EGT2
ENGINEERING TRIPOS PART IIA

Monday 2 May 2022   09.30 to 11.10

Module 3D8

GEO-ENVIRONMENTAL ENGINEERING

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 Geo-Environmental Engineering data sheet (6 pages).
Supplementary page: 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.

You may not remove any stationery from the Examination Room.

1 A two-storey concrete building is located next to a river. Due to unexpected flooding following heavy rainfall, the water level reaches 3 m on one side of the building as shown in Fig. 1. The building is founded on a raft foundation located on a 7 m thick silty sand stratum with a hydraulic conductivity of 3.5×10^{-6} m s^{-1}. An impermeable shale rock is present below this depth as shown in Fig. 1. The unit weight of concrete can be taken as 24 kN m^{-3}.

(a) Draw a flownet for seepage below the building 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) Determine the quantity of seepage through the silty sand below the building if the flood water remains at 3 m height for a day before receding. Express your answer in units of litres per m length of the building. [10%]

(c) Estimate the pore water pressures at points A and B shown in Fig.1. [10%]

(d) Calculate the factor of safety against sliding failure for this building. You may assume that the friction angle at the interface between foundation and silty sand is 32°. You can ignore the lateral resistance from the soil on the sides of the foundation. [20%]

(e) Calculate the factor of safety against rotation failure of this building. You may assume that the rotation of the building occurs about point B shown in Fig. 1. Comment on whether this building is more likely to slide or rotate. [20%]

(f) The silty sand layer was suspected to be anisotropic, with its vertical hydraulic conductivity being half of its horizontal hydraulic conductivity. Discuss how this might affect your calculations of quantity of seepage through the silty sand layer and the factors of safety against sliding and rotation of the building. You need not redraw the flownet or redo your calculations. [20%]

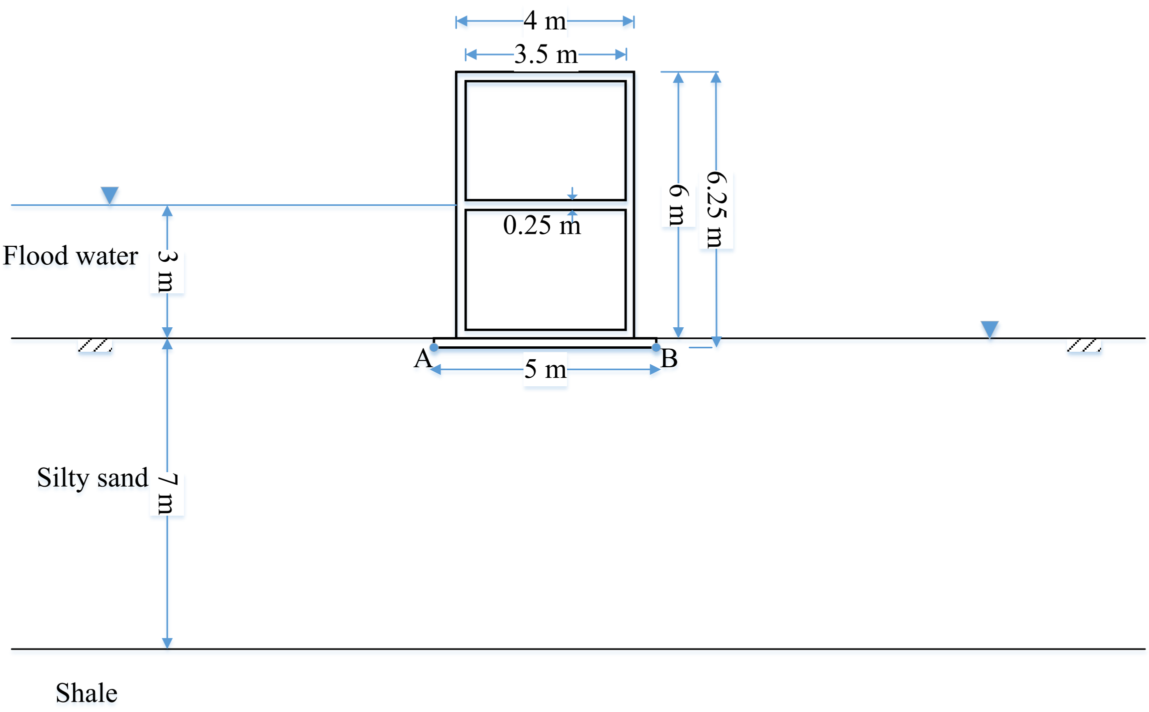

Fig. 1

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2 (a) Describe how you can determine the hydraulic conductivity of a sandy soil sample using a constant head permeameter using suitable sketches. Explain why this device cannot be used for clay samples. [20%]

(b) A fine sand sample was tested in a constant head permeameter. The sample had a diameter of 50.8 mm and a height of 80 mm. In this device, water level is held 60 mm above the top porous plate, and the water is collected into a measuring jar directly through the bottom porous plate. A flow rate of 53.2 millilitres per minute was measured through this sample. Determine the hydraulic conductivity of the soil sample. What is the average void size of this soil sample? [20%]

(c) Consider a Ground Source Heat Pump (GSHP) installed vertically at a site. The thermal conductivity is λ for the soil around the GSHP. Derive a relationship between the thermal conductivity λ, radii r_1 and r_2 and corresponding temperatures T_1 and T_2 by considering axisymmetric conditions. The depth of the GSHP is B below the ground surface and the radius of bore well is r_w ($r_w < r_1 < r_2$). You may assume that the GSHP is extracting heat energy E. [20%]

(d) At a site in Norfolk, the soil has a thermal conductivity λ of 2.9 W m^{-1} ^{o}C^{-1}. A trial GSHP was to be installed to a depth of 50 m below ground surface and the diameter of the bore well is 0.75 m. The ambient temperature of the ground is 6^{o} C. While extracting 2 kW of heat, it was noticed that the temperature of the ground was 3^{o} C at a distance of 2 m from the wall of the bore well on a horizontal plane at the mid depth of the bore well. Calculate the temperature in the ground at a distance of 5 m from the wall of the bore well on the same horizontal plane. Sketch the temperature variation along this plane. [20%]

(e) At the site in Norfolk considered in part (d) it was decided to construct a GSHP array to extract 200 kW of heat. Estimate the plan area of land required for this array and design a spatial layout of GSHPs with same dimensions as in part (d), if each one of them is extracting 2 kW of heat. For optimal performance each GSHP should not be within the radius of influence of adjacent units. [20%]

3 Briefly compare and contrast each of the four following pairs and use practical examples or scenarios to illustrate your points:

(a) The structure of illite versus montmorillonite clays. [25%]

(b) The role of pH versus redox potential in the fate of contaminants in the groundwater. [25%]

(c) Typical mobility and distribution of heavy metals versus organic contaminants in the subsurface. [25%]

(d) Chemical versus biological methods of contaminated land clean-up. [25%]

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4 A new landfill is to be designed and constructed on a site that is initially uncontaminated everywhere. A single clay liner is to be used and is designed for a long-term constant leachate concentration in the landfill of c_o = 20 mg L^{-1}. The design assumes that the main contaminant transport process within the clay liner is diffusion according to Fick's law as follows:

$$\frac{\partial c}{\partial t} = D_d^* \frac{\partial^2 c}{\partial z^2}$$

where c is the contaminant concentration at time t, z is the depth and D_d^* is the effective diffusion coefficient and is equal to 2.5×10^{-9} m^2 s^{-1}. In order to calculate the required depth of the clay liner, the following solution to the diffusion equation is used:

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

where erfc (β) is the complementary error function.

(a) How thick does the clay liner need to be if the acceptable level of contaminant concentration at the base of the clay liner cannot exceed 5% of landfill concentration c_o after 50 years of the landfill in service. [10%]

(b) How thick does the clay liner need to be now if the design life needs to be extended to 100 years. [10%]

(c) If the acceptable leachate concentration is now relaxed to 10% of the landfill concentration c_o, how would this change the design depth for the clay liner at 100 years of service. [10%]

(d) Derive the expression for the long-term steady state contaminant concentration profile within a landfill liner. [15%]

(e) Without doing any further calculations, sketch a rough profile of the contaminant concentration within the clay liner with depth for the three scenarios in parts (a), (b), and (c) and comment on the differences between them. [15%]

(f) If dispersion is also present as a contaminant transport mechanism, explain how this will impact on the diffusion coefficient and the shape of the contaminant profile. [10%]

(g) How would you expect the liner to behave in practice compared to the diffusion equation above? [10%]

 (cont.

(h) How would you expect the clay liner to behave in practice if the design calculations were based on laboratory experiments. [10%]

(i) If the physical integrity of the clay liner has been breached, give two possible reasons for this and two feasible methods of remediation to rectify the problem. [10%]

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UNIVERSITY OF CAMBRIDGE

Engineering Tripos Part IIA Paper 3D8

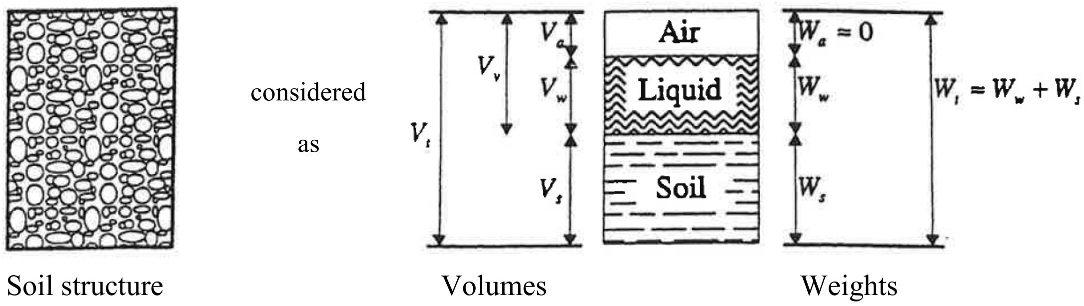
3D8
GEO-ENVIRONMENTAL ENGINEERING

DATA BOOK

January 2022

Groundwater

Soil: general definitions



Specific gravity of solid	G_s
Voids ratio	$e = V_v/V_s = n/(1-n)$
Specific volume	$v = V_t/V_s = 1+e$
Porosity	$n = V_v/V_t = e/(1+e)$
Water content	$w = W_w/W_s$
Degree of saturation	$S_r = V_w/V_v = wG_s/e$
Unit weight of water	$\gamma_w = 9.81\ kN/m^3$
Unit weight of soil	$\gamma = W_t/V_t = \left(\frac{G_s + S_r e}{1+e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\frac{G_s-1}{1+e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\frac{G_s}{1+e}\right)\gamma_w$

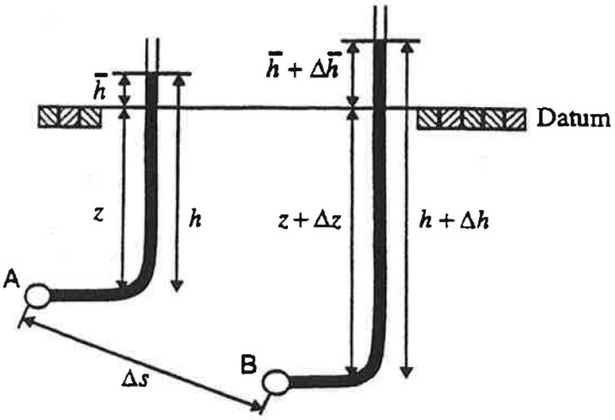
Classification of particle sizes

Boulders	larger than			200mm
Cobbles	between	200mm	and	60mm
Gravel	between	60mm	and	2mm
Sand	between	2mm	and	0.06mm
Silt	between	0.06mm	and	0.002 mm
Clay	smaller than	0.002 mm (two microns)		

D	equivalent diameter of soil particle
D_{10}, D_{60} etc.	particle size such that 10% (or 60% etc.) by weight of a soil sample is composed of finer grains.
C_U	uniformity coefficient D_{60}/D_{10}

Seepage

Excess pore water pressure



Total gauge pore water pressure at A: $p = \gamma_w h = \gamma_w\left(\bar{h} + z\right)$

B: $p + \Delta p = \gamma_w(h + \Delta h) = \gamma_w\left(\bar{h} + z + \Delta\bar{h} + \Delta z\right)$

Excess pore water pressure at A: $\bar{p} = \gamma_w \bar{h}$

B: $\bar{p} + \Delta\bar{p} = \gamma_w\left(\bar{h} + \Delta\bar{h}\right)$

Hydraulic gradient A B $i = \frac{\Delta\bar{h}}{\Delta s} = -\frac{1}{\gamma_w}\frac{\Delta\bar{p}}{\Delta s}$

Darcy's law $v = Ki$

v = superficial seepage velocity

K = coefficient of permeability or hydraulic conductivity

Typical hydraulic conductivities

$D_{10} > 10$ mm	:	non-laminar flow
10 mm > D_{10} > 1 µm	:	$K \cong 0.01(D_{10}$ in mm$)^2$ m/s
clays	:	$K \cong 10^{-9}$ to 10^{-11} m/s

Contaminant transport

Darcy's law

$$v_f = -\frac{k}{\mu n}\nabla(p + \rho g z)$$

where:

v_f	:	pore fluid velocity $= \frac{v}{n}$
v	:	Darcy superficial velocity or specific discharge
n	:	porosity
k	:	intrinsic permeability $= \frac{K\mu}{\rho g}$
K	:	Darcy permeability or hydraulic conductivity
μ	:	dynamic viscosity of pore fluid
ρ	:	density of pore fluid
p	:	fluid pressure

Governing equation for one-dimensional transport in homogeneous media

$$\frac{\partial c}{\partial t} = D_l\frac{\partial^2 c}{\partial x^2} - v_f\frac{\partial c}{\partial x} \pm \frac{\Phi}{n}$$

where:

c	:	mass of pollutant per unit volume of pore fluid (concentration)
D_l	:	coefficient of hydrodynamic dispersion $= D_d^* + D$
D_d^*	:	effective diffusion coefficient for pollutant in soil $= D_d\tau$
D_d	:	diffusion coefficient for pollutant in solution
τ	:	tortuosity of medium
D	:	coefficient of mechanical dispersion $= \alpha_l v_f$
α_l	:	dispersivity of the medium
Φ	:	chemical reactions

Error function tables

Relationships:

$$\mathrm{erf}(\beta) = \frac{2}{\sqrt{\pi}} \int_0^{\beta} \exp(-t^2)\, dt$$

$$\mathrm{erfc}(\beta) = 1 - \mathrm{erf}(\beta)$$

$$\mathrm{erf}(-\beta) = -\mathrm{erf}(\beta)$$

$$\mathrm{erfc}(-\beta) = 1 + \mathrm{erf}(\beta)$$

Tables (to four significant figures)

β	$\mathrm{erf}(\beta)$	$\mathrm{erfc}(\beta)$
0.00	0.0000	1.0000
0.05	0.0564	0.9436
0.10	0.1125	0.8875
0.15	0.1680	0.8320
0.20	0.2227	0.7773
0.25	0.2763	0.7237
0.30	0.3286	0.6714
0.35	0.3794	0.6206
0.40	0.4284	0.5716
0.45	0.4755	0.5245
0.50	0.5205	0.4795
0.55	0.5633	0.4367
0.60	0.6039	0.3961
0.65	0.6420	0.3580
0.70	0.6778	0.3222
0.75	0.7112	0.2888
0.80	0.7421	0.2579
0.85	0.7707	0.2293
0.90	0.7969	0.2031
0.95	0.8209	0.1791
1.00	0.8427	0.1573
1.10	0.8802	0.1198
1.20	0.9103	0.0897
1.30	0.9340	0.0660
1.40	0.9523	0.0477
1.50	0.9661	0.0339
1.60	0.9763	0.0237
1.70	0.9838	0.0162
1.80	0.9891	0.0109
1.90	0.9928	0.0072
2.00	0.9953	0.0047
2.20	0.9981	0.0019
2.40	0.9993	0.0007
2.60	0.9998	0.0002
2.80	0.9999	0.0001
3.00	1.0000	0.0000

Version SPGM/3

Candidate No:

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