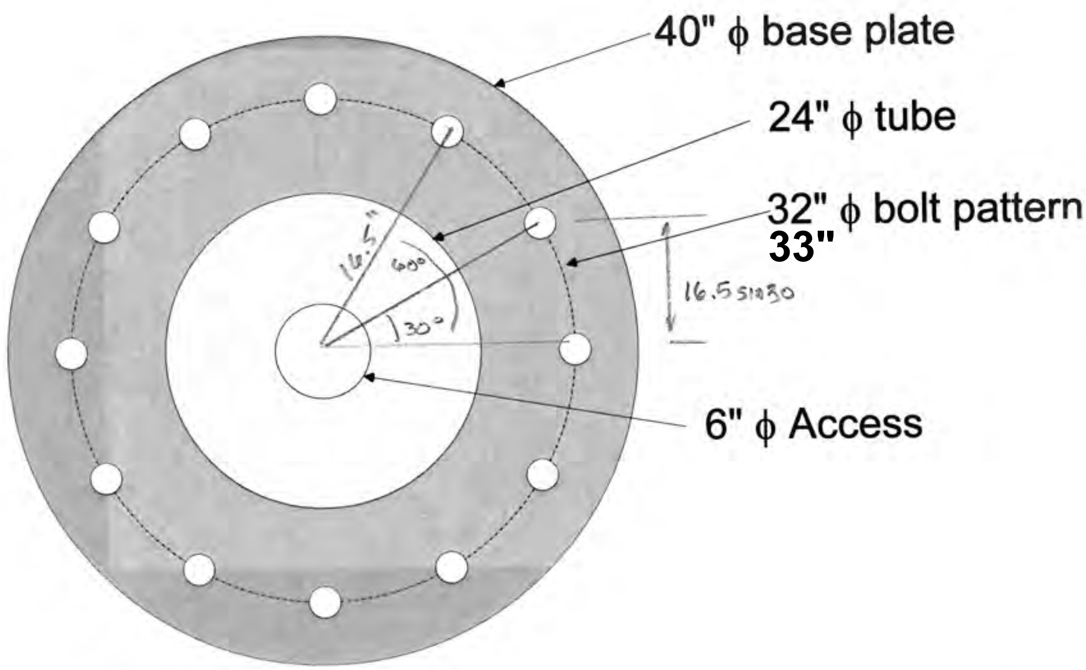
UNIVERSITY OF WYOMING
CIVIL AND ARCHITECTURAL ENGINEERING

Name:

Date: Class: Assignment:

BASE PLATE DESIGN

$P = 12.43^k$ (C) $V = 11.61^k$ $BM_u = 286.9$ ft·k $T = 196.9$ ft·k



USE AISC DESIGN GUIDE 1
BASE PLATE AND ANCHOR ROD DESIGN

DOUBLE NUT CONNECTION

ANCHOR BOLT GROUP PROPERTIES

$1\frac{1}{2}$"ϕ F1554 $F_y = 55$ ksi $F_u = 75$ ksi

ANALYZE IN FORCE PER BOLT

$n = 12$

$I = 2\left[2(16.5\sin 30)^2 + 2(16.5\sin 60)^2 + (16.5)^2\right]$

$I = 1633.5 \text{ in}^2$

$S = \frac{I}{16.5} = 99$ in

$J = \Sigma r^2 = 12(16.5)^2 = 3267 \text{ in}^2$

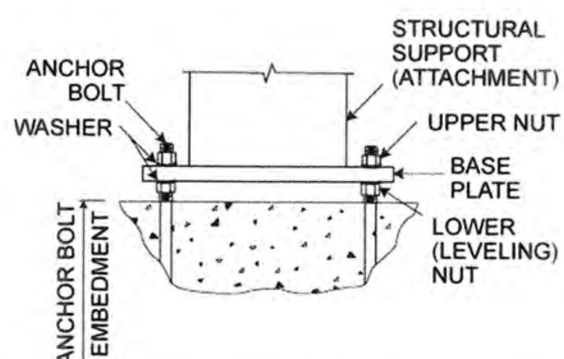


Figure C5.16-1—Typical Double-Nut Connection

Date: Class: Assignment:

ANCHOR FORCES

AXIAL $F_P = \frac{12.43}{12} = 1.04^k$ COMPRESSION

SHEAR $F_V = \frac{11.61}{12} = 0.97^k$

BENDING $F_m = \frac{BM}{S} = \frac{286.9(12)}{99} = 34.78^k$

TORSION $F_T = \frac{Tr}{J} = \frac{196.9(12)(16.5)}{3267} = 11.93^k$

COMBINE ACTIONS ON ANCHORS

ANCHOR AXIAL $= F_P + F_m = 1.04 + 34.78 = 35.82^k$
ANCHOR SHEAR $= F_V + F_T = 0.97 + 11.93 = 12.90^k$

ASSUME NO BENDING IN ANCHOR FROM SHEAR
ACCORDING TO CURRENT LTS-6 5.17.3.1 IF CLEAR DISTANCE IS LESS THAN ONE ANCHOR DIAMETER.
ASSUME NO ANCHOR AXIAL FORCE INCREASE DUE TO PRYING ACTION ACCORDING TO CURRENT LTS-6 IF BASE PLATE THICKNESS ≥ ANCHOR BOLT DIAMETER

AISC DESIGN GUIDE 1 USES AISC STEEL SPECIFICATIONS
CONSIDER TENSION/SHEAR INTERACTION

$A_b = \frac{\pi (1\frac{1}{2})^2}{4} = 1.767 \text{ in}^2$

$f_a = \frac{35.82}{1.767} = 20.27 \text{ ksi}$ $f_v = \frac{12.90}{1.767} = 7.30 \text{ ksi}$

AISC TABLE J3.2 SHEAR $\phi R_{nv} = \phi(0.563 F_u) A_b$ $\phi = 0.75$ $F_u = 75 \text{ ksi}$

$\phi F_{nv} = \phi(0.563 F_u) = 31.67 \text{ ksi}$

$\phi R_{nv} = 55.96^k > V_u = 12.90^k$

OR

$\phi F_{nv} = 31.67 \text{ ksi} > f_v = 7.30 \text{ ksi}$

ANCHOR SHEAR O.K.

AXIAL $\varphi R_{nt} = \varphi F_{nt}' A_b \qquad \varphi = 0.75$

REDUCED TENSION STRESS DUE TO TENSION SHEAR INTERACTION

$$F_{nt}' = 1.3 F_{nt} - \frac{F_{nt}}{\varphi F_{nv}} f_v \leq F_{nt}$$

WHERE $F_{nt} = 0.75 F_u = 56.25$ ksi

$$F_{nt}' = 1.3(56.25) - \frac{56.25}{31.67}(7.30) = 60 \text{ ksi}$$ NO REDUCTION

$\therefore F_{nt}' = F_{nt} = 56.25$ ksi

$$\varphi R_{nt} = 0.75(56.25)1.767 = 74.55^k > P_u = 35.82^k$$

OR

$$\varphi F_{nt}' = 0.75(56.25) = 42.19 \text{ ksi} > f_a = 20.27 \text{ ksi}$$

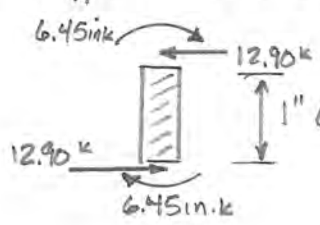
ANCHOR AXIAL OK.

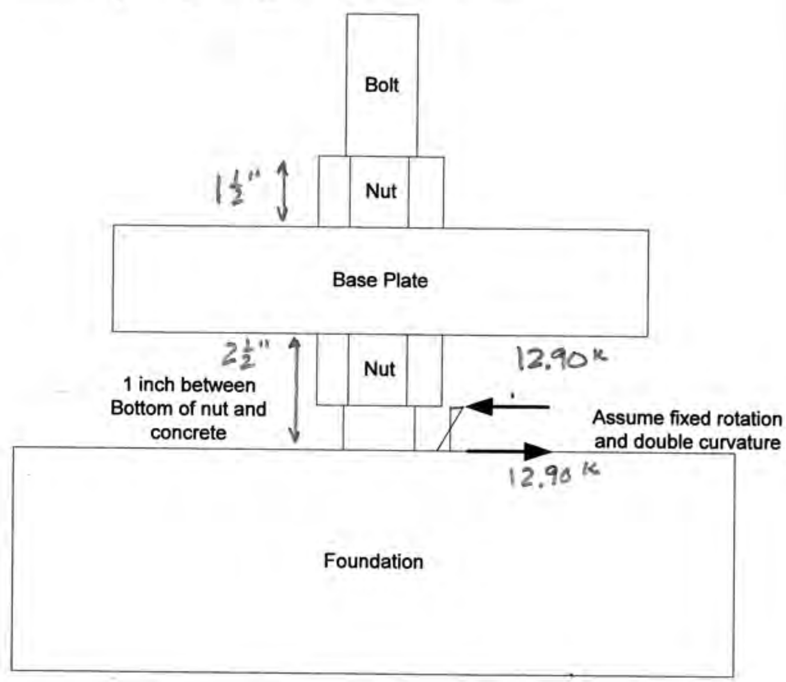
WHAT IF ANCHOR BENDING IS CONSIDERED?

AISC GUIDE 1

MOMENT IN ANCHOR

$M_A = 12.90^k(1/2") = 6.45$ in.k ← UNITS





BOLT SECTION MODULUS (ASSUMING FULL DIA)

$$S_b = \frac{\pi (1\tfrac{1}{2})^3}{32} = 0.331 \text{ in}^3$$

ADDITIONAL AXIAL STRESS DUE TO ANCHOR BENDING

$$f_m = \frac{6.45 \text{ in}\cdot\text{k}}{0.331 \text{ in}^3} = 19.47 \text{ ksi}$$

RECHECK AXIAL DESIGN OF ANCHOR WHEN CONSIDERING ANCHOR BENDING

$\phi F_{nt}' = 42.19\,ksi > f_a + f_m = 20.27 + 19.47 = 39.74\,ksi$

ANCHOR BENDING DOUBLES AXIAL STRESS IN ANCHOR

IMPACT OF ANCHOR BENDING

NO ANCHOR BENDING	WITH ANCHOR BENDING
AXIAL = 20.27 ksi	AXIAL = 20.27 ksi
BENDING = 0	BENDING = 19.47 ksi
$\phi F_{nt}' = 42.19\,ksi > 20.27\,ksi$	$\phi F_{nt}' = 42.19\,ksi > 39.74\,ksi$
PERFORMANCE RATIO = 0.48	PERFORMANCE RATIO = 0.94

WILL IMPACT DESIGN

CURRENT LTS-6

5.17.3.1—Double-Nut Anchor Bolt Connections

The design stresses on anchor bolts shall be determined in accordance with Article 5.17.4.1. In determining the compression effects, bearing of the base plate on concrete or grout shall be neglected. The allowable stresses for the anchor bolts shall be as determined in Article 5.17.4.2. Anchor bolts in double-nut connections should be pretensioned according to Article 5.17.5.

If the clear distance between the bottom of the bottom leveling nut and the top of concrete is less than the nominal anchor bolt diameter, bending of the anchor bolt from shear forces or torsion may be ignored. If the clear distance exceeds one bolt diameter, bending in the anchor shall be considered according to Article 5.17.4.3.

5.17.4.3—Bending Stress in Anchor Bolts

When the clearance between the bottom of the leveling nuts and the top of the concrete foundation exceeds one bolt diameter, bending stresses in the anchor bolts should be considered.

The combined tension and shear and compression and shear requirements of Article 5.17.4.2 shall be used to account for the combination of bending, tension, compression and shear. Eqs. 5-24 and 5-25 shall be met with the value of f_t equal to the summation of the axial tensile stress and the maximum tensile bending stress or f_c equal to the summation of the axial compressive stress and the maximum tensile bending stress.

IF CLEAR DISTANCE ≥ ANCHOR DIA - INCLUDE BENDING

EXCEPTION NOT CURRENTLY IN LRFD SLTS SPEC

PRYING ACTION CONSIDERATION

CURRENT LTS-6

5.17.3 DESIGN BASIS

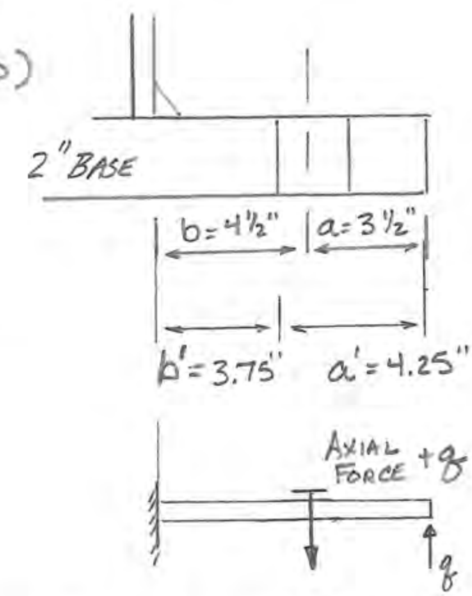
The axial force in anchor bolts that are subject to tension, or combined shear and tension, shall be calculated with consideration of the effects of the externally applied tensile force and any additional tension resulting from prying action produced by deformation of the base plate.

Prying effects of the base plate should be taken into consideration in the design strength of anchor bolt connections. However, research (NCHRP Report 412) has shown that if the base plate thickness is equal to the anchor bolt diameter, these prying effects may be neglected.

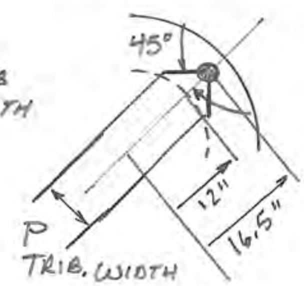
EXCEPTION NOT CURRENTLY IN LRFD SLTS SPEC

IF CHECKING PRYING ACTION
AISC STEEL MANUAL SECTION 9

(ASSUMING BASE PLATE MAY BE GROUTED)



$p = 9''$ TRIB WIDTH



THICKNESS REQUIRED
SO THAT NO PRYING ACTION
OCCURS

$$t_c = \sqrt{\frac{4Bb'}{\phi p F_u}}$$

B = BOLT TENSION = 35.82^k (CONSERV.)

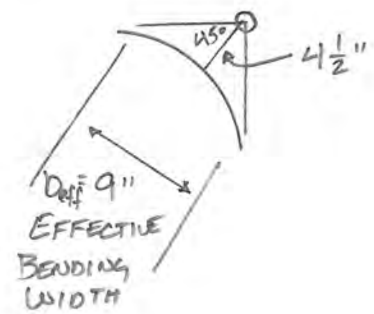
$\phi = 0.90$ $F_u = 58\,ksi$ (A36 PLATE)

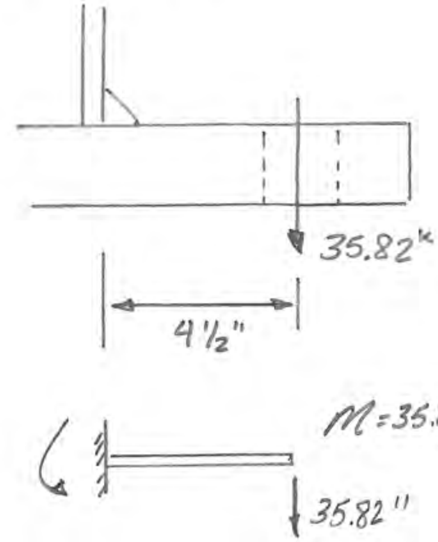
$$t_c = \sqrt{\frac{4(35.82^k)(3.75'')}{0.9(9'')\,58\,ksi}} = 1.07'' < t_P = 2''$$

∴ NO PRYING ACTION

BASE PLATE BENDING

AISC GUIDE 1 CANTILEVER APPROACH





$M = 35.82(4\frac{1}{2}) = 161.2$ in·k

BENDING SECTION IS 2"×9" A36 PLATE

$\varphi M_n = \varphi Z_x F_y \qquad Z_x = \frac{bd^2}{4} = \frac{9(2)^2}{4} = 9 \text{ in}^3 \qquad \varphi = 0.90$

$\varphi M_n = 0.9(9 \text{ in}^3)(36 \text{ ksi}) = 291.6 \text{ in·k} > 161.2 \text{ in·k}$

PLATE BENDING O.K.

STRENGTH DESIGN CHECK SUMMARY

LOADS: DEAD & WIND EXTREME I LIMIT STATE 1.1D+1.0W

STRENGTH: MONOTUBE AT SPLICE & BASE

POLE TO BASE PLATE WELD

BASE PLATE DESIGN

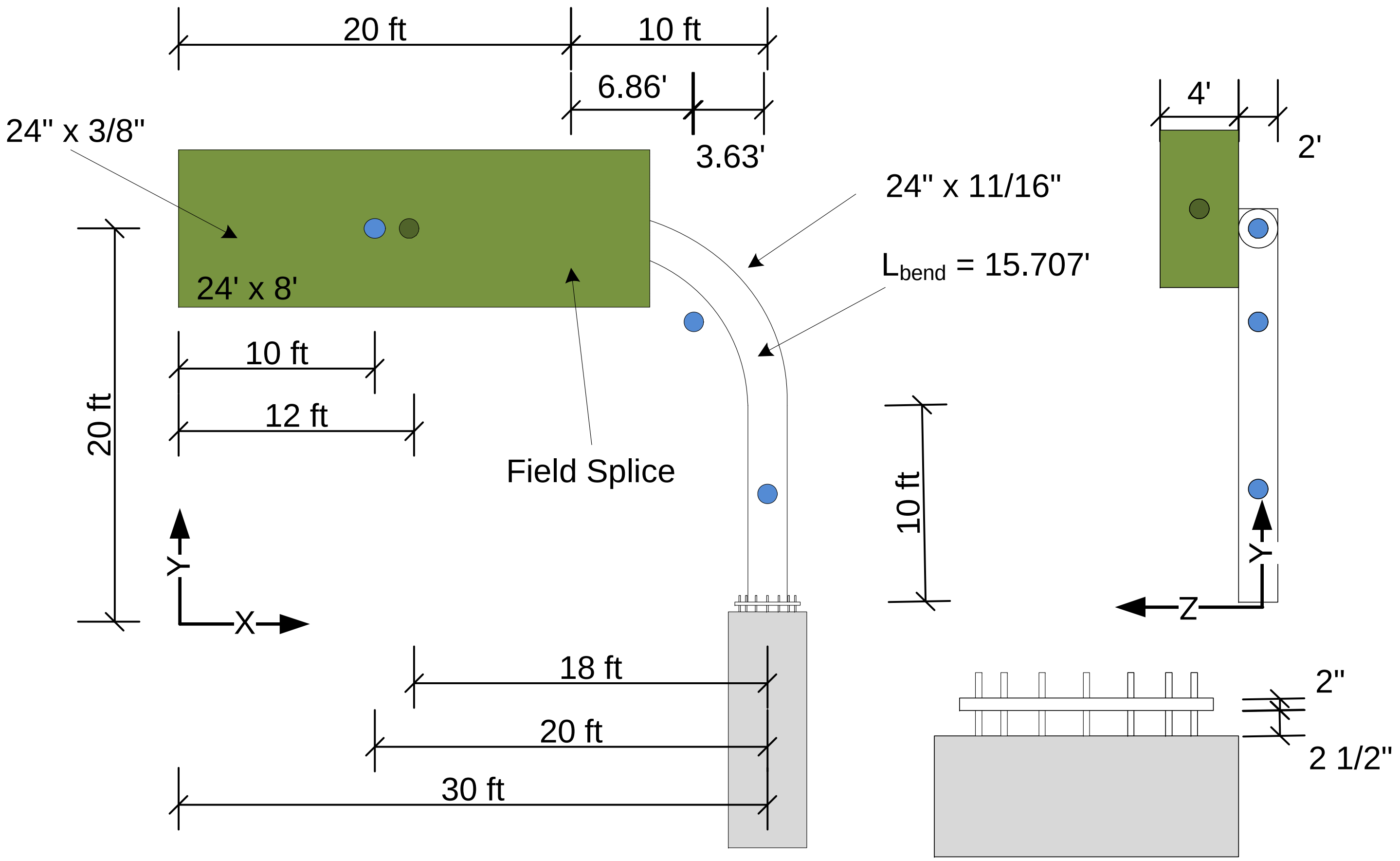
- ANCHORS
- PLATE BENDING

Design Example 9

Cantilevered Monotube Support for a Dynamic Message Sign

Problem Statement:

Design a cantileved monotube structure in Ft. Collins, CO. It will support a dynamic message sign weighing 5,000 pounds. Assume a 24" diameter circular tube fabricated from A36 steel. Bolts are ASTM A 325 bolts. The structure would cross a lifeline travelway on failure.



Fatigue Checks

Natural Wind 11.7.1.2

$I_F = 1$ Table 11.6-1

$C_d = 1.1$ Table 3.8.7-1 (pole)

$P_{NW} = 5.2\,psf(I_F)(C_d)$ 11.7.1.2-1

$C_D = 1.7$ Table 3.8.7-1 (sign)

$P_{NWsign} = 5.2(I_F)(C_d)$ 11.7.1.2-1

$P_{NWsign} = 5.2(1)(1.7) = 8.84\ psf$

$P_{NWPole} = 5.2(1)(1.1) = 5.72\ psf$

$F_{NWsign} = 8.84(24' \times 8') = 1.70^k$

$F_{NWbend} = 5.72\left(\frac{2\pi r}{4}\right)(2')$ $r = 10'$

$F_{NWbend} = 0.180^k$

$F_{NWpole(bottom)} = 5.72(10' \times 2') = 0.114^k$

Name:

2

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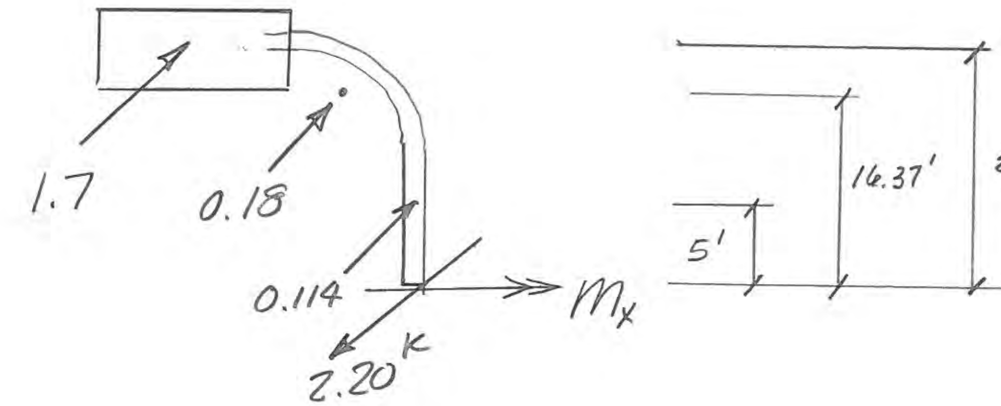
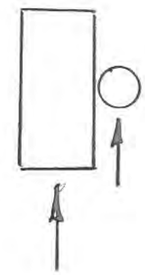


$$M_x = 1.7(20) = 34.0'^k$$
$$+ 0.18(16.37) = 2.95$$
$$+ 0.114(5) = 0.57$$
$$37.5'^k$$

Truck Gusts



$C_{d\,sign\,vert} = 1.2$

$C_{d\,pole} = 1.1$

$P_{TG} = (18.8\,psf)(I_F)(C_d)$

$P_{TG\,sign} = 18.8(1)(1.2) = 22.56\,psf$

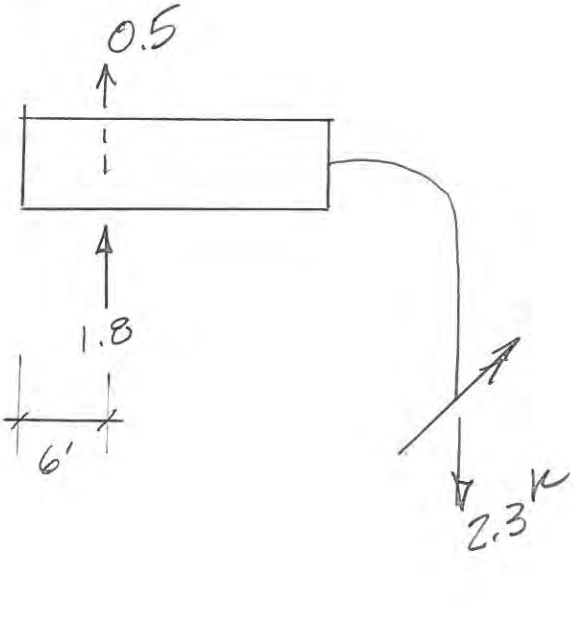
$P_{TG\,Pole} = 18.8(1)(1.1) = 20.68$

$F_{TG\,sign} = 22.56(12'\,lane \times 4') = 1.08^k$

$F_{TG\,Pole} = 20.68(12' \times 2') = 0.50^k$

$F_{TG\,total} = 1.58^k$

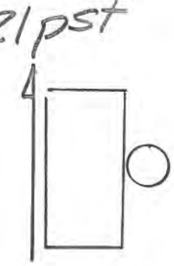
$M_{TG\,total} = 2.3^k(24') = 37.8^{'k}$



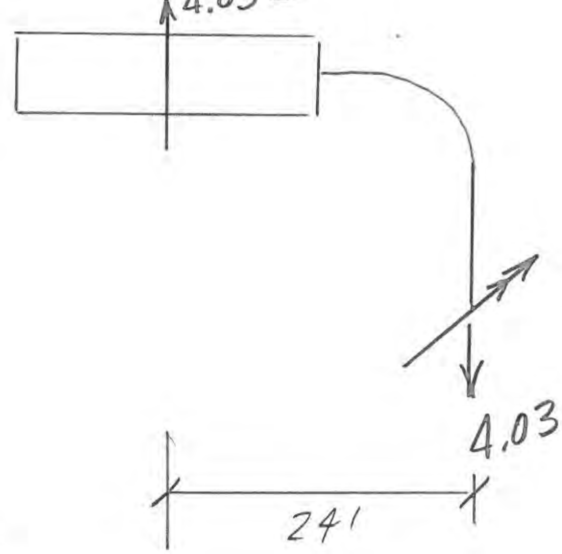
Date: Class: Assignment:

Galloping 11.7.1.1

$P_G = (21\,psf)(I_F)$ 11.7.1.1-1



$F_G = 21\,(24' \times 8') = 4.032^k$



$M_G = 4.032(24)$

$= 72.4'$

Summary:

$M_G = 72.4^{'k}$ ←

$M_{NW} = 37.5$

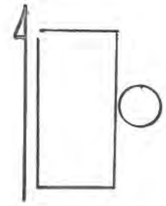
$M_{TG} = 37.8$

Use $M_{fat} = 72.4^{'k}$

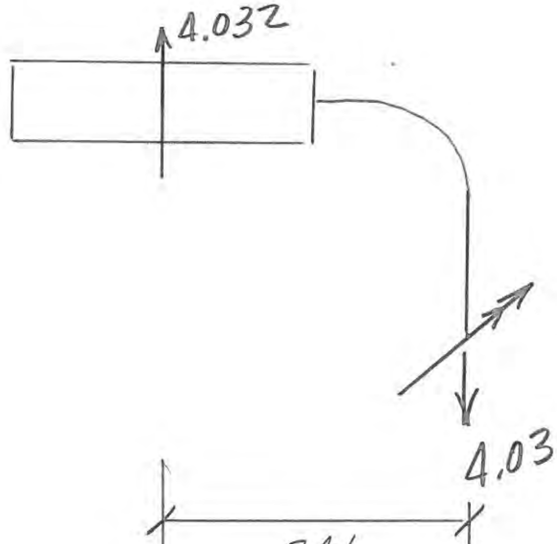
Galloping 11.7.1.1

$P_G = (21\,psf)(I_F)$ 11.7.1.1-1

21psf



$F_G = 21\,(24' \times 8') = 4.032^k$



$M_G = 4.032(24)$

$= 72.4'$

Summary:

$M_G = 72.4^{'k}$ ←

$M_{NW} = 37.5$

$M_{TG} = 37.8$

Use $M_{fat} = 72.4^{'k}$

Fatigue Resistance

$D_T = 24''$

$t_T = 11/16 = 0.6875''$

$t_{TP} = 2''$

$D_{OP} = 6''$

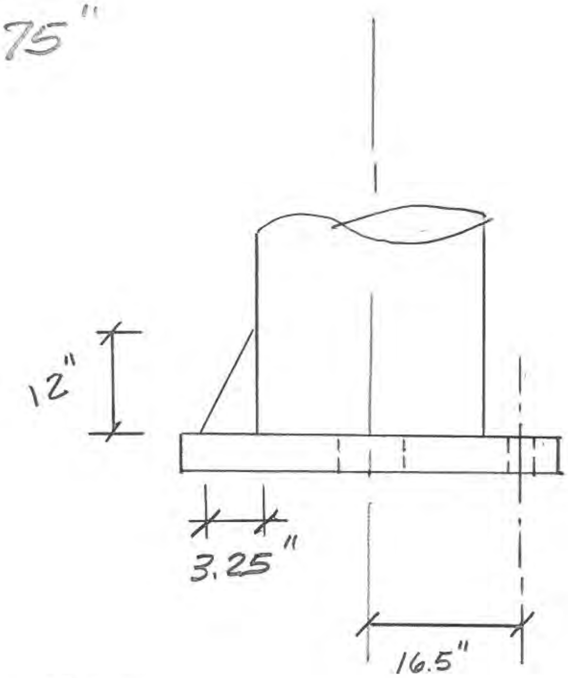
$D_{BC} = 33'$

$t_{ST} = 0.5''$

$N_{ST} = 12$

$h_{ST} = 12''$

$\alpha = 15°$



$$C_{OP} = \frac{D_{OP}}{D_T} = \frac{6}{24} = 0.25$$

$$C_{BC} = \frac{D_{BC}}{D_T} = \frac{33}{24} = 1.375$$

$$K_I = \left[(1.76 + 1.83 t_T) - 4.76\left(0.22^{K_F}\right)\right] K_F$$

K_F depends on detail.

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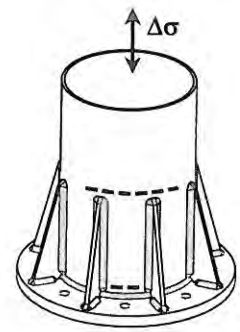
Name: 6/

Date: Class: Assignment:

Check detail at top of stiffener

6.2 Tube-to-transverse plate connections stiffened by longitudinal attachments with partial- or full penetration groove-welds, or fillet-welds in which the tube is subjected to longitudinal loading and the welds are wrapped around the attachment termination.	$K_F \leq 2.5$: 11.0 (See detail 5.4)	$K_I \leq 5.5$: 7.0 (See detail 5.4)	In tube wall at the toe of the attachment to tube weld at the termination of attachment. In tube wall at the toe of tube-to-transverse plate weld.	

Fillet-welded tube-to-transverse plate connections stiffened by longitudinal attachments	Weld toe on tube wall at the end of attachment	$K_F = \left(\frac{t_{ST}^{0.4}}{t_T^{0.7}} + 0.3\right) \times \left(0.4 \times \frac{D_T^{0.8}}{N_{ST}^{1.2}} + 0.9\right)$ Valid for: 0.25 in. $\leq t_{ST} \leq$ 0.75 in.; $8 \leq N_{ST}$; 0.25 in. $\leq t_T \leq$ 0.625 in.; 24 in. $\leq D_T \leq$ 50 in.	(11.9.3.1–14)

$$K_F = \left(\frac{0.5^{0.4}}{0.68^{0.7}} + 0.3\right)\left(0.4 \times \frac{24^{0.8}}{12^{1.2}} + 0.9\right)$$

$$= (0.99 + 0.3)(0.26 + 0.9)$$

$$= 1.29(1.16) = 1.50 \leftarrow$$

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Name:

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$$K_I = \left[(1.76 + 1.83(0.68)) - 4.76(0.22^{K_F}) \right] K_F$$

$$K_F = 1.5$$

$$K_I = [1.76 + 1.24 - 0.49] \, 1.5$$

$$K_I = 2.51(1.5) = 3.76$$

$$K_I < 5.5 \quad \therefore \ \Delta F_{TH} = 7 \text{ ksi.}$$

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Name: 8

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Check Tube-to-Plate Detail 6.2

see pg. 6

Table 11.9.3.1–2—Fatigue Stress Concentration Factors, KF

Section Type	Detail	Location	Fatigue Stress Concentration Factor for Finite Life, K_F	Section Type
Round	Fillet-welded tube-to-transverse plate connections	Fillet-weld toe on tube wall	$K_F = 2.2 + 4.6 \times (15 \times t_T + 2) \times (D_T^{1.2} - 10) \times (C_{BC}^{0.03} - 1) \times t_{TP}^{-2.5}$ Valid for: 0.179 in. $\le t_T \le$ 0.5 in.; 8 in. $\le D_T \le$ 50 in.; 1.5 in. $\le t_{TP} \le$ 4 in; 1.25 $\le C_{BC} \le$ 2.5	(11.9.3.1–12)
	Groove-welded tube-to-transverse plate connections	Groove-weld toe on tube wall	$K_F = 1.35 + 16 \times (15 \times t_T + 1) \times (D_T - 5) \times \left(\frac{C_{BC}^{0.02} - 1}{4 \times C_{OP}^{-0.7} - 3} \right) \times t_{TP}^{-2}$ Valid for: 0.179 in. $\le t_T \le$ 0.625 in.; 8 in $\le D_T \le$ 50 in.; 1.5 in. $\le t_{TP} \le$ 4 in.; 1.25 $\le C_{BC} \le$ 2.5; 0.3 $\le C_{OP} \le$ 0.9	(11.9.3.1–13)
	Fillet-welded tube-to-transverse plate connections stiffened by longitudinal attachments	Fillet-weld toe on tube wall	$K_F = \left[\left(130 \times \frac{D_T^{0.15}}{N_{ST}^{1.5}} + 1 \right) \times \left(\frac{0.13}{h_{ST} + 7} \right) \times \left(\frac{6.5}{t_{ST}^{0.5}} - 1 \right) \times K_F \text{ as per Equation (11-9.3.1-1)} \right]$ Valid for: 12 in. $\le h_{ST} \le$ 42 in.; 0.25 in. $\le t_{ST} \le$ 0.75 in.; 8 $\le N_{ST}$; 24 in. $\le D_T \le$ 50 in.	(11.9.3.1–15)

Date: Class: Assignment:

K_{F0} (without stiffener) 11.9.3.1-13

$$K_{F0} = 1.35 + 16(15t_T + 1) \times (D_T - 5) \times \frac{(C_{BC}^{0.03} - 1)}{(4C_{OP}^{-0.7} - 3)} t_{TP}^{-2.0}$$

$$K_{F0} = 1.35 + 16(15(0.68) + 1)(24 - 5) \times \left(\frac{1.375^{0.03} - 1}{4(0.25)^{-0.7} - 3}\right)(2^{-2})$$

$$K_{F0} = 1.35 + 179.2(19)\left(\frac{1.009599 - 1}{7.556}\right)(0.25)$$

$$\underbrace{\frac{1.009599 - 1}{7.556}}_{0.000846}$$

$$K_{F0} = 1.35 + 0.72$$

$$K_{F0} = 2.07$$

For stiffened connection 11.9.3.1-15

$$K_F = \left(130 \frac{D_T^{0.15}}{N_{ST}^{1.5}} + 1\right)\left(\frac{0.13}{h_{ST} + 7}\right)\left(\frac{6.5}{t_{ST}^{0.5}} - 1\right) K_{F0}$$

$$K_F = \left[130\left(\frac{24^{.15}}{12^{1.5}}\right) + 1\right]\left[\frac{0.13}{12 + 7}\right]\left[\frac{6.5}{0.5^{0.5}} - 1\right] K_{F0}$$

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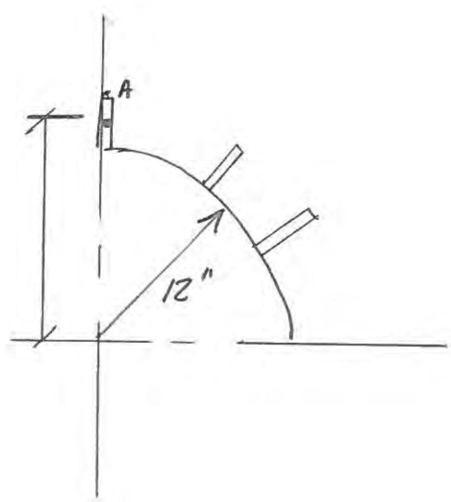
$$K_F = [5.03 + 1][0.00684][8.192][2.07]$$

$$K_F = 0.70$$

$$K_I = [1.76 + 1.83(0.68)) - 4.76(0.22^{0.7})]0.70$$

$$K_I = (3.00 - 1.64)(0.7)$$

$$K_I = 0.95 \leq 5.5 \quad \therefore \Delta F_{TH} = 7 \text{ ksi}$$



$$I_t = 3732 \text{ in}^4$$

$$A_s = 3.5(0.5) = 1.75 \text{ in}^2$$

$$D_T = 24''$$

$$r_s = \frac{24}{2} + \frac{3.25}{2} = 13.625''$$

$$J_s = 12(1.75)(13.625)^2$$

$$J_s = 3898 \text{ in}^4$$

$$I_s = \frac{J_s}{2} = 1949 \text{ in}^4$$

$$I_{Total} = 3732 + 1949 = 5681 \text{ in}^4$$

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Name: 11

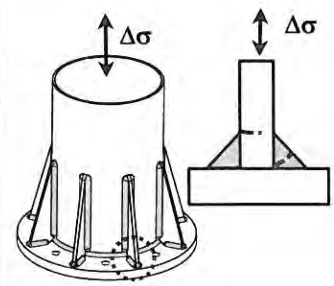
Date: Class: Assignment:

Long Stiffener to Plate Detail 6.3

$\Delta F_H = 10$ ksi.

Bolts - threads Detail 2.3

$\Delta F_{TH} = 7$ ksi

6.3 Transverse load-bearing partial joint penetration groove-welded or fillet-welded attachments where t ≤ 0.5 in. and the main member is subjected to minimal axial and/or flexural loads (When t > 0.5 in, see note c).	44.0	10.0	In base metal at the weld toe or through weld throat.	Longitudinal stiffeners welded to base plates. 

Check Limit State

At top of stiffeners: $\Delta F_{TH} = 7\ ksi$

$$\Delta f = \frac{M_{fat}}{S_{bot}} = \frac{72.4(12)}{303} = 2.9\ ksi \leq 7\ ksi.$$

$$Ratio = \frac{2.9}{7} = 0.41 \quad OK$$

At tube-to-plate: $\Delta F_{TH} = 7\ ksi$

$$\Delta f = \frac{M_{fat}}{S_{bot}} = \frac{72.4(12)}{367} = 2.4 \quad Ratio = 0.34$$

OK

$$S_{bot} = \frac{I_{Total}}{c} = \frac{5681}{15.5} = 367\ in^3$$

At bolts

$$\Delta F_{bolts} = \frac{M_{fat}}{99 A_{bolt}} = \frac{72.4(12)}{99\ in^2} = 8.8^{K}$$

$$\Delta f_{bolt} = \frac{8.8}{1.77} = 5.0\ ksi \leq 7\ ksi. \quad Ratio = 0.71$$

OK

Name:

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Assume no stiffeners w CJP weld

$K_F = 2.08$

$K_I = [(1.76 + 1.83\, t_T) - 4.76(0.22^{K_F})]\, K_F$

$K_I = [(1.76 + 1.83(0.68) - 4.76(0.22^{2.08})]\, 2.08$

$K_I = (1.83)(2.08) = 3.8$

$K_I \leq 3 \rightarrow 10$

$3. < K_I \leq 4 \rightarrow 7.0$ $\Delta F_{TH} = 7.0$ ksi.

$4 < K_I \leq 6.5 \rightarrow 4.5$

$\Delta f = \frac{72.4(12)}{303} = 2.87$ ksi.

Ratio $= \frac{2.87}{7} = 0.41$ (Room for economy!)

Try a smaller section

$t = 11/16 \times 0.41 \Rightarrow 5/16$ try $3/8''$

$$K_F = 1.35 + 16(15\,t_T + 1)(D_T - 5)\left(\frac{C_{BC}^{0.02} - 1}{4C_{op}^{-0.7} - 3}\right) t_{TP}^{-2}$$

$$K_F = 1.35 + 16(15(0.375) + 1)(24 - 5)\left(\frac{(1.375)^{0.02} - 1}{4(0.25)^{-0.7} - 3}\right)(2)^{-2}$$

$$K_F = 1.35 + 16(6.625)(19)(0.000846)(0.25)$$

$$K_F = 1.35 + 0.426 = 1.78$$

$$K_I = \left[1.76 + 1.83(0.375) - 4.76(0.22^{1.78})\right] 1.78$$

$K_I = 2.12 \leq 3.0 \quad \Delta F_{TH} = 10$ ksi.

$\Delta f = \frac{72.4(12)}{165} = 5.27 < 10$ ksi. ok

$S_{new} = 303\left(\frac{0.375}{11/16}\right) = 165\ in^3$

$Ratio = \frac{11/16}{0.375} = 1.83 \quad \frac{1}{1.83} = 0.55$

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Name:

15

Date: Class: Assignment:

Change parameters to optimize materials & fabrication