**Soil Mechanics II and Exercises [Final Exam]**

July 26, 2023 (Wed.) 10:00–12:00 Kyotsu 1 lecture room

Attention:

- The exam consists of five questions for which you are provided with five answer sheets. Write down your name and student 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.
- 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] As shown in **Figure 1-1**, an embankment is to be constructed on the uniform 20-m-thick clay layer underlain by a very stiff sand layer with negligible deformation. Assume that stress state at the middle of the layer can be used as the representative stress state of the clay layer. Let the stress increase in the clay layer due to the embankment loading follow the elastic solution of the vertical stress in ground beneath the center of an embankment.

(1) A sample was taken from the center of the clay layer and a consolidation test was conducted. The results are shown in **Table 1-1** and **Figure 1-2**. Find the consolidation yield stress (the pre-consolidation pressure) of the clay. Here, the method of obtaining the consolidation yield stress must also be explained.
(2) Answer whether this clay layer is under normal consolidation or overconsolidation.
(3) Find the vertical stress increment at the center of the clay layer due to the construction of embankment. You may use **Figure 1-3**.
(4) Find the final settlement at the top of the clay layer induced by the construction of embankment. Here, the settlement due to consolidation can be approximated by using the compressive strain at the middle of the clay layer as a representative value.
(5) The coefficient of consolidation of the clay layer is $c_v$ = 0.04 m$^2$/day. Find the settlement at one year after the construction of embankment. For simplicity, assume that the embankment was constructed instantaneously. You may use **Figure 1-4**.
(6) The sand drain method may be applied to reduce the consolidation time. Explain the mechanism of the method.

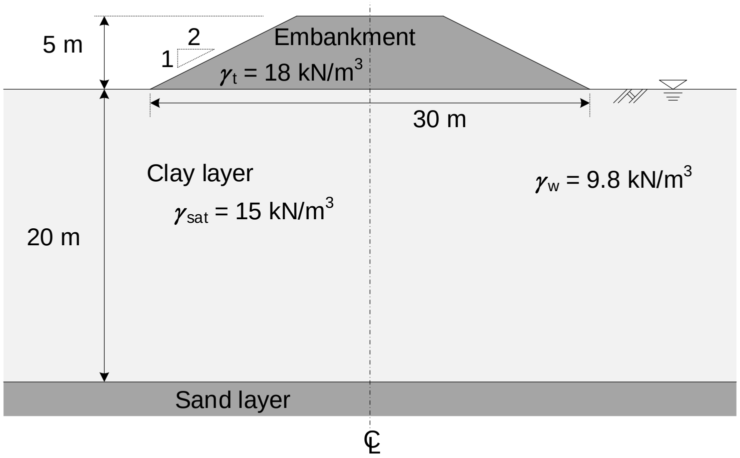


**Figure 1-1**

**Table 1-1**

| Consolidation pressure [kN/m$^2$] | Height of specimen [cm] | Void ratio |
|---|---|---|
| 0 | 2.000 | 2.839 |
| 9.8 | 1.995 | 2.829 |
| 19.6 | 1.987 | 2.814 |
| 39.2 | 1.970 | 2.781 |
| 78.5 | 1.927 | 2.699 |
| 157 | 1.819 | 2.491 |
| 314 | 1.659 | 2.184 |
| 628 | 1.505 | 1.889 |
| 1256 | 1.351 | 1.593 |

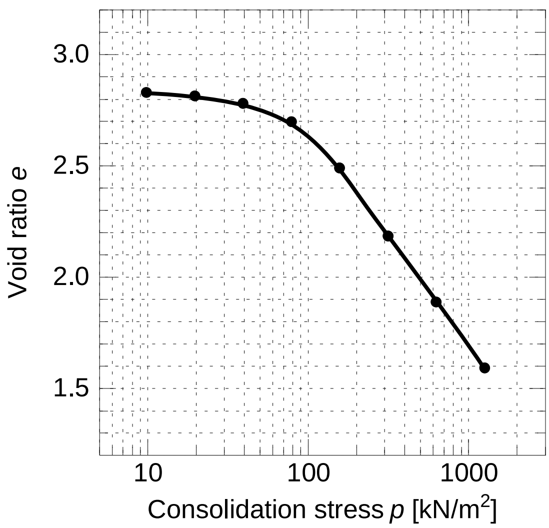


**Figure 1-2**

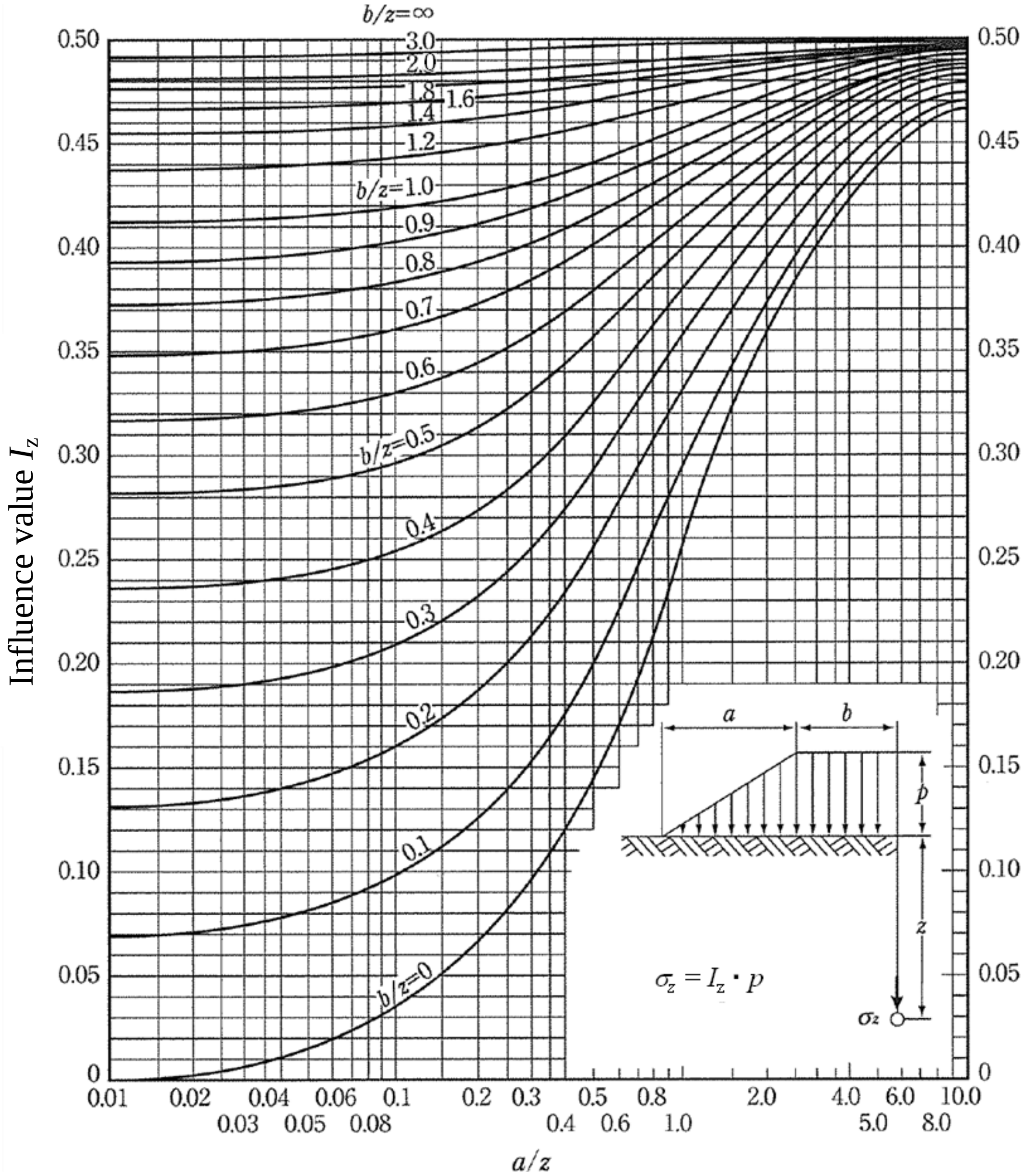


**Figure 1-3**

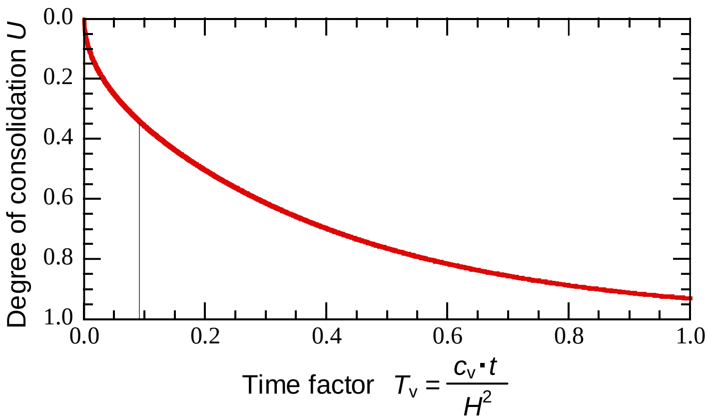


**Figure 1-4**

[Question 2] Answer the following questions regarding shear strength of soils.

According to **Figure 2-1**, the states of stress of consolidated drained triaxial tests at failure were recorded for Test 1 and Test 2, where $\sigma_r$, $\sigma_a$ and $\tau$ are confining, axial and shear stresses, respectively. Test 3, on the other hand, underwent a hollow-cylinder torsional shear test with $\tau_f$ representing shear stress at failure. Shear stress $\tau$ was zero during the triaxial tests, whereas $\tau$ was applied under the constant $\sigma_r$ and $\sigma_a$ conditions during the hollow-cylinder torsional shear test. By means of the Mohr-Coulomb failure criterion, answer the following questions.

| Test | $\sigma_r$ (kPa) | $\sigma_a$ (kPa) | $\tau$ (kPa) |
|---|---|---|---|
| 1 | 65 | 190 | 0 |
| 2 | 91 | 260 | 0 |
| 3 | 30 | 45 | $\tau_f$ |

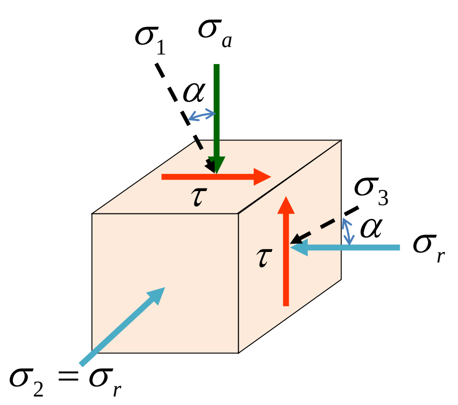


**Figure 2-1**

(1) Draw the Mohr's stress circles corresponding to the states of stress for Test 1 and Test 2 at failure and show the Mohr-Coulomb failure envelope.

(2) Find the cohesion $c$ and the friction angle $\phi$ from Test 1 and Test 2.

(3) Draw the Mohr's stress circles before and after applying the shear stress $\tau_f$ for Test 3.

(4) Derive the expressions of the major principal stress $\sigma_1$ and the minor principal stress $\sigma_2$ at failure using the shear stress $\tau_f$.

(5) Predict the shear stress $\tau_f$ at failure in Test 3.

(6) Based on (4) and (5), calculate $\sigma_1$ and $\sigma_3$ for Test 3 at failure.

(7) Use the pole method to obtain the rotation of principal axes by determining the angle $\alpha$ for Test 3 at failure.

(8) Describe the soil and site conditions for which the shear strength parameters obtained by consolidated drained triaxial tests are useful.

[Question 3] Consider a retaining wall of height $H$ (internal friction angle $\phi$, cohesion $c$, unit volume weight $\gamma$, of the backfill soil) as shown in **Figure 3-1**. Friction between the wall surface and the backfill soil is assumed to be negligible. The groundwater table is sufficiently deeper than the bottom of the retaining wall. The earth pressure acting on the retaining wall is assumed to be Rankine earth pressure. Answer the following questions.

(1) Schematically illustrate the relationship between the displacement of the retaining wall $\delta$ and the earth pressure $P$ acting on the retaining wall $P$, with $\delta$ on the horizontal axis and $P$ on the vertical axis. Clearly indicate the active earth pressure, the passive earth pressure and the earth pressure at rest. Refer to **Figure 3-1** for the direction of displacement.

(2) Illustrate Mohr's stress circles at the active failure and passive failure at depth $z$.

(3) Determine the active and passive earth pressures at depth $z$.

(4) Find the depth $z_c$ (maximum unsupported depth) where the active earth pressure is zero.

(5) Determine the resultant forces of the active and passive earth pressures acting on the retaining wall.

(6) If the backfill is clay soil, failure can be considered to occur under undrained conditions. When the undrained shear strength of the clay soil is $c_u$ and the internal friction angle is not considered, illustrate Mohr's stress circles at active failure and passive failure at depth $z$.

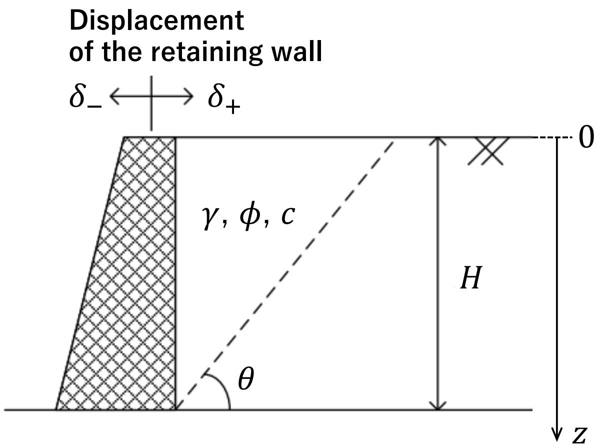


**Figure 3-1**

[Question 4] Consider the ground condition shown in **Figure 4-1** below. The Sand Layer 1 is 0.5 m thick and has a dry unit weight of 17.0 kN/m$^3$ and a saturated unit weight of 19.0 kN/m$^3$. Sand Layer 2 is located below Sand Layer 1 and has a dry unit weight of 18.0 kN/m$^3$ and a saturated unit weight of 20.0 kN/m$^3$. Other soil properties are shown in the figure. The groundwater level is located at the top of the Sand Layer 2. A concrete water channel is designed with its base at the top of the Sand Layer 2. The cross section of the concrete channel is shown in the figure. The thickness of the concrete channel is 0.2 m. The unit weight of concrete and water is 24.5 kN/m$^3$ and 9.8 kN/m$^3$, respectively. The concrete can be assumed to be impermeable.

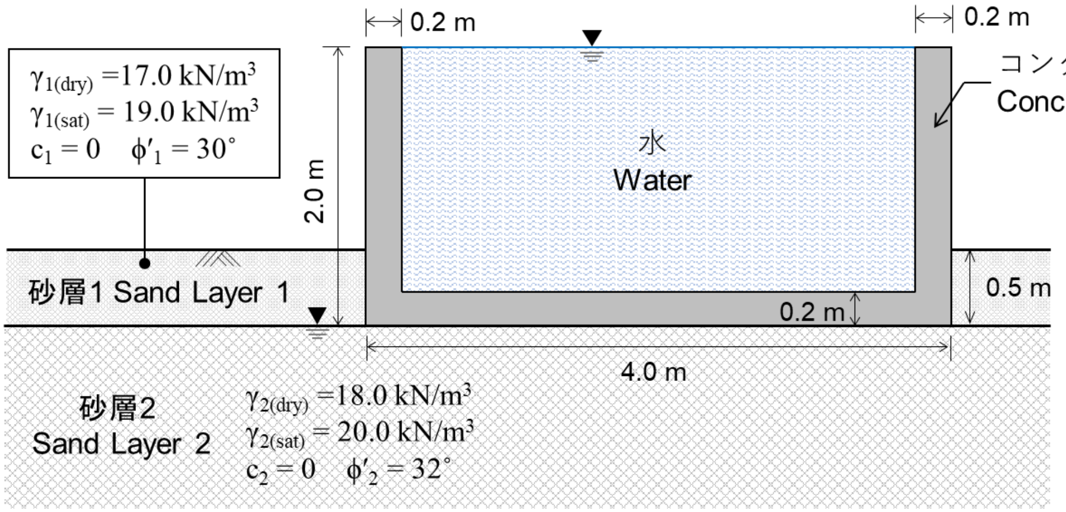


**Figure 4-1**. Ground condition and cross-section of designed water channel.

(1) Calculate the pressure at the base of the channel (at top of Sand Layer 2), assuming the channel is full of water and the pressure at the base is uniformly distributed.

(2) Write the equation developed by Terzaghi for calculation of the ultimate bearing capacity of a strip footing.

(3) Calculate the ultimate bearing capacity of the ground for the channel shown in **Figure 4-1**. Use the equations below to calculate bearing capacity factors.

$$N_c = cot\phi'(N_q - 1)$$

$$N_q = \frac{1}{1 - sin\phi'} exp\left[\left(\frac{3}{2}\pi - \phi'\right) tan\phi'\right]$$

$$N_\gamma = \left(N_q - 1\right) tan(1.4\phi')$$

At some locations, the water channel is designed as a culvert with its top at ground surface as shown in **Figure 4-2**. A critical condition for the design is when the culvert is dry (no water inside) and when the groundwater is located at the ground surface as shown in the figure. For this condition, adequate resistance against the buoyancy on the culvert is required. Friction piles with diameter of 0.2 m and length of 5.0 m are designed to resist such buoyancy. The piles are arranged with a certain spacing along the direction perpendicular to the page. The average skin friction of the piles is 50 kN/m$^2$. The culvert is fixed to the piles. Again, assume the unit weight of concrete and water to be 24.5 kN/m$^3$ and 9.8 kN/m$^3$, respectively. Answer the following question.

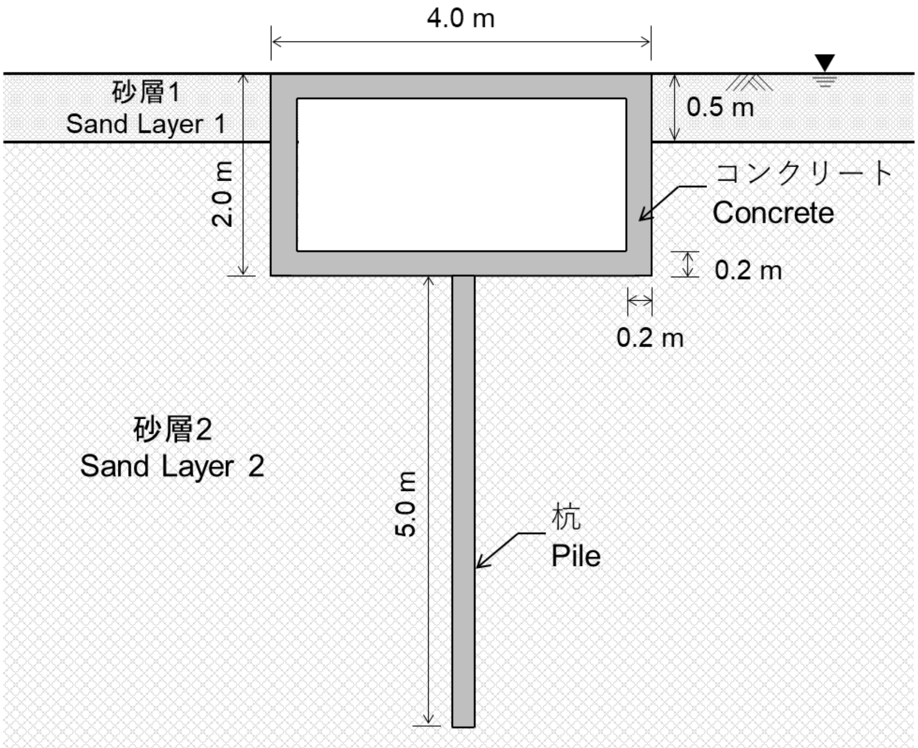


**Figure 4-2**. Concrete culvert with friction piles.

(4) Calculate the maximum possible spacing (perpendicular to the page) of those friction piles. Assume the concrete culvert has a smooth surface. Neglect the self-weight of the piles and the buoyancy acted on the piles. Assume the structural strength of the piles is adequate. Factor of safety does not need to be applied.

[Question 5] Answer the following questions.

(1) **Figure 5-1** shows a clay slope with the slope angle of 45 degrees and the height of $H$. Answer the following questions for a planar slip surface with an angle $\theta$ from the horizontal plane. The unit weight of clay is $\gamma$, the shear strength parameter is only the cohesion $c_u$ obtained by the UU test, the internal friction angle $\phi_u$ is zero.

(1-1) Express the weight $W$ of sliding block using $\gamma$, $H$ and $\theta$.

(1-2) Express the shear force $S$ on the slip plane using $W$ and $\theta$.

(1-3) Express the upper limit $S_f$ of shear force $S$ using $c_u$, $H$ and $\theta$.

(1-4) Express the slip safety factor $F_s$ using $\gamma$, $c_u$, $H$ and $\theta$.

(1-5) Find the angle $\theta$ of slip plane when the slip safety factor $F_s$ is minimized.

(2) Answer the following questions about liquefaction and ground vibration.

(2-1) **Figure 5-2** shows the schematic relationship between the void ratio $e$ and the effective confining pressure $p'$. Using the state of point B, explain the mechanism from point A at the normal consolidation state to point C during undrained shear.

(2-2) Draw a schematic diagram and explain the liquefaction strength curve. Indicate the vertical and horizontal axes of the graph, draw a schematic liquefaction strength curve, and briefly explain how to obtain this liquefaction strength curve.

(2-3) Consider the seismic response of surface ground on the bedrock. When the thickness of the surface layer $H = 15\ \mathrm{m}$ and the shear wave velocity of the surface layer $V_s = 120\ \mathrm{m/s}$, find the first-order period (dominant period, natural period) in which the ground is most prone to shaking.

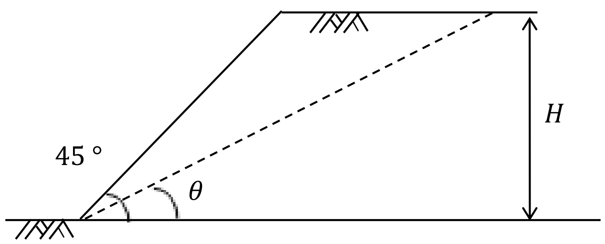


**Figure 5-1**

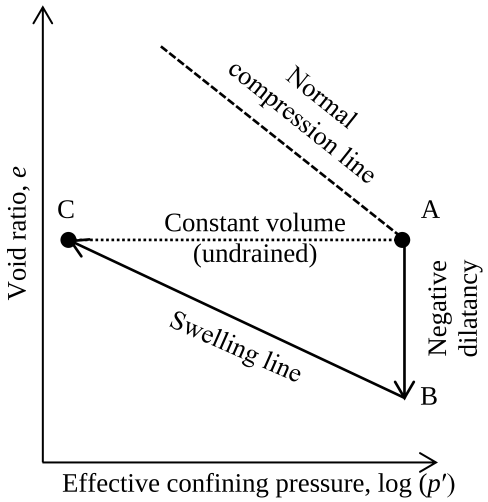


**Figure 5-2**