Version RC/5

EGT2
ENGINEERING TRIPOS PART IIA

Thursday 27 April 2017 2 to 3.30

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.*

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 Building Physics and Env. Geotechnics Data Book (15 pages)
Supplementary page: one extra copy of Fig.1 (Question 1)
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 (a) Explain briefly how a particle size distribution curve is obtained for a given soil. [10%]

(b) Why is it dangerous to use particle size distribution exclusively to determine soil behaviour? What other properties of soil would you consider to establish the soil behaviour? [20%]

(c) A horizontal stratum of coarse silt which is 15 m thick overlies bed rock. The dry unit weight of this silt is 14.6 kN m^{-3} and its void ratio is 0.78. The D_{10} size of this silt is 0.005 mm while the D_{20} size is 0.01 mm. The initial water table is located 5 m below the ground surface. The surface tension of water is 7×10^{-5} kN m^{-1}. Sketch the total and effective stress profiles with depth for the silt layer. How much rainfall is required to raise the water table to the ground surface? [20%]

(d) An earth dam was constructed with silty clay that has a hydraulic conductivity of 6.4×10^{-7} m s^{-1}. This silty clay has a very high air entry value. The upstream slope was constructed with a change in slope as shown in Fig. 1. A chimney drain was included in the body of the dam to prevent any downslope leakage. The dam is located on a thick stratum of stiff clay.

(i) Draw a flow net at steady state seepage through the dam on the extra copy of Fig. 1 provided. Highlight any limitations of the flow net that you have constructed. You must submit this copy with your script. [25%]

(ii) Determine the quantity of leakage due to seepage through the silty sand in the units of litres per day if the dam is 200 m long. [10%]

(iii) Estimate the pore water pressures at locations marked A, B, C and D in units of kPa. [15%]

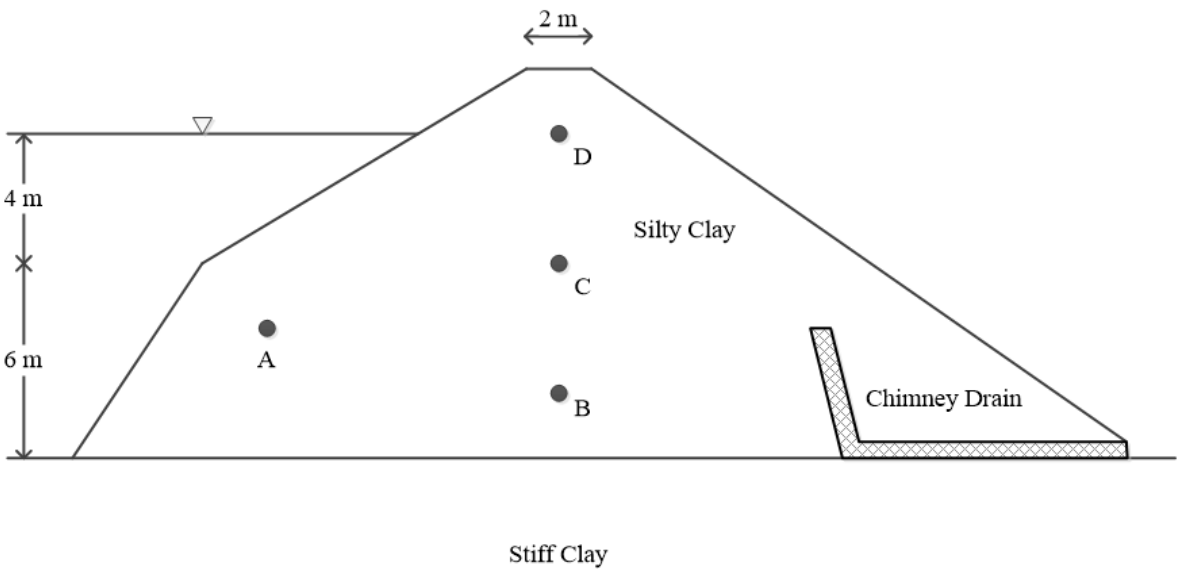

Fig. 1

2 (a) Briefly explain the contaminant transport mechanisms in ground water flow. Explain how the normalised concentration changes with time at a given location for each of the transport mechanisms. [20%]

(b) The advection-dispersion equation for contaminant transport in a porous medium is given as:

$$\frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial z^2} - v_f \frac{\partial c}{\partial z}$$

where D_l is the coefficient of longitudinal dispersion and v_f is the fluid flow velocity. This equation is applicable to a clay layer of thickness H underlying an old landfill. The concentration of the contaminant in the landfill may be taken as c_o at all times. There is an aquifer below the clay layer which removes any contaminant and hence the concentration at this depth may be taken as zero. Derive a relationship for the variation of concentration with depth in the clay layer when steady state conditions are established. [25%]

(c) A non-conventional energy farm based on ground source heat pumps (GSHP) was constructed at a site in Denmark. At this site, the soil has a thermal conductivity λ of 2.62 W m^{-1} K^{-1}. A GSHP was installed to a depth of 50 m below ground surface and the radius of the bore well is 0.4 m. While extracting 2.5 kW of heat, it was noticed that the temperature of the ground was 1 °C adjacent to the wall at the mid depth of the bore well. The ambient ground temperature at the site is 10 °C. Calculate the temperature in the ground at a distance of 2 m from the wall of the bore well on the same horizontal plane. What is the radius of influence of this GSHP. [30%]

(d) If the site considered in part (c) has a plan area of 401.5 m $\times$ 200 m, how many GSHPs with same dimensions as in part (b) can be installed, with each one of them extracting 2.5 kW of heat. For optimal performance each GSHP should not be within the radius of influence of adjacent units. Calculate the maximum heat energy that can be extracted from the GSHPs at this site. Sketch a suitable layout for their installation. [25%]

3 (a) A solid stone wall of an old college building is 1.5 m thick. The thermal conductivity of the wall λ is 3.2 W m^{-1} K^{-1} and its volumetric heat capacity ρc is 2.0 $\times$ 10^6 J m^{-3} K^{-1}. Calculate the thermal diffusivity of this wall. Explain the significance of thermal diffusivity in the context of heat flow through building materials. [20%]

(b) In periodic solutions, the temperature at any point x through a given semi-infinite material at time t can be expressed in the form:

$$\hat{T}(x) = T_1 \cdot e^{\left[\frac{-(1+i)x}{d_p}\right]}$$

$$\hat{T}_c(x,t) = \hat{T}(x) \cdot e^{\left[\frac{2\pi i t}{t_p}\right]}$$

where ˆ denotes complex quantities, $\hat{T}(x)$ is the spatial complex-valued temperature, $\hat{T}_c(x,t)$ is the time-cyclic variation of temperature, T_1 is the outdoor temperature with no phase shift, d_p is the penetration depth, and t_p is the time period of temperature variation.

(i) What is the sine solution $T(x,t)$ of the time-cyclic temperature variation shown above? Which terms in the sine component represent the amplitude change of the temperature through the material? [20%]

(ii) The heat flow through the semi-infinite material is:

$$Q(x,t) = \text{Im}\left[\hat{Q}_c(x,t)\right]$$

where $\text{Im}\left[\hat{Q}_c(x,t)\right]$ is the imaginary part that gives the sine solution of the periodic problem. Show that:

$$Q(x,t) = \frac{A\lambda\sqrt{2}}{d_p} T_1 e^{\left[\frac{-x}{d_p}\right]} \cdot \sin\left(\frac{2\pi t}{t_p} - \frac{x}{d_p} + \frac{\pi}{4}\right)$$

where A is the area of the material and λ is the thermal conductivity of the material. [30%]

(iii) For any point x in the material, show that the difference between the time at which the maximum temperature occurs and the time at which the maximum heat flow occurs is equal to $t_p/8$. What is the physical interpretation of this lag? [30%]

4 (a) A room is constructed as an extension of an existing house. The dimensions of the room are 6 m $\times$ 4 m, and it is 3 m high. The room has only one exterior wall, which is 4 m wide and has a large window of dimensions 2.5 m $\times$ 2.2 m. The room is ventilated at a rate of 0.50 air changes per hour. All spaces adjacent to the interior walls, roof, and floor are at 19 °C. The U-values of the external wall, the window, and the internal surfaces are 0.6, 2.8, and 1.6 W m^{-2} K^{-1} respectively. Neglect surface resistances. The outdoor air temperature is -2 °C.

(i) Calculate the steady state indoor air temperature of the room. [20%]

(ii) Calculate the heating demand to maintain indoor air temperature at 23 °C for a design outdoor temperature of -2 °C. [10%]

(iii) Heat will be supplied to this room by radiant ceiling heating. The ceiling surface temperature will be at 34 °C. Show that this is sufficient to maintain internal temperature at 23 °C. The emissivity of all surfaces is 0.90. Assume that the view factor is 1, and other surfaces of the room will be at 23 °C. [20%]

(b) Consider a newly constructed basement, which is air tight. The floor area of the basement is 10 m $\times$ 16 m, and the height is 2 m. The walls of the basement space are made of 250 mm thick concrete blocks whose thermal conductivity λ is 0.60 W m^{-1} K^{-1}. The ceiling of the basement has a thermal resistance of 2.5 m^2 K W^{-1}, including surface resistance at both sides. There are openings in the wall to provide natural ventilation at the rate of 0.5 air changes per hour. A layer of expanded clay aggregate has been laid on the ground. The overall U-value of the floor, including the clay aggregate, soil, and surface resistance is 0.317 W m^{-1} K^{-1}. The vapour permeability of the clay aggregate is 25×10^{-6} m^2 s^{-1}. The external air is at 8.5 °C temperature and 80 % relative humidity. Assume the same temperature and relative humidity in the ground. The temperature and relative humidity inside the building above the basement ceiling are 22 °C and 48 % respectively. Calculate the relative humidity in this basement. Draw detailed network diagrams of all calculations. Is the basement at risk of moisture problems? [35%]

(c) On a summer day, fresh air introduced into a building from outdoors is at 27 °C dry bulb temperature and 55% relative humidity. The air is cooled down to 15 °C. How much moisture will have condensed out due to cooling? [15%]

END OF PAPER