EGT2
ENGINEERING TRIPOS PART IIA

Monday 29 April 2019 2 to 3.40

Module 3D8

BUILDING PHYSICS & 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 & Env. Geotechnics Data Book (17 pages).
Supplementary page: one extra copy of Fig. 2 (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) Derive an expression to link the capillary rise in the soil to the surface tension, unit weight of water, typical pore size and wetting angle α with respect to horizontal. [15%]

(b) A 15 m thick, horizontal soil stratum is present overlying the bedrock at a site. Soil sample collected from the site gave the Particle Size Distribution Curve shown in Fig. 1. The specific gravity of the soil grains is 2.65 and the porosity of the stratum is 0.4. If the water table is 8 m below the ground surface, estimate the capillary rise. The surface tension of water is 7.3×10^{-5} kN m^{-1} and the wetting angle is 65^{o}. Sketch the pore water pressure, total and effective stress profiles with depth. [15%]

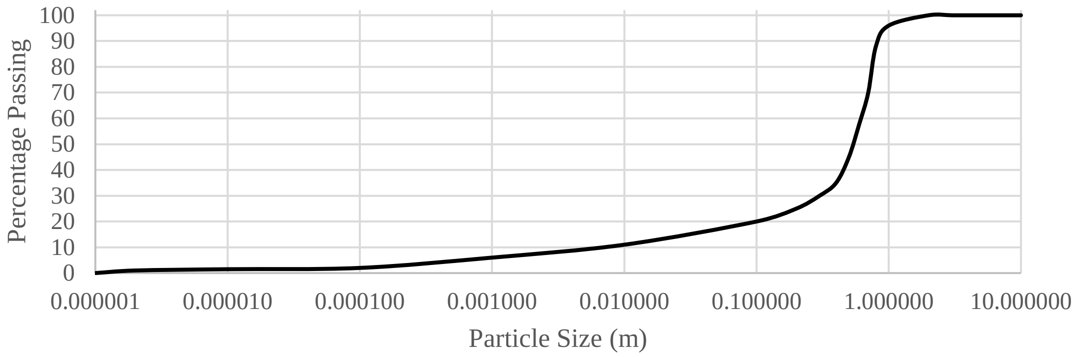

Fig. 1

(c) A rigid, concrete dam 16 m high holds a reservoir of water 12 m deep as shown in Fig. 2. The tailings water depth is 2 m on the downstream side. The dam is founded on the same soil stratum as in part b) but is underlain by an inclined Shale rock as shown in Fig. 2. The concrete dam has an inspection gallery 5 m × 4 m. The unit weight of the concrete is 24 kN m^{-3} and the saturated unit weight of the soil is 19.5 kN m^{-3}. The hydraulic conductivity of the soil is 2.3×10^{-4} m s^{-1}.

(i) Draw a 'flow net' at steady state seepage of the problem on the extra copy of Fig. 2 provided. Highlight any limitations of the flow net that you have constructed. You must submit this copy with your script. [20%]

(ii) Determine the quantity of leakage due to seepage through the silty sand in units of litres per day if the dam is 100 m long. [15%]

(iii) Calculate the factor of safety against sliding of the dam. The friction angle between concrete and the soil is 35°. You may ignore the embedment effects. [20%]

(iv) Estimate the exit hydraulic gradient at location A marked in Fig. 2 and comment on the stability of the dam. [15%]

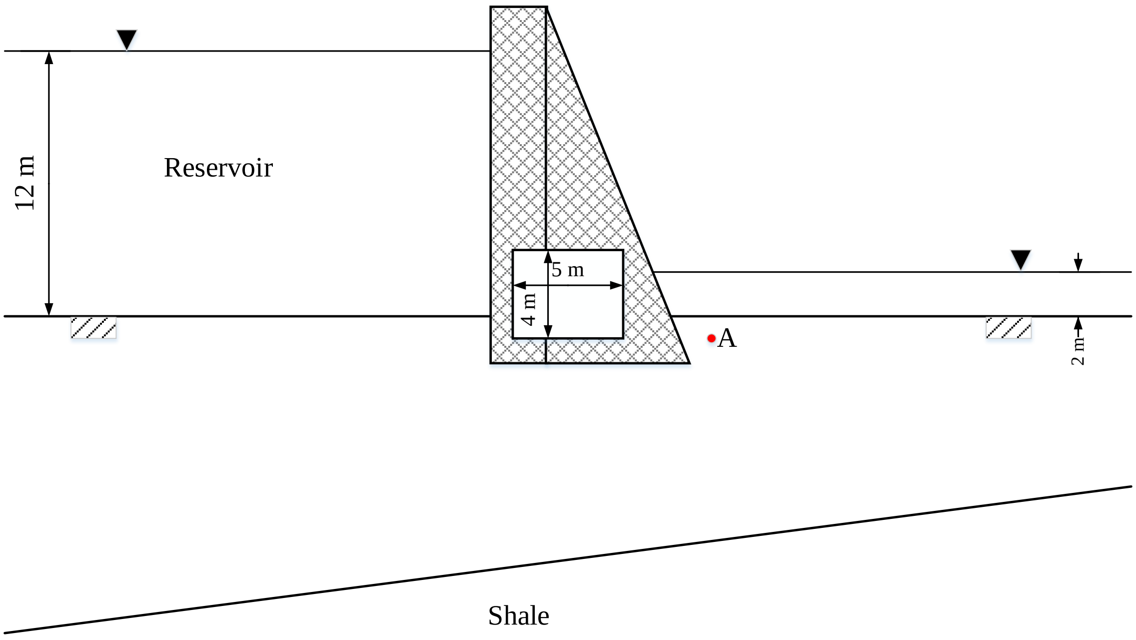

Fig. 2

2 (a) Explain briefly the contaminant transport processes of mechanical dispersion and sorption. [10%]

(b) Sorption can be considered as a retarding process that delays the contaminant transport relative to the mean flow velocity. By considering the advection-dispersion equation for the contaminant transport, show that the sorption results in a delay factor. You can assume the case of linear, equilibrium sorption. [20%]

(c) Explain briefly the analogy between Fick's law and Fourier's law. [10%]

(d) A wide landfill is founded on a silty sand layer that sandwiches a fine sand layer as shown in Fig. 3. There is an underlying, free draining aquifer that needs to be protected against contamination from the landfill. The hydraulic conductivities of the silty sand layer and the fine sand layer are 3.2×10^{-7} m s^{-1} and 4.8×10^{-5} m s^{-1} respectively. The leachate level is 1 m above the landfill base. The coefficient of hydrodynamic diffusion D_d^* for the chloride ion is 6.5×10^{-8} m^2 s^{-1} and the longitudinal dispersivity is 0.1 m, for both soils.

(i) Calculate the average vertical hydraulic conductivity and average flow velocity through the soil strata; [15%]

(ii) Calculate the hydraulic gradients and flow velocities in each of the layers; [15%]

(iii) Calculate the longitudinal hydrodynamic dispersion coefficient; [10%]

(iv) Estimate the time that it takes for the chloride ion to breakthrough into the aquifer by considering advection only and advection-dispersion. Comment on your answers. [20%]

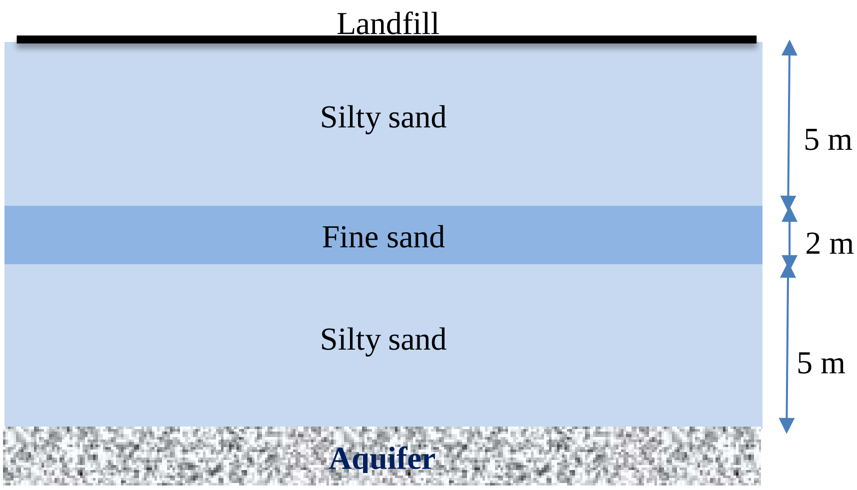

Fig. 3

3 (a) Explain the difference between thermal conductivity and thermal diffusivity as properties of building materials. [15%]

(b) (i) Derive the sine solution $T(x, t)$ of the time-cyclic temperature variation through a semi-infinite slab, given that the temperature T at any point x at time t can be expressed in the form:

$$\hat{T}_c(x,t) = T_1 \times e^{\left[\frac{-(1+i)x}{d_p}\right]} \times e^{\left[\frac{2\pi i t}{t_p}\right]}$$

where $\hat{T}_c(x,t)$ is the spatial complex-valued time-cyclic variation of temperature, T_1 is the outdoor temperature (assume no phase shift), d_p is the penetration depth, and t_p is the time-period of temperature variation. Which terms in the solution represent the change in magnitude of the temperature through the slab? [20%]

(ii) What would be the dynamic heat flow at the boundary $x = 0$ of the semi-infinite slab described in b (i)? [20%]

(iii) For any point x in the slab, 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? [20%]

(c) The annual variation in outdoor temperature $T_{ext}(t)$ over one year is given by:

$$T_{ext}(t) = T_0 + T_1 \sin\left[\frac{2\pi t}{t_p}\right]$$

where annual average temperature T_0 is 8 °C, and the seasonal temperature amplitude T_1 is 10 °C. Calculate the temperature 3 m below the ground when outdoor temperature is at a minimum. The thermal conductivity λ of the ground is 1.5 W m^{-1} K^{-1} and volumetric heat capacity ρ_c is 2.0 × 10^6 J m^{-3} K^{-1}. Recall that the penetration depth is $d_p = \sqrt{\frac{\lambda}{\rho_c} \times \frac{t_p}{\pi}}$. [25%]

4 (a) The pressure difference Δp for flow through openings is expressed as:

$$\Delta p = \frac{1}{C_{orif}^2}\left(\frac{1}{2}\rho v^2\right)$$

where ρ is the density of air, v is the air velocity, and C_{orif} is the dimensionless discharge coefficient. Show that the buoyancy-driven volumetric flow Q through a warm room with upper and lower openings whose centres are separated by height H may be estimated by:

$$Q = A^* \times C_{orif}\sqrt{2gH\left(\frac{273}{T_o} - \frac{273}{T_i}\right)}$$

where A^* is the effective area of the opening and T_o and T_i are the external and internal temperatures, respectively. Support your derivation with a clearly marked diagram showing pressure gradients and airflow. [30%]

(b) A warehouse is designed to ventilate with lower and upper openings of the same area. The heat load on the building is 17.5 kW. The building is thermally lightweight. The upper and lower openings are separated by a distance of 9 m. Assume there is no wind, so only buoyancy drives the flow. The value of the discharge coefficient is 0.6.

(i) Calculate the ventilation rate needed to maintain the difference between the internal and external temperature at less than 5 K. [15%]

(ii) Calculate the required area of the upper and lower vents. [15%]

(c) The warehouse is modified to include a mezzanine floor and an additional heat load of 17.5 kW. The mezzanine floor is comprised of a perforated floor so that the air readily mixes between the floors. The building height is increased so that there is a distance of 4 m between the low level openings and the openings on the mezzanine floor, and 9 m between the mezzanine and high level opening. The size of the upper level openings is doubled to account for the additional airflow required. The mezzanine level openings are 4 m^2 in area. What is the required area for the low level vents in order to have the same amount of air entering through the lower level vents as through the mezzanine level floor vents, so that a temperature difference is still maintained at less than 5 K? [20%]

(d) What would be the recommended strategy for ventilation in colder weather when larger temperature differences between the interior and exterior are required and it is desired that cold draughts are to be avoided? [20%]

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Version SPGM/2

Candidate No:

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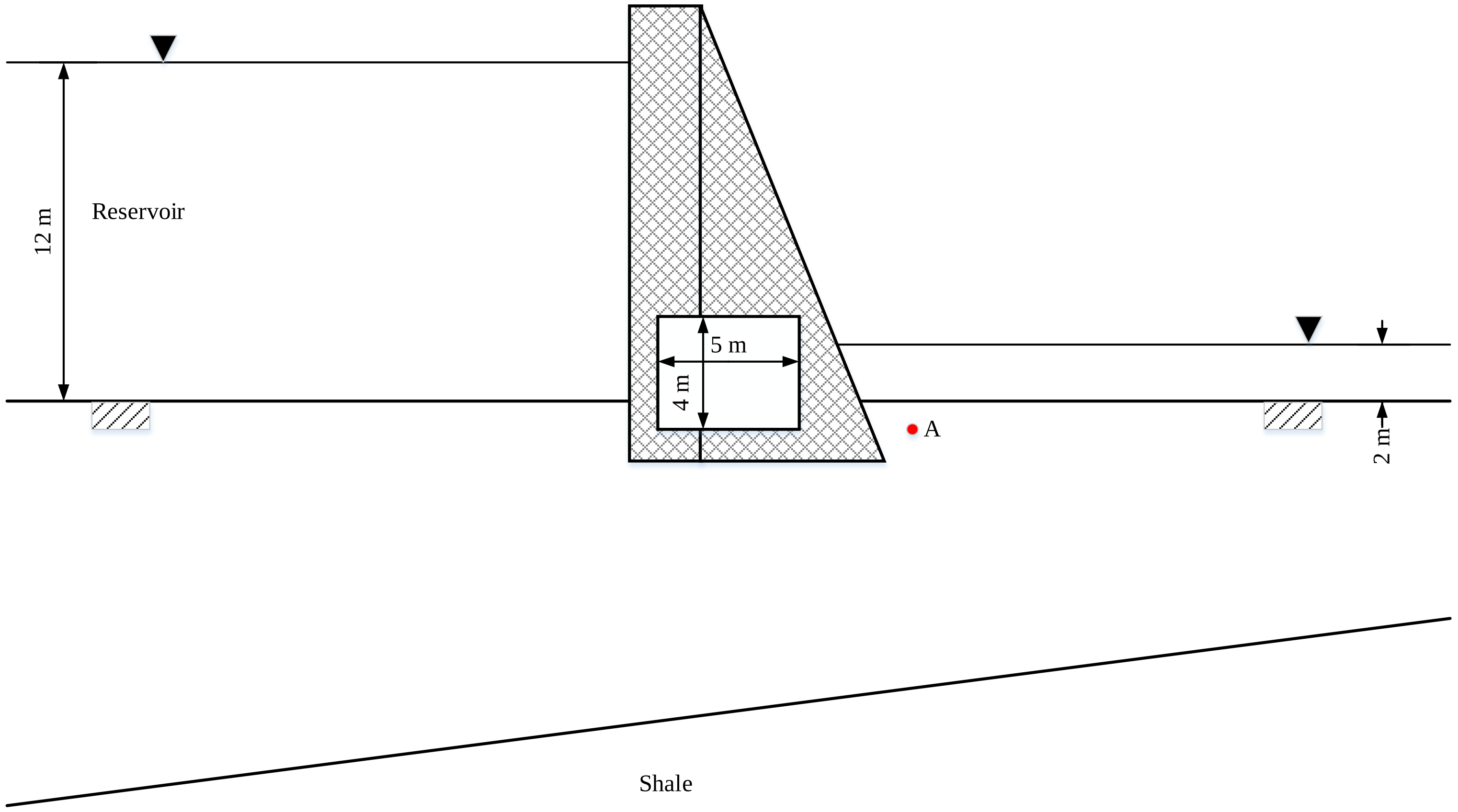

Extra copy of Fig. 2

Answers

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Q1 a) $h_c = \frac{4\ T\ sin\alpha}{\gamma_w\ D_{10}}$

b) ~ 2.7 mm

c) ii) ~ 7.45 $\times 10^6$ litres/day iii) FoS ~ 1.006 (barely safe) iv) ~0.7

Q2 d i) 3.836 $\times 10^{-7}$ m/s; 4.16 $\times 10^{-7}$ m/s

d ii) 1.3 & 6.4 $\times 10^{-3}$ in silty sand and fine sand respectively. Flow velocity in all layers is 4.16 $\times 10^{-7}$ m/s.

d iii) 1.25 $\times 10^{-8}$ m^2/s. iv) ~3 years and ~10.2 years.

Q3 c) 2.74 m; 6.5 ^{o}C.

Q4 b) i) 2.917 m^3/s. ii) 4 m^2

c) 2.9 m^2.