

Subject: Box Culvert Guardrail - Task AE Calculations

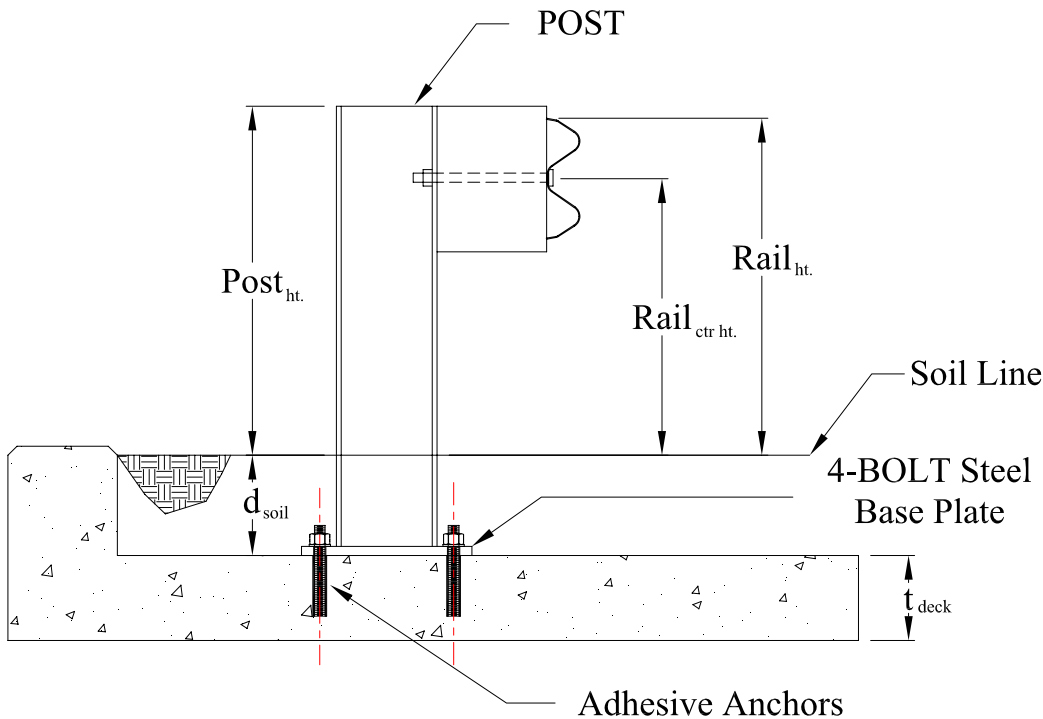
W6x9 Design

Sponsor: Washington DOT Pooled Fund

Hilti RE 500 Anchor System

7/8" Dia. Anchors Embed. 5" Max

Given the following general layout of a box culvert guardrail post anchored to a concrete box culvert section using an epoxy adhesive anchoring system. Find the limiting ultimate strength of the post design considering the different variables used in the design.



depth of soil (in.)

$d_{soil} := 18in$

Thickness of Deck (in.)

$t_{deck} := 7in$

**GUARDRAIL ON BOX CULVERT TYPICAL
CROSS-SECTION**

1.) Design Information:

***** Rail Geometry *****

$Rail_{ctrht} := 21in$ Center Height of Rail (in.)

$Rail_{ht} := Rail_{ctrht} + 6.125in$ Height to top of rail (in.)

$Post_{ht} := 27in$ Height of Post above grade (in.)

$Post_{load} := 12kips$ Load applied to Rail center (kips) $M_{load} := Post_{load} \cdot (Rail_{ht} + d_{soil})$

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Define Mathcad units ORIGIN := 1

kips ≡ kip ksi ≡ $\frac{\text{kips}}{\text{in}^2}$

Steel Beam Yield Strength: $F_y := (50) \cdot \text{ksi}$
 Beam Nominal Depth: $\text{NOMINAL_DEPTH} := (6)$
 Beam weight per foot: $\text{WEIGHT_PER_FOOT} := (9)$

🔒 Beam Data - Fri Sep 15 09:13:04 2006

***** Post Information *****

Post Data for: Nominal_depth = 6 in

$\text{Wt_per_foot} = 9 \text{ ft}^{-1} \cdot \text{lb}$

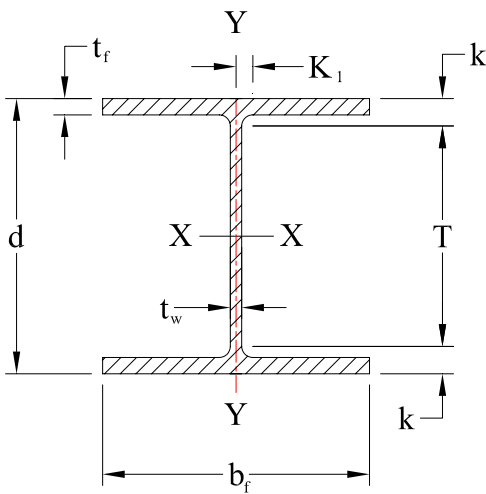
$F_y = 50 \text{ ksi}$

$\text{Wt_per_foot} = 9 \text{ ft}^{-1} \cdot \text{lb}$

Wt. per foot of length (lb/ft)

$d_n = 6$

Nominal Depth of member



$\text{Area} = 2.68 \text{ in}^2$

Area (in²)

$d = 5.9 \text{ in}$

Actual Depth of Member (in.)

$t_w = 0.17 \text{ in}$

Thickness of Web (in.)

$b_f = 3.94 \text{ in}$

Width of Flange (in.)

$t_f = 0.215 \text{ in}$

Thickness of Flange (in.)

$k = 0.56 \text{ in}$

Distance to toe of fillet (in.)

$I_x = 16.4 \text{ in}^4$

Moment of Inertia (Stg. Axis (in⁴))

$S_x = 5.56 \text{ in}^3$

Section Modulus (Stg. Axis (in³))

$Z_x = 6.23 \text{ in}^3$

Plastic Modulus (Strong Axis (in³))

$Z_y = 1.72 \text{ in}^3$

Plastic Modulus (Weak Axis (in³))

$A_f = 0.85 \text{ in}^2$

Area Flange (in²)

POST DETAILS

$r_x = 2.47 \text{ in}$ radius of gyration with respect to X-X Axis (in.)

$I_y = 2.19 \text{ in}^4$ Moment of Inertia (Weak Axis (in⁴))

$S_y = 1.11 \text{ in}^3$ Section Modulus (Weak Axis (in³))

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******* Steel & Concrete Material properties *******

$F_{y\text{steel}} := 50\text{ksi}$ Yield Strength of Steel Material (ksi)
 $F_{y\text{rebar}} := 60\text{ksi}$ Yield Strength of rebar (ksi)
 $F_u := 65\text{ksi}$ Rupture Strength of Steel Material (ksi)
 $f_c := 4000\text{psi}$ Compressive Strength of Concrete (psi)

******* Anchor Bolt Properties *******

$F_{u\text{bolts}} := 125\text{ksi}$ High Strength Super HAS Rod Material, ASTM A193, Grade B7 Material (ksi)

$\text{Dia}_{\text{bolt}} := \frac{7}{8}\text{in}$ Dia. of anchor bolts (in.) $\text{Area}_{\text{bolt}} := \pi \text{Dia}_{\text{bolt}}^2 \cdot 0.25$ $\text{Area}_{\text{bolt}} = 0.6\text{in}^2$

$\phi_{\text{bolt}} := 1.0$ Strength Reduction Factor For Bolts

$E_s := 29 \cdot 10^6\text{psi}$ Modulus of Elasticity (in.) $N_t := 2$ 2 bolts on the tension face

$A_s := \frac{\pi \cdot \text{Dia}_{\text{bolt}}^2}{4} \cdot N_t$ Area of tension bolts $A_s = 1.203\text{in}^2$

$E_c := 57000 \cdot \sqrt{\frac{f_c}{\text{psi}}}\text{psi}$ $E_c = 3604996.533\text{psi}$ $n := \frac{E_s}{E_c}$ $n = 8.04$

******* Weld Properties *******

$F_{\text{EXX}} := 70\text{ksi}$ Weld Material Strength (ksi)

$t_{\text{weld}} := \frac{1}{4}\text{in}$ Weld Size (in.)

$\phi_{\text{weld}} := 1.0$ Reduction Factor for Weld

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***** **Baseplate Properties** *****

$D := 12\text{in}$ Baseplate Length (in.)

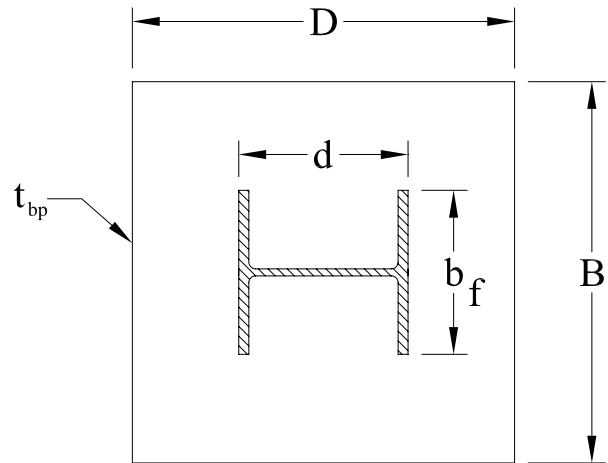
$B := 12\text{in}$ Baseplate width (in.)

$t_p := 1.000\text{in}$ Approx. Baseplate thickness (in.)

$d = 5.9\text{in}$ Depth of Post (in.)

$b_f = 3.94\text{in}$ Width of Post (in.)

$\text{Hole}_{\text{edgedist}} := 1.5\text{in}$ Distance to plate edge to hole center (in.)



BASEPLATE DETAILS

***** **Hilti Anchor Properties** *****

1.) As per page 112, 2002 Hilti Product Technical Guide,
HIT RE 500 Epoxy System, Average values for 4000 psi concrete:

$$\text{Tension} := \begin{pmatrix} 22670 \\ 63495 \\ 64730 \end{pmatrix} \text{lbf} \quad \text{Shear} := \begin{pmatrix} 16365 \\ 48455 \\ 79020 \end{pmatrix} \text{lbf}$$

$$\text{Depth}_{\text{embed}} := \begin{pmatrix} 4 \\ 7.875 \\ 10.5 \end{pmatrix} \text{in}$$

Actual Embedment Depth (inches)
, see Hilti guide

$h_{\text{ef}} := 5.00\text{in}$

Use Hilti High Strength Super HAS, 7/8" Dia. Rod:

$$\text{HIT}_{\text{ultimatetensile}} := \text{linterp}(\text{Depth}_{\text{embed}}, \text{Tension}, h_{\text{ef}})$$

Interpolate for Embedment Depth, h_{ef}

$$\text{HIT}_{\text{ultimateshear}} := \text{linterp}(\text{Depth}_{\text{embed}}, \text{Shear}, h_{\text{ef}})$$

$$\text{HIT}_{\text{ultimatetensile}} = 33.205 \text{ kips}$$

Ultimate Bond Strength
(see pg 112 Hilti 2002 Tech. Guide)

$$\text{HIT}_{\text{ultimateshear}} = 24.646 \text{ kips}$$

Ultimate shear strength of
anchor (see pg 112)

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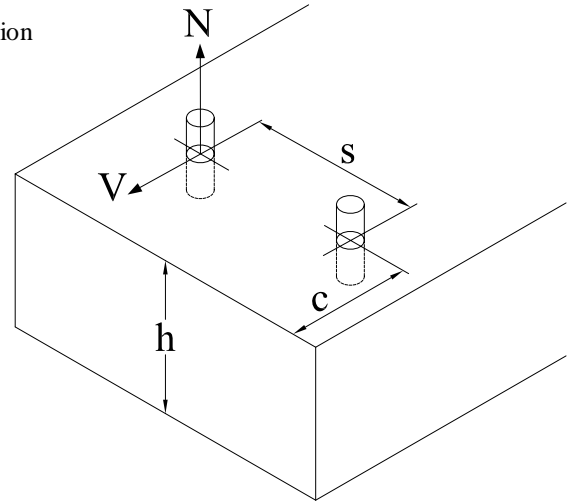
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Temperature := 110 °F Max Temperature for Temperature Reduction

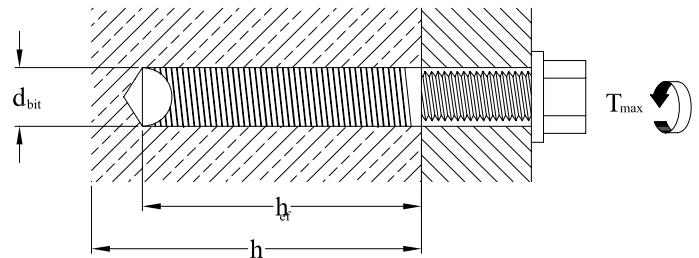
Check Load Adjustment Factors for Anchor Spacings & Clearance:

From page 119, Hilti 2002 Technical Guide

- $S_{act} := 9.0in$ Actual anchor spacing (inches)
- $C_{act} := 12in$ edge distance (inches) from concrete edge to Centerline of bolts
- $h_{nom} := 7.875in$ Standard embedment depth (inches), see page 110
- $h_{ef} = 5 in$ Actual embedment depth (in.)
- $S_{min} := 0.5 \cdot h_{ef}$ $S_{min} = 2.5 in$
- $S_{cr} := 1.5 \cdot h_{ef}$ $S_{cr} = 7.5 in$
- $C_{min} := 0.5 \cdot h_{ef}$ $C_{min} = 2.5 in$
- $C_{cr} := 1.5 \cdot h_{ef}$ $C_{cr} = 7.5 in$
- $h := t_{deck}$ Thickness of slab, (in)
- $h = 7 in$



ANCHOR DETAILS



ANCHOR GEOMETRY

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**** Calculate Hilti Reduction Factors ****

$$f_A := \begin{cases} f_A \leftarrow 0.3 \cdot \left(\frac{S_{act}}{h_{ef}} \right) + 0.55 & \text{if } S_{cr} \geq S_{act} \geq S_{min} \\ f_A \leftarrow 1.0 & \text{if } S_{act} \geq S_{cr} \\ f_A \leftarrow 0 & \text{if } S_{act} < S_{min} \end{cases}$$

$$f_A = 1$$

**** Calculate Reduction Factors for Edge Distance Tension, "f_{RN}" ****

$$f_{RN} := \begin{cases} f_{RN} \leftarrow 0.3 \cdot \left(\frac{C_{act}}{h_{ef}} \right) + 0.55 & \text{if } C_{cr} \geq C_{act} \geq C_{min} \\ f_{RN} \leftarrow 1.0 & \text{if } C_{act} \geq C_{cr} \\ f_{RN} \leftarrow 0 & \text{if } C_{act} < C_{min} \end{cases}$$

$$f_{RN} = 1$$

5.) Calculate Reduction Factors for Edge Distance Shear, "f_{RVperp}"

$$f_{RVperp} := \begin{cases} f_{RVperp} \leftarrow 0.7 \cdot \left(\frac{C_{act}}{h_{ef}} \right) - 0.05 & \text{if } C_{cr} \geq C_{act} \geq C_{min} \\ f_{RVperp} \leftarrow 1.0 & \text{if } C_{act} \geq C_{cr} \\ f_{RVperp} \leftarrow 0 & \text{if } C_{act} < C_{min} \end{cases}$$

$$f_{RVperp} = 1$$

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6.) Calculate total combined Reduction Factors for tension & shear:

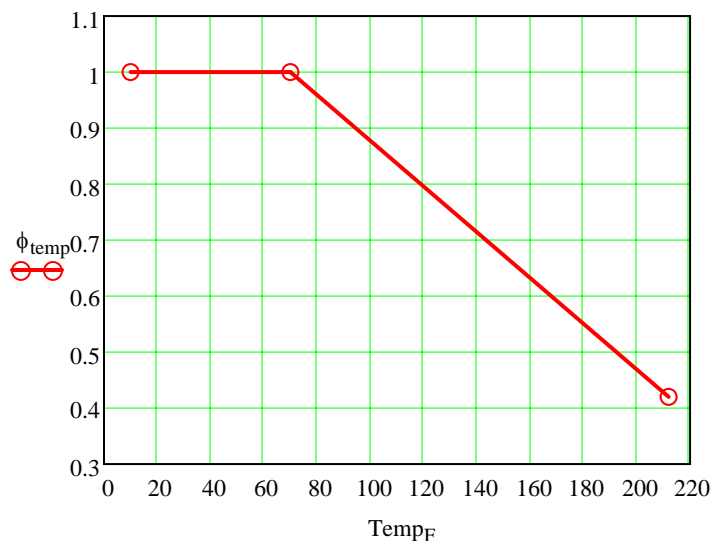
$$f_{RVperp} = 1$$

$$f_A = 1$$

$$f_{RN} = 1$$

$$\phi_{temp} := \begin{pmatrix} 1.0 \\ 1.0 \\ 0.42 \end{pmatrix} \quad Temp := \begin{pmatrix} 10 \\ 70 \\ 212 \end{pmatrix} \text{ } ^\circ\text{F} \quad F_m := Temp \quad Temp = \begin{pmatrix} 260.93 \\ 294.26 \\ 373.15 \end{pmatrix} \text{ K} \quad Temp = \begin{pmatrix} 260.93 \\ 294.26 \\ 373.15 \end{pmatrix} \text{ K}$$

$$Temp_F := \frac{[(Temp - 273.15K) \cdot \frac{9}{5}] + 32K}{K} \quad \text{Temperature conversion}$$



$$\phi_{tempreduce} := \text{linterp}(Temp, \phi_{temp}, Temperature)$$

$$\phi_{tempreduce} = 0.84$$

$$\phi_{tension} := \overrightarrow{(f_A \cdot f_{RN} \cdot \phi_{tempreduce})}$$

$$\phi_{tension} = 0.84$$

$$\phi R_{tension} := \phi_{tension} \cdot HIT_{ultimatetension}$$

$$\phi R_{tension} = 27.78 \text{ kips}$$

$$\phi_{shear} := \overrightarrow{(f_A \cdot f_{RVperp})}$$

$$\phi_{shear} = 1$$

$$\phi R_{shear} := \phi_{shear} \cdot HIT_{ultimateshear}$$

$$\phi R_{shear} = 24.65 \text{ kips}$$

Hilti Factored Anchor Strengths for
 $h_{ef} = 5.00 \text{ in}$

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7. Calculate the Plastic Strength of the Post:

$$F_y = 50 \text{ ksi} \quad \text{Yield Strength of Steel}$$

$$Z_x = 6.23 \text{ in}^3 \quad \text{Plastic Section Modulus of Post}$$

$$M_{x\text{plastic}} := F_y \cdot Z_x$$

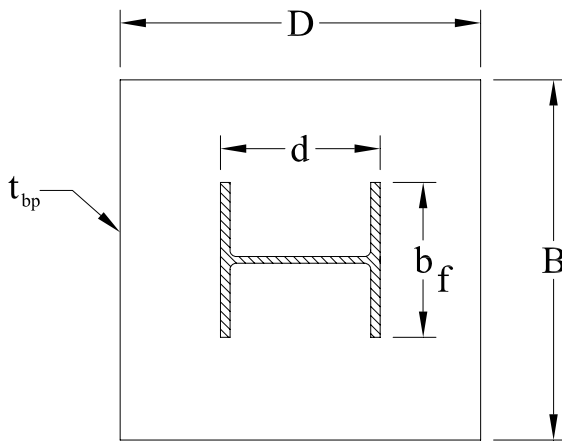
$$M_{x\text{plastic}} = 25.96 \text{ kip}\cdot\text{ft}$$

Plastic Moment

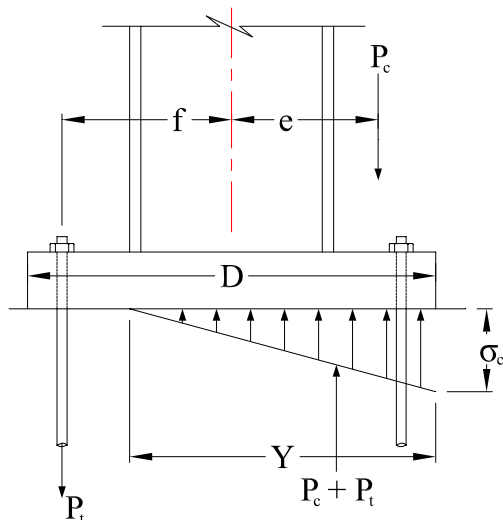
$$M_{\text{load}} = 45.12 \text{ kip}\cdot\text{ft}$$

Moment from Post Load

8.) Check Baseplate details & calculate anchor bolt forces:



BASEPLATE DETAILS



Given Basic Uplift Procedure as shown in Blodgett, "Design of Welded Structures" pages 3-3-8 through 10. and sketch w/ nomenclature showing Baseplate Geometry and distribution of force.

Find: Maximum Stress (σ_c), "Y", and force in the bolts (P_t) for applied force as shown.

This basic uplift procedure as shown in Blodgett's "Design of Welded Structures" pages 3-3-8 through 10. It solves three equations for three unknowns for any combination of vertical & applied moment to the column. You have to combine the vertical load and moment to a single vertical load at some eccentricity "e".
(Input Items in Yellow):

4 Bolts are used in the design with 2 bolts located on the tension face

$$P_c := .10 \text{ kips} \quad \text{Vertical Load on Column (kips)}$$

Select Design Moment from Above:

$$M_1 := M_{x\text{plastic}}$$

Applied Moment (k-ft.)

$$e := \frac{M_1}{P_c}$$

$$e = 3115 \text{ in} \quad \text{eccentricity (in.)}$$

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$D = 12$ in BP Length (in.) $B = 12$ in BP Width (in.) $f_c = 4000$ psi
 $d = 5.9$ in Post Depth (in.) $D = 12$ in BP Length (in.) $N_t = 2$ # Tension Bolts
 $b_f = 0.33$ ft Post Flange Width (in.)

$f := \frac{d}{2} - \text{Hole}_{\text{edgedist}}$ Distance from Col. Centerline to
 tension bolts.

From static, there are Three Equations & Three Unknowns, P_t , "Y", & σ_c :

Use Mathcad's Solve Block to find solutions. Solve Block requires "Initial guesses and uses these guesses to converge on solutions for the three unknowns, σ_c , Y, P_t :

Initial Guesses for unknowns:

$\sigma_c := 1000 \cdot \text{psi}$

$Y := .3 \cdot \text{ft}$

$P_t := 10 \cdot \text{kip}$

Given

$$\frac{1}{2} \cdot Y \cdot \sigma_c \cdot B - P_t - P_c = 0$$

Equation 1

$$P_t \cdot f + (P_c + P_t) \cdot \left(\frac{D}{2} - \frac{Y}{3} \right) - P_c \cdot e = 0$$

Equation 2

$$\sigma_c = \frac{P_t \cdot Y}{A_s \cdot n \cdot \left(\frac{D}{2} - Y + f \right)}$$

Equation 3

$$\begin{pmatrix} Y \\ \sigma_c \\ P_t \end{pmatrix} := \text{Find}(Y, \sigma_c, P_t)$$

$Y = 2.7545$ in

$\sigma_c = 2887$ psi

Compressive stress @ the Edge of the Baseplate on Compression side.

$P_t = 48$ kips

Tension Force in (N_t) Anchor Bolts

$$P_{\text{Bolt}} := \frac{P_t}{N_t}$$

$P_{\text{Bolt}} = 23.81$ kips

Tension per Bolt (kips)

... o.k. less than Factored Hilti Ultimate for $h_{\text{ef}} = 5$ in

$\phi R_{\text{tension}} = 27.78$ kips

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9.) Check Baseplate bending/thickness using forces & stress above separately.

Calculate moment in baseplate on bearing side:

$$Y = 2.75 \text{ in} \quad d_{\text{edge}} := \frac{D}{2} - \frac{b_f}{2} \quad d_{\text{edge}} = 4.03 \text{ in}$$

$$M_{\text{plate1}} := \frac{\sigma_c \cdot Y}{2} \cdot \left[\left(d_{\text{edge}} + \frac{t_f}{2} \right) - \frac{Y}{3} \right]$$

$$M_{\text{plate1}} = 12.8 \frac{\text{kip} \cdot \text{in}}{\text{in}}$$

Calculate moment in baseplate on Tension Bolt Side:

$$P_{\text{Bolt}} = 23.81 \text{ kips}$$

$$\text{Hole}_{\text{edgedist}} = 1.5 \text{ in}$$

$$d_{\text{edge}} = 4.03 \text{ in} \quad \text{Distance from Baseplate Edge to Post Edge}$$

$$\text{Bolt}_{\text{dist}} := d_{\text{edge}} - \text{Hole}_{\text{edgedist}} + \frac{t_f}{2}$$

$$\text{Bolt}_{\text{dist}} = 2.64 \text{ in} \quad \text{Distance from center of bolt to centerline of post flange}$$

$$M_{\text{plate2}} := \frac{P_{\text{Bolt}} \cdot \text{Bolt}_{\text{dist}}}{\text{Bolt}_{\text{dist}} \cdot 2} \quad M_{\text{plate2}} = 11.9 \frac{\text{kip} \cdot \text{in}}{\text{in}}$$

$$M_{\text{plate}} := \begin{cases} M_{\text{plate1}} & \text{if } M_{\text{plate1}} > M_{\text{plate2}} \\ M_{\text{plate2}} & \text{otherwise} \end{cases} \quad \text{Select worst case bending moment in plate bearing or anchor bolt tension}$$

$$M_{\text{plate}} = 12.8 \frac{\text{kip} \cdot \text{in}}{\text{in}} \quad \text{Design moment in the baseplate for thickness calculations}$$

Subtract 1/8" since procedure is little conservative

Therefore:

$$t_{\text{required}} := \sqrt{\frac{4 \cdot M_{\text{plate}}}{F_y}} \quad t_{\text{required}} = 1.01 \text{ in} \quad t_{\text{plate}} := (t_{\text{required}} - 0.125 \text{ in})$$

$$t_{\text{bp}} := \text{Round}(t_{\text{plate}}, 0.125 \text{ in}) \quad t_{\text{bp}} = 0.875 \text{ in} \quad \text{Final Baseplate Design Thickness (in.)}$$

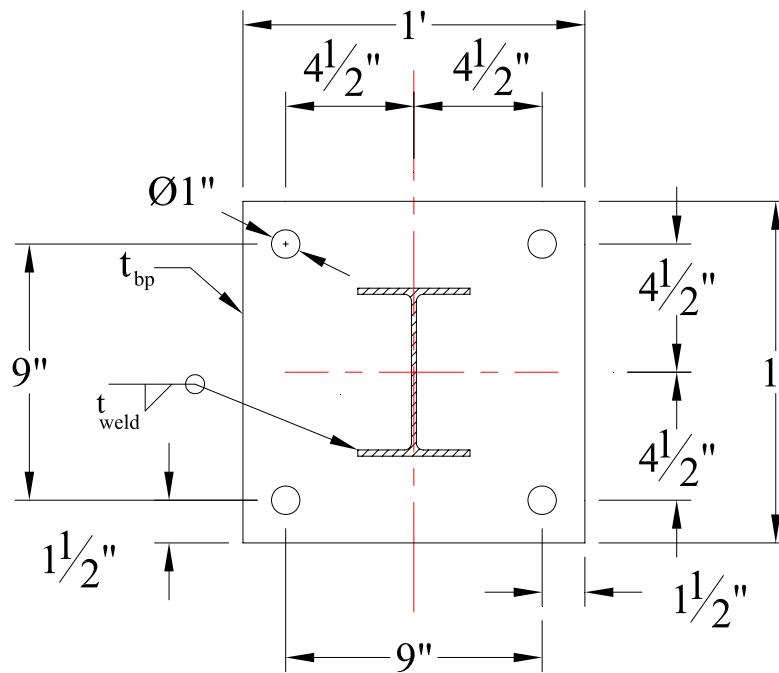
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$t_{bp} = 0.875$ in

$F_y = 50$ ksi

$t_{weld} = 0.25$ in

RECOMMENDED BASEPLATE DETAILS



**W6x8.5 & 9
BASEPLATE DETAILS**

Anchor Bolts: 7/8" Dia. A193 Threaded Rods 8 inches long, embedded 5 inches minimum

Anchorage System: Hilti RE 500 Anchoring System