Alternate Non-constrained Footing Minimum Depth Formula per EP486.1

EP486.1 §6.5.1 Minimum depth formula for non-constrained posts:

Solve iteratively Input d ≥ output d is OK

A more detailed review of EP486.1 is linked at the bottom of the Footing Design page for installation sites that have soils reports available.

$$d = \sqrt{\frac{6V_a + \frac{8M_a}{d}}{Sb}}$$

Variables changed to match the FenceDesign.com nomenclature:

Shear, $V_a = P$ Moment, $M_a = P \frac{1}{2} h$

Solve iteratively Footing Depth, D ≥ Minium Depth, d is OK

$$d = \sqrt{\frac{6P + \frac{8P\frac{1}{2}h}{D}}{SMb}}$$

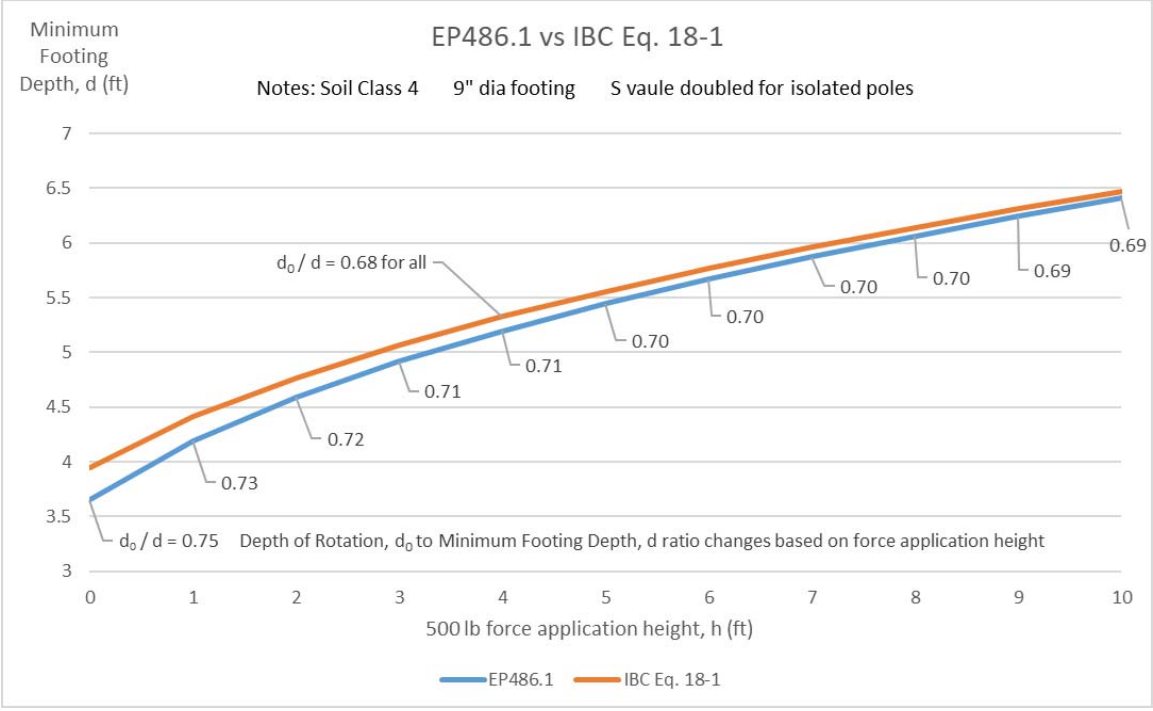
IBC Eq. 18-1 was formulated in the 1960's for highway billboard pole footings so it is based on forces being applied to the post 30' or more above grade and used a simplified set of assumptions. As the soil pressure curve changes with force application height, the IBC equation is conservative at typical fence heights. The EP486.1 formula is more accurate, provides shallower footing depths, and does so with fewer calculations steps.

IBC – Three steps each iteration

Calculate S_1	Conservatively uses $d_0 / d = ⅔$
Calculate A	Conservatively uses $d_0 / d = 0.68$
Calculate d	Conservatively uses $d_0 / d = 0.68$

EP486.1 – One step each iteration

Calculate d	d_0 / d value changes with force application height



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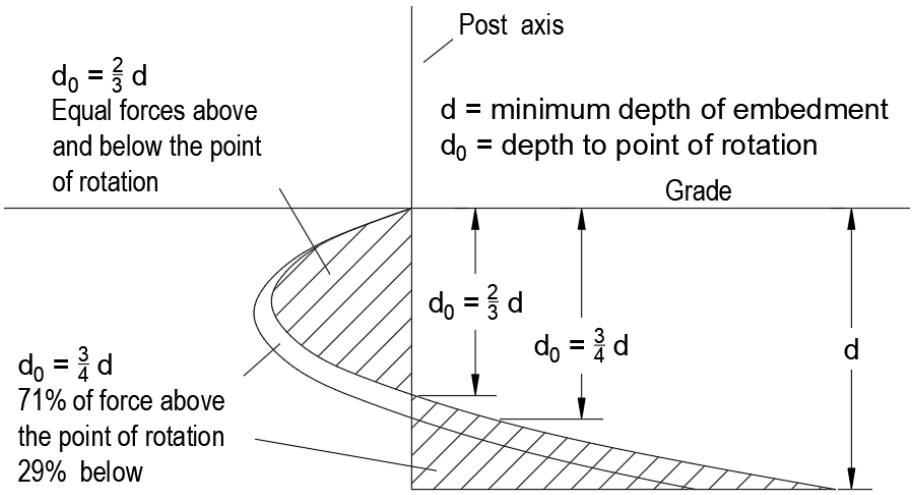
Alternate Non-constrained Footing Minimum Depth Formula per EP486.1 (cont.)

The EP486.1 minimum depth formula is derived directly from the soil pressure curve and the shape of that curve changes with the force application height.

A flag pole with most of the force at the top of the pole approaches $d_0 = \frac{2}{3}d$

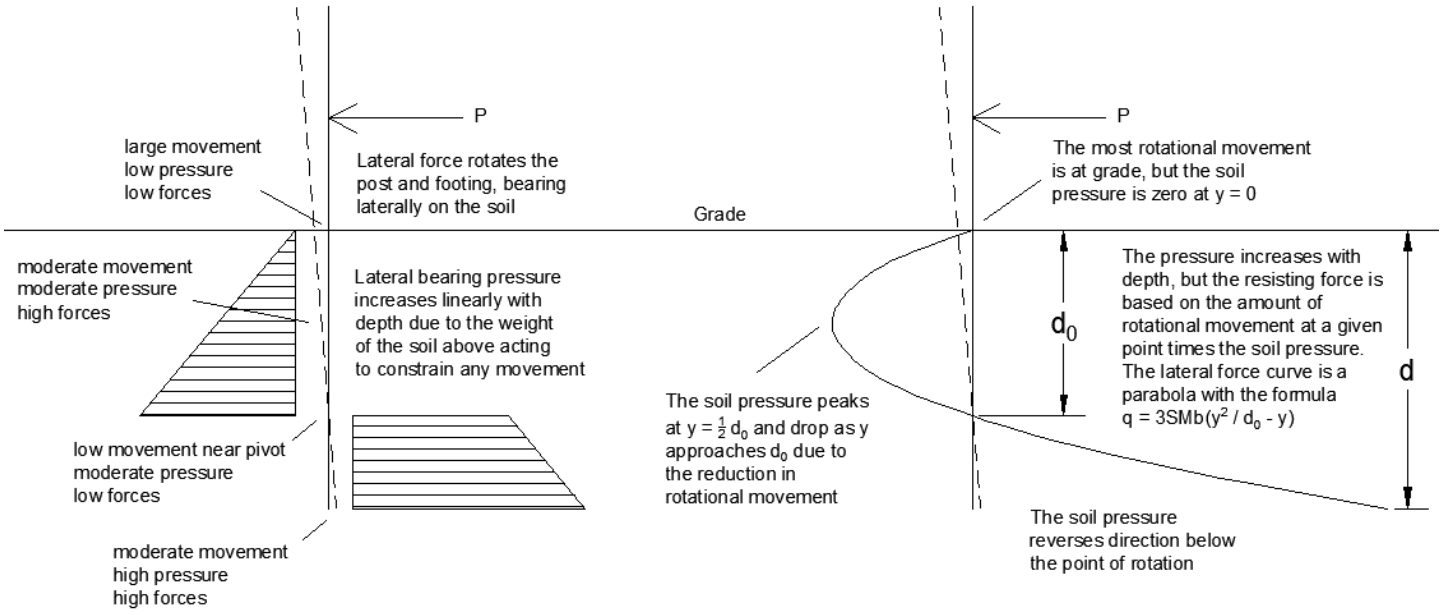
A parking bollard with the force applied close to the ground approaches $d_0 = \frac{3}{4}d$

Fence post footings typically have a d_0 / d ratio from 0.70 to 0.72



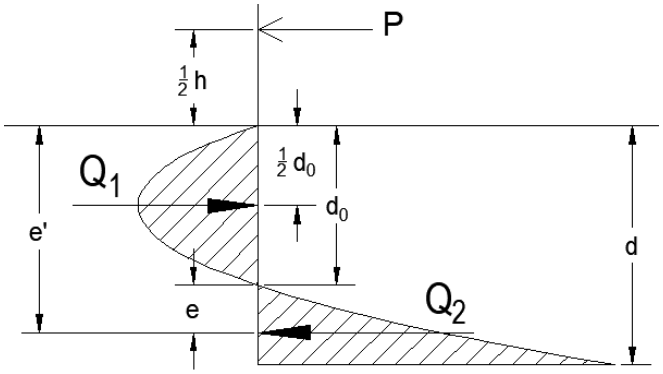
The shape of the soil force curve is a parabola. The upper portion of the curve is larger as it is resisting both rotation and shear caused by the lateral load, and the lower portion is smaller as it is only resisting the rotation.

The more movement a given point on the footing has under load, the more the soil resists the force, but the soil resisting force increases linearly with depth. The force increases with increasing depth, then reduces as the lateral movement of the footing decreases as the you approach the point of rotation. Past the point of rotation, the load reverses and increases to the bottom of the footing.

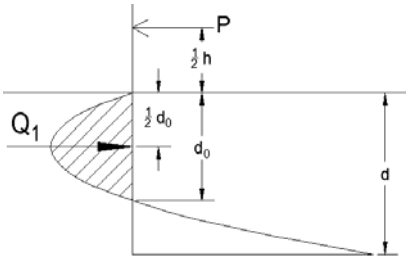


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Free Body Diagram of the footing / soil interaction



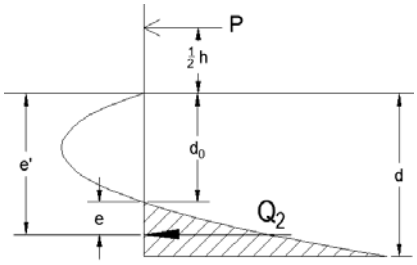
Soil force curve formula, in lbs / ft of depth: $q = 3SMb(\frac{y^2}{d_0} - y)$



Q_1 is the resultant of the area under the soil force curve from y = 0 to y = d_0.

Q_1 is applied at a distance ½d_0 below grade as that part of the curve is symmetrical.

$$Q_1 = \int_0^{d_0} q\,dy = \int_0^{d_o} 3SMb(\frac{y^2}{d_0} - y)\,dy = 3SMb(\frac{1}{3}\frac{{d_0}^3}{d_0} - \frac{1}{2}{d_0}^2) = 3SMb(\frac{1}{3}{d_0}^2 - \frac{1}{2}{d_0}^2) = -3SMb\frac{1}{6}{d_0}^2 = -\frac{1}{2}SMb{d_0}^2$$



Q_2 is the resultant of the area under the soil force curve from y = d_0 to y = d.

The total area is calculated, then Q_1 is subtracted to isolate the bottom area.

$$Q_2 = \int_{d_o}^{d} 3SMb(\frac{y^2}{d_0} - y)\,dy = 3SMb(\frac{1}{3}\frac{d^3}{d_0} - \frac{1}{2}d^2) - Q_1 = 3SMb(\frac{1}{3}\frac{d^3}{d_0} - \frac{1}{2}d^2) + 3SMb\frac{1}{6}{d_0}^2 = 3SMb(\frac{1}{3}\frac{d^3}{d_0} - \frac{1}{2}d^2 + \frac{1}{6}{d_0}^2)$$

The distance, e below d_0 where Q_2 is applied is the centroid of the lower area of the curve. The distance from grade to the centroid is calculated and then d_0 is subtracted. e' is the distance from grade to the lower centroid.

$$e = \frac{\int_{d_0}^{d} 3SMby\left(\frac{y^2}{d_0} - y\right)dy}{Q_2} - d_0 = \frac{\int_{d_0}^{d} 3SMb\left(\frac{y^3}{d_0} - y^2\right)dy}{Q_2} - d_0 = \frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 - \left(\frac{1}{4}\frac{{d_0}^4}{d_0} - \frac{1}{3}{d_0}^3\right))}{Q_2} - d_0$$

$$e = \frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 - \frac{1}{4}{d_0}^3 + \frac{1}{3}{d_0}^3)}{Q_2} - d_0 = \frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 + \frac{1}{12}{d_0}^3)}{Q_2} - d_0 \qquad e' = \frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 + \frac{1}{12}{d_0}^3)}{Q_2}$$

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Deriving the formula for Depth to the Point of Rotation, d_0

Summing the moment at the bottom of the footing @ y = d: $Q_1(d - \frac{1}{2}d_0) + Q_2(d - e') + P(\frac{1}{2}h + d) = 0$

$$-P(\tfrac{1}{2}h + d) = -\tfrac{1}{2}SMbd_0^2\,(d - \tfrac{1}{2}d_0) + 3SMb(\tfrac{1}{3}\frac{d^3}{d_0} - \tfrac{1}{2}d^2 + \tfrac{1}{6}{d_0}^2)(d - e')$$

$$-P(\tfrac{1}{2}h + d) = -\tfrac{1}{2}SMbd_0^2 d + \tfrac{1}{2}SMbd_0^2\,\tfrac{1}{2}d_0 + Q_2 d - Q_2\frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 + \frac{1}{12}{d_0}^3)}{Q_2}$$

$$-P(\tfrac{1}{2}h + d) = -\tfrac{1}{2}SMbd_0^2 d + \tfrac{1}{4}SMbd_0^3 + 3SMb(\tfrac{1}{3}\frac{d^3}{d_0} - \tfrac{1}{2}d^2 + \tfrac{1}{6}{d_0}^2)d - 3SMb(\tfrac{1}{4}\frac{d^4}{d_0} - \tfrac{1}{3}d^3 + \tfrac{1}{12}{d_0}^3)$$

$$-P(\tfrac{1}{2}h + d) = -\tfrac{1}{2}SMbd_0^2 d + \tfrac{1}{4}SMbd_0^3 + (SMb\frac{d^3}{d_0} - \tfrac{3}{2}SMbd^2 + \tfrac{1}{2}SMbd_0^2)d - (\tfrac{3}{4}SMb\frac{d^4}{d_0} - SMbd^3 + \tfrac{1}{4}SMbd_0^3)$$

$$-P(\tfrac{1}{2}h + d) = -\tfrac{1}{2}SMbd_0^2 d + \tfrac{1}{4}SMbd_0^3 + SMb\frac{d^4}{d_0} - \tfrac{3}{2}SMbd^3 + \tfrac{1}{2}SMbd_0^2 d - \tfrac{3}{4}SMb\frac{d^4}{d_0} + SMbd^3 - \tfrac{1}{4}SMbd_0^3$$

$$-P(\tfrac{1}{2}h + d) = \tfrac{1}{4}SMb\frac{d^4}{d_0} - \tfrac{1}{2}SMbd^3 \qquad \tfrac{1}{2}SMbd^3 - P(\tfrac{1}{2}h + d) = \tfrac{1}{4}SMb\frac{d^4}{d_0}$$

S is doubled rather than using M=2 in EP486.1

$$d_0 = \frac{\frac{1}{4}SMbd^4}{\frac{1}{2}SMbd^3 - P(\frac{1}{2}h + d)}\,\frac{\frac{4}{SMb}}{\frac{4}{SMb}} = \frac{d^4}{2d^3 - \frac{4P(\frac{1}{2}h + d)}{SMb}}$$

For EP486.1, $P = V_a$ $P\tfrac{1}{2}h = M_a$ $d_0 = \dfrac{d^4}{2d^3 - \frac{4V_a d}{Sb} - \frac{4M_a}{Sb}}$

EP486.1 has a typo and has no 4 next to M_a

Deriving the EP486.1 minimum depth, d formula

Summing the moments at grade: $P\tfrac{1}{2}h + Q_1\tfrac{1}{2}d_0 = Q_2 e'$

$$P\tfrac{1}{2}h + \tfrac{1}{2}SMbd_0^2\,\tfrac{1}{2}d_0 = Q_2\frac{3SMb(\frac{1}{4}\frac{d^4}{d_0} - \frac{1}{3}d^3 + \frac{1}{12}{d_0}^3)}{Q_2} \qquad P\tfrac{1}{2}h + \tfrac{1}{4}SMbd_0^3 = 3SMb(\tfrac{1}{4}\frac{d^4}{d_0} - \tfrac{1}{3}d^3 + \tfrac{1}{12}{d_0}^3)$$

$$P\tfrac{1}{2}h + \tfrac{1}{4}SMbd_0^3 = \tfrac{3}{4}SMb\frac{d^4}{d_0} - SMbd^3 + \tfrac{1}{4}SMbd_0^3 \qquad P\tfrac{1}{2}h = \tfrac{3}{4}SMb\frac{d^4}{d_0} - SMbd^3$$

$$\frac{P\frac{1}{2}h}{SMb} = \frac{3}{4}\frac{d^4}{d_0} - d^3 = \frac{3}{4}\frac{d^4(2d^3 - \frac{4Pd + 4P\frac{1}{2}h}{SMb})}{d^4} - d^3 = \frac{3}{4}2d^3 - \frac{3}{4}\frac{(4Pd + 4P\frac{1}{2}h)}{SMb} - d^3 = 1\tfrac{1}{2}d^3 - \frac{3}{4}\frac{(4Pd + 4P\frac{1}{2}h)}{SMb} - d^3$$

$$\frac{P\frac{1}{2}h}{SMb} = \frac{1}{2}d^3 - \frac{3Pd + 3P\frac{1}{2}h}{SMb} \qquad \frac{1}{2}d^3 = \frac{P\frac{1}{2}h}{SMb} + \frac{3Pd + 3P\frac{1}{2}h}{SMb} = \frac{P\frac{1}{2}h + 3Pd + 3P\frac{1}{2}h}{SMb} = \frac{3Pd + 4P\frac{1}{2}h}{SMb} \qquad d^3 = \frac{6Pd + 8P\frac{1}{2}h}{SMb}$$

$$\frac{1}{d}d^3 = \frac{1}{d}\frac{6Pd + 8P\frac{1}{2}h}{SMb} \qquad d^2 = \frac{6Pd + 8P\frac{1}{2}h}{SMbd} \qquad d = \sqrt{\frac{6Pd + 8P\frac{1}{2}h}{SMbd}} \qquad d = \sqrt{\frac{6P + \frac{8P\frac{1}{2}h}{d}}{SMb}}$$

Replace right side input d with D $d = \sqrt{\dfrac{6P + \frac{8P\frac{1}{2}h}{D}}{SMb}}$ Solve iteratively for Footing Depth, D ≥ Minimum Depth, d

To get to the EP486.1 formula Shear, $V_a = P$ Moment, $M_a = P\tfrac{1}{2}h$

M = 2 is not used in EP486.1 – S value is doubled from the soil pressure table instead – noted in green

FenceDesign.com EP486.1 §6.5.1

$$d = \sqrt{\frac{P6 + \frac{8P\frac{1}{2}h}{D}}{SMb}} \qquad d = \sqrt{\frac{6V_a + \frac{8M_a}{d}}{Sb}}$$

Solve iteratively for input d ≥ output d

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