2024 Soil Mechanics I and Exercises [Final Exam]

January 28, 2025 (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]

(1) Answer the following questions regarding the physical properties of soil

1) Express the void ratio e, water content w (%), and degree of saturation S_r (%) using the notations shown in Fig. 1 (volumes and masses of the three-phase in soil).

2) Derive the relationship $eS_r = wG_s$, assuming the specific gravity of soil particles is G_s.

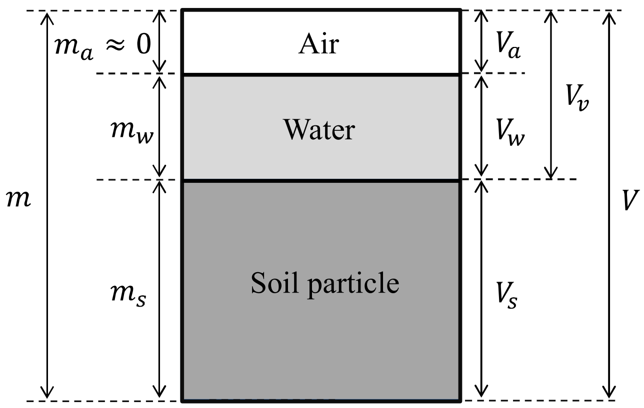

Fig. 1

(2) Consider constructing a river embankment by compacting soil excavated from a soil pit. Answer the following questions. Assume the density of water is 1.00 Mg/m^3.

1) The soil at the soil pit was tested and found to have a natural bulk density of $\rho_t = 1.70$ Mg/m^3, a water content of $w = 15.0$ %, and a specific gravity of soil particles of $G_s = 2.70$. Calculate the void ratio, degree of saturation, and dry density of the soil in its natural state at the soil pit.

2) To obtain the compaction characteristics of the soil at the soil pit, a compaction test was conducted, and the maximum dry density was determined to be $\rho_{dmax} = 1.90$ Mg/m^3, with the optimum water content $w_{opt} = 18.0$ %. If the soil is compacted at the optimum water content to achieve a compaction degree of 90.0% and used to construct an embankment with a volume of 30,000 m^3, calculate the volume of natural state soil that must be excavated from the soil pit.

3) Describe the expected benefits of soil compaction during river embankment construction in about 50 words using the following three terms: shear strength, compressibility, and permeability.

(3) Explain the following terms in 30~70 words.

1) Relative density

2) Effective stress

[Question 2]

(1) Answer the following questions, use equations where necessary.

(1-1) Briefly explain quicksand.

(1-2) Both constant head test and falling head test are used to determine hydraulic conductivity of soil. State the condition that each test will be applied.

(1-3) For the condition with seepage crossing three layers of soils, use the parameters given in Fig. 2 below, express the equivalent vertical hydraulic conductivity, k_v, of the soils when considering all layers as a whole. The vertical hydraulic conductivities (k_1~k_3) and the thicknesses (H_1~H_3) of the three layers are given in the figure.

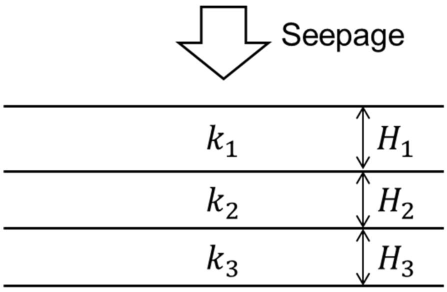

Fig. 2

(2) A lakebed consists of a sand layer 8.0 m-thick overlaying impermeable rock. The depth of water is 2.5 m. To enable excavation, two rows of parallel sheet piling are driven into the lakebed as shown in Fig. 3. The depth of penetration into the lakebed is 6.0 m. Excavation to a depth of 1.9 m below the lakebed level is carried out between the two rows of sheet piling. The water level within the excavated area is kept at the excavation level by pumping. Assume the datum is at the top of the impermeable rock. A flow net develops as shown in Fig. 3. The dry unit weight and saturated unit weight of the sand is 17.5 $\mathrm{kN/m^3}$ and 20.5 $\mathrm{kN/m^3}$, respectively. Assume the unit weight of water is 9.8 kN/m^3. Velocity head of the water does not need to be considered in the calculation. Answer the following questions:

(2-1) Calculate total head at Point A and D.

(2-2) Calculate pressure head at Point A and D.

(2-3) Calculate water pressure at Point A and D.

(2-4) Calculate vertical effective stress at Point A and D.

(2-5) If the seepage of water into the excavated space between the sheet piling is 0.25 m^3/hour per meter length (perpendicular to the paper), what is the hydraulic conductivity of the sand?

(2-6) When the water level in the lake increases, there is risk of quicksand in the excavated area. Among the locations marked by Point A, B, C and D, which location has the highest risk of quicksand occurrence? Give your answer with a brief reason.

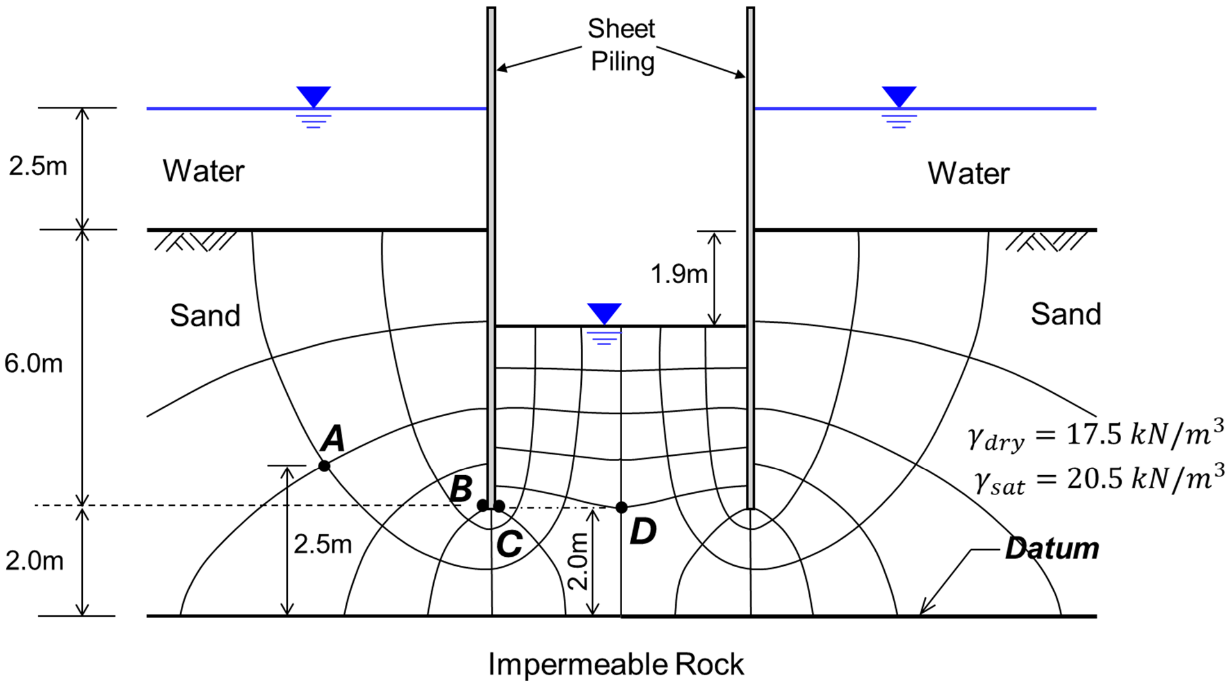

Fig. 3

[Question 3]

Consider a normally consolidated clay layer sandwiched by sand layers at both the top and bottom, as shown in Fig. 4. Due to pumping from a well in the upper sand layer, the groundwater level, initially located at point A, 3 meters below the ground surface, has decreased very quickly to point B (the boundary between the sand and clay layers). Answer the following questions. Note that the unit weight of water is 9.80 kN/m^3, the total (wet) and saturated unit weights of the sand are 18.0 kN/m^3 and 20.0 kN/m^3, respectively, and the saturated unit weight of the clay is 15.0 kN/m^3. Assume that the consolidation process follows Terzaghi's one-dimensional consolidation theory.

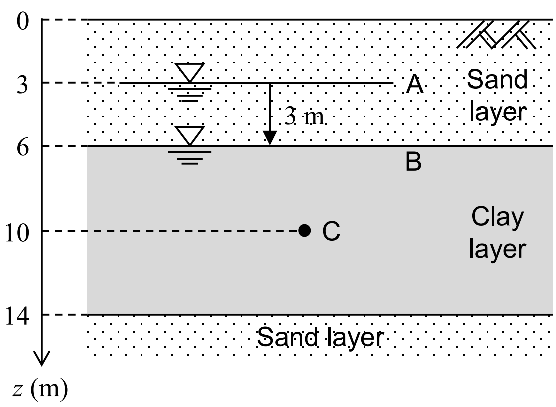

Fig. 4

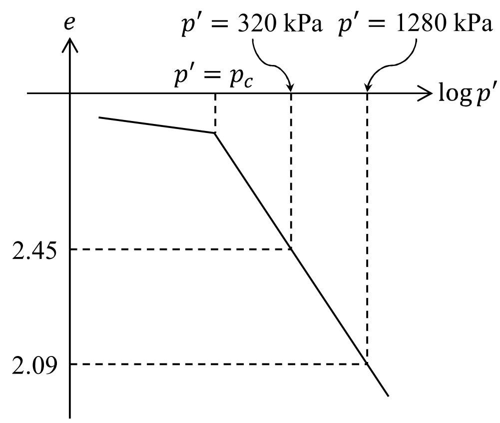

Fig. 5

(1) Draw the distribution diagrams of total stress, effective stress, and pore water pressure within the ground ($0 \leqq z \leqq 14$ m) both before and after the groundwater level decline (after a sufficient amount of time). Make sure to indicate the values at the inflection points of the lines so that the distribution diagrams are uniquely determined.

(2) An undisturbed sample was taken from the clay layer before the groundwater level decline, and a consolidation test was conducted. The relationship between void ratio and consolidation pressure (e-log p' curve) obtained from the test is shown in Fig. 5. Based on this result, calculate the final settlement [cm] of the entire clay layer due to the groundwater level decline. Assume that the initial void ratio of the clay layer, e_0, is 1.80 and that the stress and strain at the center of the clay layer (point C) can be used as representative values.

(3) The consolidation test results showed that the time required to reach an average degree of consolidation of 90% was 577 seconds. Given the time factor $T_v = 0.848$ for an average degree of consolidation of 90%, calculate the coefficient of consolidation C_v [cm^2/day]. The clay sample has a diameter of 6.00 cm and a height of 2.00 cm, and the test was conducted under double-sided drainage condition.

(4) Based on the results of the consolidation test, calculate the time [day] required for the clay layer to reach an average degree of consolidation of 90%.

(5) Assume that the bottom of the clay layer in Fig. 4 is an impermeable rock layer instead of a sand layer. If the temperature of the clay layer is artificially increased (reducing the viscosity of pore water), doubling the permeability coefficient without changing the volumetric compression characteristics of the clay layer, how will the final settlement and the time required for settlement obtained in (2) and (4) change (increase/decrease/remain unchanged)? Explain briefly with reasons.

(6) Consider the state before the groundwater level decline in Fig. 4 again. As a preloading method, an embankment was constructed on the ground surface very quickly, and after a sufficient amount of time for the settlement of the clay layer develop and converge, the embankment was removed very quickly. Calculate the uniform load [kPa (= kN/m^2)] due to the embankment required to achieve an overconsolidation ratio of 2.50 at point C after the embankment removal (after a sufficient amount of time). Also, if the groundwater level is lowered from position A to position B after this, how will the vertical displacement of the clay layer due to the groundwater level decline compare to the final settlement obtained in (2) (increase/decrease/remain unchanged)? Explain briefly with reasons.

[Question 4]

Consolidated-undrained triaxial compression test was conducted on a specimen of saturated normally consolidated clay with a confining pressure (cell pressure) of 100 kPa. The result for the shear stage (axial loading stage) is shown in the below figure. Answer the following questions.

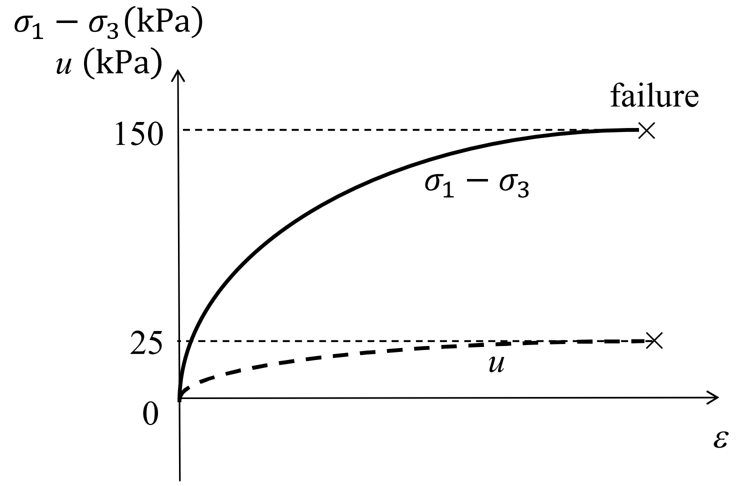

Fig. 6

(1) Draw the Mohr's circle for the total stress in the specimen when the consolidation stage was completed.

(2) In the shear stage, the specimen failed when the axial stress reached $\sigma_1 - \sigma_3 = 150$ kPa as shown in the above figure. The pore water pressure at failure was $u = 25$ kPa. Draw the Mohr's circle for the total stress at failure.

(3) Draw the Mohr's circle for the effective stress at failure indicated in (2).

(4) Assuming $c' = 0$ since the specimen was normally consolidated clay, determine ϕ'. Here, c' and ϕ' are the cohesion and the internal friction angle for the effective stress obtained from consolidated-undrained triaxial compression test, respectively.

(5) Assuming that the Mohr-Coulomb failure criterion can be applied, determine the direction of the failure plane that is expected to occur in the specimen.

(6) In the sentence in the following box, choose the answers that fit [1] and [2] among the three options given, and explain the reason why you have chosen them for [1] and [2] by using the term "dilatancy" or "dilate" in in 60 to 120 words.

> If the consolidated-drained triaxial compression test is conducted on the same clay with the same confining pressure of 100 kPa, the pore water pressure during the shear stage will [1], and the volume of drainage from the specimen will be [2].
>
> Options for [1]: increase; not change; decrease
>
> Options for [2]: positive; zero; negative