EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 29 April 2025 9.30 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
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book
Attachment: 3D8 Geo-environmental Engineering data sheet (6 pages)

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) State Darcy's law for fluid flow in granular media, giving any assumptions that need to be made in its application. [10%]

(b) A soil has two layers with thicknesses L_1 and L_2 and hydraulic conductivities K_1 and K_2 respectively. Derive expressions for the equivalent vertical and horizontal hydraulic conductivities of the soil strata. [20%]

(c) A soil deposit consisting of two layers was found at a site that is underlain by a free draining gravel stratum. The thickness of the upper soil layer is 3 m and its hydraulic conductivity is 2.60×10^{-5} m s^{-1}. The thickness of the lower soil layer is 5 m and its hydraulic conductivity is 3.84×10^{-4} m s^{-1}. Calculate the equivalent vertical and horizontal hydraulic conductivities of this two-layer system. What is the anisotropic ratio for the hydraulic conductivity of this system? [20%]

(d) A concrete gravity retaining wall has 5 m of water collected on one side as shown in Fig. 1 before any backfill soil is placed. The retaining wall was constructed on the soil deposit described in part (c). Construct an appropriate scaled drawing and sketch the seepage flownet on it for the seepage underneath the retaining wall. Estimate the leakage rate of water in the units of litres per day per metre length of the retaining wall. [25%]

(e) Estimate the uplift force acting on the retaining wall. Calculate the factor of safety against sliding of the retaining wall, if the angle of friction between concrete and soil is 30°. Take the unit weight of concrete as 24 kN m^{-3}. [25%]

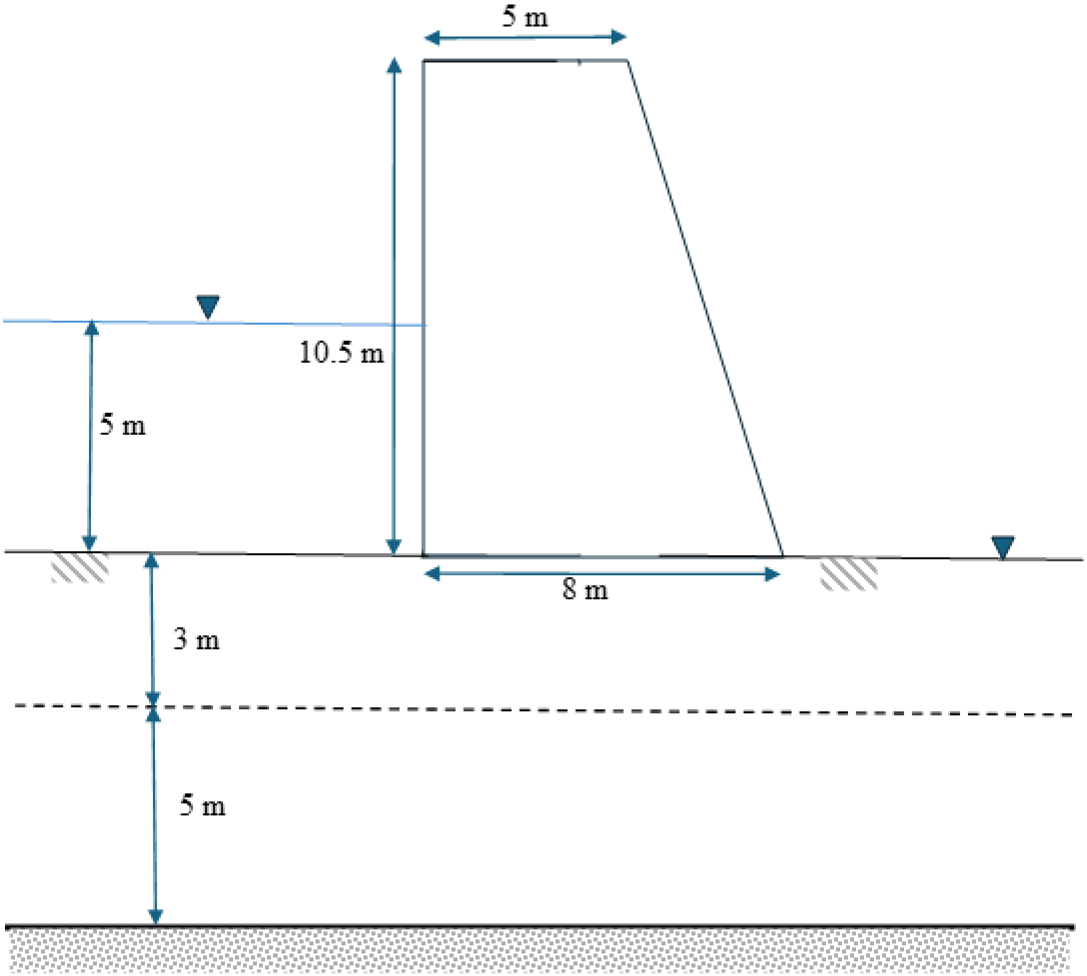

Fig. 1

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2 (a) Show that the capillary rise h_c in a fine-grained soil is given by the following equation, explaining the variables involved: [15%]

$$h_c = \frac{4\,T \sin\alpha}{\gamma_w\, D_{10}}$$

(b) Explain why there can be sudden changes in the water table in fine-grained soils such as silts, even with modest amounts of rainfall. How would the effective stresses in such soils change when such modest rainfall occurs? [15%]

(c) The silty slope shown in Fig. 2 is at an angle of 20° to the horizontal and is underlain by bedrock. The D_{10} size of this soil is 0.012 mm and the specific gravity of the silt particles is 2.7. The surface tension of water can be taken as 0.0746 N m^{-1} and the contact angle of water to the silt particles as 70° to the horizontal. The dry density of the soil is 14.6 kN m^{-3} and the hydraulic conductivity is 6.8×10^{-6} m s^{-1}. Standpipes inserted at locations A and B show water rising to 2.5 m and 2 m respectively. The horizontal distance between locations A and B is 5 m. Calculate the seepage flow through the silt layer in the units of litres per day. [25%]

(d) For the slope described in part (c), estimate the location of the phreatic surface. Sketch the total stress, pore water pressure and effective stress profiles on a vertical section through the slope at location A. You may assume that the soil above the capillary rise will be dry. [30%]

(e) Explain the parallels between seepage flow, heat flow and contaminant transport in granular materials. [15%]

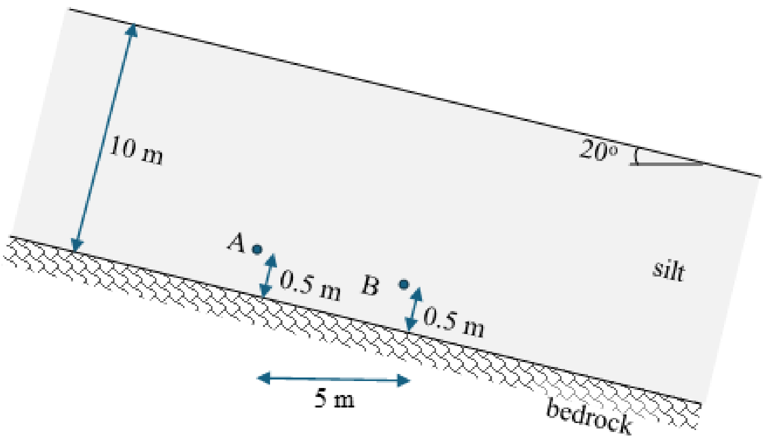

Fig. 2

3 (a) What is the definition of contaminated land under the UK Environment Act 1995 and what does this mean in practice? [10%]

(b) Explain when a contaminated site may not be classified as 'contaminated', under the Environment Act 1995. [10%]

(c) Describe one source of ground contamination and the potential risks to human health as a result. [10%]

(d) Explain how the fate of a contaminant in the groundwater is governed by solubility, pH and redox potential. [30%]

(e) How does the constituent clay mineral in clayey soils impact the fate of contaminants in the subsurface? [20%]

(f) Explain, with examples, how the soil type and extent of its contamination would impact the choices available for its remediation. [20%]

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4 A contaminated site has been remediated with the construction of a 2 m thick soil-cement in-ground barrier wall around its perimeter. The wall is constructed through sandy soils and keyed into underlying bedrock. Assume that the whole sand stratum is contaminated and hence the flow and diffusion of the contaminated groundwater into the in-ground barrier wall can be assumed to be one-dimensional. Also assume that the contaminant is already in contact with the face of the wall and that its concentration in the groundwater on the contaminated side of the barrier remains constant. The aqueous diffusion coefficient for the contaminant in the groundwater is 0.5×10^{-9} m^2 s^{-1} and the longitudinal dispersivity and tortuosity of the soil-cement barrier are 0.35 and 0.45 respectively.

When diffusion is the dominant contaminant transport mechanism, the expression for the contaminant concentration, C, in the barrier wall is given by:

$$\frac{C}{C_o} = erfc\left[\frac{z}{\sqrt{4D^*_d t}}\right]$$

When dispersion is the dominant contaminant transport mechanism, the expression becomes:

$$\frac{C}{C_o} = \frac{1}{2}\, erfc\left[\frac{z - v_f t}{\sqrt{4\, D_l\, t}}\right]$$

where C_O is the initial constant contaminant concentration in the groundwater, *erfc* is the complementary error function, z is the distance into the barrier wall from the C_O contaminant concentration end, v_f is the horizontal mean groundwater velocity, t is the time and D^*_d and D_l are the effective diffusion and longitudinal dispersion coefficients of the contaminant respectively.

(a) What is the design life of the soil-cement in-ground barrier wall if this is defined as the period during which C equals zero at the outer boundary? [20%]

(b) In practice, it is usually unrealistic to expect contaminant concentrations to be reduced to zero, and hence some very low target values are usually set. Using a target contaminant concentration emerging at the outer boundary of C/C_O = 0.01, i.e. the contaminant concentration is reduced by 99%, recalculate the design life of the in-ground barrier wall. [10%]

(cont.

(c) Also in practice, the physical integrity of the in-ground barrier wall might become compromised, through the effect of the contaminants on the barrier material and inaccuracies in the design calculations. If the development of cracks throughout the barrier wall's thickness and depth allows the groundwater to leak through at a velocity of 0.5×10^{-8} m s^{-1}, how will this change the design life of the in-ground barrier wall calculated in part (a)? [30%]

(d) Comment on the differences between the results in parts (a), (b) and (c). [20%]

(e) If sorption is to be included as an additional contaminant transport mechanism in the above calculations, explain how this will change the results in parts (a), (b) and (c). [10%]

(f) How can such in-ground barrier walls be designed to be more resilient? [10%]

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Engineering Tripos Part IIA Paper 3D8

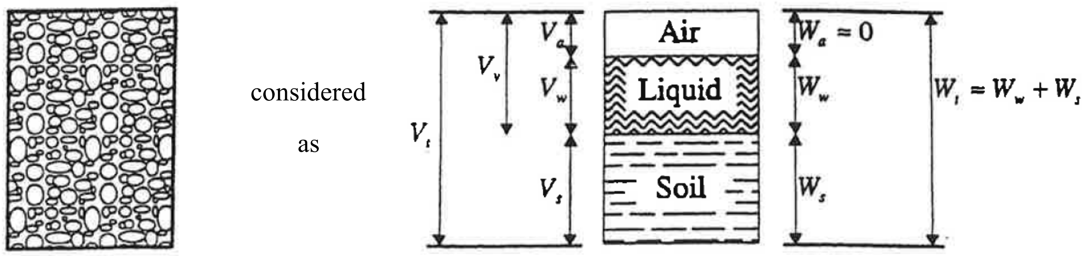
3D8
GEO-ENVIRONMENTAL ENGINEERING

DATA BOOK

January 2022

Groundwater

Soil: general definitions



Soil structure   Volumes   Weights

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	$\gamma = W_t/V_t = \left(\dfrac{G_s + S_r e}{1+e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\frac{G_s - 1}{1+e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\dfrac{G_s}{1+e}\right)\gamma_w$

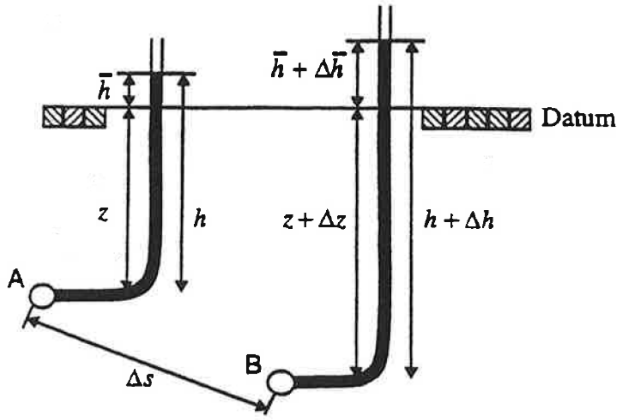
Classification of particle sizes

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: $p = \gamma_w h = \gamma_w(\bar{h} + z)$

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

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

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

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

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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

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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

ENGINEERING TRIPOS PART IIA 2025
MODULE 3D8: Geo-Environmental Engineering
Numerical Answers

Q1 (c) Kv = 6.25 x 10-5 m/s

Kh = 2.498 x 10-4 m/s

Anisotropy ratio – 2.2

(d) Q = 413 L/day/m

(e) Factor of safety against sliding = 6.64

Q2 (c) Seepage – 216.56 L/day

Q4 (a) 15.6 years

(b) 42.3 years

(c) 1.4 years