ENGINEERING TRIPOS PART IIA

Tuesday 8 May 2012 9 to 10.30

Module 3D8

BUILDING PHYSICS AND 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.*

Attachments: 3D8 Building Physics and Env. Geotechnics Data Book (23 pages)
Extra copy of Fig. 1 (Question 1)

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS
Engineering Data Book
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

Final Version

1 (a) Derive an expression for the capillary rise of water with surface tension T in a tube of diameter d. [15%]

(b) A flood protection earth dam is to be constructed at a site. Reconnaissance investigations reveal that significant quantity of clayey silt is available in the vicinity. The properties of this soil are shown in the table below.

D_{10} (μm)	D_{20} (μm)	void ratio e	hydraulic conductivity K ($\mathrm{m\ s^{-1}}$)	Unit weight of pore water γ_w ($\mathrm{kN\ m^{-3}}$)	Surface tension of pore water T ($\mathrm{kN\ m^{-1}}$)
10.0	35.0	0.65	6.25×10^{-5}	10.0	7.1×10^{-5}

Calculate the height of capillary rise that can occur above the water table in this soil. [15%]

(c) The flood protection earth dam is constructed with the cross-section shown in Fig. 1 using the clayey silt described in part (b). This soil has a low air entry value and allows air to enter into the earth dam. The bed rock has a convex profile as shown in Fig. 1, which is retained during construction to minimise the earth works.

(i) 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. [30%]

(ii) Estimate the leakage rate into the drainage blanket due to seepage of water through the earth dam. [20%]

(iii) Calculate the pore water pressure at locations A, B, C and D in the earth dam as marked on Fig. 1. [20%]

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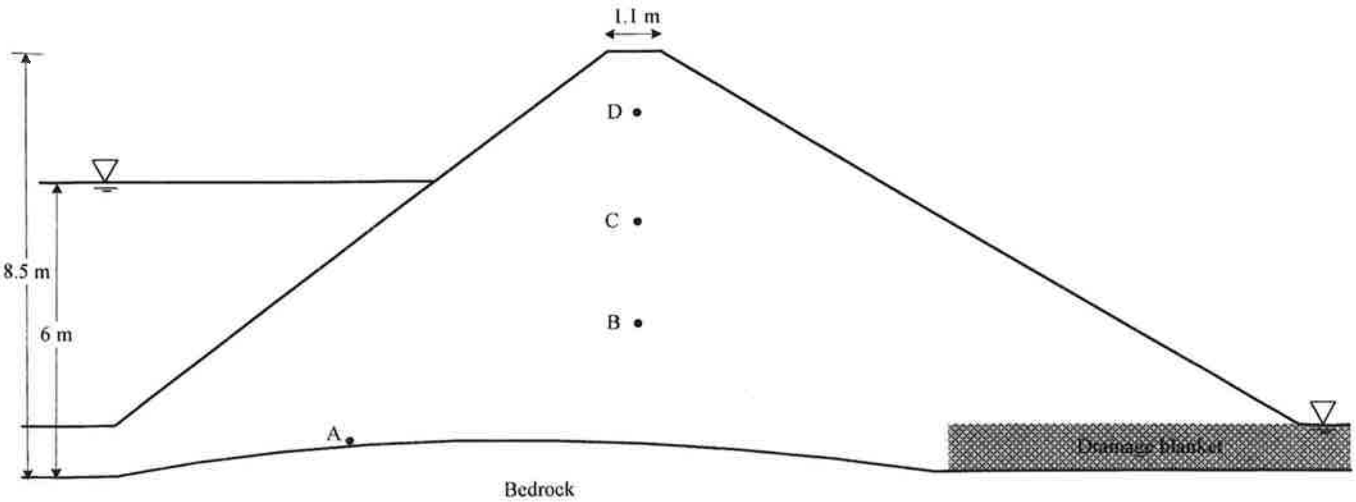

Fig. 1

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2 (a) State Fourier's law of conduction of heat and explain how it may be applied to flow of heat through soil. [15%]

(b) A vertical ground source heat pump is installed in a bore hole at a building site in a fully saturated sandy soil deposit. The depth of the bore hole is 80 m and its diameter is 0.1 m. The thermal conductivity of the soil λ is 3.1 W m^{-2} K^{-1}. During operation of the heat pump, it was observed that the steady state temperature of the ground was 3°C at a radius of 1 m and 4°C at a radius of 1.5 m from the axis of the bore hole. Calculate the quantity of heat energy extracted in 1 hour by the ground source heat pump from this single borehole. [30%]

(c) Liquid contaminant from an industrial site is to be stored in a pond within a clay layer as shown in Fig. 2. The thickness of the clay liner below the base of the pond is 4 m. The effective coefficient of diffusion of the contaminant D_d^* in the clay liner is 2.95×10^{-9} m^2 s^{-1}. The concentration of the contaminant c in the clay liner can be related to the maximum concentration c_o using the following expression:

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

where *erfc* is the complementary error function, z is the distance into the clay liner, D_d^* is the effective coefficient of diffusion and t is the time. Assume that sorption of this contaminant is negligible. You may also assume that the maximum concentration of this contaminant remains constant in the pond.

(i) Calculate the shortest time it takes for traces of the contaminant to enter the ground water in the aquifer shown in Fig. 2. [25%]

(ii) Sketch the distribution of the concentration of the contaminant with the liner thickness at this stage, marking the concentrations in terms of c_o at quarter, half and three quarter points within the clay liner. [30%]

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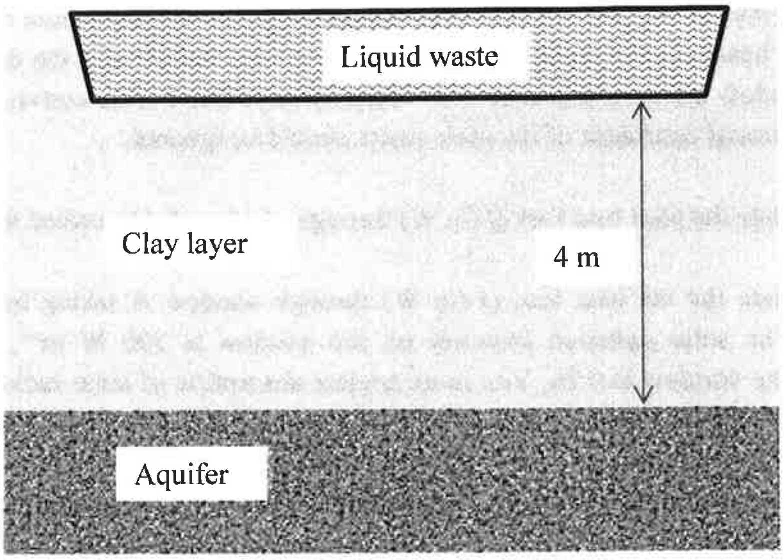

Fig. 2

(TURN OVER

3 (a) Calculate the U-value of window A, which is a regular double-glazed window. The dimensions of the window are 4.0 m × 2.0 m. The emissivity of the glass panes is 0.9. The gap-width between the glass panes is 30 mm. The gap between the glass panes is filled with air (assume that thermal conductivity λ of air is 0.026 W m^{-1} K^{-1}). The interior room air temperature is maintained at 20°C, and the average external air temperature is 0°C. The combined surface heat transfer coefficients for convection and radiation at the exterior and interior of the window are 25 and 8 W m^{-2} K^{-1} respectively. There is no convection in the air gap, and the thermal resistance of the glass panes should be ignored. [30%]

(b) Calculate the total heat loss Q (in W) through window A (described in (a)). [20%]

(c) Calculate the net heat loss Q (in W) through window A taking into account solar radiation. The solar radiation intensity on the window is 300 W m^{-2}. The solar transmittance of the window is 0.76. You must neglect absorption of solar radiation in the glass panes. [20%]

(d) Window A is to be replaced by window B. Window B has the same dimensions and gap-width as window A, but has a low-e coating on both panes of the double glazing, and the gap is filled with gas. The combined thermal resistance R of the low-e coated glass and gap of window B is 0.69 m^2 K W^{-1}. Calculate the heat loss through window B without solar radiation. Would it be possible to achieve this same heat loss by increasing the gap-width of window A (assume that no air convection will occur by increasing the gap-width)? Explain why. [30%]

4 (a) Consider a unit area (1.0 m^2) of the following wall. Materials are listed from outside to inside.

Thickness d (mm)	Material	Thermal Conductivity λ ($W\,m^{-1}\,K^{-1}$)	Vapour Permeability δ_v ($m^2\,s^{-1}$)
100	Brick	0.50	5.0×10^{-6}
120	Insulation (mineral wool)	0.04	20.0×10^{-6}
100	Concrete	0.10	10.0×10^{-6}

Calculate the temperature at the interface between the brick and the insulation layer when the external air temperature during winter is -7.0 °C, and the interior air temperature is maintained at 20 °C. The surface resistance is 0.13 $m^2\,K\,W^{-1}$ and 0.04 $m^2\,K\,W^{-1}$ at the exterior and interior respectively. [25%]

(b) Calculate whether condensation will occur at the interface between the brick and the insulation layer during winter (same conditions as in (a)). The humidity of the air by volume is 3.0 g m^{-3} and the additional moisture supply inside the building is 4.0 g m^{-3}. Ignore the resistance due to surface water vapour. [25%]

(c) Calculate the quantity of the condensate in g m^{-2} for the conditions in question 4(b) over two months (60 days) in winter. [25%]

(d) During the summer months, the average external temperature is 15 °C, and the humidity of the air by volume is 9.0 g m^{-3}. Is it possible that the condensate in the wall can dry out over two months (60 days) in the summer? Justify your answer. [25%]

END OF PAPER

CANDIDATE NUMBER

ENGINEERING TRIPOS PART IIA TUESDAY 8th MAY 2012 9 TO 10.30
MODULE 3D8 BUILDING PHYSICS & ENVIRONMENTAL GEOTECHNICS

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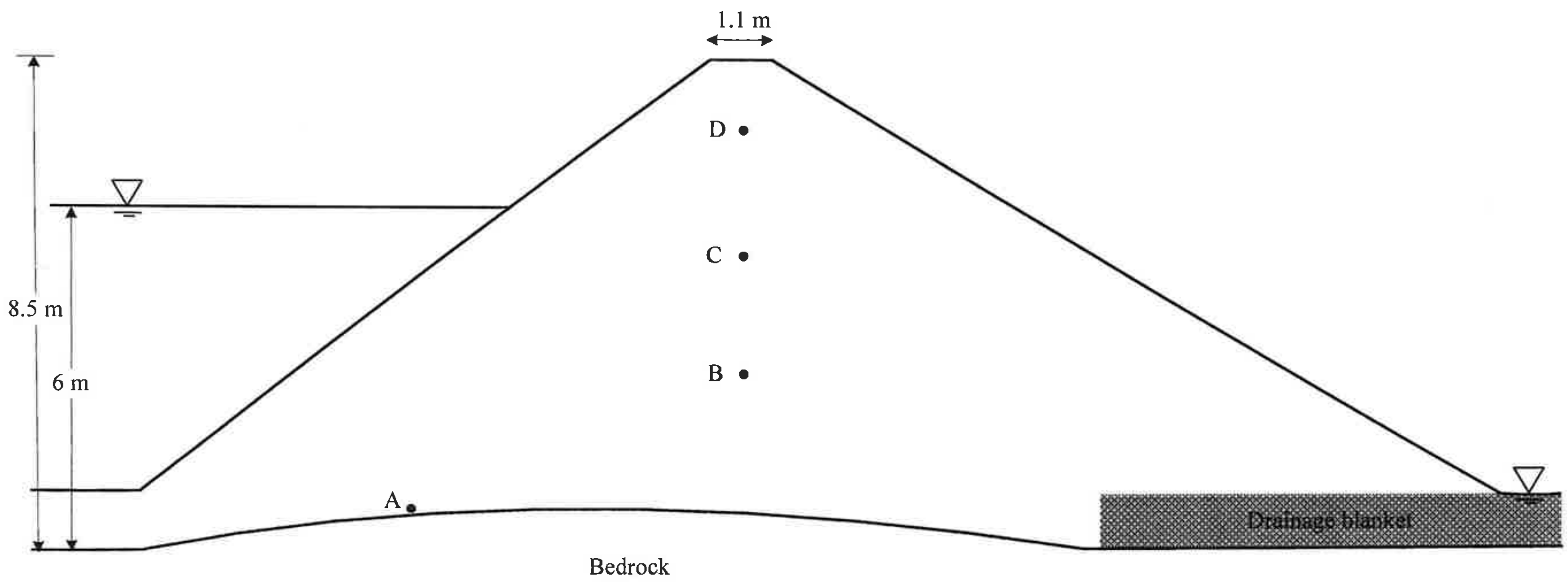

Extra copy of Fig. 1

NUMERICAL ANSWERS
ENGINEERING TRIPOS PART IIA 2009
MODULE 3D8: ENVIRONMENTAL GEOTECHNICS & BUILDING PHYSICS

Q1 Flood Protection Dam

(a) See Crib

(b) 2·84 m

(c) i. See Crib ii. $9{\cdot}37 \times 10^{-5}$ m³/s/m iii. $P_A = 48$ kPa, $P_B = 3$ kPa, $P_C = -16{\cdot}6$ kPa, $P_D = 0$ kPa

Q2 Heat and Mass Transfer through Porous Media

(a) See Crib

(b) 560·9 kJ

(c) i. 4·78 years ii. 28·9% ; 3·39% ; 0·16% ; 0%

Q3 Heat Transfer through Transparent Surfaces

(a) 2·76 W/m²K

(b) 441·98 W

(c) − 1382 W

(d) 185·6 W

Q4 Condensation in Walls

(a) 5.5°C

(b) 5·22 > 3·12

(c) $1{\cdot}23 \times 10^3$ g × (t/area)

(d) $1{\cdot}08 \times 10^3$ g × (t/area)

R. Choudhary (Principal Assessor)