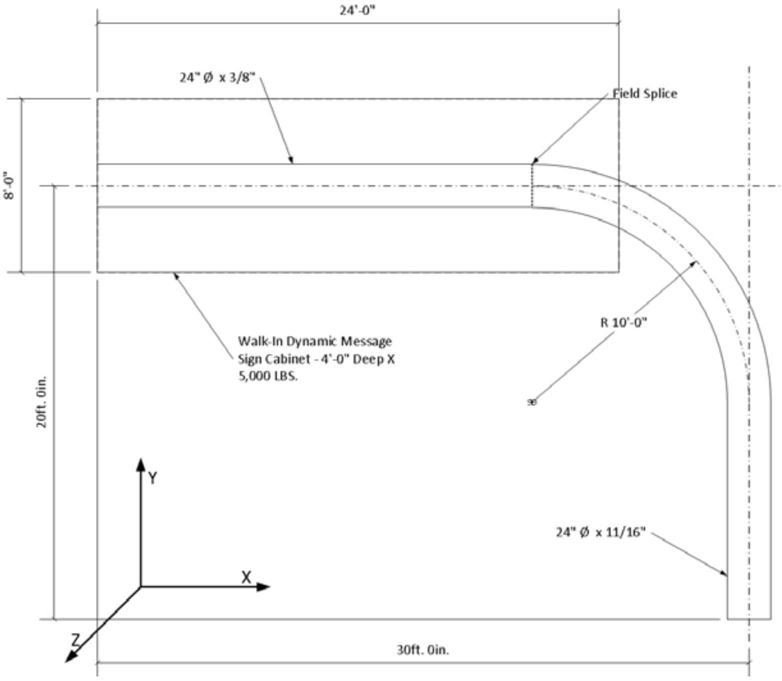
Design Example 9

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.



Reference:E:\BT\Projects\NCHRP 10-80\Examples\Release\SpecificationFunctions.xmcd(R)

Several commonly-used functions are stored in a separate include file that is used in multiple example problems. These include functions to determine C_d and resistance values for flexure, shear, and torsion for common steel shapes. You may need to reset the path to this file for your computer by right-clicking on the reference.

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Materials:

$t_{ice} := 0.25in$ $\gamma_{steel} := 490\frac{lbf}{ft^3}$ $\gamma_{ice} := 56.8\frac{lbf}{ft^3}$

$F_y := 36ksi$ $E_s := 29000ksi$

$l_{total} := 30ft$ Total sign length

$h_{total} := 20ft$ Height to the centerline of the tube

Sign:

$b_{sign} := 24ft$ $h_{sign} := 8ft$ $d_{sign} := 4ft$ $P_{sign} := 5kip$ $EPA_{sign\_x} := 32ft^2$

$BendRadius := 10ft$

Wind Loads:

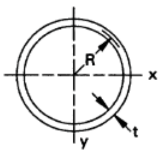
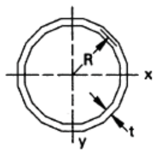
Table 3.8-1—Mean Recurrence Interval

	Risk Category		
Traffic Volume	Typical	High	Low
ADT<100	300	1700	300
100<ADT≤1000	700	1700	300
1000<ADT≤10000	700	1700	300
ADT>10000	1700	1700	300
Typical: Failure could cross travelway			
High: Support failure could stop a lifeline travelway			
Low: Support failure could not cross travelway			
Roadside sign supports: use 300 years			

MRI is 1700, therefore use Figure 3.8-2a

$V_{E1} := 120mph$ Figure 3.8-2a

Table B1-1—Estimated Sectional Properties for Common Tubular Shapes

Property	Round Tube	Hexdecagonal Tube
Moment of inertia, I	$3.14R^3t$	$3.22R^3t$
Section modulus, S	$3.14R^2t$	$3.22R^2t$
Area, A	$6.28Rt$	$6.37Rt$
Shape factor, $K_p = Z/S$	1.27	1.27
Radius of gyration, r	$0.707R$	$0.711R$
Cross-sectional constant, C	3.14	3.22
Pictorial representation		

Tubes:

The bottom tube is 24" diameter, t = 11/16"

$d_{bot} := 24in$ $\qquad t_{bot} := \frac{11}{16}in$ $\qquad r_{bend} := 10ft$ Bend radius of the tube.

$d_{bot\_out} := d_{bot} + t_{bot} = 24.7 \cdot in$

$d_{bot\_in} := d_{bot} - t_{bot} = 23.3 \cdot in$ $\qquad I := \pi \cdot \left(\frac{d_{bot}}{2}\right)^3 t_{bot} = 3732 \cdot in^4$

$A_{bot} := \pi \cdot \frac{\left(d_{bot\_out}^{\ 2} - d_{bot\_in}^{\ 2}\right)}{4} = 51.8 \cdot in^2$ $\qquad I_{bot} := \pi \cdot \frac{\left(d_{bot\_out}^{\ 4} - d_{bot\_in}^{\ 4}\right)}{64} = 3735 \cdot in^4$

$S_{bot} := \pi \cdot \frac{\left(d_{bot\_out}^{\ 4} - d_{bot\_in}^{\ 4}\right)}{32 \cdot d_{bot\_out}} = 303 \cdot in^3$ $\qquad r_{gybot} := \frac{\sqrt{d_{bot\_out}^{\ 2} + d_{bot\_in}^{\ 2}}}{4} = 8.49 \cdot in$

The top tube is 24" diameter, t = 3/8"

$d_{top} := 24in$ $t_{top} := \frac{3}{8}in$

$d_{top\_out} := d_{top} + t_{top} = 24.4 \cdot in$

$d_{top\_in} := d_{top} - t_{top} = 23.6 \cdot in$

$$A_{top} := \pi \cdot \frac{\left(d_{top\_out}^2 - d_{top\_in}^2\right)}{4} = 28.3 \cdot in^2$$

$$I_{top} := \pi \cdot \frac{\left(d_{top\_out}^4 - d_{top\_in}^4\right)}{64} = 2036 \cdot in^4$$

$$S_{top} := \pi \cdot \frac{\left(d_{top\_out}^4 - d_{top\_in}^4\right)}{32 \cdot d_{top\_out}} = 167 \cdot in^3$$

$$r_{gytop} := \frac{\sqrt{d_{top\_out}^2 + d_{top\_in}^2}}{4} = 8.49 \cdot in$$

$l_{top} := 14ft$ $l_{bot} := \frac{\pi \cdot 2 \cdot r_{bend}}{4} + 10ft = 25.7\,ft$

Load Factors:

Table 3.4-1--- Load Combinations and Load Factors

Load Combination Limit State	Description	Reference Articles	Permanent: Dead Components (DC)		Transient: Live Load (LL)	Transient: Wind (W)	Transient: Truck Gust (TrG)	Fatigue: Natural Wind Gust Vibration (NWG)	Fatigue: Vortex-Induced Vibration (VVW)	Fatigue: Combined Wind on High-level Towers	Fatigue: Galloping Induced Vibration (GVW)
			Max/Min	Mean			Apply separately				
Strength I	Gravity	3.5, 3.6, and 3.7	1.25		1.6						
Extreme I	Wind	3.5, 3.8, 3.9	1.1/0.9			1.0[a]					
Service I	Translation	10.4		1.0		1.0[b]					
Service III	Crack control for Prestressed Concrete			1.0		1.00					
Fatigue I	Infinite-life	11.7		1.0			1.0	1.0	1.0	1.0	1.0
Fatigue II	Evaluation	17.5		1.0			1.0	1.0	1.0	1.0	1.0

a. Use Figures 3.8-1, 3.8-2, or 3.8-3 (for appropriate return period)

b. Use wind map 3.8-4 (service)

Resistance Factors:

$\phi_{flexure} := 0.90$ $\phi_{shear} := 0.90$ $\phi_{weld} := 0.75$ $\phi_{torsion} := 0.95$ $\phi_{axial} := 0.90$ Article 5.5.3.2

$\phi_{bolt\_tension} := 0.75$ $\phi_{bolt\_shear} := 0.33$

Load Factors:

$\gamma_{DC\_E1} := 1.1$ $\gamma_{W\_E1} := 1.0$

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$P_{sign} = 5.00 \cdot kip$

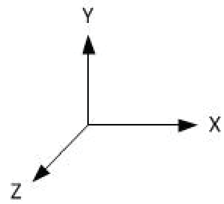
$d_{z\_sign} := l_{total} - \frac{b_{sign}}{2} = 18.0\,ft$

Tube weights:

$P_{tube\_top} := A_{top} \cdot \gamma_{steel} \cdot l_{top} = 1.35 \cdot kip$

$P_{tube\_bot} := A_{bot} \cdot \gamma_{steel} \cdot l_{bot} = 4.53 \cdot kip$

$P_{tube\_tot} := P_{tube\_top} + P_{tube\_bot} = 5.88 \cdot kip$



Tube moment arms:

$d_{z\_top\_tube} := r_{bend} + \frac{l_{top}}{2} = 17.0\,ft$

$$d_{z\_bot\_tube} := \frac{r_{bend}\,ft \cdot 0 + \left(l_{bot} - r_{bend}\right) \cdot \frac{4 r_{bend}}{3 \cdot \pi}}{l_{bot}} = 2.59\,ft$$

Distance from the centerline of the bottom of the tube to the centroid of the straight and bent tube.

Moments at the base:

$M_{z\_DCSign} := P_{sign} \cdot d_{z\_sign} = 90.0 \cdot kip \cdot ft$

$M_{z\_DCTube} := d_{z\_top\_tube} \cdot P_{tube\_top} + d_{z\_bot\_tube} \cdot P_{tube\_bot} = 34.7 \cdot kip \cdot ft$

Moments at the field splice:

$$M_{z\_DCSign\_splice} := P_{sign} \cdot \frac{l_{top}}{2} = 35.0 \cdot kip \cdot ft$$

$$M_{z\_DCTube\_splice} := P_{tube\_top} \cdot \frac{l_{top}}{2} = 9.43 \cdot kip \cdot ft$$

$$V_{DC\_sign\_splice} := P_{sign} = 5.00 \cdot kip$$

$$V_{DC\_tube\_splice} := P_{tube\_top} = 1.35 \cdot kip$$

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Areas:

$A_{sign} := b_{sign} \cdot h_{sign} = 192\,ft^2$ $\qquad EPA_{sign\_x} = 32\,ft^2$

Assume the tube is exposed all the way to the field splice.

$$A_{tube\_vert} := \left(h_{total} - r_{bend}\right) \cdot d_{bot\_out} = 20.6\,ft^2$$

Area of the tube perpendicular to the z axis

$$A_{tube\_bend} := \left(\frac{2 \cdot \pi \cdot r_{bend}}{4}\right) \cdot d_{bot\_out} = 32.3\,ft^2$$

$$A_{tube} := A_{tube\_vert} + A_{tube\_bend} = 52.9\,ft^2$$

$$A_{tube\_x} := h_{total} \cdot d_{bot\_out} = 41\,ft^2$$

Area of the tube perpendicular to the x axis

Pressures:

$z := h_{total} = 20\,ft$ — Height above ground for pressure calculation. C3.8.4.

$z_g := 900ft$ — Constant based on exposure condition. C3.8.4.

$\alpha := 9.5$ — Constant based on exposure condition. C3.8.4.

$$Factor := \frac{hr^2 \cdot lbf}{27878400 \cdot ft^4}$$

This units factor is needed for consistent units in the wind pressure equations.

$$K_z := 2.00\left(\frac{z}{z_g}\right)^{\frac{2}{\alpha}} = 1$$

Equation 3.8.4-1

$G := 1.14$ — Gust effect factor, minimum value.

$V_{E1} = 120 \cdot mph$ — Extreme I Wind Speed - Figure 3.8-2b, 1700 year mean recurrence interval.

$K_{d\_tube} := 0.95$ Directionality factor, see 3.8.5 for a round support.

$K_{d\_sign} := 0.85$ Directionality factor, see 3.8.5 for a Dynamic Message Sign.

Table 3.8.5-1—Directionality Factors, K_d

Support Type	Directionality Factor
High-mast and Pole	
Round	0.95
Square	0.9
Octagonal	0.95
Dodecagonal	0.95
Hexdecagonal	0.95
Traffic Signal	0.85
Dynamic Message Sign	0.85
Overhead Frame/Truss	0.85
Support with horizontal arms or members supporting sign and/or signals	0.85

Tube:

$C_{d\_tube\_E1} := C_{d\_cylindrical}\left(V_{E1}, d_{bot\_out}\right) = 0.45$

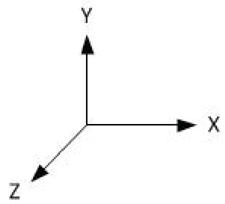
$P_{z\_tube\_E1} := 0.00256 \cdot K_z \cdot K_{d\_tube} \cdot G \cdot V_{E1}^{\;2} \cdot C_{d\_tube\_E1} \cdot Factor = 16.1 \cdot psf$

$P_{tube\_E1} := P_{z\_tube\_E1} \cdot A_{tube} = 0.85 \cdot kip$ — Causes moment about the x axis

$P_{tube\_E1\_z} := P_{z\_tube\_E1} \cdot A_{tube\_x} = 0.663 \cdot kip$ — Causes moment about the y axis (torsion at the base plate).

$M_{x\_E1} := P_{tube\_E1} \cdot d_{z\_bot\_tube} = 2.21 \cdot kip \cdot ft$

$M_{y\_E1} := P_{tube\_E1\_z} \cdot \dfrac{h_{total}}{2} = 6.63 \cdot kip \cdot ft$



Sign:

$C_{dSign} := C_{d\_sign}\left(\dfrac{b_{sign}}{h_{sign}}\right) = 1$

$P_{z\_sign\_E1} := 0.00256 \cdot K_z \cdot K_{d\_sign} \cdot G \cdot V_{E1}^{\;2} \cdot C_{dSign} \cdot Factor = 38.1 \cdot psf$

$P_{sign\_E1} := P_{z\_sign\_E1} \cdot A_{sign} = 7.32 \cdot kip$

$M_{x\_sign\_E1} := P_{sign\_E1} \cdot h_{total} = 146 \cdot kip \cdot ft$

$M_{y\_sign\_E1} := P_{sign\_E1} \cdot d_{z\_sign} = 132 \cdot kip \cdot ft$ — Torsion at the base of the tube.

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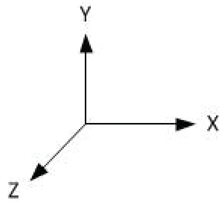
Resistance Factors:

$\phi_{flexure} = 0.90$ $\phi_{shear} = 0.90$ $\phi_{weld} = 0.75$ $\phi_{torsion} = 0.95$ $\phi_{axial} = 0.90$

$\gamma_{DC\_E1} = 1.10$ $\gamma_{W\_E1} = 1.00$

Extreme Event I, Maximum Wind plus Dead



Actions at the field splice:

Assume that all the moment from the sign is carried by the field splice.

$M_{z\_DCSign\_splice} = 35.0 \cdot kip \cdot ft$ $M_{z\_DCTube\_splice} = 9.43 \cdot kip \cdot ft$

$V_{DC\_sign\_splice} = 5.00 \cdot kip$ $V_{DC\_tube\_splice} = 1.347 \cdot kip$

$$M_{splice\_E1} := \sqrt{\left[\gamma_{DC\_E1} \cdot \left(M_{z\_DCSign\_splice} + M_{z\_DCTube\_splice}\right)\right]^2 + \left(\gamma_{W\_E1} \cdot P_{sign\_E1} \cdot \frac{l_{top}}{2}\right)^2} = 70.8 \cdot kip \cdot ft$$

$$V_{splice\_E1} := \sqrt{\left[\gamma_{DC\_E1} \cdot \left(V_{DC\_sign\_splice} + V_{DC\_tube\_splice}\right)\right]^2 + \left(\gamma_{W\_E1} \cdot P_{sign\_E1}\right)^2} = 10.1 \cdot kip$$

Actions at the tube base:

$M_{x\_sign\_E1} = 146 \cdot kip \cdot ft$ $M_{z\_DCSign} = 90 \cdot kip \cdot ft$ $M_{z\_DCTube} = 34.7 \cdot kip \cdot ft$

$M_{y\_sign\_E1} = 132 \cdot kip \cdot ft$

$P_{sign\_E1} = 7.32 \cdot kip$

$M_{tube\_E1} := \sqrt{\left[\gamma_{DC\_E1} \cdot \left(M_{z\_DCSign} + M_{z\_DCTube}\right)\right]^2 + \left(\gamma_{W\_E1} \cdot M_{x\_sign\_E1}\right)^2} = 201 \cdot kip \cdot ft$

$T_{tube\_E1} := \gamma_{W\_E1} \cdot M_{y\_sign\_E1} = 132 \cdot kip \cdot ft$ torsion

$V_{tube\_E1} := \gamma_{W\_E1} \cdot \left(P_{sign\_E1} + P_{tube\_E1}\right) = 8.18 \cdot kip$

$P_{u\_tube} := \gamma_{DC\_E1} \cdot \left(P_{sign} + P_{tube\_tot}\right) = 12.0 \cdot kip$

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$A_{shear\_splice} := \frac{A_{top}}{2} = 14.14 \cdot in^2$ $d_{top} = 24 \cdot in$ $t_{top} = 0.375 \cdot in$

$Z_{top} := \frac{d_{top\_out}^3}{6} - \frac{d_{top\_in}^3}{6} = 216 \cdot in^3$

$L_{v\_splice} := l_{top} = 14\,ft$

$L_{t\_splice} := \pi \cdot d_{top} = 75 \cdot in$

$V_n := V_{n\_roundTube}\left(A_{shear\_splice}, d_{top}, t_{top}, E_s, F_y, L_{v\_splice}\right) = 305 \cdot kip$

$J_{top} := 2 \cdot I_{top} = 4072 \cdot in^4$

$F_{nt} := F_{nt\_roundTube}\left(F_y, E_s, d_{top}, t_{top}, L_{v\_splice}\right) = 21.60 \cdot ksi$

$T_n := A_{top} \cdot F_{nt} \cdot \left(\frac{d_{top}}{2}\right) = 610.7\,ft \cdot kip$

$M_n := M_{n\_roundTube}(d_{top}, t_{top}, E_s, F_y, Z_{top}, S_{top}) = 630 \cdot kip \cdot ft$

$M_{splice\_E1} = 70.8 \cdot kip \cdot ft$ $\quad V_{splice\_E1} = 10.12 \cdot kip$ $\quad T_{tube\_E1} = 131.8 \cdot kip \cdot ft$

$$InteractionValue := \left(\frac{M_{splice\_E1}}{\phi_{flexure} \cdot M_n}\right) + \left(\frac{V_{splice\_E1}}{\phi_{shear} \cdot V_n} + \frac{T_{tube\_E1}}{\phi_{torsion} \cdot T_n}\right)^2 = 0.19$$

$InteractionCheck_{splice\_E1} :=$ if (InteractionValue ≤ 1.0, "OK", "No Good") = "OK"

Resistance at the Tube Splice

Resistance at the Tube Base

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$A_{shear\_base} := \frac{A_{bot}}{2} = 25.9 \cdot in^2$ $\quad d_{bot} = 24 \cdot in$ $\quad t_{bot} = 0.688 \cdot in$

$$Z_{bot} := \frac{d_{bot\_out}^3}{6} - \frac{d_{bot\_in}^3}{6} = 396 \cdot in^3$$

$k_{tube} := 2.1$ $\quad r_{gytube} := 0.707 \cdot \frac{d_{bot}}{2} = 8.48 \cdot in$

$$kl\_over\_r_{tube} := \frac{k_{tube} \cdot l_{total}}{r_{gytube}} = 89.1$$

$L_{v\_base} := l_{total} = 30\,ft$

$L_{t\_base} := \pi \cdot d_{bot} = 75 \cdot in$

$Q := 1.0$

$V_n := V_{n\_roundTube}\left(A_{shear\_base}, d_{bot}, t_{bot}, E_s, F_y, L_{v\_base}\right) = 307 \cdot kip$

$J_{top} := 2 \cdot I_{top} = 4072 \cdot in^4$

$F_{nt} := F_{nt\_roundTube}\left(F_y, E_s, d_{bot}, t_{bot}, L_{v\_base}\right) = 21.6 \cdot ksi$

$T_n := A_{bot} \cdot F_{nt} \cdot \frac{d_{bot}}{2} = 1120\,ft \cdot kip$

$M_n := M_{n\_roundTube}\left(d_{top}, t_{top}, E_s, F_y, Z_{top}, S_{top}\right) = 630 \cdot kip \cdot ft$

$P_n := P_{n\_roundTube}\left(A_{bot}, F_y, kl\_over\_r_{tube}, E_s, Q\right) = 1229 \cdot kip$

$M_{tube\_E1} = 201 \cdot kip \cdot ft$ $\quad V_{tube\_E1} = 8 \cdot kip$ $\quad P_{u\_tube} = 11.97 \cdot kip$

$T_{tube\_E1} = 132 \cdot kip \cdot ft$

$\frac{P_{u\_tube}}{P_n} = 0.010$ $\quad \frac{T_{tube\_E1}}{T_n} = 0.118$

$$InteractionValue := \left(\frac{M_{tube\_E1}}{\phi_{flexure} \cdot M_n}\right) + \left(\frac{V_{tube\_E1}}{\phi_{shear} \cdot V_n} + \frac{T_{tube\_E1}}{\phi_{torsion} \cdot T_n}\right)^2 = 0.38$$

$InteractionCheck_{splice\_E1} :=$ if (InteractionValue ≤ 1.0, "OK", "No Good") = "OK"

Resistance at the Tube Base

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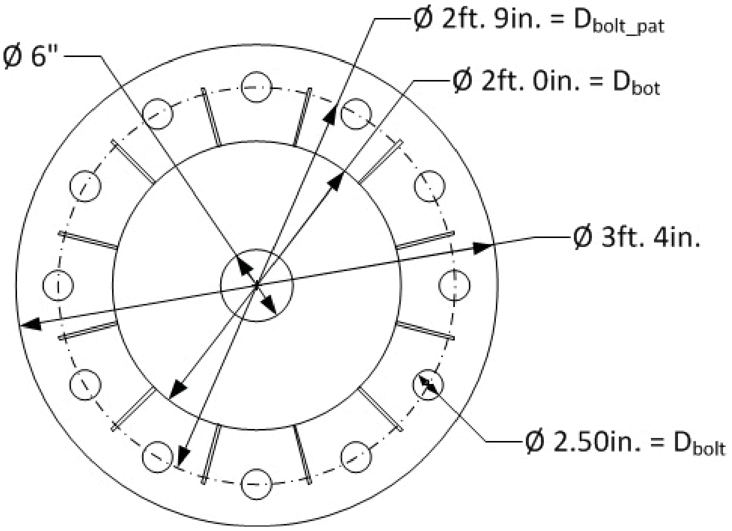


$t_{min} := 2in$ — Minimum base plate thickness, 5.6.3.

Bolts:

$\phi_{bolt\_tension} = 0.75$ $\phi_{bolt\_shear} = 0.33$

$n_{bolts} := 12$ $F_{y\_bolts} := 55ksi$ $F_{u\_bolts} := 70ksi$

$D_{bolt} := 1.00in$

$$A_{bolt} := \frac{\pi}{4} \cdot \left(D_{bolt}\right)^2 = 0.79 \cdot in^2$$

$$D_{bolt\_pat} := 33.0in$$

See figure above for geometry.

$$C_{bolts} := \frac{D_{bolt\_pat}}{2} = 17 \cdot in$$

$$I_1 := A_{bolt} \cdot C_{bolts}^{\ 2} = 214 \cdot in^4$$

$$I_2 := A_{bolt} \cdot \left(C_{bolts} \cdot \sin(60deg)\right)^2 \cdot 2 = 321 \cdot in^4$$

$$I_3 := A_{bolt} \cdot \left(C_{bolts} \cdot \sin(30deg)\right)^2 \cdot 2 = 107 \cdot in^4$$

$$I_{bolts} := 2 \cdot \left(I_1 + I_2 + I_3\right) = 1283 \cdot in^4$$

Tension in bolts, Extreme Event I:

$$P_{u\_bolt} := \left(\frac{M_{tube\_E1} \cdot C_{bolts}}{I_{bolts}}\right) \cdot A_{bolt} = 24.3 \cdot kip$$

Shear in bolts, Extreme Event I:

$$V_{u\_bolt} := \frac{V_{tube\_E1}}{n_{bolts}} = 0.68 \cdot kip$$

Shear in bolts from torsion, Extreme Event I:

$$T_{u\_bolt} := \frac{T_{tube\_E1}}{D_{bolt\_pat} \cdot n_{bolts}} = 4.00 \cdot kip$$

Total Shear:

$$V_{u\_bolt} := V_{u\_bolt} + T_{u\_bolt} = 4.68 \cdot kip$$

Bolt Resistances:

$$P_{n\_bolt} := \phi_{bolt\_tension} \cdot F_{u\_bolts} \cdot A_{bolt} = 41.2 \cdot kip$$

$$V_{n\_bolt} := \phi_{bolt\_shear} \cdot F_{u\_bolts} \cdot A_{bolt} = 18.1 \cdot kip$$

Combined Bolt Resistance:

$$InteractionValue_{bolts} := \left(\frac{P_{u\_bolt}}{P_{n\_bolt}}\right)^2 + \left(\frac{V_{u\_bolt}}{V_{n\_bolt}}\right)^2 = 0.414$$

$$InteractionCheck_{bolts} := if\left(InteractionValue_{bolts} \le 1.0, \text{"OK"}, \text{"No Good"}\right) = \text{"OK"}$$

$$F_{y\_bp} := 36ksi$$

Calculate an eccentricity equal to half the distance from the center of the bolt to the toe of the weld. Assume a weld size.

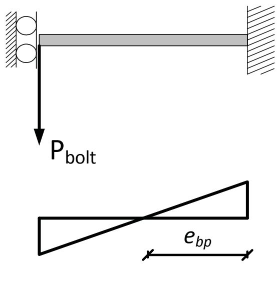
$t_{weld} := 0.50in$

$d_{bolt} := \left(\frac{D_{bolt\_pat} - d_{bot}}{2}\right) = 4.50 \cdot in$

Distance from the face of the tube to the center of a bolt.

$d_{weld\_bolt} := \frac{D_{bolt\_pat}}{2} - t_{weld} = 16.00 \cdot in$

$e_{bp} := \frac{d_{weld\_bolt}}{2} = 8 \cdot in$



Moment Diagram in Base Plate

$M_{bp} := P_{u\_bolt} \cdot e_{bp} = 16.21 \cdot kip \cdot ft$

$\theta_{bolt} := \frac{360deg}{n_{bolts}} = 30 \cdot deg$

Each bolt covers an arc of 30 degrees

$d_e := \frac{d_{bot} + t_{weld} + e_{bp}}{2} = 16.25 \cdot in$

$b_{bp\_section} := 2 \cdot atan\left(\frac{\theta_{bolt}}{2}\right) \cdot d_e = 8.32 \cdot in$

The width of a 30 degree arc at the location of eccentricty

$t_{min} = 2 \cdot in$

Table 5.6.3-1

$Z_{bp} := \frac{b_{bp\_section} \cdot t_{min}^2}{4} = 8.32 \cdot in^3$

$M_{n\_bp} := F_{y\_bp} \cdot Z_{bp} = 25 \cdot kip \cdot ft$

$ratio_{bp} := \frac{M_{bp}}{\phi_{flexure} \cdot M_{n\_bp}} = 0.72$

$InteractionCheck_{bp} := if\left(ratio_{bp} \le 1.0, "OK", "No Good"\right) = "OK"$

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Weld Design

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$\phi_{weld} = 1$ $F_{EXX} := 70ksi$ $F_{n\_weld} := 0.60 \cdot F_{EXX} = 42 \cdot ksi$

$M_{tube\_E1} = 201 \cdot kip \cdot ft$ $V_{tube\_E1} = 8 \cdot kip$

$t_{weld} = 0.5 \cdot in$

$radius_{bot} := \frac{d_{bot}}{2} = 12 \cdot in$

$S_{weld} := \pi \cdot radius_{bot}^{2} = 452 \cdot in^{2}$

Section modulus of the outer weld pattern.

$V_{u\_weld} := \sqrt{\left(\frac{M_{tube\_E1}}{S_{weld}}\right)^2 + \left(\frac{V_{tube\_E1}}{2 \cdot \pi \, radius_{bot}}\right)^2} = 5.32 \cdot \frac{kip}{in}$

Resultant shear on the weld.

$V_{n\_weld} := t_{weld} \cdot F_{n\_weld} = 21.0 \cdot \frac{kip}{in}$

Factored resistance of the outer weld.

$ratio_{weld} := \frac{V_{u\_weld}}{\phi_{weld} \cdot V_{n\_weld}} = 0.34$

WeldCheck := if(ratio$_{weld}$ < 1.00, "OK", "No Good")

WeldCheck = "OK"

The 1/2" weld supplies adequate capacity.

Weld Design

Fatigue Limits

Fatigue Limits

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$D_T := d_{bot} = 24.0 \cdot in$ External diameter of a round tube.

$D_{BC} := D_{bolt\_pat} = 33.0 \cdot in$ Diameter of a circle through the fasteners in the transverse plate.

$N_B := 12$ Number of fasteners in the transverse plate.

$t_T := t_{bot} = 0.6875 \cdot in$ Thickness of the tube.

$t_{TP} := t_{min} = 2.00 \cdot in$ Thickness of the transverse plate.

$D_{OP} := 4in$ Diameter of the concentric opening in the tranverse plate. Assume a value.

$$C_{OP} := \frac{D_{OP}}{D_T} = 0.17$$

$$C_{BC} := \frac{D_{BC}}{D_T} = 1.38$$

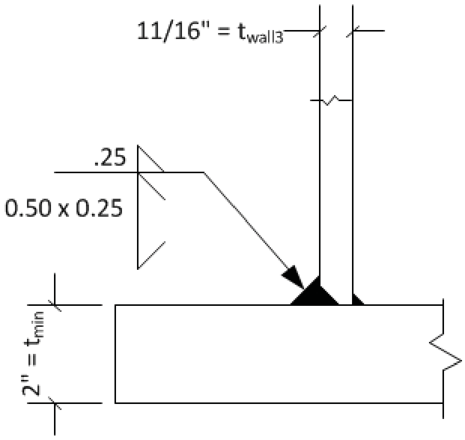
$t_{ST} := 0$ Stiffener thickness, not applicable for this case

$N_{ST} := 0$ Number of stiffeners, NA

$h_{ST} := 0$ Height of stiffeners, NA

$N_S := 1$ Number of sides for multi-sided tube, NA

$r_b := 0$ Inside bend radius, use 0 for a round tube



4.6 Full penetration groove-welded tube-to-transverse plate connections welded from both sides with back-gouging (without backing ring). From Table 11.9.3.1-1.

Groove-welded tube-to-transverse plate connections: Section type for equation 11.9.3.1-13. From Table 11.9.3.1-2.

$K_{F\_pole} := K_F\left(13, D_T, D_{BC}, N_B, t_T, t_{TP}, D_{OP}, t_{ST}, N_{ST}, h_{ST}, N_S, r_b\right) = 1.85$ See included sheet.

$K_{I\_pole} := \left[\left(1.76 + 1.83 \cdot \frac{t_T}{in}\right) - 4.76 \cdot 0.22^{K_{F\_pole}}\right] \cdot K_{F\_pole} = 5.04$ Equation 11.9.3.1-1

$\Delta F_{TH\_weld} := \text{Delta\_F}\left(K_{I\_pole}\right) = 7.0 \cdot ksi$

$\Delta F_{TH\_bolts} := 7.0ksi$ See Table 11.9.3.1-1, 2.3

Fatigue Limits

Natural Wind Gusts

Natural Wind Gusts (11.7.1.2):

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The maximum yearly mean wind velocity of National Weather Stations in Ft. Collins, CO is 11.2 mph.

C11.6 states the cantilevers supporting variable message may be classified as fatigue category 1.

$I_F := 1.0$ Table 11.6-1

$C_{dSign} = 1.19$

$V_{mean} := 11.2mph$

$C_{d\_pole} := C_{d\_cylindrical}\left(V_{mean}, d_{top}\right) = 1.10$ Table 3.8.7-1 Different arm Cd due to lower wind speed.

$p_{NW\_pole} := 5.2\frac{lbf}{ft^2} \cdot C_{d\_pole} \cdot I_F = 5.72 \cdot psf$ Equation C11.7.1.2-1

$p_{NW\_sign} := 5.2\frac{lbf}{ft^2} \cdot C_{dSign} \cdot I_F = 6.19 \cdot psf$

$P_{NW\_pole} := p_{NW\_pole} \cdot \left(A_{tube}\right) = 0.303 \cdot kip$ Wind force times the area of pole exposed.

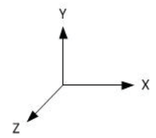
$P_{NW\_sign} := p_{NW\_sign} \cdot \left(A_{sign}\right) = 1.188 \cdot kip$ Wind force times the area of the sign.

$P_{NW\_total} := P_{NW\_pole} + P_{NW\_sign}$

$M_{xNW\_pole} := P_{NW\_pole} \cdot h_{total} = 6.05 \cdot kip \cdot ft$

$M_{xNW\_sign} := P_{NW\_sign} \cdot h_{total} = 23.8 \cdot kip \cdot ft$

$M_{xNW\_total} := M_{xNW\_pole} + M_{xNW\_sign} = 29.8 \cdot kip \cdot ft$



$$\sigma_{NW\_weld} := \frac{M_{xNW\_total} \cdot \frac{d_{bot}}{2}}{I_{bot}} = 1.149 \cdot ksi$$

$$ratio_{NW} := \frac{\sigma_{NW\_weld}}{\Delta F_{TH\_weld}} = 0.16$$

$$CheckWeld_{NW} := if(ratio_{NW} \le 1.0, "OK", "No Good") = "OK"$$

Natural Wind Gusts

Truck Gusts

Truck Gusts (11.7.1.3):

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$b_{sign} = 24\,ft$ $\qquad$ $d_{sign} = 4\,ft$

$$C_{dSign\_vertical} := C_{d\_sign}\left(\frac{b_{sign}}{d_{sign}}\right) = 1.2$$

$$p_{TG\_sign} := 18.8psf \cdot C_{dSign\_vertical} \cdot I_F = 22.6 \cdot psf$$

$$p_{TG\_pole} := 18.8psf \cdot C_{d\_pole} \cdot I_F = 20.7 \cdot psf$$

$$P_{TG\_sign} := p_{TG\_sign} \cdot \left(b_{sign} \cdot d_{sign}\right) = 2.17 \cdot kip$$

$$P_{TG\_pole} := p_{TG\_pole} \cdot \left(l_{total} \cdot d_{top}\right) = 1.24 \cdot kip$$

$$M_{zTG\_sign} := P_{TG\_sign} \cdot \left(l_{total} - \frac{b_{sign}}{2}\right) = 39.0 \cdot kip \cdot ft$$