# 2021 Soil Mechanics II and Exercises Final Exam

July 28, 2021 (Wed.) 10:00–12:00 Kyotsu 4 Lecture Room + Online

Attention:

- The exam consists of five questions.
- Use of non-programmable calculators are permitted. However, programmable calculators and calculator functions of mobile phones are prohibited.
- Wherever necessary, specify the units in your answers.

[In-class participants]

- Five answer sheets are provided. 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.

[Online participants]

- You must keep your camera ON throughout Zoom connection during the exam.
- You must finish writing at 12:00 and complete submitting the answer sheets via PandA by 12:10. Your submission will not be accepted after the deadline regardless of any reason. Give yourself ample time to get through PandA for submitting the answer sheets.
- You may answer a major question over multiple answer sheets but do not answer multiple major questions on the same answer sheet. You must indicate your name and student ID on all the sheets.
- Any suspicious behavior through camera will result in failed credit of the course and serious penalties.

[Question 1] Answer the following questions regarding the stress in ground and soil consolidation.

(1) A circular tank with a radius $R$ = 2.0 m is planned to place on the sandy ground whose bulk unit weight $\gamma_t$ = 16.0 kN/m$^3$. To determine how deep should a borehole be drilled for sample collection, the guideline of ASCE (1972) is followed. By knowing that the circular foundation will exert a uniform pressure $q$ = 160 kN/m$^2$ on the sandy ground surface and the water table is sufficiently far, the required minimum depth of boring is approximated as follows:

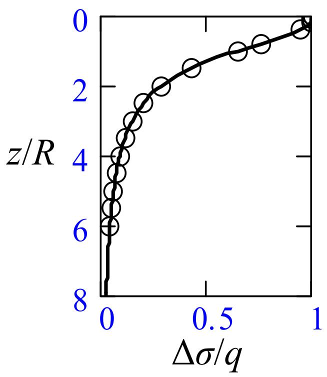
   i. Estimate depth $D1$ at which $\Delta\sigma/q = 0.1$ where $\Delta\sigma$ is the increase in vertical stress at depth $D1$ and $q$ is the net stress on the foundation.
   ii. Estimate depth $D2$ at which $\Delta\sigma/\sigma'_o = 0.05$ where $\Delta\sigma$ is the increase in vertical stress at depth $D2$ and $\sigma'_o$ is the effective overburden pressure at depth $D2$.
   iii. Choose the smaller of $D1$ and $D2$.

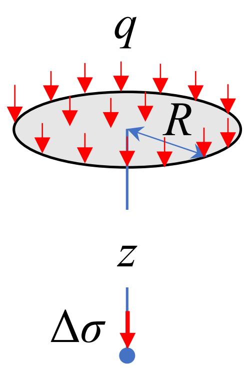
   Assuming that the ground is a semi-infinite elastic body, the vertical stress $\Delta\sigma$ below the center of a uniformly distributed pressure $q$ on a circular area of radius $R$ at depth $z$ is determined by Eq. (1) for which Table 1 may be used in estimation.

$$\Delta\sigma = q\left(1-\left(\frac{1}{1+\left(z/R\right)^{-2}}\right)^{3/2}\right) \qquad \text{Eq. (1)}$$

Table 1: The variation of $\Delta\sigma/q$ with $z/R$ [Eq. (1)]

| $z/R$ | $\Delta\sigma/q$ | $z/R$ | $\Delta\sigma/q$ |
|---|---|---|---|
| 0.0 | 1 | 2.5 | 0.200 |
| 0.1 | 0.999 | 3.0 | 0.146 |
| 0.2 | 0.992 | 3.5 | 0.111 |
| 0.4 | 0.949 | 4.0 | 0.087 |
| 0.8 | 0.756 | 4.5 | 0.070 |
| 1.0 | 0.646 | 5.0 | 0.057 |
| 1.5 | 0.424 | 5.5 | 0.048 |
| 2.0 | 0.284 | 6.0 | 0.040 |




(2) After completion of borehole drilling, a homogeneous and saturated 2-m-thick layer of normally consolidated clay was unexpectedly found between depths of 5.0~7.0 m. Laboratory tests on a clay sample showed that the saturated unit weight of clay $\gamma_{sat}$ = 19.0 kN/m$^3$, the initial void ratio $e_0$ = 0.5 and the compression index $C_c$ = 0.75. Given the unit weight of water $\gamma_w$ = 9.8 kN/m$^3$, find the consolidation settlement of 575a circular tank if the groundwater level is located at the same level as a clay layer as shown in Figure 1. Note that, immediate settlement of ground can be neglected and the stress state at the middle of the clay layer can be used in calculation of one-dimensional consolidation settlement.

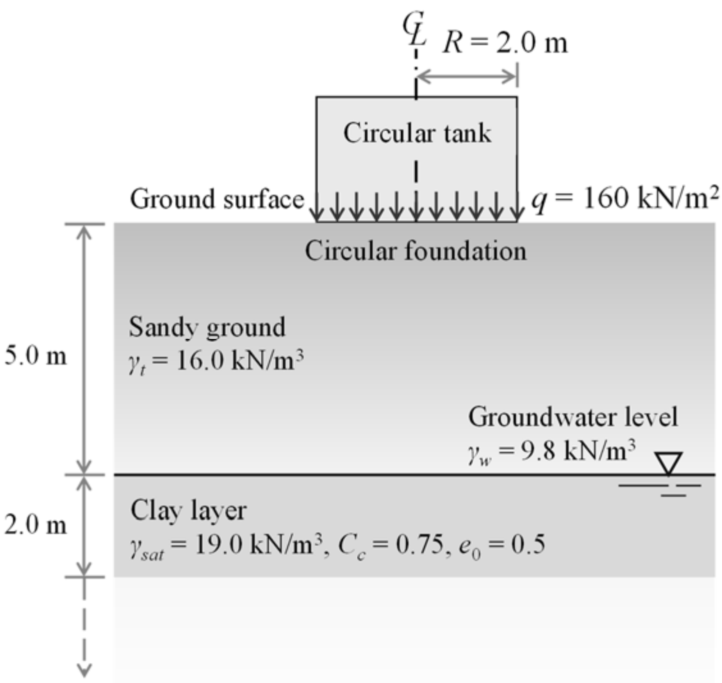



Figure 1

[Question 2] Answer the following questions.

(1) An unconfined compression test was conducted on a sample taken from a clay ground. In the unconfined compression test, although no confining pressure is applied, the effective stress of the specimen is equal to the effective stress in the ground.

(1-1) Describe how the pore water pressure changes before and after the sample was taken from the ground.

(1-2) In order to maintain the effective stress of the specimen equal to the effective stress in the ground, describe the conditions under which the specimen should be stored, focusing on the void ratio.

(2) Derive the Mohr-Coulomb failure criterion using the maximum principal stress $\sigma_1$, the minimum principal stress $\sigma_3$, the cohesion $c$, and the internal friction angle $\phi$.

(3) A consolidated undrained triaxial compression test was conducted on a clay sample with a confining pressure $\sigma_3$ of 100 kN/m$^2$. At failure, the axial stress $\sigma_1$ was 196 kN/m$^2$ and the excess pore water pressure $u_w$ was 57.0 kN/m$^2$.

(3-1) Determine the mean effective stress $p'$ and Skempton's pore pressure coefficient $A_f$.

(3-2) Determine the stress ratio at failure $M_f$ of the clay.

(3-3) Next, if the same clay sample is used in a consolidated drained triaxial compression test with a confining pressure $\sigma_3$ of 100 kN/m$^2$, determine the mean effective stress $p'$ and the axial differential stress $q$ expected at failure.

(3-4) Draw the effective stress paths in the $p' - q$ plane for the above consolidated drained triaxial compression test and the consolidated undrained triaxial compression test.

(3-5) Draw the relationship between the volumetric strain $\varepsilon_v$ and axial strain $\varepsilon_a$ expected in the consolidated drained triaxial compression test.

[Question 3] Answer all the following questions.

Figure 2 represents a rigid retaining wall of height 4 m with a sand backfill. The groundwater table changes with rainfall, and the current depth is $z$ m ($0 < z < 4$) from the backfill surface. The earth pressure acting on the retaining wall can be assumed as Rankine earth pressure. There is no friction between the retaining wall and the sand backfill. The wet unit weight of sand $\gamma_t$ is 15 kN/m$^3$. The saturated unit weight of sand $\gamma_{sat}$ is 19 kN/m$^3$. The unit weight of water $\gamma_w$ is simply 10 kN/m$^3$. The internal friction angle $\phi'$ is 30 degrees, and the cohesion $c'$ is 0 kN/m$^2$.

(1) Draw the pore water pressure profile acting on the back side of the retaining wall per unit length (perpendicular to the section) through the depth $z$.
(2) Find the resultant force of the pore water pressure acting on the back side of the retaining wall per unit length (perpendicular to the section) through the depth $z$.
(3) Draw the earth pressure profile acting on the back side of the retaining wall per unit length (perpendicular to the section) through the depth $z$.
(4) Find the resultant force of the earth pressure acting on the back side of the retaining wall per unit length (perpendicular to the section) through the depth $z$.
(5) Find the resistance force of friction along the base of the retaining wall per unit length (perpendicular to the section). The unit weight of retaining wall is 25 kN/m$^3$, the width of retaining wall is 2m, and the friction coefficient is 0.3.
(6) Investigate the sliding of the retaining wall when the groundwater table changes with rainfall. The factor of safety can be assumed to be 1.

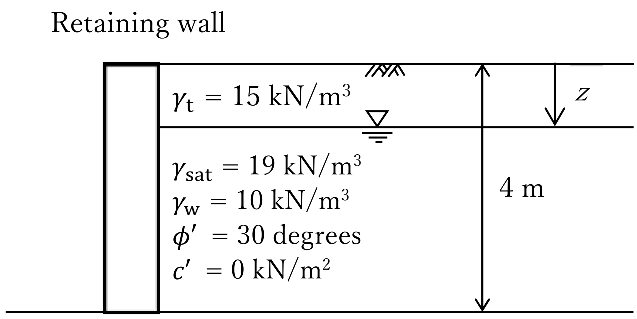



Figure 2

[Question 4] Answer the following questions.

(1) Describe the reason within 30 words why the bearing capacity of the ground needs to be estimated.

(2) Draw failure mechanism of the ground for the derivation of the Terzaghi's bearing capacity equation.

(3) Draw the distribution of axial force on a pile that negative friction appears.

[Question 5]

(1) Answer the following questions regarding the slope stability.

(1-1) Figure 3 shows an infinite slope. Consider a sliding surface at depth $H_f$ as shown in Figure 3 that is parallel to the slope surface. From the balance of the forces acting on the soil area abcd between the ground surface and the sliding surface, find the safety factor, $F$ against the sliding failure. Derivation processes of the safety factor must be described. Here, $N$ and $S$ are the normal and tangential forces acting on the base of the area abcd, respectively. Neglect the balanced forces, $E$ acting on the right and left sides of this area abcd. Assume that the groundwater table is well below the sliding surface. If the shear strength along the sliding surface is governed by the Mohr-Coulomb failure criterion ($\tau = c + \sigma \tan\phi$), formulate the safety factor, $F$ for the assumed failure, in terms of $c$, $\gamma_t$, $H_f$, $\sigma$, $\phi$, $\theta$.

(1-2) In order to increase the safety factor, $F$ against the sliding failure in (1-1), ground anchors are installed into the slope as shown in Figure 4. The ground anchors are installed at an angle $\alpha$ from the horizontal plane, and its installation interval is $L$ (a ground anchor is installed at the area abcd). The tension of each anchor is $T$. Ground anchors are installed to achieve the following two objectives: (1) Increase the normal force acting on the sliding surface (clamping effect), and (2) Increase the resistance force against the sliding of slope (straining effect). Formulate the safety factor, $F$ by considering both two effects, in terms of $c$, $\gamma_t$, $H_f$, $\sigma$, $\phi$, $\theta$, $L$, $\alpha$, $T$. Here, neglect the stiffness of the ground anchors.

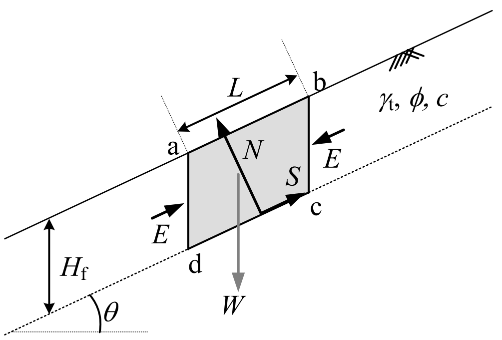



Figure 3

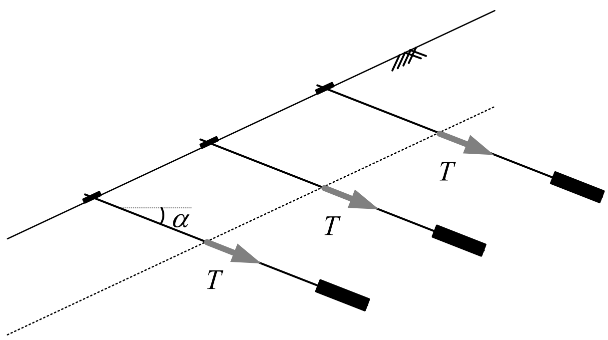



Figure 4

(2) Answer the following questions regarding the wave propagation and liquefaction.

(2-1) An undrained cyclic torsional shear test was performed on saturated loose sand with a constant shear stress ratio for which liquefaction occurred at a certain number of repetitions was judged. Draw the schematic view of the experimental results on all five graphs shown in Figure 5.

(2-2) When evaluating the liquefaction characteristics of a sand, a series of experiments (e.g. hollow torsional test, triaxial test) is performed with different shear stress ratios on the same sand. Explain the reason for this by illustrating the "liquefaction strength curve" obtained from a series of experiments.

(2-3) Explain the reason why the ground liquefies during an earthquake. Underline three places in your answer where you think they are important.

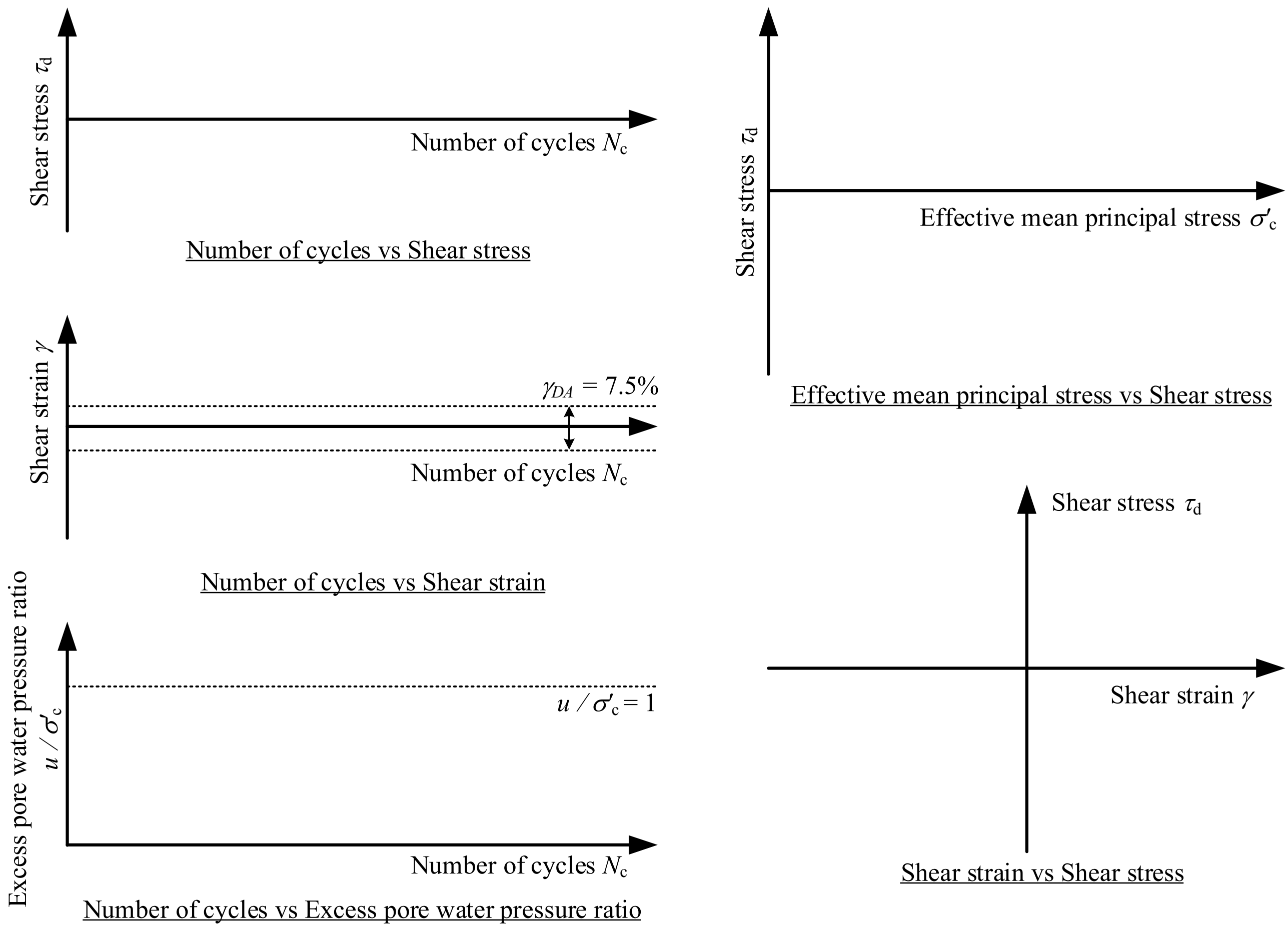



Figure 5