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ENGINEERING TRIPOS PART IIA

Friday 13 May 2005 2.30 to 4.00

Module 3D6

ENVIRONMENTAL ENGINEERING II

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:
Special datasheets (6 pages)

Supplementary page:
Extra copy of Fig.1 (Question 1).

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) Describe the terms pressure head, pore water pressure, datum and potential head used for measuring water pressure in porous media. How are they related? [20%]

(b) Describe briefly the procedure you would adopt to construct a flownet for seepage flow through a porous medium. How would you use the flownet to estimate the rate of seepage flow. [20%]

(c) A concrete dam is to be constructed to retain a height of 10 m of water as shown in Fig.1. The dam is to be constructed on a silty sand bed that has a hydraulic conductivity K of 3.5×10^{-6} m s^{-1} and a porosity of 0.4. The thickness of the silty sand layer is estimated to be 10m and bedrock is encountered below this depth. The concrete dam may be considered impermeable. In order to reduce the seepage flow a sheet pile is to be driven vertically down to a depth of 3m below the base of the dam, at the upstream face of the dam as shown in Fig. 1.

(i) Draw a flownet for seepage on the copy of Fig. 1 provided on a separate sheet. This sheet must be handed in with your answer. Draw attention to any shortcomings which remain in your solution. [30%]

(ii) Estimate the rate of leakage per metre of dam. [10%]

(iii) Without further calculations, discuss the effects on the rate of leakage and uplift force on the dam of increasing the depth of the sheet pile wall and moving the location of the sheet pile wall towards the toe of the dam. [20%]

(cont.

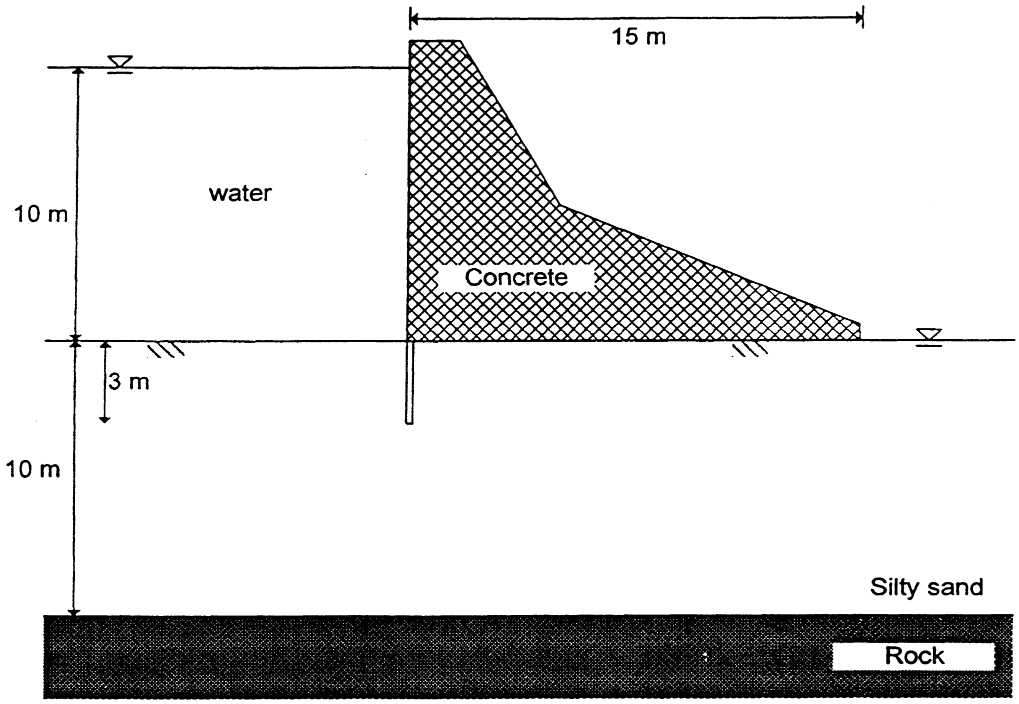

Fig.1

(TURN OVER

2 (a) Derive the expression for the effective vertical hydraulic conductivity K, of a soil deposit consisting of two horizontal layers of depths L_1 and L_2, and with hydraulic conductivities K_1 and K_2, respectively. [20%]

(b) A laboratory test suitable for the measurement of the hydraulic conductivity of fine-grained soils is the falling head test shown schematically in Fig. 2. In the figure, L is the length of the soil sample and A is its cross-sectional area. The soil sample is placed between two filter stones to prevent any loss of soil. The base of the soil sample is taken as the datum. A standpipe of internal area a is connected to the top of the sample. The standpipe is filled with water and a measurement is made of the time t_1 for the water level, above the base of the sample, to fall from h_o to h_1. At any intermediate time t the water level is h. Derive an expression for the hydraulic conductivity of the soil. [30%]

(c) A clayey silt sample is tested in this apparatus. The sample has a length L of 0.1 m and cross-sectional area A of 1025 mm^2. The internal cross-sectional area of the standpipe a is 12 mm^2. Readings taken of the level of water in the standpipe above the base of the sample h with time t are as follows:

h (m)	1.000	0.940	0.900	0.880	0.800	0.745	0.660	0.460
t (hrs)	0	0.2	0.5	1.0	3.5	5.5	8.8	19.0

Show that the value for the hydraulic conductivity of the clayey silt is 1.172×10^{-8} m s^{-1}. [20%]

(cont.

(d) The same apparatus is then used to test a layered soil sample. The top half of the sample with a length of 0.05 m was the same clayey silt in part (c) but the lower half of the soil sample with a length of 0.05 m is clay. The overall hydraulic conductivity K of the whole sample is determined using this apparatus and is found to be 4.3×10^{-9} m s^{-1}. Determine the hydraulic conductivity of the clay. [30%]

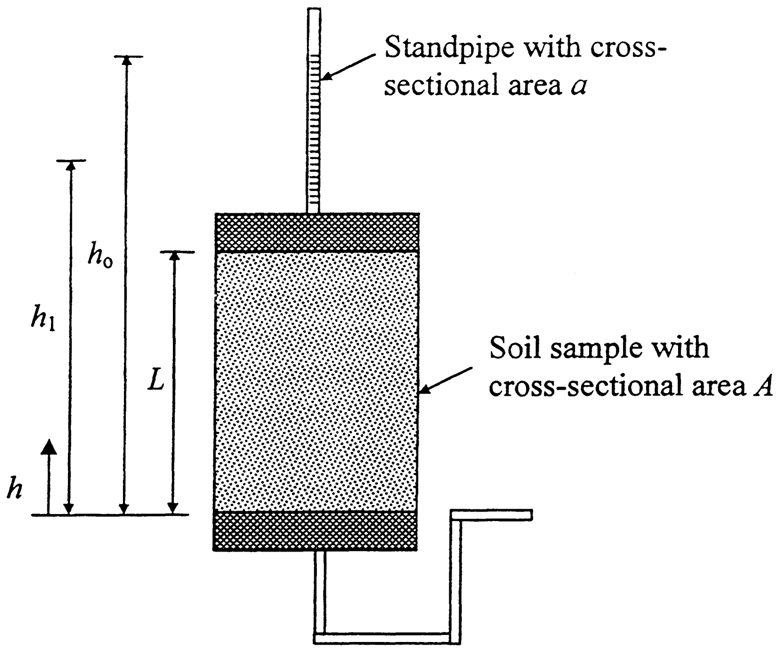

Fig. 2

3 (a) Describe briefly molecular diffusion and mechanical dispersion as solute transport mechanisms. [20%]

(b) 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 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 $\alpha_l = 0.3$ m. The concentration of the contaminant c in the soil may be related to the maximum concentration c_o of the contaminant using the following expression:

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

where $erfc$ is the complementary error function, z is the depth, D_l is the longitudinal dispersion coefficient, v_f is the mean pore fluid velocity 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.

(i) 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%]

(ii) The health and safety standards require that the 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) Name any two types of geosynthetics you would use in designing a modern landfill and explain the function they would fulfil. [20%]

(d) Explain briefly what role in-ground barriers can play in preventing contaminant transport in porous media. List their advantages and disadvantages. [20%]

4 The owner of a contaminated site in London is considering the conversion of the site into a residential development. He is keen to consider elements of sustainability in his regeneration scheme.

The ground conditions at the site consist of 6–8 m of made ground (variable fill), overlying 1–2 m of natural sand and gravel deposits, overlying London clay to a depth of 25 m. The groundwater level is at the top of the sand and gravel deposits. The contaminants present in the site soils are mainly heavy metals including zinc, copper, nickel, cadmium and lead, which have been found in high and also variable concentrations across the site.

(a) Considerations of costs and risk have led the owner to select stabilisation/solidification as the remediation technique for the contaminated site. What are the issues likely to impact on the sustainability of stabilisation/solidification? [20%]

(b) What are the available tools for assessing the sustainability of remediation techniques? [20%]

(c) In terms of sustainability, what are the reasons for and against the disposal of the contaminated site soil to a landfill. [20%]

(d) What are the possible implications of climate change on the site soil treated by stabilisation/solidification and on any remaining untreated contaminated soil on the site? [20%]

(e) What are the implications of the implementation of the EU Landfill Directive on the regeneration project? [20%]

END OF PAPER

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Engineering Tripos Part IIA Paper 3D6

ENVIRONMENTAL ENGINEERING II

DATA BOOK

January 2003

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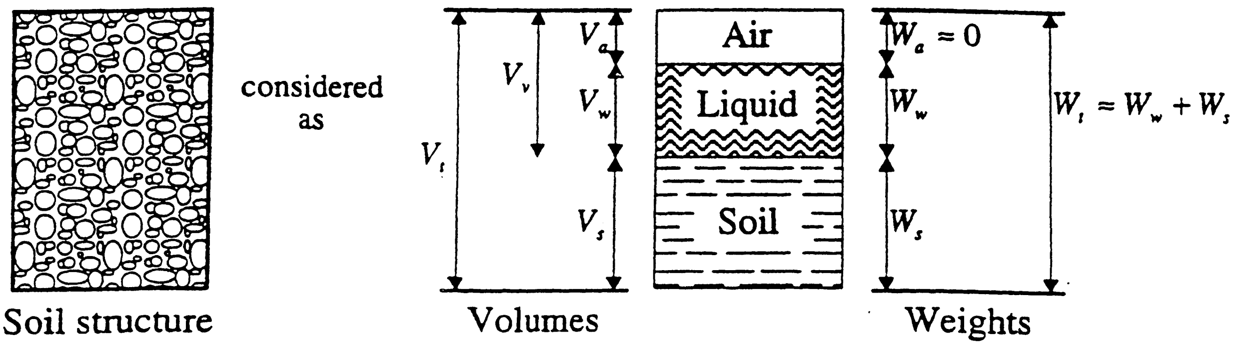
Groundwater

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)		

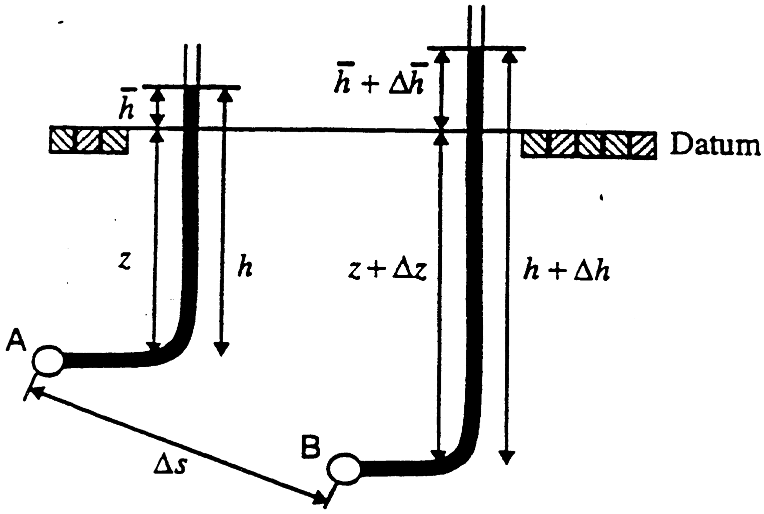
D — equivalent diameter of soil particle

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

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 $> D_{10} > 1\mu$m	:	$K \cong 0.01\ (D_{10}$ 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 $= \dfrac{v}{n}$
- v : Darcy superficial velocity or specific discharge
- n : porosity
- k : intrinsic permeability $= \dfrac{K\mu}{\rho g}$
- 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

PART IIA 2005

3D6 Environment engineering II

3D6 Environmental Engineering II:

Principal Assessor: **Dr S P G Madabhushi**

Answers:

Q(1) c(i) Leakage rate $q = 10.5 \times 10^{-6}$ m^3/s per 1m width of the dam

Q(2) c) Hydraulic conductivity K of silty clay $= 1.172 \times 10^{-8}$ m/s
d) Hydraulic conductivity K of clay $= 2.633 \times 10^{-9}$ m/s

Q(3) b) 57.63 years
c) 2.1 m