Version SPGM/2

EGT2
ENGINEERING TRIPOS PART IIA

Monday 1 May 2023 9.30 to 11.10

Module 3D8

GEO-ENVIRONMENTAL ENGINEERING

*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

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D8 Geo-Environmental Engineering data sheet (6 pages)
Supplementary page: Extra copy of Fig. 1 (Question 1)
Engineering Data Book

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

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

You may not remove any stationery from the Examination Room.

1 A 24 m high earth dam with a chimney drain was constructed as shown in Fig. 1. The earth dam retains water to a depth of 22 m when the reservoir is full, leaving a freeboard of 2 m as shown in Fig. 1. The dam was built by compacting silty clay and has a saturated unit weight of 19.1 kN m^{-3}, voids ratio of 0.6 and a hydraulic conductivity of 4.6×10^{-7} m s^{-1}. The silty clay has an air entry value of -100 kPa. You may assume that the drain has infinite hydraulic conductivity relative to the silty clay. An impermeable shale rock is present below the dam as shown in Fig. 1.

(a) Draw a flownet for seepage through the earth dam on the copy of Fig. 1 provided in the attachments. This sheet must be handed in with your answer. Draw attention to any shortcomings in your solution. [20%]

(b) Determine the quantity of seepage that would flow out of the drain at the downstream face of the earth dam. Express your answer in the units of litres per day, if the length of the earth dam is 200 m. [15%]

(c) Estimate the pore water pressures within the dam at locations A, B, C and D shown in Fig. 1. Calculate the vertical effective stresses at points A, B and C. [25%]

(d) Estimate the water flow velocity between points C and D. [15%]

(e) The reservoir level on the upstream side of the dam falls rapidly to 0 m i.e. to the base level of the dam. Explain how this might affect the pore water pressures you calculated in part (c) above. What dangers might such a sudden drawdown pose to the safety of the earth dam? [25%]

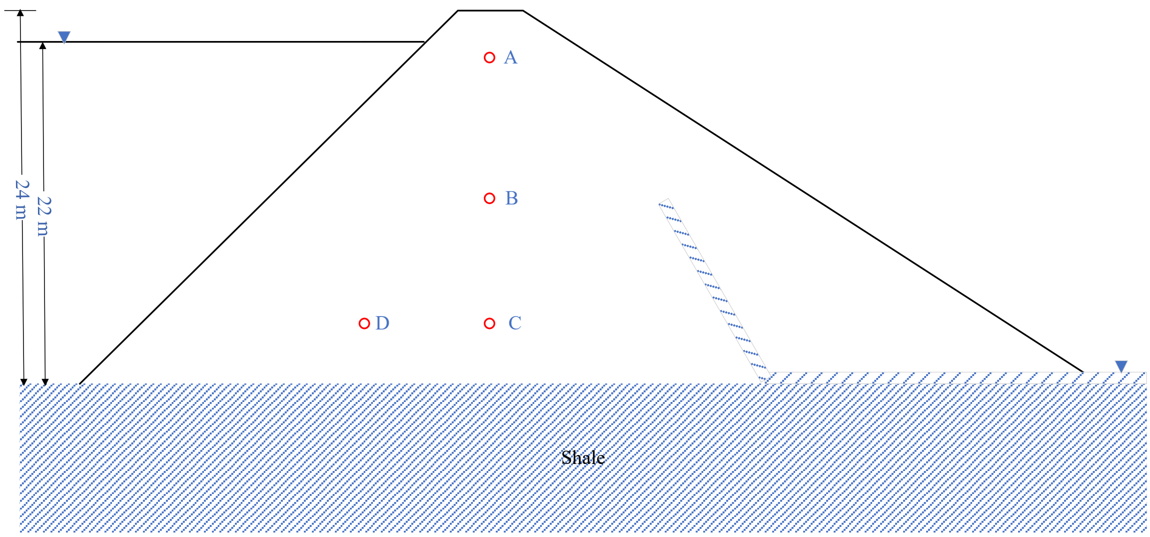

Fig. 1

2 (a) State Darcy's law for fluid flow and Fourier's law for heat flow through granular material, drawing on the similarities between these. What is the main difference between fluid flow and heat flow in granular media? [15%]

(b) Derive an equation to relate the flow rate Q from a bore well with a hydraulic conductivity K of the aquifer. Assume that B is the thickness of the aquifer and h_1 and h_2 are the hydraulic heads at radii r_1 and r_2 respectively. [20%]

(c) A bore well with a diameter of 200 mm was sunk into an aquifer that is 5 m thick in a field. The aquifer is sandwiched between thick clay layers. When the rate of pumping from this well is 400 litres per minute, it was observed that pore water pressures at points A and B that are at radial distances of 1 m and 5 m from the well wall drop by 30 kPa and 10 kPa respectively. Points A and B are at an elevation of 2.5 m above the base of the aquifer. Estimate the hydraulic conductivity of the aquifer. What type of soil do you think the aquifer is formed from? [25%]

(d) The rate of pumping from the bore well in part (c) is doubled. Estimate the drop in pore water pressures at the same radial distances as in part (c). What would be your best guess of the radius of influence of this bore well for this rate of pumping? [20%]

(e) You have discovered that an impermeable slurry wall will be constructed in the field, at a radial distance of 6 m from the centre of the bore well. The slurry wall penetrates deep into the ground and is keyed into the clay layer underlying the aquifer. Consider the rate of pumping in part (c) above. Estimate how the pore water pressures will change at the radial distances given in part (c) in the presence of the slurry wall. [20%]

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3 (a) Define the two main sorption processes, namely adsorption and absorption. [10%]

(b) Briefly describe the main sorption mechanisms. [20%]

(c) Table 1 shows data from a batch sorption isotherm experiment on a soil for cadmium ions (Cd^{2+}). For each sample, 250 grams of soil was equilibrated with 500 mL of solution. Calculate q, the equilibrium sorbed mass of Cd^{2+} (in mg g^{-1}), in each case and plot the sorption isotherm (q versus equilibrium solute concentration). Calculate the partitioning coefficient K_d for this isotherm. [40%]

Table 1 Results of batch sorption tests

Sample number	Initial Cd^{2+} concentration (mg L^{-1})	Final Cd^{2+} concentration (mg L^{-1})
1	20	0.15
2	50	0.40
3	100	0.78
4	200	1.58
5	500	3.96

(d) Define the cation exchange capacity of clay and explain how and why its range changes between the three different types of clay minerals, namely Kaolinite, Illite and Montmorillonite. [30%]

4 (a) Explain how you would distinguish between the dominant contaminant transport mechanisms using the Peclet Number P_e. [25%]

(b) A soil is used as a barrier for cadmium (Cd) contaminated water. The Cd contamination can be idealised as a constant concentration source of 75 mg L^{-1} (i.e. c_0). Design the thickness of the barrier such that no Cd escapes from it (i.e. $c/c_0 < 0.001$) for a period of at least 200 years and comment on your answers. Assume diffusive transport only and linear sorption, with a partition coefficient, K_d, of 0.25 L g^{-1}. The bulk density ρ_b and porosity n of the soil in situ are 1900 kg m^{-3} and 0.45 respectively. The effective diffusion coefficient D_d^* for Cd is 5.5×10^{-10} m^2 s^{-1}. [40%]

The diffusive transport equation is:

$$\frac{c}{c_o} = \text{erfc}\left[\frac{z}{\sqrt{4\,D_d^*\,t}}\right]$$

where z is length and t is time, and the retardation factor, R_d, due to linear sorption is given by:

$$R_d = \left(1 + \frac{\rho_b}{n}\,K_d\right)$$

(c) Without doing further calculations, explain how the thickness of the barrier calculated in part (b) above would change, and why, if:

(i) dispersive transport is also involved; [5%]

(ii) the calculations assume no sorption; [5%]

(iii) multiple heavy metals are present. [5%]

(d) Apart from using a barrier, list three other remediation techniques that would be applicable to prevent the spreading of Cd from a contaminated site and explain why and how these techniques would be applied in practice. What would determine whether the remediation is carried out in-situ or ex-situ? [20%]

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Candidate No:

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