UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIA

Friday 7 May 2004 2.30 to 4.00

Module 3D6

ENVIRONMENTAL ENGINEERING II

Answer not more than ***three*** *question*

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: 3D6 Datasheets (6 pages)

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

(TURN OVER

1 (a) Predictions of effects due to climate change have been achieved by modelling interactions of complex systems over long periods by specialist bodies such as the Hadley Centre in the UK. Describe the difficulties that arise from the uncertainties associated with these models in terms of planning new water resources projects now. [20%]

(b) Describe the ways in which Urban Pollution Management (UPM) and integrated modelling can help to meet the requirements of the *environmental, social* and *economic* aspects of urban drainage systems. [30%]

(c) Conventional urban drainage has been based on the concept of removing surface water as fast as possible. Discuss the problems that arise from this type of system with regard to:

(i) capacity;
(ii) pollution;
(iii) groundwater;
(iv) habitats. [40%]

(d) The technical components of sustainable water management systems tend to be fairly simple but, in order for them to be effective, the engineer must also carry out consultation with stakeholders. Describe the involvement and likely priorities, and suggest ways in which various requirements may be accommodated in terms of an integrated water resources management scheme. [10%]

2 (a) (i) Derive an expression for the capillary rise of water with surface tension T in a tube of diameter d. [20%]

(ii) A soil sample obtained from a site was subjected to sieve analysis and sedimentation analysis. The resulting particle size distribution is shown in Figure 1. Using this, estimate the height of capillary rise above the general ground water table. The surface tension T may be taken as 5×10^{-5} kNm^{-1} at the ambient temperature of the ground water. [20%]

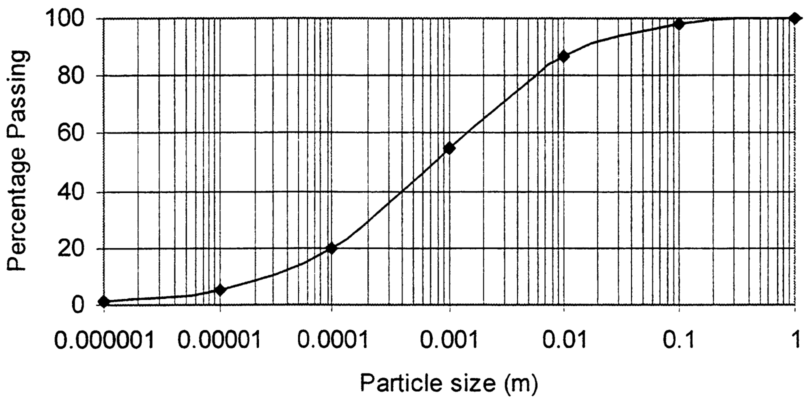

Fig. 1

(iii) The ground water in a wide pit at this site rose 5 m above the bedrock. Sketch the pore water pressure distribution above and below the ground water table marking the zone of capillary rise. Using bedrock as the datum, determine the potential head at a depth of 2 m below the ground water table. It may be assumed that there is no ground water flow at the site. [20%]

(b) A circular tube well that has a diameter of 120 mm was driven into a confined aquifer sandwiched between impermeable layers. The aquifer has a thickness of 2.5 m. The horizontal hydraulic conductivity of the aquifer was estimated as 1.5×10^{-3} ms^{-1}. The pumping has resulted in a potential head difference of 1.8 m between the water level in the tube well and that in an observation well with its axis located 2.2 m away. Calculate the rate Q at which water is being pumped from the tube well. [40%]

3 (a) Ground water flow was observed at a stratified site. Site investigations have revealed that the site has two 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. [30%]

(b) Soil samples taken from the site were subjected to laboratory tests. The hydraulic conductivities of the two layers were found to be 2.8×10^{-5} ms^{-1} and 1.5×10^{-8} ms^{-1}. The thicknesses of the two layers were 2.8 m and 5.1 m respectively. Two standpipes inserted at a distance of 10 m apart in the direction of flow indicated a potential head drop of 5 m. Calculate the equivalent horizontal hydraulic conductivity of the two layers. Considering a unit width of the strata estimate the rates of flow of water through each of the strata. [30%]

(c) An old landfill has a single clay liner at its base. The thickness of this liner is 2.5 m and it is in direct contact with the leachate in the landfill. The concentration of the leachate can be taken as a constant c_0. The hydraulic conductivity of the clay is 3.5×10^{-9} ms^{-1}. The expression for the contaminant concentration c in the liner is given by

$$\frac{c}{c_0} = erfc\left[\frac{z}{\sqrt{4D_d^* t}}\right],$$

where *erfc* is the complementary error function, z is the depth, D_d^* is the effective diffusion coefficient and t is the time. The aqueous diffusion coefficient for the contaminant in the landfill is 0.85×10^{-9} m^{2}s^{-1} and the tortuosity of the clay is 0.4. Calculate how long it will take for the contaminant to break through the base liner of the landfill (take this to be when $\frac{c}{c_0} = 0.001$). At what depth within the liner will $\frac{c}{c_0} = 0.7$? Sketch the corresponding concentration profile within the clay liner. [40%]

4 Write brief notes on each of the following:

(a) The similarities and differences between molecular diffusion and mechanical dispersion as solute transport mechanisms in porous media; [25%]

(b) Different types of geosynthetic materials used in various landfill components; [25%]

(c) Electro-kinetic land remediation; [25%]

(d) Use of in-ground barriers to prevent contaminant migration, and their advantages and disadvantages. [25%]

END OF PAPER

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Engineering Tripos Part IIA Paper 3D6

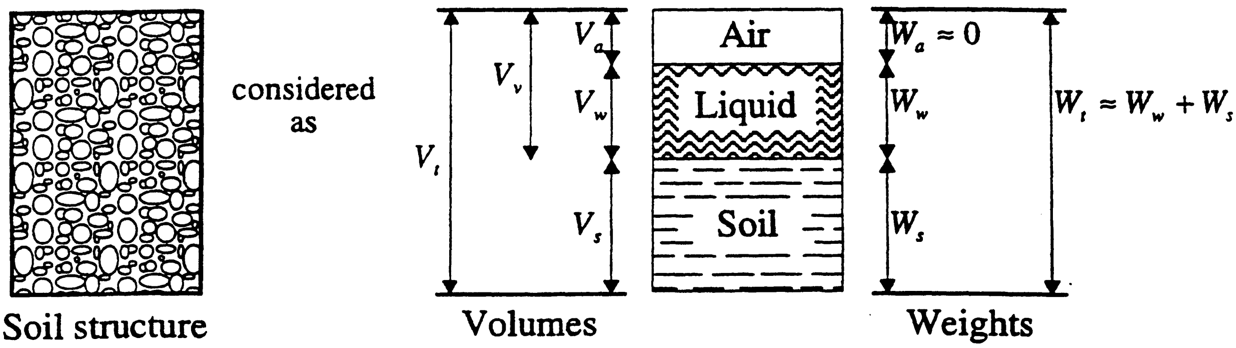
ENVIRONMENTAL ENGINEERING II

DATA BOOK

January 2003

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	γ_w	$=$	9.81 kN/m³
Unit weight of soil	γ	$=$	$W_t/V_t = \left(\frac{G_s + S_r e}{1 + e}\right)\gamma_w$
Buoyant unit weight	γ'	$=$	$\gamma - \gamma_w = \left(\frac{G_s - 1}{1 + e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	γ_d	$=$	$W_s/V_t = \left(\frac{G_s}{1 + e}\right)\gamma_w$

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)		

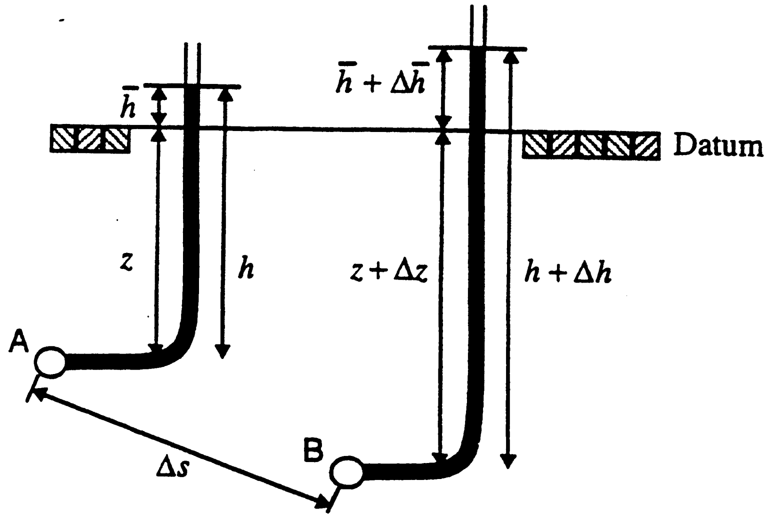
D — equivalent diameter of soil particle

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

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 $\quad i = -\dfrac{\Delta\bar{h}}{\Delta s} = -\dfrac{1}{\gamma_w}\dfrac{\Delta\bar{p}}{\Delta s}$

Darcy's law $\quad v = Ki$

v = superficial seepage velocity

K = coefficient of permeability or hydraulic conductivity

Typical hydraulic conductivities

$D_{10} > 10$ mm	:	non-laminar flow
10 mm $> D_{10} >$ 1μm	:	$K \cong 0.01\ (D_{10}$ 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