Shallow Foundation Soil Bearing Capacity Calculator

Foundations are commonly used to transfer structural loads into the ground below a structure and are critical to stability in the long term. However, the ability of the soil to safely support them is dictated by their ultimate bearing capacity. This is the physical maximum pressure between the foundation and soil that can be applied without triggering a shear failure, potentially causing excessive settlement or failing the entire foundation system. The capacity is influenced by various parameters including the soil type, foundation shape and depth, groundwater conditions, and the load application. This is based on Terzaghi's method, which is quite simple and limited in applications and accuracy (Smith, 2014). Various modifications can be made, leading to Eq 1 below; a simplified version from Eurocode 7 (Smith, 2014). The equation consists of three terms that represent different contributing factors, accounting for soil cohesion, overburden and soil weight in their respective order.

$$q_u = c' N_c \, s_c + q' N_q \, s_q + 0.5 \, \gamma' \, B' \, N_\gamma \, s_\gamma \tag{1}$$

Where,

- q_u = ultimate soil bearing capacity (kN/m^2)
- c' = soil effective cohesion (kN/m^2)
- q' = effective overburden pressure at the base level (kN/m^2)
- γ' = average effective unit weight of soil below base (kN/m^2)
- B'= effective foundation width (m)
- N_c, N_q, N_γ = bearing resistance factors for cohesion, overburden and weight respectively
- s_c, s_q, s_γ = shape factors for cohesion, overburden and weight respectively

The effective soil cohesion is often a provided soil property and requires no altercations, whereas the effective overburden pressure and unit weight heavily vary with the presence of a groundwater table, and its location relative to the foundation base. There are four potential scenarios; no water; the water above; the water below but still relevant to the failure envelope; and the water significantly below such that it is irrelevant. Figure 3 shows a general shear failure envelope, in the case that a groundwater table is present underneath the footing.

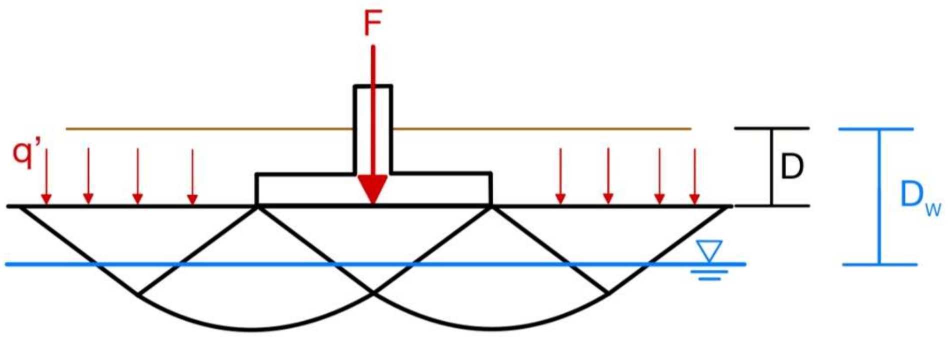

Figure 1 General Shear Failure Envelope with Groundwater Table Below

If groundwater is present, its relative position is trivial to find by comparing the depth of the foundation and water table, where the larger of the two is the lowest. If the difference between these is greater than the foundation width, as represented in Eq 2, water has a negligible influence on the failure envelope and can be ignored.

$$D_w - D > B \tag{2}$$

Where,

- D = Foundation depth (m)
- D_w = Groundwater table (m)
- B = Foundation width (m)

If there is no significant groundwater then the effective unit weight is just equal to the unit weight, under the soil's typical conditions, so,

$$\gamma' = \gamma \tag{3}$$

Where,

- γ = Soil unit weight (kN/m^2)

The effective overburden pressure can then be found as,

$$q' = \gamma D \tag{4}$$

If the water is above or level with the footing, then the effective unit weight is equivalent to the weight per unit volume after including buoyant forces (Baban, 2016).

$$\gamma_b = \gamma_{sat} - 9.81 \tag{5}$$

$$\gamma' = \gamma_b \tag{6}$$

Where,

- γ_{sat} = Saturated unit weight (kN/m^2)
- γ_b = Buoyant unit weight (kN/m^2)

The effective overburden pressure is then a summation of the effective soil weight from the saturated and non-saturated, shown in Eq 7.

$$q' = \gamma D_w + \gamma_b (D - D_w) \tag{7}$$

Lastly, if the water is below, the effective overburden pressure is still calculated using Eq 3, but the effective unit weight is a weighted average, between the saturated and non-saturated soils and their depths (Baban, 2016).

$$\gamma' = \gamma_b + \frac{D_w - D}{D_w}(\gamma - \gamma_b) \tag{8}$$

Moving on to the other parameters, for the bearing resistance factors to be calculated, the effective friction angle is used, however, it is dependent on the type of failure we expect. In the case of a general shear failure, it can be left unchanged, however, if local or puncturing shear is a risk, then it should be reduced, using the equation below. This is when the failure envelope shown in Figure 3, does not fully develop so failure occurs earlier.

$$\phi'_{LSF} = \tan^{-1}\left(\frac{2}{3}\tan\left(\phi'_{GSF}\right)\right) \tag{9}$$

Where,

- ϕ'_{GSF} = effective friction angle for general shear (rad)
- ϕ'_{LSF} = effective friction angle for local or puncturing shear (rad)

Now, the bearing resistance factors can be found using the chosen angle.

$$N_q = e^{\pi \tan\phi'} \tan^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) \tag{10}$$

$$N_c = \left(N_q - 1\right)\cot\phi' \tag{11}$$

$$N_\gamma = 2\left(N_q - 1\right)\tan\phi' \tag{12}$$

Where,

- ϕ' = effective friction angle for the relevant shear failure (rad)

A column carries the load from the structure and directs it to a footing or pad foundation, and in turn, the earth. Since the column is not always connected to the centre of the footing, the influence of any eccentricity must be accounted for. This is done by calculating and using effective dimensions for the foundation, in the equations below.

$$B' = B - 2e_b \tag{13}$$

$$L' = L - 2e_l \tag{14}$$

Where,

- B' = Effective foundation width (m)
- L' = Effective foundation length (m)
- B = Foundation width (m)
- L = Foundation length (m)
- e_b = eccentricity in the direction of B (m)
- e_l = eccentricity in the direction of L (m)

It is important to note that the eccentricities are measured from the centrelines, then their effects can then be incorporated into the shape factors, shown below (European Committee for Standardization [CEN], 2004b), but the formula for calculating them relies on the foundation shape.

Irrespective of shape,

$$s_c = \frac{s_q N_q - 1}{N_q - 1} \tag{15}$$

For rectangular footings,

$$s_q = 1 + \frac{B'}{L'}\sin\phi' \tag{16}$$

$$s_\gamma = 1 - 0.3\frac{B'}{L'} \tag{17}$$

For square or circular footings,

$$s_q = 1 + \sin\phi' \tag{18}$$

$$s_\gamma = 0.7 \tag{19}$$

Now, the ultimate soil-bearing capacity can be found using Eq 1.

$$q_u = c'N_c\, s_c + q'N_q\, s_q + 0.5\,\gamma'\,B'\,N_\gamma\, s_\gamma \tag{1}$$

The ultimate capacity, however, is focused on the physical capabilities of the soil, just on the verge of failure. This is dangerous, especially in the face of uncertainty and variation found in soil properties and construction. For further safety, it can be modified into an allowable bearing capacity through the application of a safety factor, to be used for design calculations.

$$q_a = \frac{q_u}{FoS} \tag{20}$$

Assumptions and Limitations

Summary of Key Assumptions and Limitations:

- Single, vertical, static load
- Footing is shallow, rigid, and level
- Only rectangular, square, or circular footings
- Single soil layer is drained, homogeneous, and isotropic
- Only general, local, or puncturing shear failure is considered

The allowable bearing capacity calculations implemented, particularly in Eq 1, are a simplified form of what is found in Eurocode 7. As shown below, the complete equation contains various other factors, all of which increase the complexity of calculations and their exclusion limits the applicability of the tool.

$$q_u = c'N_c\, s_c\, b_c\, i_c + q'N_q\, s_q\, b_q\, i_q + 0.5\,\gamma'\,B'\,N_\gamma\, s_\gamma b_c\, i_c$$

The foundation is assumed only to be connected to a single loading column, where the load is applied vertically, from the column centre. This removes any influence on the soil from inclined or horizontal loads, which would skew the failure envelope in their direction and reduce the soil’s bearing capacity. Additionally, the foundation base is assumed to be level and horizontal, so no tilt in the ground surface or footing is included. Eurocodes, however, incorporate these through load inclination factors, and base inclination factors, for cohesion, overburden and weight, i_c, i_q and i_γ, for load inclination, and b_c, b_q and b_γ for the base.

This method is only applicable to shallow, rigid foundations, and to a set number of shapes. As a rigid body, the pressure can be taken to be uniformly distributed, as well as soil settlement. The shape factor equations, particularly Eq 16 to 19, are only valid for square, rectangular, and circular footings, limiting the method's applicability to more complex geometries.

This method is for soils under drained conditions, making it suitable for granular soils, like sand, and not finer ones, or undrained conditions, like clay. Another key assumption is that the soil beneath the footing is considered deep, homogenous and isotropic, only composed of a single soil type. Properties are assumed to be consistent with depth, so values for unit weight, saturated unit weight, cohesion, and friction angle are the same at any point in the soil. It also assumes that the single soil type extends indefinitely below the footing, with no other layers. This means the effects of layered soil profiles, impermeable rock, or soil variation will not be captured with this method. If present, the groundwater table is assumed to be steady at the given depth, but seasonal and weather changes, impacting the effective stresses and bearing capacity, are not accounted for.

This method only considers general, local, or puncturing shear failures and does not address any settlement related failure modes, making it unsuitable for serviceability limit states. Furthermore, loads are assumed to be purely static, with no dynamic effects and no seismic activity accounted for.

References

European Committee for Standardization (CEN). (2004b). *Eurocode 7: Geotechnical design - Part 1: General rules.* EN 1997-1. Brussels. European Committee for Standardization.

Smith, I. (2014). *Smith's Elements of Soil Mechanics*. Wiley.