VERSION AAT/8

EGT2
ENGINEERING TRIPOS PART IIA

Friday 26 April 2024 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

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) Explain briefly how a particle size distribution (PSD) curve is constructed for a given soil sample using sieves. What can you say about the soil type based on the PSD curve? [10%]

(b) Explain the difference between the intrinsic permeability and the hydraulic conductivity of a porous medium. How are they related? [10%]

(c) A cut-and-cover twin tunnel is to be constructed in a silty sand layer with a hydraulic conductivity of 2.6×10^{-6} m s^{-1}. A clay layer overlies the silty sand layer which in turn overlies an inclined shale formation as shown in Fig. 1. Two standpipes installed at locations A and B show that water rises in them to 5 m and 0.8 m respectively above the ground level, i.e. the top of the clay layer. The tunnel is to be constructed with concrete that has a unit weight of 24 kN m^{-3}. The outside dimensions of the twin tunnel are 6 m × 3 m as shown in Fig. 1 and the thickness of all the tunnel walls is 0.5 m.

(i) Draw a flownet for seepage around the tunnel on the copy of Fig. 1 provided in the attachment. Draw attention to any assumptions you made and any shortcomings in your solution. Estimate the flow rate through the silty sand layer using the flownet.

An additional copy of Fig. 1 is attached to the back of this paper. It should be detached and handed in with your answers. [20%]

(ii) Estimate the pore water pressures around the tunnel and sketch the pressure distribution on a cross-sectional view of the tunnel. [25%]

(iii) If there were to be no seepage flow, what would be the buoyant force acting on the tunnel and the net weight of the tunnel. Assume the water table in this case would be at the ground surface, i.e. at the top of the clay layer. [10%]

(iv) In the presence of seepage, estimate the buoyant force acting on the tunnel and the net weight of the tunnel. Comment on the effect of seepage on the stability of the tunnel against floatation. [25%]

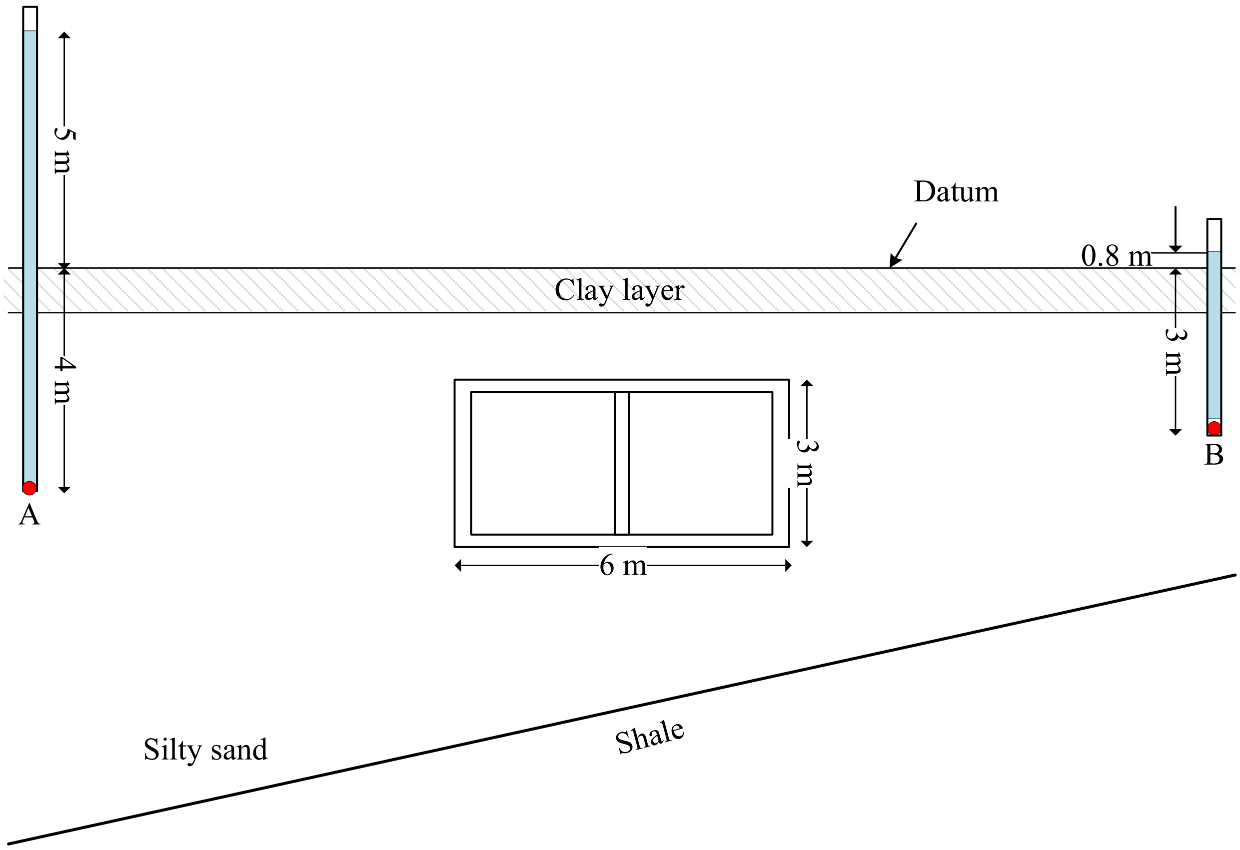

Fig. 1

2 (a) Draw the parallels between Darcy's law for seepage flow and Fourier's law for heat flow in granular media. [10%]

(b) What are main differences between seepage flow and heat flow in granular media? [10%]

(c) An undisturbed cube soil sample with 0.1 m sides was obtained from an oil field. It was tested in a constant head permeameter. A constant head of 0.15 m was maintained. In the laboratory, 100 ml of water passed through the sample in a period of 30 minutes. Calculate the hydraulic conductivity of the soil sample. [20%]

(d) If hydraulic oil with a viscosity of 32 times that of water and a density 860 kg m^{-3} was used in the experiment, how long will it take to collect 50 ml of hydraulic oil that seeps through the soil sample using the same experimental setup as in part (c)? [20%]

(e) A point heat source was installed at the centre of the cube sample. The point source was heated at a rate of 100 Watts. Steady state conditions were allowed to be established. It was observed that the temperature at a radial distance of 0.03 m from the centre was 60 ºC and at a radial distance of 0.035 m from the centre was 50 ºC. Estimate the thermal conductivity of the soil sample. Sketch the isotherms on a cross-sectional view of the soil sample. [25%]

(f) The soil sample is now subjected to the water flow as in part (c) and the heat from the point source as in part (e). Sketch the isotherms on a cross-sectional view of the soil sample for this scenario. No additional calculations are required. [15%]

3 (a) Clays have sufficiently small particle size that their interactions and engineering properties are highly dependent on their component minerals and affected by the forces between the surfaces of adjacent particles.

(i) Explain with a schematic diagram why there are charges present on the surface of clay particles. [10%]

(ii) Describe the forces that act between clay particles and draw a graph of how those forces vary with the distance between the clay particles and the concentration of ions in solution. [20%]

(iii) Explain the effect of the net force on clay particles on their resulting structure giving an example of a resulting practical impact. [30%]

(b) Discuss why contamination of the subsurface is such a complex challenge and present a justified argument as to why risk-based remediation approaches are the most effective and sustainable solutions. Use examples to illustrate your answers. [40%]

(TURN OVER

4 A site investigation at an old landfill shows that a contaminant has leaked from the landfill into the underlying saturated soil. An aquifer exists 12 m below the landfill. The maximum concentration of the contaminant in the landfill C_o is 6.2 mg L^{-1}. The vertical mean pore fluid velocity $v_f = 1.5 \times 10^{-9}$ m s^{-1}, the effective diffusion coefficient of the contaminant $D_d^* = 1.3 \times 10^{-9}$ m^2 s^{-1} and the longitudinal dispersivity of the site $\alpha = 0.3$m. The concentration of the contaminant C in the soil may be related to C_o using the following expression:

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

where erfc is the complementary error function, z is the depth, D_l is the longitudinal dispersion coefficient and t is the time. Assume that the flow is one-dimensional and that sorption of this contaminant is negligible. You may also assume that the maximum concentration of this contaminant remains constant in the landfill.

(a) How long will it take for the first sign of the contaminant to reach the aquifer? You may take $C/C_o = 0.0001$ at this stage. [20%]

(b) The health and safety standards require that soil containing concentrations above 3.2 mg L^{-1} is to be removed. Estimate the depth beneath the landfill base to which the site must be excavated to satisfy this requirement, if the contaminant has just started to appear in the aquifer. [20%]

(c) If multiple cracks form along the whole depth of the soil beneath the landfill, how will this change the time it takes for the first sign of the contaminant to reach the aquifer? [10%]

(d) Based on calculations likely to have been carried out at the time the landfill was designed and newly constructed, how long would it have taken for the first sign of the contaminant to reach the aquifer. [10%]

(e) Suggest a repair strategy that you would deploy to minimise further contaminant leakage for the landfill. [10%]

(f) If you are to completely redesign and rebuild the landfill to minimise leakage of contaminants, what modern design elements would you incorporate and what considerations would you take into account? [15%]

(g) If a new landfill, identical to that in part (f) above, has been built on another site, where the underlying soil has a higher cation exchange capacity, how would you expect this difference to impact the fate of any contaminants leaking from that landfill? [15%]

END OF PAPER

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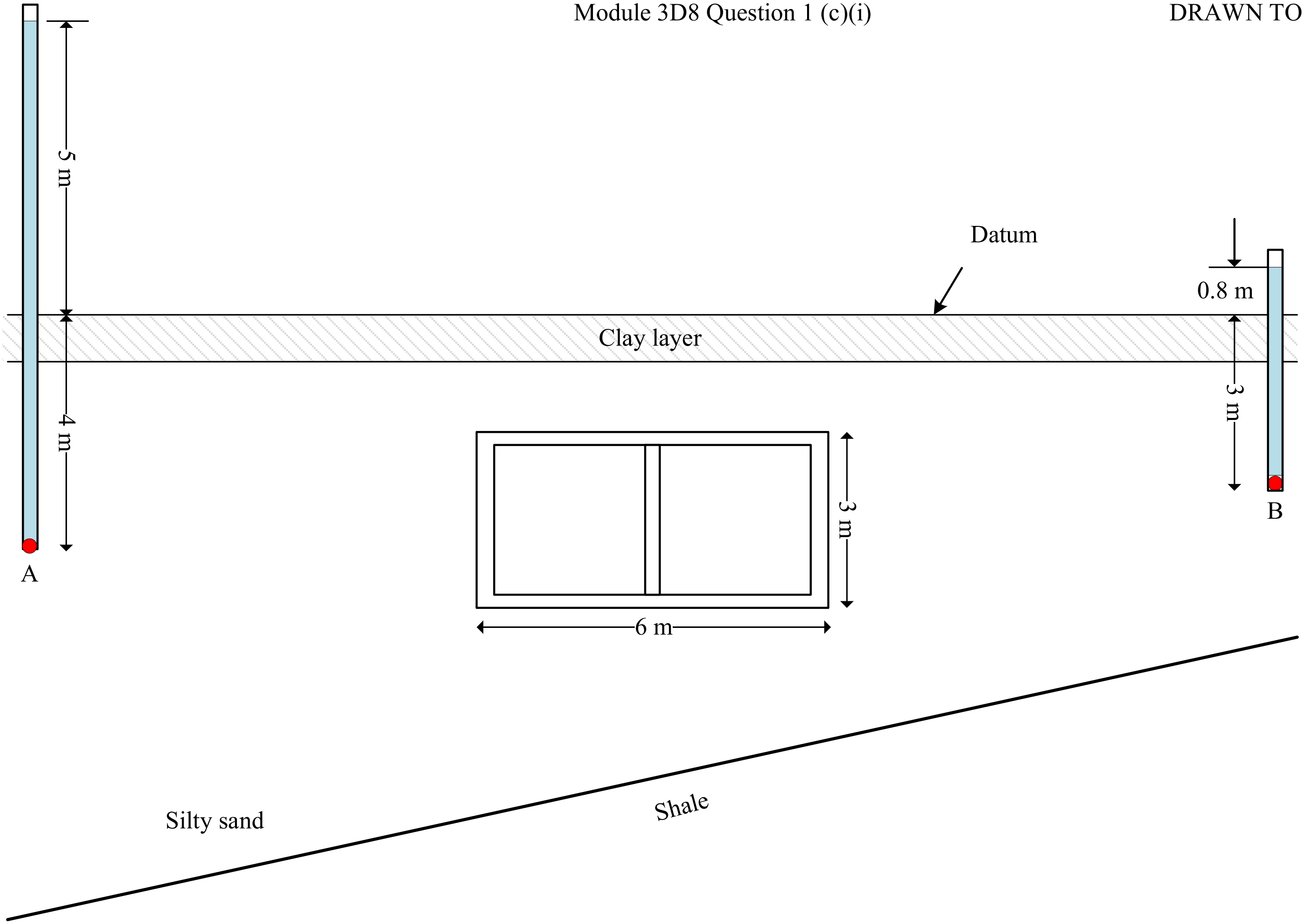
Candidate No:

ENGINEERING TRIPOS PART IIA FRIDAY 26 APRIL 2024 09:30 TO 11:10

Module 3D8 Question 1 (c)(i) DRAWN TO SCALE



Extra Copy of Fig. 1 Question 1 (c)(i)

UNIVERSITY OF CAMBRIDGE

Engineering Tripos Part IIA Paper 3D8

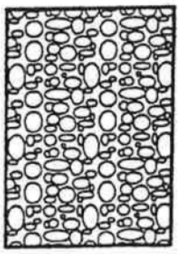
3D8
GEO-ENVIRONMENTAL ENGINEERING

DATA BOOK

January 2022

Groundwater

Soil: general definitions



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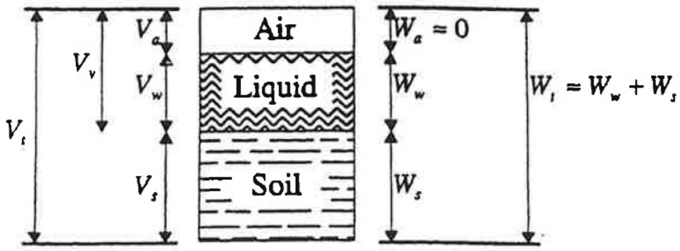


Soil structure | Volumes | Weights

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

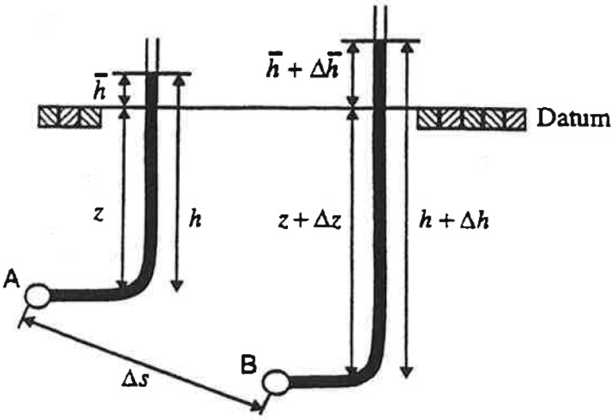
Classification of particle sizes

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

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	:	$K \cong 0.01(D_{10}\text{ in mm})^2$ 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:

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

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

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

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

Tables (to four significant figures)

β	erf(β)	erfc(β)
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

3D8: Geo-environmental Engineering

2024

Numerical Answers

Q1

(c) (iii) Weight of tunnel 108kN/m, Net upward force 72kN/m

(iv) Overall net upward force 42kN/m

Q2

(c) K = 3.7037 x 10-6 m/s

(d) time taken for 50ml 9.29 hours

(e) Thermal conductivity 2.652 W/m/oC

Q3

None

Q4

(a) Time t = 57.63 years
(b) Depth z = 2.64 m
(c) Time t = 209.3 years
(d) Time t = 112 year