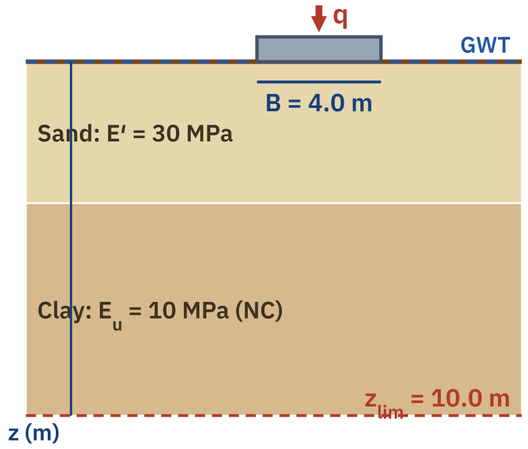
Geotechnical lecture presentation · Settlement

Total settlement: clay and sand layers

Lecture: combining immediate (elastic) settlement and clay consolidation in a profile of clay and sand layers, center, corner and rigid footing, time-dependent total settlement; worked examples throughout.

$S = S_e + S_c$ | Clay and sand layers | Steinbrenner | Stress path | Center · corner · rigid | Settlement–time curve



Introduction

What will we learn in this lecture?

- Separating settlement by layer type: **cohesive** layer = immediate settlement + consolidation, **granular** layer = elastic settlement only
- To combine **Steinbrenner** (immediate) and **stress path** (consolidation) calculations in the same slices
- To see the effect of the excavation: the **net pressure** governs immediate settlement, while **heave and recompression** govern consolidation
- Determining the **center** and **corner** settlement of a flexible footing, and the rigid footing and differential settlement from the total settlement
- $\mathbf{S(t) = S_e + \Sigma\, U_i(t)\, S_{c,i}}$ to construct the settlement–time curve
- To verify that the module result equals the sum of the single-type modules (Elastic + Consolidation)

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 profile: 6 m of normally consolidated clay over 4 m of sand; 4 × 6 m footing, q = 150 kPa. Settlements are in mm.

Total settlement = immediate settlement + consolidation

THEORY

$$S = S_e + S_c \qquad \text{cohesive layer: } S_e(\text{undrained}) + S_c \qquad \text{granular layer: } S_e(\text{drained})$$

Both components are computed **in the same slices**, with the same Boussinesq stress increase, the same excavation and the same computation depth. The solution is **analytical**: closed-form influence factors, slice-by-slice stress path and Terzaghi theory; there are no finite elements.

Saturated clay does not change volume while the load is applied (v = 0.5): this is its immediate settlement. Water drains slowly and the clay compresses along the stress path: this is consolidation. Since sand releases its water immediately, its settlement is entirely elastic.

> In a single profile type, the module gives **the same result** as the Elastic Settlement or Consolidation module (Example 6).

> The type of each layer is selected in the Soil profile table and determines which parameters the layer will require.

LAYER TYPE

Layer	Immediate settlement	Consolidation
Cohesive	Undrained E_u, v = 0.5	available: C_c, C_r, C_s, e_0, σ'_p (or m_v), C_v
Granular	drained E', v'	none

Hooke's law and Steinbrenner coefficients

THEORY

The settlement beneath a fully flexible footing carrying net pressure q_{net} is the integral of the vertical strain (Boussinesq stresses, homogeneous half-space):

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

Closed-form solution for the corner of a rectangle (Steinbrenner):

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

m′ = L′/B′, n′ = z/B′. **Center**: α = 4, B′ = B/2; **corner**: α = 1, B′ = B.

Since v = 0.5 in the cohesive layer, $I_s = F_1$ and $(1 - v^2) = 0.75$.

ELASTIC SETTLEMENT MODULI

The formulas for F_1, F_2, A_0, A_1, A_2 and detailed examples are in the Elastic Settlement presentations; here only their results are used for summation.

Layered profile and net pressure

THEORY

A layer between the depths z_{top} and z_{bottom} of the foundation level contributes its I_s difference with its own E and v:

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

Excavation removes the effective overburden stress at the base level; in a single-modulus elastic soil the unloading is recovered on reloading, and the immediate settlement is governed by the **net pressure**:

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

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

The result does not depend on slice thickness; slices only serve the tables and colour zones.

NEDEN FARKLI?

Immediate settlement is computed with the **net pressure** and consolidation with the **effective stress increase** along the stress path; excavation affects the two in different ways.

Stress path and slice compression

THEORY

In cohesive slices, consolidation is computed along the **stress path**, not in a single step from the initial to the final stress: swelling due to excavation (C_s), on reloading first the recompression that reverses the heave, recompression with C_r up to σ'_p, and virgin compression with C_c beyond it:

$$\sigma'_{v0} \xrightarrow{C_s} \sigma'_{exc} \xrightarrow{C_s} \sigma'_{v0} \xrightarrow{C_r} \sigma'_p \xrightarrow{C_c} \sigma'_{final} \qquad \sigma'_p = OCR \cdot \sigma'_{v0}$$

$$S_c = \sum (S_b + S_r + S_v)\,, \quad f = \frac{\Delta H}{1 + e_0} \qquad \Delta\sigma_{load} = q\, I_z(z') \qquad \sigma'_{final} = \sigma'_{exc} + \Delta\sigma_{load}$$

In NC clay (OCR = 1): $S = C_c\, f \log(\sigma'_{final}/\sigma'_{v0})$ (without excavation).

Heave is negative; $S_{net} = S_c + S_{heave}$. In the **preserved** option, settlement is measured from the original ground, and in the **reset to zero** option from the heaved base.

Design depth: $I_z(z') = p$ (commonly 10%) or the base of the profile; the m_v method is a linear option.

DETAIL

The full account of the stress path, the regimes, the excavation and the time curve is given in the Consolidation presentation.

Problem statement

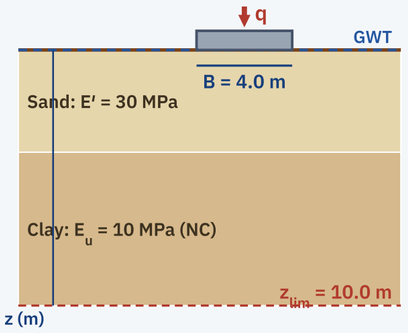
EXAMPLE

Given

Profile	**sand 0–4 m:** $E' = 30\ \mathrm{MPa},\ \nu' = 0.30, \gamma_{sat} = 19$ · **clay 4–10 m (NC):** $E_u = 10\ \mathrm{MPa},\ \nu = 0.5, e_0 = 1.0,\ C_c = 0.30,\ C_v = 2\ \mathrm{m^2/year}, \gamma_{sat} = 18$
Foundation	**4 × 6 m flexible rectangle, $q = 150\ \mathrm{kPa}$, at the ground surface; GWT at the surface; calculation depth 10 m (base of the profile)**
Excavation	**none (q_{net} = 150 kPa)**

REQUIRED

Centre and **corner** immediate settlement S_e of each layer.



Solution

SOLUTION

1. Sand (0–4 m): k = q(1 − ν′²)/E′ = 150(0.91)/30 000 = 0.004550; 8 I_s(4) = 2.7351

$$\Delta S_e = k\,[(\alpha B' I_s)_4 - 0] = 0.004550(2.7351) = \mathbf{12.4\ mm}$$

2. Clay (4–10 m): k = 150(0.75)/10,000 = 0.011250; 8 I_s(4) = 2.3398; 8 I_s(10) = 3.9643

$$\Delta S_e = 0.011250(3.9643 - 2.3398) = \mathbf{18.3\ mm}$$

At the center S_e = 12.4 + 18.3 = **30.7 mm**; at the corner 3.4 + 9.8 = **13.2 mm** (at the corner α = 1, B′ = B).

Check the solution in GeoTerva ↗

Boussinesq, influence depth and the m_v method

THEORY

For a rectangle B × L below the center of the footing with the Newmark corner coefficient, and for a strip with the closed-form α:

$$\Delta\sigma = q\, I_z(z') \qquad I_z = 4\, I_{köşe}(m, n)\ \ (m = \tfrac{B}{2z'},\ n = \tfrac{L}{2z'}) \qquad I_{z,\text{strip}} = \frac{\alpha + \sin\alpha}{\pi}$$

Influence depth: $I_z(z')$ = p (commonly 10%); square 2.09 B, 2.55 B for L = 1.5 B, strip 6.34 B. If the base of the profile is selected, the calculation ends at the last layer (in rock or dense gravel).

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

m_v method: $\Delta H = m_v\, \Delta\sigma'\, H$; linear, $C_c/C_r/C_s$ are not combined.

IN THIS PROFILE

The calculation depth is the base of the profile (10 m); a rigid base is assumed. For the clay layer at z = 7 m, $I_z(z' = 7) = 0.1916$.

Problem statement

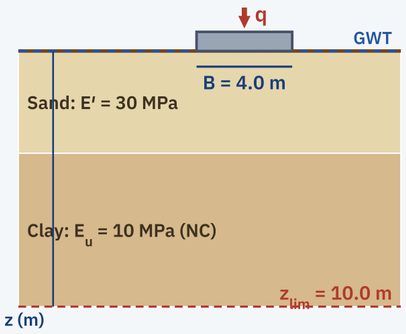
EXAMPLE

Given

Profile	**sand 0–4 m:** $E' = 30\ \mathrm{MPa},\ \nu' = 0.30,\ \gamma_{sat} = 19$ · **clay 4–10 m (NC):** $E_u = 10\ \mathrm{MPa},\ \nu = 0.5,\ e_0 = 1.0,\ C_c = 0.30,\ C_v = 2\ \mathrm{m^2/year},\ \gamma_{sat} = 18$
Foundation	**4 × 6 m flexible rectangle,** $q = 150\ \mathrm{kPa}$**, at the ground surface; GWT at the surface; calculation depth 10 m (base of the profile)**
Slice	**clay single slice,** $H = 6$ **m, midpoint** $z = 7$ **m;** $f = H/(1+e_0) = 3$ **m**
Stresses	$\sigma'_{v0} = 9.19(4) + 8.19(3) = 61.33\ \mathrm{kPa}$

REQUIRED

I_z, $\Delta\sigma$, σ'_{final} and **S_c**.



Solution

SOLUTION

1 Boussinesq (z′ = 7 m): m = 2/7 = 0.2857; n = 3/7 = 0.4286

$$I_z = 4\,I_{köşe}(0.2857;\,0.4286) = 4(0.0479) = \mathbf{0.1916} \qquad \Delta\sigma = 150(0.1916) = 28.75\ \text{kPa}$$

2 Final stress and compression (NC: $\sigma'_p = \sigma'_{v0}$)

$$\sigma'_{final} = 61.33 + 28.75 = 90.08\ \text{kPa}$$

$$S_c = C_c f \log\frac{\sigma'_{final}}{\sigma'_{v0}} = 0.30(3)\log\frac{90.08}{61.33} = \mathbf{150.2\ mm}$$

The consolidation settlement of the clay is **150.2 mm**: about **4.9 times** the immediate settlement (30.7 mm). In soft NC clay the main settlement comes from consolidation.

Check the solution in GeoTerva ↗

Center, corner and rigid footing

THEORY

For each slice the immediate and (in the cohesive layer) consolidation components are summed; the total over the layers down to z_{lim} gives the **center** settlement of the flexible footing:

$$S = \sum \Delta S_e + \sum (\Delta S_b + \Delta S_r + \Delta S_v) \quad [+ S_{heave}]$$

$$S_{köşe} = S_{e,köşe} + S_c \qquad S_{rigid} = 0.93\, S_e + S_c \qquad S_{diff} = S_e - S_{e,köşe}$$

For the corner, **only the immediate settlement** takes the corner rectangle's own value; consolidation comes from the stress path on the center line and is taken as the same at the corner.

A rigid foundation settles uniformly: the immediate component is about 0.93 times that of the flexible center, and the consolidation component equals that of the center.

Excavation: the immediate part is computed with q_{net}, and the clay heave and recompression likewise; for the "retained" option, $S = S_e + S_c + S_{heave}$.

IF CLAY IS DOMINANT

Since consolidation is the same at the centre and the corner, in clay-dominated profiles **differential settlement** is only the difference in the immediate component.

Problem statement

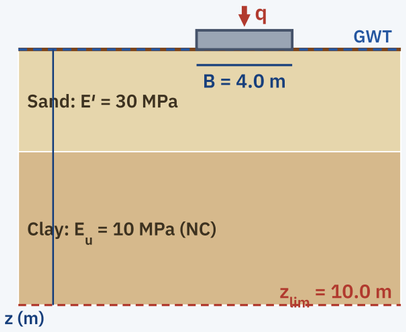
EXAMPLE

Given

Profile	**sand 0–4 m: $E' = 30\ \mathrm{MPa},\ \nu' = 0.30, \gamma_{sat} = 19$ · clay 4–10 m (NC): $E_u = 10\ \mathrm{MPa},\ \nu = 0.5, e_0 = 1.0,\ C_c = 0.30,\ C_v = 2\ \mathrm{m^2/year}, \gamma_{sat} = 18$**
Foundation	**4 × 6 m flexible rectangle, $q = 150\ \mathrm{kPa}$, at the ground surface; GWT at the surface; calculation depth 10 m (base of the profile)**
Previous examples	**S_e: centre 30.7, corner 13.2 mm; S_c = 150.2 mm (Examples 1 and 2)**

REQUIRED

Center, corner, rigid total settlement; differential settlement; the share of the immediate component.



Solution

SOLUTION

1 Totals

$$S_{center} = 30.7 + 150.2 = \mathbf{181.0\ mm} \qquad S_{köşe} = 13.2 + 150.2 = \mathbf{163.4\ mm}$$

$$S_{rigid} = 0.93(30.7) + 150.2 = \mathbf{178.8\ mm} \qquad S_{diff} = 30.7 - 13.2 = \mathbf{17.5\ mm}$$

	S_e (mm)	S_c (mm)	total (mm)
center (flexible)	30.7	150.2	**181.0**
corner (flexible)	13.2	150.2	**163.4**
rigid	28.6	150.2	**178.8**

Immediate settlement is only **17%** of the total; the differential settlement is 17.5 mm. Since the consolidation of the clay is the same at the center and at the corner, the corner settles by 90% of the center.

Check the solution in GeoTerva ↗

Problem statement

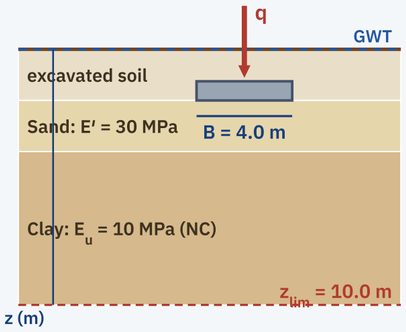
EXAMPLE

Given

Profile	**sand 0–4 m ($E' = 30,\ \nu' = 0.30,\ \gamma_{sat} = 19$) · clay 4–10 m (NC; $E_u = 10,\ e_0 = 1.0,\ C_c = 0.30,\ C_s = C_r = 0.06,\ \gamma_{sat} = 18$); GWT at the surface**
Excavation	**wide excavation (I_{exc} = 1), depth 2 m; at the foundation excavation base**
Foundation	**4 × 6 m, $q_{gross} = 150\ \mathrm{kPa}$; calculation depth 10 m**
Slices	**sand 2–4 m (H = 2 m), clay 4–10 m (z = 7 m, f = 3 m)**

REQUIRED

q_{net}, S_e; swelling of the clay and S_c; total settlement (stored and reset).



Solution (1/3)

SOLUTION

1 Net pressure: $q_{uplift} = \sigma'_{v0}(2\text{ m}) = 9.19(2) = 18.38$ kPa

$$q_{net} = 150 - 18.38 = \mathbf{131.62}\ \text{kPa}$$

2 Immediate settlement: sand (z′ 0–2 m) k = 0.003992; clay (z′ 2–8 m) k = 0.009872 ($k = q_{net}(1 - \nu^2)/E$)

$$\text{sand}: \Delta S_e = 0.003992(1.5131 - 0) = 6.0\ \text{mm}$$

$$\text{clay}: \Delta S_e = 0.009872(3.6370 - 1.0554) = 25.5\ \text{mm}$$

The net excavation pressure dropped from 150 to 131.6 kPa; immediate settlement from 30.7 to **31.5 mm** (the top 2 m of sand was excavated, so the clay was loaded less).

Solution (2/3)

SOLUTION

3 Clay: stress path (z′ = 5 m: $I_z = 0.3204$)

$$\sigma'_{exc} = 61.33 - 18.38 = 42.95 \text{ kPa} \qquad \Delta\sigma = 150(0.3204) = 48.05 \text{ kPa}$$

$$\text{heave} = -0.06(3)\log\frac{61.33}{42.95} = -27.8 \text{ mm} \qquad \sigma'_{final} = 42.95 + 48.05 = 91.00 \text{ kPa}$$

4 NC clay ($\sigma'_p = \sigma'_{v0}$): S_b recovers the swelling, S_v is virgin compression

$$S_b = 0.06(3)\log\frac{61.33}{42.95} = 27.8 \text{ mm} \qquad S_v = 0.30(3)\log\frac{91.00}{61.33} = 154.2 \text{ mm}$$

$$S_c = S_b + S_v = \mathbf{182.1 \text{ mm}}$$

Solution (3/3)

SOLUTION

	S_e (mm)	S_c (mm)	heave (mm)	total (mm)
without excavation (Example 3)	30.7	150.2	0	**181.0**
excavated, **preserved** (from the original ground)	31.5	182.1	-27.8	**185.8**
excavated, **set to zero** (from the heaved base)	31.5	182.1	—	**213.6**

Total settlement measured from the original ground is **185.8 mm** (S_e + S_c + heave); measured from the heaved base it is **213.6 mm**. The difference equals the heave (27.8 mm).

Check the solution in GeoTerva ↗

Immediate settlement at once, consolidation over time

THEORY

$$T_v = \frac{C_v\, t}{H_{dr}^2} \qquad U(T_v) = 1 - \sum_{m=0}^{\infty} \frac{2}{M^2} e^{-M^2 T_v} \qquad M = \frac{\pi(2m+1)}{2}$$

$$S(t) = S_e + \sum_i U_i(t)\, S_{c,i} \;\; [+ S_{heave}] \qquad t = \frac{T_v\, H_{dr}^2}{C_v}$$

S_e is present **immediately** ($t = 0^+$); consolidation proceeds in each cohesive layer with its own C_v and H_{dr}: H_{dr} = H (one-way) or H/2 (two-way).

$T_{v,50} = 0.197$; $T_{v,90} = 0.848$; $T_v < 0.05$'te $U = 2\sqrt{(T_v/\pi)}$.

The curve is the sum of the layer curves; the t_{50} and t_{90} values of the system are read from this sum. In a profile with no cohesive layer there is no time curve: the entire settlement is immediate.

With the "preserved" option the curve starts at zero heave and ends at the net deformation.

SAND + CLAY

Sand settles immediately; **clay determines the shape of the time curve**.

Problem statement

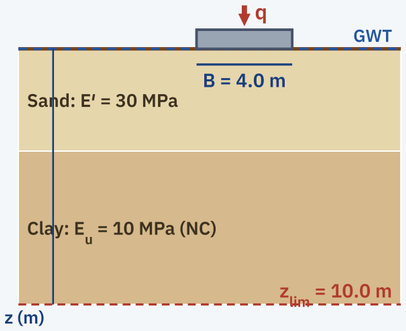
EXAMPLE

Given

Profile	**sand 0–4 m:** $E' = 30\ \mathrm{MPa},\ \nu' = 0.30, \gamma_{sat} = 19$ · **clay 4–10 m (NC):** $E_u = 10\ \mathrm{MPa},\ \nu = 0.5, e_0 = 1.0,\ C_c = 0.30,\ C_v = 2\ \mathrm{m}^2/\mathrm{year}, \gamma_{sat} = 18$
Foundation	**4 × 6 m flexible rectangle, $q = 150\ \mathrm{kPa}$, at the ground surface; GWT at the surface; calculation depth 10 m (base of the profile)**
Previous examples	**S_e = 30.7 mm (Example 1); S_c = 150.2 mm (Example 2); no excavation**
Drainage	**clay drains at the top (sand) and at the bottom (stiff base): double drainage, H = 6 m**
Times	**t = 0.25; 0.5; 1; 2; 4; 8 years**

REQUIRED

H_{dr}, t_{50}, t_{90} and S(t); settlement at t = 0⁺.



Solution (1/2)

SOLUTION

1 Drainage path and durations (C_v = 2 m²/year)

$$H_{dr} = \frac{H}{2} = 3\ \text{m} \qquad t_{50} = \frac{0.197(3^2)}{2} = \mathbf{0.89}\ \text{year} \qquad t_{90} = \frac{0.848(3^2)}{2} = \mathbf{3.82}\ \text{year}$$

2 Initial and final settlement

$$S(0^+) = S_e = 30.7\ \text{mm} \qquad S(\infty) = S_e + S_c = 30.7 + 150.2 = \mathbf{181.0\ mm}$$

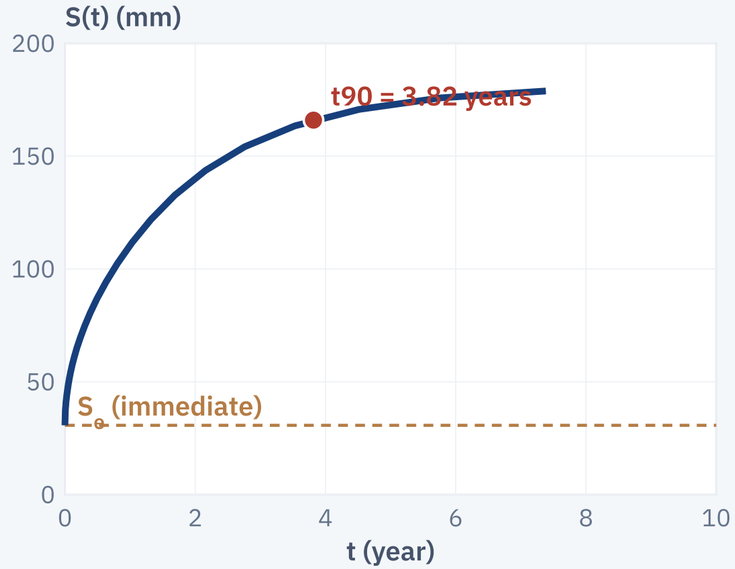
As soon as the load is applied, the settlement is 30.7 mm (17% of the total); 90% of the clay consolidation is completed in **3.82 years**.

Solution (2/2)

SOLUTION

t (year)	U	$S_c(t)$ (mm)	$S(t) = S_e + S_c(t)$ (mm)
0.25	0.266	40.0	**71**
0.50	0.376	56.5	**87**
1.00	0.531	79.8	**110**
2.00	0.729	109.6	**140**
4.00	0.910	136.7	**167**
8.00	0.990	148.7	**179**

Total settlement in 1 year is 110 mm (61% of the final value), and 167 mm in 4 years (92%). The curve starts with immediate settlement and rises with the consolidation of the clay.



Check the solution in GeoTerva ↗

Problem statement

EXAMPLE

Given

Profile	**clay only, 0–6 m (NC): $E_u = 10$ MPa, $e_0 = 1.0$, $C_c = 0.30$, $\gamma_{sat} = 18$; GWT at the surface**
Foundation	**4 × 6 m, $q = 150$ kPa, no excavation; design depth 6 m (base of the profile)**
Comparison	**Elastic Settlement (Cohesive) + Consolidation modules**

REQUIRED

Compare S_e, S_c and the total from the Total Settlement module with the results of the two single-type modules.

Solution

SOLUTION

Module	S_e (mm)	S_c (mm)	total (mm)
Elastic Settlement: Cohesive Soil	35.3	—	—
Consolidation	—	591.6	—
sum of the two modules	35.3	591.6	**626.9**
Total Settlement (2D)	35.3	591.6	**626.9**

The Total Settlement module is **exactly identical** to the sum of the two modules for a single-type profile (626.9 mm). The corner sum is 601.5 mm ($S_{e,corner}$ = 9.9 + S_c), the rigid footing 624.4 mm.

Check the solution in GeoTerva ↗

Problem statement

EXAMPLE

Given

Profile	**Embankment, sandy 0–2 m (E = 12 MPa) · Clay-1 2–7 m (E_u = 8 MPa; C_c = 0.25; OCR = 1.6) · Sand 7–11 m (E = 35 MPa) · Clay-2 11–20 m (E_u = 15 MPa; C_c = 0.30; OCR = 1.3) · Gravelly sand 20–30 m (E = 70 MPa)**
Footing, excavation	**10 × 15 m, q_{gross} = 120 kPa; excavation depth 2 m (excavation plan = foundation); GWT 2 m**
Design depth	**influence depth, p = 10%**
Result	**Example project of the Total Settlement module**

REQUIRED

S_e and S_c layer by layer, heave; centre, corner, rigid total; t_{50} and t_{90}.

Solution (1/2)

SOLUTION

1 Excavation and design depth

$$q_{lift} = \sigma'_{v0}(2) = 18(2) = 36.0\ \text{kPa} \qquad q_{net} = 120 - 36.0 = \mathbf{84.0}\ \text{kPa}$$

$$z_{lim} = D_f + z' = 2 + 25.47 = \mathbf{27.47}\ \text{m}$$

The fill (0–2 m) is removed by excavation; the calculation covers four layers from 2 m to z_{lim} = 27.5 m. The last layer (gravelly sand) is cut by z_{lim}; the contribution of deeper layers is small.

Solution (2/2)

SOLUTION

Layer	z (m)	S_e (mm)	S_c (mm)	heave (mm)	total = S_e + S_c + heave (mm)
Clay-1 (CL, soft)	2.0 – 7.0	20.8	198.4	-62.6	156.6
Sand (SM, medium dense)	7.0 – 11.0	5.6	—	—	5.6
Clay-2 (CH, hard)	11.0 – 20.0	14.1	27.0	-6.5	34.6
Gravelly sand (dense)	20.0 – 27.5	1.2	—	—	1.2
Total (center)		**41.7**	**225.4**	**-69.1**	**198.0**

Centre **198.0 mm** = S_e 41.7 + S_c 225.4 – swell 69.1 (retained); corner 168.7 mm, rigid 195.1 mm. Time: t_{50} = 0.72 years, t_{90} = 3.71 years. The module gives the same values.

Check the solution in GeoTerva ↗

Points to keep in mind when reading the results

THEORY

Foundation level = excavation base; uniform pressure under a fully flexible footing; rigid footing ≈ 0.93 × flexible center at the sudden part.

Immediate settlement: stresses of a homogeneous half-space in each layer (with its own ν); cohesive layer undrained ($\nu = 0.5$), granular layer drained; no embedment correction ($I_f = 1$).

Consolidation: one-dimensional Terzaghi; hydrostatic pore water pressure, the GWT is not affected by the excavation; σ'_p is the maximum past stress, it does not decrease with excavation; the stress increase is taken along the vertical below the center.

Settlement positive, heave negative; the selector in the header flips it (the engine stays classical).

Out of scope: secondary compression, consolidation of granular layers, Schmertmann and SPT/CPT charts, modulus increasing with depth within a layer (subdivide the layer), foundation rigidity and soil–structure interaction, 2D/3D consolidation, finite elements, bearing capacity, liquefaction.

Summary

Key points

$S = S_e + S_c$: cohesive layer = undrained immediate settlement + consolidation; granular layer = drained elastic settlement only

Immediate settlement (Steinbrenner): $\Delta S_e = q_{net}\, \alpha\, B'\, (1 - \nu^2)/E \cdot [I_s(z_{bottom}) - I_s(z_{top})]$; $q_{net} = q_{gross} - \sigma'_{v0}(D_{exc})$

Consolidation: stress path $\sigma'_{v0} \rightarrow \sigma'_{exc} \rightarrow \sigma'_{v0} \rightarrow \sigma'_{p} \rightarrow \sigma'_{final}$ (C_s, C_r, C_c); in NC clay $S_c = C_c\, f \log(\sigma'_{final}/\sigma'_{v0})$

Centre $S_e + S_c$; **corner** $S_{e,corner} + S_c$; **rigid** $0.93\, S_e + S_c$; differential settlement = difference of the immediate components

Excavation: the immediate part with q_{net}, the clay by swelling + recompression; "preserved" $S = S_e + S_c + S_{swelling}$, "reset" $S_e + S_c$

Time: $S(t) = S_e + \Sigma\, U_i(t)\, S_{c,i}$; $T_{v,50} = 0.197$, $T_{v,90} = 0.848$; $H_{dr} = H$ (single) or $H/2$ (double)

For a single soil type the result is **exactly the same** as the Elastic Settlement or Consolidation module

References

Das, B.M. (2016). Principles of Foundation Engineering, 8th ed. Cengage.

Das, B.M. (2018). Principles of Geotechnical Engineering, 9th ed. Cengage — Ch. 10–11 (stress increase, consolidation settlement, time rate).

Steinbrenner, W. (1934). Tafeln zur Setzungsberechnung. Die Strasse, 1, 121–124.

Terzaghi, K. (1943). Theoretical Soil Mechanics. Wiley.

Duncan, J.M. & Buchignani, A.L. (1976). An engineering manual for settlement studies. University of California, Berkeley.

Kulhawy, F.H. & Mayne, P.W. (1990). Manual on Estimating Soil Properties for Foundation Design. EPRI EL-6800.

NOTE

All numerical examples have been produced with the module's own calculation engine; the module gives the same values (example slices: dz = layer thickness).

GeoTerva

Online geotechnical analysis

From theory to practice

Build your own layered clay and sand profile in GeoTerva; the module gives the settlement and the time curve together.

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