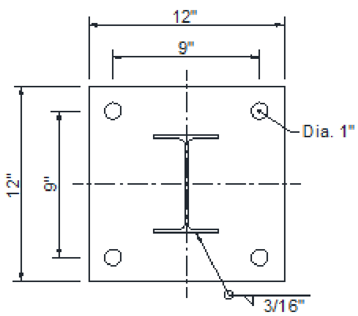
SUBJECT:
Professional Opinion 21-06
TxDOT Transition Posts Low Fill Culvert Design

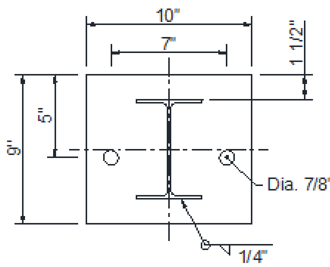
Given the following two layouts of a guardrail post, find the limiting ultimate strength of the post design. The posts are anchored to concrete using an epoxy adhesive anchoring system.

A: Low Fill Box Culvert Post

B: Transition Post Tested in TXDOT 0-6954

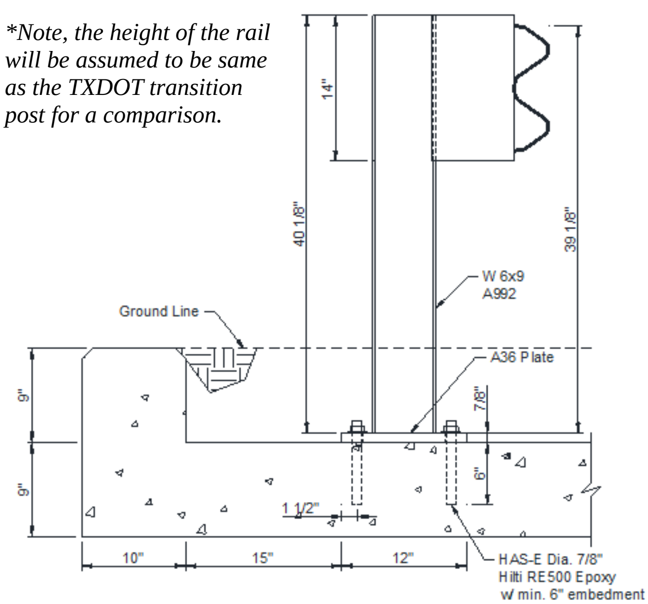


(a-1) Base Plate

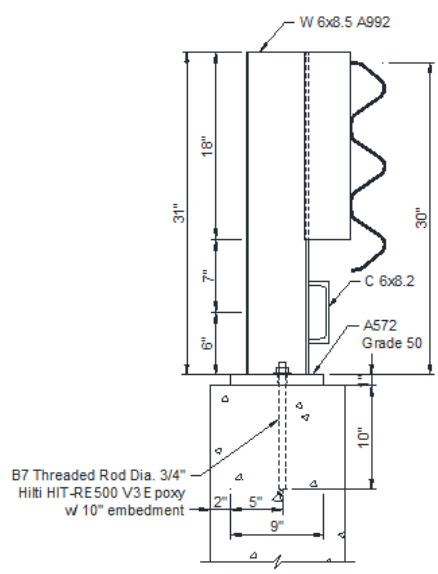


(b-1) Base Plate

**Note, the height of the rail will be assumed to be same as the TXDOT transition post for a comparison.*



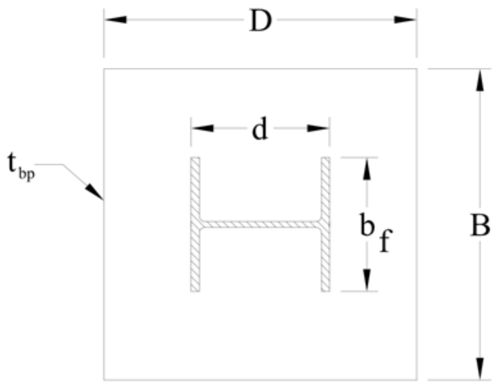
(a-2) Post Elevation



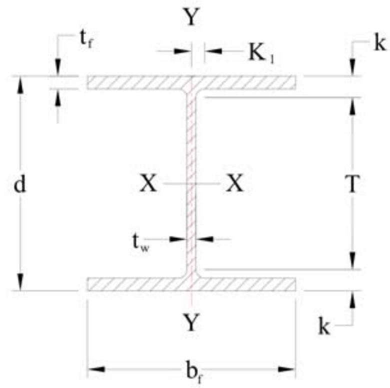
(b-2) Post Elevation

	A	B
Post:	*W 6 x 9*	*W 6 x 8.5*
Baseplate:	*A36 Steel*	*A572 Grade 50 Steel*
Bolt:	*HAS-E dia. 7/8'' (B7 Grade)*	*Thread rod dia. 3/4'' (B7 Grade)*
Adhesive:	*Hilti RE 500*	*Hilti HIT-RE 500 V3*
Embedment:	*Min. 6 in.*	*Standard 10 in.*

1. General Information



Base Plate Details



Post Details

	A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TxDOT 0-6954 - W 6 x 8.5
Base Plate Properties:		
Baseplate length:	$D_a := 12\ in$	$D_b := 9\ in$
Baseplate width:	$B_a := 12\ in$	$B_b := 10\ in$
Baseplate thickness:	$t_{p\_a} := 0.875\ in$	$t_{p\_b} := 1\ in$
Baseplate yield strength:	$F_{y\_plate\_a} := 36\ ksi$	$F_{y\_plate\_b} := 50\ ksi$
Baseplate rupture strength:	$F_{u\_plate\_a} := 58\ ksi$	$F_{u\_plate\_b} := 65\ ksi$
Post Properties:		
Section depth:	$d_a := 5.9\ in$	$d_b := 5.83\ in$
Flange width:	$b_{f\_a} := 3.94\ in$	$b_{f\_b} := 3.94\ in$
Flange thickness:	$t_{f\_a} := 0.215\ in$	$t_{f\_b} := 0.195\ in$
Web thickness:	$t_{w\_a} := 0.17\ in$	$t_{w\_b} := 0.17\ in$
Moment inertia:	$I_{xx\_a} := 16.4\ in^4$	$I_{xx\_b} := 14.9\ in^4$
	$I_{yy\_a} := 2.19\ in^4$	$I_{yy\_b} := 1.98\ in^4$
Section modulus:	$S_{xx\_a} := 5.56\ in^3$	$S_{xx\_b} := 5.14\ in^3$
	$S_{yy\_a} := 1.11\ in^3$	$S_{yy\_b} := 1.01\ in^3$
Plastic modulus:	$Z_{xx\_a} := 6.29\ in^3$	$Z_{xx\_b} := 5.77\ in^3$
	$Z_{yy\_a} := 1.72\ in^3$	$Z_{yy\_b} := 1.56\ in^3$
Post yield strength:	$F_{y\_post\_a} := 50\ ksi$	$F_{y\_post\_b} := 50\ ksi$
Post rupture strength:	$F_{u\_post\_a} := 65\ ksi$	$F_{u\_post\_b} := 65\ ksi$

	A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TxDOT 0-6954 - W 6 x 8.5
Rail Geometry:		
Rail height:	$Rail_{h\_a} := 30\ in$	$Rail_{h\_b} := 30\ in$
Load applied to rail:	$P_{post\_a} := 10\ kip$	$P_{post\_b} := 10\ kip$
Moment applied to rail:	$M_{post\_a} := P_{post\_a} \cdot Rail_{h\_a}$	$M_{post\_b} := P_{post\_b} \cdot Rail_{h\_b}$
	$M_{post\_a} = 25\ kip \cdot ft$	$M_{post\_b} = 25\ kip \cdot ft$
Bolt Properties (B7 Grade):		
Diameter:	$d_{bolt\_a} := 0.875\ in$	$d_{bolt\_b} := 0.75\ in$
Tensile strength:	$f_{u\_bolt\_a} := 125\ ksi$	$f_{u\_bolt\_b} := 125\ ksi$
Nominal area:	$A_{bolt\_a} := \frac{\pi \cdot d_{bolt\_a}^{\ 2}}{4}$	$A_{bolt\_b} := \frac{\pi \cdot d_{bolt\_b}^{\ 2}}{4}$
	$A_{bolt\_a} = 0.6\ in^2$	$A_{bolt\_b} = 0.44\ in^2$
Embedment depth:	$h_{ef\_a} := 6\ in$	$h_{ef\_b} := 10\ in$
Weld Properties:		
Weld material strength:	$F_{EXX\_a} := 70\ ksi$	$F_{EXX\_b} := 70\ ksi$
Weld size:	$t_{weld\_a} := 0.1875\ in$	$t_{weld\_b} := 0.25\ in$
Concrete Properties:		
Concrete strength:	$f'_{c\_a} := 4000\ psi$	$f'_{c\_b} := 4000\ psi$

2. Bolt Strength

Bolt Steel Strength -Tension:

Reductino for area: $\phi_t := 0.75$

Tensile strength:

$R_{nt\_a} := \phi_t \cdot f_{u\_bolt\_a} \cdot A_{bolt\_a}$ $\qquad R_{nt\_b} := \phi_t \cdot f_{u\_bolt\_b} \cdot A_{bolt\_b}$

$R_{nt\_a} = 56.37\ kip$ $\qquad R_{nt\_b} = 41.42\ kip$

Bolt Steel Strength - Shear:

Shear strength reduction: $\phi_v := 0.75$

Reduction for thread: $\phi_{vth} := 0.75$

Shear strength:

$R_{nv\_a} := \phi_v \cdot \phi_{vth} \cdot f_{u\_bolt\_a} \cdot A_{bolt\_a}$

$R_{nv\_b} := \phi_v \cdot \phi_{vth} \cdot f_{u\_bolt\_b} \cdot A_{bolt\_b}$

$R_{nv\_a} = 42.28\ kip$ $\qquad R_{nv\_b} = 31.06\ kip$

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

Bond (Epoxy) Strength - Tension and Shear:

$d_{bolt\_a} := 0.875\ in$ $\qquad d_{bolt\_b} := 0.75\ in$ $\qquad$ *Bolt diameter*

$h_{ef\_a} = 6\ in$ $\qquad h_{ef\_b} = 10\ in$ $\qquad$ *Embedment depth*

Conrete/Bond strength of Hilti HIT-RE V500 V3 anchoring system as per Table 25 in "North American Product Technical Guide, Volumn 2: Anchor Fastening, Edition 19".

$$Embed\_a := \begin{bmatrix} 3.5 \\ 7.875 \\ 10.5 \end{bmatrix} in \qquad Embed\_b := \begin{bmatrix} 6.75 \\ 9 \\ 15 \end{bmatrix} in$$

$$Tension\_a := \begin{bmatrix} 6460 \\ 21805 \\ 33570 \end{bmatrix} lbf \qquad Tension\_b := \begin{bmatrix} 17305 \\ 26640 \\ 55035 \end{bmatrix} lbf$$

$$Shear\_a := \begin{bmatrix} 13915 \\ 46960 \\ 72300 \end{bmatrix} lbf \qquad Shear\_b := \begin{bmatrix} 37265 \\ 57375 \\ 118535 \end{bmatrix} lbf$$

Concrete/Bond strength for tension:

$R_{nt\_bond\_a} := \text{linterp}\left(Embed\_a, Tension\_a, h_{ef\_a}\right)$

$R_{nt\_bond\_b} := \text{linterp}\left(Embed\_b, Tension\_b, h_{ef\_b}\right)$

$R_{nt\_bond\_a} = 15.23\ kip$ $\qquad R_{nt\_bond\_b} = 31.37\ kip$ $\qquad$ *Tension - concrete/bond strength*

Bond strength for shear:

$R_{nv\_bond\_a} := \text{linterp}\left(Embed\_a, Shear\_a, h_{ef\_a}\right)$

$R_{nv\_bond\_b} := \text{linterp}\left(Embed\_b, Shear\_b, h_{ef\_b}\right)$

$R_{nv\_bond\_a} = 32.8\ kip$ $\qquad R_{nv\_bond\_b} = 67.57\ kip$ $\qquad$ *Shear - concrete/bond strength*

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

Load adjustment factor for temperatuer - Tension:

$Temp := 110\ °F$

$\phi_{temp} := 1.0$ *for temperature less than 120°F*

Load adjustment factor for anchor spacing - Tension and Shear:

A	B	
$S_{bolt\_a} := 9\ in$	$S_{bolt\_b} := 7\ in$	*Bolt spacing*
$C_{bolt\_a} := 25.5\ in$	$C_{bolt\_b} := 7\ in$	*Edge distacne from center of bolt to concrete edge*
$h_{ef\_a} = 6\ in$	$h_{ef\_b} = 10\ in$	*Embedment depth*
$S_{min\_a} := 0.5 \cdot h_{ef\_a} = 3\ in$	$S_{min\_b} := 0.5 \cdot h_{ef\_b} = 5\ in$	*Min. spacing*
$S_{cr\_a} := 1.5 \cdot h_{ef\_a} = 9\ in$	$S_{cr\_b} := 1.5 \cdot h_{ef\_b} = 15\ in$	*Critical spacing*
$C_{min\_a} := 0.5 \cdot h_{ef\_a} = 3\ in$	$C_{min\_b} := 0.5 \cdot h_{ef\_b} = 5\ in$	*Min. edge distance*
$C_{cr\_a} := 1.5 \cdot h_{ef\_a} = 9\ in$	$C_{cr\_b} := 1.5 \cdot h_{ef\_b} = 15\ in$	*Critical edge distance*

Load adjustment factor for anchor spacing - Tension and Shear:

$$f_{A\_a} := \begin{cases} \text{if } S_{bolt\_a} < S_{min\_a} & 0 \\ \text{if } S_{bolt\_a} \ge S_{cr\_a} & 1.0 \\ \text{if } S_{cr\_a} \ge S_{bolt\_a} \ge S_{min\_a} & 0.3 \cdot \left(\dfrac{S_{bolt\_a}}{h_{ef\_a}}\right) + 0.55 \end{cases}$$

$$f_{A\_b} := \begin{cases} \text{if } S_{bolt\_b} < S_{min\_b} & 0 \\ \text{if } S_{bolt\_b} \ge S_{cr\_b} & 1.0 \\ \text{if } S_{cr\_b} \ge S_{bolt\_b} \ge S_{min\_b} & 0.3 \cdot \left(\dfrac{S_{bolt\_b}}{h_{ef\_b}}\right) + 0.55 \end{cases}$$

$f_{A\_a} = 1$

$f_{A\_b} = 0.76$

A: Low Fill Box Culvert Post - W 6 x 9

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

Load adjustment factor for edge distance - Tension:

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

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

$f_{RN\_a} = 1$ $\quad$ $f_{RN\_b} = 0.76$

Load adjustment factor for edge distance - Shear:

$$f_{RV\_a} := \begin{cases} 0 & \text{if } C_{bolt\_a} < C_{min\_a} \\ 1.0 & \text{if } C_{bolt\_a} \ge C_{cr\_a} \\ 0.54 \cdot \left(\frac{C_{bolt\_a}}{h_{ef\_a}}\right) - 0.09 & \text{if } C_{cr\_a} \ge C_{bolt\_a} \ge C_{min\_a} \end{cases}$$

$$f_{RV\_b} := \begin{cases} 0 & \text{if } C_{bolt\_b} < C_{min\_b} \\ 1.0 & \text{if } C_{bolt\_b} \ge C_{cr\_b} \\ 0.54 \cdot \left(\frac{C_{bolt\_b}}{h_{ef\_b}}\right) - 0.09 & \text{if } C_{cr\_b} \ge C_{bolt\_b} \ge C_{min\_b} \end{cases}$$

$f_{RV\_a} = 1$ $\quad$ $f_{RV\_b} = 0.29$

Final load adjustment factor - Tension:

$\phi_{tension\_a} := f_{A\_a} \cdot f_{RN\_a} \cdot \phi_{temp}$ $\quad$ $\phi_{tension\_b} := f_{A\_b} \cdot f_{RN\_b} \cdot \phi_{temp}$

$\phi_{tension\_a} = 1$ $\quad$ $\phi_{tension\_b} = 0.58$

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5	

Final load adjustment factor - Shear:

$\phi_{shear\_a} := f_{A\_a} \cdot f_{RV\_a}$	$\phi_{shear\_b} := f_{A\_b} \cdot f_{RV\_b}$	
$\phi_{shear\_a} = 1$	$\phi_{shear\_b} = 0.22$	

Final concrete/bond strength:

$\phi_{tension\_a} \cdot R_{nt\_bond\_a} = 15.23$ ***kip***	$\phi_{tension\_b} \cdot R_{nt\_bond\_b} = 18.12$ ***kip***	*Tension*
$\phi_{shear\_a} \cdot R_{nv\_bond\_a} = 32.8$ ***kip***	$\phi_{shear\_b} \cdot R_{nv\_bond\_b} = 14.79$ ***kip***	*Shear*

Re-call bolt steel strength:

$R_{nt\_a} = 56.37$ ***kip***	$R_{nt\_b} = 41.42$ ***kip***	*Tension*
$R_{nv\_a} = 42.28$ ***kip***	$R_{nv\_b} = 31.06$ ***kip***	*Shear*

Controlling Bolt Strength:

Tension strength:

$$R_{nt\_bolt\_a} := min\left(\phi_{tension\_a} \cdot R_{nt\_bond\_a}, R_{nt\_a}\right)$$

$$R_{nt\_bolt\_b} := min\left(\phi_{tension\_b} \cdot R_{nt\_bond\_b}, R_{nt\_b}\right)$$

$R_{nt\_bolt\_a} = 15.23$ ***kip***	$R_{nt\_bolt\_b} = 18.12$ ***kip***	*Tension*

Shear strength:

$$R_{nv\_bolt\_a} := min\left(\phi_{shear\_a} \cdot R_{nv\_bond\_a}, R_{nv\_a}\right)$$

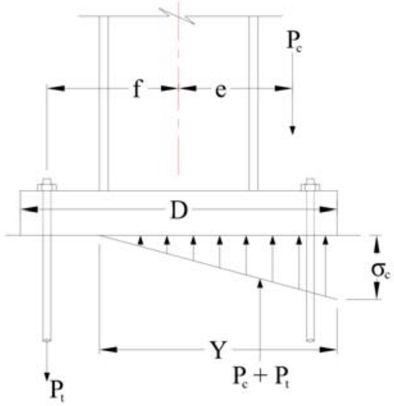
$$R_{nv\_bolt\_b} := min\left(\phi_{shear\_b} \cdot R_{nv\_bond\_b}, R_{nv\_b}\right)$$

$R_{nv\_bolt\_a} = 32.8$ ***kip***	$R_{nv\_bolt\_b} = 14.79$ ***kip***	*Shear*

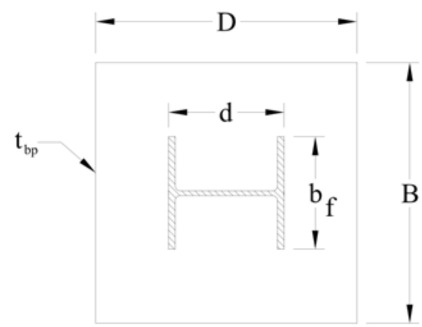
3. Allowable Lateral Force on Rail

3.1 Find applied force on baseplate and bolts due to combined lateral force and moment:

Basic uplift procedure as shown in Blodgett, "Design of Welded Structures" pages 3-3-8 through 10, and sketch with nomenclature showing baseplate geometry and distribution of force.



Distribution of Stress and Force



Base Plate Details

Given the uplift procedure, solve for three unknowns

- Maximum Stress, σ_c
- Depth of Stress Block, Y
- Force on Bolts, Pt

Combine vertical load and moment to a single vertical load at an eccentricity "*e*".

$P_c := 1\ kip$ *Assume vertical load on column*

Set the applied moment: *start with a moment of 15 kip-ft.*

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5	
$M_{1\_a} := 15\ kip \cdot ft$	$M_{1\_b} := 15\ kip \cdot ft$	
$e_a := \frac{M_{1\_a}}{P_c} = 180\ in$	$e_b := \frac{M_{1\_b}}{P_c} = 180\ in$	*Eccentricity*
$D_a = 12\ in$	$D_b = 9\ in$	*Length of baseplate*
$B_a = 12\ in$	$B_b = 10\ in$	*Width of baseplate*

$d_a = 5.9\ in$	$d_b = 5.83\ in$	*Depth of post*
$b_{f\_a} = 3.94\ in$	$b_{f\_b} = 3.94\ in$	*Width of post (flange)*
$Hole_{edge\_a} := 1.5\ in$	$Hole_{edge\_b} := 4\ in$	*Distance from center of bolt hole to edge of the base plate*
$d_{c\_to\_b\_a} := \frac{D_a}{2} - Hole_{edge\_a}$	$d_{c\_to\_b\_b} := \frac{D_b}{2} - Hole_{edge\_b}$	*Distance from center of column to tension bolt*
$n_{t\_a} := 2$	$n_{t\_b} := 2$	*Number of bolts on tension side*

From static, there are Three Equations & Three Unknowns, *Pt*, *Y*, & *σc*.

Initial estimates required. Use these estimates to converge on solutions for the three unknowns.

A: Low Fill Box Culvert Post - W 6 x 9

Guess Values

$P_{t\_a} := 20\ kip \qquad Y_a := 4\ in \qquad \sigma_{c\_a} := 2000\ psi$

Constraints

$$\frac{1}{2} \cdot Y_a \cdot \sigma_{c\_a} \cdot B_a - P_{t\_a} - P_c = 0$$

$$P_{t\_a} \cdot d_{c\_to\_b\_a} + \left(P_c + P_{t\_a}\right) \cdot \left(\frac{D_a}{2} - \frac{Y_a}{3}\right) - P_c \cdot e_a = 0$$

$$\sigma_{c\_a} = \frac{P_{t\_a} \cdot Y_a}{A_{bolt\_a} \cdot n_{t\_a} \cdot \left(\frac{D_a}{2} - Y_a + d_{c\_to\_b\_a}\right)}$$

Solver

$$\begin{bmatrix} P_{t\_a} \\ Y_a \\ \sigma_{c\_a} \end{bmatrix} := \text{find}\left(P_{t\_a}, Y_a, \sigma_{c\_a}\right)$$

$P_{t\_a} = 17.38\ kip$	*Force on bolt on tension side*
$Y_a = 1.39\ in$	*Depth of stress block*
$\sigma_{c\_a} = 2204.67\ psi$	*Maximum stress*

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

Guess Values

$P_{t\_b} := 50\ kip \qquad Y_b := 1\ in \qquad \sigma_{c\_b} := 4000\ psi$

Constraints

$$\frac{1}{2} \cdot Y_b \cdot \sigma_{c\_b} \cdot B_b - P_{t\_b} - P_c = 0$$

$$P_{t\_b} \cdot d_{c\_to\_b\_b} + \left(P_c + P_{t\_b}\right) \cdot \left(\frac{D_b}{2} - \frac{Y_b}{3}\right) - P_c \cdot e_b = 0$$

$$\sigma_{c\_b} = \frac{P_{t\_b} \cdot Y_b}{A_{bolt\_b} \cdot n_{t\_b} \cdot \left(\frac{D_b}{2} - Y_b + d_{c\_to\_b\_b}\right)}$$

Solver

$$\begin{bmatrix} P_{t\_b} \\ Y_b \\ \sigma_{c\_b} \end{bmatrix} := \text{find}\left(P_{t\_b}, Y_b, \sigma_{c\_b}\right)$$

$P_{t\_b} = 37.31\ kip$ — *Force on bolt on tension side*

$Y_b = 0.87\ in$ — *Depth of stress block*

$\sigma_{c\_b} = 8847.2\ psi$ — *Maximum stress*

A: Low Fill Box Culvert Post - W 6 x 9

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

3.2 Check tension force on bolts:

$P_{bolt\_a} := \frac{P_{t\_a}}{n_{t\_a}} = 8.69\ kip \qquad P_{bolt\_b} := \frac{P_{t\_b}}{n_{t\_b}} = 18.66\ kip$

Re-call the tension strength of the bolts:

$R_{nt\_bolt\_a} = 15.23\ kip \qquad R_{nt\_bolt\_b} = 18.12\ kip$ — *Tension*

(Continued on next page.)

A: Low Fill Box Culvert Post - W 6 x 9

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

$$Check_{pt\_a} := \text{if } P_{bolt\_a} \le R_{nt\_bolt\_a} \;\Vert\; \text{"O.K."} \;\text{else}\; \Vert\; \text{"N.G."}$$

$$Check_{pt\_b} := \text{if } P_{bolt\_b} \le R_{nt\_bolt\_b} \;\Vert\; \text{"O.K."} \;\text{else}\; \Vert\; \text{"N.G."}$$

Check bolt tension capacity.

$Check_{pt\_a} = \text{"O.K."}$ $Check_{pt\_b} = \text{"N.G."}$

3.3 Check moment on baseplate:

Moment on baseplate on Bearing Side:

$Y_a = 1.39\ in$ $Y_b = 0.87\ in$

$$M_{plate1\_a} := \frac{\sigma_{c\_a} \cdot Y_a}{2} \cdot \left(\frac{D_a - d_a + t_{f\_a}}{2} - \frac{Y_a}{3}\right)$$

$$M_{plate1\_b} := \frac{\sigma_{c\_b} \cdot Y_b}{2} \cdot \left(\frac{D_b - d_b + t_{f\_b}}{2} - \frac{Y_b}{3}\right)$$

$M_{plate1\_a} = 4.13\ \frac{kip \cdot in}{in}$ $M_{plate1\_b} = 5.34\ \frac{kip \cdot in}{in}$

Moment on baseplate on Tension Bolt Side:

$P_{bolt\_a} = 8.69\ kip$

$Hole_{edge\_a} = 1.5\ in$

$$d_{f\_to\_b\_a} := \frac{D_a}{2} - \frac{d_a}{2} - Hole_{edge\_a} + \frac{t_{f\_a}}{2}$$

$$d_{f\_to\_b\_b} := -\frac{D_b}{2} + \frac{d_b}{2} + Hole_{edge\_b} + \frac{t_{f\_b}}{2}$$

Distance from center of bolt to centerline of post flange

$d_{f\_to\_b\_a} = 1.66\ in$ $d_{f\_to\_b\_b} = 2.51\ in$

A: Low Fill Box Culvert Post - W 6 x 9

$$M_{plate2\_a} := \frac{P_{bolt\_a} \cdot d_{f\_to\_b\_a}}{2 \cdot d_{f\_to\_b\_a}}$$

$$M_{plate2\_a} = 4.35 \ \frac{kip \cdot in}{in}$$

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

$$M_{plate2\_b} := \frac{P_{bolt\_b} \cdot d_{f\_to\_b\_b}}{2 \cdot d_{f\_to\_b\_b}}$$

$$M_{plate2\_b} = 9.33 \ \frac{kip \cdot in}{in}$$

Critical moment on base plate:

$$M_{plate\_a} := \max\left(M_{plate1\_a}, M_{plate2\_a}\right)$$

$$M_{plate\_a} = 4.35 \ \frac{kip \cdot in}{in}$$

$$M_{plate\_b} := \max\left(M_{plate1\_b}, M_{plate2\_b}\right)$$

$$M_{plate\_b} = 9.33 \ \frac{kip \cdot in}{in}$$

Plastic moment capacity of baseplate:

$$M_{pn\_plate\_a} := \frac{F_{y\_plate\_a} \cdot t_{p\_a}^{\ 2}}{4}$$

$$M_{pn\_plate\_a} = 6.89 \ \frac{kip \cdot in}{in}$$

$$M_{pn\_plate\_b} := \frac{F_{y\_plate\_b} \cdot t_{p\_b}^{\ 2}}{4}$$

$$M_{pn\_plate\_b} = 12.5 \ \frac{kip \cdot in}{in}$$

Check moment on baseplate:

$Check_{M\_a} :=$ if $M_{plate\_a} \le M_{pn\_plate\_a}$
  "O.K."
else
  "N.G."

$Check_{M\_b} :=$ if $M_{plate\_b} \le M_{pn\_plate\_b}$
  "O.K."
else
  "N.G."

Check baseplate moment capacity.

$Check_{M\_a} =$ "O.K."

$Check_{M\_b} =$ "O.K."

- The low fill box culvert post has reserve strength to resist the applied moment whereas the TXDOT transtion post has inadequate bolt strength.

- Re-do the evaluation to find the maximum allowable moment for both post.

A: Low Fill Box Culvert Post - W 6 x 9

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

3.4 Find maximum allowable moment:

From an iteration procedure, the following moment is found to be the maximum allowable moment that the bolt and base palte can resist.

$M_{1\_a} := 23.5\ kip \cdot ft$ $\qquad$ $M_{1\_b} := 14.5\ kip \cdot ft$ $\qquad$ *Maximum allowable moment*

$e_a := \dfrac{M_{1\_a}}{P_c} = 282\ in$ $\qquad$ $e_b := \dfrac{M_{1\_b}}{P_c} = 174\ in$ $\qquad$ *Eccentricity*

Tension force in bolts:

$P_{bolt\_a} := \dfrac{P_{t\_a}}{n_{t\_a}} = 13.77\ kip$ $\qquad$ $P_{bolt\_b} := \dfrac{P_{t\_b}}{n_{t\_b}} = 18.02\ kip$ $\qquad$ *Tension force on bolts*

$R_{nt\_bolt\_a} = 15.23\ kip$ $\qquad$ $R_{nt\_bolt\_b} = 18.12\ kip$ $\qquad$ *Tension capacity of bolts*

$Check_{pt\_a} :=$ if $P_{bolt\_a} \le R_{nt\_bolt\_a}$
“O.K.”
else
“N.G.”

$Check_{pt\_b} :=$ if $P_{bolt\_b} \le R_{nt\_bolt\_b}$
“O.K.”
else
“N.G.”

Check bolt tension capacity.

$Check_{pt\_a} =$ “O.K.” $\qquad$ $Check_{pt\_b} =$ “O.K.”

Moment on baseplate:

$M_{plate1\_a} = 6.42\ \dfrac{kip \cdot in}{in}$ $\qquad$ $M_{plate1\_b} = 5.16\ \dfrac{kip \cdot in}{in}$ $\qquad$ *Moment on baseplate on bearing side*

$M_{plate2\_a} = 6.88\ \dfrac{kip \cdot in}{in}$ $\qquad$ $M_{plate2\_b} = 9.01\ \dfrac{kip \cdot in}{in}$ $\qquad$ *Moment on baseplate on tension bolt side*

$M_{plate\_a} := \max\left(M_{plate1\_a}, M_{plate2\_a}\right)$ $\qquad$ $M_{plate\_b} := \max\left(M_{plate1\_b}, M_{plate2\_b}\right)$

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5	
$M_{plate\_a}=6.88\ \frac{kip \cdot in}{in}$	$M_{plate\_b}=9.01\ \frac{kip \cdot in}{in}$	*Maximum moment on baseplate*
$M_{pn\_plate\_a}=6.89\ \frac{kip \cdot in}{in}$	$M_{pn\_plate\_b}=12.5\ \frac{kip \cdot in}{in}$	*Plastic moment capacity of baseplate*

$Check_{M\_a} :=$ if $M_{plate\_a} \le M_{pn\_plate\_a}$ ‖ "O.K." else ‖ "N.G."

$Check_{M\_b} :=$ if $M_{plate\_b} \le M_{pn\_plate\_b}$ ‖ "O.K." else ‖ "N.G."

Check baseplate moment capacity.

$Check_{M\_a} =$ "O.K."　　$Check_{M\_b} =$ "O.K."

<u>*3.5 Check plastic strength of post:*</u>

A	B	
$F_{y\_post\_a}=50\ ksi$	$F_{y\_post\_a}=50\ ksi$	*Post yielding strength*
$Z_{xx\_a}=6.29\ in^3$	$Z_{xx\_b}=5.77\ in^3$	*Post plastic modulus*
$M_{xx\_plastic\_a} := F_{y\_post\_a} \cdot Z_{xx\_a}$	$M_{xx\_plastic\_b} := F_{y\_post\_b} \cdot Z_{xx\_b}$	*Post plastic moment*
$M_{xx\_plastic\_a}=26.21\ kip \cdot ft$	$M_{xx\_plastic\_b}=24.04\ kip \cdot ft$	

$Check_{PM\_a} :=$ if $M_{1\_a} \le M_{xx\_plastic\_a}$ ‖ "O.K." else ‖ "N.G."

$Check_{PM\_b} :=$ if $M_{1\_b} \le M_{xx\_plastic\_b}$ ‖ "O.K." else ‖ "N.G."

Check palstic moment capacity of post,

$Check_{PM\_a} =$ "O.K."　　$Check_{PM\_b} =$ "O.K."

3.6 Equivalent lateral force on rail:

A: Low Fill Box Culvert Post - W 6 x 9	**B**: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5	
$M_{1\_a} = 23.5\ kip \cdot ft$	$M_{1\_b} = 14.5\ kip \cdot ft$	*Maximum allowable moment*
$Rail_{h\_a} = 30\ in$	$Rail_{h\_b} = 30\ in$	*Height of rail*
$P_{post\_a} := \frac{M_{1\_a}}{Rail_{h\_a}} = 9.4\ kip$	$P_{post\_b} := \frac{M_{1\_b}}{Rail_{h\_b}} = 5.8\ kip$	*Maximum allowable lateral force*

4. Conclusion

The strength of the given two layouts of a guardrail post is evaluated. As the calculation result shown, the maximum moment and the lateral force that the each post can resist is,

A: Low Fill Box Culvert Post - W 6 x 9

- Maximum moment capacity: $M_{1\_a} = 23.5\ kip \cdot ft$
- Maximum lateral force on rail: $P_{post\_a} = 9.4\ kip$
- Controlling failure mode: Bending moment of the baseplate.

B: Transition Post Tested in TXDOT 0-6954 - W 6 x 8.5

- Maximum moment capacity: $M_{1\_b} = 14.5\ kip \cdot ft$
- Maximum lateral force on rail: $P_{post\_b} = 5.8\ kip$
- Controlling failure mode: Pull-out tension of the adehesive bolt.

As shown, the low fill box culvert post (W6x9) possess higher capacity than the transition post tested in TXDOT 0-6954 (W6x8.5). Therefore, it seems feasible to use the low fill box culvert post instead of the TXDOT transition post.