ENGINEERING TRIPOS PART IIA

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Friday 25 April 2008 9 to 10.30

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Module 3D2

GEOTECHNICAL 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.*

*Attachment: Soil Mechanics Data Book (19 pages)*

| STATIONERY REQUIREMENTS | SPECIAL REQUIREMENTS |
|---|---|
| Single-sided script paper | Engineering Data Book |
| Graph paper | CUED approved calculator allowed |

**You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator**

1 A self-boring pressuremeter test is undertaken in a stiff clay at a depth of 4 m. The water table is at a depth of 2.5 m. The unit weight of the clay is 19 $kN/m^3$ and the critical state angle of friction is $\phi_{crit}$ is 20°. Results of the test, including an unload-reload loop, are given below in terms of the cavity pressure $\sigma_c$ and the cavity strain $\varepsilon_c$, which is defined as the radial movement of the pressuremeter divided by the current radius (expressed as a percentage).

| Pressure $\sigma_c$ kPa | Cavity strain $\varepsilon_c$ % |
|---|---|
| 0 | 0 |
| 40 | 0 |
| 90 | 0 |
| 120 | 0.2 |
| 150 | 0.3 |
| 225 | 0.7 |
| 300 | 1.2 |
| 345 | 1.5 |
| 240 | 1.3 |
| 150 | 1.1 |
| 300 | 1.4 |
| 350 | 1.6 |
| 450 | 2.4 |
| 550 | 4.4 |
| 650 | 8.4 |

(a) Estimate the coefficient of horizontal earth pressure at rest, $K_0$. Without making calculations, speculate regarding the stress history of the clay. [20%]

(b) Deduce the initial shear modulus, $G_i$, and the value, $G_{ur}$, from the unload-reload loop data. Comment briefly on the difference. [20%]

(c) Estimate the undrained shear strength of the clay. [30%]

(d) The pore pressure in the soil at the cavity wall was measured by a transducer incorporated in the pressuremeter. Estimate the pore pressure when the pressuremeter pressure reached 650 kPa. [30%]

2 A long, wide basement is to be excavated between stiff diaphragm walls constructed through the entire depth $H$ of a horizontal bed of firm clay overlying bedrock. The properties of the clay, unit weight $\gamma$ and undrained shear strength $c_u$, can be assumed to be constant with depth. The lateral earth pressure coefficient around the diaphragm walls can be taken as unity following their casting. All ground deformation can be regarded as occurring in plane strain, and the entire construction process can be taken as undrained.

(a) The base of each wall can be formed in a shallow socket in the bedrock so as effectively to provide a pinned joint. Otherwise, the wall will not receive any structural support while a shallow excavation of depth $D$ takes place on one side. By neglecting wall friction, and assuming triangular zones of soil deformation either side of the wall, establish a deformation mechanism by which the mobilisation of soil strength can be seen as being induced by wall rotation. [30%]

(b) Sketch distributions of lateral earth pressure acting on the wall after excavation. Assuming an isotropic response in the clay as it mobilises shear strength $c_{mob} < c_u$ on both sides of the wall, write an expression from which $c_{mob}$ could be derived. Show that for relatively deep, smooth, walls with shallow excavations, the ratio $c_{mob}/\gamma D \rightarrow 0.25$ as $D/H \rightarrow 0$. [40%]

(c) In the case of a clay stratum with depth $H$ = 10 m and unit weight $\gamma$ = 18 kN/m$^3$, an undisturbed sample was taken from 5 m depth and subjected to a triaxial compression test. The following stress-strain data was obtained.

| Deviatoric stress $q$ kPa | Axial strain $\varepsilon_a$ % |
|---|---|
| 0 | 0 |
| 18 | 0.1 |
| 25 | 0.2 |
| 40 | 0.5 |
| 57 | 1 |
| 80 | 4 |

Estimate the deflection of the top of the wall when a depth $D$ = 2 m has been excavated from one side. Suggest two methods by which this estimate could be improved. [30%]

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3 (a) What are the main challenges for engineers working with silts and clays whose specific volume lies above the critical state line drawn on a ($v$, ln $\sigma'$) plot? Sketch stress paths to illustrate your answer and offer a micromechanical explanation for the behaviour. What control methods are generally applied for construction on very soft soils? What additional factors are involved in the undrained stress-strain behaviour of very sensitive soils, and what extra construction control measures are applicable in these cases? [40%]

(b) A soft marine clay is found to have properties similar to those listed for kaolin in the Data Book. Deep excavation is taking place at a characteristic depth of 15 m, in a location where the water table lies at 2 m depth below ground surface. The clay is not found to be significantly sensitive.

(i) Oedometer tests on samples recovered from 15 m suggest that the soil is lightly overconsolidated with an effective preconsolidation stress $\sigma'_c$ of 130 kPa. Sketch the possible stress history on a ($v$, $\sigma'$) diagram, mark both $\sigma'_c$ and the in-situ vertical effective stress $\sigma'_o$, and calculate corresponding specific volumes $v_c$ and $v_o$. [20%]

(ii) Estimate the yield stress $\tau_y$ and the ultimate undrained shear strength $c_u$ of the soil at 15 m depth using SSA Cam Clay and mark corresponding points Y and U on a ($\tau$, $\sigma'$) diagram and the existing ($v$, $\sigma'$) diagram. Sketch an approximate undrained stress path in simple shear for the clay at 15 m. [20%]

(iii) The engineer responsible for the works has previous experience of glacial tills, and believes that a "factor of safety" of 1.25 is generally adequate for clays. Mark this assumed safe state A on your diagrams. Make short notes agreeing or disagreeing with the engineer's assumption in this case. Adopt a Limit State Design perspective, and offer reasons for any different recommendation that you may have. [20%]

4 (a) What is the main challenge for engineers working with soils whose specific volume lies below the critical state line drawn on a ($v$, ln $\sigma'$) plot? Discuss the relative dangers incurred in drained and undrained shearing of such soils, and sketch stress paths to illustrate your answer. Offer a micromechanical explanation for the behaviour. [20%]

(b) A long wide slope in apparently homogeneous glacial till of clayey, silty sand with unit weight $\gamma = 20$ kN/m$^3$ is to be cut back to a slope angle of 22°, removing more than half the depth of the pre-existing material. The till will then form a parallel layer about 6 m deep resting on top of a sloping impermeable bedrock. Groundwater monitoring over a 12 month period showed that the phreatic surface in the till ran parallel to bedrock and at an elevation 5 m above it in the wet season, and at 2 m above bedrock in the dry season. Three very slow, drained triaxial compression tests on vertical cores taken from the till were conducted under constant lateral effective stresses of 25 kPa, 100 kPa and 400 kPa respectively, and their peak strengths were recorded at deviatoric stresses of 75 kPa, 250 kPa and 840 kPa respectively. The laboratory noted that whereas the two samples confined at the lower stresses failed on shear surfaces whilst they were dilating, the third sample tended initially to contract in volume before ultimately incurring large, uniform, plastic strains.

(i) Find the peak secant angle of friction $\phi_{max}$ of each of the three samples of glacial till. [20%]

(ii) Deduce a value for the critical state friction angle $\phi_{crit}$, and create an approximate expression for the linear variation of $\phi_{max}$ with the logarithm of the mean effective stress $p'$ for values of $p'$ smaller than some stated critical state value $p_{crit}$. [20%]

(iii) Use "infinite slope" analyses, and other carefully justified assumptions, to determine whether the cut slope should fail either in the dry season or the following wet season, if the corresponding groundwater conditions from the previous monitoring exercise are exactly duplicated. [30%]

(iv) Should the responsible engineer be concerned about the long-term safety of the slope? If so, explain why. [10%]

**END OF PAPER**