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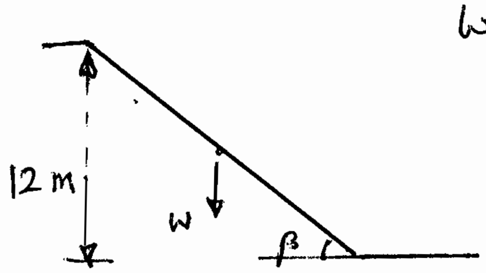
1 a) Several types of reactions can take place within the waste (MSW). These can be
i) oxidation / Reduction reactions
ii) Precipitation reactions
iii) Biological reactions (aerobic or anaerobic). [10%]

The precise reactions that occur depend on the waste composition.

b) Waste deposited next to a clay liner can result in waste-soil liner interaction. This can happen along the base liner or along the side slopes of a land fill.
The waste - soil liner interactions are important because the properties of the soil liner can change due to the interaction. Presence of hydrocarbons such as Kerosene, Benzene etc. can alter the hydraulic conductivity of the soil liner. The hydraulic conductivity is known to increase by several orders of magnitude in the presence of certain hydrocarbons. This can adversely effect the break through time of the leachate through the soil liner. ie reduce the break through time. [10%]

c) Self weight stress $\sigma_{Ta} = \dfrac{W \sin\beta - F}{1 \times t}$

where $F = W \cos\beta \tan\delta_L$.



Weight of the geomembrane = 16 kg/m²
Thickness = 4 mm.
Consider 1m strip into the plane of paper.

Slope length = $\frac{12}{\sin 60} = 13.856$ m.

Weight of geomembrane $W = 13.86 \times 1 \times 16 \times 9.81$
$= 2.175$ kN/m.

$\delta_L = 9°$.

Frictional resistance $F = 2.175 \cos 60 \tan 9°$
$= 0.1722$ kN/m

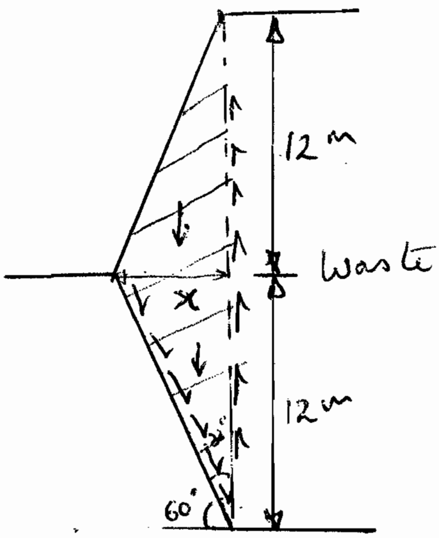
Self-weight tension:

$$\sigma_{TA} = \frac{2.175 \sin 60 - 0.1722}{1 \times 0.004} = 427.8 \text{ kPa}$$

∴ Self weight induced tensile stress in the geomembrane $= \underline{0.428 \text{ MPa}}$. [20%]

1 d) Friction angle between waste and geomembrane $\delta_U = 6°$.

Unit weight of waste $\gamma_{waste} = 6 \text{ kN/m}^3$.



$$\frac{x}{12} = \tan 30°$$

$$x = 6.928 \text{ m}.$$

Weight of the waste $W_{waste} = \frac{1}{2} \times 6.928 \times 24 \times 6$

$$W_{waste} = 498.8 \text{ kN/m}.$$

Waste in the shaded area will settle causing downdrag on the geomembrane. If no resistance is assumed by virtue of shear strength of waste, then this triangle will settle.

$$(\sigma_T)_{downdrag} = \frac{W_{waste} \cos\beta \tan\delta_U}{1 \times t} = \frac{498.8 \times \cos 60 \tan 6}{1 \times 0.004}$$

$$= 6553.65 \text{ kPa}$$

$$\simeq 6.554 \text{ MPa}.$$

$$\therefore \sigma_T = (\sigma_T)_{self weight} + (\sigma_T)_{downdrag} = 0.428 + 6.554$$

$$= \underline{6.982} < \underline{13.9} \text{ MPa}$$

(so OK)

Considering the shear strength of the waste, the estimated downdrag will reduce compared to the value above.

[30%]

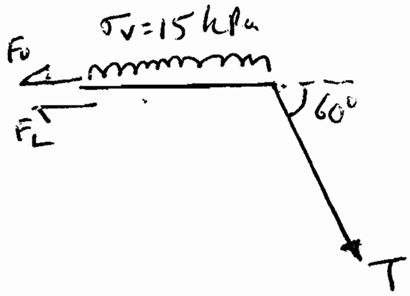
1e) Tensile stress in the geomembrane from part d) = 6.928 MPa

$\therefore$ Tensile force/m $T = 6.928 \times 10^6 \times 1\text{m} \times 0.004$

$T = 27928$ N

Assume 1m of cover with soil of unit weight 15 kN/m3.

$\therefore \sigma_V = 15$ kPa.



$F_U = 15 \tan \delta_U L$.

$= 15 \tan 6 \, L$.

$F_L = (15 + T \sin 60) L \tan \delta_L$

$= (15 + T \sin 60) L \tan 9°$

$T \cos 60 = F_U + F_L = L [15 \tan 6° + 15 \tan 9 + T \sin 60 \tan$

$$\therefore L = \frac{27928 \cos 60}{15(\tan 6 + \tan 9) + 27928 \sin 60 \tan 9}$$

$L = 3.6415$ m

use anchor length $L =$ **4 m**.

[30%]

2 a) Volume of Rain water $= 400 \times 500 \times 1.3 \times \frac{20}{100}$

$= 52000 \text{ m}^3$.

Leachate produced $= 52000 \text{ m}^3$.

Total volume $= \underline{104\,000 \text{ m}^3}$.

Height of leachate in drainage layer ($n = 0.5$) $= \frac{104\,000}{400 \times 500 \times 0.5} = \underline{1.04 \text{ m}} < \underline{1.2 \text{ m}}$ ok

∴ Given cover depth of 120 mm is sufficient.

Spacing :- $k_{drainage} = 2.4 \times 10^{-2} \text{ m/s}$.

$$Q = \frac{104\,000}{365 \times 24 \times 3600} = 3.2978 \times 10^{-3} \text{ m}^3/\text{s}$$

Flow rate q across the breadth (assuming uniform flow) $= \frac{Q}{500} = 6.5956 \times 10^{-6} \text{ m}^2/\text{s}$

Using Data book equation for pipe spacing

$h_{max} = 1.04$

$$L = 2 \times 1.04 \times \sqrt{\frac{2.4 \times 10^{-2}}{6.5956 \times 10^{-6}}}$$

$L = 125.47 \text{ m}$.

Use a pipe spacing of $\underline{125 \text{ m}}$. so: 3 pipes @ 125 m spacing

Flow thro' pipes: $Q = 3.2978 \times 10^{-3} \text{ m}^3/\text{s}$

Flow in each pipe: $1.6489 \times 10^{-3} \text{ m}^3/\text{s}$

Manning's Constant for PVC $= \eta = 0.009$.

Limit velocity $v = 1\,m/s$.

Assume 1/2 full pipe (gravity flow).

$$\therefore R_h = \frac{A}{P} = \frac{\frac{\pi r^2}{2}}{\pi r} = \frac{r}{2}$$

$$v = \frac{1.486}{\eta} R_h^{2/3} s^{1/2}$$

$$1 = \frac{1.486}{0.009} \times \left(\frac{r}{2}\right)^{2/3} \left(\frac{1}{1500}\right)^{1/2}$$

radius = 0.2272 m

Pipe Diameter = 0.454 m.

So pipes available at site (D = 560 mm) can be used.

$$q = v \times A = 1 \times \frac{1}{2} \times \frac{\pi}{4} \times 0.56^2 = 0.123\ m^3/s \gg 1.6489 \times 10^{-3}\ m^3/s.$$

So <u>OK</u>

<u>Pipe deflection</u>:-

$$\Delta y = 0.0025 \times \frac{D^2}{t}$$

$$= 0.0025 \times \frac{0.56^2}{0.05} \times 25.4 = 0.398\ \text{mm}$$

Thicker wall pipes are desirable, although this is a very conservative empirical rule.

2b) Initial volume of liquid waste

$$V = \pi r^2 \times b \times n.$$

$$= \pi \times 200^2 \times 6 \times 0.3$$

$$= 0.226 \times 10^6 \ m^3.$$

With time the radial distance increases due to diffusion

$$r' = r + 2.3\sqrt{D d r}.$$

$$= 200 + 2.3\sqrt{0.8 \times 200}$$

$$= \underline{229.09} \ m.$$ [20%]

2 c) **Continental Shelf**

Continental shelves are shallow platforms adjacent to land masses. Ocean floor here is characterised by irregular topography with banks, basins and valleys. Total width is around 75 km. The depth here ranges from 100 m to 200 m. Waste deposited here would not spread widely on the sea floor.

[15%]

Continental Slope

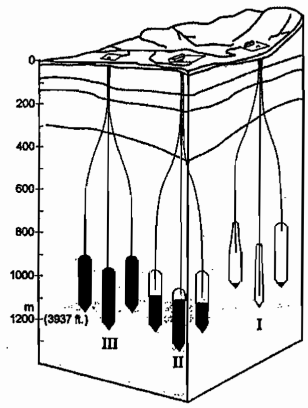
This is the region between the Deep Ocean floor and the continental shelf. Their width ranges from 20 km to 100 km. Waste deposited here would spread along the slope and can be distributed over a wide area on the sea floor.

2 d) **Solution mined caverns**

Liquid waste can be disposed off into space formed underground by solution mining in the past. An outline of a solution mined cavern is shown below. The 'space' is filled with brine solution and when the waste is injected the brine solution is displaced. This gives 'control' on the movement of the liquid waste as the volume of brine solution can be monitored.

i) Waste lighter than brine solution : The scheme would involve pumping of liquid waste from the top and removing the brine solution from the bottom of the cavern.

ii) Waste heavier than brine solution: This scheme would involve pumping of liquid waste into the base of the cavern and removing the brine solution from the top.



[15%]

3 (a) (i) Targeted sampling: Relies on professional judgement in identifying potential areas of contamination based on available information. No. of samples depends on objective of investigation, affected by factors such as (i) degree of confidence required, (ii) nature of contamination and (iii) number of stages of investigation. [10%]

(ii) Non-targeted or systematic sampling: Sample locations based on defined sampling pattern and spacing e.g. simple random, stratified random, square grid and herringbone (consider the most efficient). No. of samples required based on statistical techniques and depends on objectives of sampling. Objectives include: (i) prove no contaminant hotspots, (ii) determine spatial variation of contaminant concentration, (iii) identify the extent of land exceeding guideline values. [10%]

(b) Arithmetic mean = 161.25

Standard deviation = 86.59 $\left(=\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}\right)$

T from Table for n = 8 is 1.895

Calculated upper bound is 219.26

The calculated upper bound is less than the soil guideline value, hence it can be concluded that no action is warranted based on the mean value test.

However, one concentration value (350) exceeds the soil guideline value. Such values will require further consideration despite the mean value test having been passed.
Problem of acceptance or rejection of maximum values that exceed SGVs is not straightforward because of the need to balance primary goal of health protection with the recognition that contaminants in soils often have high sampling and analytical uncertainties. Hence there is a need to address whether this maximum value in the set is likely to have come from the same population of measurements or whether it is a statistical outlier which may indicate a localised area of contamination. To determine if an outlier, the maximum value test should be applied. Based on the results decision needs to be made as to whether extra sampling and analysis may be required. [40%]

(c)Tolerable Daily Intake (TDI):

Amount of chemical that can be ingested daily over a lifetime without appreciable health risk. Expressed in mass of substance per kg of body weight/day (mg kg^{-1} bw d^{-}1). Originates from setting of standards of dietary safety for food additives – based on toxicological studies in animals divided by a safety factor, e.g. 100, to cover to humans.

Mean Daily Intake (MDI):

Average 'background intake' to which people may be exposed to. Expressed in mass of substance/day (mg d^{-1}).

Tolerable Daily Soil Intake (TDSI):

A proportion of the TDI (mg kg^{-1} bw d^{-1}) allocated to exposure to contaminants in soil which takes into account MDI i.e. TDI - MDI (MDI converted into right units)

Tolerable Daily Soil Intake:

TDSI = TDI – MDI   OK when MDI < TDI

But for some contaminants MDI ≥ TDI

It could be argued that nothing can be allocated to contaminated soil

However this is considered impractical – argument is that there is huge variation around the average MDI for contaminants. Hence:

For MDI < 0.8 TDI, then TDSI = TDI – MDI

For MDI ≥ 0.8 TDI, then TDSI = 0.2 x TDI [40%]

4 (a) Five from the following: Density; volatility (i.e vapour pressure or boiling point); solubility; adsorption (coefficient); Henry's Law constant (ratio of amount in air/ amount in water, under equilibrium conditions);viscosity. [10%]

(b) Any 3 from: Benzene, toluene, ethylbenzene, xylenes, MTBE (methyl t-Butyl ether), aliphatic hydrocarbons (C6-C17), or aromatic hydrocarbons. [15%]

(c) MTBE (benzene is an acceptable answer if no MTBE was present in the petroleum). Reason: MTBE has very low retardation factor and moves almost at the same velocity as the groundwater.- extra marks if say because of high solubility , low Henry's Law constant, and/ or low adsorption constant [15%]

(d) Phytoremediation

<u>(i) Phytostabilisation (organic and inorganic):</u>

Mechanism uses certain plant species to immobilise contaminants making them stable through:

- precipitation or immobilisation within the root zone - using proteins and enzymes produced by plant. This mechanisms may reduce fraction of contaminant that is bioavailable
- adsorption onto the roots – proteins and enzymes directly associate with root cell walls can bind and stabilise contaminants on exterior of the root membranes
- absorption and accumulation into the roots – Proteins and enzymes present on root cell walls can also facilitate transfer of contaminants across root membrane, can be sequestered within roots or get transferred to shoots

Mechanism applicable to the site contaminant conditions. [20%]

<u>(ii) Rhizodegradation (organics):</u>

Mechanism uses certain plant species to breakdown contaminants through the bioactivity that exists in the rhizosphere:

- Protein and enzymes exuded from plant directly metabolise organic contaminants leading to degradation, metabolism or mineralisation of contaminants
- Natural substances released by plant e.g. sugars, alcohols, acids contain organic carbon that provides food for soil miroorganisms thereby enhancing their biological activity

Mechanism applicable to the site contaminant conditions. [20%]

<u>(iii) Phytoaccumulation (inorganics):</u>

Uses metal or salt accumulating plants that translocate and concentrate soil contaminants into the roots and aboveground shoots and leaves.

Certain plants called hyperaccumulators absorb unusually large amounts of metals in comparison to other plants (1000-10,000 mg/kg dry weight) and halophytes, similarly with salts (NaCl, MgCl).

Inorganic readily available for plant uptake: Ni, Zn, As, Cu, Moderately available: Co, Mn, Fe, Not available: Pb, Cr

Mechanism not applicable to the site contaminant conditions. [20%]

The above mechanisms could also be illustrated with sketches.