Spread footing - Stability and Soil bearing

This document analyzes the design of the rectangular spread footing for sign, signal and lighting support structures in terms of its stability and soil bearing. The calculation is based on AASHTO LRFD (Load and Resistance Factor Design).

References:
- AASHTO LRFD Specification for Structural Supports for Highway Signs, Luminaires and Traffic Signals
- AASHTO LRFD Bridge Design Specification
- FDOT Structures Manual

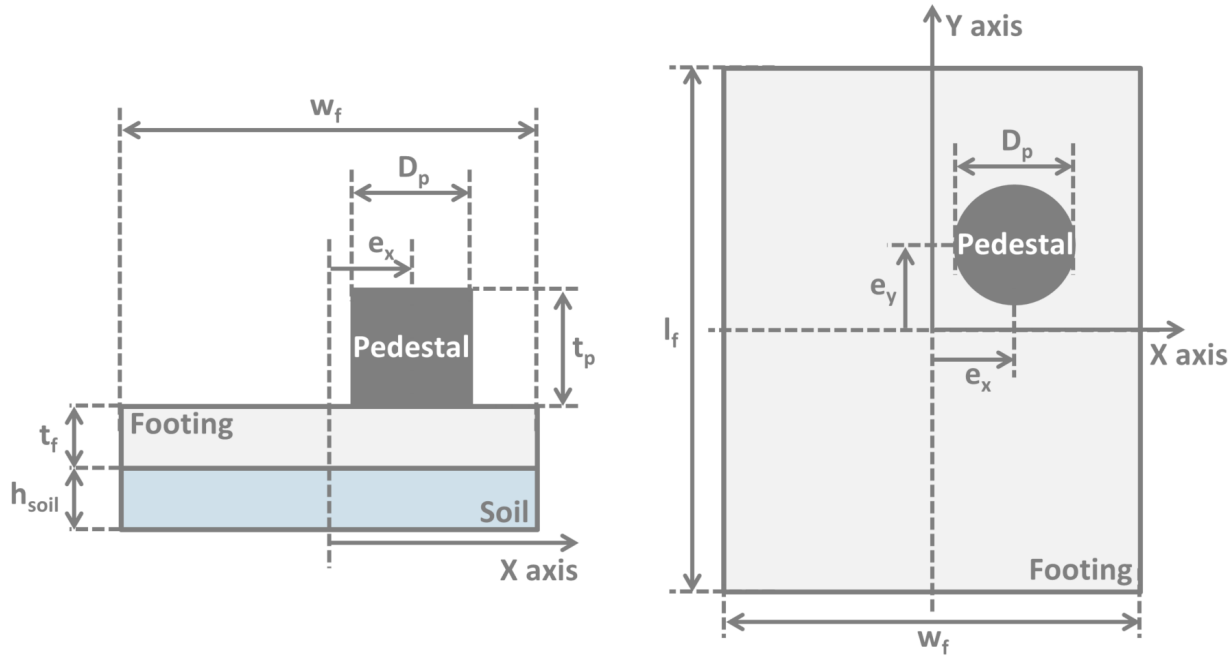

Figure : Footing and Pedestal
(Left : Front view, Right : Top view)

Design parameters

Design wind speed

Basic wind speed $V_{basic} := 150\ \mathbf{mph}$

Service wind speed $V_{service} := 90\ \mathbf{mph}$

Soil properties

Unit weight	$\gamma_{soil} := 50 \frac{lbf}{ft^3}$
Friction angle	$\phi_{soil} := 35\ deg$
Nominal bearing resistance	$q_n := 5500\ psf$

Concrete properties

Unit weight	$\gamma_{concrete} := 145 \frac{lbf}{ft^3}$
Speficifed compressive strength	$f_c := 5500\ psi$

Footing and Pedestral design parameters

Length of footing	$l_f := 12\ ft$
Width of footing	$w_f := 16\ ft$
Thickness of footing	$t_f := 2.5\ ft$
Diameter of pedestal	$D_p := 5\ ft$
Thickness of pedestal	$t_p := 4\ ft$
Offset of pedestal in X-direction	$e_x := 36\ inch$
Offset of pedestal in Y-direction	$e_y := 80\ inch$
Height of soil	$h_{soil} := 3\ ft$
Depth at which passive earth pressure of the soil or embankment shall be neglacted	$h_r := 2\ inch$

Load of superstructure settings

Dead Load

Axial load $P_{DC} := -6.2\ \mathbf{kip}$

Moment of Y-direction $M_{DC\_x} := 0\ \frac{\mathbf{kip}}{\mathbf{ft}^{-1}}$

Moment of X-direction $M_{DC\_y} := -55.2\ \frac{\mathbf{kip}}{\mathbf{ft}^{-1}}$

Wind Load

Force of X-direction $V_{WS\_x} := -0.4\ \mathbf{kip}$

Force of Y-direction $V_{WS\_y} := 8.1\ \mathbf{kip}$

Moment of X-direction $M_{WS\_x} := -165.60\ \frac{\mathbf{kip}}{\mathbf{ft}^{-1}}$

Moment of Y-direction $M_{WS\_y} := -43.20\ \frac{\mathbf{kip}}{\mathbf{ft}^{-1}}$

Torque $T_{WS} := -163.30\ \frac{\mathbf{kip}}{\mathbf{ft}^{-1}}$

Moment and Force calculation

Dead load factor $\gamma_{DC} := 1.1$

Weight of Footing $W_f := \gamma_{concrete} \cdot \left(l_f \cdot w_f \cdot t_f + \frac{\pi \cdot D_p^{\,2}}{4} \cdot t_p \right) = 80.988\ \mathbf{kip}$

Weight of Soil $W_s := \gamma_{soil} \cdot \left(l_f \cdot w_f - \frac{\pi \cdot D_p^{\,2}}{4} \right) \cdot h_{soil} = 25.855\ \mathbf{kip}$

Factored load $P_F := \gamma_{DC} \cdot \left(W_f + W_s - P_{DC} \right) = 124.347\ \mathbf{kip}$

Moment of external forces
X-direction

$$M_{F\_x} := \gamma_{DC} \cdot \left(M_{DC\_x} + P_{DC} \cdot e_y \right) + \left(M_{WS\_x} - V_{WS\_y} \cdot \left(t_f + t_p \right) \right)$$

$$M_{F\_x} = -263.717 \text{ kip foot}$$

Moment of external forces
Y-direction

$$M_{F\_y} := \gamma_{DC} \cdot \left(M_{DC\_y} - P_{DC} \cdot e_x \right) + \left(M_{WS\_y} + V_{WS\_x} \cdot \left(t_f + t_p \right) \right)$$

$$M_{F\_y} = -86.060 \text{ kip foot}$$

Factored torque

$$T_F := T_{WS} - V_{WS\_x} \cdot e_y + V_{WS\_y} \cdot e_x = -136.333 \text{ kip foot}$$

Analysis of Overturning

Resistance factor for overturning $\phi_{ot} := 0.6$

Longitudinal

Moment of Resistance $M_{R\_x} := \phi_{ot} \cdot \frac{P_F \cdot l_f}{2} = 447.650 \text{ kip foot}$

Moment of Driving $M_{D\_x} := \left| M_{F\_x} \right| = 263.717 \text{ kip foot}$

Ratio, Driving / Resistance $Ratio_{long} := \frac{M_{D\_x}}{M_{R\_x}} = 0.589$

Check the condition $Status_{long} := \begin{cases} \text{"Satisfied"} & M_{R\_x} \geq M_{D\_x} \\ \text{"Violated"} & \text{otherwise} \end{cases}$

$Status_{long} = \text{"Satisfied"}$

Transverse

Moment of Resistance

$$M_{R\_y} := \phi_{ot} \cdot \frac{P_F \cdot w_f}{2} = 596.867 \text{ kip foot}$$

Moment of Driving

$$M_{D\_y} := \left| M_{F\_y} \right| = 86.060 \text{ kip foot}$$

Ratio, Driving / Resistance

$$Ratio_{trans} := \frac{M_{D\_y}}{M_{R\ v}} = 0.144$$

Check the condition

$$Status_{trans} := \begin{cases} \text{"Satisfied"} & M_{R\_y} \geq M_{D\_y} \\ \text{"Violated"} & \text{otherwise} \end{cases}$$

$$Status_{trans} = \text{"Satisfied"}$$

Analysis of Torsional capacity

Torsional resistance
by passive earth pressure

$$K_p := \tan\left(45 \cdot \text{deg} + \frac{\phi_{soil}}{2}\right)^2 = 3.690$$

$$T_p := K_p \cdot \gamma_{soil} \cdot \left(h_{soil} + \frac{t_f}{2} - h_r\right) \cdot t_f \cdot \left(\left(\frac{l_f}{2}\right)^2 + \left(\frac{w_f}{2}\right)^2\right)$$

$$T_p = 188.353 \text{ kip foot}$$

Torsional resistance
between soil and foundation

$$\mu := \tan\left(\phi_{soil}\right) = 0.700$$

$$T_{sf} := \mu \cdot P_F \cdot \left(\frac{w_f}{2} - \frac{w_f^2}{6 \cdot l_f}\right)$$

$$T_{sf} = 386.973 \text{ kip foot}$$

Resistance factor for torsion $\phi_t := 0.8$

Resistance factor for earth pressure $\phi_{ep} := 0.5$

Resistance torque $T_R := \phi_{ep} \cdot T_p + \phi_t \cdot T_{sf} = 403.755\ \textbf{kip foot}$

Ratio, Driving / Resistance $Ratio_T := \frac{|T_F|}{T_R} = 0.338$

Check the condition $Status_{torque} := \begin{cases} \text{"Satisfied"} & T_R \geq |T_F| \\ \text{"Violated"} & \text{otherwise} \end{cases}$

$Status_{torque} = \text{"Satisfied"}$

Calculation for Bearing capacity on Soil

Loading eccentricity

$$ecc_x := \frac{M_{F\_y}}{P_F} = -0.692\ \textbf{ft}$$

$$ecc_y := -\frac{M_{F\_x}}{P_F} = 2.121\ \textbf{ft}$$

Check Eccentric load limitations

$$Status_{ecc} := \begin{cases} \text{"Satisfied"} & |ecc_x| \leq \frac{1}{3} \cdot w_f \textbf{ and } |ecc_y| \leq \frac{1}{3} \cdot l_f \\ \text{"Violated"} & \text{otherwise} \end{cases}$$

$Status_{ecc} = \text{"Satisfied"}$

Reduced dimensions for the eccentrically loaded footing

$$w_{reduced} := w_f - 2 \cdot |ecc_x| = 14.616\ \text{ft}$$

$$l_{reduced} := l_f - 2 \cdot |ecc_y| = 7.758\ \text{ft}$$

Resistance with reduced dimensions

$$q_{reduced} := \frac{P_F}{w_{reduced} \cdot l_{reduced}} = 1096.584\ \text{psf}$$

Bearing resistance factor

$$\phi_b := 0.45$$

Checnk, Driving / Resistance

$$Ratio_b := \frac{q_{reduced}}{\phi_b \cdot q_n} = 0.443$$

Check the condition

$$Status_{bearing} := \begin{cases} \text{"Satisfied"} & \phi_b \cdot q_n \geq q_{reduced} \\ \text{"Violated"} & \text{otherwise} \end{cases}$$

$$Status_{bearing} = \text{"Satisfied"}$$