ENGINEERING TRIPOS   PART IIA

Tuesday 27 April 2010   9 to 10.30

Module 3D6

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: Environmental Engineering II Data Book (6 pages)
Extra copy of Fig. 1 (Question 1)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book
Graph paper	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 (a) Explain briefly the stages involved in the formation of soil particles from rocks. [10%]

(b) A new porous drain is to be constructed in a 12 m thick sandy silt layer overlying impermeable bedrock as shown in Fig. 1. The water table at this site is 1 m below the ground surface. The properties of the sandy silt are given in the table below. Assume that the drain will contain air at atmospheric pressure. You may also assume that the size of the drain is small compared to the thickness of the sandy silt layer.

Specific gravity of particles G_s	D_{10} (mm)	D_{20} (mm)	void ratio e	hydraulic conductivity K (m s^{-1})	Unit weight of pore water γ_w (kN m^{-3})	Surface tension of pore water T (kN m^{-1})
2.65	0.065	0.15	0.65	5.75×10^{-6}	10.0	7.1×10^{-5}

(i) Draw a flownet for seepage into the drain 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%]

(ii) Estimate the leakage rate due to seepage of water into the drain through the sandy silt deposit. [20%]

(iii) Calculate the pore water pressure at locations A, B and C around the drain as marked on Fig. 1. Explain why these may be different from the hydrostatic pore water pressures at these locations. [30%]

(c) How much rainfall is required to raise the water table at this site to the ground surface, assuming all the water infiltrates into the ground? If the water table were to be raised to the ground surface, how would your estimate of the leakage rate into the drain change? [20%]

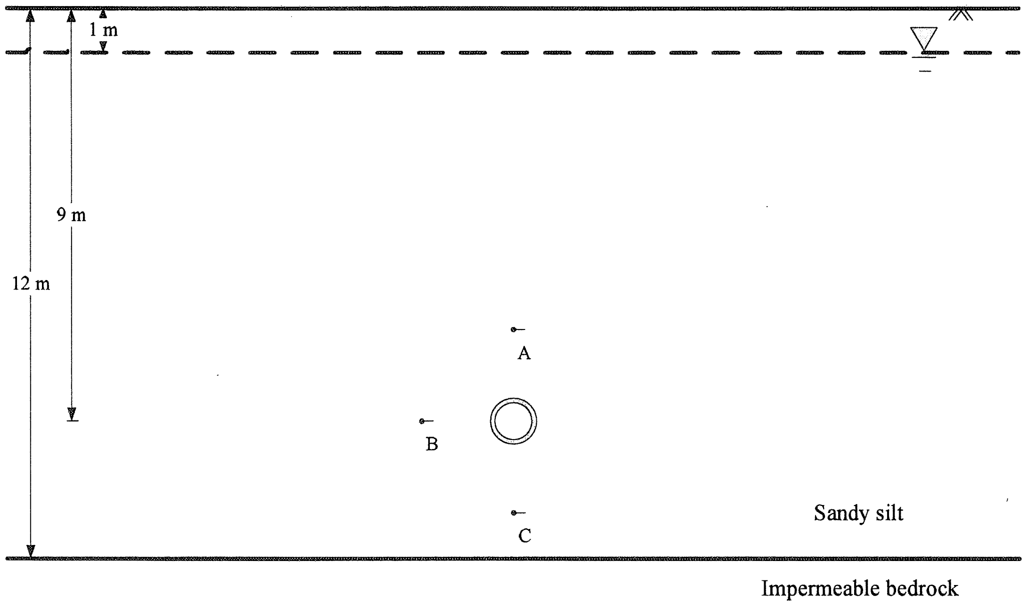


Fig. 1

2 (a) A ground water flow survey is conducted at a prospective construction site. Site investigations have revealed that the site has two fully saturated, horizontal layers with hydraulic conductivities K_1 and K_2, and thicknesses L_1 and L_2 respectively. Assuming the ground water flow to be parallel to the stratified layers, derive an expression for the equivalent horizontal hydraulic conductivity. [25%]

(b) Soil samples taken from the above site were subjected to laboratory tests. The hydraulic conductivities of the top and bottom layers were found to be 3.6×10^{-5} m s^{-1} and 6.3×10^{-5} m s^{-1} respectively. The thicknesses of the top and bottom layers were 3.2 m and 5.4 m respectively. Two standpipes were inserted at the same level and 10 m apart horizontally in the direction of flow, recorded a potential head drop of $\bar{h}$ m. If the flow rate through the top layer was 3.8×10^{-6} m^3 s^{-1} per meter width, calculate the value of $\bar{h}$ and the flow rate of water through the bottom layer. [25%]

(c) The concentration c of a contaminant in the soil may be related to the maximum concentration c_o of the contaminant using the following expression:

$$\frac{c}{c_o} = \frac{1}{2}\operatorname{erfc}\left[\frac{z - v_f t}{\sqrt{4 D_l t}}\right]$$

where z is the distance from the source, D_l is the longitudinal dispersion coefficient, v_f is the mean pore fluid velocity and t is the time. Using this expression, determine the concentration profile in the top and bottom layers 100 m downstream from a line source of contaminant after 360 days. It may be assumed that the line source of the contaminant maintains a constant concentration of 15 mg litre^{-1}. The effective diffusion coefficient of the contaminant D_d^* is 5.3×10^{-9} m^2 s^{-1} for both layers. The longitudinal dispersivities α_l are 0.25 m and 0.35 m and the porosities are 0.45 and 0.55 for the top and bottom layers respectively. Assume transverse dispersivity is negligible. [50%]

3 (a) Describe briefly the term 'sorption' of a contaminant. Distinguish between linear and non-linear sorption. [20%]

(b) By considering the governing equation for 1-D solute transport;

$$\frac{\partial(nc)}{\partial t} = -\frac{\partial}{\partial x}\left\{J_{dispersion} + J_{advection}\right\} \pm \Phi$$

where linear sorption $\Phi = -\rho_b K_d \frac{\partial c}{\partial t}$ and ρ_b is the bulk density of soil and K_d is the distribution coefficient. Show that the effect of sorption on solute transport is an apparent slowing down of the dispersive and advective processes. [30%]

(c) The introduction of the EU Landfill Directive through the UK Landfill Regulation (2002) brought about major changes to the way waste is being landfilled.

(i) One change is that certain wastes are banned from landfilling. List four such wastes. [10%]

(ii) Another change is the classification of landfills into three classes. Describe each class and the type of waste it will accept. [30%]

(iii) A third change is that most waste destined to landfill must be subject to prior treatment. Define the 'three point test' which the treatment needs to be based on. [10%]

4 (a) Briefly describe each of the following five technologies used in land remediation:

(i) Excavation and disposal to landfill; [15%]

(ii) Use of cover system; [15%]

(iii) In-situ immobilisation; [15%]

(iv) Soil washing; [15%]

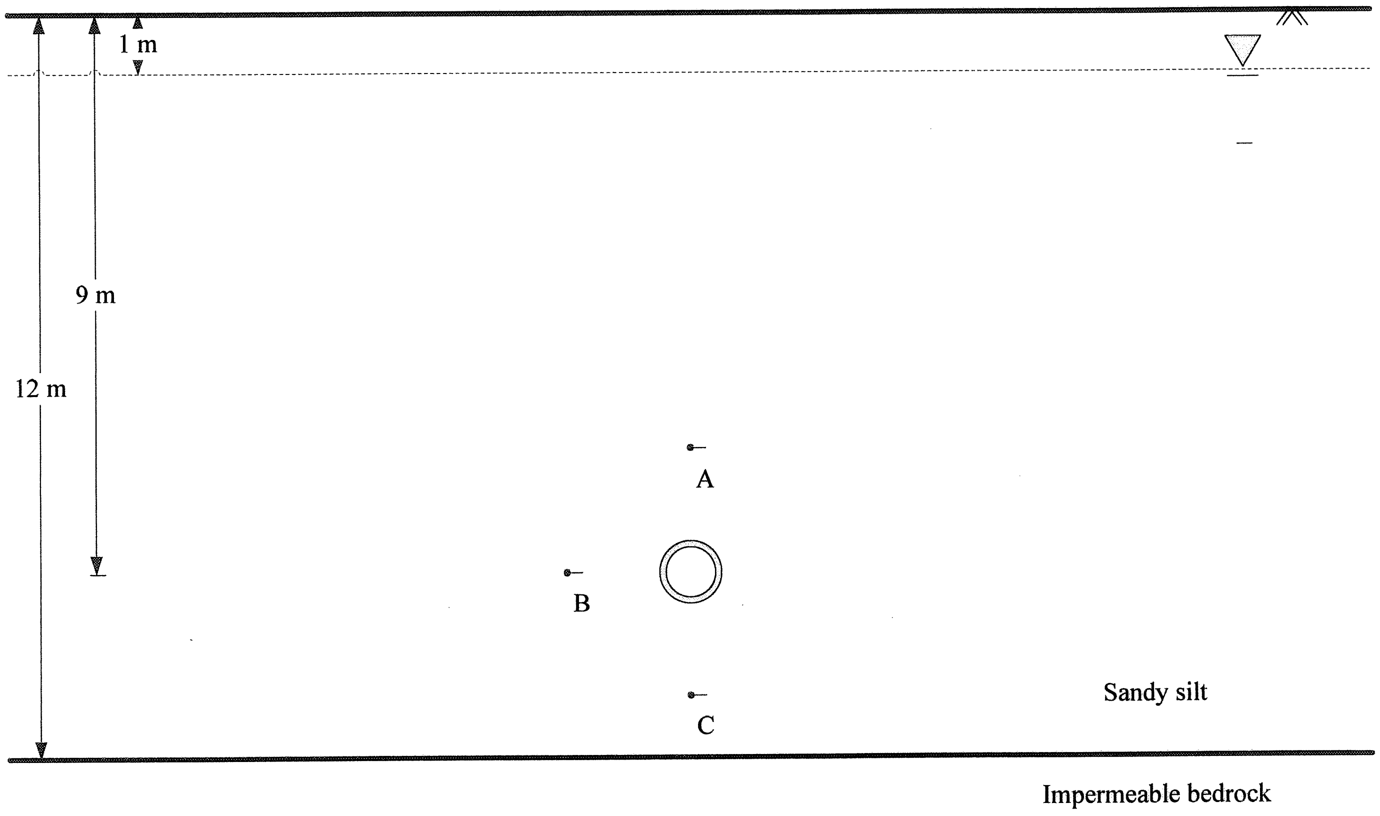
(v) Ex-situ bioremediation. [15%]

(b) For each of the above five technologies list one major positive and one major negative sustainability related impact. [25%]

END OF PAPER

ENGINEERING TRIPOS PART IIA TUESDAY 27 April 2010 9 TO 10.30
MODULE 3D6 ENVIRONMENTAL GEOTECHNICS

DRAWN TO SCALE



Extra Copy of Fig. 1

UNIVERSITY OF
CAMBRIDGE

Engineering Tripos Part IIA Paper 3D6

ENVIRONMENTAL ENGINEERING II

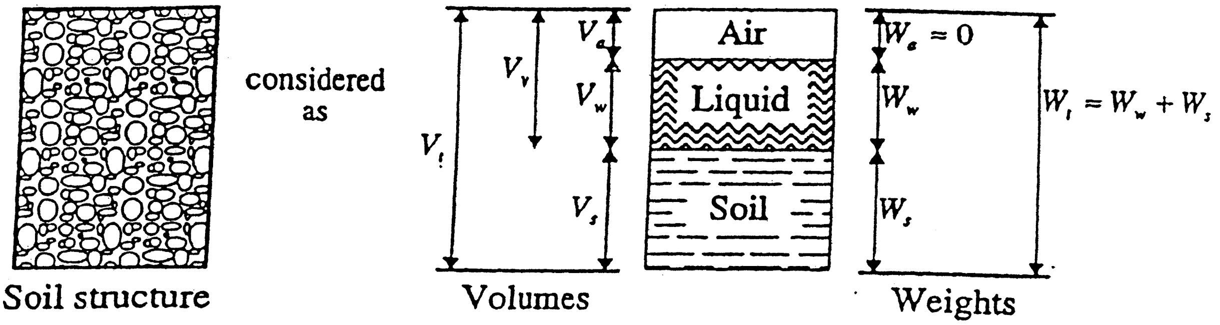
DATA BOOK

January 2003

UNIVERSITY OF CAMBRIDGE

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	$\gamma_w = 9.81\ \text{kN/m}^3$
Unit weight of soil	$\gamma = W_t/V_t = \left(\dfrac{G_s + S_r e}{1 + e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\dfrac{G_s - 1}{1 + e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\dfrac{G_s}{1 + e}\right)\gamma_w$

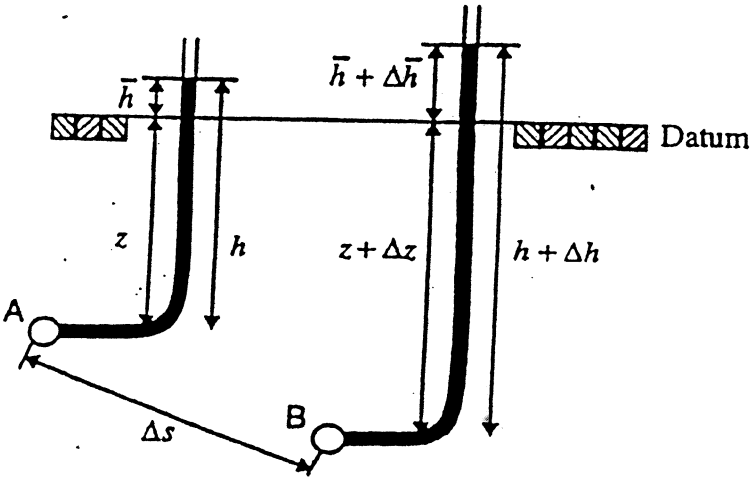
Classification of particle sizes

Boulders	larger than			200 mm
Cobbles	between	200 mm	and	60 mm
Gravel	between	60 mm	and	2 mm
Sand	between	2 mm	and	0.06 mm
Silt	between	0.06 mm	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 $i=-\dfrac{\Delta\bar{h}}{\Delta s}=-\dfrac{1}{\gamma_w}\dfrac{\Delta\bar{p}}{\Delta s}$

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

UNIVERSITY OF
CAMBRIDGE

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

UNIVERSITY OF
CAMBRIDGE

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