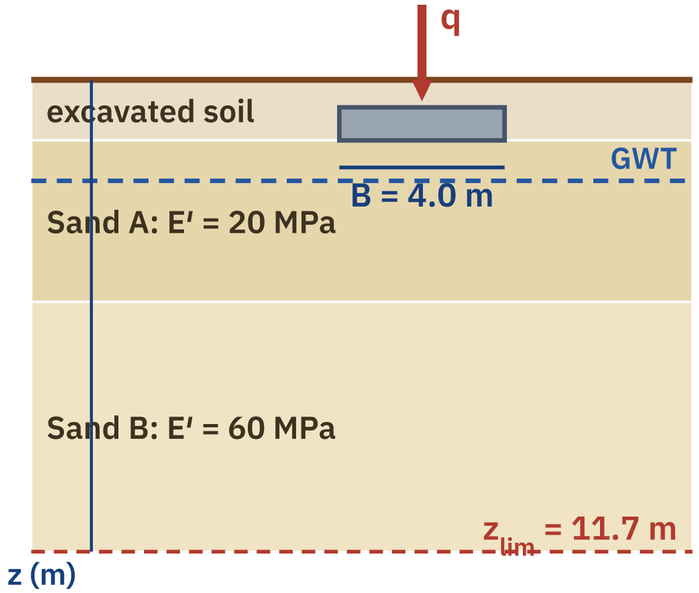
Geotechnical lecture presentation · Settlement

Elastic settlement: granular soil

Lecture: from elasticity theory to Steinbrenner coefficients, from a layered profile to flexible and rigid foundations; sand and gravel layers behave drained (E′, ν′); a worked example in every topic.

Hooke's law | Steinbrenner coefficients | Layered profile | Net pressure | Flexible and rigid footing | Worked examples



Based on the GeoTerva Theory page · geoterva.com

Introduction

What will we learn in this lecture?

- **From Hooke's law** to the settlement integral: $\varepsilon_z = [\Delta\sigma_z - \nu(\Delta\sigma_x + \Delta\sigma_y)]/E$ and $S = \int \varepsilon_z \, dz$
- To compute the **Steinbrenner coefficients** (F_1, F_2, I_s) and to find the **center** and **corner** settlement of a rectangular footing
- To treat granular layers as **drained**: $E'/p_a = \alpha\, N_{60}$, $\nu' \approx 0.25–0.35$
- To sum the **layered profile** using the difference $I_s(z_{lower}) - I_s(z_{upper})$
- Determining the **net pressure** (excavation effect) and the **design depth** (influence depth)
- To distinguish **flexible** and **rigid** foundation settlement (rigid ≈ 0.93 × flexible center)

LECTURE FLOW

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

1 · **Theory**: what is the rule, why is it so?

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

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

Example foundation: 4 m × 6 m flexible rectangular footing, q = 180 kPa, excavation depth 1.5 m, GWT 2.5 m; sand layer. Settlements are in mm.

What does this module calculate?

THEORY

This module considers **only granular** (sand, gravel) layers and computes **elastic settlement**: since sand releases its water immediately, its settlement is entirely elastic.

From the **Boussinesq** stresses of the soil under load, the strain is found **by Hooke's law**, and the integral of the strain is the settlement.

Immediate settlement of clay layers is in the Elastic Settlement module, consolidation in the Consolidation module, and the sum of all in the Total Settlement module.

The solution is **analytical**: closed-form influence factors and layer-by-layer summation; no finite elements.

Beyond this: the Schmertmann method, SPT/CPT charts, modulus increasing with depth (Mayne–Poulos), foundation rigidity and soil–structure interaction.

LAYER TYPE

	Granular
Behavior	drained
E	E' (e.g. αN_{60})
v	0.25 – 0.35

Hooke's law and settlement integral

THEORY

Beneath a **perfectly flexible** footing carrying net pressure q_{net}, the soil is a semi-infinite homogeneous elastic medium (Boussinesq stresses). Hooke's law gives the vertical strain, and its integral gives the settlement:

$$S = \int \varepsilon_z \, dz = \int \frac{\Delta\sigma_z - \nu\,(\Delta\sigma_x + \Delta\sigma_y)}{E}\, dz$$

Lateral stresses depend on v; therefore deformation and settlement vary with **both E and v**.

As v increases, lateral stresses **reduce** the vertical strain: at the same E′, a soil with v = 0.5 settles less than one with v = 0.3.

Settlement is **inversely proportional** to E: doubling the modulus halves the settlement.

NOTATIONS

q_{net}: net pressure (applied after excavation)

$\Delta\sigma_z$, $\Delta\sigma_x$, $\Delta\sigma_y$: stress increments

E, v: elastic constants of the layer

ε_z: vertical strain (compression +)

Problem statement

EXAMPLE

Given

Stress increase	$\Delta\sigma_z = 100\ \mathrm{kPa},\ \Delta\sigma_x = \Delta\sigma_y = 40\ \mathrm{kPa}$
Soil	$E' = 20\ \mathrm{MPa},\ \nu' = 0.30$
Slice	**thickness 1.0 m**

REQUIRED

Determine the vertical strain and the compression of the slice; compare with the v = 0 (one-dimensional) assumption.

Solution

SOLUTION

1 Vertical strain

$$\varepsilon_z = \frac{\Delta\sigma_z - \nu(\Delta\sigma_x + \Delta\sigma_y)}{E} = \frac{100 - 0.30(40 + 40)}{20{,}000} = \frac{76.0}{20{,}000} = \mathbf{0.00380}$$

2 Compression of the slice (H = 1.0 m)

$$\Delta S = \varepsilon_z H = 0.00380(1.0) = \mathbf{3.80}\ \text{mm}$$

3 Comparison: v = 0

$$\varepsilon_z = \frac{100}{20{,}000} = 0.00500 \ \Rightarrow\ \Delta S = 5.00\ \text{mm}$$

Lateral stresses (v = 0.30) reduce the deformation by **24%**: 3.80 mm, versus 5.00 mm for one-dimensional.

Check the solution in GeoTerva ↗

Closed-form solution for the corner

THEORY

For the **corner** of a uniformly loaded rectangle the integral has a closed-form solution (Steinbrenner):

$$S = q_{net}\,\alpha\,B'\,\frac{1-\nu^2}{E}\,I_s \qquad I_s = F_1 + \frac{1-2\nu}{1-\nu}\,F_2$$

$$F_1 = \frac{A_0 + A_1}{\pi} \qquad F_2 = \frac{n'}{2\pi}\tan^{-1} A_2$$

m′ = L′/B′ and n′ = z/B′ (B′ is the short side of the corner rectangle). The **center** is the corner of four (B/2 × L/2) rectangles: α = 4, B′ = B/2. The **corner** is the corner of the whole rectangle: α = 1, B′ = B. Any other point is the algebraic sum of the four rectangles having a corner at that point.

> For v = 0.5, (1 − 2v) = 0: **$I_s = F_1$** and (1 − v²) = 0.75.

NOTATIONS

α: number of corner rectangles (4 at the center, 1 at the corner)
B′: short side of the corner rectangle
m′ = L′/B′, n′ = z/B′
z: depth from the footing level
I_s: shape factor

A_0, A_1, A_2 and the slice boundary

THEORY

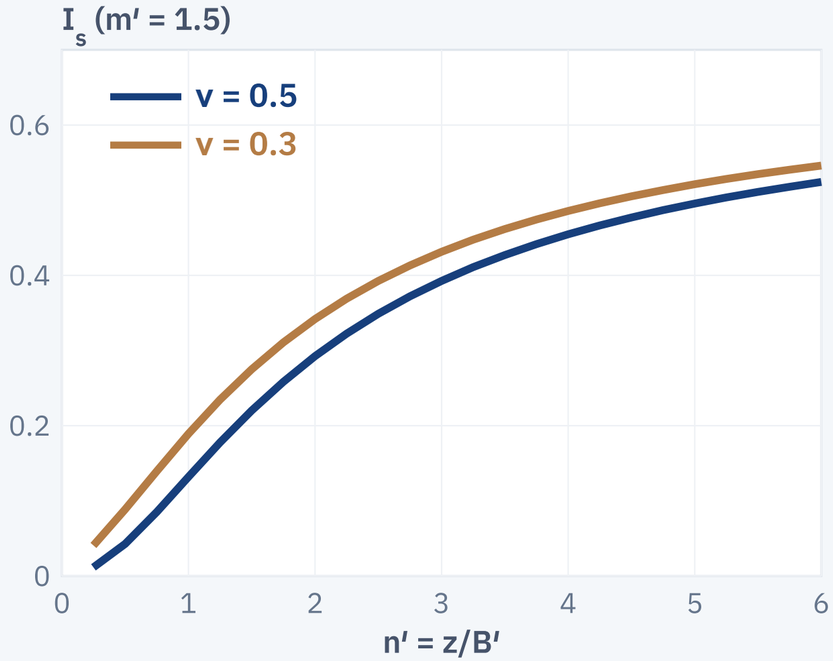
$$A_0 = m' \ln \frac{\left(1+\sqrt{m'^2+1}\right)\sqrt{m'^2+n'^2}}{m'\left(1+\sqrt{m'^2+n'^2+1}\right)}$$

$$A_1 = \ln \frac{\left(m'+\sqrt{m'^2+1}\right)\sqrt{1+n'^2}}{m'+\sqrt{m'^2+n'^2+1}} \qquad A_2 = \frac{m'}{n'\sqrt{m'^2+n'^2+1}}$$

Strip ($m' \to \infty$): $F_1 = \ln(1+n'^2)/2\pi$ and $F_2 = (n'/2\pi)\tan^{-1}(1/n')$; at its edge $\alpha = 2$, $B' = B$.

The engine computes the formulas directly; no charts or rounded tables are needed.

I_s increases with depth and **slowly saturates**: the contribution of deep layers is limited (on the side $m' = 1.5$).



Problem statement

EXAMPLE

Given

Foundation	**B × L = 4 × 6 m, at depth z′ = 4 m below the center (from the foundation level)**
Corner rectangle	**B/2 × L/2 = 2 × 3 m ⇒ B′ = 2 m, m′ = 1.5, n′ = z′/B′ = 2.0**
Soil	$\nu' = 0.30$

REQUIRED

Find the values of **A_0, A_1, A_2, F_1, F_2** and **I_s**.

Solution

SOLUTION

1 A_0, A_1, A_2 (square roots: $\sqrt{(m'^2 + 1)} = 1.8028$; $\sqrt{(m'^2 + n'^2)} = 2.5000$; $\sqrt{(m'^2 + n'^2 + 1)} = 2.6926$)

$$A_0 = 1.5 \ln \frac{(1 + 1.8028)(2.5000)}{1.5(1 + 2.6926)} = \mathbf{0.3527} \qquad A_1 = \ln \frac{(1.5 + 1.8028)\sqrt{5}}{1.5 + 2.6926} = \mathbf{0.5662}$$

$$A_2 = \frac{1.5}{2(2.6926)} = \mathbf{0.2785}$$

2 F_1, F_2 and I_s

$$F_1 = \frac{0.3527 + 0.5662}{\pi} = \mathbf{0.2925} \qquad F_2 = \frac{2}{2\pi} \tan^{-1}(0.2785) = \mathbf{0.0865}$$

$$I_s = F_1 + \frac{1 - 2(0.30)}{1 - 0.30} F_2 = \mathbf{0.3419}$$

$I_s = F_1 + 0.5714\, F_2 =$ **0.3419**; if $\nu' = 0.5$, $F_1 = 0.2925$ would remain (14% less).

Check the solution in GeoTerva ↗

Drained modulus E′ and ν′

THEORY

Since sand releases its water immediately, it behaves in a drained manner; its settlement is entirely elastic. In the source (Das), the modulus of sand is obtained from the SPT with **$E'/p_a = \alpha\, N_{60}$** ($p_a \approx 100$ kPa):

$$\frac{E'}{p_a} = \alpha\, N_{60} \qquad \alpha = 5\ (\text{fine-grained sand})\ \ 10\ (\text{clean NC})\ \ 15\ (\text{clean OC})$$

The modulus of sand **increases** with depth: divide a thick layer into several layers with increasing E′.

ν′ is typically 0.25–0.35; ν′ must be < 0.5 (ν′ ≥ 0.5 cannot be entered for a granular layer).

Elastic settlement also varies with ν′: it decreases as ν′ increases.

α FOR SAND

α	E′ (N_{60} = 20)
5	10 MPa
10	20 MPa
15	30 MPa

Problem statement

EXAMPLE

Given

Sand	$N_{60} = 20$, $p_a = 100$ kPa; $\alpha = 5,\ 10,\ 15$
Poisson's ratio	$\nu' = 0.25;\ 0.30;\ 0.35$ **(E′ = 20 MPa)**
Reference	**Single-layer settlement for α = 10, ν′ = 0.30: S = 29.0 mm (Example 6)**

REQUIRED

For each α, **E′**; settlement for ν′ = 0.25, 0.30, 0.35 and 0.5.

Solution

SOLUTION

1 $E' = \alpha N_{60} p_a$ (N_{60} = 20; p_a = 100 kPa)

$$E' = \alpha N_{60} p_a: \quad 5(20)(0.1) = \mathbf{10}\ \text{MPa},\ \ 10(20)(0.1) = \mathbf{20},\ \ 15(20)(0.1) = \mathbf{30}\ \text{MPa}$$

v′	0.25	0.30	0.35	0.50
S (mm)	30.1	29.0	27.7	22.8
$S / S_{v'=0.30}$	1.038	1.000	0.955	0.786

When E′ changes from 10 → 30 MPa, settlement goes from 58 → 19 mm (inversely proportional). v′ from 0.25 → 0.35 changes settlement by only 8%; if v′ = 0.5 it would be 21% less.

Check the solution in GeoTerva ↗

Excavation first removes the load

THEORY

Excavation removes the **effective overburden stress** at the base level (GWT unchanged). When a single module is used for both unloading and reloading, the elastic heave of the excavation is recovered on reloading; the immediate settlement is governed by the **net pressure**:

$$q_{net} = q_{gross} - \sigma'_{v0}(D_{exc})$$

$\sigma'_{v0}(D_{exc})$: initial effective stress at the excavation base (γ above the GWT, $\gamma' = \gamma_{sat} - \gamma_w$ below it).

If $q_{net} \leq 0$, no settlement occurs (a negative value is elastic heave).

If there is no excavation, $q_{net} = q_{gross}$ (the pressure is applied at the ground surface).

NEDEN NET?

The load equal to the weight of soil removed during excavation is **restored** when the foundation is built. Settlement of the soil arises only from the pressure **added on top of** this load.

Problem statement

EXAMPLE

Given

Load	$q_{gross} = 180$ kPa; **excavation depth** $D_{exc} = 1.5$ m
Soil	$\gamma = 18.5$ kN/m^3, $\gamma_{sat} = 19.5$ kN/m^3
GWT	**(a) 2.5 m (below the excavation base) · (b) 1.0 m (above the excavation base)**

REQUIRED

In each case, find the $\sigma'_{v0}(D_{exc})$ and q_{net} values.

Solution

SOLUTION

1. (a) GWT 2.5 m > 1.5 m: no water at excavation base

$$\sigma'_{v0} = \gamma D_{exc} = 18.5(1.5) = 27.75\ \text{kPa} \ \Rightarrow\ q_{net} = 180 - 27.75 = \mathbf{152.25}\ \text{kPa}$$

2. (b) GWT at 1.0 m: excavation base is 0.5 m below the water (γ′ = 19.5 − 9.81 = 9.69 kN/m³)

$$\sigma'_{v0} = 18.5(1.0) + 9.69(0.5) = 23.345\ \text{kPa} \ \Rightarrow\ q_{net} = 180 - 23.345 = \mathbf{156.66}\ \text{kPa}$$

If the water is above the excavation base, the removed effective stress decreases and the net pressure **increases** from 152.2 to 156.7 kPa: a high GWT amplifies immediate settlement.

Check the solution in GeoTerva ↗

Influence depth: Δσ = p · q

THEORY

The stress increase under the load decreases with depth but does not become zero; a lower bound on the total is required: **the computation depth z_{lim}**. The module offers two rules:

Influence depth: the depth below the center at which the Boussinesq stress increase falls to **p** (commonly p = 10%): I(z′) = p and $z_{lim} = D_f + z'$.

Base of the profile: the calculation ends at the last layer (a rigid base such as rock or dense gravel; Steinbrenner's layer with a rigid base).

If the profile ends above z_{lim}, the last layer continues to z_{lim} with the same properties.

$$I = \frac{\Delta\sigma_z}{q} = 4\, I_{corner}(m, n) \qquad m = \frac{B}{2z'},\ n = \frac{L}{2z'}$$

z′/B (p = %10 | %20)

L/B	p = %10	p = %20
1.0	2.09 B	1.40 B
1.5	2.55 B	1.70 B
2.0	2.92 B	1.94 B
5.0	4.33 B	2.68 B
strip	6.34 B	3.13 B

Problem statement

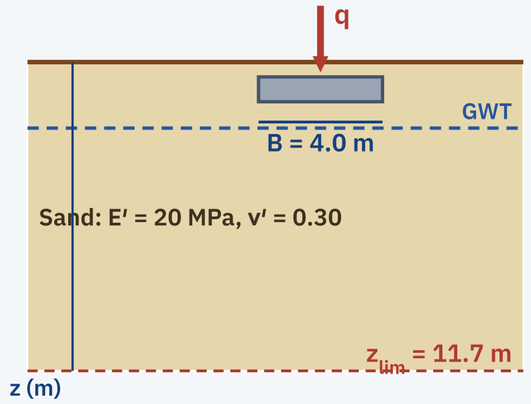
EXAMPLE

Given

Foundation	**B × L = 4 × 6 m (L/B = 1.5), at the excavation base; D_f = 1.5 m**
Rule	**influence depth, p = 10% (I = 0.10)**
Formula	$I = 4\,I_{corner}(m,n),\ m = B/2z',\ n = L/2z'$

REQUIRED

z′ and **z_{lim}**; the value of I for z′ = 4 m and 10.19 m.



Solution

SOLUTION

1 z′ = 4 m: m = 2/4 = 0.5; n = 3/4 = 0.75

$$I = 4\,I_{corner}(0.5;\ 0.75) = 4(0.1071) = \mathbf{0.4283}$$

2 Condition I = 0.10: by bisection

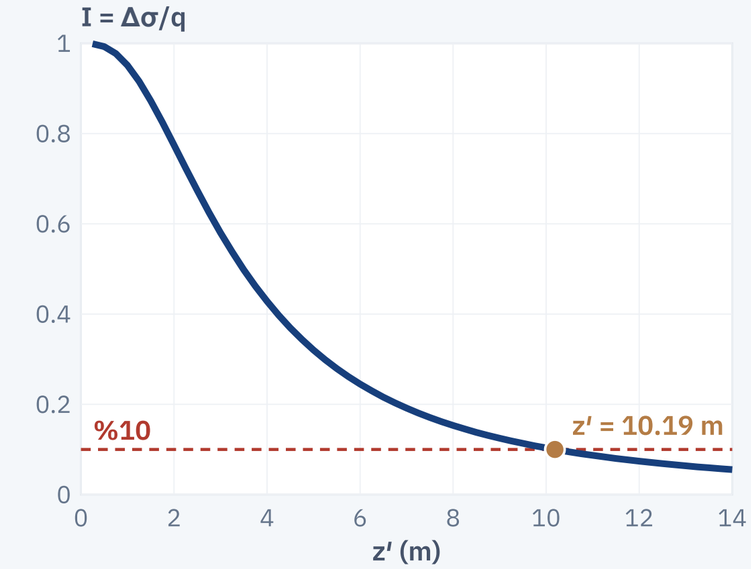
$$z' = \mathbf{10.19}\ \mathrm{m} \quad (= 2.55\,B)$$

$$z_{lim} = D_f + z' = 1.5 + 10.19 = \mathbf{11.69}\ \mathrm{m}$$

3 Check: z′ = 10.19 m ⇒ m = 2/z′, n = 3/z′

$$m = 0.1963,\ n = 0.2945$$

$$I = 4(0.0250) = \mathbf{0.1000}$$



It is summed to a depth of 10.19 m (2.55 B); beyond that is the zone of less than 10% of the pressure. For a square footing 2.09 B, for a strip 6.34 B: **a wide footing acts deeper**.

Check the solution in GeoTerva ↗

Layer contribution: difference in I_s

THEORY

A layer between z_{top} and z_{bottom} (from the foundation level) contributes the **difference of the semi-infinite medium solution between two depths**, with its own E and v:

$$\Delta S = q_{net}\,\alpha\,B'\,\frac{1-\nu^2}{E}\,\left[I_s(z_{bottom}) - I_s(z_{üst})\right]$$

This is the integral of the Hooke deformation over the layer (with homogeneous half-space stresses): for this assumption it is **exact**; the result does not depend on the slice thickness Δz (the slices serve only the tables and the colour areas).

It replaces the **weighted average modulus** in the single-layer formula.

A layer whose stiffness increases with depth should be divided into several layers.

TOTAL

The settlement of the profile is the **sum** of the layer contributions up to z_{lim}: $S = \Sigma\,\Delta S_i$.

Only the part of each layer between the foundation level and z_{lim} is counted.

Problem statement

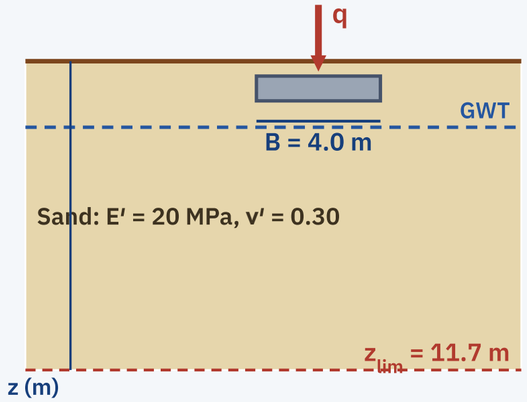
EXAMPLE

Given

Foundation	**rectangular, B × L = 4 × 6 m, base depth D_f = 1.5 m (excavation base)**
Load	$q_{gross} = 180\ \mathrm{kPa}$ **(flexible footing, uniform pressure)**
Soil	**single layer sand:** $E' = 20\ \mathrm{MPa},\ \nu' = 0.30,\ \gamma = 18.5\ \mathrm{kN/m^3}$**; GWT 2.5 m**
Design depth	**influence depth, p = 10% (Example 5): z′ = 10.19 m, z_{lim} = 11.69 m; the layer continues to this depth**

REQUIRED

Centre settlement **S** of the flexible foundation.



Solution (1/2)

SOLUTION

1 Net pressure (Example 4a) and coefficient k = $q_{net}(1 - \nu^2)/E$

$$q_{net} = 152.25\ \text{kPa} \qquad k = \frac{q_{net}(1-\nu^2)}{E} = \frac{152.25(0.91)}{20{,}000} = 0.006927\ (\text{dimensionless})$$

2 Center: α = 4, B′ = B/2 = 2 m, m′ = 1.5; z′ = 10.19 m ⇒ n′ = z′/B′ = 5.094

$$A_0 = 0.6569,\ A_1 = 0.9097,\ A_2 = 0.0545$$

$$F_1 = 0.4986,\ F_2 = 0.0441 \ \Rightarrow\ I_s = \mathbf{0.5239}$$

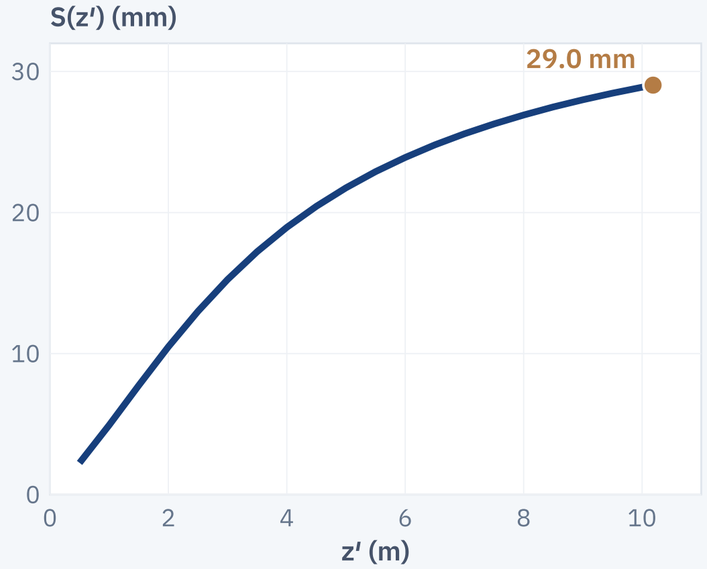
Solution (2/2)

SOLUTION

3 Settlement: $S = k \cdot \alpha\, B' \cdot I_s$

$$S = 0.006927\,(4)(2)(0.5239) = 0.006927(4.1909)$$
$$= 0.02903\ \text{m} = \mathbf{29.0\ mm}$$

Centre settlement **29.0 mm**. In the graph S(z′): most of the settlement occurs within the upper 2B (8 m); the contribution of the deeper layers is small.



Check the solution in GeoTerva ↗

Problem statement

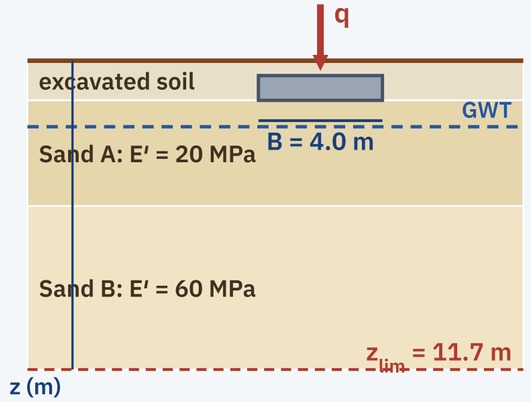
EXAMPLE

Given

Foundation, load	**$B \times L = 4 \times 6$ m, $q_{gross} = 180$ kPa, $D_f = 1.5$ m $\Rightarrow q_{net} = 152.25$ kPa**
Layer A	**4 m thickness from the foundation level: $E' = 20$ MPa**
Layer B	**below, up to z_{lim}: $E' = 60$ MPa**
Design depth	**$z'_{lim} = 10.19$ m**

REQUIRED

Find the **midpoint** settlement of each layer and the total; compare with a single layer.



Solution (1/2)

SOLUTION

1 Layer coefficients k = $q_{net}(1 - \nu^2)/E$ and $\alpha\, B'\, I_s$ (center; Example 2 and 6)

$$k_A = \frac{152.25(0.91)}{20{,}000} = 0.006927 \qquad k_B = \frac{152.25(0.91)}{60{,}000} = 0.002309$$

$$8\, I_s(z' = 4) = 8(0.3419) = 2.7351 \qquad 8\, I_s(z'_{lim}) = 4.1909$$

When the profile is divided into two layers, each layer is summed **with its own modulus**, through the increase of I_s over its own range.

Solution (2/2)

SOLUTION

2 Layer settlements and total

$$\Delta S_A = k_A (8I_s)_4 = 0.006927(2.7351) = 18.9 \text{ mm}$$

$$\Delta S_B = k_B \left[(8I_s)_{lim} - (8I_s)_4\right] = 0.002309(4.1909 - 2.7351) = 3.4 \text{ mm}$$

$$S = \Delta S_A + \Delta S_B = \mathbf{22.3 \text{ mm}}$$

The total center settlement is **22.3 mm** (engine: 22.3 mm). The single-layer case (E = 20 MPa) gave 29.0 mm: since the lower layer is **stiffer**, the settlement decreased by **23%**; layer A carries 85% of the total.

Check the solution in GeoTerva ↗

Center, corner and rigid settlement

THEORY

The formulas give the settlement of a **perfectly flexible** footing: **maximum at the center**, minimum at the corner; their difference is the **differential settlement** of the flexible footing. A rigid footing settles **uniformly**: about 0.93 times the flexible center value:

$$S_{rigid} \approx 0.93\, S_{center} \qquad S_{diff} = S_{center} - S_{köşe}$$

Centre: α = 4, B′ = B/2. Corner: α = 1, B′ = B (corner of the full rectangle).

Embedment: the Fox depth factor I_f (depending on D_f/B, B/L and ν) reduces the settlement of an embedded foundation. The module takes I_f = 1: no correction, **on the safe side**.

NOTE

A real footing lies between flexible and rigid. The module gives the two extreme values; intermediate stiffness and soil–structure interaction are outside its scope.

Problem statement

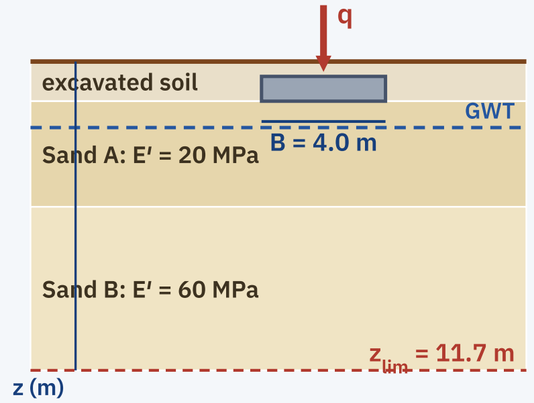
EXAMPLE

Given

Profile	**Example 7: Layer A (4 m) and Layer B; z'_{lim} = 10.19 m**
Foundation	**flexible, 4 × 6 m**
Corner	**α = 1, B′ = B = 4 m ⇒ m′ = L/B = 1.5; n′ = z′/4**

REQUIRED

Corner settlement, **rigid** footing settlement and **differential** settlement of a flexible footing.



Solution

SOLUTION

1 4·I_s values for the corner (n′ = z′/4)

$$z' = 4\ (n' = 1):\ 4\,I_s = 0.7565$$

$$z'_{lim} = 10.19\ (n' = 2.547):\ 4\,I_s = 1.5865$$

2 Corner settlement

$$S_{köşe} = k_A(0.7565) + k_B(1.5865 - 0.7565) = 5.2 + 1.9 = \mathbf{7.2\ mm}$$

3 Rigid and differential

$$S_{rigid} = 0.93(22.3) = \mathbf{20.7\ mm} \qquad S_{diff} = 22.3 - 7.2 = \mathbf{15.2\ mm}$$

Center 22.3, corner 7.2, rigid 20.7 mm; the differential settlement of the flexible foundation is **15.2 mm**. The corner settles only 32% of the center.

Check the solution in GeoTerva ↗

Problem statement

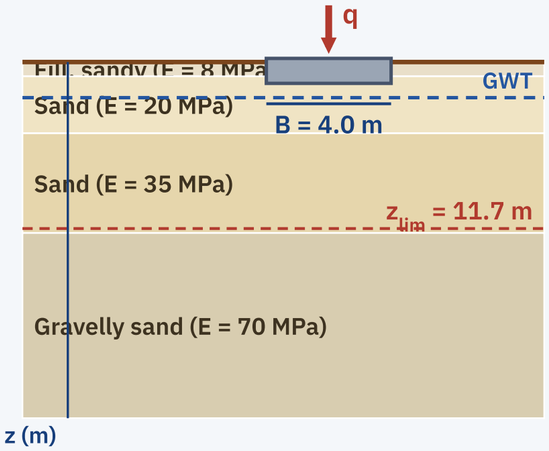
EXAMPLE

Given

Foundation	**B × L = 4 × 6 m, q_{gross} = 180 kPa, excavation depth 1.5 m, GWT 2.5 m**
Profile	**Fill, sandy 0–1 m: E′ = 8 MPa; Sand 1–5 m: E′ = 20 MPa; Sand 5–12 m: E′ = 35 MPa; Gravelly sand 12–25 m: E′ = 70 MPa**
Design depth	**influence depth, p = 10%**

REQUIRED

Layer-by-layer **center** and **corner** settlement; flexible center, corner, rigid and differential settlement.



Solution (1/2)

SOLUTION

1 Net pressure (excavation base 1.5 m)

$$\sigma'_{v0}(1.5) = 27.25\ \text{kPa} \quad \Rightarrow \quad q_{net} = 180 - 27.25 = \mathbf{152.75}\ \text{kPa}$$

2 Calculation depth and layers

$z_{lim} = 1.5 + 10.19 = \mathbf{11.69}$ m the layer above the excavation base is removed

The excavation base (1.5 m) is within the Sand layer: only the part of the layers below 1.5 m is counted. z_{lim} = 11.69 m, which remains within the Sand layer, so that layer is truncated.

Solution (2/2)

SOLUTION

Layer	z (m)	H (m)	E (MPa)	k (×10⁻³)	ΔS center (mm)	ΔS corner (mm)
Sand (SM, loose–medium dense)	1.50 – 5.00	3.50	20	6.950	17.3	4.6
Sand (SM, medium dense)	5.00 – 11.69	6.69	35	3.972	6.8	3.7
Total					**24.1**	**8.3**

Centre **24.1 mm**, corner 8.3 mm, rigid 22.4 mm, differential 15.8 mm. The module gives the same values.

Check the solution in GeoTerva ↗

Points to keep in mind when reading the results

THEORY

Assumptions:

- Foundation level = excavation base; uniform pressure on a fully flexible footing.
- In each layer, the stresses of a **homogeneous half-space** (with that layer's v).
- Each layer is granular and settles **drained** (E′, v′).
- No embedment correction; rigid footing ≈ 0.93 × flexible center.
- Sign convention: settlement is **positive**; the selector in the header switches to the convention where upward settlement is positive.

Out of scope: clay layers; Schmertmann, SPT/CPT charts, modulus increasing with depth, foundation rigidity and soil–structure interaction, finite elements.

COLOUR AREAS

Section views show the stress increase, modulus, strain and S(z) settlement with colour bands; the centre value at the footing level is the resulting settlement.

Summary

Key points

Hooke: $\varepsilon_z = [\Delta\sigma_z - \nu(\Delta\sigma_x + \Delta\sigma_y)]/E$; $\mathbf{S = \int \varepsilon_z\, dz}$; inversely proportional to E

Steinbrenner: $S = q_{net}\, \alpha\, B'\, (1 - \nu^2)/E \cdot I_s$; $I_s = F_1 + (1 - 2\nu)/(1 - \nu)\, F_2$; center $\alpha = 4$, $B' = B/2$; corner $\alpha = 1$, $B' = B$

Sand: $E'/p_a = \alpha\, N_{60}$ ($\alpha = 5, 10, 15$), $\nu' \approx 0.25$–0.35; as ν' increases, settlement decreases

Layered: $\Delta S = q_{net}\, \alpha\, B'\, (1 - \nu^2)/E \cdot [I_s(z_{bottom}) - I_s(z_{top})]$; independent of slice thickness

Net pressure $q_{net} = q_{gross} - \sigma'_{v0}(D_{exc})$; **influence depth** $I(z') = p$ (2.09 B for square, 2.55 B for L = 1.5 B, 6.34 B for strip)

Flexible: center > corner (differential settlement); **rigid** ≈ 0.93 × center; no embedment correction ($I_f = 1$)

References

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NOTE

All numerical examples have been produced with the module's own calculation engine; the module gives the same values.

GeoTerva

Online geotechnical analysis

From theory to practice

Compute the example project in this lecture step by step in GeoTerva: the module opens with this model.

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