3D6 Environmental Geotechnics   April/May 2010

Q1 a) The soil particles are formed through the following stages from rock:
- Mountain building / Volcanic eruption
- Erosion and weathering
- Transportation by wind and water
- Subsequent sedimentation
- Chemical alteration
- Cementation
- Compression   [10%]

Q1b)i) See flow net on next page.   [20%]

Q1 b) ii) $q = K \, \Delta \bar{h} \times \dfrac{N_f}{N_{\bar{h}}}$

$N_f = 4 \times 2 = 8$

$N_{\bar{h}} = 6$

$\therefore q = 5.75 \times 10^{-6} \times 7 \times \dfrac{8}{6} = 5.367 \times 10^{-5} \; m^3/s/m$

[20%]

Q1 b iii) Consider A, B, C points $\Rightarrow$ Elevation heads

$y_A = 5m$; $y_B = 3m$; $y_c = 1m$.

Potential heads $\left\{ \begin{array}{l} \bar{h}_A = 5.35 \; m \\ \bar{h}_B = 4.75 \; m \\ \bar{h}_c = 5.2 \; m . \end{array} \right.$

Pressure heads $h_A = 0.35 \; m$ $\Rightarrow$ Pore pressures
$h_B = 1.75 \; m$ $p_A = 3.5 \; kPa$
$h_c = 4.2 \; m$ $p_B = 17.5 \; kPa$
$p_c = 42 \; kPa$.

[30%]

Hydrostatic pore pressures will be $p_A = 50 \; kPa$; $p_B = 70 \; kPa$ $p_c = 90 \; kPa$

The pore pressures in the soil at A, B, C drop due to seepage flow.

Q1 c) Capillary Rise
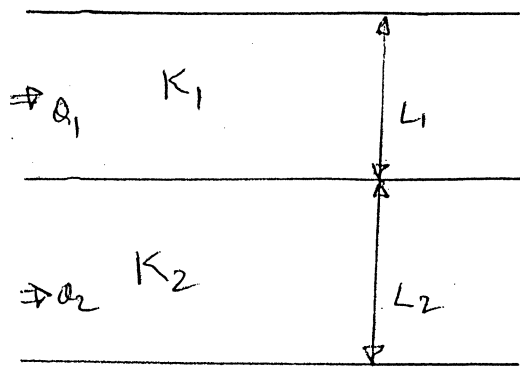$h_c = \dfrac{4 \, T}{\gamma_w \, D_{10}} = \dfrac{4 \times 7.1 \times 10^{-5}}{10 \times 0.065/1000} = 0.437 \; m$.

$\therefore$ A depth of $0.437m$ above water table will be saturated but in suction

This leaves $(2m - 0.437m)$ to be filled by rain water.

$e = 0.65 \Rightarrow n = e/1+e = 0.394. \Rightarrow 0.616 \; m$ of rainfall.

If water table is raised to surface, 'q' will increase by approximately $9/7$ ths.

[20%]

[20/.]

Extra Copy of Fig. 1

.2 a)

$Q = Q_1 + Q_2$

$Q_1 \neq Q_2 \quad \Rightarrow v_1 \neq v_2$

$\Delta \bar{h} = \delta \bar{h}_1 \pm \delta \bar{h}_2$

$\Rightarrow i = i_1 = i_2 \qquad A = L \times$

Layer 1 $\quad Q_1 = v_1 L_1 = K_1 L_1 i$

Layer 2 $\quad Q_2 = v_2 L_2 = K_2 L_2 i$

$\therefore Q_1 + Q_2 = (K_1 L_1 + K_2 L_2) i$

$\therefore$ Specific discharge for whole deposit $\quad v = Q / L_1 + L_2$

$$v = \boxed{\frac{(K_1 L_1 + K_2 L_2) \times i}{L_1 + L_2}}$$

$\therefore K_{horizontal} = \dfrac{K_1 L_1 + K_2 L_2}{L_1 + L_2}$ for the whole deposit   [30

b) $\quad K_1 = 3.6 \times 10^{-5}$ m/s $\quad K_2 = 6.3 \times 10^{-5}$ m/s $\qquad$ For info only

$L_1 = 3.2$ m $\qquad\qquad L_2 = 5.4$ m.

Porosities $n_1 = 0.45 \qquad\qquad n_2 = 0.55$

$\therefore K_{hor} = \dfrac{(3.6 \times 3.2 + 6.3 \times 5.4) \times 10^{-5}}{3.2 + 5.4} = 5.295 \times 10^{-5}$ m/s

Top layer $\quad Q_1 = K_1 L_1 i$

$3.8 \times 10^{-6} = 3.6 \times 10^{-5} \times 3.2 \times \dfrac{\bar{h}}{10} \qquad \Rightarrow \bar{h} = 0.33$ m.

Bottom layer $\therefore Q_2 = K_2 L_2 i = 6.3 \times 10^{-5} \times 5.4 \times \dfrac{0.33}{10}$

$= 1.122 \times 10^{-5}$ m³/s /m   [30%

Q 2 c)

$$C_0 = 15 \text{ mg/L}$$

$$D_d^* = 5.3 \times 10^{-9} \text{ m}^2/\text{s}$$

Top layer :- Flow velocity $v_t = K_1 i = 3.6 \times 10^{-5} \times \frac{0.33}{10}$

$$v_t = 1.188 \times 10^{-6} \text{ m/s}$$

$$\therefore (v_b)_t = \frac{v_t}{n_1} = \frac{1.188 \times 10^{-6}}{0.45} = 2.64 \times 10^{-6} \text{ m/s} \quad \checkmark$$

Bottom layer : $v_B = K_2 i = 6.3 \times 10^{-5} \times \frac{0.33}{10}$

$$v_B = 2.079 \times 10^{-6}$$

$$(v_b)_B = \frac{v_B}{n_2} = \frac{2.079 \times 10^{-6}}{0.55} = 3.78 \times 10^{-6} \text{ m/s} \quad \checkmark$$

Top layer:

$$(D_L)_t = D_d^* + \alpha_L (v_b)_t = 5.3 \times 10^{-9} + 0.25 \times 2.64 \times 10^{-6}$$

$$= 6.653 \times 10^{-7}$$

Bottom layer:

$$(D_L)_B = 5.3 \times 10^{-9} + 0.35 \times 3.78 \times 10^{-6} = 1.3283 \times 10^{-6}$$

$Z = 100 \text{ m}$. $t = 360 \text{ days} = 360 \times 24 \times 3600$

Consider top layer: $\frac{C}{C_0} = \frac{1}{2} \text{erfc} \left[\frac{100 - 2.64 \times 10^{-6} \times 360 \times 24 \times 3600}{\sqrt{4 \times 6.653 \times 10^{-7} \times 360 \times 24 \times 3600}} \right]$

$$= \frac{1}{2} \text{erfc} [1.9659] \quad \checkmark$$

$$\frac{C}{C_0} = \frac{1}{2} \times 0.005553$$

$$\Rightarrow C = \frac{15}{2} \times 0.005553 = 0.04164 \text{ mg/L}$$

Q2c) Consider the bottom layer:

$$\frac{C}{C_0} = \frac{1}{2} \, \text{erfc} \left[\frac{100 - 3.78 \times 10^{-6} \times 360 \times 24 \times 3600}{\sqrt{4 \times 1.3283 \times 10^{-6} \times 360 \times 24 \times 3600}} \right]$$

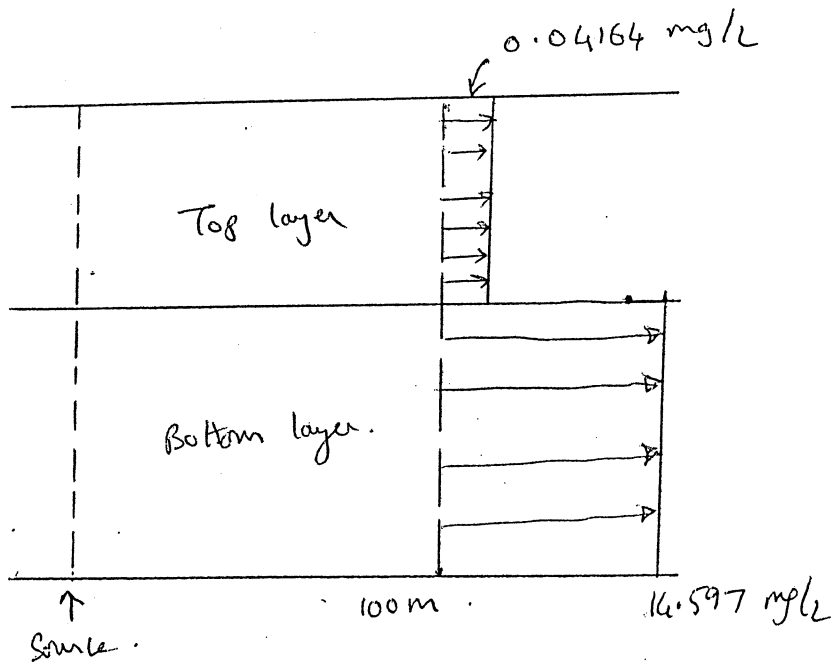$$= \frac{1}{2} \, \text{erfc} \, [-1.367] \quad \checkmark$$

Using Data
Sheet} $\text{erfc} \, [-1.367] = 1 + \text{erf} \, [1.367]$

$$= 1 + 0.9463$$

$$= 1.9463$$

$$\therefore \frac{C}{C_0} = \frac{1}{2} \times 1.9463$$

$$\Rightarrow C = \frac{15}{2} \times 1.9463 = 14.59725 \, mg/L$$

0.04164 mg/L

Top layer

Bottom layer.

(Not to scale)

↑
Source.

100 m

14.597 mg/L

[50%]

-5-

Q3 a) Sorption is a mechanism which removes contaminant from solution. Two types of sorption processes exist:
- Adsorption: solute accumulates on the surface of the grains
- Absorption: solute is sucked into the inside of the grains.

A convenient and common representation of sorption is to say that S, the mass of contaminant adsorbed on the solid phase per unit mass of solids, is proportional to the concentration in solution:

$$S = \frac{mass.of.cont.(M)}{mass.of.solid(M_s)} = K_d.c$$

where K_d is the distribution coefficient. This representation is valid for rapid adsorption or exchange reactions, where the phases are in equilibrium. Information on the rates of reaction between solute and soil grains is required for non-linear, non-equilibrium sorption.
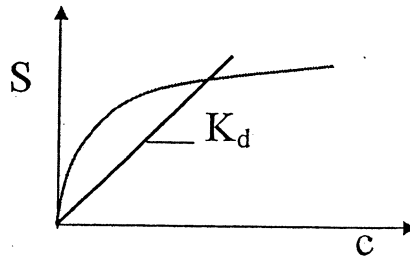
[20%]

3 b) Consider the governing equation:

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

which by substitution is:

$$\frac{\partial(nc)}{\partial t} = \frac{\partial}{\partial x}\left\{n.D_l\frac{\partial c}{\partial x}\right\} - \frac{\partial}{\partial x}\left\{n.v_f.c\right\} \pm \Phi$$

for one-dimensional transport.

For homogenous soils with steady state flow n, D_l and v_f will be constant and the one-dimensional transport equation reduces to the classic form of the advection-dispersion equation:

$$\frac{\partial c}{\partial t} = D_l\frac{\partial^2 c}{\partial x^2} - v_f\frac{\partial c}{\partial x} \pm \frac{\Phi}{n}$$

which for a particular case of linear, equilibrium adsorption becomes:

$$\frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial x^2} - v_f \frac{\partial c}{\partial x} \pm \frac{\rho_b}{n} K_d \frac{\partial c}{\partial t}$$

$$\underbrace{\left[1 + \frac{\rho_b}{n} K_d\right]}_{R_d > 1} \frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial x^2} - v_f \frac{\partial c}{\partial x}$$

where R_d is the retardation factor. Rearranging gives:

$$\frac{\partial c}{\partial t} = \frac{D_l}{R_d} \frac{\partial^2 c}{\partial x^2} - \frac{v_f}{R_d} \frac{\partial c}{\partial x}$$

or alternatively:

$$\frac{\partial c}{\partial \left(\frac{t}{R_d}\right)} = D_l \frac{\partial^2 c}{\partial x^2} - v_f \frac{\partial c}{\partial x}$$

so that the effect of the adsorption is to reduce the apparent dispersion coefficient and the apparent advective velocity of the contaminant.

[30%]

Q3 c) Banned wastes:
- Waste in liquid form. This does not include sludges but includes waste load containing free draining liquid.
- Waste which is explosive, corrosive, oxidising or flammable
- Hospital and other clinical waste which is infectious
- New chemical substances whose effects on man or environment are unknown
- Whole tyres from July 2003 and shredded tyres from July 2006

Landfill site classification
Inert landfills: Can only accept inert wastes that meet relevant acceptance criteria. Inert waste is defined as substances which: will not undergo significant physical, chemical or biological change, will not dissolve, will not burn, will not physical or chemically react, will not biodegrade, will not adversely affect other materials it comes in contact with, has insignificant total leachability or pollutant content, any produced leachate will have insignificant ecotoxicity. Examples of inert wastes are: glass, glass packaging, glass based fibrous materials, bricks, tiles and ceramics, concrete, soils and stones (excluding topsoil and peat)
Hazardous waste landfills: Can only accept hazardous wastes that meet relevant acceptance criteria. Hazardous wastes include substances that are: explosive, Oxidising, Flammable,

Irritant, Harmful (e.g. by inhalation of digestion), Toxic, Carcinogenic, Corrosive, Infectious,Toxic for reproduction, Mutagenic, Ecotoxic, release toxic gases in contact with water, air or acid, yield another substance that possesses any of above characteristics
Non-hazardous waste landfills: May accept any waste which is not hazardous which includes; municipal waste, other non-hazardous wastes (including inert wastes) and in certain circumstances, **stable, non-reactive hazardous wastes** provided they are placed in a separate cell.
Three point test:
must be physical/thermal/chemical or biological process including sorting
must change the characteristics of the waste
must do so to: reduce its quantity, reduce its hazardous nature, facilitate its handling, or enhance its recovery

Q4 (a)
(i) Excavation and disposal to landfill:
The contaminated soil is excavated and taken off site to a suitable landfill providing a permanent solution for the site. It is applicable to many wastes and involves well established techniques. A good definition of contaminant boundary determining the extent of contamination requiring removal is essential. There might be limitations on the depth of excavation, due to nearby buildings and potential problems if groundwater is shallow. Although has been relatively cheap, cost of landfilling is increasing.

(ii) Cover system
Placement of a cover over the contaminated soils, and can range from single layer of top soil (old design system) to multi-layered construction, usually consisting of a combination of natural low permeability material (clay) and geomembranes as well as drainage layer and vegetation. The purpose is to (i) control infiltration into the landfill, (ii) control gas emissions, (iii) resist erosion of the waste, (iv) protect the public from contact with the waste, (v) minimise odours and (vi) give a better appearance e.g. using vegetation. Could be cost effective for large contaminated land areas, but problematic if groundwater is already contaminated.

(iii) In-situ immobilisation
Involves the addition of binders, to physically and chemical immobilise the contaminants within the soil usually resulting in the formation of a solid matrix. In-situ this is usually applied using augers resulting in soil-binder columns or wall sections. Binding materials often contain cement, silicates, lime, thermo-plastics or polymers. The technique has been demonstrated to be successful in immobilising inorganic contaminants such as heavy metals, but is less effective in containing organic pollutants. Problems include interference of some contaminants with the binding and setting processes. Conventional equipment and readily available materials are used. The hazardous properties of the contaminated materials are reduced in the short-term. The handling or engineering properties of the treated materials may improve. It is however sometimes difficult to select a suitable reagent if a complex mixture of chemicals is present and the long-term performance is uncertain.

(iv) Soil washing
Employs either mechanical separation or aqueous leaching to remove contaminants from contaminated soils. Involves the use of high speed jets, attrition and various agitation and washing systems. Exploits physical soil and contaminant properties e.g. particle or contaminant density, surface chemistry,

magnetism, contaminant volatility, solubility, etc. Contaminants are removed from the soil, uses familiar technologies, flexible and relatively inexpensive. Treatment of extracted water and process water required, and is more effective in granular soils.

(v) Ex-situ Bioremediation

Use of living micro-organisms to destroy, remove or transform the hazardous contaminant. Involves one or more of the following mechanisms: Biodegradation: Decomposition of compound into smaller chemical subunits – might not result in complete mineralisation, Biotransformation: Conversion of contaminant to less toxic and/or less mobile form, Bioaccumulation: Accumulation of contaminants within tissues of biological organisms, in harvestable biomass (phytoremediation) and Mobilisation/Immobilisation: Mobilisation of contaminants into solution then separated from soil, e.g. produced acids can mobilise heavy metals, or immobilisation by sorption on plant roots.

Aerobic degradation requires oxygen e.g. $C_6H_{14} + 9.5\ O_2 \rightarrow 6\ CO_2 + 7\ H_2O$ while anaerobic degradation includes a range of reduction processes e.g. nitrate to nitrogen, iron III to iron II, sulphate to hydrogen sulphide and CO_2 to methane

Bioremediation is implemented using either Biostimulation: involveing addition of nutrients, oxygen and/or moisture to stimulate micro-organisms in soils or Bioaugmentation involving addition of specially prepared 'cultures' of micro-organisms.

Ex-situ application includes: treatment beds, windrows, biopiles and bioreactors.

b. Sustainability advantages (middle column) and disadvantages (column to right):

Soil washing	• Reduced transportation • Reduced waste • Short duration	• High energy use • Impact on landfill site • Fill use • High intensity operation • High noise
Ex-situ bioremediation	• Destruction of contaminants • Low transportation • Low disturbance	• Impact on landfill site • High intensity operation • High noise • Fill use
Cover system	• Low waste • Low emissions • Rapidity • Reduced transportation • Low energy use	• Some contaminants remain • Impact on landfill site • High noise

In-situ Stabilisation/ Solidification	• Low intensity operations • Low waste generation • Low disturbance • Low transportation • Low noise • Low natural resources use • Low exposure to contaminants	• High CO_2 emissions & energy use due to cement production • Contaminants remain • Changes in soil properties • high energy use • Long term impacts • Future remediation may be difficult
Excavation and disposal to landfill	• Complete removal of contaminants • Advanced design and monitoring systems • Possible remediation in landfill	• High transportation • High waste production • High material use • Impact on landfill site • High energy use • High disturbance • Long term impacts