EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 21 April 2015 14.00 to 15.30

Module 3D2

GEOTECHICAL ENGINEERING II

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: Geotechnical Engineering Data Book (19 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 Two triaxial tests are performed on reconstituted Kaolin clay samples. All samples are isotopically compressed to $\sigma_a = \sigma_r = 230$ kN m^{-2} and then swelled back to $\sigma_a = \sigma_r = 200$ kN m^{-2}, in which σ_a is the total axial stress and σ_r is the total radial stress. The water pressure (or back pressure) is kept constant at 100 kN m^{-2} during this stage. The properties of Kaolin clay are given in the Geotechnical Engineering Data Book. Use the Cam-clay model when necessary to answer the following questions.

(a) Compute the specific volume v of the samples after consolidation and swelling. [10%]

(b) The first sample is sheared by keeping the total radial stress σ_r constant and increasing the total axial stress σ_a in drained conditions. The back pressure is kept constant at 100 kN m^{-2}.

(i) Find the deviator stress q and the corresponding v at the critical state. [20%]

(ii) Plot the corresponding effective stress path in $p' - q$ space and state path in $v - \ln p'$ space, in which $p' = (\sigma'_a + 2\sigma'_r)/3$ and $q = \sigma'_a - \sigma'_r$. Sketch the Cam-clay yield surface and evaluate the approximate stress state at yield from the graph. [20%]

(c) The second sample is sheared by keeping the total mean pressure p constant in undrained conditions.

(i) Explain how to conduct such a test in a triaxial apparatus. [10%]

(ii) Find the deviator stress q and the corresponding pore pressure when the sample yields. [15%]

(iii) Find the deviator stress q and the corresponding excess pore pressure at the critical state. [15%]

(iv) Will the effective stress path be different if the sample is sheared in conventional triaxial compression by keeping the total radial stress σ_r constant and increasing the total axial stress σ_a in undrained conditions? [10%]

2 A series of simple shear tests is conducted on natural sand samples. The sand has a maximum void ratio e_{max} of 0.9 and a minimum void ratio e_{min} of 0.5. The critical state friction angle is 32 degrees and the aggregate crushing strength σ_c of the sand is 20,000 kN m^{-2}.

(a) Describe the features of a simple shear apparatus and how shearing is performed using this apparatus. [10%]

(b) Using Bolton's relative dilatancy index I_R, find the relationship between void ratio e and normal effective stress σ' at the critical state for this sand. [20%]

(c) One sample is compacted dense and has a void ratio of e = 0.7 after applying a confining stress of 500 kN m^{-2}. Another sample is compacted loose and has a void ratio of e = 0.85 after applying a confining stress of 500 kN m^{-2}.

(i) If the two samples are sheared in drained conditions, plot the possible stress paths of the two samples in $\sigma' - \tau$ space, giving salient values. Also sketch the shear stress – shear strain relationship and the void ratio – shear strain relationship of the samples. [35%]

(ii) When the two samples are sheared in undrained conditions, plot the possible stress paths of the two samples in $\sigma' - \tau$ space, giving salient values. Estimate the excess pore pressures at failure. Also sketch the shear stress – shear strain relationship of the samples. Discuss the results. [35%]

3 A circular tunnel of radius $r_0 = 4$ m is to be constructed with its axis at a depth of 35 m in a saturated clay. Prior to the tunnel being constructed, two types of instrument are installed in the clay at the position of the tunnel axis with minimal disturbance in boreholes drilled from the ground surface. One of these is a stress cell measuring total radial stress and the other is a pore pressure transducer. The clay, which is assumed to be isotropic, has an elastic shear modulus, G, of 30 MN m^{-2}, an undrained shear strength, s_u, of 250 kN m^{-2}, and a bulk unit weight of 20 kN m^{-3}. The groundwater level is at the ground surface.

Assume that the tunnel construction process can be idealised as an axisymmetric contracting cylindrical cavity being unloaded from the original in-situ stress, analogous to cylindrical cavity contraction.

(a) Using the Geotechnical Engineering Data Book, calculate the maximum radial ground deformation at the tunnel boundary which can be allowed if all of the clay is to remain elastic and yield just prevented. [40%]

(b) What is the tunnel support pressure that would be measured by the stress cell corresponding to the radial ground deformation that you have calculated in (a)? What would be the corresponding reading of the pore pressure transducer? [30%]

(c) During construction, the tunnel support pressure is in fact reduced to a lower value than the value required to maintain all of the clay in an elastic state (as calculated in (b)). Larger radial ground deformations then occur. After yield has occurred, a circular plastic zone is surrounded by a circular elastic zone. Within the elastic zone, at any radius r, the radial and circumferential stresses, σ_r and σ_θ respectively, are given by the following expressions:

$$\sigma_r = \sigma_0 - G\,\delta A/\pi r^2$$

$$\sigma_\theta = \sigma_0 + G\,\delta A/\pi r^2$$

where σ_0 is the insitu total stress in the ground, G is the elastic shear modulus and δA is the decrease in cross-sectional area of the tunnel. Show that the radius of the plastic zone, r_p, is given by the following expression:

$$r_p / r_0 = (G/ s_u \cdot \delta A/A)^{0.5}$$

where A is the cross-sectional area of the tunnel and the other symbols are as defined above. [30%]

4 A diaphragm wall is installed as part of a deep excavation for an underground station, as shown in Fig. 1, in order to retain a uniform clay, for which the bulk unit weight is 20 kN m^{-3} (above and below the water table) and the angle of friction ϕ'_{crit} = 28°. Originally the clay had been deposited one-dimensionally under normally consolidated conditions and the ground level had been at a maximum of 25 m above the present ground level, and at that time the water level was at the ground surface. The 25 m of soil has since been eroded and the water level is now 1 m below the present ground level.

(a) Calculate the total and effective vertical and horizontal stresses experienced by soil element X at a depth of 8 m, as follows:

(i) Using the expression in the Geotechnical Engineering Data Book for the coefficient of horizontal earth pressure K_{0nc}, calculate the original maximum stresses when the ground level was 25 m higher. [15%]

(ii) Assuming that the present day value of K_0 = 1.0, calculate the stresses immediately before the wall is installed and the overconsolidation ratio. [15%]

(iii) Plot the critical state line and the calculated stresses in terms of t, s' and s (as defined in the Geotechnical Engineering Data Book), showing the effective stress history in terms of stress paths. [10%]

(b) Following wall installation, the deep excavation is undertaken rapidly under undrained conditions and a strutting system installed equivalent to applying a uniform horizontal pressure P_h = 100 kN m^{-2}. Assuming that the wall is smooth and that the clay behaves elastically and isotropically, calculate the change of pore pressure for the soil element X. Show the total and effective stress paths on the same graph as you have plotted for (a)(iii). [30%]

(cont.

(c) After the deep excavation has been completed, the equivalent support pressure from the strutting system P_h is kept constant at 100 kN m^{-2}, although the pore pressure in the clay begins to steadily increase. By how much would the pore pressure have to increase before the effective stress state of the soil element X reaches the critical state line? [30%]

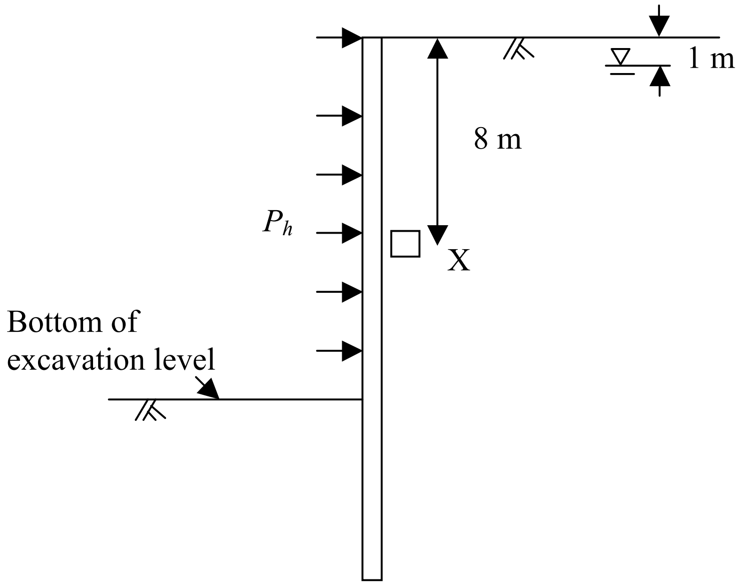

Fig. 1

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