2022 Soil Mechanics I and Exercises Final Exam

January 31, 2023 (Tue.) 13:15–15:15 @ Research Bldg. No.9 W2

Attention:

- The exam consists of four questions for which you are provided with four 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.
- Use of non-programmable calculators 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.
- Wherever necessary, specify the units in your answers.

[Question 1] Answer the following questions. Assume that the density of water ρ_w is 1.00 Mg/m^3 (= g/cm^3).

(1) Show that the relationship $e \cdot S_r = w \cdot G_s$ holds for the void ratio e, water content w, the degree of saturation S_r, and the specific gravity of soil particles G_s. You may use a figure if necessary.

(2) In order to construct an embankment, soil is to be taken from a soil pit having the following parameters. Find the void ratio *e*, the porosity *n*, and the degree of saturation S_r of the soil in its natural state.

Soil particle density, ρ_s	2.70 Mg/m^3
Natural water content, w_n	20.0%
Total (wet) density, ρ_t	1.80 Mg/m^3
Maximum dry density, ρ_{dmax}	1.80 Mg/m^3

(3) 5,400 m^3 of soil was excavated from the soil pit described in (2) to construct an embankment with a degree of compaction of 90.0%. Find the mass *m* of the moist soil taken and the volume of the constructed embankment *V*.

(4) Draw the general relationships between water content and dry density, shear strength, and hydraulic conductivity of compacted soil using Fig. 1. Copy Fig. 1 on your answer sheets and illustrate them so that the relationship between the peaks of dry density, shear strength, and hydraulic conductivity and the optimum water content is clearly shown. In the compaction curve, zero air-void curve should be also included.

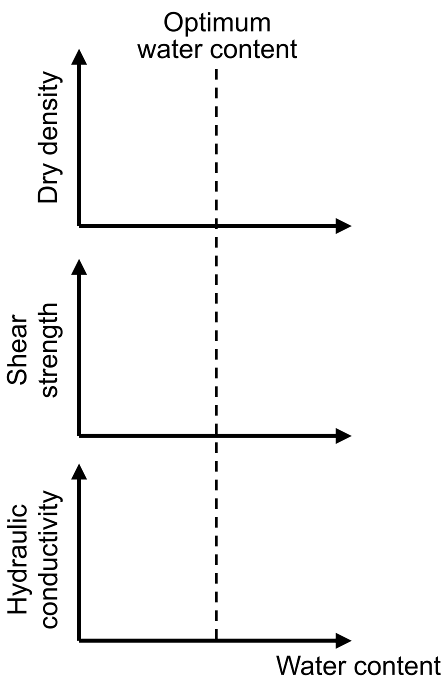


Fig. 1

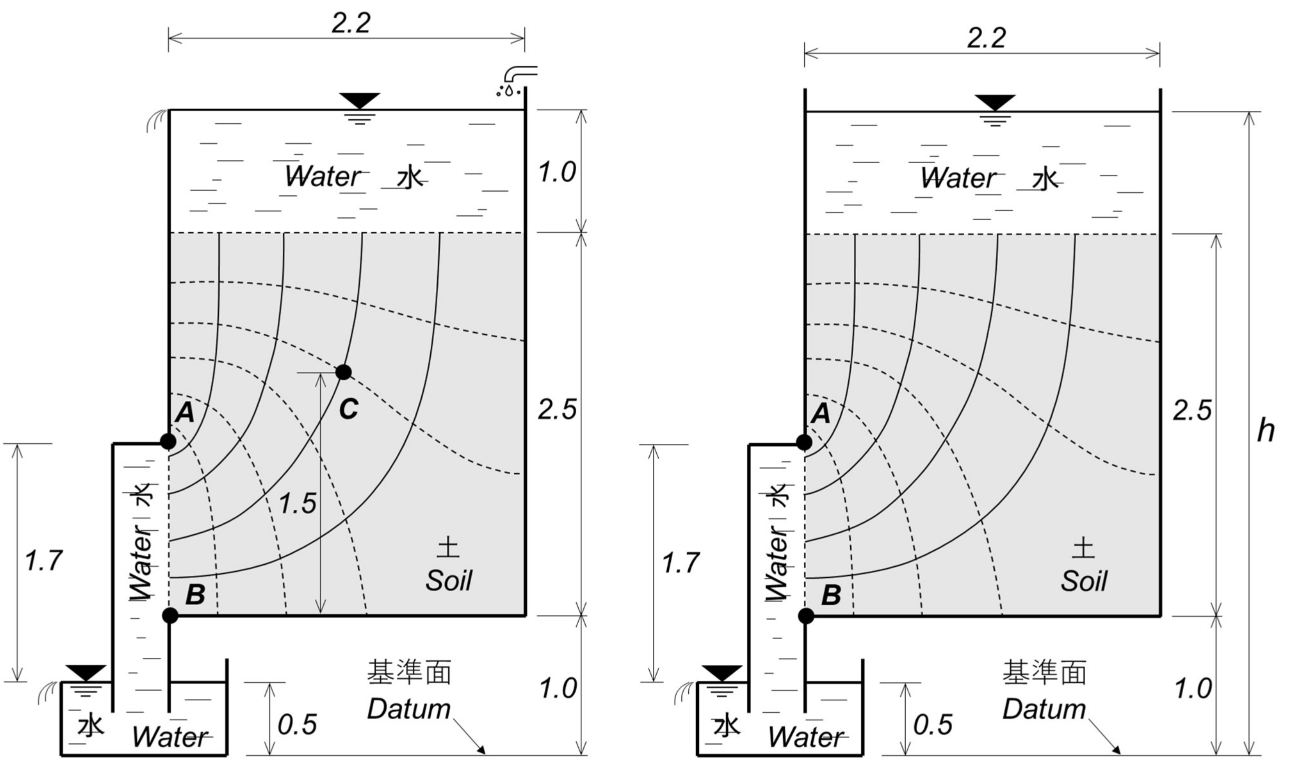
(5) Answer two measures or methods that are effective in constructing embankments having high dry density.

[Question 2] Fig. 2(a) and (b) show the setup of a filter made of soil. The flow net within the soil body is also shown in the figure. The flow net is drawn so that each element surrounded by flowlines and equipotential lines is approximately a square. A screen is placed along AB to retain the soil while allowing water to flow through. The location of the datum is given in the figure. The thickness of the soil body (i.e., perpendicular to the page) is 1 m.

First, refer to Fig. 2(a), the soil body is made of sand and a steady-state flow is maintained. The water levels on the upper side and the lower side are kept constant, with inflow on the upper side and drainage on the lower side. The flow rate through the sand is 2.88 m^3/hr. Answer questions (1) to (4) below. In the calculation, the velocity head can be assumed to be negligible.

(1) Find the elevation head, pressure head, and total head at point A;
(2) Find the elevation head, pressure head, and total head at point B;
(3) Find the elevation head, pressure head, and total head at point C;
(4) Find the hydraulic conductivity (in m/s) of the soil.

(5) Now refer to Fig. 2(b), the soil body is made of silty sand. Initially (t = 0) the water level on the upper side is h = 4.5m. The inflow of water is disabled. The water level on the upper side reduces with time and it can be expressed by $h = 4.5 - 0.02t$ where t represents time (with unit of hour). After 10 hours, it is found that the upper water level drops to h = 4.3 m. The water level in the lower tank is kept constant by allowing drainage. Assume there is no loss of material in the soil body and the flow net does not change during this period. Calculate the hydraulic conductivity (in m/s) of the silty sand.



(a). For question (1) through (4).　　(b). For question (5).

Fig. 2. Flow through a filter (all numbers have a unit of meter).

[Question 3] Consider the construction of an embankment on the ground surface of a normally consolidated clay soil surrounded by an impermeable bedrock layer at the bottom and a sand layer at the top, as shown in Fig. 3. It is assumed that the embankment is constructed in a very short period and that a uniform load of 100 kN/m^2 is instantaneously applied to the ground surface due to the embankment construction. Answer the following questions regarding the one-dimensional consolidation settlement and consolidation time of the clay layer.

The unit weight of water is 9.81 kN/m^3, the total (wet) unit weight of the sand is 19.0 kN/m^3, and the saturated unit weight of the clay before loading is 17.0 kN/m^3. The clay layer before embankment construction is under the normally consolidated state, and the consolidation follows Terzaghi's one-dimensional consolidation theory. Furthermore, the groundwater surface is assumed to be always located at the boundary between the sand and clay layers, and the consolidation settlement of the sand layer due to loading is assumed to be negligible.

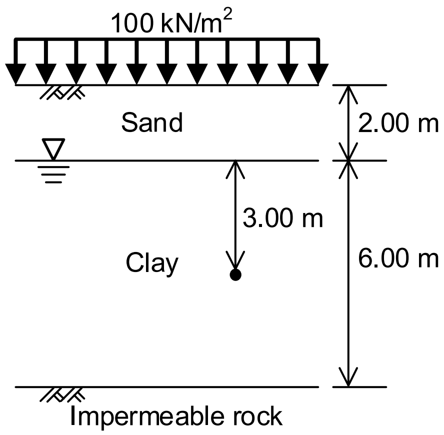


Fig. 3

(1) Find the (i) initial vertical total stress, (ii) initial pore water pressure, and (iii) initial vertical effective stress at the center of the clay layer before the embankment construction, respectively.

(2) Find the (i) total vertical stress, (ii) pore water pressure, and (iii) effective vertical stress in the center of the clay layer immediately after the uniform load is applied on the ground surface due to the embankment construction. Briefly explain how these values change when consolidation is completed after sufficient time has passed, comparing to the condition immediately after the loading.

(3) As a result of the consolidation test on clay samples collected from the center of the clay layer before embankment construction, it was found that the initial void ratio e_0 = 1.00 and the compression index C_c = 1.20. Based on these results, find the final settlement of the entire clay layer due to the embankment construction. You may use the stress value at the center of the clay layer as a representative value.

(4) In the consolidation test of the clay sample, it took 424 seconds to reach 90% of the degree of consolidation. If the time factor for 90% degree of consolidation is Tv = 0.848, find the coefficient of consolidation Cv [m^2/s]. Assume that the dimensions of the clay sample are 6.00 cm in diameter and 2.00 cm in height, and that the consolidation test was conducted under double-sided drainage condition.

(5) Find the time [days] required for the clay layer to reach the degree of consolidation of 90%.

(6) If a pressure greater than 100 kN/m^2 was applied to the ground surface since the initial state and before the construction of the embankment, briefly explain how does it change the time required to reach 90% degree of consolidation for the same clay layer (increase, decrease, or no change), together with the reason. Assume that the coefficient of consolidation *Cv* is constant during the consolidation process.

[Question 4] Answer the following questions.

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

1) Draw a Mohr's stress circle for the stress state shown in Fig. 4. Indicate the center coordinate and the radius of the stress circle.
2) Using the Mohr's stress circle drawn in 1), find the maximum and minimum principal stresses and the direction of each principal plane (i.e., the planes on which these principal stresses act).
3) Using the Mohr's stress circle drawn in 1), find the vertical and shear stresses acting on plane A-A'.

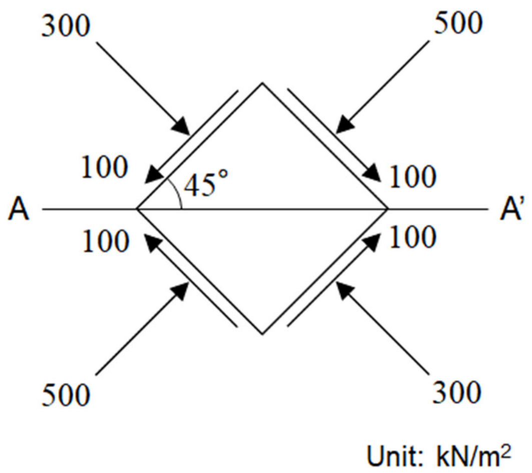


Fig. 4

(2) A consolidated-undrained ($\overline{\text{CU}}$) triaxial compression test was conducted on a saturated silty sand under lateral pressure σ_3 = 250 kN/m^2. Failure occurred when axial pressure σ_1 = 450 kN/m^2 and pore water pressure u_w = 150 kN/m^2 were reached. The failure plane was inclined 60° counterclockwise from the maximum principal stress plane.

1) Draw the Mohr's stress circles for the total stress and effective stress at failure.
2) Find the vertical effective stress σ'_f and shear stress τ_f acting on the failure plane.
3) Assuming that the Mohr-Coulomb failure criterion holds, find cohesion c' and internal friction ϕ' of the silty sand used in the test.
4) In the consolidated-undrained triaxial compression tests of loose sand or normally consolidated clay, positive excess pore pressure is generally generated. Explain the reason in terms of dilatancy. Note that the pressure is assumed to be positive in compression.