Version SPGM/4

EGT2
ENGINEERING TRIPOS PART IIA

Monday 3 May 2021 9.00 to 10.40

Module 3D8

ENVIRONMENTAL GEOTECHNICS

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 and at the top of each answer sheet.*

STATIONERY REQUIREMENTS
Write on single-sided paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed.
Attachment: 3D8 Environmental Geotechnic data sheet (6 pages).
You are allowed access to the Engineering Data Books, online or as your hard copy.

10 minutes reading time is allowed for this paper at the start of the exam.

The time taken for scanning/uploading answers is 15 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers.

1 (a) Derive the relationship between 'void ratio' and 'porosity' of a granular medium. [10%]

(b) An earth dam that is 10 m high holds a reservoir of water 9 m deep as shown in Fig. 1. The earth dam is constructed by compacting silty clay and is founded on an impermeable Shale rock formation as shown in Fig. 1. A highly permeable blanket drain that extends 10 m into the dam is provided to protect the downstream slope as shown in Fig. 1. The saturated unit weight of the silty clay is 19.5 kN m^{-3} and its hydraulic conductivity is 3.8×10^{-9} m s^{-1}. It may be assumed that the silty clay has a high air entry value.

(i) Draw a 'flow net' at steady state seepage of the problem on a scaled diagram of Fig. 1. Highlight any limitations of the flow net that you have constructed. [20%]

(ii) Determine the quantity of leakage due to seepage through the silty clay in units of litres per day if the earth dam is 500 m long. [10%]

(iii) Estimate the pore water pressures at points A, B and C that lie on the centre line of the earth dam as shown in Fig.1. [20%]

c) It was discovered that the earth dam has developed anisotropy due to compaction of the dam during construction that resulted in different hydraulic conductivities in the horizontal and vertical directions. The vertical conductivity is 3.8×10^{-9} m s^{-1}. The horizontal hydraulic conductivity is now found to be four times as high as the vertical hydraulic conductivity.

(i) Redraw the flow net for these anisotropic conditions. Comment on any assumptions you had to make. [20%]

(ii) Determine the quantity of leakage for this condition. Compare this to the isotropic case. [20%]

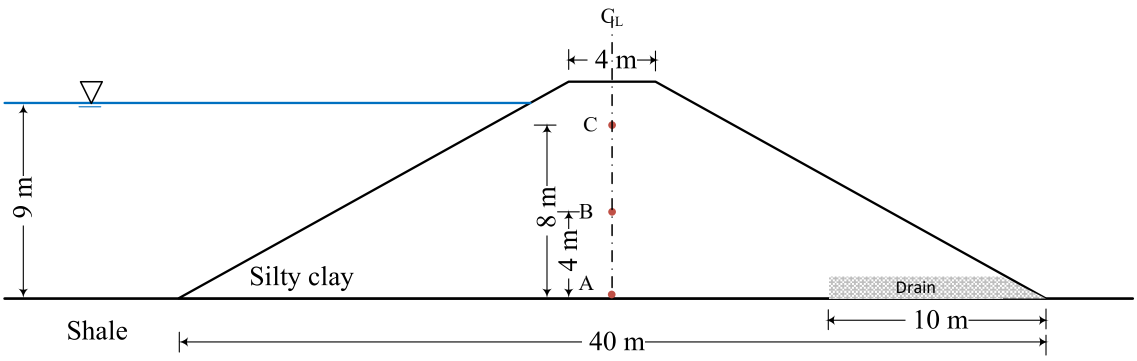

Fig. 1

2 (a) Explain briefly the terms ‘thermal conductivity’, ‘volumetric heat capacity’ and ‘thermal diffusivity’ with respect to granular media. [10%]

(b) The falling head permeameter shown in Fig. 2 is to be used to determine the hydraulic conductivity of a granular soil. Derive an expression for the hydraulic conductivity in terms of the length of the sample L, cross-sectional area of the sample A, the cross-sectional area of the tube a, the head h and time t. [20%]

(c) A fine silty sand was tested in the permeameter shown in Fig. 2 using water as the pore fluid. The results obtained taking the datum at the base of the soil sample are shown in the table 1 below. The diameter of the soil sample is 50 mm and the length of the sample is 100 mm. The area ratio between the soil sample and the tube is 2500. Determine the hydraulic conductivity of the soil. Comment on the quality of the data.

Table 1

t (min)	0	1	2	4	16	32	64	128	256
h (mm)	200	195	192.5	187.5	160	150	140	121	113

t (min)	512	750	1024	1525	2048	2500
h (mm)	98	60	74	79	42	32.7

[40%]

(d) A fine silty sand deposit is contaminated with hydraulic oil at a factory site. This soil is the same as that tested in the falling head permeameter in part (b). The unit weight of the hydraulic oil is 8.1 kN m^{-3} and its kinematic viscosity is 18 cSt. The unit weight of water can be taken as 9.81 kN m^{-3} and the kinematic viscosity of water is 1 cSt. Determine the hydraulic conductivity of the soil with respect to the hydraulic oil. [30%]

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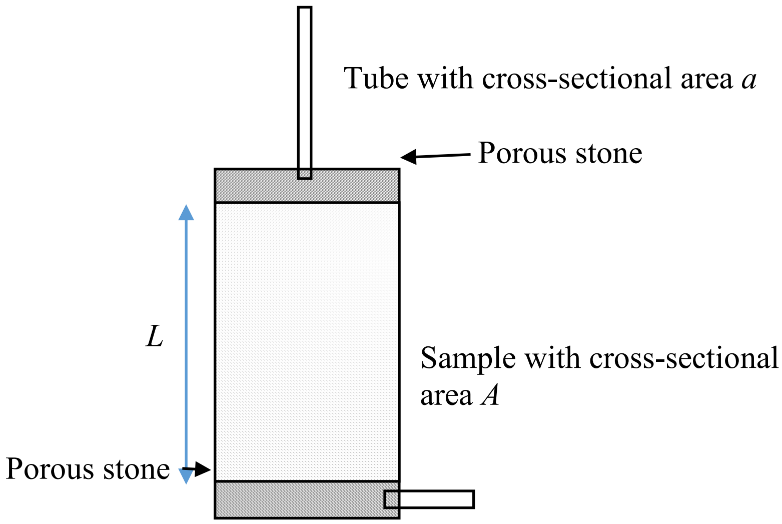
Tube with cross-sectional area a
Porous stone
L
Sample with cross-sectional area A
Porous stone

Fig. 2

3 (a) Compare and contrast the mineralogical properties of the two clay classes of kaolinites and montmorillonites with specific reference to:

(i) the impact on their engineering properties and associated applications; [15%]

(ii) the impact on their performance in contaminant transport processes and remediation techniques. [15%]

(b) Batch tests for cadmium (Cd) adsorption on to a smectite sample were conducted at a fixed temperature. The procedure was as follows: 1 g samples of air-dried smectite were mixed with 50 ml of cadmium solutions of varying concentration; the slurries were shaken for 24 hours, centrifuged and filtered to remove solids and samples of the supernatant solution were analysed for cadmium. The experiment was repeated at pH 4 and pH 8. The results are shown in table 2 below.

Table 2

pH 4	
Initial Cd concentration (mg/l)	Equilibrium Cd concentration (mg/l)
10	6.7
20	13.8
40	28
80	56
100	70

pH 8	
Initial Cd concentration (mg/l)	Equilibrium Cd concentration (mg/l)
10	3.8
50	8.2
100	19.6
200	46.8
400	100.2

(i) Plot the adsorption isotherm for cadmium on smectite for each pH and describe the sorption behaviour highlighting salient points in each case. Calculate relevant parameters and comment on your answers. [25%]

(ii) Explain why the sorption behaviour is different at the two different pH values. [10%]

(c) Give three practical examples of how the structure of a clay could become flocculated or dispersed. Explain the reasons for this change for each case. [15%]

(d) Explain with the aid of sketches, how petroleum leaking from an underground storage tank would spread in a soil and groundwater environment of your choice, in both the short and long terms. How does this depend on the soil type and the chemical and physical properties of the pollutant constituents? How would you go about remediating such a contaminated site? [20%]

4 A surface impoundment is to be sited on the top of an intact, 10 m thick, clay stratum. The vertical hydraulic conductivity of the clay is 1.5×10^{-9} m s^{-1} and its void ratio is 0.7. The clay stratum is underlain by a free flowing groundwater aquifer. The maximum concentration of the liquid contaminant in the surface impoundment is 24.5 mg L^{-1}. A 3 m deep surface impoundment will be designed to hold the liquid contaminant. Assume that the liquid contaminant is in direct contact with the top clay surface and that its flow and dispersion through the clay stratum can be assumed to be one-dimensional. The effective diffusion coefficient D_d* of the contaminant in this clay is 5.4×10^{-9} m^2 s^{-1} and the longitudinal dispersivity of the clay is $\alpha_l = 0.3$ m. The bulk density of the clay can be taken as 1900 kg m^{-3}.

When dispersion is the dominant contaminant transport mechanism, the expression for the contaminant concentration, c, within the clay layer can be related to the initial constant concentration of the contaminant, c_o, in the surface impoundment by:

$$\frac{c}{c_o} = \frac{1}{2}\, erfc\left[\frac{z - v_f\, t}{\sqrt{4\, D_l\, t}}\right]$$

where *erfc* is the complementary error function, z is the depth within the clay stratum, v_f is the vertical mean pore fluid velocity within the clay stratum, t is time and D_l is the longitudinal dispersion coefficient of the contaminant respectively. You may assume that the maximum concentration of the contaminant remains constant at the surface of the clay stratum and that sorption is negligible. For all the question parts below, the aquifer can be considered initially free from any contamination.

(a) If dispersion is the dominant contaminant transport mechanism within the clay stratum, how long will it take for the concentration of the contaminant at the clay-aquifer interface to reach 0.0245 mg L^{-1}. [25%]

(b) Sketch a rough distribution of the contaminant concentration within the clay stratum, at the stage reached in part (a), marking the concentrations at quarter, half and three quarters depths within the clay layer. Highlight salient points and comment on your findings. [25%]

(c) For a purely advective contaminant transport, how long will it take for the contaminant to reach the clay-aquifer interface? Comment on the difference to your answer to part (a). [10%]

(d) If sorption cannot be ignored, and the distribution coefficient for the contaminant in the clay is 5 L kg^{-1}, when will the first sign of the contaminant reach the aquifer? Add a rough sketch on the figure produced for part (b) highlighting main changes expected. Comment on your answers. [20%]

(e) Suggest four remedial measures to reduce the possibility of the contaminant reaching the aquifer. [20%]

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