

County: Any

Design: BRG

Date: 10/2007

Hwy: Any

Ck Dsn: BRG

Date: 10/2007

FOOTING DESIGN EXAMPLE

Design: Based on AASHTO LRFD 2007 Specifications, TxDOT LRFD Bridge Design Manual, and TxDOT Project 0-4371
 17' - 6" x 8' x 6' Footing
 Rectangular 8' x 5' column, two 4' diameter drilled shafts

Limitations: This example will only work when both drilled shafts are in compression (does not encompass drilled shafts in tension).

Footing Design- Strut and Tie (AASHTO LRFD 5.6.3)

f_c = the concrete compressive strength, f'_c $f_c = 3.6 \frac{\text{kip}}{\text{in}^2}$

f_y = yield strength of the reinforcement $f_y = 60 \frac{\text{kip}}{\text{in}^2}$

W_{col} = column width $W_{col} = 8\text{ft}$

D_{col} = column depth $D_{col} = 5\text{ft}$

h = depth of footing $h = 6\text{ft}$

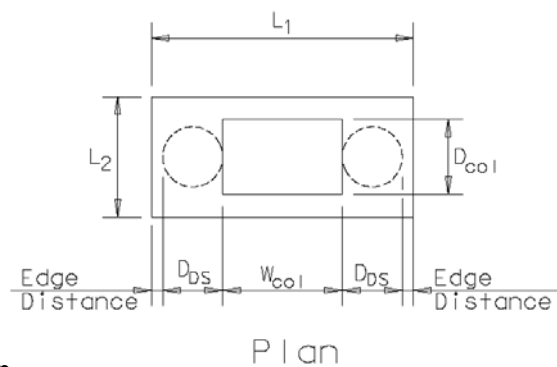
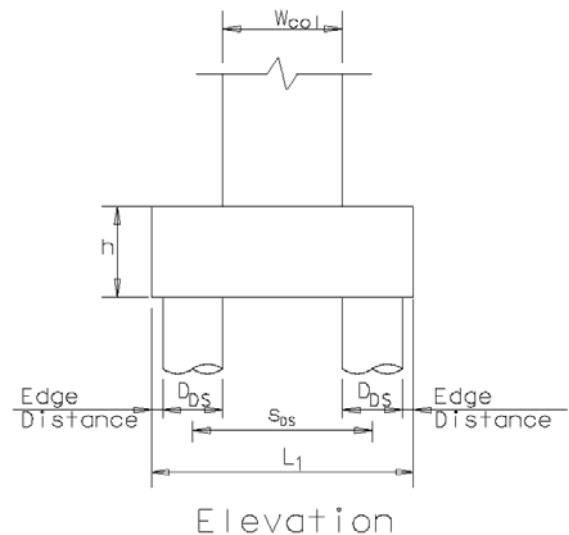
L_1 = dimension along the longitudinal axis of the footing $L_1 = 17.5\text{ft}$

L_2 = dimension along the transverse axis of the footing $L_2 = 8\text{ft}$

D_{DS} = drilled shaft diameter $D_{DS} = 4\text{ft}$

EdgeDistance = the clear space between the drilled shaft and the end of the footing EdgeDistance = 9in

s_{DS} = the distance between the centroids of the two drilled shafts $s_{DS} = L_1 - 2 \cdot \text{EdgeDistance} - D_{DS}$
 $s_{DS} = 12\text{ft}$



Initially assume that 11 ~ #10 bars will be used for the tension tie reinforcement.

Size_{bar} = the size of the tension reinforcement bars

$$\text{Size}_{\text{bar}} = 10$$

N_b = number of the tension reinforcement bars

$$N_b = 11$$

A_b = area of a single tension reinforcement bar

$$A_b = 1.27 \text{ in}^2$$

d_b = diameter of tension reinforcement bar

$$d_b = 1.27 \text{ in}$$

d_{stirrup} = diameter of #6 stirrup

$$d_{\text{stirrup}} = 0.75 \text{ in}$$

cc_{bot} = clear cover for the transverse reinforcement from the bottom of the footing to the edge of the reinforcement bar

$$\text{cc}_{\text{bot}} = 3 \text{ in}$$

cc_{side} = clear cover for the transverse reinforcement from the side of the footing to the edge of the reinforcement bar

$$\text{cc}_{\text{side}} = 3 \text{ in}$$

EndCover = concrete cover from the edge on the footing to the end of the reinforcement bar

$$\text{EndCover} = 3 \text{ in}$$

d_c = thickness of concrete cover measured from extreme tension fiber to center of the closest tension reinforcement bar

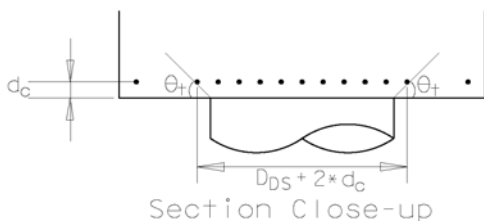
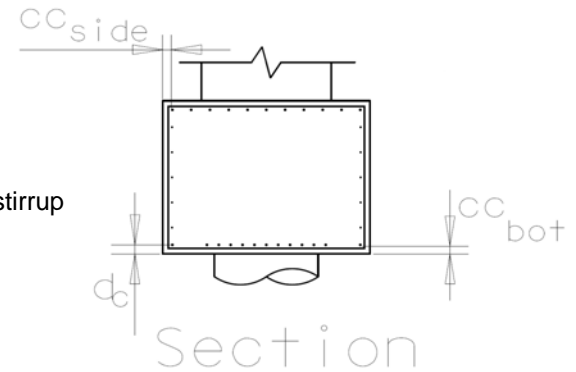
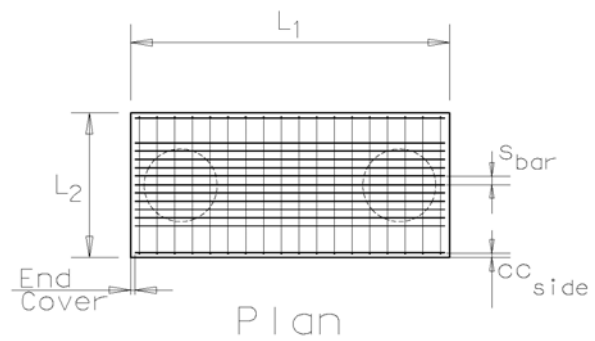
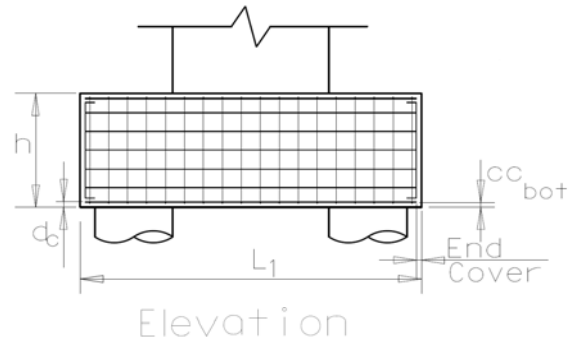
$$d_c = \text{cc}_{\text{bot}} + \frac{d_b}{2} + d_{\text{stirrup}}$$

$$d_c = 4.4 \text{ in}$$

s_{bar} = the distance between the centroids of the tension tie reinforcement bars

$$s_{\text{bar}} = \frac{D_{\text{DS}} + 2 \cdot d_c}{N_b - 1}$$

$$s_{\text{bar}} = 5.7 \text{ in}$$



Note: The tension tie reinforcement must be close enough to the drilled shaft to be considered in the truss analysis. Therefore, the tension tie reinforcement must be within a $\theta_t = 45$ degree distribution angle (i.e. no more than d_c away from the drilled shaft on either side) per TxDOT LRFD Bridge Design Manual.

Step One: Draw Idealized Truss Model and Solve for Member Forces

(AASHTO LRFD 5.6.3.2 and TxDOT LRFD Bridge Design Manual)

Draw Idealized Truss Model:

First, Solve for Reactions:

The loads transferred from the column to the footing are:

$$M_u = 3075 \text{ kip}\cdot\text{ft}$$

$$P_u = 1559 \text{ kip}$$

Note: Design for the worst case created by a positive M_u (clockwise) which generates the maximum force in strut BC and node C in the truss model on the following page.

Setting the moment about the right column equal to zero:

$$R_1 = \frac{P_u \cdot \left(\frac{s_{DS}}{2} \right) - M_u}{s_{DS}}$$

$$R_1 = 523.3 \cdot \text{kip}$$

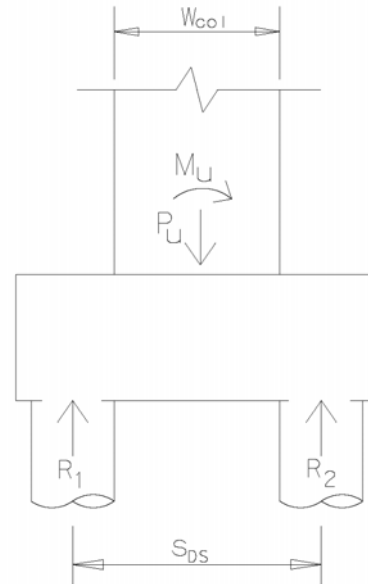
Setting the moment about the left column equal to zero:

$$R_2 = \frac{P_u \cdot \left(\frac{s_{DS}}{2} \right) + M_u}{s_{DS}}$$

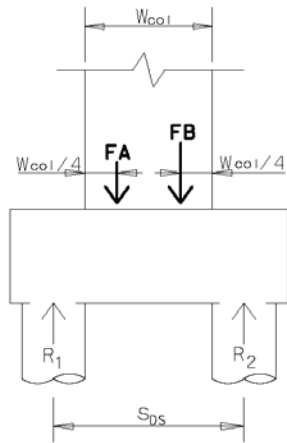
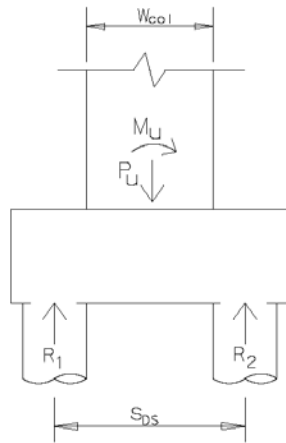
$$R_2 = 1035.8 \cdot \text{kip}$$

The following truss model is not applicable for footings with drilled shafts in tension. Check if both drilled shafts are in compression:

$$\text{if} \left[(R_1 > 0) \wedge (R_2 > 0), \text{"OK"}, \text{"NG"} \right] = \text{"OK"}$$



Then convert M_u and P_u into two concentrated loads located a distance of $W_{col}/4$ in from each side of the column.



$$F_A = \frac{-M_u}{\frac{W_{col}}{2}} + \frac{P_u}{2}$$

$$F_A = 10.8 \text{ kip}$$

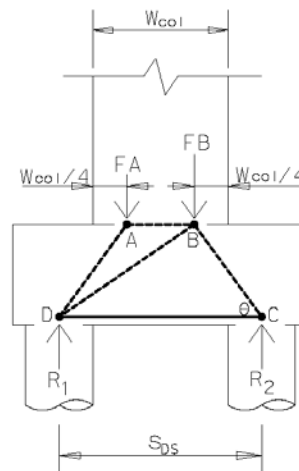
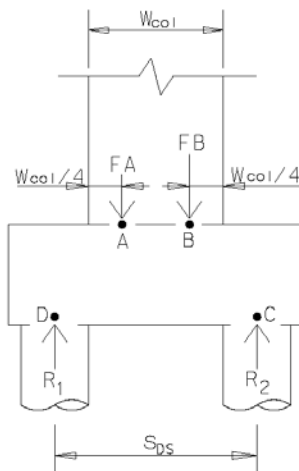
$$F_B = \frac{M_u}{\frac{W_{col}}{2}} + \frac{P_u}{2}$$

$$F_B = 1548.3 \text{ kip}$$

Both F_A and F_B are in compression. If F_A were in tension, the below truss model would not work.

Next place a node at all loads and reactions.

Finally draw the most rational truss model.



Assume nodes A and B are located at the concentrated loads, F_A and F_B , at the top of the footing.

Assume nodes C and D are located at the center of the drill shafts and a distance of d_c above the top of the Drilled Shafts.

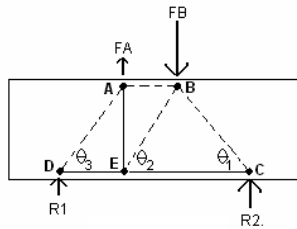
Note: Nodes represent the center of compression struts or tension ties.

Dashed lines represent compression struts and the solid lines represent tension ties, or reinforcement.

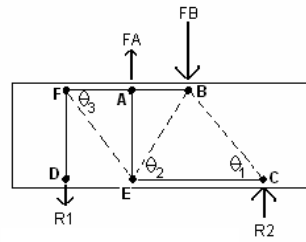
How to draw a rational truss model:

- 1) Draw straight lines from node to node to represent the members, struts and ties.
- 2) Try to place the tension ties where reinforcement is normally located (i.e. avoid diagonal tension ties).
- 3) If the angle, θ , between the tension tie and compression strut is too small the compression force will take another route making the current truss model invalid. Therefore, the angle between the compression strut and the tension tie must be greater than 26 degrees per TxDOT LRFD Bridge Design Manual.

In a case where both drilled shafts and column forces are not in compression see alternate truss models below.



One column force in tension



One column force and one drilled shaft in tension

Solve for Member Forces:

Since node C and strut BC have the maximum loads, solve for the forces in BC and CD to design for the worst case.

$$\theta = \text{atan} \left(\frac{h - d_c}{\frac{s_{DS}}{2} - \frac{W_{col}}{4}} \right)$$

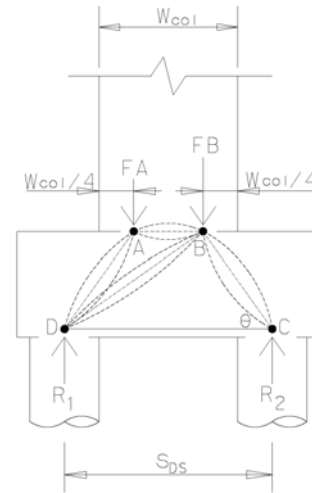
$$\theta = 54.6 \cdot \text{deg}$$

$$BC = \frac{R_2}{\sin(\theta)}$$

$$BC = 1270 \cdot \text{kip (compression)}$$

$$CD = BC \cdot \cos(\theta)$$

$$CD = 735 \cdot \text{kip (tension)}$$



The figure above shows the boundaries of the compression struts. Strut AB is positioned such that the footing and the column concrete are being utilized. In the case where the column concrete cannot be utilized, nodes A and B should be located at the center of the strut, which will be inside the footing instead of at the top of the footing.

Step Two: Choose Tension Tie Reinforcement for Tie CD

Assume #10 bars at 5.7in spacing

$$f_y = 60 \cdot \text{ksi}$$

$$\phi = 0.9 \quad (\text{AASHTO LRFD 5.5.4.2})$$

$$A_{\text{req}} = \frac{CD}{\phi \cdot f_y}$$

$$A_{\text{req}} = 13.6 \cdot \text{in}^2$$

$$A_b = 1.27 \cdot \text{in}^2$$

$$N_b = 11$$

$$A_{\text{steel}} = A_b \cdot N_b$$

$$A_{\text{steel}} = 13.97 \cdot \text{in}^2$$

if($A_{\text{steel}} \geq A_{\text{req}}$, "good", "no good, add more steel") = "good"

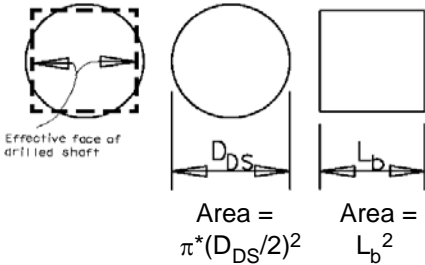
Step Three: Anchorage of Tension Tie (AASHTO LRFD 5.6.3.4.2 and 5.11.2)

x = the distance from the effective face of the drilled shaft to where the full development of reinforcement is required

$$x = \frac{d_c}{\tan(\theta)}$$

$$x = 3.1 \cdot \text{in}$$

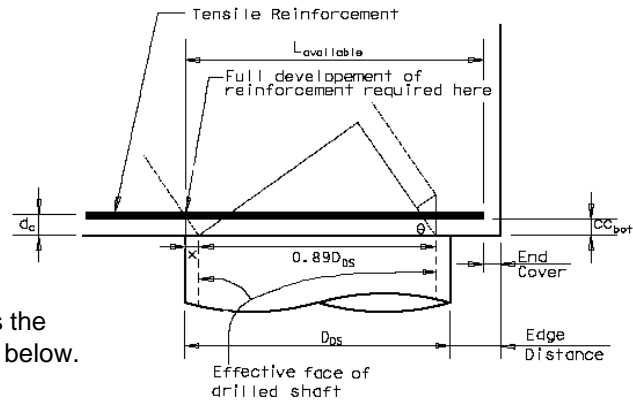
The effective face of the drilled shaft is assumed as the side dimension of the equivalent square as defined below.



$$L_b^2 = \pi \cdot (D_{DS}/2)^2$$

$$L_b = D_{DS}/2 \cdot \pi^{0.5}$$

$$L_b = 0.89 \cdot D_{DS}$$



ELEVATION NODE C

(TxDOT Project 0-4371 Section 5.5)

$$L_{available} = \text{EdgeDistance} + \frac{D_{DS}}{2} + 0.89 \cdot \frac{D_{DS}}{2} + x - \text{EndCover}$$

$$L_{available} = 54.5 \cdot \text{in}$$

Check if the required development length can be reduced:

L_{db} factors: (AASHTO LRFD 5.11.2.1.3)

- 1) Check if the clear cover, cc_{side} , is not less than 3in and the reinforcement bar spacing, s_{bar} , is not less than 6in.

$$cc_{side} = 3 \cdot \text{in}$$

$$s_{bar} = \frac{D_{DS} + 2 \cdot d_c}{N_b - 1}$$

$$s_{bar} = 5.7 \cdot \text{in}$$

Since s_{bar} is less than 6in, factor₁ = 1.0.

$$\text{factor}_1 = 1.0$$

- 2) Check ratio of $A_{required}/A_{provided}$.

Since the footing is being designed, the factor of $A_{required}/A_{provided}$ is assumed to be 1.0.

$$\text{factor}_2 = 1.0$$

- 3) Check if the reinforcement is enclosed in a spiral.

Since the footing reinforcement is not enclosed in a spiral, the factor is taken as 1.0.

$$\text{factor}_3 = 1.0$$

For #11 bars or smaller:

$$L_{db} = \max \left[1.25 \cdot A_b \cdot \frac{f_y}{(f_c \cdot \text{kip})^{0.5}}, 0.4d_b \cdot f_y \cdot \frac{\text{in}^2}{\text{kip}}, 12\text{in} \right] \quad (\text{AASHTO LRFD 5.11.2.1.1})$$

$$L_{db} = 50.2 \cdot \text{in}$$

$$L_d = L_{db} \cdot \text{factor}_1 \cdot \text{factor}_2 \cdot \text{factor}_3$$

$$L_d = 50.2 \cdot \text{in}$$

if ($L_{\text{available}} > L_d$, "good", "hook required") = "good"

Step Four: Node Geometry (TxDOT Project 0-4371 Section 5.5)

CCT Node - a node which is bounded by two struts (C) and one tie (T)

CCC Node - a node which is bounded by three struts (C)

w_s = the width of a strut in plane of the truss model

w_t = the width of the tie, or in a CCC node w_t is based on the compression force due to bending of the beam which can be conservatively assumed as the height of the compression block. For simplicity in this design example w_t is always taken as the width of a tension tie. Using the width of a tension tie instead of the height of the compression block in most cases should not significantly effect the final result.

L_b = the bearing length corresponding to a node

Node A & D Geometry:

Since the forces at nodes B and C are larger than those at nodes A and D, the controlling nodal or strut failure will not occur at nodes A and D.

Node C Geometry:

Assume the bearing length as the side face dimension of the equivalent square for the drilled shaft.

$$L_b = 0.89 \cdot D_{DS}$$

$$L_b = 42.7 \cdot \text{in}$$

w_t is the smaller of:

$$2 \cdot cc_{\text{bot}} + d_b = 7.3 \cdot \text{in}$$

$$6 \cdot d_b \cdot 2 = 15.2 \cdot \text{in}$$

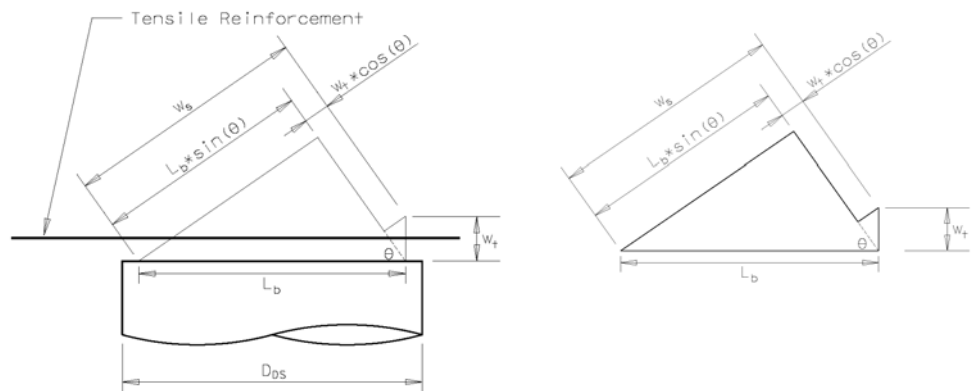
$$w_t = 7.3 \cdot \text{in}$$

$$w_t \cdot \cos(\theta) = 4.2 \cdot \text{in}$$

$$L_b \cdot \sin(\theta) = 34.8 \cdot \text{in}$$

$$w_s = w_t \cdot \cos(\theta) + L_b \cdot \sin(\theta)$$

$$w_s = 39 \cdot \text{in}$$



NODE C GEOMETRY
(strut BC and tie CD)

Node B Geometry

Due to the ambiguity of a node as complex as node B (two diagonal struts and one horizontal strut), this design example only focuses on strut BC.

Node B (strut BC) Geometry:

The overall bearing length of node B is $W_{col} / 2$, but since there is more than one strut at node B the bearing length will be divided into individual bearing lengths for each strut. The bearing lengths are proportional to the amount of load in each strut. In this example, for simplicity, the bearing length of Node B is divided into two equal sections to accommodate the two diagonal struts.

$$L_{b2} = \frac{W_{col}}{4}$$

$$L_{b2} = 24.0 \cdot \text{in}$$

For simplicity w_{t2} is taken as the height of the tension tie instead of the height of the compression block. The height of the tension tie at Node B is assumed to be the same as Node C, w_t .

$$w_{t2} = w_t$$

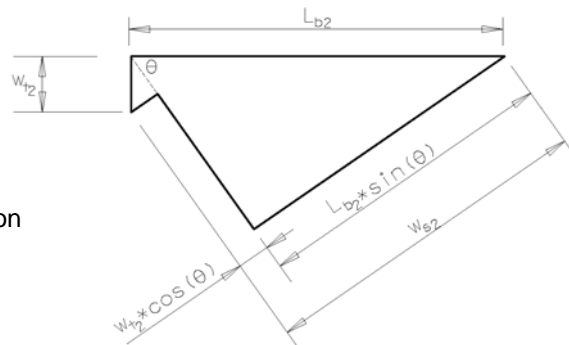
$$w_{t2} = 7.3 \cdot \text{in}$$

$$w_{t2} \cdot \cos(\theta) = 4.2 \cdot \text{in}$$

$$L_{b2} \cdot \sin(\theta) = 19.6 \cdot \text{in}$$

$$w_{s2} = w_{t2} \cdot \cos(\theta) + L_{b2} \cdot \sin(\theta)$$

$$w_{s2} = 23.8 \cdot \text{in}$$



ELEVATION NODE B
(strut BC)

Step Five: Check Capacity of Diagonal Struts (TxDOT LRFD Bridge Design Manual and TxDOT Project 0-4371 Section A.2.1)

Strut BC will control, because of the high compressive force. The interface at Node B will control, because it has the smallest cross-sectional area.

$$\nu = \min \left(\frac{0.85 \cdot \tan(\theta) \cdot L_b \cdot \frac{\text{kip}^{0.5}}{\text{in}}}{f_c^{0.5} \cdot w_{s2} \cdot \sin(\theta)}, \frac{0.85 \cdot L_b}{w_{s2} \cdot \sin(\theta)}, 0.85 \right)$$

(TxDOT Project 0-4371 Section A.2.1 Eq. A-7 and TxDOT LRFD Bridge Design Manual)

$$\nu = 0.850$$

b_{BC} = Effective width of strut BC at node B

$$b_{BC} = \frac{W_{col}}{4}$$

$$b_{BC} = 24.0 \cdot \text{in}$$

$$\phi = 0.70$$

$$\phi P_n = \phi \cdot \nu \cdot f_c \cdot w_{s2} \cdot b_{BC}$$

(TxDOT Project 0-4371 Section A.2.1 Eq. A-9 and TxDOT LRFD Bridge Design Manual)

$$\phi P_n = 1222 \cdot \text{kip}$$

$$R_2 = 1036 \cdot \text{kip}$$

$$\text{if}(\phi P_n > R_2, \text{"good"}, \text{"no good"}) = \text{"good"}$$

Step Six: Crack Control Reinforcement in Struts (TxDOT LRFD Bridge Design Manual and TxDOT Project 0-4371 Section A.2.2)

Strut BC will control, because it deals with the largest applied stresses:

L_{strut} = length of strut

$$L_{strut} = \frac{h - d_c}{\sin(\theta)}$$

$$L_{strut} = 82.9 \cdot \text{in}$$

$$b_{min} = \min(w_s, w_{s2})$$

$$b_{min} = 24 \cdot \text{in}$$

b_{ef} = maximum effective strut width

$$b_{ef} = \max \left(\frac{L_{strut}}{3}, b_{min} + \frac{L_{strut}}{6} \right)$$

(TxDOT Project 0-4371 Section A.2.2 and TxDOT LRFD Bridge Design Manual)

$$b_{ef} = 37.6 \cdot \text{in}$$

m = slope of the dispersion of compression

$$m = \frac{2b_{ef}}{b_{ef} - b_{min}}$$

(TxDOT Project 0-4371 Section A.2.2 and TxDOT LRFD Bridge Design Manual)

$$m = 5.44$$

b = the average width of the strut measured perpendicular to the plane of the truss

$$b = \frac{0.89 \cdot D_{DS} + D_{col}}{2}$$

$$b = 51.4 \cdot \text{in}$$

$$\rho_{min} = BC / (2 \cdot f_y \cdot b \cdot L_{strut} \cdot m) \text{ but not less than } 0.003$$

(TxDOT Project 0-4371 Section A.2.2 Eq. A-15 and TxDOT LRFD Bridge Design Manual)

$$\rho_{min} = \max \left(0.003, \frac{BC}{2 \cdot f_y \cdot b \cdot L_{strut} \cdot m} \right)$$

$$\rho_{min} = 0.0030$$

Horizontal (Skin) Reinforcement:

Assuming size #7 bars and 9" spacing

$$s_{bar_h} = 9 \text{in}$$

$$A_{b_h} = 0.60 \text{in}^2$$

*****This check requires that both side faces of the footing be reinforced with the specified bar size at the spacing shown.**

Vertical Reinforcement (Two Legs - Stirrups):

Assuming size #7 bars and 9" spacing

$$s_{bar_v} = 9 \text{in}$$

$$A_{b_v} = 0.60 \text{in}^2$$

For the transverse direction of the strut, conservatively use the width of the larger node:

$$\rho = \left[\left(\frac{2 \cdot A_{b_h}}{\max(D_{col}, 0.89 \cdot D_{DS}) \cdot s_{bar_h}} \right)^2 + \left(\frac{2A_{b_v}}{\max(D_{col}, 0.89 \cdot D_{DS}) \cdot s_{bar_v}} \right)^2 \right]^{0.5}$$

(TxDOT Project 0-4371 Section A.2.2 Eq. A-14 and TxDOT LRFD Bridge Design Manual)

$$\rho = 0.0031$$

$$\text{if}(\rho > \rho_{min}, \text{"Good"} , \text{"NG, add more reinforcement"}) = \text{"Good"}$$

**Use the same bars and spacing throughout the footing

Step Seven: Check Nodal Zone Stress Limits (AASHTO LRFD 5.6.3.5, TxDOT LRFD Bridge Design Manual and TXDOT Project 0-4371 Section A.3.3.2)

The nodes are all significantly large. By inspection, nodal failure will not occur.