3D8 - Cribs

Q1 a)

Air entry value = -180 kPa.

Datum $\overline{h=0\,m}$

$h=0\,m$
$2.75\,m$
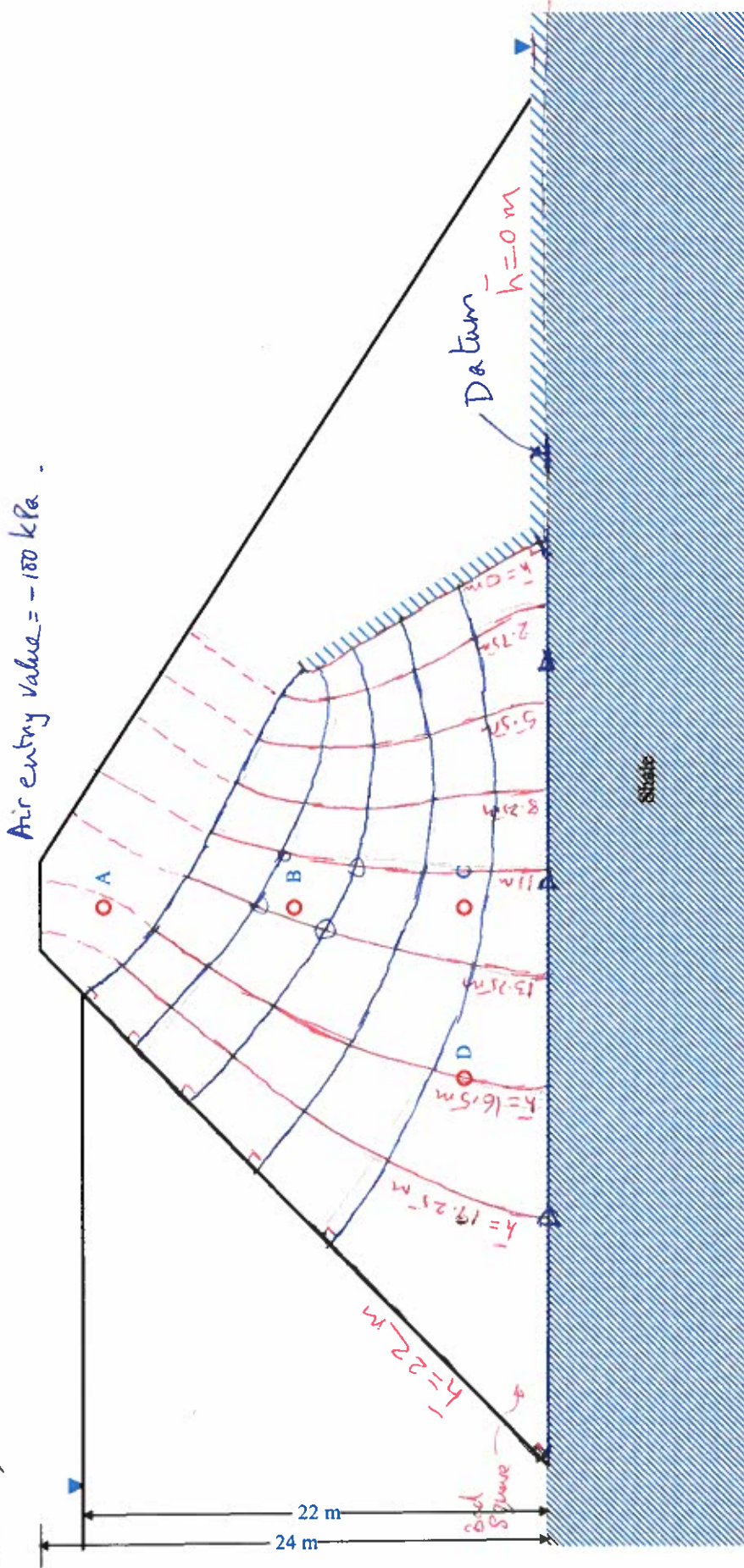$5.5\,m$
$8.25\,m$
$11\,m$
$13.75\,m$
$h=16.5\,m$
$h=19.25\,m$
$h=22\,m$

A
B
C
D

22 m
24 m

$N_f = 5$
$N_h = 8$

limitations: Some bad squares.
Non orthogonal points between flow lines & equipotentials.

[20%]

-1-

Q 1b)

$$Q = K \, \Delta \bar{h} \, \frac{N_f}{N_{\bar{h}}}$$

From 1a) $N_f = 5$ $N_{\bar{h}} = 8$

$K = 4.6 \times 10^{-7}$ m/s.

$\Delta \bar{h} = 22$ m

$\therefore Q = 6.325 \times 10^{-6}$ m³/s/m Seepage through the earth dam

$= 546.48$ litres/day/m

For 200m long dam $Q = 109296$ litres/day.

All this water will flow out from the drain, as the drain is infinitely more permeable than the dam body

so $Q_{drain} = \underline{\underline{109296 \text{ litres/day}}}$ $\boxed{[15\%]}$

c) Take datum at the base of the dam (see 1a))
From figure elevation heads are

$y_A = 21.1$ m

$y_B = 11.92$ m

$y_C = y_D = 3.97$ m

Potential heads from flow net

$\bar{h}_A \approx 16$ m $\Rightarrow$ $h_A = \bar{h}_A - y_A = 16 - 21.2 = -5.2$ m

$\bar{h}_B \approx 14.25$ m $h_B = \bar{h}_B - y_B = 14.25 - 11.92 = 2.33$ m

$\bar{h}_C \approx 12.25$ m $h_C = \bar{h}_C - y_C = 12.25 - 3.97 = 8.28$ m

$\bar{h}_D \approx 16.5$ m $h_D = \bar{h}_D - h_D = 16.5 - 3.97 = 12.53$ m.

$\therefore$ Pore Pressures at A, B, C, D are

$P_A = h_A \times \gamma_w = -52$ kPa

$P_B = 23.3$ kPa

$P_C = 82.8$ kPa

$P_D = 125.3$ kPa.

∴ Effective stresses are;

$$\gamma_{sat} = 19.1 \text{ kN/m}^3.$$

$$\sigma_A' = \gamma_{sat}[24 - 21.1] - (-52) = 107.39 \text{ kPa}$$

$$\sigma_B' = 19.1(24 - 11.92) - 23.3 = 207.43 \text{ kPa}$$

$$\sigma_C' = 19.1(24 - 3.97) - 82.8 = 299.77 \text{ kPa}$$

[25%]

1 d) Darcy's Law $\quad \vartheta = K i = K \frac{d\bar{h}}{ds}$

$$d\bar{h} = \bar{h}_D - \bar{h}_C = 16.5 - 12.25 = 4.25 \text{ m}$$

$$d_S = 6.72 \text{ m} \Rightarrow i = \frac{dh}{ds} = \frac{4.25}{6.72} = 0.632.$$
(from figure)

$$\therefore \quad \vartheta = 4.6 \times 10^{-7} \times 0.632 = \underline{2.91 \times 10^{-7} \text{ m/s}}.$$

(Quite small, so Darcy's law is applicable)

$$\left[\text{Not required } \vartheta_f = \frac{\vartheta}{n} = 7.76 \times 10^{-7} \text{ m/s}\right]$$
$$n = \frac{e}{(1+e)} = 0.375$$

[15%]

e) If there is a sudden draw down of upstream reservoir, then the body of the earth dam will stay saturated initially. Therefore the pore water pressures in the earth dam will go into suction pressures. There will not be any flow, therefore the flownet will disappear.

At points C & D; $p_C = p_D = -3.97 \times 10 \simeq -39.7 \text{ kPa}$ (@ suction).

At B: $p_B = -11.92 \times 10 \simeq -119.2 \text{ kPa}$ (suction)

At A; $p_A = -21.1 \times 10 \simeq -211 \text{ kPa}$ (suction)

As the air entry value of silty clay is -100 kPa, the dam will start to desaturate upto a level slightly below point B. The main danger to the earth dam due to sudden drawdown is the upstream slope failures can occur, as there is not hydrostatic pressure acting on it.

[25%]

u/s slope failure — de-saturated
· A
· B — saturated
· D · C

−3−
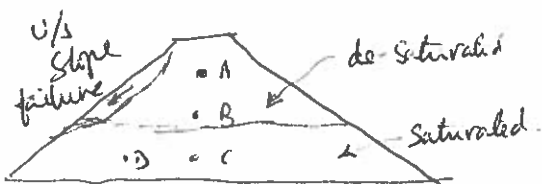
2 a) Darcy's law states that the flow velocity through granular media is proportional to the hydraulic gradient

$$\vartheta \propto i \quad \text{or} \quad \vartheta \propto \frac{d\bar{h}}{ds}$$

$$\vartheta = Ki$$

where 'K' is the hydraulic conductivity of the granular medium.

Fourier's law states that the heat flow in a body is proportional to the temperature gradient

$$H \propto \frac{dT}{dx}$$

$$H = A\lambda \frac{dT}{dx} \quad \text{where } \lambda \text{ is the thermal conductivity & A is the}$$
cross-sectional area the heat is flowing through.

The main difference between water flow and heat flow through a granular medium is the speed of flow. Water flow can be quite quick whereas heat flow occurs quite slowly.   [15%]

b)
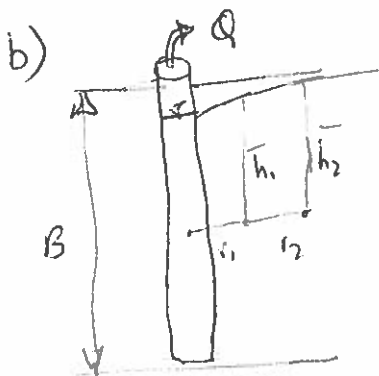
$$Q = Av = AKi$$

$$= 2\pi r B K \frac{d\bar{h}}{dr}.$$

$$\Rightarrow \frac{dr}{r} = \frac{2\pi BK}{Q} d\bar{h}$$

Integrating both sides
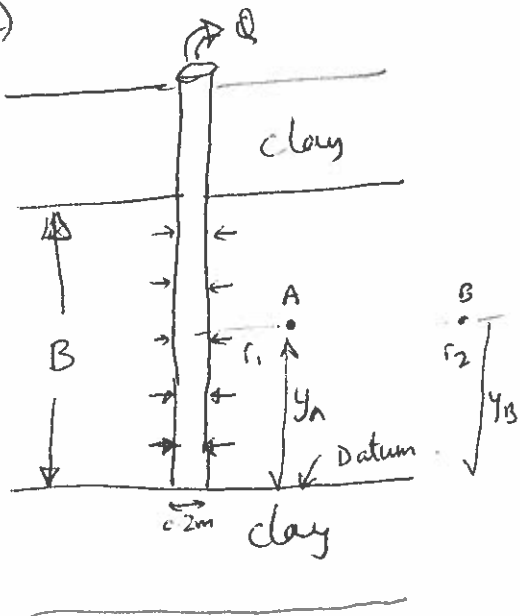
$$\int_{r_1}^{r_2} \frac{dr}{r} = \frac{2\pi BK}{Q} \int_{\bar{h}_1}^{\bar{h}_2} d\bar{h}$$

$$\ln \frac{r_2}{r_1} = \frac{2\pi BK}{Q} (\bar{h}_2 - \bar{h}_1)$$

$$\therefore K = \frac{Q}{2\pi B} \frac{1}{(\bar{h}_2 - \bar{h}_1)} \ln\left(\frac{r_2}{r_1}\right)$$

$$\text{or} \quad Q = \frac{2\pi BK}{\cancel{(\cdots)}} \ln\left(\frac{r_1}{r_2}\right)(\bar{h}_2 - \bar{h}_1) \qquad [20\%]$$

－4－

2 c)

$Q = 400 \text{ L/m} = 0.4 \text{ m}^3/\text{min}$
$\qquad = 6.67 \times 10^{-3} \text{ m}^3/\text{s}$

$r_1 = 1.1 \text{ m} \qquad B = 5 \text{ m}$
$r_2 = 5.1 \text{ m}$

At A $\quad \Delta P_A = 30 \text{ kPa} \qquad \gamma_w = 9.81 \approx 10 \text{ kN/m}^3$

$\therefore \Delta h_A = 3.058 \text{ m}$
$\qquad \Delta h_B = 1.019 \text{ m}$
$\qquad d\bar{h} = 2.038 \text{ m}$

$$K = \frac{Q}{2\pi B} \frac{1}{d\bar{h}} \ln\left(\frac{r_2}{r_1}\right) = \frac{6.67 \times 10^{-3}}{2 \times \pi \times 5 \times 2.038} \ln\left[\frac{5.1}{1.1}\right]$$

$$= 1.5966 \times 10^{-4} \text{ m/s}$$

$$K \simeq 1.6 \times 10^{-4} \text{ m/s}$$

Using Hazen's formula $\quad K = \frac{D_{10}^2}{100} \Rightarrow D_{10} = 0.126 \text{ mm}$
This corresponds to a fine sand $\hfill [25\%]$

2 d) Q is doubled.
$\qquad Q = 800 \text{ L/m}$
$\qquad = 0.013 \text{ m}^3/\text{s}$

$$d\bar{h} = \frac{0.013}{2\pi \times 5 \times 1.6 \times 10^{-4}} \ln\left(\frac{5.1}{1.1}\right) = 4.0658 \text{ m} = dh$$
$\qquad\qquad$ (as elevation heads are) same

$\Delta P = 39.91 \text{ kPa}$. Total pressure drop.
$\qquad \simeq 40 \text{ kPa}$.
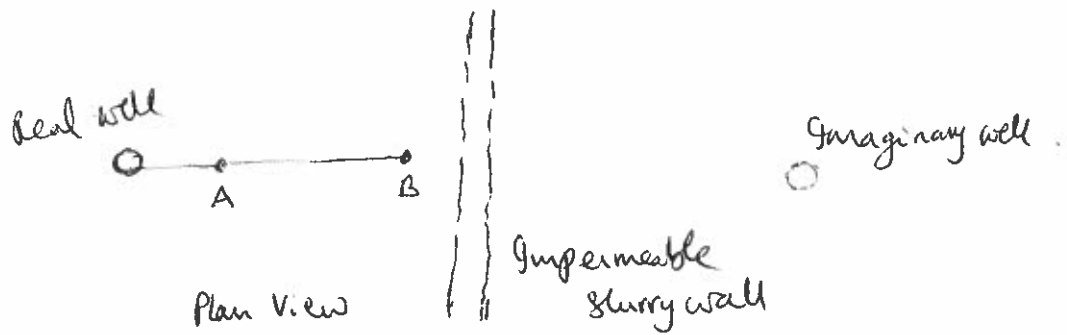This pressure drop will occur largely at A than at B.
$\Delta P \propto \frac{1}{\ln r} \qquad \Delta P_A \simeq \frac{\ln\left(\frac{r_2}{r_1}\right)}{\ln r_1} \times \Delta P =$
Assume it will be in proportion to original pressure drops
$\qquad \Delta P_a = \frac{30}{40} \times 40 = 30 \text{ kPa} ; \quad \Delta P_B = 10 \text{ kPa}$
$\therefore$ Total pressure drop = $P_A = 60 \text{ kPa}$ & $P_B = 20 \text{ kPa}$ at this increased pumping rate. $\hfill [20\%]$

-5-

2 e) If the slurry wall is constructed at 6m;

Real well
O
A   B

Plan View   Impermeable
                 slurry wall

Imaginary well
O

Use image theory, there will be an imaginary well extracting fluid
at the same rate Q as the real well on the other side.

∴ The pressure drops at all points will happen due to both the
wells extracting fluid.

The pressure head drop (at A) = 2 × 30 kPa = 60 kPa
                       (at B) = 2 × 10 kPa = 20 kPa
                       "

Note these pressure head drops are similar to doubling the
pumping rate in part d).

[20%]

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3. (a) Absorption is the process in which one substance permeates into another. Adsorption is the process in which a substance accumulates on the surface of another forming a thin film. In many cases, both adsorption and absorption can be very difficult to distinguish as separate processes. In general, the more hydrophobic an organic compound is, the more likely it will adsorb onto the soil. [10%]

(b) There are a range of sorption mechanisms:
(i) adsorption of an ion via formation of outer-sphere complex;
(ii) loss of hydration water & formation of inner-sphere complex;
(iii) lattice diffusion & isomorphic substitution within mineral lattice;
(iv) rapid lateral diffusion and formation either of a surface polymer, or
(v) adsorption on an edge (which maximises the number of bonds to the atom);
(vi) upon particle growth, surface polymers end up embedded in the lattice structure;
(vii) adsorbed ion can diffuse back in solution, either as a result of dynamic equilibrium or as a product of surface redox reactions. [20%]

(c)

Sample	Initial C (mg/l)	Final C (mg/l)	Change in C (mg/l)	Sorbed (mg)	q (mg/g)
1	20	0.15	19.85	9.925	0.0397
2	50	0.40	49.60	24.8	0.0992
3	100	0.78	99.22	49.61	0.1984
4	200	1.58	198.42	99.21	0.3968
5	500	3.96	496.04	248.02	0.9921
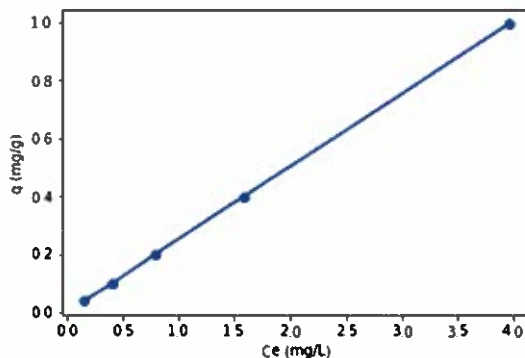
K_d is the gradient of the linear portion of the curve and is therefore approximately 0.25 L/g. [40%]

(d) The CEC is the ability of a clay to adsorb exchangeable ions on its surface and is a function of the mineral structure and the size of the particles. It is calculated as the weight of a cation held on the surface of 100g dry weight of the mineral, usually conveniently defined in milliequivalent (meq) per 100g dry soil.
Kaolin has very little isomorphous substitution in its crystal lattice, limiting the magnitude of its effective surface charge. In addition, it 1:1 mineral structure and the strength of the hydrogen bond between the layers prevents hydration between the layers and allows the build up of many layers, hence has the largest size. As a result of those structural properties, kaolin has the lowest CEC of 5-15 meq/100g.
Montmorillonite has a 2:1 mineral structure and as a result has a weak bond between the layers. In addition there is also isomorphous substitution with 1/6th of the Al ions in the octahedral sheets replaced with Mg ions. This results in a charge efficiency. Water molecules also enter between the montmorillonite sheets hence exhibiting strong swelling characteristics. The weak bonds lead to small particle size and the net change leads to a high CEC of 100-500 meq/100g clay.
Illite is in between the two other clays. It has a 2:1 mineral structure where K has the right size to fit into the holes in the silica sheets. The lattice is hence less susceptible to breakage compared to Montmorillonite. Hence it size is intermediate and so is its CEC of around 20-23 meq/100g. [30%]

4. (a) The dominance of the respective dispersion mechanisms can be demonstrated by plotting the longitudinal hydrodynamic dispersion coefficient divided by the coefficient of aqueous diffusion against the Peclet Number for diffusion Pe. Pe = vf d/Dd, where d is either the average particle size or the average size of the heterogeneities. Pe is a dimensionless parameter which indicates the relative magnitude of advective processes over diffusive processes. [25%]
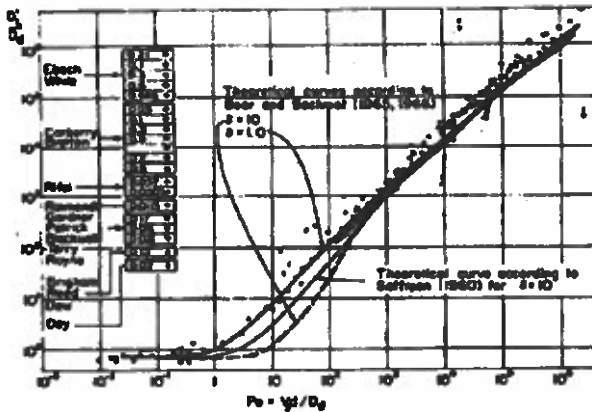
On log-log axes this plot indicates that:

Pe < 1 Dl is independent of vf and diffusion is the dominant dispersive mechanism, so Dl ~ Dd*

Pe > 10 slope is approximately equal to one, diffusion is negligible in comparison with mechanical dispersion, so Dl ~ α vf.

1 < Pe <10 both diffusion and mechanical dispersion play a role in the contaminant transport.

(b) The solution of the advection dispersion equation for diffusion only is given by:

$$\frac{C}{C_0} = erfc\left(\frac{z}{\sqrt{4D_d * t}}\right)$$

Here, C_0 is 75 mg/L, $D_d* = 5.5 \times 10^{-10}$ m²s. The D_d* term is to be divided by R_d below:

$$R_d = \left(1 + \frac{\rho_b}{n} K_d\right)$$

Here, ρ_b = 1900 kg/m³, n = 0.45 and K_d = 0.25 L/g. R_d therefore equals 1056.

Therefore after 200 years (6.31x10⁹ seconds):

C/C₀ = erfc (8.72 * z) = 0.001

This gives 8.72 * z equal to 2.325 so z (the thickness of the barrier) = 0.267 m (minimum).
[40%]

(c) (i) the thickness of the wall would need to become thicker since dispersive flow is faster.

(ii) With no sorption, the barrier wall will need to become thicker, since sorption retards the contaminant transport process.

(iii) If multiple heavy metals are present, then they will have different diffusion profiles and hence the fastest moving ion will be considered in the calculations using its D*. [15%]

(d) Apart from constructing a barrier, a Cd contaminated soil and groundwater can be remediated using one of the following: Pump & treat: pump contaminated water and treat, can only be done in-situ and for the groundwater treatment. stabilisation/solidification: mixing with cementitious binders, can apply to both soil and groundwater, can be applied both in-situ and ex-situ, and this will depend on the volume of the contaminated material. The fact that the groundwater is contaminated likely to be that in situ treatment would be best and precipitation: as hydroxide using lime, lime would be added to the soil. Likewise both in situ and ex-situ are options, could be applied via a permeable reactive barrier. [20%]