ENGINEERING TRIPOS PART IIA

FRIDAY 13 May 2.30 to 4

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 hand margin.*

Attachments: Environmental Engineering Part II Data Book (6 pages)
Extra copy of Fig. 1 (Question 2)

STATIONERY REQUIREMENTS
Single-sided script 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

Version 2

1 (a) At sites X and Y the soils and their properties are as follows:

Site X	Site Y
Clay	Moist rounded sand
Specific gravity 2.7	Specific gravity 2.65
Dry density 1.62 g cm^{-3}	Moisture content 8.8%
Air voids 10%	Degree of saturation 0.4
Liquid Limit 30%	Maximum void ratio 0.85
Plastic Limit 17%	Minimum void ratio 0.35

(i) Calculate the moisture content and liquidity index for the clay at site X. [10%]

(ii) Calculate the void ratio and relative density of the sand at site Y. [10%]

(iii) If the soils at both sites are contaminated which one would be easier to clean up and why? [10%]

(b) A stratified soil consists of a layer of silt 2 m thick, with a permeability of 2×10^{-7} m s^{-1}, overlying a layer of sand 3 m thick with a permeability of 5×10^{-5} m s^{-1}.

(i) For horizontal flow through the stratified soil, derive the expression for the effective permeability of the system and calculate its value. Also calculate the ratio of the quantity of water flowing through each layer. [35%]

(ii) For vertical flow through the stratified soil, derive the expression for the effective permeability of the system and calculate its value. Also calculate the ratio of the head losses in each layer. [35%]

2 A water reservoir is constructed on top of an existing embankment, as shown in Fig. 1, the level of which is maintained as shown in the figure. The embankment is saturated and the base of the embankment is impermeable.

(a) Draw a flownet for the water seepage through the embankment and calculate the long-term steady state water seepage quantity through the embankment and out onto the slope surface in m^3 $year^{-1}$. Use the copy of Fig. 1 supplied and attach it to your answer book. Highlight salient points on the flownet and mark the potential head values on the equipotential lines you draw. The permeability of the embankment material can be taken as 0.5×10^{-7} m s^{-1}. [50%]

(b) What recommendation would you make to minimise water leakage onto the slope surface? [10%]

(c) What is the value of the pore water pressure at position X on Fig. 1? [10%]

(d) If the water in the reservoir becomes contaminated through an accidental spill, suggest two suitable in-situ remedial measures for such contaminated water. [10%]

(e) If the porosity of the embankment is 0.3, how long will it take for the contaminated water to first appear at point Y on the slope? [20%]

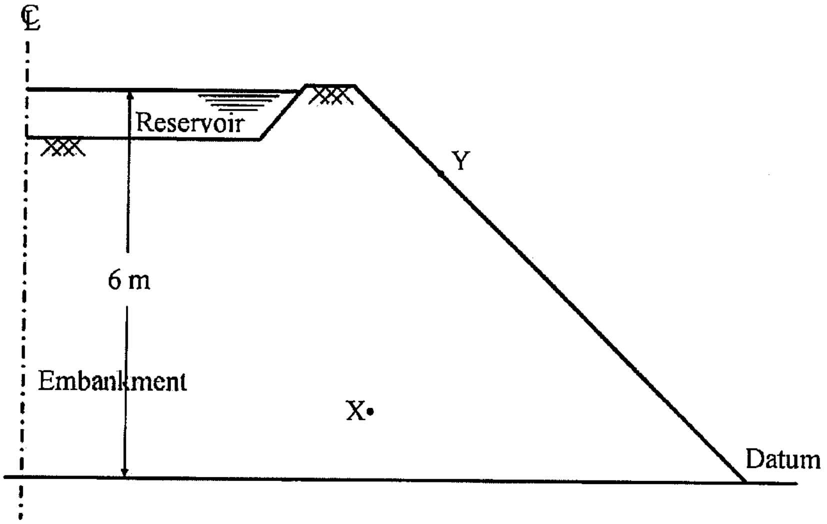

Fig. 1

3 (a) Clean-up methods, which are used to reduce the volume or hazardous nature of contaminants present on a contaminated site rather than simply to contain them, are commonly divided into the four categories given below. Briefly describe the general principles of the methods in each category and give an example technology from each, explaining its principles of operation and main advantages and disadvantages.

(i) Physical methods; [20%]

(ii) Thermal methods; [20%]

(iii) Chemical methods; [20%]

(iv) Biological methods. [20%]

(b) Explain how both historical and new land contamination are managed in the UK. [20%]

4 A contaminated site has been remediated with the construction of a 2 m thick soil-cement in-ground barrier wall around its perimeter. The wall is constructed through sandy soils and keyed into underlying bedrock. Assume that the whole sand stratum is contaminated and hence the flow and diffusion of the contaminated groundwater into the in-ground barrier wall can be assumed to be one-dimensional. Also assume that the contaminant is already in contact with the face of the wall and that its concentration in the groundwater on the contaminated side of the barrier remains constant. The aqueous diffusion coefficient for the contaminant in the groundwater is $0.5 \times 10^{-10}\ \mathrm{m^2\ s^{-1}}$ and the longitudinal dispersivity and tortuosity of the soil-cement barrier are 0.35 and 0.45 respectively.

When diffusion is the dominant contaminant transport mechanism, the expression for the contaminant concentration, c, in the barrier wall is given by

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

and when dispersion is the dominant contaminant transport mechanism, the expression becomes

(Cont

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

where c_o is the initial constant contaminant concentration in the groundwater, erfc is the complementary error function, z is the distance into the barrier wall from the c_o contaminant concentration end, v_f is the horizontal mean groundwater velocity, t is the time and $D_d{}^*$ and D_l are the effective diffusion and longitudinal dispersion coefficient of the contaminant respectively.

(a) What is the design life of the soil-cement in-ground barrier wall if this is defined as the period during which c/c_0 equals zero at the outer boundary? [20%]

(b) In practice, it is usually unrealistic to expect contaminant concentrations to be reduced to zero, and hence usually some very low target values are set. Using a target contaminant concentration emerging at the outer boundary of $c/c_o = 0.01$, i.e. the contaminant concentration is reduced by 99%, recalculate the design life of the in-ground barrier wall. [10%]

(c) Also in practice, the physical integrity of the in-ground barrier wall might become compromised, through the effect of the contaminants on the barrier material and other inaccuracies in the design calculations. This could lead to the developments of cracks throughout the barrier wall's thickness and depth allowing the groundwater to leak through at a velocity of 0.5×10^{-8} m s^{-1}. How will this change the design life of the in-ground barrier wall calculated in (a) above? [30%]

(d) Comment on the differences between the results in parts (a), (b) and (c) above. [20%]

(e) How can such in-ground barrier walls be designed to be more sustainable? [10%]

(f) A small amount of heavily contaminated soil from the site needs to be disposed of in a landfill. What is the procedure for determining which class of landfill the waste will need to go to? [10%]

END OF PAPER

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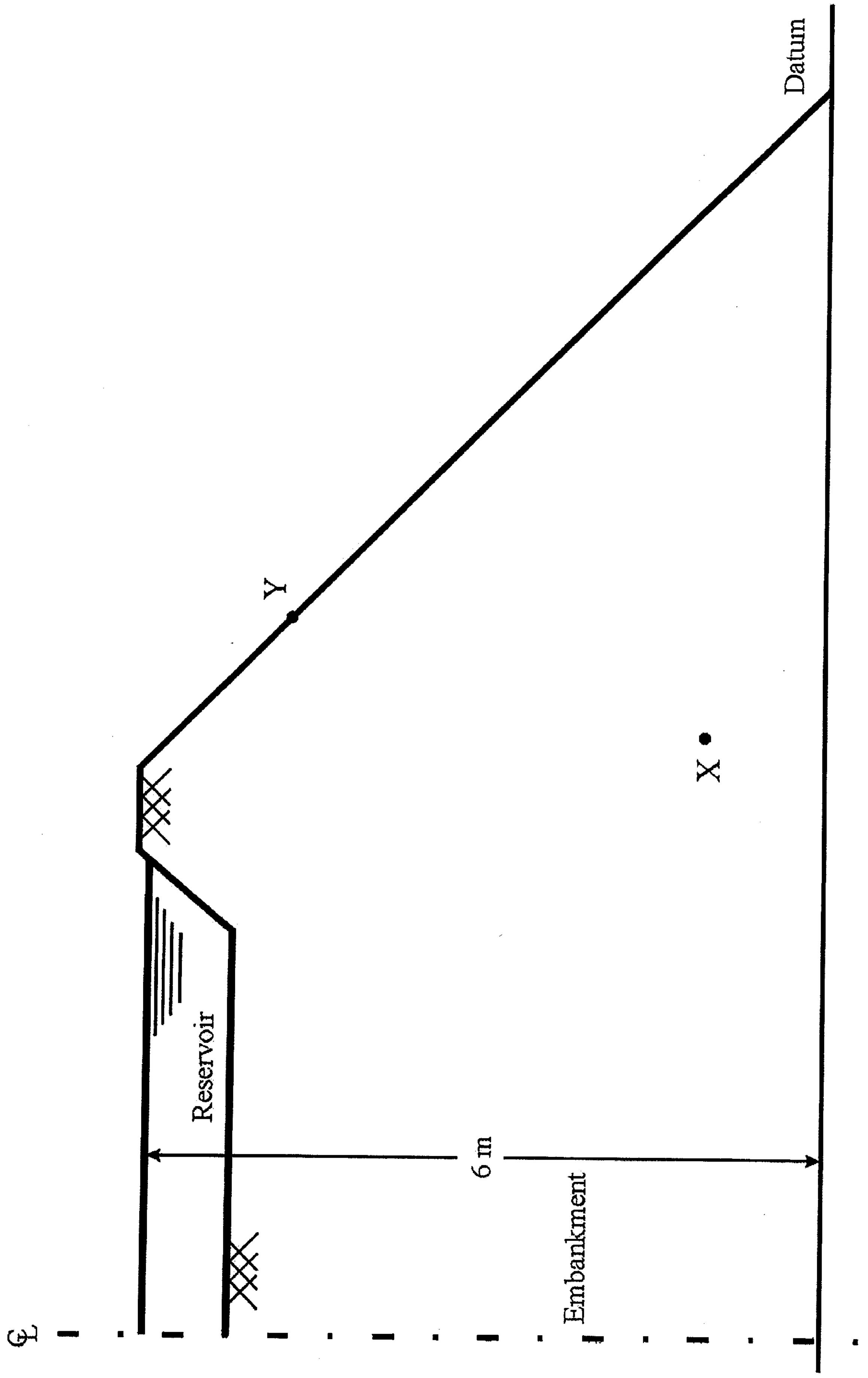
Copy of Fig. 1 for question 2; to be detached and handed in with script.



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Engineering Tripos Part IIA Paper 3D6

ENVIRONMENTAL ENGINEERING II

DATA BOOK

January 2003

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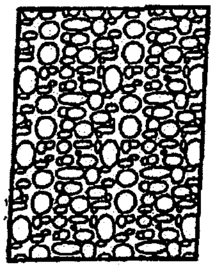
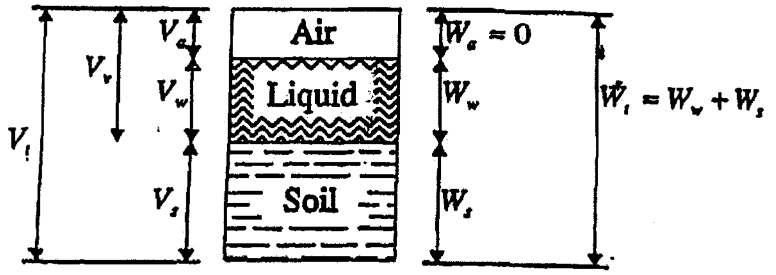
Groundwater

Soil: general definitions



Soil structure

considered as



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	$\gamma_w = 9.81\ \text{kN/m}^3$
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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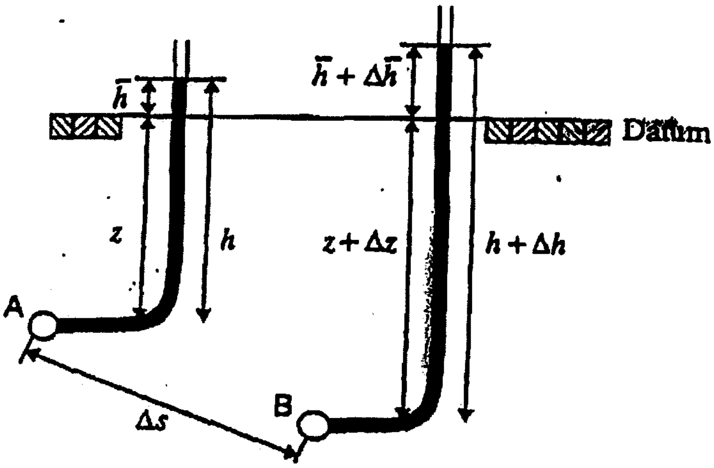
Classification of particle sizes

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}

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

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 $> D_{10} >$ 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:

$$\mathrm{erf}(\beta)=\frac{2}{\sqrt{\pi}}\int_0^\beta \exp\left(-t^2\right)dt$$

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

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

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

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

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MODULE 3D6: ENVIRONMENTAL GEOTECHNICS

Numerical Answers

1. (a) (i) 18.3%, 0.1.
    (ii) 0.582, 0.536
   (b) (i) 3×10^{-5} m/s, 1/375
    (ii) 5×10^{-7} m/s, 166/1

2. (a) 4.73 m^3/year/m
   (c) 32kPa
   (e) ~1.2 years

4. (a) 156 years
   (b) 423 years
   (c) 1.53 years

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20 May 2011