2023 Soil Mechanics I and Exercises [Final Exam]

January 30, 2024 (Tue.) 13:15–15:15

Notes:

- The examination consists of four questions for which you are provided with four answer sheets and one diagram.
- Write down your name and student ID number on every sheet including the diagram sheet. Note that any sheets without your name may not be graded.
- Use one answer sheet per question and answer them in sequence, starting from [Question 1]. If the front page of an answer sheet is insufficient to complete your answer, <u>continue your answer on the back side of the same sheet of paper</u>. Be careful not to spread the answer to a single question across multiple sheets of paper. Note that answers given over multiple sheets of paper may not be graded.
- Wherever necessary, specify the units in your answers.
- In addition to personal writing instruments, use of non-programmable calculators and rulers are permitted. However, programmable calculators and calculator functions of mobile phones are prohibited.
- Any attempt at cheating on the exam will result in failed credit of the course and serious penalties.

[Question 1] Answer the following questions.

(1) Consider the construction of an embankment by collecting soil from a nearby excavation site for residential land development. Assuming that the density of water is 1.00 Mg/m^3, answer the following questions.

1) To determine the physical properties of the soil, a soil sample with a volume of 4.00 m^3 is collected from the excavation site, and its mass is measured to be 8.00 Mg. The water content of the soil is 18.0%, and the soil particle density is 2.50 Mg/m^3. Find the wet density, dry density, void ratio, and degree of saturation of the soil in its natural state at the site.
2) An embankment with a height of 2.00 m and an area of 2.00×10^4 m^2 is constructed by compacting the soil collected from the excavation site while adding water by sprinkling. If the target dry density is 1.50 Mg/m^3, find the volume of soil in its natural state that should be taken from the excavation site.
3) Find the mass of water to be added by sprinkling to make the degree of saturation of the embankment 80.0% after compaction. Also, find the water content and air content (i.e., air volume / total volume) of the embankment at this degree of saturation.
4) State whether it is possible to compact the soil to a dry density of 1.80 Mg/m^3 while maintaining the water content in 3) and give reasons for this. You may use a diagram if necessary.
5) Attempting embankment construction under conditions 2) and 3), it has been found that the dry density of the embankment is not uniform in the vertical direction; the dry density of the upper layer above a certain height is 1.42 Mg/m^3, while the dry density of the lower layer below the height is 1.55 Mg/m^3. Find the height of the boundary between the upper and lower layers, as well as the water content and degree of saturation in each layer. Assume that the mass of water contained in the upper and lower layers is equal.

(2) Briefly explain the following terms, giving definitions with mathematical expressions.

1) Relative density
2) Coefficient of uniformity
3) Plasticity index

[Question 2] Answer the following questions about the seepage flow in the soil.

(1) A permeability test was conducted in the horizontal direction on a specimen consisting of two layers of different soils: Soil 1 (thickness H_1 [cm], coefficient of permeability k_1 [cm/s]) and Soil 2 (thickness H_2 [cm], coefficient of permeability k_2 [cm/s]) (see Figure 2-1). Answer the following questions. Note that the boundary between the layers is horizontal, and unit depth (perpendicular to the page) is considered in all questions.

1) Explain Darcy's law.
2) With $H_1 = 10$ cm and $H_2 = 20$ cm, a permeability test was conducted on the specimen by applying 15 cm head difference between the left and right sides. During the test, 27.0 cm^3 of water flowed out from the downstream side in 10 minutes. Calculate the value of the equivalent horizontal coefficient of permeability k_h, considering Soil 1 and Soil 2 as a single layer.
3) Next, with $H_1 = 25$ cm and $H_2 = 5$ cm, a permeability test was conducted on the specimen by applying a 20 cm head difference between the left and right pipes. During the test, 54.0 cm^3 of water flowed out from the downstream side in 10 minutes. Together with the results of the permeability test in question 2), calculate the values of the coefficient of permeability k_1 and k_2 for Soil 1 and Soil 2, respectively.

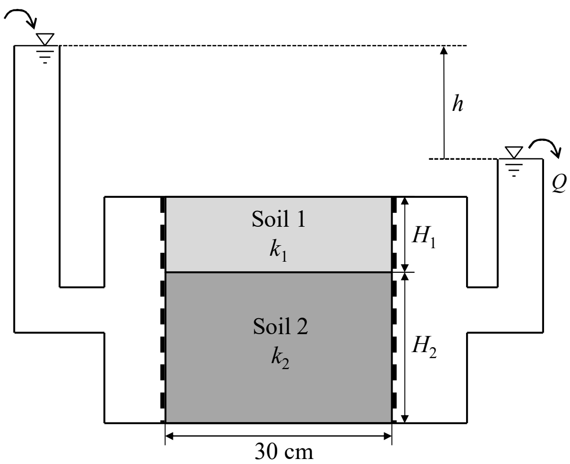

Figure 2-1

(2) Consider an earth dam of a reservoir constructed on a horizontal impermeable layer as shown in Figure 2-2. Assume that the water level of the reservoir reaches up to 12 m height from the impermeable layer, and a drainage system is installed at the foot of the downstream side of the dam, which is in a steady state. Answer the following questions.

1) In Figure 2-2, the phreatic surface and streamlines (flow lines) from the reservoir to the drainage system are depicted. Explain the criteria that should be met when drawing a flow net. Then, complete the flow net by adding equipotential lines (draw them on the diagram provided).

2) Given that the daily leakage rate per unit depth (perpendicular to the page) from the inner side of the dam was measured to be 0.58 m^3 and the coefficient of permeability of the soil can be approximated by Hazen's formula $k = 70D^2$ [cm/s] (D: effective grain diameter [cm]), calculate the effective grain diameter of the fill material constituting the earth dam. Then, based on this, determine which of the grain size distribution curves (a), (b), or (c) in Figure 2-3 is expected to represent the fill material. Note that the reference plane for elevation head is the top surface of the impermeable layer, and the total (piezometric) head is assumed to be zero along the boundary between the fill and the drainage system.

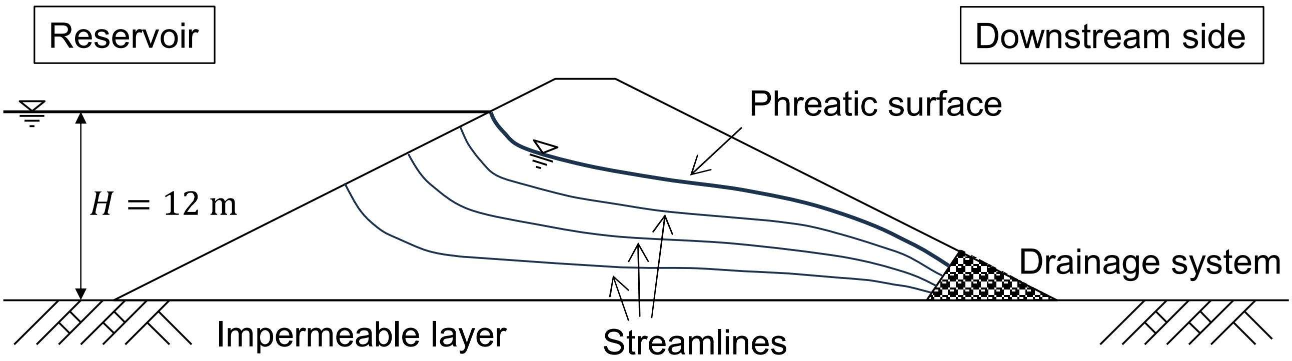

Figure 2-2

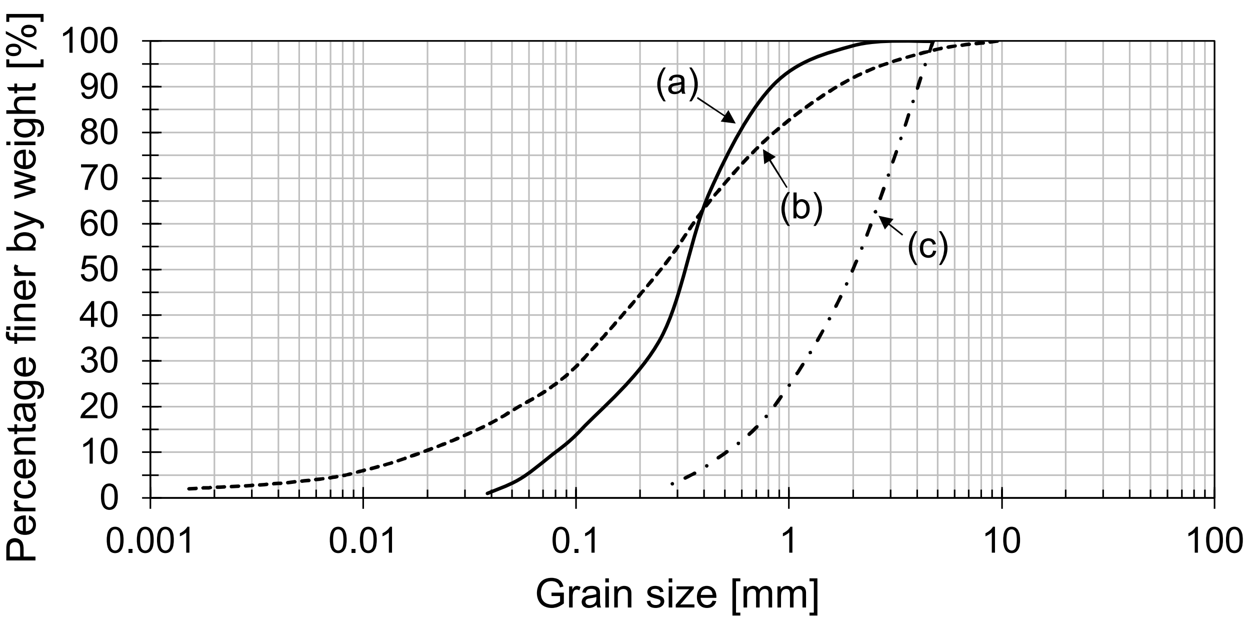

Figure 2-3

[Question 3] Answer the following questions.

(1) As shown in Figure 3-1, there is a ground consisting of a 6 m thick sand layer and a 10 m thick clay layer on an impermeable bedrock. Here, the saturated unit weight of the sand layer below the groundwater table, γ_{sat}, is 20 kN /m^3, and the wet unit weight of the sand layer in the area where the groundwater table drops, γ_t, is assumed to be 19 kN /m^3, which is the same as that of the soil above the groundwater table. In addition, the saturated unit weight of the clay layer is 17 kN / m^3, the initial void ratio, e_0, is 1.5, the coefficient of compressibility, m_v, is 8.0 × 10^{-4} m^2/kN, and the coefficient of consolidation, c_v, is 50 cm^2/day. Furthermore, the unit weight of water is γ_w = 10 kN/m^3.

1) Find the effective stress at the bottom of the sand layer when the groundwater level is 1m from the ground surface.
2) Pumping up groundwater lowered the groundwater level to 4m from the ground surface. At this time, find the effective stress at the bottom of the sand layer.
3) The clay layer will consolidate and settle due to the above groundwater pumping. Find the volumetric strain and final settlement due to this consolidation.
4) Find the time it takes for the degree of consolidation to reach 90 %. Note that the time factor is 0.85 when the degree of consolidation is 90 %.
5) After that, when pumping of groundwater was stopped, the groundwater level rose to the ground surface. At this time, find the overconsolidation ratio at the top surface of the clay layer. The overconsolidation ratio is the ratio of the consolidation yield stress (the maximum stress that has been applied to the clay in the past) to the effective overburden pressure (the stress that the clay is currently experiencing).

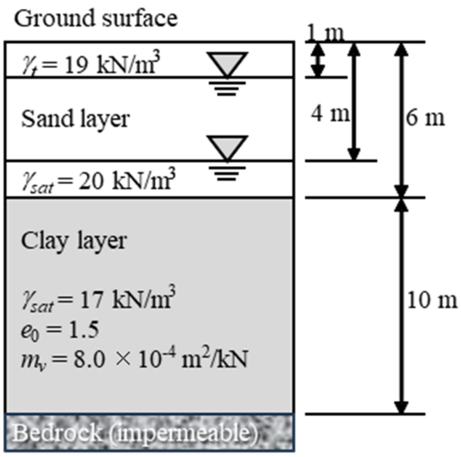

Figure 3-1

(2) Answer the following questions regarding consolidation of clay.

1) Answer whether the following statement is true or false as a prerequisite for one-dimensional consolidation theory.

(a) The soil is assumed to be fully saturated, and the soil pores are completely filled with water.

(b) It is assumed that consolidation is also important in the horizontal direction, and horizontal deformation is also taken into account.

(c) The soil particles themselves are assumed to be compressed, and consolidation occurs through compression of both soil particles and pores.

(d) The hydraulic conductivity is assumed to be constant throughout the consolidation process.

(e) The flow of pore water is assumed to follow Darcy's law, and the flow of water is laminar.

(f) The stress-strain relationship in soil is nonlinear, and changes in stress are not proportional to changes in strain.

(g) The soil is assumed to be homogeneous and isotropic, and the physical and mechanical properties are constant within the clay layer and independent of direction.

2) Derive Terzaghi's consolidation theory using the following four equations. Also, express the relationship between the consolidation coefficient C_v and other soil parameters by equation.

$$v = -\frac{k}{\gamma_w}\frac{\partial u}{\partial z}$$

$$\frac{\partial v}{\partial z} = \frac{\partial \varepsilon}{\partial t}$$

$$d\varepsilon = m_v d\sigma'$$

$$\frac{\partial \sigma}{\partial t} = \frac{\partial \sigma'}{\partial t} + \frac{\partial u}{\partial t} = 0$$

In above equations, v is the flow rate of pore water, k is the hydraulic conductivity of the target clay layer, γ_w is the unit weight of water, u is the pore water pressure, z is the depth from the ground surface, t is the time, ε is the vertical strain, m_v is the coefficient of compressibility, and σ' is the effective stress.

[Question 4] Answer the following questions.

(1) The stress state at a certain point in the ground is given in Figure 4-1.

1) Draw a Mohr's stress circle and find the maximum and minimum principal stresses.
2) Find the direction of the major principal plane (i.e., the plane where the maximum principal stress acts).
3) Find the normal and shear stresses acting on plane A-A′.

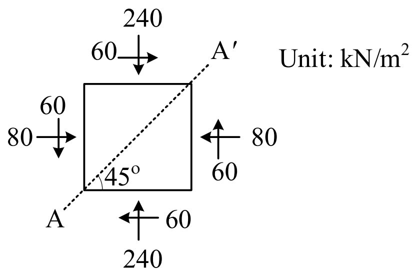

Figure 4-1

(2) A consolidated undrained ($\overline{CU}$) triaxial compression test was conducted on a saturated normally consolidated clay under lateral pressure $\sigma_3 = 200$ kN/m^2. Failure occurred when axial pressure $\sigma_1 = 500$ kN/m^2 and pore water pressure $u_w = 50$ kN/m^2 were reached.

1) Draw the Mohr's stress circles for total stress and effective stress at failure.
2) By assuming that the Mohr-Coulomb failure criterion is satisfied, determine the internal friction angle ϕ' of this clay based on the effective stress. Note that cohesion $c' = 0$ kN/m^2 can be adopted for normally consolidated clays.

(3) Answer the following questions regarding shear tests for sand and clay. Graphics and equations may be used if necessary.

1) Explain how to determine the internal friction angle ϕ and cohesion c of a soil from the direct shear test.
2) Consolidated drained (CD) and consolidated undrained ($\overline{CU}$) triaxial compression tests were conducted on a saturated dense sandy soil, with the latter having greater shear strength. Discuss the reasons for this, focusing on the dilatancy of the soil.
3) Explain why consolidated drained (CD) triaxial compression tests are generally not conducted on clays.
4) Explain the sensitivity ratio obtained by the unconfined compression test.