EGT2
ENGINEERING TRIPOS PART IIA

Thursday 26 April 2018 2 to 3.40

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 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.

1 (a) List three fundamental influences on the permeability of soils. Which of these does the Hazen empirical method allow for and how? [10%]

(b) Explain why the vertical and horizontal hydraulic conductivities of a soil stratum are usually different, highlighting the causes and impacts of this anisotropy. [10%]

(c) A pumping well, 200 mm in diameter, was driven into an aquifer 7 m in thickness that is embedded between two layers of stiff clay. The aquifer is a sandy layer with a hydraulic conductivity of 2×10^{-3} m s^{-1}. Water is being pumped out of the well at a rate of 1700 m^3 per day. If the water table in the far field, measured at 35 m away from the centre of the well, is 9 m above the base of the aquifer, what is the maximum drawdown in the well? [25%]

(d) A large, 200 m long and 30 m wide, tank demonstration experiment is shown in Fig. 1. It involved the installation of two impermeable retaining walls in a saturated soil and the excavation of the soil in between as shown. The walls are propped to prevent rotational failure (props not shown). The water level is maintained at the ground level on both sides of the retaining walls. The permeability of the soil is 1×10^{-5} m s^{-1}.

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

(ii) What is the volume of the water that is being pumped out of the base of the excavation to keep it dry? [10%]

(iii) What is the pore water pressure at point A at the base of the retaining wall on the excavated side? [10%]

(iv) Some excavations run the risk of causing soil liquefaction. Explain why this is unlikely to be the case here. [10%]

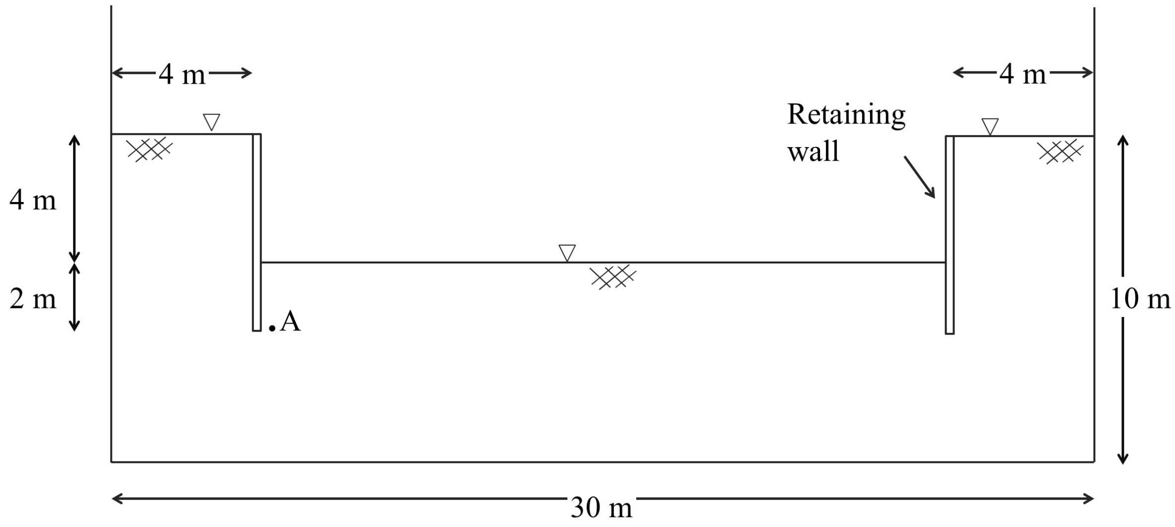


Fig. 1

(TURN OVER

2 (a) State the three main sources of groundwater contamination, giving an example of each. [10%]

(b) Describe briefly both molecular diffusion and mechanical dispersion as solute transport mechanisms. [10%]

(c) Explain how you would distinguish between the dominant contaminant transport mechanisms using the Peclet Number, *Pe*. [10%]

(d) An old landfill has a single clay liner at its base. The liner is 4.0 m thick and it is in direct contact with the leachate in the landfill. The concentration of the leachate can be taken as a constant, c_o. Assuming advection is negligible, the expression for the contaminant concentration c in the liner is given by:

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

where $erfc$ is the complementary error function, z is the depth, D_d^* is the effective diffusion coefficient, and t is the time. The aqueous diffusion coefficient for the contaminant in the landfill is 0.9×10^{-9} m^2 s^{-1} and the tortuosity of the clay is 0.35.

(i) Calculate the length of time it will take for the contaminant to break through the base liner of the landfill. [20%]

(ii) At what depth within the liner will $\frac{c}{c_o} = 0.5$ at the break through time? [20%]

(iii) Sketch the corresponding concentration profile within the clay layer. [10%]

(iv) What would the steady state concentration profile look like and why? Sketch it on your answer to part (iii). [10%]

(v) Assuming advection is not negligible, what would the steady state concentration profile look like in this case and why? Sketch it on your answer to part (iii). [10%]

3 (a) Explain the meaning of operative temperature in the context of building physics applications. [10%]

(b) The general form of net radiation heat exchange Q between two black body surfaces i and j (emissivity = 1) at temperatures T_i and T_j respectively is:

$$Q_{i,j} = A_i F_{i,j} \sigma (T_i^4 - T_j^4)$$

where A_i is the area of surface i, $F_{i,j}$ is the view factor, and σ is the Stefan-Boltzmann constant. Since the temperature span in building physics applications is small, it is common practice to simplify the above equation and express it as a function of the mean temperature $\bar{T}$. The radiation heat exchange across the two surfaces is thus:

$$Q_{i,j} = K_{i,j}^r (T_i - T_j) \quad \text{where} \quad K_{i,j}^r = A_i F_{i,j} 4\sigma (\bar{T}_{i,j}^3)$$

(i) For $T_i > T_j$, show that the percentage error due to this simplification is:

$$\left(\frac{\triangle}{\bar{T}}\right)^2 \times 100\%$$

where $\triangle = (T_i - T_j)/2$. [30%]

(ii) Calculate the percentage error introduced by the above simplification for the case when temperature difference of the wall surfaces across the cavity is 10 °C, and the mean temperature of the cavity is 0 °C. [15%]

(iii) Consider an enclosure with two surfaces of areas A_1 and A_2 at temperatures T_1 and T_2 respectively. The emissivities of the two surfaces are ε_1 and ε_2. The radiative surface conductance K^s in W K^{-1} of the two surfaces is expressed as:

$$K_1^s = \frac{\varepsilon_1 A_1}{1-\varepsilon_1} 4\sigma T_1^3 \quad \text{and} \quad K_2^s = \frac{\varepsilon_2 A_2}{1-\varepsilon_2} 4\sigma T_2^3$$

One can use the simplified general form $K_{i,j}^r$, given above, to estimate the radiative conductance between the two surfaces. Accounting for the radiative surface conductance, and using the rules of network analysis, show that when $\frac{T_1}{T_2} \approx 1$, the net radiant heat transfer between surface 1 and 2 is:

$$Q_{1,2} = \frac{4\sigma A_i (\bar{T}^3)(T_1 - T_2)}{\frac{1-\varepsilon_1}{\varepsilon_1} + \frac{1}{F_{1,2}} + \frac{1-\varepsilon_2}{\varepsilon_2}\frac{A_1}{A_2}}$$

[30%]

(iv) Calculate the net radiation exchange $Q_{1,2}$ between two parallel surfaces of a unit area of glass. Both glass surfaces have emissivity of 0.9. The temperature of the two surfaces T_1 and T_2 are 10 °C and 20 °C respectively. [15%]

4 (a) Show that the buoyancy driven pressure difference Δp_s driving airflow in stack ventilation can be written as:

$$\Delta p_s = \rho_{273} g H \left(\frac{273}{T_o} - \frac{273}{T_i} \right)$$

Support the derivation with a diagram roughly indicating the pressure gradients and the airflow. In the above formulation, ρ_{273} is the density of air at 273 K, H is the height separating the upper and lower opening, g is the gravitational constant, and T_o and T_i are the external and internal temperatures respectively. [20%]

(b) Consider a small building comprising of a ground floor, with an attic above. The attic is ventilated with outdoor air, and therefore assume that the temperature in the attic is the same as the external air temperature. The external air temperature is 0 °C and the relative humidity is 65 %. The internal temperature of the ground floor is 21 °C and the relative humidity is 40 %. The distance between the openings on the ground floor level and the attic floor (the ceiling of the ground floor) is 4 m. There is a rectangular door on the ceiling (horizontal) of size 0.6 m × 0.8 m. There is a 3.0 mm wide and 200 mm deep air gap around this door.

(i) Calculate the buoyancy driven air pressure difference between the ground floor and the attic. [10%]

(ii) Calculate the airflow through the gap in the horizontal door to the attic. [25 %]

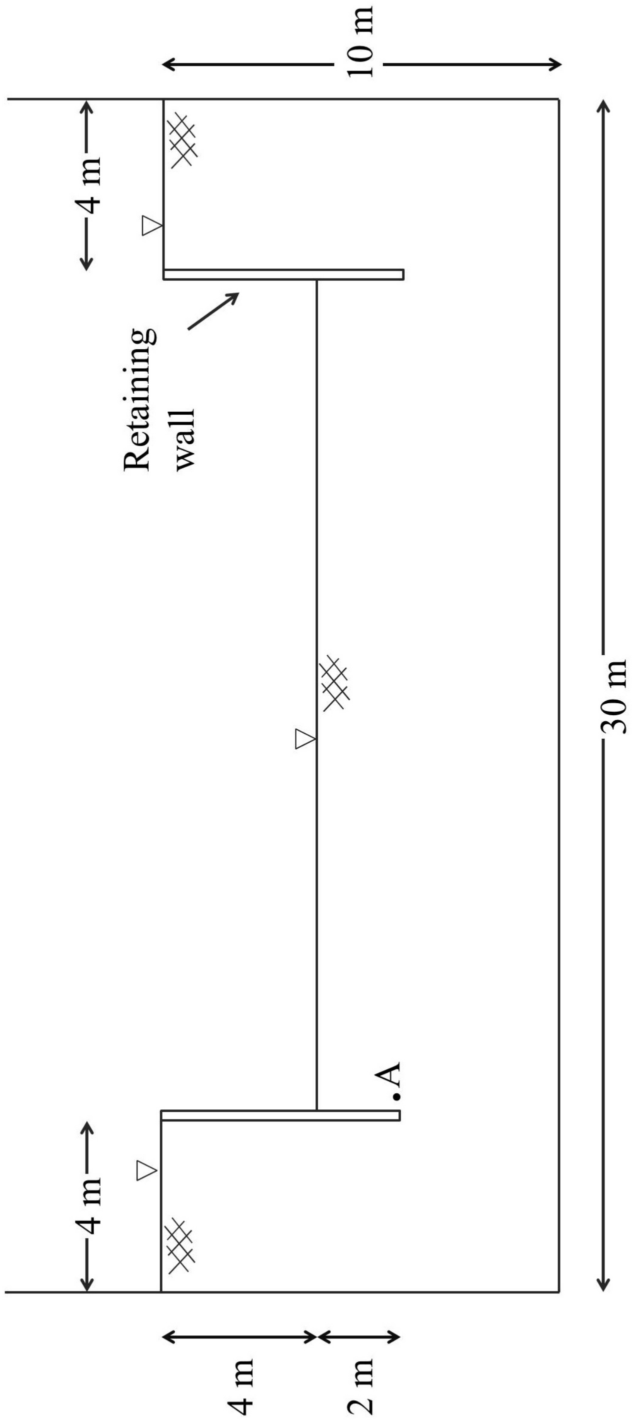
(iii) The attic is ventilated with an air exchange rate of 0.3 ACH. The volume of the attic is 120 m^3. Calculate the relative humidity in the attic resulting from external air and the airflow from the ground floor. Show a network diagram to support the calculations. [25 %]

(iv) The area of the attic floor is 90 m^2, and the vapour resistance is 3×10^6 s m^{-1}. Calculate the diffusion of moisture through the attic floor. To what extent does it change the relative humidity in the attic? [20 %]

END OF PAPER

Version RC/4 Candidate Number:

EGT2
ENGINEERING TRIPOS PART IIA
Thursday 26 April 2018, Module 3D8, Question 1.



Extra copy of Fig. 1 for Question 1.