ENGINEERING TRIPOS PART IIA

Friday 26 April 2013 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.*

Attachments:
3D8 Building Physics and Env. Geotechnics Data Book (17 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 An L-shaped concrete weir is to be constructed to act as a flood defence on a silty sand layer as shown in Fig. 1. The silty sand layer is underlain by shale with an inclined interface as shown in Fig. 1. In the extreme case, the concrete weir will retain flood waters to a height of 4 m. An upstream blanket made from compacted clay is added to minimise the seepage loss below the weir.

(a) Draw a flownet for seepage below the concrete weir 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) The hydraulic conductivity of the silty sand layer is estimated to be 2.3×10^{-3} ms^{-1}. Estimate the leakage rate below the weir in the units of litres per year. You may assume that the flood waters remain at the height of 4 m throughout. [10%]

(c) Sketch the uplift pressures acting on the concrete weir. [10%]

(d) The friction angle between concrete and the silty sand is 25°. Calculate the factor of safety against sliding. Take unit weight of concrete as 24 kNm^{-3}. Also calculate the factor of safety against rotation about point A shown in Fig. 1. [30%]

(e) Assume that the L-shaped concrete weir and the upstream blanket are constructed at the same time. If the concrete weir is liable to some settlement, what is the main failure mode you will consider for this structure? Qualify your answer by recalculating the factor of safety against sliding. [30%]

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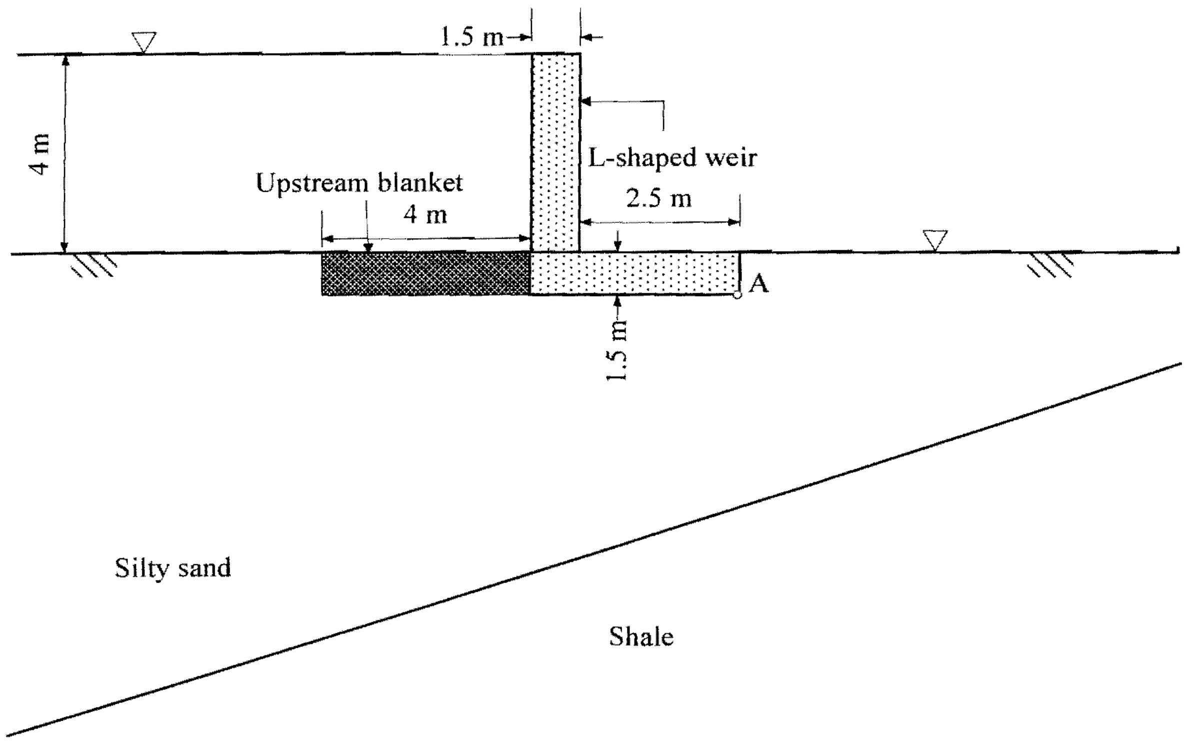

Fig. 1

(TURN OVER

2 (a) By considering a Ground Source Heat Pump (GSHP) installed vertically, derive a relationship between the temperatures T_1 and T_2 and corresponding radii r_1 and r_2 in the soil from the centre of the pipe. Assume axisymmetric conditions. The depth of the GSHP is B below the ground surface and the radius of the bore well is r_w ($r_w < r_1 < r_2$). Assume that the GSHP is extracting heat energy E per unit time and that the thermal conductivity is λ for soil around the GSHP. [20%]

(b) At a particular site the soil has a thermal conductivity λ of 2.8 $\mathrm{Wm^{-1}K^{-1}}$. A GSHP has been installed to a depth of 100 m below ground surface and the radius of the bore well is 0.5 m. While extracting 1.5 kW of heat, it was noticed that the temperature of the ground was 3° C at a distance of 2 m from the wall of the bore well on a horizontal plane at the mid depth. The ambient temperature of the ground is 6 $^{\circ}$C. Calculate the temperature in the ground at a radius of 5 m from the wall of the bore well on the same horizontal plane. [20%]

(c) If the site considered in part (b) has a plan area of 300 m × 300 m, how many GSHPs with same dimensions as in part (b) can be installed, with each one of them extracting 1.5 kW of heat. For optimal performance each GSHP should not be within the radius of influence of adjacent units. [20%]

(d) Describe briefly the contaminant transport mechanisms of diffusion, mechanical dispersion, advection and sorption. [15%]

(e) 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 variation of concentration with depth in the clay layer when steady state conditions are established. [25%]

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3 (a) A semi-detached house in the English countryside has cavity walls of four layers. The outer layer is 120 mm thick brick, the second layer is an 80 mm air cavity, the third layer is 100 mm of concrete block, and the innermost layer is 10 mm dense plaster. The convective heat transfer coefficient of the air cavity is 0.5 $Wm^{-2}K^{-1}$. The temperatures at the enclosing surfaces of the air cavity are 10 and 15 °C, and the emissivity of both surfaces is 0.8. The thermal conductivity of air is 0.024 W $m^{-1}K^{-1}$. Assuming that the wall is exposed to outside winds, calculate the U-value of the wall. [30%]

(b) The U-value of the wall described in (a) does not comply with current building regulations, which require U-values of 0.35 Wm^{-2} K^{-1}. Hence it is decided to fill the air-cavity with insulation. What should the minimum thermal conductivity of the insulation be in W/mK to bring the U-value of the wall to current standards? [20%]

(c) Calculate the temperature at the interface of the brick and the insulation layer of this wall during a cold winter night when external air temperature is −8.0 °C, and the interior air temperature is maintained at 19 °C. [20%]

(d) For this same wall, the vapour permeability δ_v in m^2 s^{-1} of brick is 5.0×10^{-6}, of insulation is 20.0×10^{-6}, and of concrete block is 10.0×10^{-6}. Consider a unit area of the insulated cavity wall. Using the results of part (c), determine whether condensation will occur on a cold winter night at the interface between the brick and the insulation layer. The humidity of the air by volume is 3.0 gm^{-3} and the additional moisture supply inside the building is 4.0 gm^{-3}. Ignore the vapour resistance due to the inner plaster layer and at interior and exterior surfaces. Suggest a remedy for avoiding any condensation in the insulation layer. [30%]

(TURN OVER

4 (a) A lecture hall of floor area 100 m^2 and height of 5 m is occupied by 40 students. A minimum air change rate of 5 litres per second is required per student for adequate ventilation. The external wall area of the hall is 50 m^2 and the window area is 15 m^2. The U-values of the wall and window are 0.35 and 1.5 W $m^{-2}K^{-1}$ respectively. The daily average solar radiation transmitted into the room is 100 W. How much heat must be released through the heating system to maintain a daily average temperature of 20 °C during the winter period, when the external average temperature is 2 °C? Show a network diagram representing this problem, including all heat losses and gains to the internal air temperature node. [40%]

(b) Give two conditions when dynamic analysis of heat transfer is advantageous over steady state analysis in buildings. [10%]

(c) For a material thick enough to be considered a semi-infinite slab, the temperature at location x and time t due to a step change can be calculated by:

$$T(x,t) = T_0 + (T_1 - T_0)\cdot\left(\frac{2}{\sqrt{\pi}}\int_{s=\frac{x}{\sqrt{4at}}}^{\infty} e^{-s^2}\,ds\right)$$

where, at $t = 0$, $0 \le x \le \infty$: $T = T_0$ is the initial temperature, and at $t \ge 0$, $x = 0$: $T = T_1 - T_0$ is the boundary condition. a is the thermal diffusivity of the material. Using this formulation, derive the expression for heat flow at the boundary of a semi-infinite slab $Q\ (x,t)$ in Watts due to step change in temperature. In doing so, explain the significance of thermal effusivity b in energy efficient buildings. [50%]

END OF PAPER

Final version

CANDIDATE NUMBER

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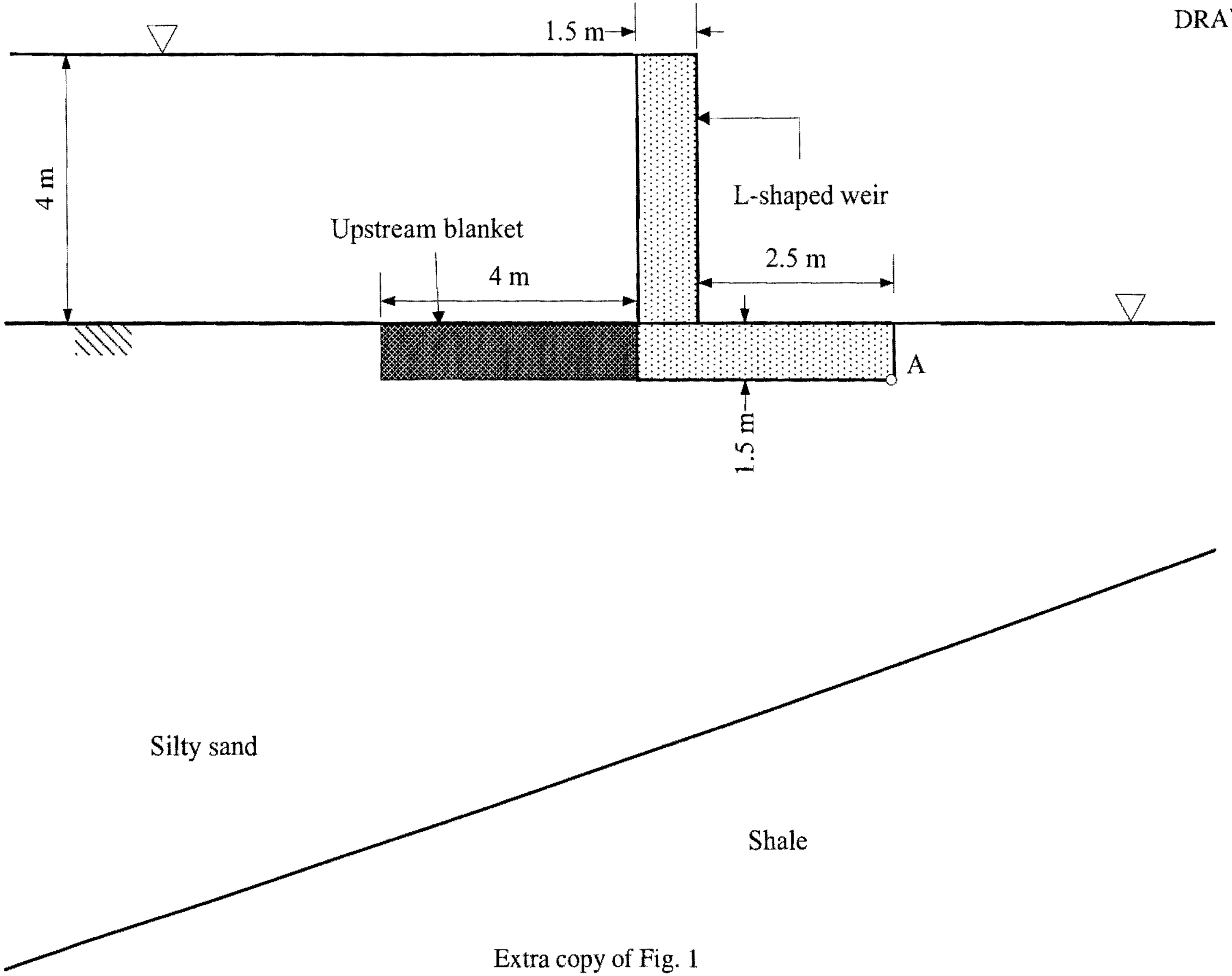

Extra copy of Fig. 1