Texas Transportation Institute

Project #: 405160-00005

W8x21 Design

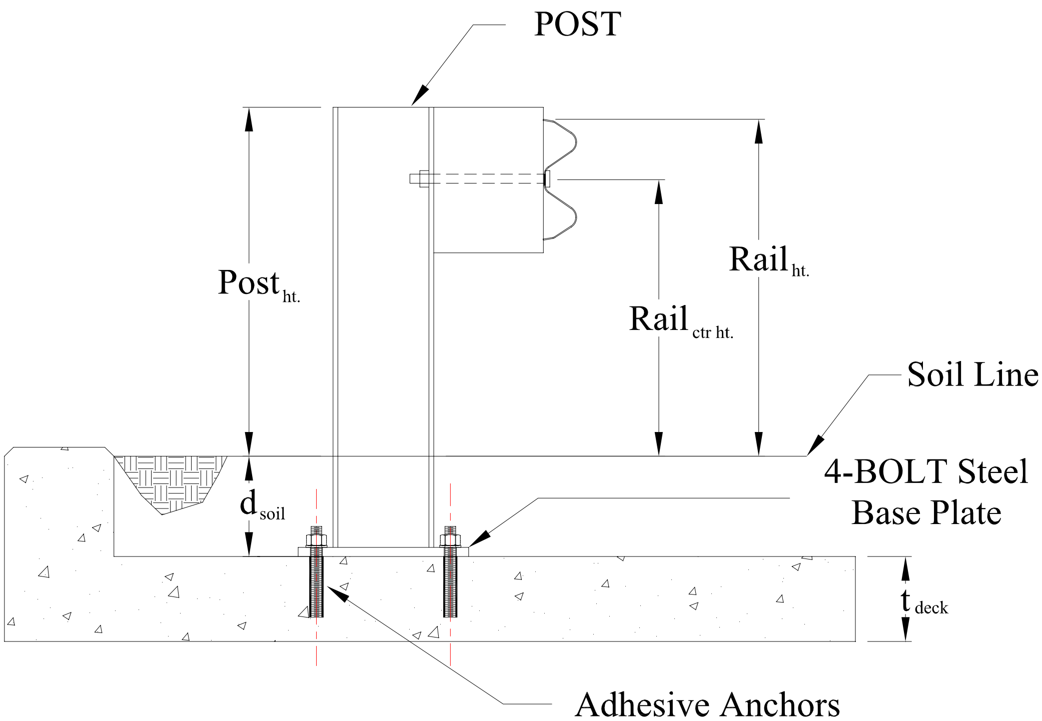
Hilti RE 500 Anchor System

7/8" Dia. Anchors Embed. 10" Max

Subject: **Box Culvert Guardrail - Task AE Calculations**

Sponsor: **Washington DOT Pooled Fund**

Given the following general latout 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.



GUARDRAIL ON BOX CULVERT TYPICAL CROSS-SECTION

depth of soil (in.)

$d_{soil} := 18in$

Thickness of Deck, Slab or Footing (in.)

$t_{deck} := 14in$

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.)

$Post_{load} := 20kips$ Load applied to Rail center (kips)

$M_{load} := Post_{load} \cdot (Rail_{ctrht} + d_{soil})$

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Define Mathcad units ORIGIN := 1

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

Steel Beam Yield Strength: $F_y := (50) \cdot ksi$
Beam Nominal Depth: NOMINAL_DEPTH := (8)
Beam weight per foot: WEIGHT_PER_FOOT := (21)

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

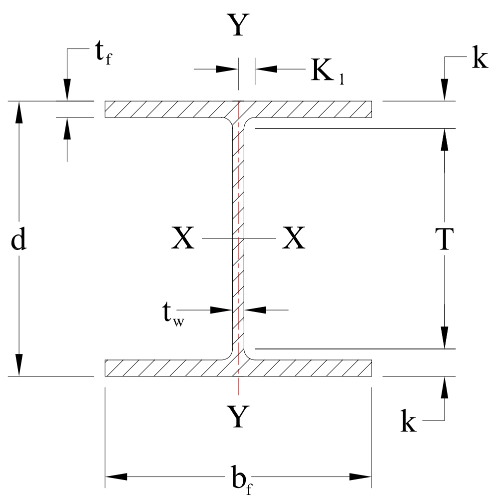
******* Post Information *******

$Wt\_per\_foot = 21\,ft^{-1}\,lb$ $\quad F_y = 50\,ksi$

Post Data for: Nominal_depth = 8 in

$Wt\_per\_foot = 21\,ft^{-1} \cdot lb$ Wt. per foot of length (lb/ft)

$d_n = 8$ Nominal Depth of member



POST DETAILS

$Area = 6.16\,in^2$ Area (in^2)

$d = 8.28\,in$ Actual Depth of Member (in.)

$t_w = 0.25\,in$ Thickness of Web (in.)

$b_f = 5.27\,in$ Width of Flange (in.)

$t_f = 0.4\,in$ Thickness of Flange (in.)

$k = 0.81\,in$ Distance to toe of fillet (in.)

$I_x = 75.3\,in^4$ Moment of Inertia (Stg. Axis (in^4))

$S_x = 18.2\,in^3$ Section Modulus (Stg. Axis (in^3))

$Z_x = 20.4\,in^3$ Plastic Modulus (Strong Axis (in^3))

$Z_y = 5.69\,in^3$ Plastic Modulus (Weak Axis (In^3))

$A_f = 2.11\,in^2$ Area Flange (in^2)

$r_x = 3.49\,in$ radius of gyration with respect to X-X Axis (in.)

$I_y = 9.77\,in^4$ Moment of Inertia (Weak Axis (in^4))

$S_y = 3.71\,in^3$ Section Modulus (Weak Axis (in^3))

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

$F_{ysteel} := 50ksi$ Yield Strength of Steel Material (ksi)

$F_{yrebar} := 60ksi$ Yield Strength of rebar (ksi)

$F_u := 65ksi$ Rupture Strength of Steel Material (ksi)

$f'_c := 4000psi$ Compressive Strength of Concrete)psi)

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

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

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

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

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

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

$E_c := 57000 \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi$ $E_c = 3604996.533\,psi$ $n := \frac{E_s}{E_c}$ $n = 8.04$

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

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

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

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

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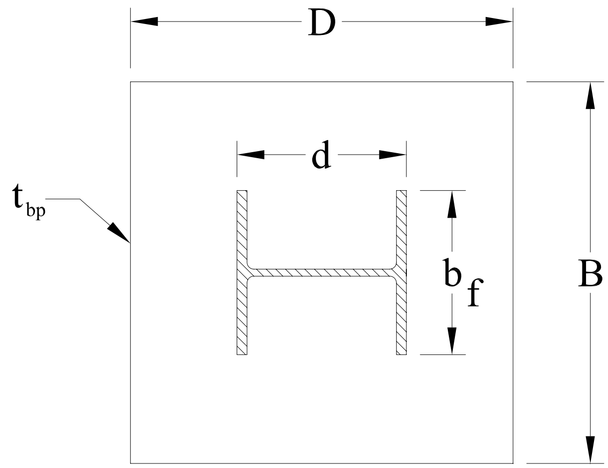

BASEPLATE DETAILS

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

$D := 14in$ Baseplate Length (in.)

$B := 14in$ Baseplate width (in.)

$t_p := 1.000in$ Baseplate thickness (in.)

$d = 8.28\,in$ Depth of Post (in.)

$b_f = 5.27\,in$ Width of Post (in.)

$Hole_{edgedist} := 1.5in$ Distance to plate edge to hole center (in.)

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

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

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

$$Depth_{embed} := \begin{pmatrix} 4 \\ 7.875 \\ 10.5 \end{pmatrix} in$$

Actual Embedment Depth (inches)
, see Hilti guide

$h_{ef} := 10.5000in$

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

$$HIT_{ultimatetensile} := linterp(Depth_{embed}, Tension, h_{ef})$$

$$HIT_{ultimateshear} := linterp(Depth_{embed}, Shear, h_{ef})$$

Interpolate for Embedment Depth, h_{ef}

$HIT_{ultimatetensile} = 64.73\,kips$ Ultimate Bond Strength
(see pg 112 Hilti 2002 Tech. Guide)

$HIT_{ultimateshear} = 79.02\,kips$ Ulitmate shear strength of
anchor (see pg 112)

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Temperature := 110 °F Max Temperature for Temperature Reduction

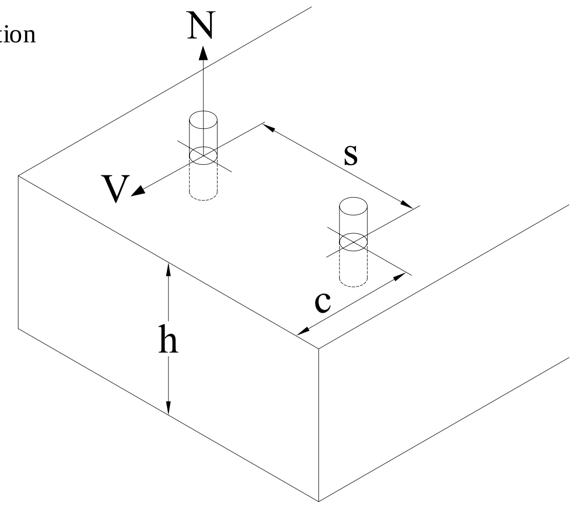
Check Load Adjustment Factors for Anchor Spacings & Clearance:

From page 119, Hilti 2002 Technical Guide

$S_{act} := 11.0in$ 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



ANCHOR DETAILS

$S_{min} := 0.5 \cdot h_{ef}$ $S_{min} = 5.25\,in$

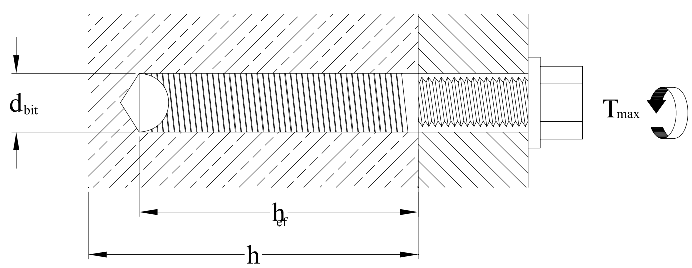
$S_{cr} := 1.5 \cdot h_{ef}$ $S_{cr} = 15.75\,in$

$C_{min} := 0.5 \cdot h_{ef}$ $C_{min} = 5.25\,in$

$C_{cr} := 1.5 \cdot h_{ef}$ $C_{cr} = 15.75\,in$

$h := t_{deck}$ Thickness of slab, (in)

$h = 14\,in$



ANCHOR GEOMETRY

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$S_{act} = 11\,in$

$h_{ef} = 10.5\,in$

$S_{cr} = 15.75\,in$

**** Calculate Hilti Reduction Factors Spacing Tension & Shear ******

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

$f_A = 0.864$

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

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

$f_{RN} = 0.89$

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

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

$f_{RVperp} = 0.75$

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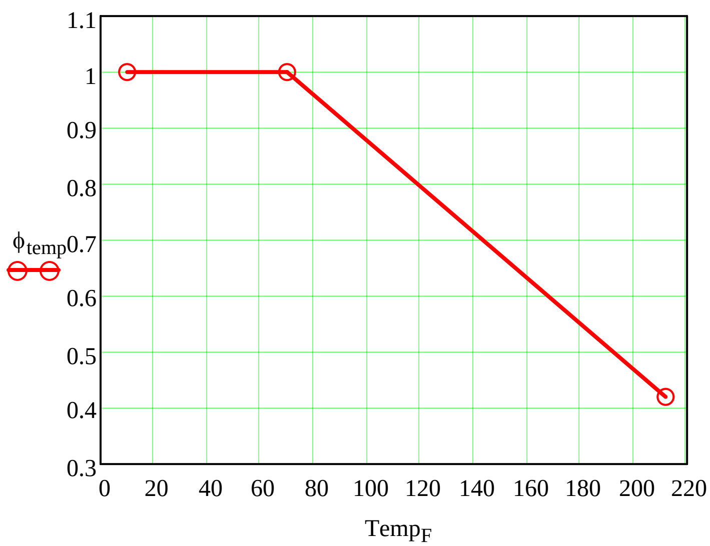
6.) Calculate total combined Reduction Factors for tension & shear:

$f_{RVperp} = 0.75$ $f_A = 0.86$ $f_{RN} = 0.89$

$\phi_{temp} := \begin{pmatrix} 1.0 \\ 1.0 \\ 0.42 \end{pmatrix}$ $Temp := \begin{pmatrix} 10 \\ 70 \\ 212 \end{pmatrix} °F$ $F := Temp$ $Temp = \begin{pmatrix} 260.93 \\ 294.26 \\ 373.15 \end{pmatrix} K$ $Temp = \begin{pmatrix} 260.93 \\ 294.26 \\ 373.15 \end{pmatrix} K$

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



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

$\phi_{tempreduce} = 0.84$

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

$\phi_{tension} = 0.65$ $\phi_{shear} = 0.65$

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

$\phi R_{tension} = 41.79\ kips$ $\phi R_{shear} = 51.22\ kips$ Hilti Factored Anchor Strengths for $h_{ef} = 10.50\ in$

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7. Calculate the Plastice Strength of the Post:

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

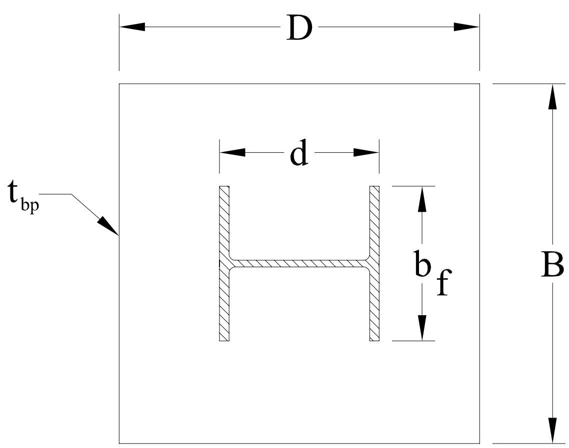
$Z_x = 20.4\,\text{in}^3$ Plastic Section Modulus of Post

$M_{xplastic} := F_y \cdot Z_x$

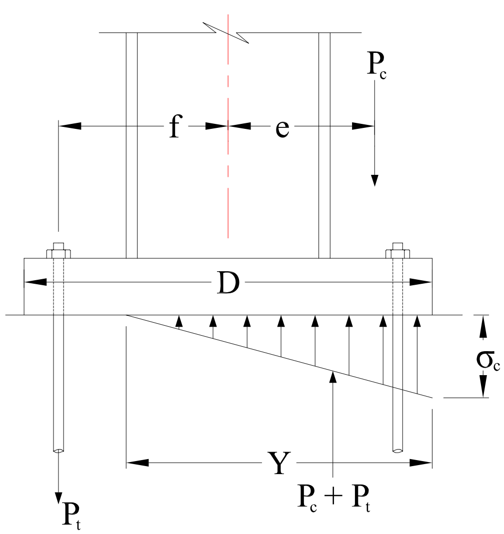
$M_{xplastic} = 85\,\text{kip}\cdot\text{ft}$ Plastic Moment

$M_{load} = 65\,\text{kip}\cdot\text{ft}$ 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 Blodget'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 he deign with 2 bolts located on the tension face

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

Select Design Moment from Above:

$M_1 := M_{load}$ Applied Moment (k-ft.)

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

$e = 7800\,\text{in}$ eccentricity (in.)

Subject: **Box Culvert Guardrail - Task AE Calculations**

$D = 14\,in$ BP Length (in.) $B = 14\,in$ BP Width (in.) $f'_c = 4000\,psi$

$d = 8.28\,in$ Post Depth (in.) $D = 14\,in$ BP Length (in.) $N_t = 2$ # Tension Bolts

$b_f = 5.27\,in$ Post Flange Width (in.)

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

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

Initial Guesses for unknowns: $\sigma_c := 1000 \cdot psi$ $Y := .3 \cdot ft$ $P_t := 10 \cdot kip$

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

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

$Y = 3.0253\,in$

$\sigma_c = 4269\,psi$ Compressive stress @ the Edge of the Baseplate on Compression side.

$P_t = 90\,kips$ Tension Force in (N_t) Anchor Bolts

$P_{Bolt} := \frac{P_t}{N_t}$ $P_{Bolt} = 45.15\,kips$ Tension per Bolt (kips)

... o.k. close to Factored Hilti Ultimate for $h_{ef} = 10.5\,in$ $\phi R_{tension} = 41.79\,kips$

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

Calculate moment in baseplate on bearing side:

$Y = 3.03\,in$ $\quad d_{edge} := \frac{D}{2} - \frac{b_f}{2}$ $\quad d_{edge} = 4.37\,in$

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

$$M_{plate1} = 22.96\,\frac{kip \cdot in}{in}$$

Calculate moment in baseplate on Tension Bolt Side:

$P_{Bolt} = 45.15\,kips$

$Hole_{edgedist} = 1.5\,in$

$d_{edge} = 4.37\,in$ Distance from Baseplate Edge to Post Edge

$$Bolt_{dist} := d_{edge} - Hole_{edgedist} + \frac{t_f}{2}$$

$Bolt_{dist} = 3.07\,in$ Distance from center of bolt to centerline of post flange

$$M_{plate2} := \frac{P_{Bolt} \cdot Bolt_{dist}}{Bolt_{dist} \cdot 2} \qquad M_{plate2} = 22.57\,\frac{kip \cdot in}{in}$$

$$M_{plate} := \begin{cases} M_{plate1} & \text{if } M_{plate1} > M_{plate2} \\ M_{plate2} & \text{otherwise} \end{cases}$$

Select worst case bending moment in plate bearing or anchor bolt tension

$M_{plate} = 22.96\,\frac{kip \cdot in}{in}$ Design moment in the baseplate for thickness calculations

Substract 1/8" since procedure is little conservative

Therefore: $t_{prequired} := \sqrt{\frac{4 \cdot M_{plate}}{F_y}}$ $\quad t_{prequired} = 1.36\,in$ $\quad t_{plate} := (t_{prequired} - 0.125\,in)$

$t_{bp} := Round(t_{plate}, 0.125\,in)$ $\quad t_{bp} = 1.25\,in$ Final Baseplate Design Thickness (in.)

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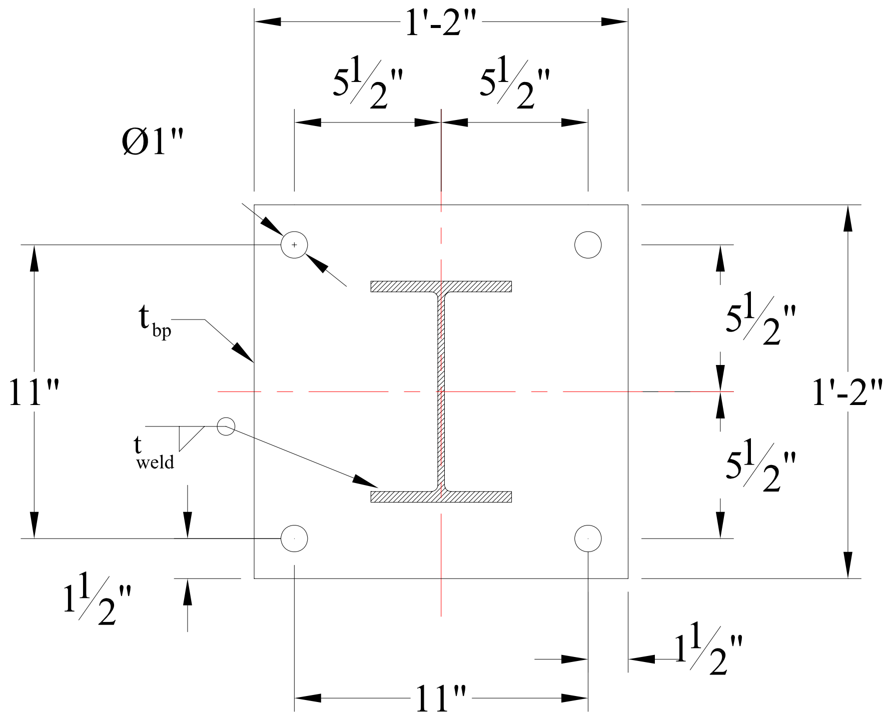
$t_{bp} = 1.25\,in$

$F_y = 50\,ksi$

$t_{weld} = 0.25\,in$

RCOMMENDED BASEPLATE DETAILS



W8x21
BASEPLATE DETAILS

Anchor Bolts: 7/8" Dia. A193 Threaded Rods, 14 inches Long, embedded 10.5 inches minimum

Anchorage System: Hilti RE 500 Anchoring System

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