Soil Mechanics II and Exercises [Midterm Exam]

June 7, 2023 (Wed.) 8:45-10:15 Kyotsu 1 lecture room

Attention:

- The exam consists of three questions for which you are provided with three answer sheets. Write down your name and ID number on every answer sheet. 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, use **the back page of the same answer sheet** after clearly indicating your intent.
- Scores for each question are equally weighted.
- 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.
- Wherever necessary, specify the units in your answers.
- Any attempt at cheating on the exam will result in failed credit of the course and serious penalties.

[Question 1]

(1) Answer the following questions about Terzaghi's consolidation equation.

(1-1) In the derivation of Terzaghi's consolidation equation, there are some assumptions as listed from (a) to (f). Answer the terms in ① through ⑥.

(a) Soil compression and water flow occur in [①].

(b) The void spaces in the ground are always [②] by water.

(c) Water flow obeys [③].

(d) Soil compression is proportional to [④].

(e) [⑤] of soil particles and water is negligible.

(f) Coefficient of permeability is [⑥].

(1-2) Terzaghi's consolidation equation is derived as follows using Eqs. (1) to (4). Show the formulas in ⑦ to ⑩ in Eqs. (1) to (4).

(Terzaghi's consolidation equation) $$\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2}$$

Relation between effective stress and strain: $d\varepsilon =$ [⑦] Eq. (1)

Constant total stress condition: $\frac{\partial \sigma}{\partial t} =$ [⑧] $= 0$ Eq. (2)

Darcy's law: $v = -k\frac{\partial h}{\partial z} =$ [⑨] $\frac{\partial u}{\partial z}$ Eq. (3)

Continuity equation for water: $\frac{\partial v}{\partial z} =$ [⑩] Eq. (4)

where, c_v is coefficient of consolidation, σ is total stress, σ' is effective stress, u is excess pore water pressure, t is time, ε is soil strain, m_v is coefficient of volume compressibility, v is pore water velocity, k is coefficient of permeability, h is total head, z is the position coordinate and γ_w is unit weight of water.

(1-3) Select the assumption(s) on which Eq. (4) is based from (a) to (f) in question (1-1) and explain the reason.

(2) A saturated 5 m-thick clay layer is sandwiched between sand layers on the top and bottom. When a soil sample was taken from this clay layer and a consolidation test was conducted, it took 10 minutes for the 2 cm-thick specimen to reach 50% consolidation. Find the coefficient of consolidation, c_v and time required for this clay layer to reach 90% consolidation. You may use the values in Table 1.

Table 1

Degree of consolidation U [%]	10	20	30	40	50	60	70	80	90
Time factor T_v	0.008	0.031	0.071	0.127	0.197	0.287	0.403	0.567	0.848

(3) When a triangular distributed load shown in Figure 1 is applied on the surface of a ground, the vertical stress σ_z at Point A can be given by the Eq. (5). Using Eq. (5), show the vertical stress σ_z at point A shown in Figure 2. Herein, the ground behavior is assumed to be linearly elastic.

$$\sigma_z = \frac{p}{\pi} \cdot \theta \qquad \text{Eq. (5)}$$

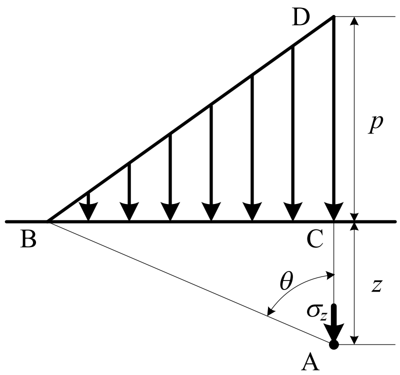

Figure 1

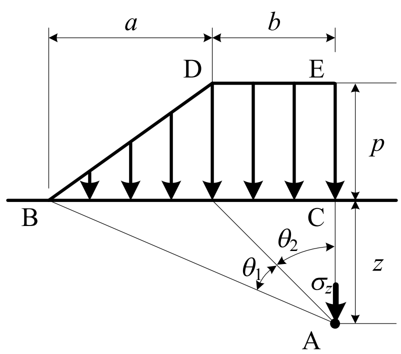

Figure 2

[Question 2]

Consolidated-drained triaxial compression test (CD test) and consolidated-undrained triaxial compression test ($\overline{CU}$ test) are conducted on isotropically consolidated samples of clay. If the samples are consolidated at the same consolidation pressure p'_o and then sheared with constant confining pressure, the effective mean stress p'_f and stress deviator q_f at failure will be different between the CD and $\overline{CU}$ tests. Conversely, if the same p'_f and q_f at failure are achieved under both CD and $\overline{CU}$ tests, the samples must experience different consolidation pressure p'_o and confining pressure. To demonstrate these behaviors, triaxial tests were performed on three saturated samples of normally consolidated clay. Test 1 employs the CD test while Test 2 and Test 3 employ the $\overline{CU}$ test. During the tests, the confining pressures are maintained constant from the consolidation stage to the shearing stage. The values at failure for excess pore water pressure u_f, p'_f, q_f and the value of p'_o are partially described in Table 2. Note that the unknown (a), (b), (c) and (d) are required for the subsequent calculations.

Table 2

Descriptions	Test 1 (CD)	Test 2 ($\overline{CU}$)	Test 3 ($\overline{CU}$)
Consolidation pressure, p'_o (kN/m^2)	200	200	(c)
Mean effective pressure at failure, p'_f (kN/m^2)	284	(a)	284
Stress deviator at failure, q_f (kN/m^2)	252	93	252
Excess pore water pressure at failure, u_f (kN/m^2)	0	(b)	(d)

Assuming that the material properties of the samples used for each test are the same and the cohesion $c' = 0$, answer the following questions.

(1) Express the equations for p'_f and q_f in terms of the principal effective stresses σ'_{1f} and σ'_{3f} at failure under triaxial compression test, and find the values of σ'_{1f} and σ'_{3f} for Test 1.

(2) According to the Mohr-Coulomb failure criterion, determine the angle of internal friction ϕ' from Test 1

(3) Determine the slope of the failure line (stress ratio at failure) M from Test 1.

(4) Calculate (a) for Test 2

(5) Calculate (b) for Test 2.

(6) Find the shear strength ratio c_u/p'_o of Test 2 where c_u is the undrained shear strength

(7) As c_u/p'_o is constant for normally consolidated clay, calculate (c) for Test 3.

(8) Calculate (d) for Test 3.

(9) Obtain Skempton's pore pressure coefficient at failure A_f of Test 3.

(10) Draw the relationship among the failure line, the effective stress paths of Test 1, Test 2 and Test 3 in the p'-q plane. Specify the values of (a), (b), (c) and (d) on the figure.

[Question 3]

A retaining wall with a height of 6 m was constructed as shown in Figure 3. The wall is vertical on its two sides and the wall surface is smooth. Behind the wall there are two layers of soil. The thickness and properties of each soil layer are indicated in the figure. Note that for soil layer 1, the unit weight under dry condition is 17 kN/m^3 and for soil layer 2, the unit weight is 17.5 kN/m^3 and 19 kN/m^3 for dry and saturated condition, respectively. The soil is normally consolidated. The groundwater table is located at the top of soil layer 2. The unit weight of water γ_w is 9.8 kN/m^3. Answer the following questions.

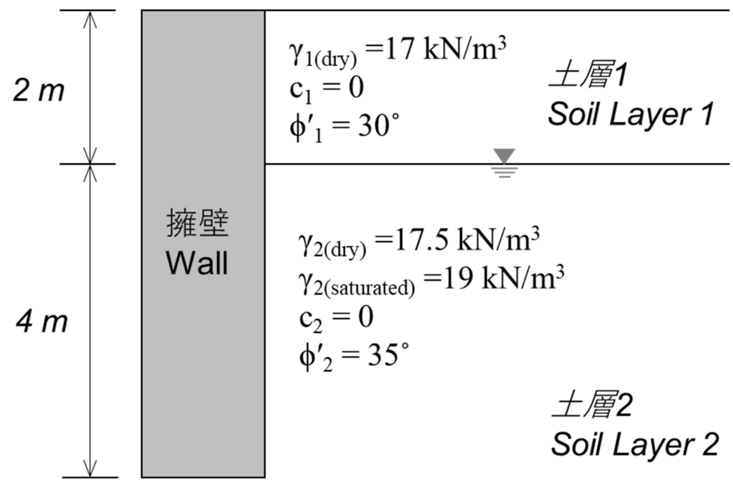

Figure 3

(1) Assume the wall is under at-rest condition with no lateral displacement. Draw the diagram of lateral earth pressure distribution on the wall and the diagram of water pressure distribution on the wall. The magnitude of the pressure at the top and bottom of each soil layer should be marked on the diagram. The lateral earth pressure coefficient for at-rest condition in normally consolidated soil can be calculated using the empirical formula of $K_0 = 1 - sin\phi'$.

(2) Following question (1), calculate the total resultant force on the wall (per unit length perpendicular to the figure) for the at-rest condition, then determine the point of application of the resultant force.

(3) If outward displacement of the wall occurs, using the Rankine theory and assuming an active state, calculate the total resultant force on the wall (per unit length perpendicular to the figure).

(4) Now, assume an at-rest condition for the wall again. The space behind the wall was used for stockpiling which can be assumed as a uniform surcharge of q. The stockpiling lasted for a long time and it was removed later. These conditions are illustrated in Figure 4. Take a small soil element A from the soil mass to study the stress evolution. In the Figure 5 provided below (copy it to your answer sheet), schematically draw the stress path at the element A from Condition 1 to 2 and from Condition 2 to 3, with horizontal axis representing effective horizontal stress and vertical axis being effective vertical stress.

Hint: through past studies it was found that the at-rest lateral earth pressure coefficient K_0 for overconsolidated soil may be calculated by $K_0 = (1 - \sin\phi')OCR^{\sin\phi'}$ where the OCR refers to overconsolidation ratio.

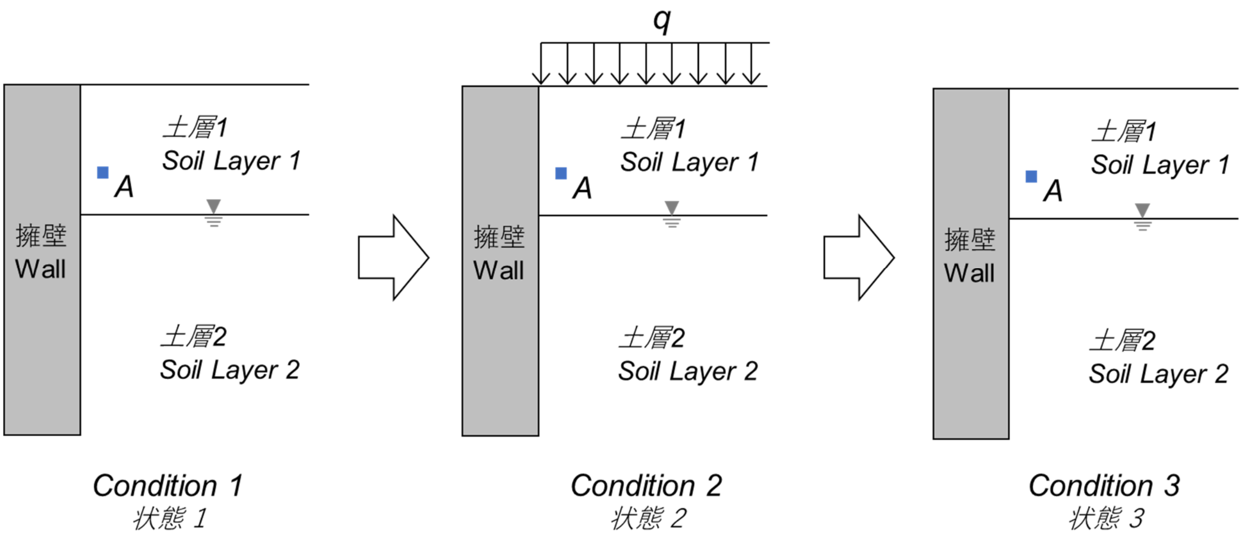

Figure 4　Change in conditions behind wall.

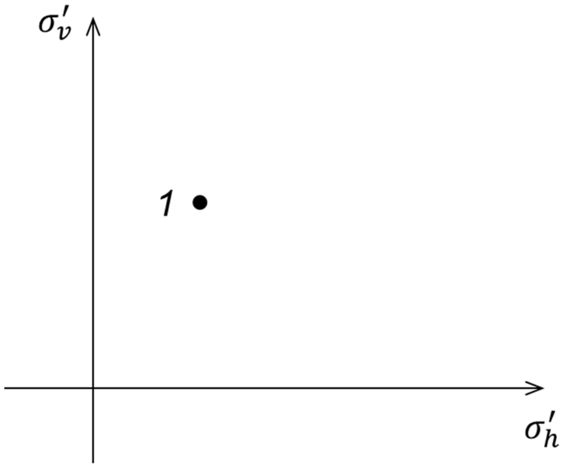

Figure 5　Stress path plot for Point A (the stress under condition 1 is given).