PART IIA 2005

3D6 — 3D6: Environment engineering II

Principal Assessor: Dr S P G Madabhushi

Datasheet: Environmental Engineering II Data Book

1. a) Pressure head is defined as the height to which water would rise in a standpipe inserted at a given location in soil.

Pore water pressure is the hydrostatic water pressure at a given location.

Pore water pressure p is related to pressure head h as

$$h = \frac{p}{\gamma_w}$$ where γ_w is the unit weight of pore water.

Datum is an arbitrary elevation in the soil stratum above which all the pressure heads are measured. The vertical distance of a given location above datum is the elevation y. Potential head $\bar{h}$ is defined as

$$\bar{h} = h + y$$

for that location.

Potential head difference between two locations governs the flow of pore water through the porous medium.

[20%]

b) The procedure one needs to adopt to construct a flow net is as follows:

1. Fix the datum above which the potential heads are described.
2. Draw the problem geometry and allocate hydraulic conductivity k for each stratum.
3. Locate the impermeable boundaries (ie k differs by orders of magnitude)
4. Locate boundaries where potential head $\bar{h}$ is constant. Establish maximum and minimum potential heads and divide there difference to give a convenient Δh.
5. Draw initial flowlines ie along impermeable boundaries
6. Label atmospheric boundary (or phreatic surface)
7. Draw flow net of lines. First draw the flow lines and then the equipotentials separated by Δh. Remember that flowlines and equipotentials must intersect at right angles and they form curvilinear squares.

8. Note where changes are needed and adjust.

9. Label the equipotential lines

10. Interpolate between the equipotentials to find $\bar{h}$ at any required locations. Convert these to pore water pressure p using

$$p = (\bar{h} - y)\gamma_w$$

11. Calculate flow quantities using

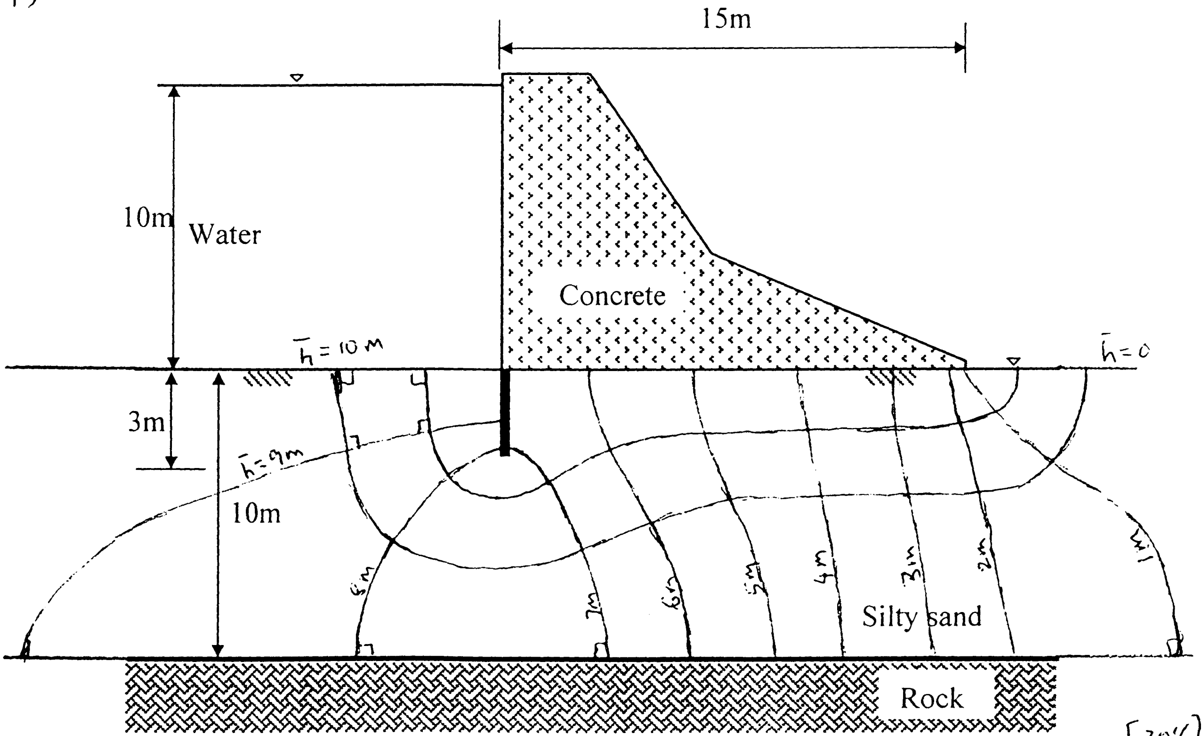
$$q = K \Delta \bar{h} \frac{N_f}{N_h}$$

where $N_f \rightarrow$ Number of flow lines
$N_{\bar{h}} \rightarrow$ Number of equipotentials

[20%]

1c) Follow the above procedure to construct a flownet

i)



[30%]

$N_f = 3 \quad N_{\bar{h}} = 10 \quad . \quad \Delta \bar{h} = 10m.$

ii)

$$q = K \times \Delta h \times \frac{N_f}{N_{\bar{h}}} = 3.5 \times 10^{-6} \times 10 \times \frac{3}{10}$$

$= 10.5 \times 10^{-6}\ m^3/s$ /1m width of dam

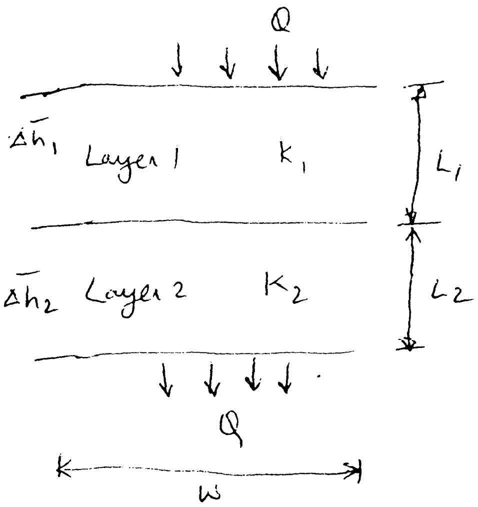
or 331.13 m^3/year/1m width of dam. [10%]

1C iii) By increasing the length of the sheet pile wall, the leakage rate through the soil below the dam will decrease. There is less space for the water to go through, if the sheet pile wall is longer.

By moving the sheet pile wall towards the toe of the dam the leakage rate does not change much. However, more of the dam is now subjected to uplift pressures increasing the total uplift force on the dam. Therefore it is better to have the sheet pile wall as far upstream as possible. So leave it where it is.

[20%]

2a) Consider two soil strata as follows, with a width of w and 1m into the page



Let k_{ze} be the equivalent vertical hydraulic conductivity

Let Q be the flow rate entering and leaving the strata.

As all of this has to go through both layers (continuity of mass flow rate)

$$Q = Q_1 = Q_2$$

Let Δh_1 & Δh_2 be the potential head drops in each of the layer.

Let Δh be overall drop in the potential head.

$$\Delta h = \Delta h_1 + \Delta h_2 \quad \rightarrow (1)$$

Consider layer 1: Applying Darcy's law.

$$Q_1 = K_1(\Delta h_1 / L_1) \times w \times 1$$

$$\therefore \Delta h_1 = \frac{Q_1 L_1}{K_1 \cdot w} \quad \rightarrow (2)$$

Consider layer 2: Applying Darcy's law

$$Q_2 = K_2(\Delta h_2 / L_2) \times w \times 1.$$

$$\therefore \Delta h_2 = \frac{Q_2 L_2}{K_2 \quad w} \quad \rightarrow (3)$$

For overall flow through the strata

$$Q = K_{v}\left(\frac{\bar{\Delta h}}{L_1+L_2}\right) \cdot W \times 1$$

$$\therefore \bar{\Delta h} = \frac{Q(L_1+L_2)}{K_v \ W \times 1} \rightarrow (4)$$

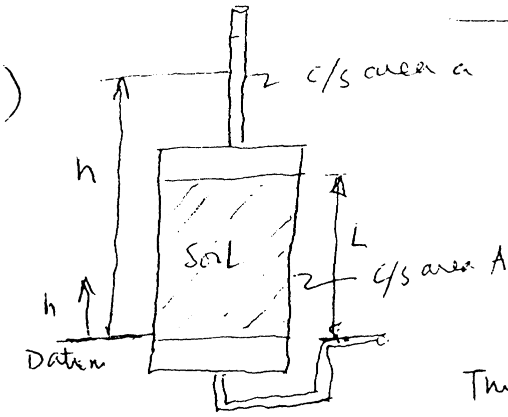
Substituting (2), (3) & (4) into (1) and cancelling W, Q, Q_1, Q_2, we get

$$\frac{L_1+L_2}{K_v} = \frac{L_1}{K_1} + \frac{L_2}{K_2}$$

$$\Rightarrow K_v = \frac{L_1+L_2}{\frac{L_1}{K_1}+\frac{L_2}{K_2}} \quad \text{(QED)}$$

[20%]

2 b)



Let the head of water in standpipe be h at some time 't'.
Consider a drop of 'dh' in head in time dt
Volume of fluid drop in stand pipe = dh . a.
This volume should pass through the soil sample in time dt.
Volume of fluid going through soil sample = q.dt = K i A. dt

$$i = h/L$$

$$\therefore q.dt = K.\frac{h}{L} A \ dt$$

$$dh \, a = K\frac{h}{L}A \cdot dt$$

$$\frac{dh}{h} = \frac{KA}{aL} \cdot dt$$

Integrating between the limits $h = h_0$ at $t = 0$ and $h = h_1$ at $t = t_1$

$$\int_{h_1}^{h_0}\frac{dh}{h} = \frac{KA}{aL}\int_{t_1}^{0} dt$$

$$\ln\frac{h_0}{h_1} = \frac{KA}{aL} t_1$$

$$\boxed{K = \frac{aL}{At} \ln\frac{h_0}{h_1}}$$

[20%]

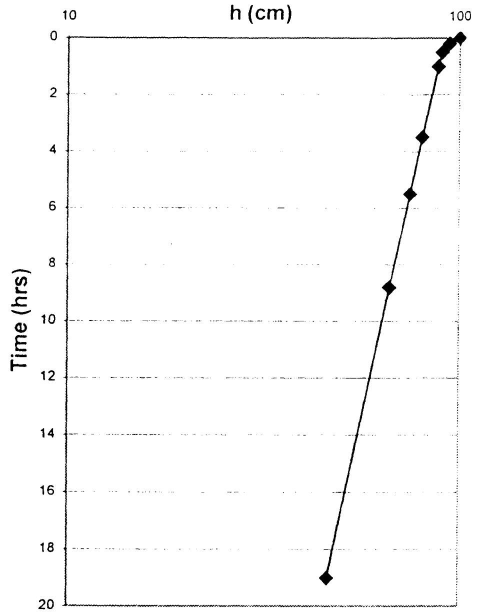
2 c) Use the result from part b)

c/s area of Sample $A = 1025\ mm^2$

c/s area of stand pipe $a = 12\ mm^2$

Length of Sample $L = 0.1\ m$.

The initial values of a falling head permeameter may be erroneous. Therefore plot a graph between Ln h & time and use the slope of the line.



Slope of the line $\frac{Ln\ h}{t} =$

$$\frac{\ln(88/46)}{18} = 0.03604$$

$$K = \frac{aL}{At} \ln\left(\frac{h_0}{h_1}\right)$$

$$= \frac{12}{1025} \times 0.1 \times \frac{0.03604}{60 \times 60}$$

$$K = 1.172 \times 10^{-8}\ m/s$$

[30%]

2 d) Hydraulic conductivity of clayey silt above $K_1 = 1.172 \times 10^{-8}$.

length of this sample now $= L_1 = 0.05\ m$.

Let hydraulic conductivity of clay be K_2

Length of this sample $= L_2 = 0.05\ m$

Overall hydraulic conductivity of the layered sample $K_v = 4.3 \times 10^{-9}\ m/s$.

$$K_v = \frac{L_1 + L_2}{\frac{L_1}{K_1} + \frac{L_2}{K_2}}$$

$$4.3 \times 10^{-9} = \frac{0.1}{\frac{0.05}{1.172 \times 10^{-8}} + \frac{0.05}{K_2}}$$

$$K_2 = 2.633 \times 10^{-9}\ m/s$$

Hydraulic conductivity of the clay sample $= 2.633 \times 10^{-9}\ m/s$

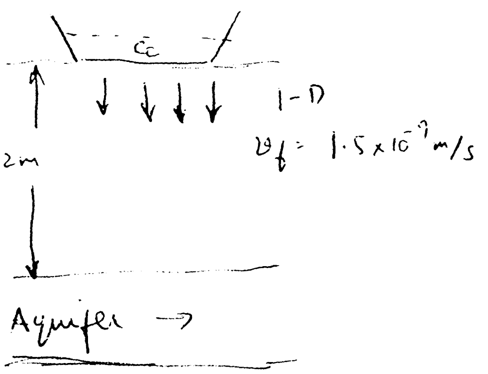
[30%]

3a) Molecular diffusion is due to differences in concentration of the contaminant and follows the Fick's laws. In porous media diffusion occurs along concentration gradients but the co-efficient of diffusion ~~cab~~ is modified to take into account the tortuosity of the paths the contaminant has to take through the porous media.

Mechanical dispersion is mixing that occurs in a porous media as a consequence of local variations in velocity around some mean flow velocity. The contaminant gets mixed and transported due to these changes in flow velocities.

[20%]

3 b)
(i)



$$\frac{c}{c_0} = \frac{1}{2}\,\text{erfc}\left[\frac{z - v_f t}{\sqrt{4 D_L t}}\right]$$

$D_d^* = 1.3\times10^{-9}\ m^2/s$; $v_f = 1.5\times10^{-9}\ m/s$

$\alpha_1 = 0.3$

$$D_L = D_d^* + \alpha_1 \cdot v_f.$$

$$\therefore\ D_L = 1.3\times10^{-9} + 0.3\times1.5\times10^{-9}$$

$$= 1.75\times10^{-9}\ m^2/s.$$

$$\frac{c}{c_0} = \frac{1}{2}\,\text{erfc}\left[\frac{z - 1.5\times10^{-9}\times t}{\sqrt{4\times1.75\times10^{-9}\times t}}\right]$$

For the first sign of the contaminant to appear in the aquifer.

$z = 12m$. When the contaminant just appears, in the aquifer we can take $c/c_0 = 0.0001$ (small value).

$$\frac{c}{c_0} = 0.0001 = \frac{1}{2}\,\text{erfc}(\beta)$$

From tables

erfc (β)		β
0.0007	→	2.4
0.0002	→	?
0.0000	→	3

MANY CANDIDATES TRIED TO INTERPOLATE & MADE NUMERICAL ERRORS

From tables: for 0.0002 we get

$\beta = 2.60$

$$2.6 = \beta = \frac{12 - 1.5\times10^{-9}\times t}{\sqrt{4\times1.75\times10^{-9}\times t}}$$

$$\Rightarrow -2.175\times10^{-4}\sqrt{t} + 1.5\times10^{-9}t - 12 = 0$$

Solve this quadratic in $\sqrt{t}$;

$$\sqrt{t} = \frac{-2.175\times10^{-4} \pm \sqrt{(-2.175\times10^{-4})^2 + 4\times12\times1.5\times10^{-9}}}{2\times1.5\times10^{-9}}$$

$t = 1817477192$ sec or 57.63 years [20%]

3b(ii) H&S requirements are to keep $C \leq 3.2$ mg/L

Initial concentration of contaminant $C_o = 6.2$

$$\therefore C/C_o = \frac{3.2}{6.2} = 0.5161$$

$$C/C_o = \frac{1}{2}\,\mathrm{erfc}\left[\frac{3 - v_L\times t}{\sqrt{4D_L\times t}}\right]$$

$$0.5161 = \frac{1}{2}\,\mathrm{erfc}\left[\frac{3 - 1.5\times10^{-9}\times1817477192}{\sqrt{4\times1.75\times10^{-9}\times1817477192}}\right]$$

$$0.5161 = \frac{1}{2}\,\mathrm{erfc}\left[\frac{3 - 2.7262}{12.7223}\right]$$

$$1.0322 = \mathrm{erfc}\left[\frac{3 - 2.7262}{12.7223}\right]$$

From error function tables, interpolate

$\mathrm{erfc}(\beta)$	β
1.1125	→ −0.1
1.0322	→ ?
1	→ 0.0

For $\mathrm{erfc}(\beta) = 1.0322$ $\beta \to -0.02862$

$$\frac{3 - 2.4452}{12.7223} = -0.02862 \quad \Rightarrow 3 = 2.0811 \text{ m}$$

$$3 \simeq 2.1 \text{ m}$$

∴ Excavate to a depth of 2.1 m below landfill. [20%]

3 (c) Many types of geosynthetics are used in the construction of a modern landfill.

Type	function
Geotextile	→ to provide support to landfill liners. These are structural members. Also they can allow through drainage
Geomembranes	→ Geomembranes are used as barrier layers. They prevent leachate from escaping from the landfill. They are not structural members and should be protected from structural loads and abrasive, sharp objects.
Geogrids	→ These are structural members often used to provide support to other layers at specific locations
Geopipes	→ Used in leachate collection systems to collect and remove leachate from the base of the landfill

[20%]

3 d) In-ground barriers are used to control/alter ground water flow regimes with the view to prevent contaminant migration. These can take the form of clay liners in combination with geomembranes in the case of landfills or vertical barriers such as slurry walls.

Advantages: 1. It is possible to use in-ground barriers to prevent contamination migration either from a specific site or from reaching a specific site

2. Local hydrogeology can be taken advantage of in designing the barriers.

Disadv. 1. The contaminant is not actually removed from ground. Therefore there is no reduction in the quantity of contaminant present in ground.

2. Barriers may have some finite life.

3. Barriers may have local construction faults and therefore may lose their functionality

[20%]

4 (a) Issues likely to impact on the sustainability of stabilisation/solidification (S/S):
Negative issues:
(i) Long-term performance and effectiveness.
(ii) Quantity of CO_2 generated due to use of cement-based binders.
(iii) Contaminants are not removed, problem transferred to future generation.
(iv) Currently difficult to remediate the soil after S/S treatment.
Positive issues:
(i) Minimal generation of waste
(ii) Low use of natural resources
(iii) Puts an immediate stop to spreading of contamination, protecting the environment.
(iv) Limited transport and related impact. [20]

(b) There are decision support tools including cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis. They consider many of the aspects of sustainable remediation including social, economic and environmental and score the various components. Categories include: benefits vs costs of remediation, environmental impact, protection of the environment, natural resources, intergenerational risk, involvement of all stakeholders etc. Difficult to put a value, monetary or otherwise, on some factors - usually due to lack of information. Hence difficult to do a comprehensive assessment of the sustainability of remediation techniques. Expand further on the various points above. [20]

(c) Case for landfilling includes:
(i) Complete removal of contamination from the site, no future liability or risk of recontamination.
(ii) Landfills are now very advanced in their design that containment system is assumed to stop spreading of contamination, leakage detection systems give warning to any breach of the containment system.
(iii) All other remediation techniques are only partially effective, hence residual contamination will remain.
Case against landfilling include:
(i) Landfilling simply transfers the problem to another site and to future generation.
(ii) Containment systems are not effective for ever (intergenerational risk)
(iii) Transfer of waste to landfill results in large use of energy and cause significant emissions.
(iv) Exposure of contamination likely to cause numerous pollution. [20]

(d) Implications of climate change:
(i) hotter drier summers will lead to drying out and cracking of the soil surface causing upwards capillary suction of water from depth and an increased risk of exposure of contaminated material at the ground surface.
(ii) Hotter ground temperatures may also increase the mobility of certain contaminants in the ground.
(iii) Higher intensity rainfall will challenge soil infiltration capacity and increase the risk of soil erosion and particulate spread of contamination.
(iv) Seasonal rise in groundwater level may bring clean groundwater into more contact with ground contamination.
(v) The expected more cyclic weather around freezing point, could impact on the durability of the stabilised./solidified system at shallow depths
(vi) The chemical and biological properties within the soil will be affected, the net result will depend on the severity of the different climate conditions.
(vii) Hydration and strength development of cementitious binders takes a lone time in the presence of contaminants. Changes in climate conditions will affect this: Heat will accelerate it, both dry and wet weather will hinder it. [20]

(e) Implication of the implementation of the EU Landfill directive on the remediation of the site.
This will relate to the need to landfill a contaminated soil. Hence in order to landfill any contaminated soil from the remediation process:
(i) it must be treated
(ii) the resultant product must not be a prohibited waste
(iii) the product must be characterised and assessed as to whether it is hazardous or non-hazardous
(iv) the product must comply with the acceptance criteria fro the post appropriate class of landfill.
The main implications of these requirements will be cost and availability of landfill. The dependency on landfill should be reduced in favour of the use of treatment technologies. [20]