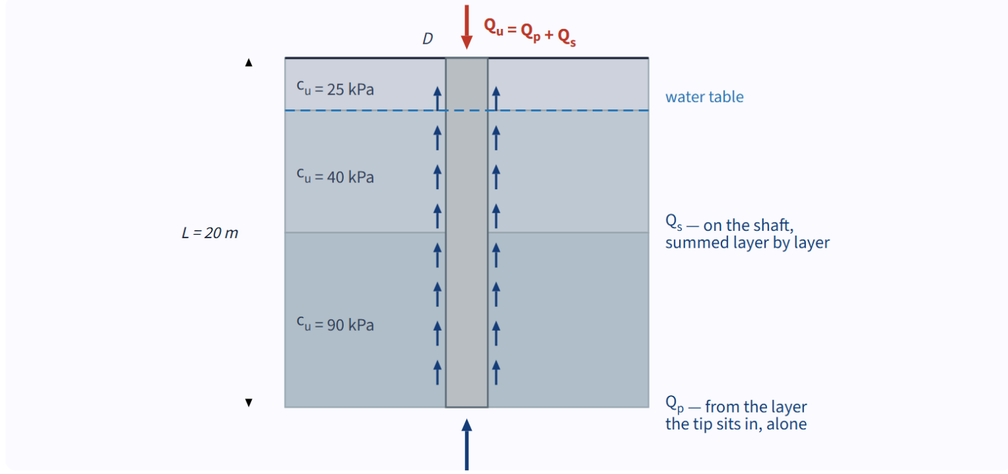
Geotechnical lecture presentation · Piles

Pile bearing capacity in clay

Lecture: undrained end bearing, shaft friction by the α, λ and β methods, bored pile. The theory of each method, followed by a worked example.

Meyerhof · Vesic | α · λ · β methods | Bored pile | Worked examples



Based on the GeoTerva Theory page · geoterva.com

What will we learn in this lecture?

- To be able to explain why clay is treated as **undrained** ($\varphi = 0$) and where effective stress still comes into play
- To be able to calculate the **tip resistance** by two methods: Meyerhof ($N^*_c = 9$) and Vesic (rigidity)
- To be able to calculate the shaft friction with **three approaches**: α, λ and β
- To be able to apply the special rules of the **bored pile**: $\alpha^* = 0$ in both lengths, its own base expression
- To reach the **allowable bearing capacity** and interpret the results of the approaches together

LECTURE FLOW

Each method is covered in **three steps**:

1 · **Theory**: how does the method work, why so?

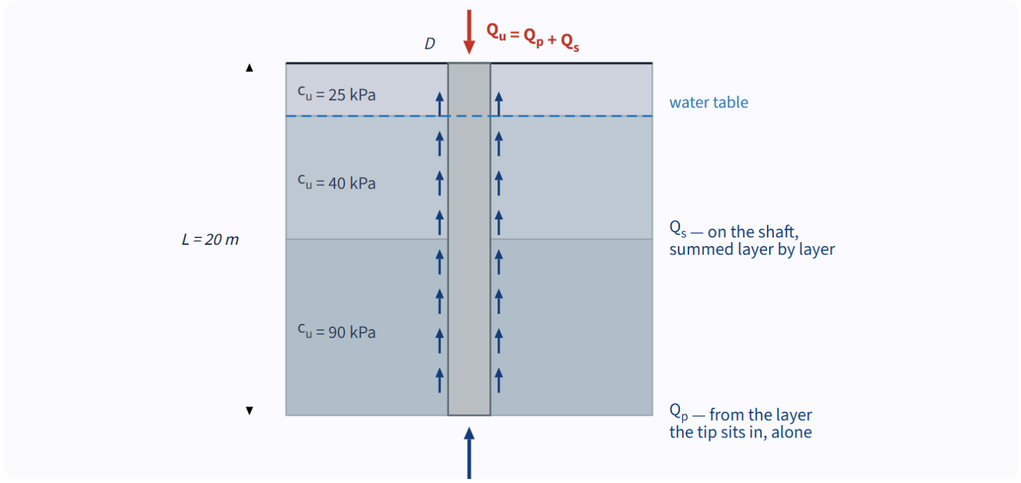
2 · **Problem statement**: given and required

3 · **Solution**: step by step, with numbers

Most of the examples use the same pile: a pipe pile 20 m long passing through three clay layers.

The load is transferred in two ways

THEORY



The pile transfers its load to the soil **by two paths at once**: the clay beneath the tip resists as a deep foundation with **end resistance** (Q_p), and the clay along the shaft resists with **adhesion** (Q_s).

$$Q_u = Q_p + Q_s \qquad Q_{all} = \frac{Q_u}{FS}$$

In clay the **shaft resistance** is summed layer by layer; the **tip resistance** comes only from the layer in which the tip is located.

In a typical profile, the tip is a very small part of the total: in the example pile about **one-ninth**; the shaft about eight-ninths. The uncertainty lies mainly in the shaft.

In this lecture: **single pile**, clay, driven or bored, constant section.

Why is clay treated with φ = 0?

THEORY

In saturated clay the structural load arrives **much faster** than the water can drain; the clay is sheared **without a change in volume**. In this case the strength is a single number: the **undrained shear strength** c_u, and the friction angle is zero.

$$\varphi = 0 \qquad \tau_f = c_u$$

Major difference from sand: the resistance no longer increases in proportion to effective stress. A pile in clay is not "a pile in sand with different numbers".

Nevertheless, **two methods** use effective stress: the λ method (its average along the length) and the β method (relies entirely on it). Therefore the **GWT** matters here too; it does not affect the end bearing or the α method.

EFFECTIVE STRESS (FOR λ AND β)

$$\sigma' = \sum \gamma_i h_i \qquad \text{(above GWT)}$$
$$\sigma' = \sum (\gamma_{sat,i} - \gamma_w) h_i \qquad \text{(below GWT)}$$

γ_w = 9.81 kN/m³

In layered soil the slope of σ′ changes in each layer and at the GWT

Problem statement

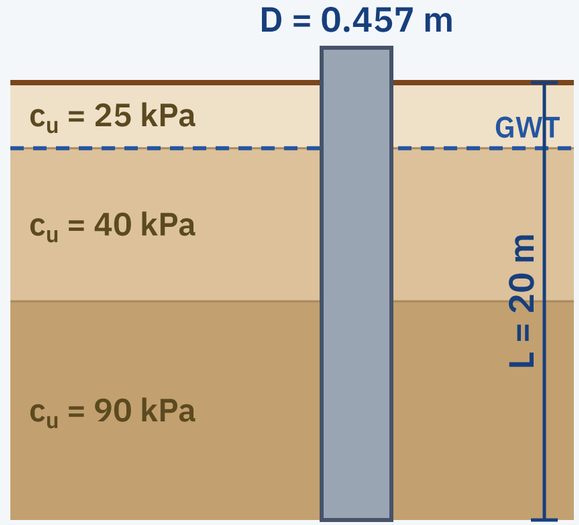
EXAMPLE

Given

Clay 1 (0–3 m)	$c_u = 25\ \mathrm{kPa},\ \gamma = 16\ \mathrm{kN/m^3}$
Clay 2 (3–10 m)	$c_u = 40\ \mathrm{kPa},\ \gamma = 17\ \mathrm{kN/m^3}$
Clay 3 (10–20 m)	$c_u = 90\ \mathrm{kPa},\ \gamma = 18\ \mathrm{kN/m^3}$
Groundwater (GWT)	**at 3.0 m depth**
Pile	**pipe pile, D = 0.457 m, L = 20 m**
Unit weight of water	$\gamma_w = 9.81\ \mathrm{kN/m^3}$

REQUIRED

At the layer boundaries (3, 10 and 20 m) find the **effective vertical stress** and along the rod the **average effective stress** σ'_0.



Solution (1/2)

SOLUTION

1 3 m (GWT) and layer boundaries: below the GWT, $\gamma' = \gamma - \gamma_w$

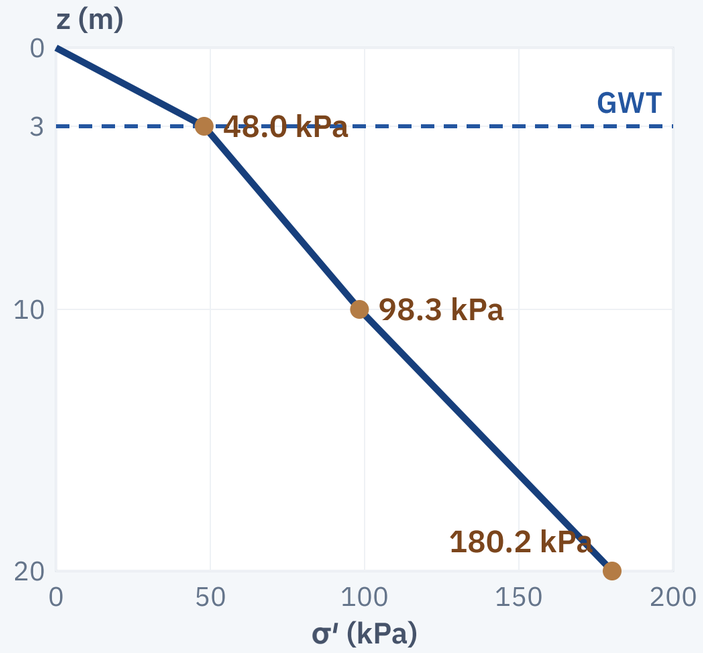
$$\sigma'(3) = 16(3) = \mathbf{48.0}\ \mathrm{kPa}$$

2 10 m depth (end of the second layer)

$$\sigma'(10) = 48.0 + (17 - 9.81)(7) = \mathbf{98.3}\ \mathrm{kPa}$$

3 20 m depth (pile tip)

$$\sigma'(20) = 98.3 + (18 - 9.81)(10) = \mathbf{180.2}\ \mathrm{kPa}$$



Solution (2/2)

SOLUTION

4 Area of the σ′ diagram in each layer (trapezoid)

$$A_1 = \tfrac{1}{2}(0 + 48.0)(3) = 72.0$$
$$A_2 = \tfrac{1}{2}(48.0 + 98.3)(7) = 512.2$$
$$A_3 = \tfrac{1}{2}(98.3 + 180.2)(10) = 1{,}392.8$$

5 Average effective stress: total area / length

$$\bar{\sigma}'_o = \frac{A_1 + A_2 + A_3}{L} = \frac{1{,}977.0}{20} = \mathbf{98.85}\ \mathrm{kPa}$$

The average is smaller than half the value at the end (98.8 < 90.1): the stress does not increase linearly with depth; the slope changes at the GWT. This σ̄′ₒ value will be used in the λ method.

Check the solution in GeoTerva ↗

End bearing: clay below the pile tip

THEORY

In undrained saturated clay the friction angle is zero; the **net ultimate end bearing** of the pile is the product of the undrained cohesion of the clay below the tip and a coefficient:

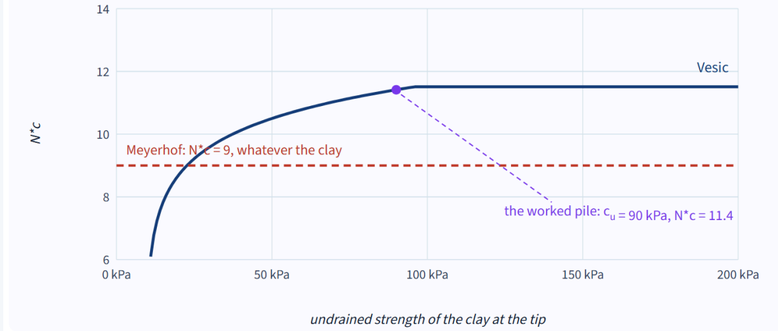
$$Q_p = A_p\, q_p = A_p\, c_u\, N_c^*$$

c_u : undrained shear strength of the clay **below the tip**

N^*_c : bearing capacity factor (two approaches below)

A_p : area of the pile tip

> The strength of the clay that the pile **passes through** does not act on the tip: that strength belongs to the shaft.



Two approaches: Meyerhof takes the coefficient as **9**; Vesic relates the coefficient to the **rigidity** of the clay.

Meyerhof: constant nine

THEORY

In saturated clay, under undrained conditions, the net ultimate load in Meyerhof form is given by the **classic nine coefficients**:

$$Q_p \approx N_c^* \, c_u \, A_p = 9 \, c_u \, A_p$$

c_u : undrained cohesion of the soil below the pile tip

Requires no other input; as long as the pile is deep (a few diameters suffice) it does not depend on depth.

Simplicity is its strength; its weakness is the same: it does not account for the stiffness of the clay.

The end resistance is small relative to the shaft, so it affects the total capacity very little; therefore a simple value is often sufficient.

Problem statement

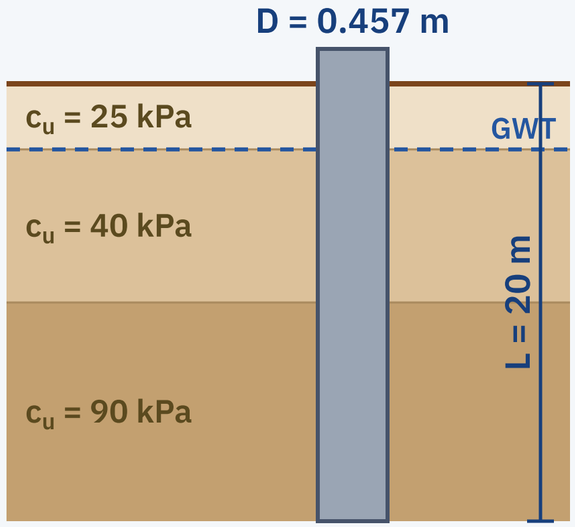
EXAMPLE

Given

Pile	**pipe pile, driven**
Diameter	**D = 0.457 m**
Length	**L = 20 m**
Clay below the tip	$c_u = 90\ \mathrm{kPa}$

REQUIRED

Determine the **tip resistance** Q_p of the pile by the **Meyerhof** method.



Solution

SOLUTION

1 Area of the pile tip

$$A_p = \frac{\pi D^2}{4} = \frac{\pi (0.457)^2}{4} = \mathbf{0.1640}\ \mathrm{m^2}$$

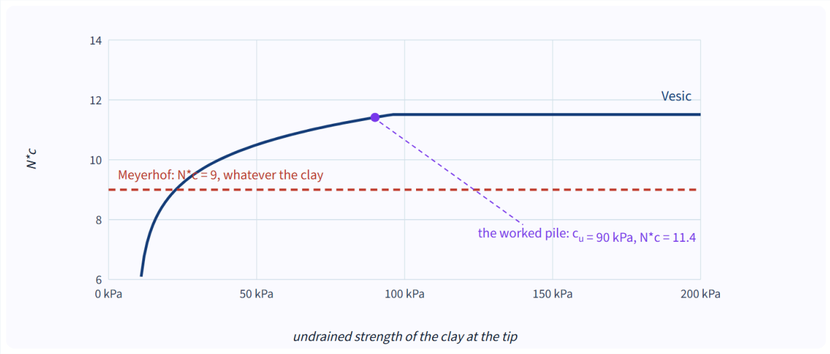
2 Unit end resistance (N*c = 9)

$$q_p = 9\, c_u = 9(90) = \mathbf{810}\ \mathrm{kPa}$$

3 Tip resistance

$$Q_p = A_p\, q_p = 0.1640(810) = \mathbf{132.9}\ \mathrm{kN}$$

The method required no other input: only c_u below the tip. Q_p = **132.9 kN**.



Check the solution in GeoTerva ↗

Vesic: stiffness enters N*c

THEORY

Vesic, from **cavity expansion** theory: the coefficient for the φ = 0 case is derived from the reduced rigidity index of the clay. In saturated clay the volume change in the plastic zone is zero; the reduction drops out and **$I_{rr} = I_r$**:

$$N_c^* = \frac{4}{3}\left(\ln I_{rr} + 1\right) + \frac{\pi}{2} + 1 \qquad I_r = \frac{E_s}{3\,c_u}$$

SINGLE INPUT: c_u below the tip

O'Neill and Reese (1999): $I_r \approx 50$ ($c_u/p_a = 0.24$), 150 (0.48), 250 – 300 (≥ 0.96). The module approximates this as follows:

$$I_r = 347\,\frac{c_u}{p_a} - 33 \;\le\; 300$$

N^*_c — I_{rr} RELATIONSHIP

I_{rr}	N^*_c
10	6.97
20	7.90
40	8.82
60	9.36
80	9.75
100	10.04
200	10.97
300	11.51

As I_{rr} increases the coefficient rises slowly: logarithm

Problem statement

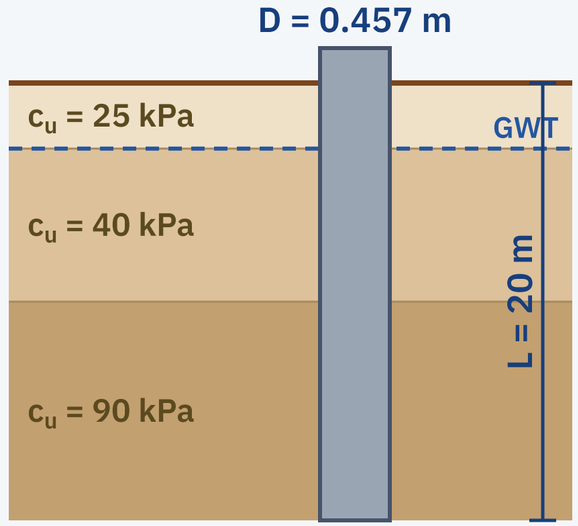
EXAMPLE

Given

Pile	**Same as Example 2: D = 0.457 m, L = 20 m**
Clay below the tip	$c_u = 90\ \text{kPa}$
Atmospheric pressure	$p_a = 100\ \text{kPa}$

REQUIRED

Using the **Vesic (1977)** method, find the **end resistance** Q_p of the pile and compare it with Meyerhof.



Solution (1/2)

SOLUTION

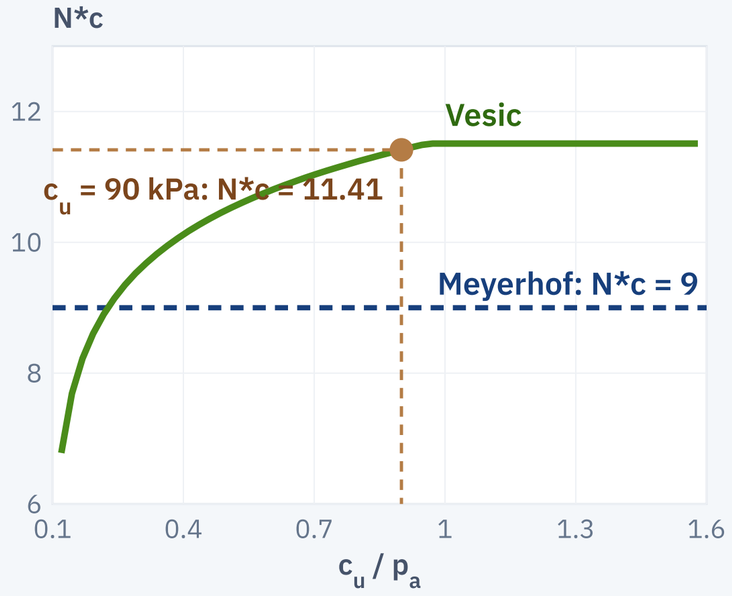
1 Rigidity index ($I_{rr} = I_r$, since there is no volume change in clay)

$$I_{rr} = I_r = 347\,\frac{90}{100} - 33 = \mathbf{279.3} \quad (\leq 300)$$

2 N*c coefficient

$$N_c^* = \frac{4}{3}\,(\ln 279.3 + 1) + \frac{\pi}{2} + 1 = \mathbf{11.41}$$

The green curve in the figure is Vesic's factor: for c_u = 90 kPa, **N^*_c = 11.41**, about 27% more than Meyerhof's 9.



Solution (2/2)

SOLUTION

3 Unit end bearing

$$q_p = c_u\, N_c^* = 90(11.41) = \mathbf{1{,}027}\ \mathrm{kPa}$$

4 Tip resistance

$$Q_p = A_p\, q_p = 0.1640(1{,}027) = \mathbf{168.5}\ \mathrm{kN}$$

Meyerhof: 132.9 kN, **Vesic: 168.5 kN**; the difference is about 27%. Since the tip is a small part of the total, this difference shifts the total capacity very little.

Check the solution in GeoTerva ↗

Shaft friction: where the capacity is mainly determined

THEORY

In clay the shaft resistance is the sum of unit friction over the shaft surface:

$$Q_s = \sum f\, p\, \Delta L$$

Many of the variables that determine unit friction cannot be measured easily; therefore there are **three approaches**:

α method: friction from **undrained strength** only (total stress, short term)

λ method: a combination of the **average effective stress** along the length with the average strength; a single coefficient for the whole pile

β method: **effective stress** and consolidated friction angle (drained, long term)

In the example pile, the shaft carries about **nine-tenths** of the total; the uncertainty lies here as well.

α: a fraction of the strength

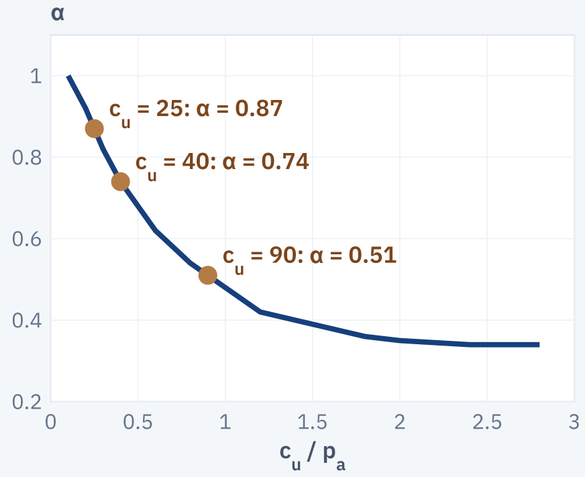
THEORY

Unit friction is the undrained strength multiplied by an **empirical adhesion factor α**:

$$f = \alpha\, c_u \qquad Q_s = \sum \alpha\, c_u\, p\, \Delta L$$

α : adhesion factor; it **decreases** as the clay becomes stronger (a stronger clay mobilizes a smaller fraction of its strength)
α is in fact a function of **effective stress** as well as c_u (Sladen, Randolph–Murphy/API, NGI-99 recommendations)

> This module interpolates the **table (c_u/p_a – α)** shown alongside; the α of the layer can also be entered manually.



α TABLE (SUMMARY)

c_u / p_a	α

Problem statement

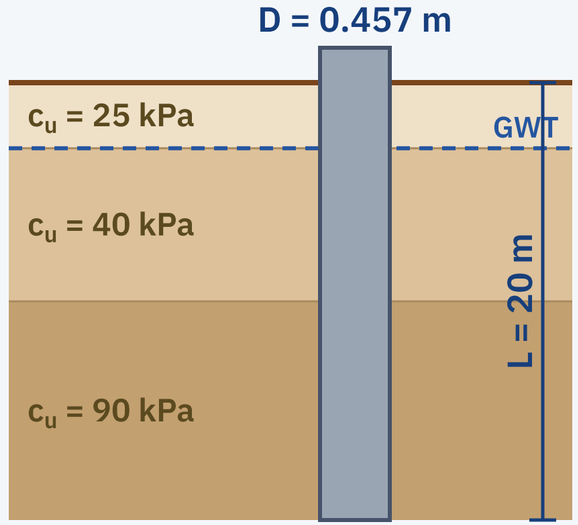
EXAMPLE

Given

Clay 1 (0–3 m)	$c_u = 25\ \text{kPa},\ \gamma = 16\ \text{kN/m}^3$
Clay 2 (3–10 m)	$c_u = 40\ \text{kPa},\ \gamma = 17\ \text{kN/m}^3$
Clay 3 (10–20 m)	$c_u = 90\ \text{kPa},\ \gamma = 18\ \text{kN/m}^3$
Groundwater (GWT)	**at 3.0 m depth**
Pile	**pipe pile, D = 0.457 m, L = 20 m**
Perimeter	$p = \pi D = \pi(0.457) = 1.436\ \text{m}$

REQUIRED

Using the **α method**, find the pile's **shaft friction** Q_s. (α by linear interpolation from the table; p_a = 100 kPa)



Solution

SOLUTION

1 α values: for c_u/p_a = 0.25; 0.40; 0.90 from the table

$$\alpha_1 = 0.87,\ \alpha_2 = 0.74,\ \alpha_3 = 0.51$$

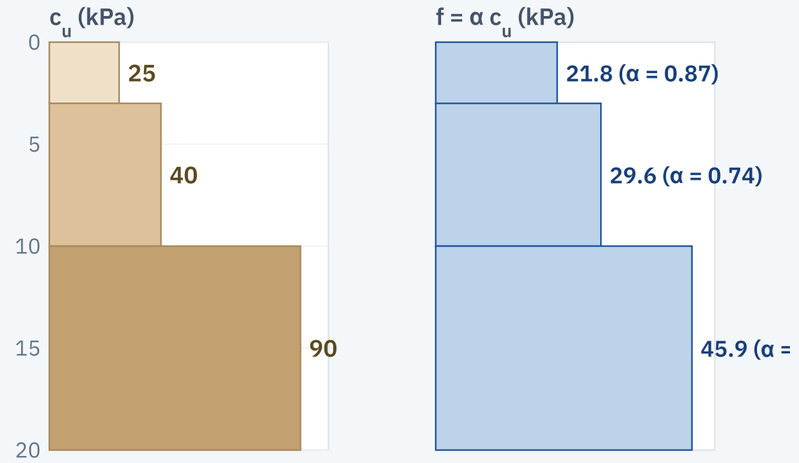
2 Unit friction in each layer $f = \alpha\, c_u$

$$f_1 = 21.8\ ,\ f_2 = 29.6\ ,\ f_3 = 45.9\ \text{kPa}$$

3 $Q_s = p\, \Sigma\, f\, H$

$$Q_s = 1.436\,[21.8(3) + 29.6(7) + 45.9(10)] = \mathbf{1{,}050}\ \text{kN}$$

Contributions: 94 + 297 + 659 = **1,050 kN**. The strongest clay gives the largest f, but with a smaller ratio of c_u (α = 0.51).



Check the solution in GeoTerva ↗

λ: a single average for the entire length

THEORY

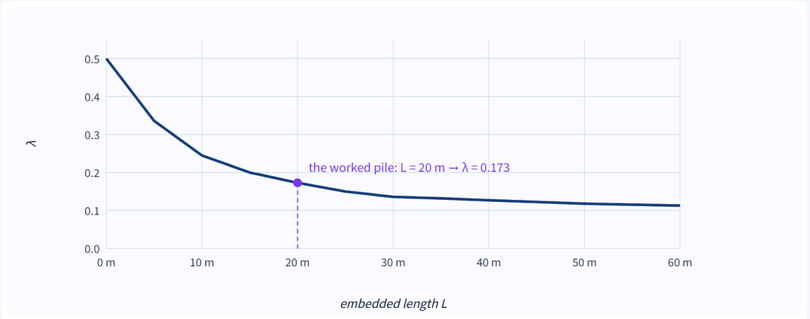
Vijayvergiya and Focht (1972): the **soil displaced** by the pile generates a passive lateral pressure at every depth, and the average unit friction follows from this:

$$f_{av} = \lambda\,(\bar{\sigma}'_o + 2\,\bar{c}_u) \qquad Q_s = p\,L\,f_{av}$$

$\bar{\sigma}'_o$: **average effective vertical stress** along the embedded length (area of the σ′ diagram / L)

$\bar{c}_u$: average undrained strength, **thickness-weighted**: $(c_{u1}L_1 + c_{u2}L_2 + \ldots)/L$

λ : coefficient depending on the pile **length** (at the side)



λ — EMBEDMENT LENGTH

L (m)	λ
0	0.500
5	0.336
10	0.245
15	0.200
20	0.173
30	0.136
40	0.127

Problem statement

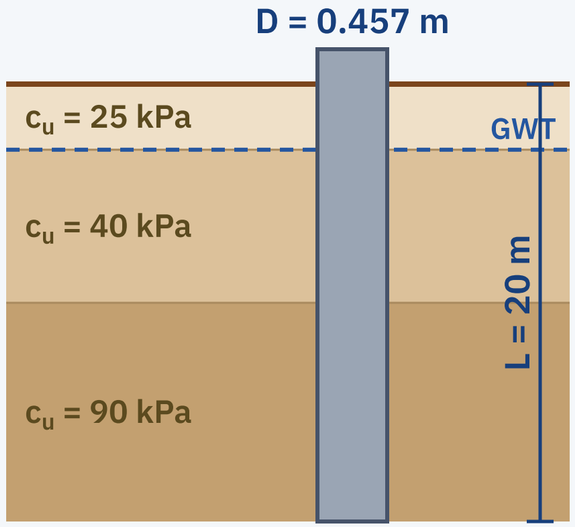
EXAMPLE

Given

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Clay 3 (10–20 m)	$c_u = 90\ \text{kPa},\ \gamma = 18\ \text{kN/m}^3$
Groundwater (GWT)	**at 3.0 m depth**
Pile	**pipe pile, D = 0.457 m, L = 20 m**
Average effective stress	$\bar{\sigma}'_o = 98.85\ \text{kPa}$ **(Example 1)**

REQUIRED

Using the **λ method**, find the **shaft friction** Q_s of the pile.



Solution

SOLUTION

1 Average strength (thickness-weighted)

$$\bar{c}_u = \frac{25(3) + 40(7) + 90(10)}{20} = \mathbf{62.75}\ \text{kPa}$$

2 λ (L = 20 m, from the table) and the average unit friction

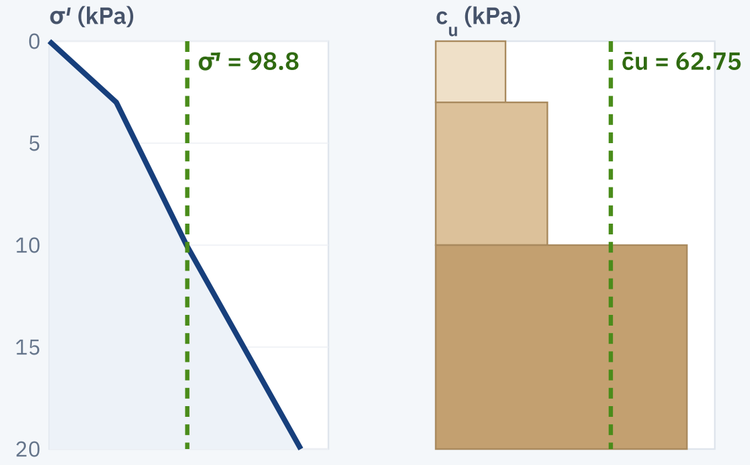
$$\lambda = 0.173$$

$$f_{av} = \lambda(\bar{\sigma}'_o + 2\bar{c}_u) = 0.173\,(98.85 + 2(62.75)) = \mathbf{38.81}\ \text{kPa}$$

3 Shaft friction

$$Q_s = p\,L\,f_{av} = 1.436(20)(38.81) = \mathbf{1{,}114}\ \text{kN}$$

The λ method combines the two averages: **1,114 kN**. In the figure, the area on the left is $\bar{\sigma}'_o$ and the line on the right is $\bar{c}_u$.



Check the solution in GeoTerva ↗

β: effective stress and remolded crust

THEORY

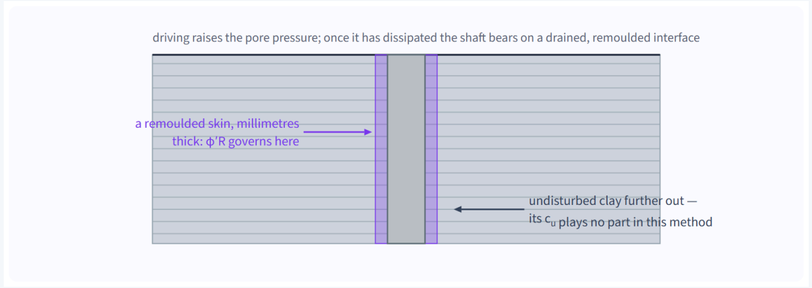
Burland's effective stress approach (with Meyerhof's overconsolidation correction): it does not consider undrained strength at all; it is derived from the **vertical effective stress** and the drained friction angle of the **remoulded** clay (c′ = 0):

$$f = \beta\,\sigma'(z) \qquad \beta = K\tan\delta,\quad \delta = \varphi'_R$$

$$\beta = (1-\sin\varphi'_R)\tan\varphi'_R\sqrt{OCR}$$

K : coefficient of lateral earth pressure; conservatively taken **at rest**, increases with √OCR for overconsolidated clay

For OCR = 1 the expression reduces by itself to the normally consolidated form



φ′R and OCR are **entered**, not read from the ground by correlation (in the module it opens with φ′R = 30°, OCR = 1).

f, together with σ′(z), **increases with depth** within the layer; it steps at the boundary where β changes.

Problem statement

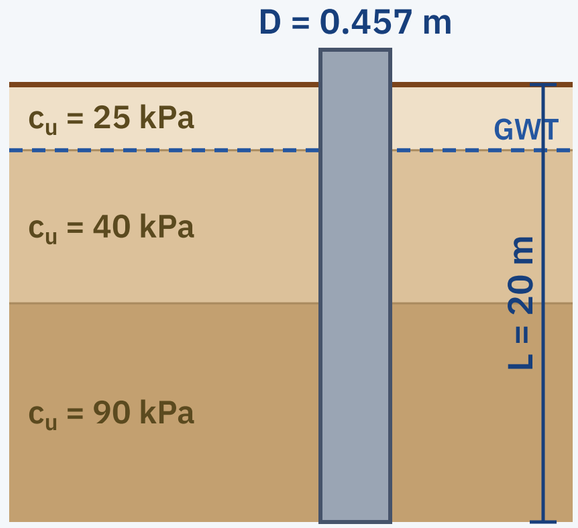
EXAMPLE

Given

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Clay 2 (3–10 m)	$c_u = 40\ \text{kPa},\ \gamma = 17\ \text{kN/m}^3$
Clay 3 (10–20 m)	$c_u = 90\ \text{kPa},\ \gamma = 18\ \text{kN/m}^3$
Groundwater (GWT)	**at 3.0 m depth**
Remolded friction angle	$\varphi'_R = 30^\circ$ **(three layers)**
Overconsolidation ratio	$OCR = 1;\ 1;\ 2$ **(layer 3 overconsolidated)**
Pile	**D = 0.457 m, L = 20 m**

REQUIRED

Using the **β method**, find the **shaft friction** Q_s of the pile. (Layer average σ′ values from the areas of Example 1.)



Solution (1/2)

SOLUTION

1 β coefficients

$$\beta_{1,2} = (1 - \sin 30^\circ)\tan 30^\circ = \mathbf{0.289} \qquad \beta_3 = 0.289\sqrt{2} = \mathbf{0.408}$$

2 Layer average effective stresses (area / thickness)

$$\bar{\sigma}'_1 = \frac{72}{3} = 24.0, \quad \bar{\sigma}'_2 = \frac{512.2}{7} = 73.2, \quad \bar{\sigma}'_3 = \frac{1{,}392.8}{10} = 139.3\ \text{kPa}$$

Solution (2/2)

SOLUTION

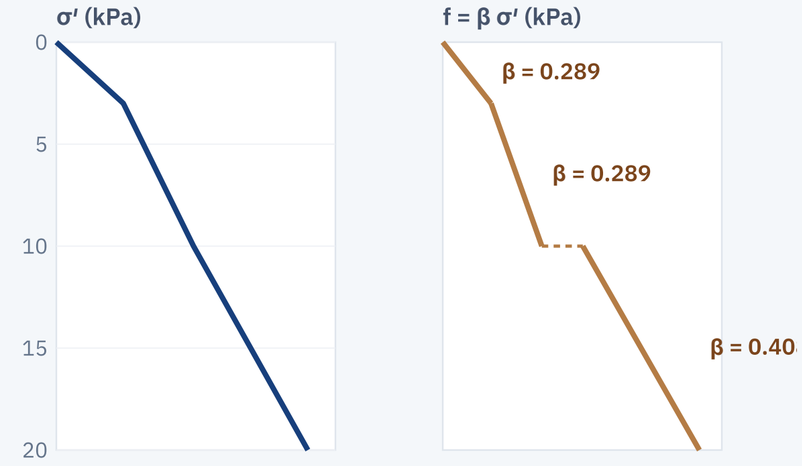
3 Average unit shaft friction of the layer $\bar{f} = \beta\,\bar{\sigma'}$

$$\bar{f}_1 = 6.93, \quad \bar{f}_2 = 21.12, \quad \bar{f}_3 = 56.86 \text{ kPa}$$

4 Shaft friction $Q_s = p\,\Sigma\,\bar{f}\,H$

$$Q_s = 1.436\,[6.93(3) + 21.12(7) + 56.86(10)] = \mathbf{1{,}058} \text{ kN}$$

The mean is the **true integral** of the stress in the layer (not the average of the two ends): if the GWT intersects the layer, the two can differ by more than 10%. The result is **1,058 kN**.



Check the solution in GeoTerva ↗

Three approaches, same pile

THEORY



In this profile the three are within **a few percent** of each other. But **in principle** they do not agree; the agreement is a property of this profile.

For a very **long** pile, λ decreases because of the coefficient

In **overconsolidated** clay, β increases with √OCR

In **soft** normally consolidated clay, α increases toward the full strength of the soil

An honest reading: in clay the shaft resistance is known with an uncertainty of about **one-fifth** of the calculated value. On large projects a **load test** is therefore worth its cost.

Bored piles have their own rules

THEORY

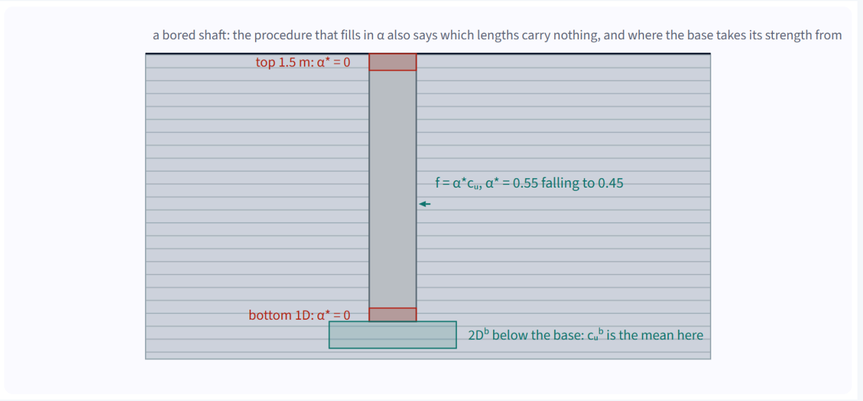
The hole is drilled and concrete is poured: the soil is not displaced; the clay on the borehole wall draws water and **softens**, debris collects beneath the base, and **larger settlement** is required to develop the base resistance. The O'Neill and Reese procedure modifies both halves.

$$\alpha^* = 0 \;\; (\text{top } 1.5 \text{ m and below } 1D) \qquad \alpha^* = 0.55 \;\; (\text{elsewhere})$$

α* = 0.55 ($c_u/p_a \le 1.5$), decreasing to 0.45 at 2.5

The top 1.5 m is the most disturbed soil, most prone to shrinking away from the shaft; the lower one diameter is the length over which the base already sets the soil in motion

Layer thicknesses do not change: depth and σ′ remain as in the profile, only the friction-bearing length changes



$$q_p = \min\left[6c_{ub}\left(1 + 0.2\frac{L}{D_b}\right),\; 9c_{ub},\; 40p_a\right]$$

c_{ub}: average c_u in the **2D$_b$** zone below the base. If D_b > 1.91 m, q_p is reduced by a factor $F_r \le 1$.

Problem statement

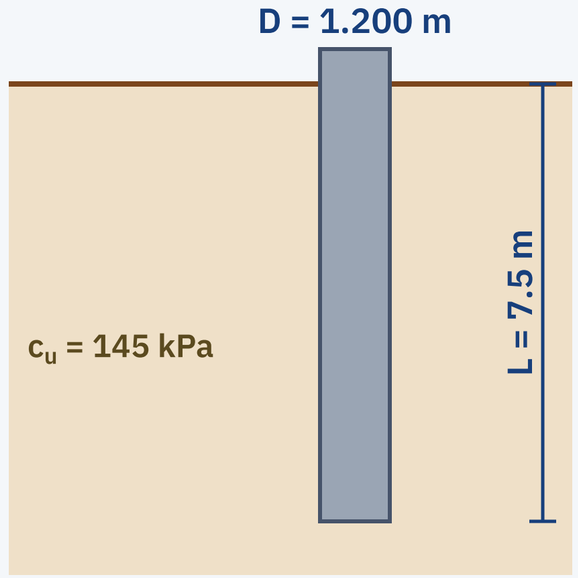
EXAMPLE

Given

Pile	**fore (bored) pile, circular section**
Diameter and length	**$D = D_b = 1.2$ m, $L = 7.5$ m**
Clay (homogeneous)	$c_u = 145$ kPa, $\gamma = 18$ kN/m^3
Groundwater	**none**
Factor of safety	**FS = 3**

REQUIRED

Find the **end bearing**, **shaft friction** and **allowable bearing capacity** of the bored pile.



Solution (1/2)

SOLUTION

1 Average strength in the $2D_b$ zone below the base and the base expression

$$c_{ub} = 145\ \text{kPa} \qquad 6c_{ub}\left(1 + 0.2\frac{7.5}{1.2}\right) = 1{,}957.5\ ; \quad 9c_{ub} = 1{,}305\ ; \quad 40p_a = 4\,000$$

2 q_p = the smallest of the three; since $D_b = 1.2\ \text{m} \le 1.91\ \text{m}$, $F_r = 1$

$$q_p = \min(1{,}957.5;\ 1{,}305;\ 4\,000) = \mathbf{1{,}305}\ \text{kPa}$$

3 Base area and end resistance

$$A_b = \frac{\pi(1.2)^2}{4} = 1.131\ \text{m}^2 \qquad Q_p = A_b\, q_p = \mathbf{1{,}476}\ \text{kN}$$

$9c_{ub}$ governs: the formula $6c_{ub}(1 + 0.2L/D_b)$ gives a larger value, but the $9c_u$ cap comes into play. Q_p = **1,476 kN**.

Solution (2/2)

SOLUTION

4 α* and the friction-bearing length (1.5 m is neglected at the top and 1D at the bottom)

$$\alpha^* = 0.55 \quad (c_u/p_a = 1.45 \le 1.5)$$

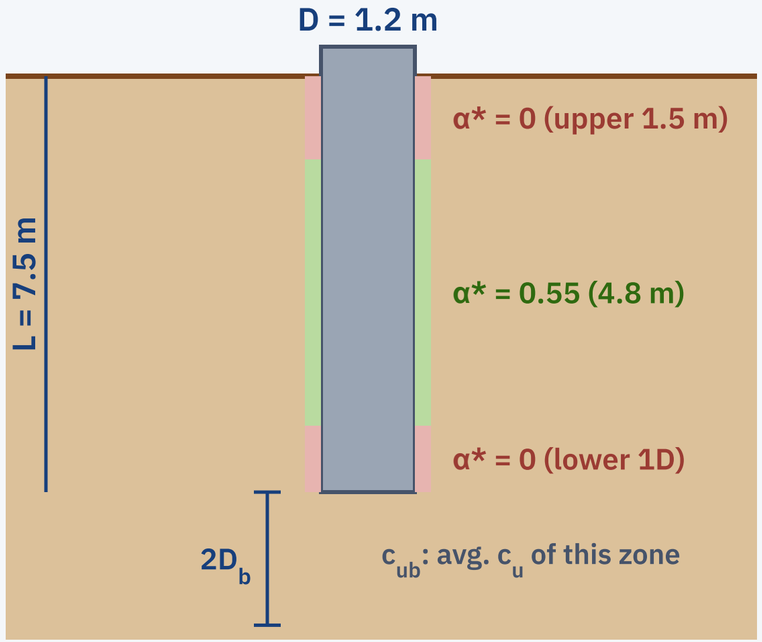
$$L_{eff} = 7.5 - 1.5 - 1.2 = \mathbf{4.8}\ \text{m}$$

5 Shaft friction

$$Q_s = \pi D\, \alpha^* c_u\, L_{eff} = \pi(1.2)(0.55)(145)(4.8) = \mathbf{1{,}443}\ \text{kN}$$

6 Ultimate and allowable bearing capacity

$$Q_u = 1{,}476 + 1{,}443 = 2{,}919\ \text{kN} \qquad Q_{all} = \frac{Q_u}{3} = \mathbf{973}\ \text{kN}$$



Check the solution in GeoTerva ↗

Total with a single factor of safety

THEORY

The ultimate capacity is the sum of the two components; the allowable capacity is found by applying **a single factor of safety to the entire sum**:

$$Q_{all} = \frac{Q_p + Q_s}{FS}$$

Usual **FS = 2.5 – 4** for a single pile

Upper end: when the soil is known only from a few boreholes, when the clay is **stiff and fissured**, or when a **loading test** is not planned

The end and shaft methods can be selected **independently** of each other; the results are interpreted together

Problem statement

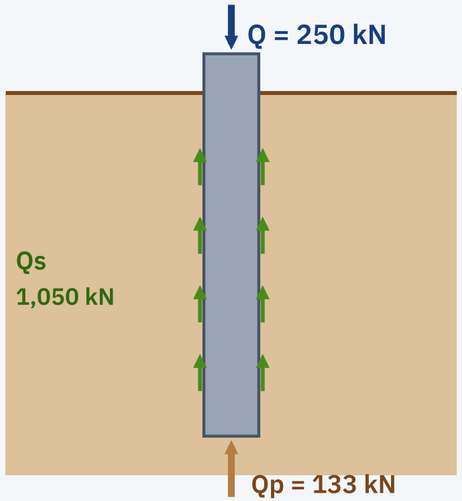
EXAMPLE

Given

Tip resistance	Q_p = 132.9 kN (Meyerhof, Example 2)
Shaft friction	Q_s = 1,050 kN (α method, Example 4)
Factor of safety	FS = 4
Working load on the pile	Q = 250 kN

REQUIRED

What is the **allowable bearing capacity** Q_{all} of the pile? Is the working load **sufficient**?



Solution

SOLUTION

1 Ultimate bearing capacity

$$Q_u = Q_p + Q_s = 132.9 + 1{,}050.1 = \mathbf{1{,}183}\ \text{kN}$$

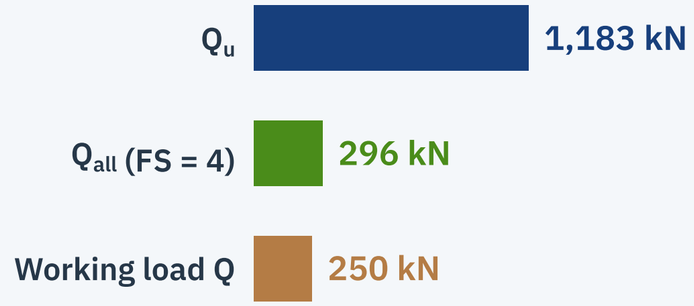
2 Allowable bearing capacity

$$Q_{all} = \frac{Q_u}{FS} = \frac{1{,}183}{4} = \mathbf{296}\ \text{kN}$$

3 Check

$$Q = 250\ \text{kN} \ \leq \ Q_{all} = 296\ \text{kN} \ \Rightarrow \ \text{sufficient}$$

Utilization ratio Q / Q_{all} = 250 / 296 = **0.85**. The shaft carries about 89% of the total.



Check the solution in GeoTerva ↗

Same pile: Q_u and Q_{all} (FS = 4)

THEORY

Q_u · Q_{all} (kN)

	Q_s: α 1,050 kN	Q_s: λ 1,114 kN	Q_s: β 1,058 kN
Q_p: Meyerhof 132.9 kN	1,183 · **296**	1,247 · **312**	1,191 · **298**
Q_p: Vesic 168.5 kN	1,219 · **305**	1,283 · **321**	1,227 · **307**

Across the six combinations Q_u ranges only between **1,183 – 1,283 kN**: since the tip is small, the choice affects the total very little; the real difference lies in the shaft friction.

Interpret the range, do not rely on a single number

Shaft friction is **about nine-tenths** of the total

For major works, verify with a **pile load test**

Summary

Key points

Clay is **undrained** ($\varphi = 0$, $\tau_f = c_u$); resistance is not proportional to effective stress

Tip: Meyerhof $N^*_c = 9$; Vesic $N^*_c = f(I_{rr})$, $I_r \approx 347 c_u / p_a - 33$; the tip resistance is a small part of the total

α: $f = \alpha c_u$ · **λ**: $f_{av} = \lambda(\bar{\sigma} + 2\bar{c}_u)$ · **β**: $f = \beta\sigma'$, $\beta = (1 - \sin\varphi'_R)\tan\varphi'_R\sqrt{OCR}$

Bored pile: $\alpha^* = 0$ (top 1.5 m, bottom 1D), $q_p = \min[6c_{ub}(1 + 0.2L/D_b), 9c_{ub}, 40p_a]$

$Q_{all} = (Q_p + Q_s)/FS$, $FS = 2.5 - 4$

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NOTE

The figures in this presentation are taken from the GeoTerva Theory page; all numerical examples were produced with the module's own calculation library, and the module gives the same values.

GeoTerva

Online geotechnical analysis

From theory to practice

Calculate the example pile in this presentation step by step in GeoTerva: the numbers are the same.

Open the module →

Theory page →

Open on your phone
The example modules need no registration.

If you would like to use them in your lectures: info@geoterva.com