

Exam Soil Mechanics

Bachelor 2nd year, CiT/CTW

Module/course code: 202000065-1A: Safety and Risk in Delta's – Soil Mechanics

Date: 16 October 2025

Time: 13.45-15.45 (+25% for students who may use extra time)

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Instructors: Hongyang Cheng

Type of test: Exercises, Open questions.

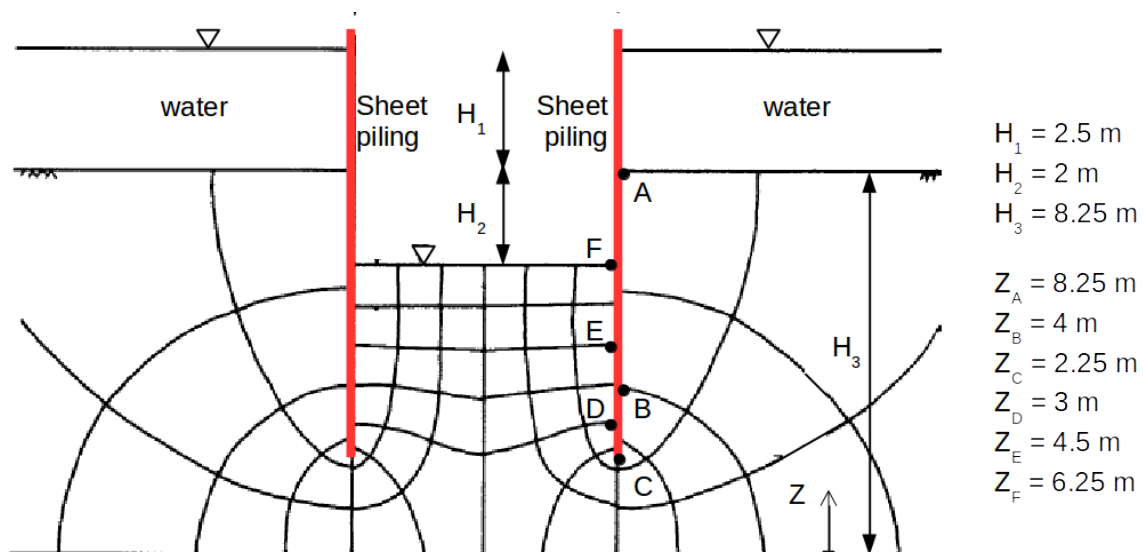
Allowed aids: Scientific calculator, formula sheet, English-Dutch dictionary.

Attachments: Formula sheet.

Exercise 1 (40 points)

A river bed consists of a layer of sand 8.25m thick ($\gamma_{\text{sat}} = 19\text{kN/m}^3$) overlying impermeable rock. The depth of water (H_1) above the river bed is 2.50 m. A long cofferdam is formed by driving two lines of sheet piling to a depth of 6.00 m below the level of the river bed (from point A to Point C). Excavation within the cofferdam to a depth of 2.00 m below bed level is carried out (from Point A to Point F). The water level within the cofferdam is kept at excavation level by pumping. The flow of water into the cofferdam is $7 \times 10^{-5} \text{ m}^2/\text{s}$ per unit length.

- ?/6.0 a) identify the equipotential and the flow lines (draw them with different colours/styles on the test paper or on your paper);
- ?/10.0 b) determine the coefficient of permeability of the sand;
- ?/8.0 c) compute the total head the pore pressure at points A to F (deduce the points elevation from the drawing);
- ?/8.0 d) calculate the effective stress at points E and B (deduce the points elevation from the drawing).
- ?/8.0 e) Calculate the factor of safety (FS) against heaving for the soil between the two levels indicated by Point E and Point F.

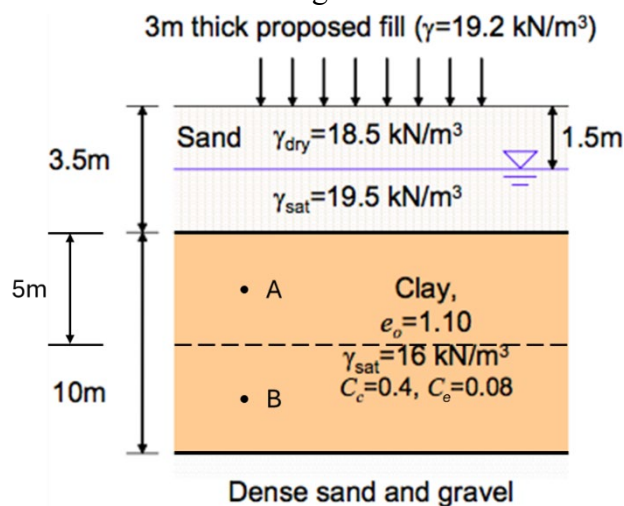


Exercise 2 (35 points)

A 3-meter thick compacted fill (represented by the distributed load) is to be placed over the soil profile shown below for pre-loading purposes. Consolidation tests on samples taken from the clay layer produced the following results, which are considered to be representative of the whole clay layer:

- $C_c = 0.4$;
- $C_e = 0.08$;
- $e_0 = 1.1$;
- $\sigma'_{\max} = 70 \text{ kPa}$

- ?/27.0 a) Divide the clay layer into two idealised sub-layers of 5 m each, as shown below. Calculate the stresses at the middle of the two layers (Point A and Point B) before and after the compacted fill is placed. Calculate the total settlement within the clay layer, assuming the strain at Point A and Point B is representative of their own layers.
- ?/8.0 b) Explain how $\sigma'_{\max}$ is measured experimentally and argue how preloading help controlling foundation settlement during construction.



Exercise 3 (25 points)

The following results were obtained from direct shear tests on specimens of a sand compacted to the in-situ density:

Normal stress (kN/m^2)	50	100	200	300
Shear stress at failure (kN/m^2)	36	80	154	235

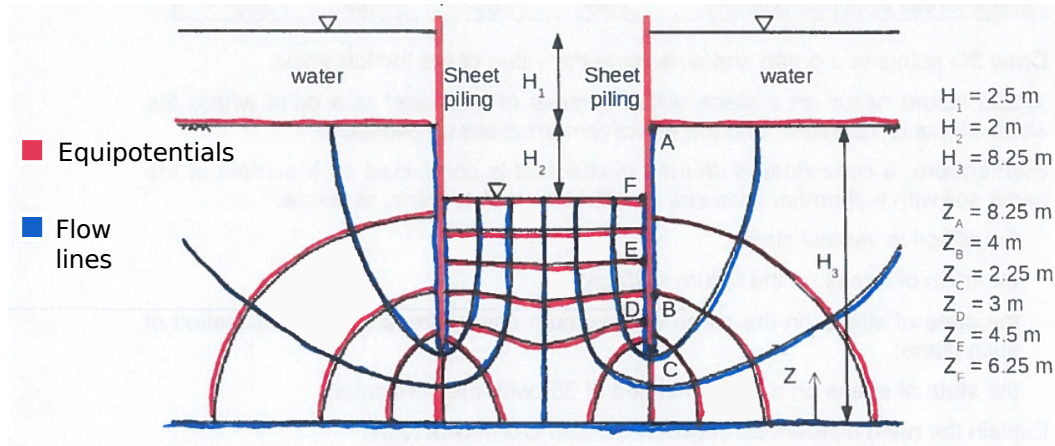
- ?/4.0 a) Draw the points in a graph and determine the value of the friction angle.
- ?/4.0 b) Would failure occur on a plane within a mass of this sand at a point where the shear stress is 122 kN/m^2 and the effective normal stress 246 kN/m^2 ?
- ?/13.0 c) Furthermore, a consolidated drained triaxial test is conducted on a sample of the same soil with a chamber pressure of 100 kN/m^2 . Determine, at failure:
- the effective vertical stress;
 - the state of stress on the failure surface;
 - the state of stress on the plane of maximum shear stress and the inclination angle of such plane;
 - the state of stress on a plane inclined of 35° with the horizontal.
- ?/4.0 d) Explain the main differences between CD and CU triaxial tests.

Exam Grondmechanica, October 2025, solutions

Exercise 1

Part a.

3.0+3.0 for labelling equipotential and flow lines. -1.0 per missing boundary of flow and equipotential lines.



Note that in this figure vertical walls are also red but they must not be confused with equipotential lines.

Part b.

$$q = Kh \frac{N_F}{N_D}, \quad N_F = 6, \quad N_D = 10, \quad h_A = Z_A + \frac{u_A}{\gamma_w}, \quad u_A = \gamma_w H_1, \quad u_F = 0 \text{ KPa}$$

$$\Rightarrow h_A = Z_A + \frac{\gamma_w}{\gamma_w} H_1 = 8.25 + 2.5 = 10.75 \text{ m}$$

$$\Rightarrow h_F = Z_F + \frac{u_F}{\gamma_w} = Z_F = 6.25 \text{ m}$$

$$\Rightarrow h_u = h_A = 10.75 \text{ m}$$

$$h_u - h_D = h_A - h_F = 10.75 - 6.25 = 4.5 \text{ m}$$

$$K = \frac{q N_D}{h N_F} = \frac{7 \cdot 10^{-5} \cdot 10}{4.5 \cdot 6} \simeq 2.6 \cdot 10^{-5} \frac{\text{m}}{\text{s}}$$

Part c.

$$\Delta h = \frac{h}{N_D} = \frac{4.5}{10} = 0.45 \text{ m}$$

$$h_P = h_u - n_{D,P} \Delta h, \quad \forall P = A, \dots, F$$

$$u_P = \gamma_w (h_P - Z_P)$$

POINT	Z [m]	n_D	h [m]	u [KPa]
A	8.25	0	10.75	25
B	4	2	9.85	58.5
C	2.25	4	8.95	67
D	3	6	8.05	50.5
E	4.5	8	7.15	26.5
F	6.25	10	6.25	0

3.0 in total 0.5 each

Part d.

$$\gamma_{sat} = 19 \text{ kN/m}^3$$

$$\sigma' = \sigma - u$$

$$\sigma_E = \gamma_{sat}(H_{EF}) = 19 \text{ kN/m}^3 \cdot (6.25 - 4.5) \text{ m} = 33.25 \text{ kN/m}^2$$

$$\sigma'_E = \sigma_E - u_E = (33.25 - 26.5) \text{ kN/m}^2 = 6.75 \text{ kN/m}^2$$

$$\sigma_B = \gamma_{sat}(H_{AB}) + H_1 \gamma_w = 19 \text{ kN/m}^3 \cdot (8.25 - 4) \text{ m} + 2.5 \text{ m} \cdot 10 \text{ kN/m}^2 = 105.75 \text{ kN/m}^2$$

$$\sigma'_B = \sigma_B - u_B = 105.75 - 58.5 = 47.25 \text{ kN/m}^2$$

Part e.

$$\Delta h_{EF} = 2 \times \Delta h = 2 \times 0.45 = 0.90 \text{ m}$$

$$\Delta L_{EF} = Z_F - Z_E = 6.25 - 4.5 = 1.75 \text{ m}$$

$$i_{EF} = \frac{\Delta h_{EF}}{\Delta L_{EF}} = \frac{0.90}{1.75} = 0.5143$$

$$\gamma_{sat} = 19 \text{ kN/m}^3$$

$$\gamma_w = 10 \text{ kN/m}^3$$

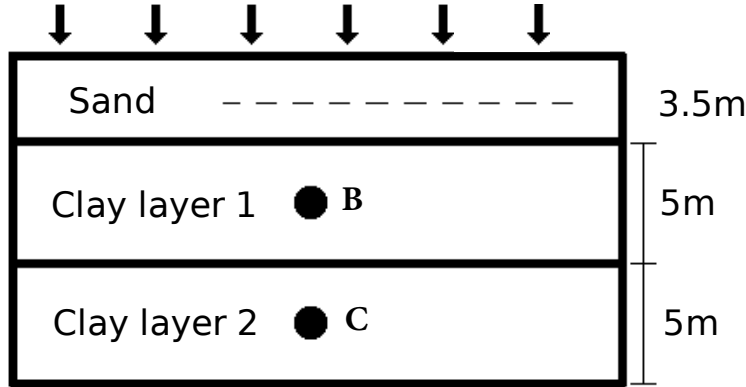
$$\gamma' = \gamma_{sat} - \gamma_w = 19 - 10 = 9 \text{ kN/m}^3$$

$$FS_{heave} = \frac{\gamma'}{i_{EF} \gamma_w} = \frac{9}{0.5143 \times 10} = \frac{9}{5.143} = 1.75$$

Exercise 2

Part 1.

If I split the clay layer in two parts, I have to calculate two settlements and sum them up.



Layer 1:

$$\sigma_B = \gamma_d \cdot 1.5 + \gamma_{sat} \cdot 2 + \gamma_{sat}^C \cdot \left(\frac{10}{2}\right) \cdot \frac{1}{2} = 18.5 \cdot 1.5 + 19.5 \cdot 2 + 16 \cdot 2.5 = 106.75 \text{ KN/m}^2$$

$$u_B = 10(2 + 2.5) = 45 \text{ KN/m}^2$$

$$\sigma'_B = (106.75 - 45) \text{ KN/m}^2 = 61.75 \text{ KN/m}^2$$

$$\sigma'_{B,f} = \sigma'_B + \Delta\sigma = 61.75 + 57.6 = 119.35 \text{ KN/m}^2$$

$$\text{We have: } OCR = \frac{\sigma'_{max}}{\sigma'_{Bi}} > 1, \quad \sigma'_{max} < \sigma'_F$$

$$\Delta e = -C_e \log \frac{\sigma'_{max}}{\sigma'_B} - C_c \log \frac{\sigma'_{B,f}}{\sigma'_{max}} = -0.08 \log \frac{70}{61.75} - 0.4 \log \frac{119.35}{70} = -0.004 - 0.093 = -0.097$$

$$S_{oed}^{(1)} = -\frac{\Delta e}{1 + e_0} H_1 = -\frac{-0.097}{1 + 1.1} \cdot 5 = 0.232 \text{ m}$$

Layer 2:

$$\sigma'_C = \sigma'_B + [\gamma_{sat}^C (Z_B - Z_C)] = 61.75 + (16 - 10) \cdot 5 \text{ m} = 91.75 \text{ KN/m}^2$$

$$\sigma'_{Cf} = \sigma'_C + \Delta\sigma = 149.35$$

$$\text{We have: } OCR = 1, \quad \text{and } \sigma'_C > \sigma'_{max}, \text{ so:}$$

$$\Delta e = -C_c \log \frac{\sigma'_{Cf}}{\sigma'_C} = -0.4 \log \frac{149.35}{91.75} = -0.085$$

$$S_{oed}^{(2)} = -\frac{\Delta e}{1 + e_0} H_2 = -\frac{-0.085}{1 + 1.1} \cdot 5 = 0.202 \text{ m}$$

Final results:

$$S_{oed} = S_{oed}^{(1)} + S_{oed}^{(2)} = 0.232 + 0.202 = 0.434 \text{ m}$$

Part 2.

The maximum effective stress σ'_{max} is measured when the slope of the consolidation curve changes significantly, indicating a switch from the re-consolidation line to the virgin consolidation line. Pre-loading is used before construction to overconsolidate the soil. A big weight is applied on the soil before construction and then removed. After the soil is overconsolidated, for a given change in stress $\Delta\sigma'$ due to construction, the corresponding change in void ratio Δe is determined by the elastic compression index

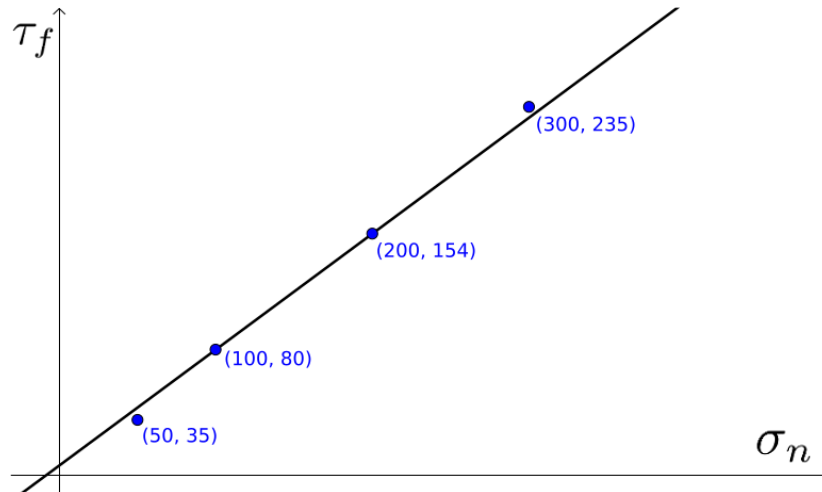
C_e on the elastic/reconsolidation branch. Being $C_e \ll C_c$, the settlement during due construction will be smaller.

4.0 for preloading

Exercise 3

Part 1.

σ_n	50	100	200	300
$[KN/m^2]$				
σ_f	35	80	154	235
$[KN/m^2]$				



1.0 for the axes and labels
1.0 for drawing the points
2.0 for getting the friction angle right. It's fine if cohesion is estimated too.

$$\phi' = \arctan \frac{80}{100} \simeq 38.5^\circ$$

$$\phi' = \arctan \frac{154}{200} \simeq 37.5^\circ \quad \text{etc} \dots$$

average: $\phi' \simeq 38^\circ$

Part 2.

Considering a friction angle of $\phi' = 38^\circ$, for $\sigma_n = 246 KN/m^2$:

$$\tau_f = \sigma'_n \tan \phi' = 246 \tan 38 = 192 KN/m^2$$

Since $192 KN/m^2 > 122 KN/m^2$, the point lies below the yield locus and failure will not happen.

Part 3.

CD test with $\sigma'_r = 100 KN/m^2$ on the same soil so $\phi' = 38^\circ$

-Effective vertical stress:

Failure plane:

$$\theta = 45 + \frac{\phi'}{2} = 45 + \frac{38}{2} = 64^\circ \text{ failure plane.}$$

Thus, at failure:

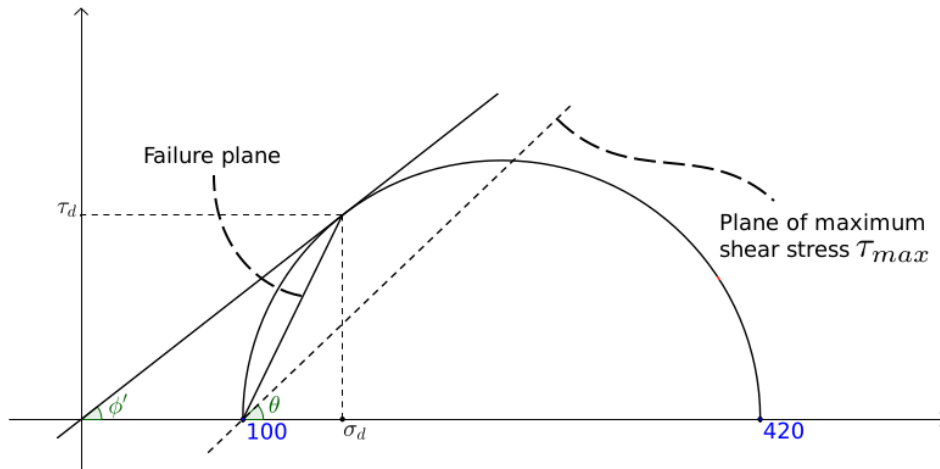
$$\sigma'_a = \sigma'_o \tan^2(\theta) = 100 \tan^2(64) = 420 KN/m^2$$

-State of stress on the failure surface: Mohr circle

data:

$$\sigma'_c = \frac{\sigma'_a + \sigma'_r}{2} = \frac{420 + 100}{2} = 260 KN/m^2$$

$$R = \frac{\sigma'_a - \sigma'_r}{2} = \frac{420 - 100}{2} = 160 \text{ kN/m}^2 \quad 1.0$$



$$\sigma'_d = \sigma'_c + R \cos 2\theta = 260 + 160 \cos 2 \cdot 64 = 161 \text{ kN/m}^2 \quad 1.0$$

$$\tau_f = R \sin 2\theta = 160 \sin 2 \cdot 64 = 126 \text{ kN/m}^2 \quad 1.0$$

$$(\text{or } \tau_f = \sigma'_d \tan \phi' = 161 \tan 38^\circ \simeq 126).$$

-state of stress on the plane of maximum shear stress and its inclination:

maximum shear stress:

$$\sigma_n = \sigma_C = 260 \text{ kN/m}^2 \quad \sigma_{max} = R = 160 \text{ kN/m}^2 \quad 1.0$$

inclination:

$$\theta(\tau_{max}) = 45^\circ \quad 1.0$$

-State of stress on a plane inclined of 35° with the horizontal:

$$\sigma_n = \frac{\sigma_a + \sigma_r}{2} + \frac{\sigma_a - \sigma_r}{2} \cos 2\theta_n = \frac{420 + 100}{2} + \frac{420 - 100}{2} \cos 2 \cdot 35 \simeq 315 \text{ kN/m}^2 \quad 1.0$$

$$\tau_n = R \sin 2\theta_n = 160 \sin 2 \cdot 35 \simeq 150 \text{ kN/m}^2 \quad 1.0$$

Part 4.

CD: drainage is allowed with the valve open in both the initial (consolidation) and shear stages.

CU: drainage is allowed in the initial stage (consolidation) but it is forbidden during shear.

CD tests give the property of the soil in the long term, while a CU test typically refers to the soil characteristics in the short term (time scale of permeability much bigger than the rate of application of the load). However, also long term properties can be obtained from a CU test, via proper equations.

CU is quicker (and then cheaper) than CD.

2.0 for drained/undrained condition

2.0 for speed/rate of the test