ENGINEERING TRIPOS PART IIA

Tuesday 28 April 2009 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: Special data sheets (6 pages)
Extra copy of Fig. 1 (Question 1)

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS
Engineering Data Book
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

1 (a) Explain briefly how soil particles are formed from rocks. How does the shape of individual soil particles change when transported by a river from the origin of the river to its confluence into the sea? [15%]

(b) A concrete weir is to be constructed below ground in a sandy silt deposit as shown in Fig.1. The hydraulic conductivity of the sandy silt is 4.3×10^{-6} m s^{-1}. On the downstream side of the weir an impermeable blanket 4 m in length is to be constructed as shown in Fig. 1.

(i) Draw a flownet for seepage 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) The width of the river channel at the location of the concrete weir is 200 m. Estimate the leakage rate due to seepage of water through the sandy silt deposit and the quantity of water that leaks below the weir in a week. [20%]

(iii) Sketch the distribution of the uplift pressures acting on the base of the concrete weir. [20%]

(c) The friction angle between concrete and the sandy silt is 25°. The unit weight of concrete may be taken as 24 kN m^{-3}. Calculate the factor of safety against sliding of the concrete weir, ignoring any passive resistance offered by the silty sand. Comment on how the factor of safety against sliding would change if the impermeable blanket downstream of the weir is not constructed. [25%]

(cont.

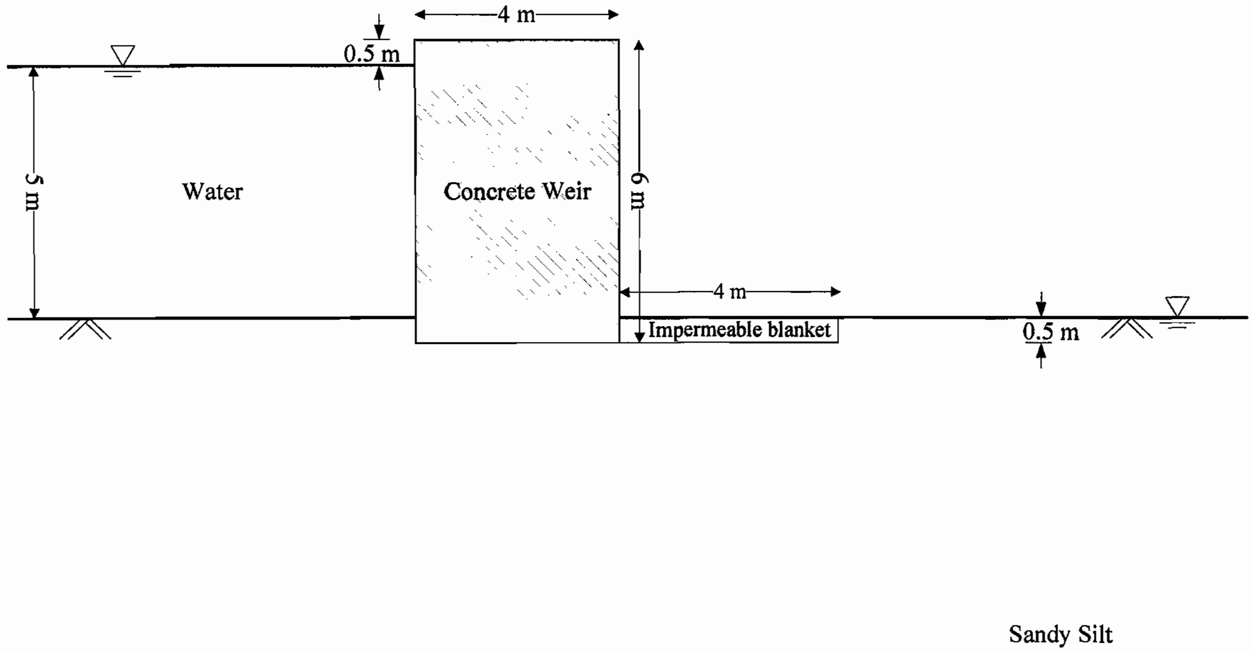

Fig. 1

(TURN OVER

2 (a) Describe briefly how you would use a falling head permeameter to determine the hydraulic conductivity of a soil sample. What types of soils will be suitable to be tested in such a device. 4

[20%]

(b) Derive the following relationship for the hydraulic conductivity, K, of a soil sample in terms of the cross-sectional area, a, of the falling head tube, the cross-sectional area, A, of the soil sample, the length, L, of the soil sample and the measured potential heads, h_1, and h_2, at two different times t_1, and t_2, respectively.

$$K = \frac{aL}{A(t_2 - t_1)} \ln\left(\frac{h_2}{h_1}\right)$$ 4

[20%]

(c) An undisturbed soil sample was tested in a falling head permeameter. The soil sample had a diameter of 50.8 mm and a length of 101.6 mm. The area ratio between the soil sample and the falling head tube and the soil sample is 2000. The head of water above the base of the soil sample was recorded at different times as shown in the table below.

h (m)	1.00	0.94	0.90	0.88	0.80	0.75	0.66	0.46	0.35	0.25	0.15	0.10
t (hrs)	0.0	0.3	0.6	1.2	3.8	5.3	8.9	18.3	25.5	34.5	47.5	66.0

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Calculate the hydraulic conductivity of the soil sample in the units of m s^{-1}. [30%]

(d) An identical soil sample as in part (c) above was tested using an oil with a density of 950 kg m^{-3} and a dynamic viscosity of 28×10^{-3} Ns m^{-2}. You may assume that the dynamic viscosity of water is 1.003×10^{-3} Ns m^{-2}. The initial potential head of the oil was 1.0 m. Estimate the time it would take for the potential head to drop to 0.745 m. State clearly any assumptions you had to make. 6

[30%]

3 (a) A liquid contaminant is to be stored on an 8 m thick clay layer. The void ratio of the clay is 0.8 and its hydraulic conductivity is 1.2×10^{-9} m s^{-1}. The clay layer is underlain by a 3 m thick sand layer which has a hydraulic conductivity of 2×10^{-3} m s^{-1}. Below the sand layer there is a gravel stratum that conducts ground water freely. The maximum concentration of the contaminant in the surface impoundment is 12.8 mg L^{-1}. The depth of the liquid contaminant is designed 3 m above the top of the clay layer. The effective diffusion coefficient of the contaminant $D_d^* = 4.3 \times 10^{-9}$ m^2 s^{-1} in this clay and the longitudinal dispersivity of the clay is α_l = 0.25 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:

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

where z is the depth, D_l is the longitudinal dispersion coefficient, v_f is the mean pore fluid velocity and t is the time. You may also assume that the maximum concentration of this contaminant remains constant at the surface of the clay layer and sorption is negligible.

(i) How long will it take for the first sign of the contaminant to reach the sand layer, if the sand layer is initially free from any contamination. [20%]

(ii) Sketch the distribution of the concentration of the contaminant with the thickness of the clay layer at this stage, marking the concentrations at quarter, half and three quarter points within the clay layer. [30%]

(b) The 'Waste Hierarchy' provides a theoretical framework to be used as a guide for ranking waste management options.

(i) Outline the different waste management options within the Waste Hierarchy stating their rank order. [10%]

(ii) Discuss the various options available for the use of waste as a resource giving examples where appropriate. [40%]

4 (a) Explain briefly how you would use the following techniques to remediate a contaminated site, giving the advantages and disadvantages of each technique:

(i) excavation and redeposition in landfills; 4 [20%]

(ii) vitrification; 3 [15%]

(iii) biological methods of clean-up. 3 [15%]

(b) The UK Environment Agency, in its guidance document entitled 'Cost-benefit analysis for the remediation of land contamination (1999)', provided a methodology for the comparison of two or more options for the remediation of a contaminated site.

(i) Briefly outline how a cost-benefit analysis is performed and highlight some of its advantages and disadvantages. [25%]

(ii) Briefly describe the various steps of the proposed methodology leading to the selection of the preferred option. [25%]

END OF PAPER

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Engineering Tripos Part IIA Paper 3D6

ENVIRONMENTAL ENGINEERING II

DATA BOOK

January 2003

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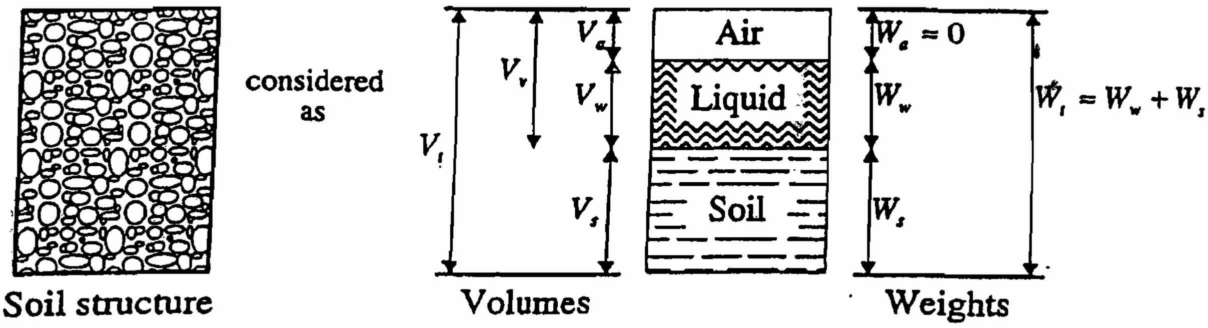
Groundwater

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

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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}

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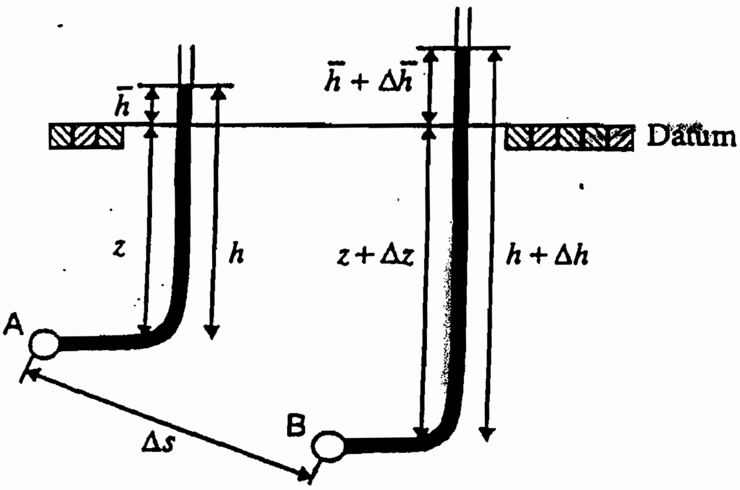
Seepage

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

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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:

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

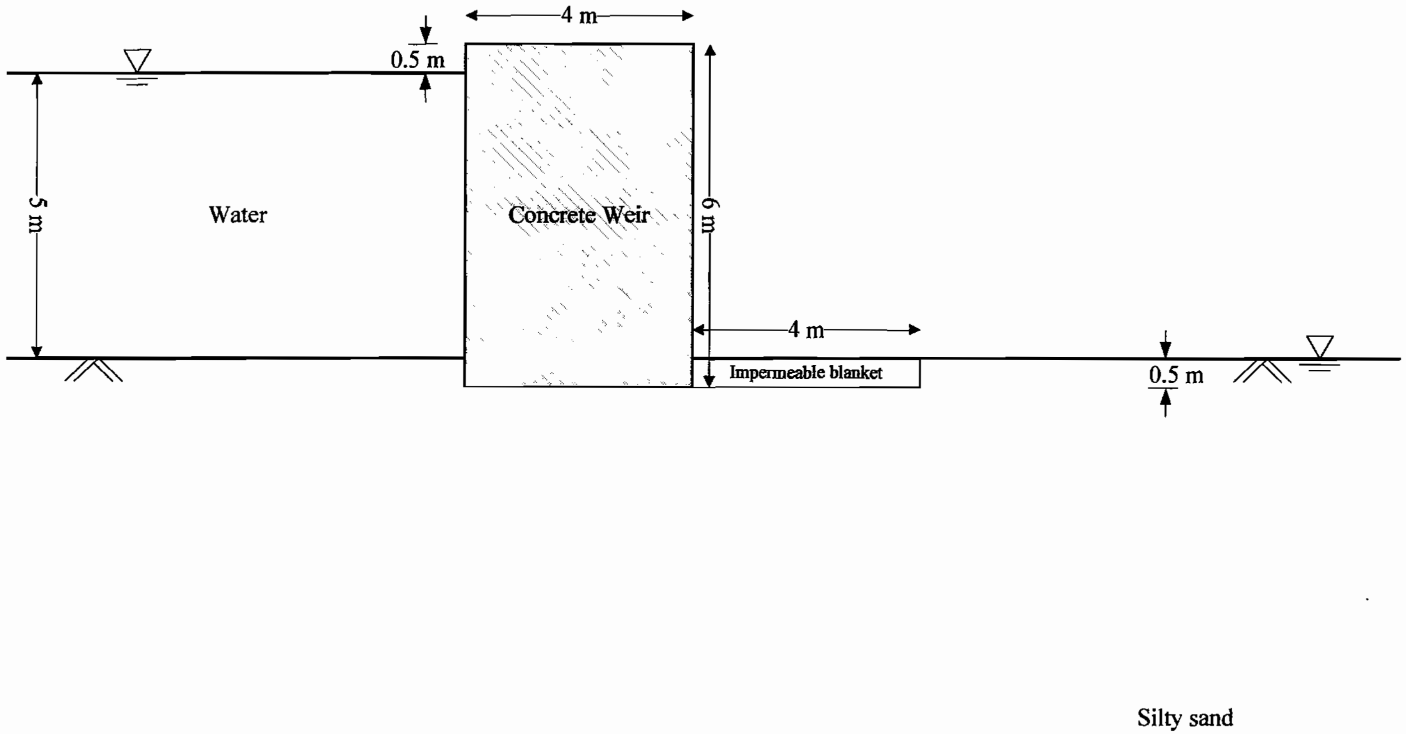
$$\operatorname{erfc}(\beta) = 1 - \operatorname{erf}(\beta)$$

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

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

Tables (to four significant figures)

β	$\operatorname{erf}(\beta)$	$\operatorname{erfc}(\beta)$
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



Extra Copy of Fig. 1

3D6 Environmental Geotechnics

Answers

Q1b) ii) 1083.6 m^3
1c) FoS =1.6

Q2 c) $K = 1.88 \times 10^{-10}$ m/s
2 d) 27 days

Q 3a) i) 11.86 years