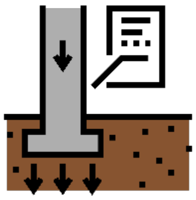

How to use Montogue's Shallow Foundation Bearing Capacity Calculator

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■ 1. Vesić's General Bearing Capacity Equation

The program uses the general bearing capacity equation proposed by Vesić in the 1970s. The pertaining equation is

$$q_n = c'N_c s_c d_c b_c i_c g_c v_c + \sigma'_{zD} N_q s_q d_q b_q i_q g_q v_q + \frac{1}{2}\gamma' B N_\gamma s_\gamma d_\gamma b_\gamma i_\gamma g_\gamma v_\gamma$$

where

→ c' is cohesive strength (or undrained shear strength s_u in total stress analyses);

→ σ'_{zD} is the vertical effective stress at a depth D below the ground surface (D is the depth of the foundation). The total stress σ_{zD} may be used in total stress analyses;

→ γ' is the effective unit weight of the soil (which may require correction depending on the depth of the water table relatively to the footing; see below);

→ N_c, N_q, N_γ are Vesić's bearing capacity factors;

→ s_c, s_q, s_γ are shape factors;

→ d_c, d_q, d_γ are depth factors;

→ b_c, b_q, b_γ are base inclination factors;

→ i_c, i_q, i_γ are load inclination factors;

→ g_c, g_q, g_γ are ground inclination factors;

→ v_c, v_q, v_γ are soil compressibility factors;

■ 2. Data Input

2.1. Effective friction angle (degrees): This is the angle ϕ' in the soil's Mohr-Coulomb failure envelope $\tau = c' + \sigma tan\ \phi'$. For a total stress analysis, the undrained friction angle ϕ_T may be entered instead.

2.2. Effective cohesion (kN/m^2 or lb/ft^2): This is the vertical intercept c' in the soil's Mohr-Coulomb failure envelope $\tau = c' + \sigma tan\ \phi'$. For a total stress analysis, the undrained shear strength s_u may be entered instead.

2.3. Footing width (B) (m or ft): This is, wait for it, the width of the footing.

2.4. Footing length (L) (m or ft): This is, you guessed it, the length of the footing. For a square footing, $B = L$.

In principle, a strip footing could be simulated by entering a very large value in the footing length field, but problems of this nature have not been tested.

2.5. Foundation depth (D) or *groundwater depth* (D_w) (m or ft): Following Coduto *et al.* (2016), three cases are defined depending on the relative magnitudes of D, D_w, and the width B.

→ *Case 1: $D_w \leq D$ (water table is shallower than the footing).*

In this case, the effective unit weight γ' to be used in the third term of the bearing capacity equation is the buoyant weight γ_b, namely

$$\gamma' = \gamma_b = \gamma - \gamma_w$$

where γ is the dry unit weight of the soil and γ_w = 9.81 kN/m^3 or 62.43 lb/ft^3 is the unit weight of water at ambient temperature. In Case 1, the second term in the bearing capacity formula is also affected, but the appropriate correction is implicit in the computation of effective stress σ'_{zD}.

→ *Case 2: $D_w \leq D \leq D + B$ (water table is shallower than the lower limit of the zone of influence).*

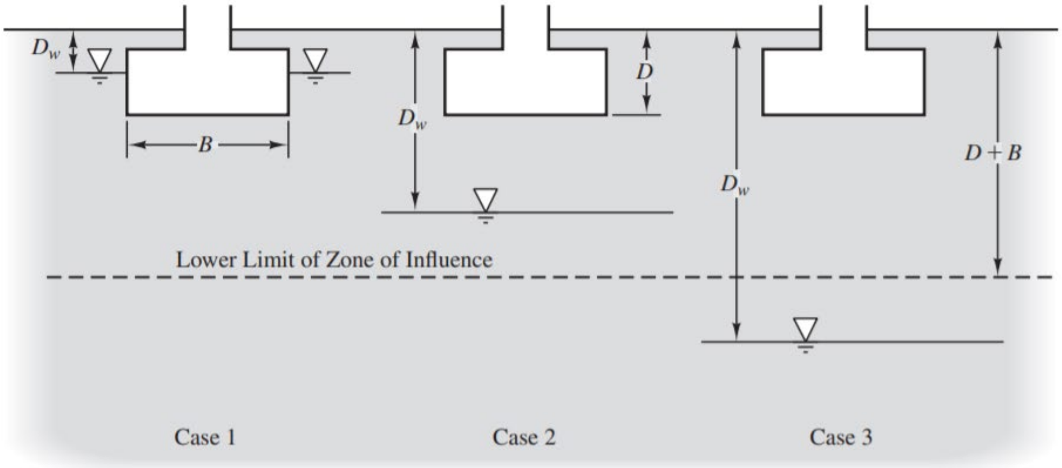
In this case, the effective unit weight γ' is expressed as

$$\gamma' = \gamma - \gamma_w \left[1 - \left(\frac{D_w - D}{B}\right)\right]$$

→ *Case 3: $D + B \leq D$ (water table is lower than the lower limit of the zone of influence).*

In this case, no groundwater correction is necessary and the effective unit weight γ' of the soil is taken as the dry unit weight γ:

$$\gamma' = \gamma$$



2.6. Soil unit weight (dry) and *soil unit weight (saturated)* (kN/m^3 or lb/ft^3): These are the average unit weights of the soil under consideration. At present, the program only supports calculation of bearing capacity in soils constituted of a single homogeneous layer.

> The saturated unit weight is only required for calculations pertaining to groundwater case 1. In cases 2 and 3, enter the dry unit weight and leave the saturated unit weight as zero. A very deep water table can be simulated by entering a very large number in the groundwater depth field.

2.7. Footing base inclination (degrees): This is the inclination of the footing base relatively to the horizontal.

2.8. Applied normal load (kN or lb): This is the intensity of the load component that acts perpendicularly to the base of the footing.

2.9. Applied shear load (kN or lb): This is the intensity of the load component that acts parallel to the base of the footing.

> In Vesić's model, applied normal and shear loads affect bearing capacity only through the load inclination factors, which can be unrealistic and requires careful judgment on part of the engineer.

2.10. Ground surface inclination (degrees): This is the declivity of the nearby slope relatively to the horizontal.

2.11. Modulus of elasticity (kN/m^2 or lb/ft^2): This is Young's modulus for the soil layer in which the footing is constructed. This quantity is used solely to compute the shear modulus G_s, which is related to Young's modulus (E) and Poisson's ratio (μ) by the elasticity-theory equation

$$G_s = \frac{E}{2(1+\mu)}$$

2.12. Poisson's ratio (dimensionless): Poisson's ratio is approximately equal to 0.3 for most soils and has no use in the program besides calculating the shear modulus G_s.

2.13. Shear modulus (kN/m² or lb/ft²): This mechanical parameter is used to compute Vesić's soil compressibility factors. By default, the shear modulus is calculated from Young's modulus and Poisson's ratio using the relationship shown in 2.11; entering a shear modulus will override this calculation.

2.14. Factor of safety (dimensionless): Dividing the nominal bearing capacity by the factor of safety yields the allowable bearing capacity. Likewise, dividing the gross axial load by the factor of safety gives the gross allowable load.

■ 3. Data Output

3.1. Nominal bearing capacity (kN/m² or ksf): As mentioned in Section 1, the nominal bearing capacity q_n is determined with Vesić's bearing capacity equation.

3.2. Gross axial load (kN or kip): The gross axial load is obtained by multiplying the nominal bearing capacity by the base area of the footing:

$$Q_n = q_n \times (B \times L)$$

3.3. Allowable bearing capacity (kN/m² or ksf): The allowable bearing capacity is obtained by dividing the nominal bearing capacity by the factor of safety:

$$q_{\text{all}} = \frac{q_n}{\text{FS}}$$

3.4. Gross allowable load (kN or kip): The gross allowable load is obtained by dividing the gross axial load by the factor of safety:

$$Q_{\text{all}} = \frac{Q_n}{\text{FS}}$$

3.5. Multiplying factors: As shown in Section 1, Vesić's bearing capacity equation incorporates seven sets of factors that account for several phenomena.

3.5.1. Vesić's bearing capacity factors

Vesić's bearing capacity factors are functions of the friction angle ϕ' only:

$$N_q = e^{\pi \tan\phi'} \tan^2\left(45^\circ + \frac{\phi'}{2}\right)$$

$$N_c = \frac{N_q - 1}{\tan\phi'} \;\left(\text{for } \phi' > 0\right)$$

$$N_c = 5.14 \;\left(\text{for } \phi' = 0\right)$$

$$N_\gamma = 2\left(N_q + 1\right)\tan\phi'$$

3.5.2. Shape factors

Shape factors reflect the influence of footing shape on bearing capacity estimates. The factors are given by

$$s_c = 1 + \frac{B}{L}\left(\frac{N_q}{N_c}\right)$$

$$s_q = 1 + \left(\frac{B}{L}\right)\tan\phi'$$

$$s_\gamma = 1 - 0.4\left(\frac{B}{L}\right)$$

where B is footing width and L is footing length.

3.5.3. Depth factors

Depth factors reflect the influence of footing depth on bearing capacity estimates. The equations to use depend on footing depth-to-width ratio and friction angle:

$D/B \leq 1$	
ϕ = 0	**ϕ' > 0**
$d_c = 1 + 0.4\left(\frac{D}{B}\right)$ $d_q = d_\gamma = 1.0$	$d_c = d_q - \frac{1 - d_q}{N_c \tan\phi'}$ $d_q = 1 + 2\tan\phi'\left(1 - \sin\phi'\right)^2\left(\frac{D}{B}\right)$ $d_\gamma = 1.0$
$D/B > 1$	
ϕ = 0	**ϕ' > 0**
$d_c = 1 + 0.4\underbrace{\tan^{-1}\left(\frac{D}{B}\right)}_{\text{radians}}$ $d_q = d_\gamma = 1.0$	$d_c = d_q - \frac{1 - d_q}{N_c \tan\phi'}$

	$$d_q = 1 + 2\tan\phi'(1-\sin\phi')^2 \underbrace{\tan^{-1}\left(\frac{D}{B}\right)}_{\text{radians}}$$ $$d_\gamma = 1.0$$

3.5.4. Load inclination factors

Load inclination factors account for the application of loads that do not act perpendicular to the base of the footing, but still act through its centroid; the latter observation implies that loads must not be eccentric, as Vesić did not consider eccentricity in his model. The equations to use are

$$i_c = 1 - \frac{mV}{Ac'N_c} \geq 0$$

$$i_q = \left(1 - \frac{V}{P + \dfrac{Ac'}{\tan\phi'}}\right)^m \geq 0$$

$$i_\gamma = \left(1 - \frac{V}{P + \dfrac{Ac'}{\tan\phi'}}\right)^{m+1} \geq 0$$

For loads inclined in the *B* direction, exponent *m* is stated as

$$m = \frac{2 + B/L}{1 + B/L}$$

For loads inclined in the *L* direction, exponent *m* is stated as

$$m = \frac{2 + L/B}{1 + L/B}$$

where *V* is the applied shear load, *P* is the applied normal load, $A = B \times L$ is the base area of the footing, *c'* is effective cohesion (or undrained shear strength in total stress analyses), and ϕ' is drained friction angle (or undrained friction angle in total stress analyses).

3.5.5. Base inclination factors

Base inclination factors consider the effect of footing base inclination on bearing capacity estimates. The factors are given by

$$b_c = 1 - \frac{\alpha}{147^\circ}$$

$$b_q = b_\gamma = \left(1 - \frac{\alpha \tan \phi'}{57^\circ}\right)^2$$

where α is the angle (degrees) that the base of the footing makes with the horizontal. If the base of the footing is level, all of the *b* factors become equal to 1 and may be ignored.

3.5.6. Ground inclination factors

Footings near the top of a slope have a lower bearing capacity than those on level ground, and Vesić's *g* factors quantify this reduction. The factors are given by

$$g_c = 1 - \frac{\beta}{147^\circ}$$

$$g_q = g_\gamma = \left(1 - \tan \beta\right)^2$$

where β is the angle (degrees) that the slope makes with the horizontal. If the ground surface is level, all of the *g* factors become equal to 1 and may be ignored.

3.5.7. Vesić's soil compressibility factors

Vesić proposed three additional factors to take into account the change of failure mode in soil (i.e., local shear failure). The change of failure mode is due to soil compressibility, and has been incorporated into factors v_c, v_q, and v_γ, each of which can be determined in three steps:

Step 1. Calculate the *rigidity index*, I_r, of the soil at a depth approximately $B/2$ below the foundation, or

$$I_r = \frac{G_s}{c' + q' \tan \phi'}$$

where G_s is the shear modulus of the soil, c' is effective cohesion, ϕ' is drained friction angle, and q' is the effective overburden pressure at a depth of $D + B/2$. The shear modulus can be entered directly into the program or calculated from the modulus of elasticity (E) and Poisson's ratio (μ) using the relationship

$$G_s = \frac{E}{2(1+\mu)}$$

Step 2. Compute the critical rigidity index, $I_{r(cr)}$, which is expressed as

$$I_{r(\mathrm{cr})} = \frac{1}{2}\left\{\exp\left[\left(3.30 - 0.45\frac{B}{L}\right)\cot\left(45^{\circ} - \frac{\phi'}{2}\right)\right]\right\}$$

Step 3. If $I_r \geq I_{r(\mathrm{cr})}$, then

$$v_c = v_q = v_\gamma = 1$$

However, if $I_r < I_{r(\mathrm{cr})}$, then

$$v_q = v_\gamma = \exp\left\{\left(-4.4 + 0.6\frac{B}{L}\right)\tan\phi' + \frac{(3.07\sin\phi')\left[\log_{10}(2I_r)\right]}{1+\sin\phi'}\right\}$$

For $\phi = 0$,

$$v_c = 0.32 + 0.12\left(\frac{B}{L}\right) + 0.60\log_{10}(I_r)$$

For $\phi' > 0$,

$$v_c = v_q - \frac{1 - v_q}{N_q \tan\phi'}$$

5. References

→ CODUTO, D.P., KITCH, W.A. and YEUNG, M.R. (2016). *Foundation Design: Principles and Practices.* 3rd edition. Upper Saddle River: Pearson.

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