2013 Soil Mechanics II and Exercise - Final Exam

2013/07/31 (Wed) 10:00～12:00 Room: Kyotsu-4

Attention:

- There are five questions and five 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 side of an answer sheet is not enough for answering one specific question, you can use the back side of the same answer sheet, after clearly mentioning so. All questions bear equal mark.
- Non-programmable calculators are permitted, but calculators that have programming functions and all types of mobile phones are prohibited.
- If you behave maliciously during the exam, you will not be entitled to get any credit on this subject.
- Wherever necessary, show the units in your answers.

【1】Answer the followings questions regarding consolidation of clayey soil ground:

(1) A clay layer of thickness *H* lies above an impermeable rock layer. Assume that the ground water level coincides with the ground surface. After the rapid application of a load over the clay layer, the consolidation process can be analyzed based on Terzaghi's one dimensional consolidation equation shown below:

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2} \qquad (1)$$

Here, u: excess pore water pressure (= pore water pressure – hydrostatic pore water pressure), c_v: consolidation coefficient, t: time, and z: coordinate along the depth direction.

(a) If the upper surface of the clay layer (i.e., the ground surface) is represented as $z = 0$, and the lower surface of the clay layer (i.e., the upper surface of the impermeable rock layer) as $z = H$, then write the boundary condition for the upper surface of the clay layer ($z = 0$).

(b) Write down the boundary condition for the lower surface of the clay layer ($z = H$). [Hint: Think about the condition where the flow rate becomes zero in Darcy's Law.]

(2) If immediately after the rapid application of the load, the excess pore water pressure (u) is equal to u_0 [i.e., $u = u_0$ (constant)] then, considering this as the initial condition, find the solution of the consolidation equation shown above.

(3) *Sand drain* is one of the ground improvement methods used for accelerating the consolidation of soft ground. Explain the principles behind this method.

【2】Answer the following questions:

(1) Triaxial tests of soil specimens are generally performed in two consecutive steps: a *consolidation* followed by *shearing*. Based on the drainage conditions during these steps, the triaxial tests are classified in three types. What are those types? Mention the drainage condition, and the principal stresses in terms of the total stress and the effective stress, at each step for the three test types.

(2) What is an *unconfined compression test* and which triaxial test resembles it better? If the maximum value of the compressive stress obtained from this test is q_u, then show the shear strength of this test specimen using a Mohr's stress circle.
Also, comment on why the unconfined compressive strength is used in the case of short term stability analysis.

(3) A saturated sand specimen was tested under drained conditions. The specimen failed at a deviator stress $(\sigma_1 - \sigma_3)$ of 360 kPa when the cell pressure (σ_3) was 100 kPa. Assume $c^{'} = 0$ for this sand specimen.

(i) Find the value of the effective internal friction angle, $\phi^{'}$.
(ii) What would the value of the deviator stress be if another identical specimen is tested under a cell pressure of 200 kPa?
(iii) Represent the above two tests with Mohr's stress circles and Mohr-Coulomb failure envelopes.

【3】Answer the following questions:

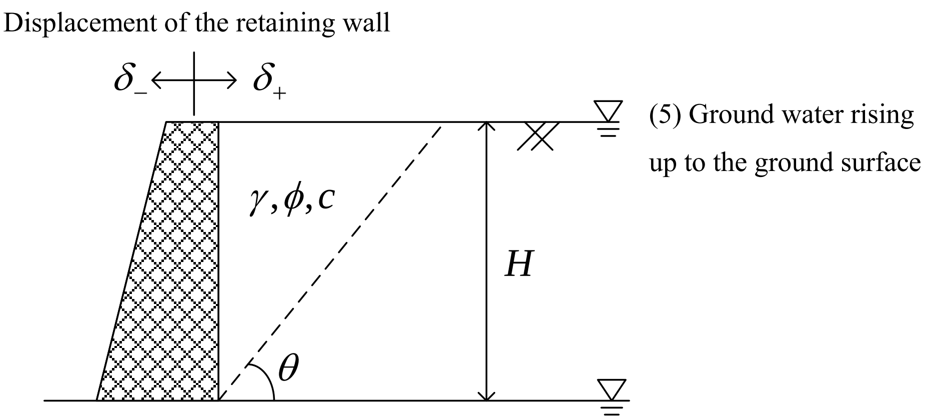
(1) The figure below represents a retaining wall of height H. Let the frictional angle, the cohesion, and the unit weight of the soil behind the wall be ϕ, c, and γ, respectively. Draw a graphic showing the three types of representative earth pressure that act on the retaining wall, taking the displacement of the retaining wall (δ) along the horizontal axis and the earth pressure along the vertical axis. Refer to the figure for the direction of displacement of the retaining wall.

(2) Based on Coulomb's earth pressure theory, determine the earth pressure acting on the retaining wall when it moves towards the soil side ($\delta+$ direction). Assume that the cohesion, c, of the soil behind the retaining wall is zero. Also, assume that the surface of the wall is smooth and, hence, there is no friction between the retaining wall and the soil.
Show the force polygon diagram using the forces that act on the soil wedge shown in the figure. Use appropriate symbols for the forces shown in the force polygon diagram and explain each of those forces. Assume that the ground water table lies far below the retaining wall.

(3) Based on Coulomb's earth pressure theory mentioned in (2), briefly explain the procedure of determining the earth pressure acting on the retaining wall when it moves towards the soil side ($\delta+$ direction).

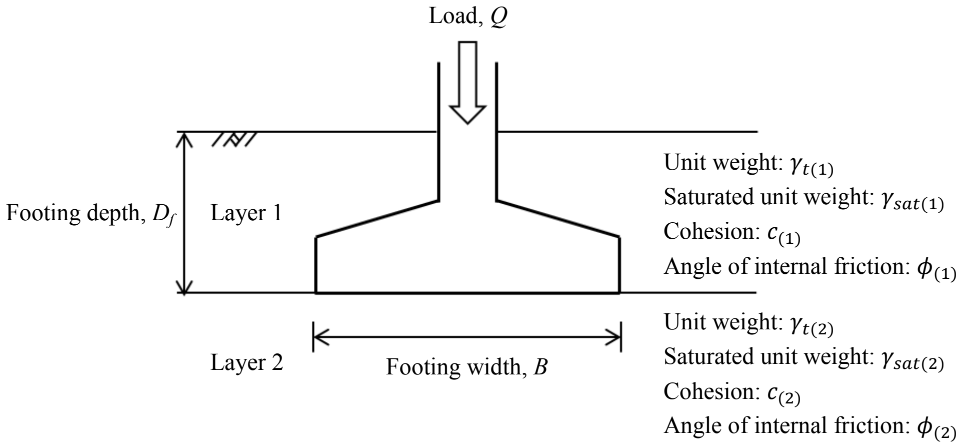
(4) While reassessing the conditions of the soil behind the retaining wall, it was found that the cohesion of the soil, c, was not equal to zero. Under this new condition, and based on Rankine's earth pressure theory, obtain the earth pressure that acts on the retaining wall when it moves away from the soil ($\delta-$ direction).
Also, show the earth pressure distribution along the height (H) of the retaining wall. For this, assume that the friction between the retaining wall and the soil behind is zero and that the ground water table lies far below the retaining wall.

(5) Explain the difference in the magnitudes of the active resultant earth pressure (resultant of the earth pressure and the water pressure) when the ground water table behind the retaining wall (i) lies at the bottom surface of the retaining wall and (ii) is rising up to the ground surface. Focus your answer on the difference in the earth pressure and the water pressure under those two conditions. Assume the unit weight of water as γ_w.



【4】Answer the following questions about foundation design:

(1) The following figure represents a strip (long) footing.



(a) Using the parameters shown in the abovefigure, explain the difference between *shallow* and *deep* foundation.

(b) Using the bearing capacity factors, N_c, N_γ, and N_q, the ultimate soil-bearing capacity, q_u, can be calculated using Terzaghi's bearing capacity equation as follow:

$$q_u = Q/B = \left[①\right] N_c + \frac{1}{2}\left[②\right] B N_\gamma + \left[③\right] D_f N_q$$

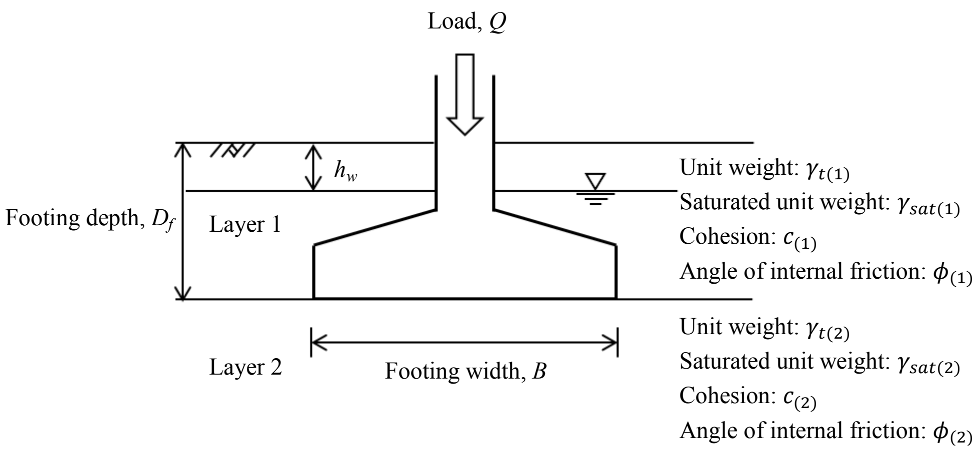
Assuming that the water table is located far below the footing, indicate what soil parameters correspond to ①, ②, and ③ in the previous equation.

(c) By introducing the factor of safety, F_S, in the above equation, derive the equation corresponding to the allowable bearing capacity, $q_{allowable}$.

(d) As shown in the following figure, assume that the water table has risen to a depth of h_w below the ground surface. If Terzaghi's ultimate bearing capacity equation is represented this time as:

$$q_u = Q/B = \left[④\right] N_c + \frac{1}{2}\left[⑤\right] B N_\gamma + \left[⑥\right] N_q$$

indicate what soil parameters correspond to ④, ⑤, and ⑥. Use γ_w as the unit weight of water.

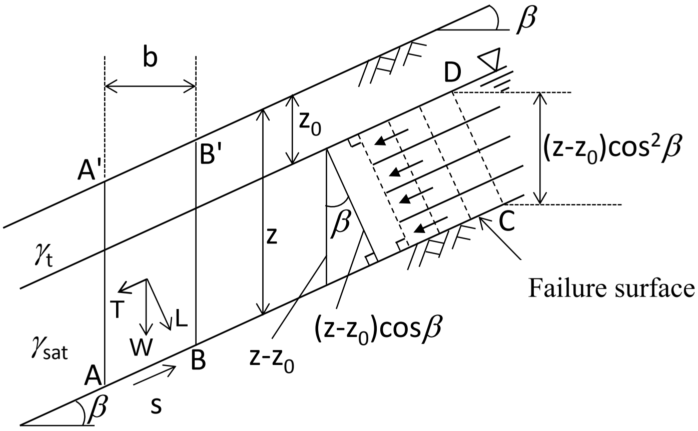


(2) Explain the following concepts using figures:

- Local shear failure and general shear failure
- Negative skin friction

【5】Answer the following questions:

(1) As shown in the figure below, the ground water table lies at a depth z_0 from the ground surface. Assume a steady seepage flow with the flow parallel to the slope surface. Fill up the blank squares ① ~ ⑦ with the appropriate expressions, and also answer questions (a) and (b).



Let the unit weight of the soil above the ground water table be γ_t. Similarly, let the saturated unit weight of the soil below the ground water table be γ_{sat}. The flow net is as shown in the figure above, with flow lines parallel to the ground surface, and equipotential lines perpendicular to the ground surface and the failure surface. On the shown flow net, the points C and D lying on the same equipotential line have equal total water heads. If the potential water head and the pressure water head are represented by h_e and h_p, respectively, then the total water heads at points C and D can be written as:

$$h_e(C)+h_p(C)=h_e(D)+h_p(D)$$

Therefore, the pressure water head at point C, $h_p(C)$ can be written as:

$$h_p(C)=\{h_e(D)-h_e(C)\}+h_p(D)=(z-z_0)\cos^2\beta$$

Following the above equation, the pore water pressure, u, that acts on the failure surface can be written as:

$$u=h_p(C)\cdot\gamma_w= \boxed{\quad ① \quad} \qquad (1)$$

Here, γ_w is the unit weight of water. Next, we will calculate the normal stress, σ, and the shear stress, τ, that act on the bottom surface of the sliding soil mass (A′ABB′) that has a width of b, as shown in above figure. To do so, we will first calculate the weight of the sliding soil mass, W. The weight of the sliding soil mass (A′ABB′) is written as:

$$W= \boxed{\quad ② \quad} \qquad (2)$$

The length of the bottom of the sliding soil mass, $\overline{\mathrm{AB}}$ is expressed as:

$$\overline{\mathrm{AB}}= \boxed{\quad ③ \quad} \qquad (3)$$

Using equations (2) and (3), σ and τ mentioned above are calculated as shown in Equations (4) and (5). Here, L and T are the vertical (normal) and parallel (shear) components of W (weight of sliding soil) that act at the bottom surface of the sliding soil mass.

$$\sigma=L/\overline{\mathrm{AB}}= \boxed{\quad ④ \quad} \qquad (4)$$

$$\tau=T/\overline{\mathrm{AB}}= \boxed{\quad ⑤ \quad} \qquad (5)$$

From Equations (1) and (4), the effective normal stress that acts on the failure surface is given by:

$$\sigma'=\sigma-u= \boxed{\quad ⑥ \quad} \qquad (6)$$

Here, $\gamma'=\gamma_{sat}-\gamma_w$: Submerged unit weight of the soil mass.

If the cohesion and the angle of internal frictional of the soil is represented by c' and ϕ', then the shear strength,

s, of the soil can be represented by $s = c' + \sigma' \tan\phi'$. Now, the factor of safety, F_s can be obtained as shown below using the results of equations (5) and (6):

$$F_s = \frac{s}{\tau} = \boxed{\quad ⑦ \quad} \qquad (7)$$

(a) Find the factor of safety when the ground water table lies on the ground surface. At this condition, also find the critical height, H_c, for which the soil mass starts to slide.

(b) Find the factor of safety when $c' = 0$, and the ground water table lies far below the failure surface ($\gamma' = \gamma_t$, $\gamma_{sat} = \gamma_t$).

(2) In five lines or less, explain the mechanism of soil liquefaction. In addition to that, list five countermeasures against liquefaction, briefly indicating the <u>principles behind them</u> (i.e., why do they work).

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【1】In regards with the consolidation of clayey soil ground, answer the following questions:

As shown in Fig. 1-1, the horizontally layered soil ground consists of a sand layer (5 m thick), a fully saturated clay layer (3 m thick) and an impermeable layer. Ground water table lies on the upper boundary of saturated clay layer. Bulk unit weight of sand layer, γ_t=20.0 kN/m^3. From the depth of GL-6.5 m, sample of saturated clay was obtained and one dimensional consolidation test was done. From the test, saturated unit weight, γ_{sat}=23.1 kN/m^3, compression index, C_c=1.0, swelling index, C_s=0.10, maximum past pressure, p_y=120 kN/m^2, and initial void ratio, e_0=2.78 were obtained.

In order to construct a building of reinforced concrete, the soil ground is excavated up to 3 m depth. Let the height and the equivalent surcharge load of each floor including basement of that building be 3 m and 9 kN/m^2, respectively. Assume that the saturated clay layer was in normally consolidated state before the excavation. At this condition, answer the questions below.

Here onward, consider that the base of the excavation is wide enough and consolidation due to surcharge load of reinforced concrete building is one dimensional. In addition, the amount of deformation of clay layer is approximated as the representative strain value at the center of the clay layer. Take unit weight of water as 9.81 kN/m^3.

(1) If 3 m of the sand layer is excavated, then determine the vertical displacement (expansion or swell) at the bottom surface of this excavation. Consider the vertical swell at the bottom surface of excavation is due to the swell of clay layer only. Here, swell (or expansion) of the sand layer neglected.

(2) Now, from the condition of (1), 10-floor building [one basement and 9 other floors above the ground] is constructed. At this condition, determine the final settlement of the bottom surface of the excavation in comparison to its initial condition before the excavation. [Hint: Settlement of normally consolidated clay = Final settlement].

(3) When 10-floor building [one basement and 9 other floors above the ground] is constructed, consolidation continues up to 90% of its final settlement. Determine the time taken to reach 90% of final settlement. Take time factor, T_v=0.848 for 90% degree of consolidation (U=90%) and consolidation coefficient, c_v=80 cm^2/day. Here, the consolidation settlement is considered to be only due normal consolidation.

(4) Determine total number of floors that is possible to be included in the building so that there occurs no consolidation settlement in comparison to its initial condition which is before the excavation.

(5) Time dependent consolidation process that takes place within the saturated clay layer can be analyzed by using Terzaghi's one dimensional consolidation equation. Write down the equation of Terzaghi's one dimensional consolidation. Explain the symbols (parameters) used in that equation.

In addition, referring to Fig. 1-1, write down the boundary conditions at the upper boundary (drain condition) and lower boundary (undrain condition) of saturated clay layer.

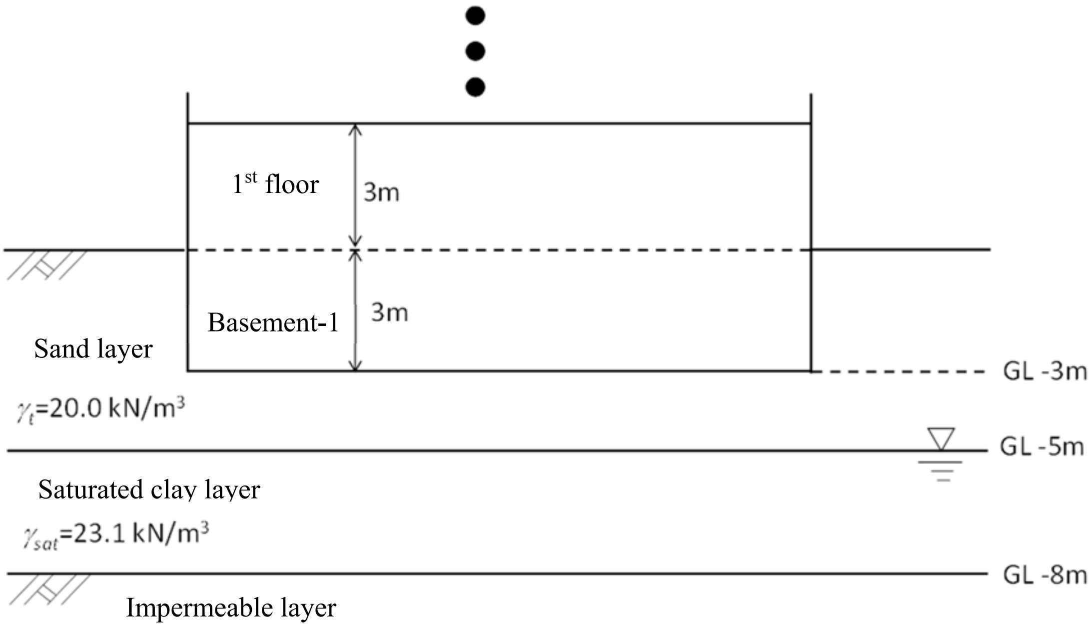


Fig. 1-1

【2】In regard with failure criterion of soil, answer the following questions:

(1) Undrained triaxial compression test was conducted for a normally consolidated saturated clay specimen. Confining pressure at the end of consolidation was 100 kN/m^2. Deviator stress and excess pore water pressure measured at failure during undrained shearing were 200 kN/m^2 and 80 kN/m^2, respectively. Taking the value of cohesion as zero, answer the following questions:

(a) Plot Mohr's stress circles (total as well as effective) along with Mohr-Coulomb's failure line. In the plot, show the values of major and minor principal stresses also.

(b) In reference to effective stress plot, find the internal friction angle of this soil specimen.

(c) In reference to (b), determine failure angle that the failure plane makes with major principal plane.

(d) In reference to (b) and (c), determine the normal and shear stresses that act on the failure plane.

(e) Plot total stress path and effective stress path in p, p′-q space for this test showing the values of p, p′ and q at the start and failure states of shearing. [Here, p: mean total stress, p′: mean effective stress, q: deviator stress].

(f) Determine pore water pressure coefficient, A_f at failure.

(2) Three direct shear box tests were conducted for the dry sand under constant stress condition. Let the normal forces applied at each test be N_1, N_2 and N_3 [$N_1 > N_2 > N_3$]. Answer the following questions:

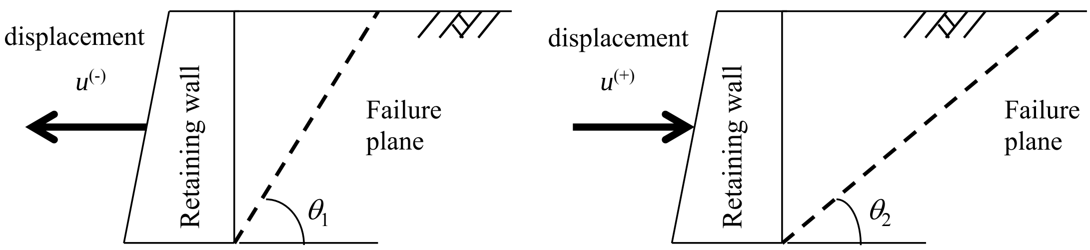
(a) How do you obtain the strength parameter of this sand? Explain in brief with graphs.

(b) Depending on the void ratio, behavior of graphs of volume change with change in horizontal displacement varies. Draw graphs and comment on this matter.

(3) Explain briefly Sensitivity and Quick clay in regards with clayey soil.

【3】Answer the following questions:

(1) In reference to Fig. 3-1, draw a graph showing the relationship between the displacement {$u^{(-)}$ and $u^{(+)}$} of the retaining wall and the earth pressure, P that acts on that wall. Also, within the graph, indicate the earth pressures which represent equivalent active and passive earth pressures.



a) Active state   b) Passive state

Fig. 3-1

(2) Explain the conditions at which Rankine's earth pressure theory and Coulomb's earth pressure theory become equal.

(3) Retaining wall of height, H is constructed on the horizontal soil ground (unit weight, γ) as shown in Fig. 3-2. Explain the active earth pressure that is calculated based on Coulomb's earth pressure theory using Force Polygon diagram. Take δ as the friction angle that acts between the retaining wall and the soil behind the wall.

In the Force Polygon diagram, indicate all the force vectors. Also, explain the component of each of those force vectors.

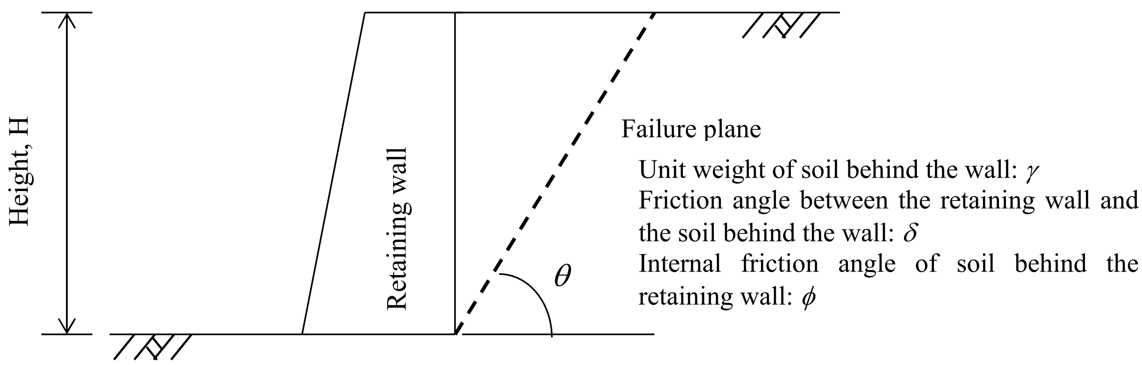


Fig. 3-2

(4) As shown in Fig. 3-3, it is thought to set up a freely supported sheet pile after the excavation of a soil ground. Let H_1 be the excavation depth from the soil ground surface and H_2 be the depth from the excavated surface to the base of the sheet pile.

At this condition, calculate the resultant earth pressure, P_2 that acts on excavation side.

Also, calculate the position, h_2 at which this resultant force P_2 acts.

Take unit weight, cohesion and internal friction angle of the soil ground as γ, 0 and ϕ, respectively.

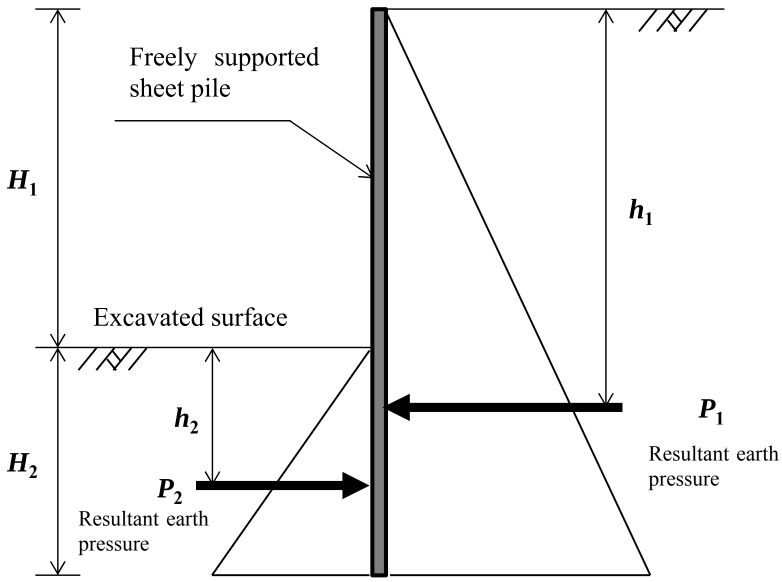


Fig. 3-3

(5) In regards with earth pressure distribution along the freely supported sheep pile as shown in Fig. 3-3, draw the graphs of earth pressure distribution along the excavated side and retaining side of the sheet pile. While drawing the graphs, compare the distribution of earth pressure for the conditions when cohesion of the soil is equal to c and zero, respectively. Also, comment on this matter.

【4】Answer the following questions:

(1) In relation with slope stability, answer the following questions:

Fellenius method (Sweden method) is one of the slope stability analysis methods where failure plane is assumed to be a circular arc and the failing soil mass is divided into n number of slices. During this method following three conditions are considered; a) the condition of equilibrium of forces along the direction perpendicular to the failure plane, b) the condition of equilibrium of sliding moment and resisting moment around the center of circular arc, and (c) the conditional factor of safety (F_S) with respect to Mohr-Coulomb failure condition.

Now, for the condition where pore water pressure is developed within the slope due to rain fall, write down the conditional equations (a)~(c) mentioned above. From these conditional equations, derive following calculation equation of slope stability factor.

$$F_S = \frac{\sum(W_i \cos\alpha_i - U_i)\tan\phi_i}{W_i \sin\alpha_i} \qquad (1)$$

Here, in regards with i[th] slice:

Internal friction angle of soil=ϕ_i, cohesion=0, sloping angle of the failure plane=α_i, self-weight of the slice=W_i, pore water pressure=U_i.

Summation represents the summation of all the slices divided for the sliding soil mass above the failure plane.

(2) Considering the equation (1), explain why landslides are more likely to occur when it rains.

(3) Regarding the liquefaction of soil ground, answer the following questions:

(a) Explain general mechanism of liquefaction.

(b) List three countermeasures against liquefaction and explain the principles behind them.

【5】If B=foundation width, D_f=depth of foundation from the ground surface for a strip foundation, answer the following questions:

(1) In order to derive Terzaghi's general bearing capacity equation, correctly draw the failure pattern of foundation ground that is assumed by Terzaghi and explain it.

(2) Terzaghi's bearing capacity equation consists of three terms. Write down Terzaghi's bearing capacity equation and explain the meaning of each of those terms.

(3) In regard with the equation expressed in (2), derive the allowed bearing capacity, q_a if factor of safety is F.