3D6 ENVIRONMENTAL GEOTECHNICS

Q1a) Soil particles are uncemented particles that form due to weathering of rocks. All three types of rocks namely Igneous, Sedimentary & metamorphic rocks undergo weathering and erosion that leads to formation of soil particles. Weathering and erosion are caused by Thermal cycles, frost damage, rain, abrasion (rock-rock, rock-ice, rock-soil) and chemical reactions. Particle breakage can also occur during transportation by air or wind.

In the upper reaches of a river, the soil particles will be angular and tend to have larger sizes. As the soil particles get transported by the river their shape becomes sub-angular to rounded. Also smaller particles form due to further breakage during transportation. These fine sands, silts or clay particles get deposited near the confluence of the river with the sea often forming fertile deltas. [15%]

1b ii) Leakage rate $q = K \Delta h \frac{N_f}{N_h}$ $m^3/s/m$

Hydraulic Conductivity of Sandy silt $K = 4.3 \times 10^{-6}$ m/s

From Flownet $N_f = 5$ $N_h = 12$.

Head driving the flow $\Delta h = 5.0$ m.

$\therefore q = 4.3 \times 10^{-6} \times 5 \times \frac{5}{12} = 8.9583 \times 10^{-6}$ $m^3/s/m$.

Width of the River channel = 200 m.

$\therefore$ Quantity of water that leaks in a week

$= q \times 200 \times 7 \times 24 \times 3600$

$= 1083.6$ m^3. [20%]

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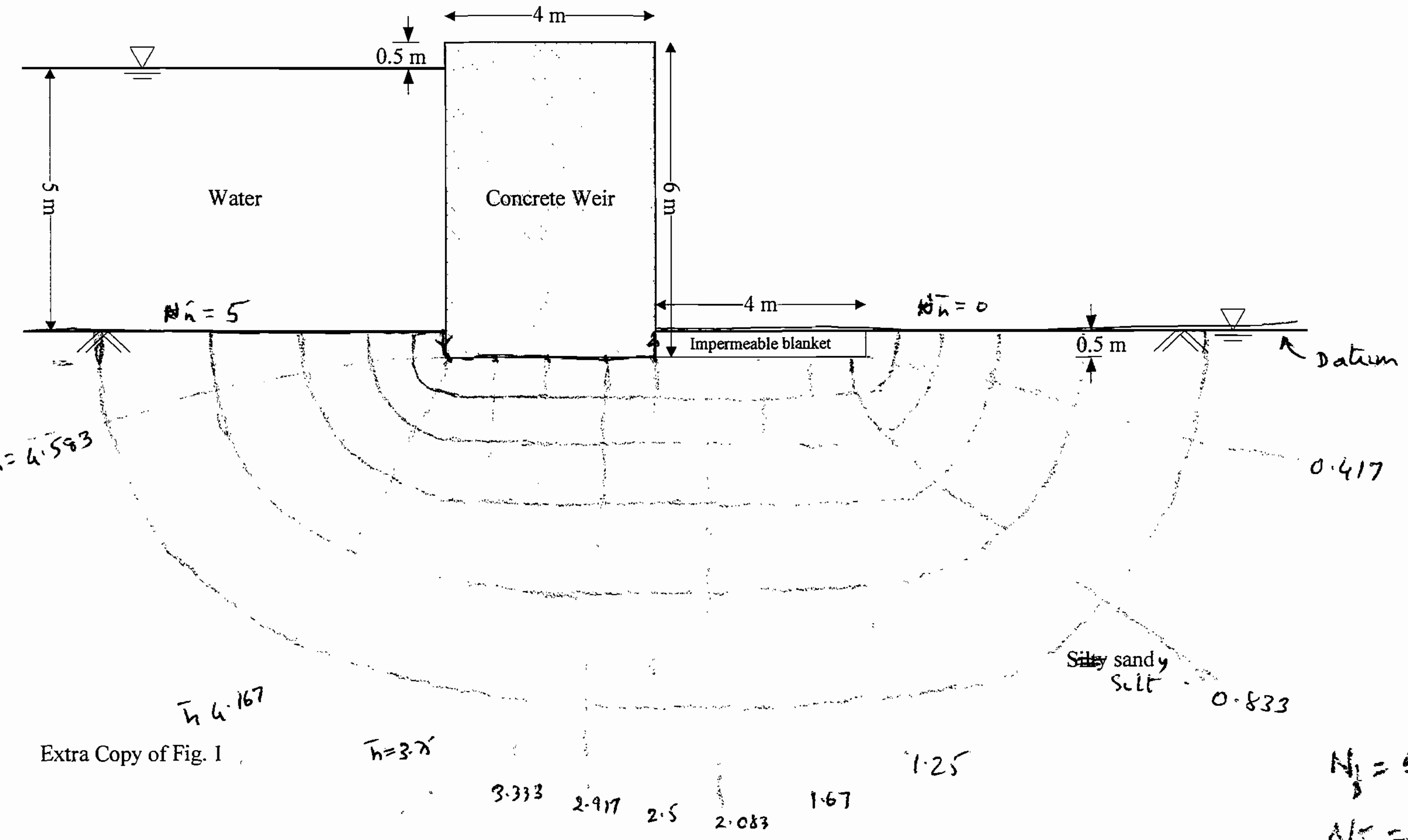
Q1b(i)



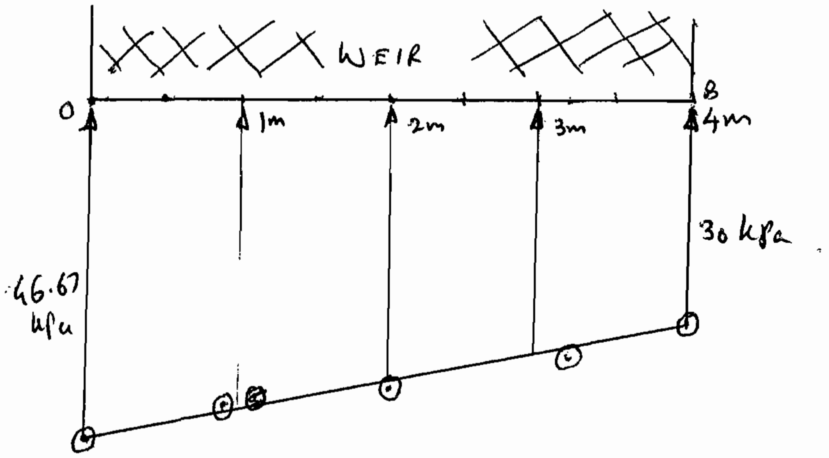
Extra Copy of Fig. 1

$N_f = 5$

$N_h = 12$

[20%]

1 b iii) Uplift pressure distribution on base of the weir



From flownet :

At 0 $\bar{h} = 4.167$ m . $y = -0.5$ m ⇒ $h = 4.667$ m ⇒ $p = \gamma_w h = 46.67$ kPa

At B $\bar{h} = 2.5$ m $y = -0.5$ m ⇒ $h = 3.0$ m ⇒ $p = 30$ kPa

Check at intermediate points : @ 0.93 m $p = (3.75 + 0.5) \times 10 = 42.5$ kPa
@ 2.0 m $p = (3.33 + 0.5) \times 10 = 38.3$ kPa
@ 3.2 m $p = 34.2$ kPa .

[20%]

1 c) Weight of the Concrete weir = $W = 6m \times 4m \times 24$ kN/m³ = 576 kN/m .

Uplift force $U = \frac{1}{2}[46.67 + 30]\, 4 = 153.34$ kN/m

∴ $W' = W - U = 576 - 153.34 = 422.7$ kN/m .

Hydrostatic force due to water on U/s = $\frac{1}{2} \times 50 \times 5 = 125$ kN/m .

FoS against sliding = $\frac{W' \tan\phi}{125} = \frac{422.7 \times \tan 25^\circ}{125} = 1.577 \simeq \underline{1.6}$

If the downstream blanket is not constructed then the uplift pressures will change from ≃ 50 kPa on U/s side to 0 on d/s side .

∴ $U = \frac{1}{2} \times 50 \times 4 = 100$ kN/m .

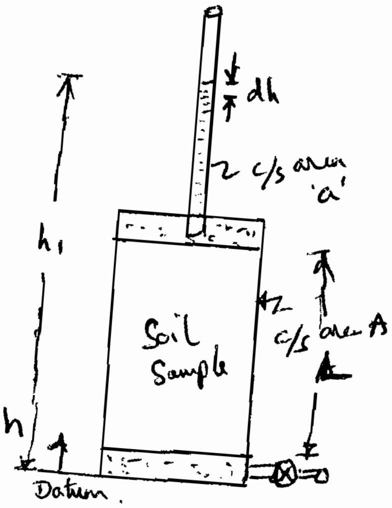
$W' = 476$ kN/m

FoS against sliding = $\frac{476 \times \tan 25^\circ}{125} = 1.776 \simeq \underline{1.8}$

However, you need to check the exit hydraulic gradients to ensure 'no liquefaction' at the downstream side.

[25%]

2a)



A falling head permeameter is used to determine the hydraulic conductivity of low hydraulic conductivity soils such as silty clays or clays. The soil sample is set up in a cell with porous ends. A falling head tube is inserted at the top. The bottom porous stone is connected to drainage, through a stop valve. The sample is set-up and fully saturated. The experiment begins from opening the stop valve and starting to measure time using a stop clock. The head of water in the falling head tube is measured at different times usually over a period of days.

A falling head permeameter is used when the hydraulic conductivity of the soil sample (clay, silty clay) etc is so small that no appreciable flow occurs that can be measured as in a constant head permeameter.

[20%]

b) Let the initial head be h_1 in the falling head tube at time t_1 which falls to a head of h_2 at a subsequent time t_2.

Let 'dh' be a small drop in head that occurs in a small time 'dt'.

The quantity of water $= dh \cdot a$ and rate of flow $= \frac{dh \cdot a}{dt}$. $\rightarrow$ ①

The same fluid must move through the soil sample.

Using Darcy's law $v = K \cdot i$.

$\therefore$ Rate of flow $q = v \times A = K i A$.

The drop in head 'h' occurs over the length of sample 'L'.

$$\therefore i = h/L \Rightarrow Q = KA\,h/L \rightarrow ②$$

Equating ① & ②

$$\frac{dh\,a}{dt} = KA\,h/L \Rightarrow \frac{dh}{h} = \frac{KA}{aL}\,dt \rightarrow ③$$

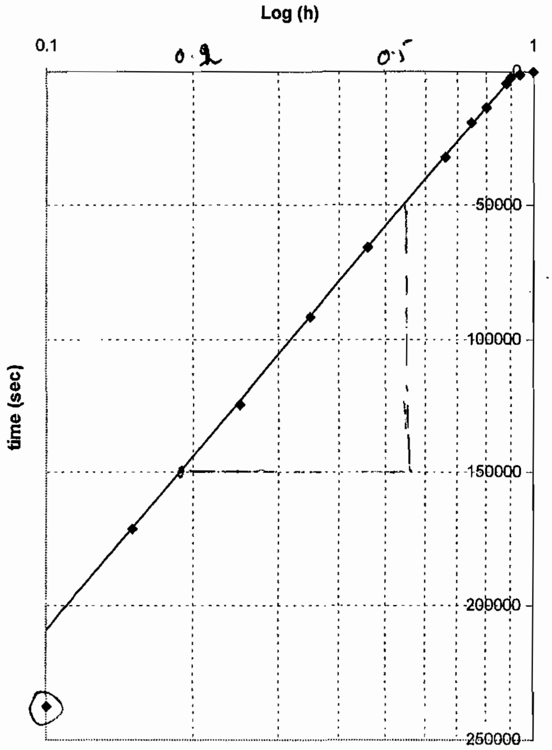
Integrating ③ within limits

$$\int_{h_1}^{h_2} \frac{dh}{h} = \frac{KA}{aL}\int_{t_1}^{t_2} dt \Rightarrow \ln\frac{h_2}{h_1} = \frac{KA}{aL}(t_2-t_1)$$

$$\Rightarrow K = \frac{aL}{A(t_2-t_1)}\ln\left(\frac{h_2}{h_1}\right)$$ QED

[20%]

2 c)



Ignore the first few points as the flow regime is setting up. Data suggests that last point is an erroneous point, ignore it.

Slope of the line

$$= \frac{150000 - 50000}{0.55 - 0.18}$$

Reciprocal slope $= 3.7 \times 10^{-6}$.

Length of Sample $= 0.1016$ m

Area ratio $= 2000 = \frac{A}{a}$

$$\therefore K = \frac{aL}{A} \times \text{reciprocal slope of line}$$

$$= \frac{1}{2000} \times 0.1016 \times 3.7 \times 10^{-6}.$$

Hydraulic Conductivity K $= 1.8796 \times 10^{-10}$ m/s. [30%]

2 d) Hydraulic conductivity with water.

$$K_w = k \frac{\gamma_w}{M_w}.$$

Similarly $K_{oil} = k \frac{\gamma_{oil}}{M_{oil}}$.

$$\therefore K_{oil} = K_w \times \frac{\gamma_{oil}}{M_{oil}} \times \frac{M_w}{\gamma_w} = 1.8796 \times 10^{-10} \times \frac{950}{1000} \times \frac{9.8}{9.8} \times \frac{1.003 \times 10^{-3}}{28 \times 10^{-3}}.$$

$$\therefore K_{oil} = 6.3966 \times 10^{-12} \text{ m/s}.$$

$$\Delta t = \frac{aL}{AK} \ln\left(\frac{h_2}{h_1}\right) = \frac{1}{2000} \times \frac{0.1016}{6.3966 \times 10^{-12}} \times \ln\left[\frac{0.765}{1}\right] = 2337905.12 \text{ sec}$$

$= 27$ days !! [30%]

3 a) $K_{clay} = 1.2 \times 10^{-9}$ m/s

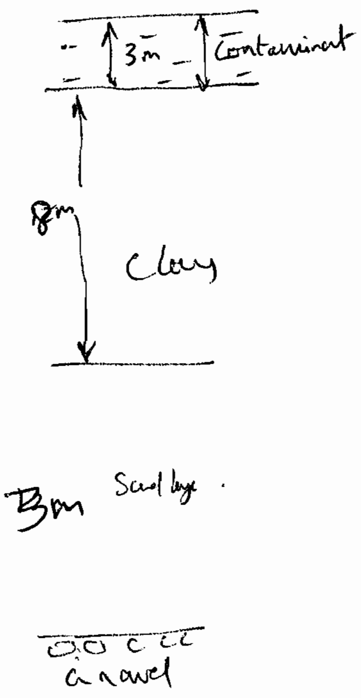
Thickness of clay $z = 8$ m

$C_0 = 12.8$ mg/L

$n = \frac{e}{1+e} = \frac{0.8}{1.8} = 0.444$

$K_{sand} = 2 \times 10^{-3}$ m/s

Thickness of Sand layer = 3 m



$$\therefore K_{vertical} = \frac{8+3}{\frac{8}{1.2\times10^{-9}} + \frac{3}{2\times10^{-3}}} = 1.65 \times 10^{-9} \text{ m/s}.$$

$$v = K_v \cdot i = 1.65 \times 10^{-9} \times \frac{3}{11}$$

$$= 4.5 \times 10^{-10} \text{ m/s}. \Rightarrow v_f = \frac{v}{n} = 1.0125 \times 10^{-9}$$

$$D_L = D_d^* + \alpha_L v_f.$$

$$= 4.3 \times 10^{-9} + 0.25 \times 1.0125 \times 10^{-9}$$

$$D_L = 4.5531 \times 10^{-9}$$

(i) For first signs to appear $C/C_0 = 0.0000 \Rightarrow \beta = 3$ from error function tables

$$\frac{z - v_f t}{\sqrt{4 D_L t}} = 3$$

$$\frac{8 - 4.5\times10^{-10} \cdot t}{\sqrt{4 \times 4.5531 \times 10^{-9} \times t}} = 3$$

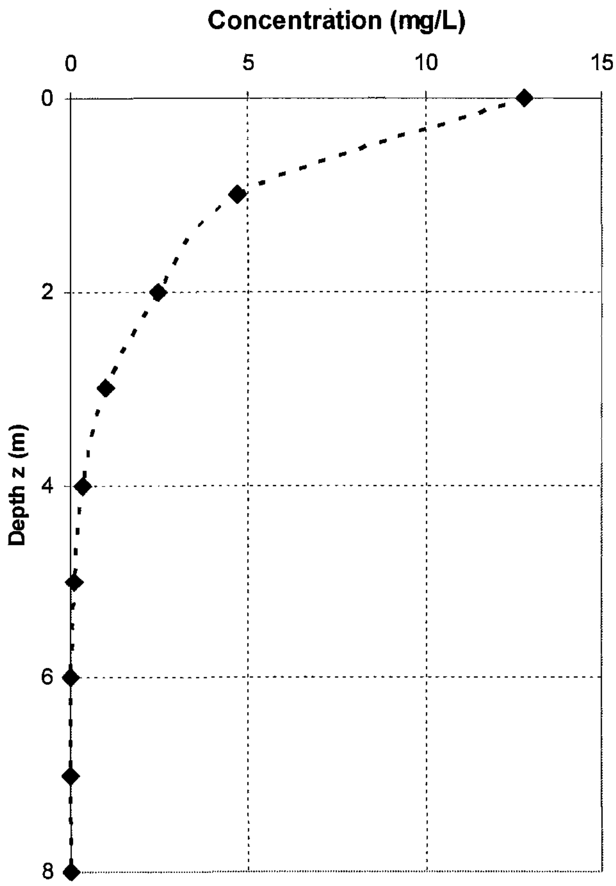
[20%]

Solving the quadratic $t = 376.19 \times 10^{6}$ sec

or 11.86 years ✓

Q3 a) ii)

z =	0	1	2	3	4	5	6	7	8
Beta		0.2379	0.6210	1.0041	1.3871	1.7702	2.1532	2.5363	3.00
erfc(beta)		0.7367	0.3801	0.1558	0.0501	0.0125	0.0026	0.0004	0
conc (mg/L)	12.8	4.7147	2.4326	0.9969	0.3204	0.0799	0.0164	0.0023	0



Candidates need to work out for z = 2, 4 and 6 m only.

[30%]

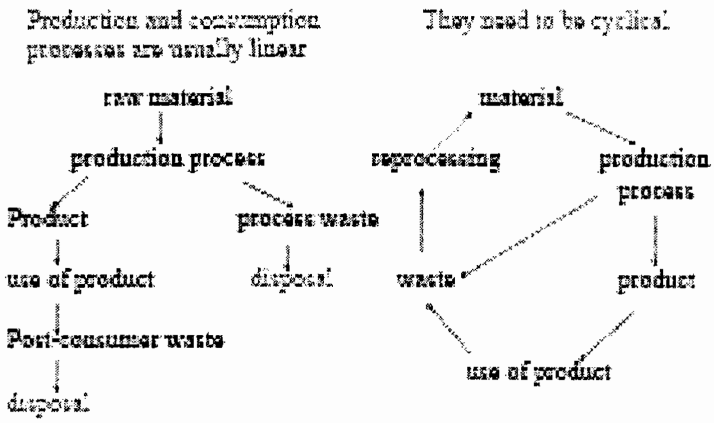
3(b) (i) The Waste Hierarchy provides a theoretical framework which should be used as a guide for ranking the waste management options being considered as part of the Best Practicable Environmental Option assessment.
Waste management options include:

- Reduction of waste generation: Often most effective environmental solution
- Re-use of waste: products and materials can sometimes be used again for the same or a different purpose
- Recycling, composting & energy recovery: Value can be recovered from waste through recycling, composting or energy recovery
- Disposal: only if none of the above offer an appropriate solution should waste be disposed of

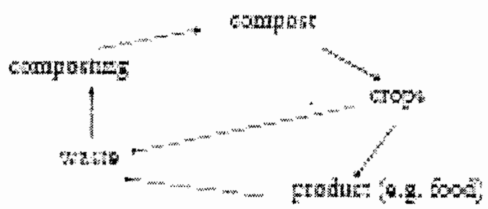
Moving waste management 'up the hierarchy' is a key objective of government waste policy. 10%

(ii) Waste as a resource:

- Recycling and composting: 20%



- With exception of paper, wood and some textiles, most biodegradable organic materials cannot easily be recycled
- However, these materials can be made into compost which growers can use to replace peat and fertilisers
- This allows creation of similar closed loop



- Energy from fuel: 20%

- Where it does not make sense to recycle, consideration should be given to using waste as fuel
- Can be done directly (i) in incinerators
  (ii) in industrial plant such as cement kilns
  or indirectly (i) creating refuse derived fuel
  (ii) through processes e.g. gasification
- Not all waste is suitable for use as fuel - inorganic waste such as glass and metals have no calorific value – but highly suitable for recycling
- Use as fuel can reduce CO_2 emissions by displacing the use of more polluting virgin fuel
- It sometimes also reduces other emissions e.g. burning tyres in cement kilns reduces the quantity of nitrogen oxides released

Q4 a) Solution:

i) Excavation and re-deposition in landfills

Contaminated solids and semi-solids are excavated and removed from a site and then deposited in a well- designed landfill or containment facility. A good definition of the contaminant boundaries is vital to determine the extent of the necessary excavation.

Advantages:

- Provides a permanent solution for site excavated
- It is applicable to many wastes, especially metal contaminants as these tend to concentrate in the top layers of soil
- There is potential for integration with other remedial methods prior to deposition
- It is technically easy for designers and contractors
- Relatively cheap, at current landfill costs

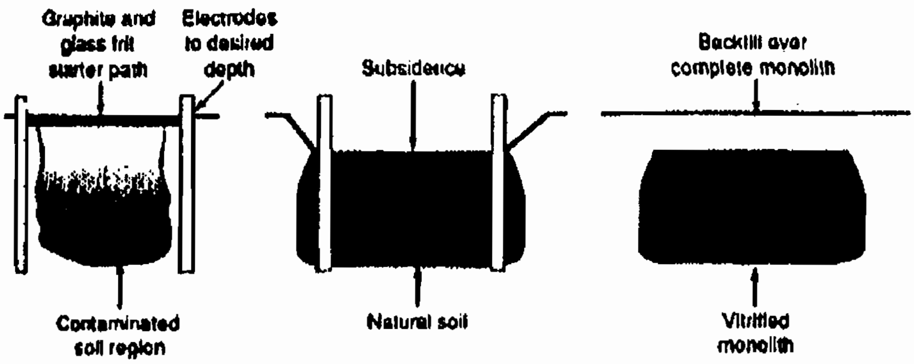
Disadvantages:

- There is no reduction in volume or hazardous properties of the material
- There may be limitations on depth of excavation due to nearby buildings etc
- Moving the contaminant may lead to a health risk and the need for regulatory controls
- A suitable new containment facility must be found
- There is a risk of legal liability if the new site becomes contaminated

[20%]

ii) Vitrifiction

Very high temperatures (up to 2000°C for some systems,) generated using large AC electric currents are applied to destroy organic contaminants and trap others in a glassy product due to melting soil grains.



Advantages:

- The hazardous properties of contaminants are permanently reduced
- Uses well-established technology

Disadvantages:

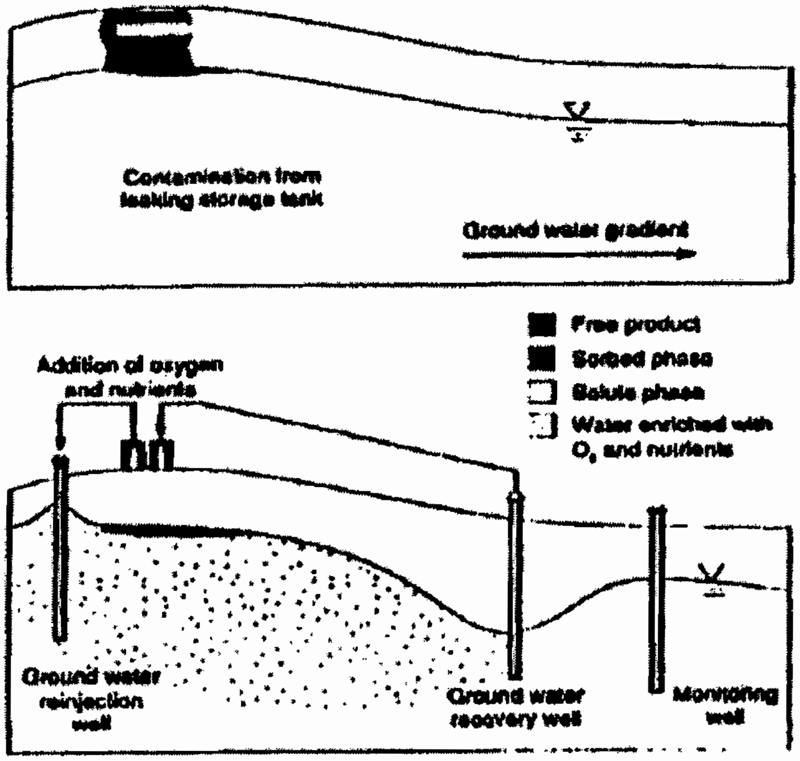
- Generally very expensive
- May produce gas and particle emissions

- Metals are not destroyed

[15%]

(iii) **Biological methods of clean-up**

In bioremediation, living micro-organisms are used to destroy, remove or transform the hazardous contaminant. It is necessary to optimise the biological activity in anaerobic/aerobic conditions and is applied both *ex-situ* and *in-situ.*



In situ remediation

Advantages:

- the hazardous properties of the contaminants are permanently reduced
- naturally occurring microbes present in the soil can be used
- could be inexpensive
- particularly suited to organic contaminants, and suitable containment-specific micro-organisms may be available

Disadvantages:

- a more toxic product may be produced
- nutrients and oxygen (for aerobic micro-organisms) need to be supplied
- gas and odours are produced e.g. methane
- some organic pollutants are not easily degraded
- the reaction may be slowed by the presence of heavy metals or pesticides
- long treatment times may be necessary

[15%]

4(b) (i) Cost-benefit analysis: 25%

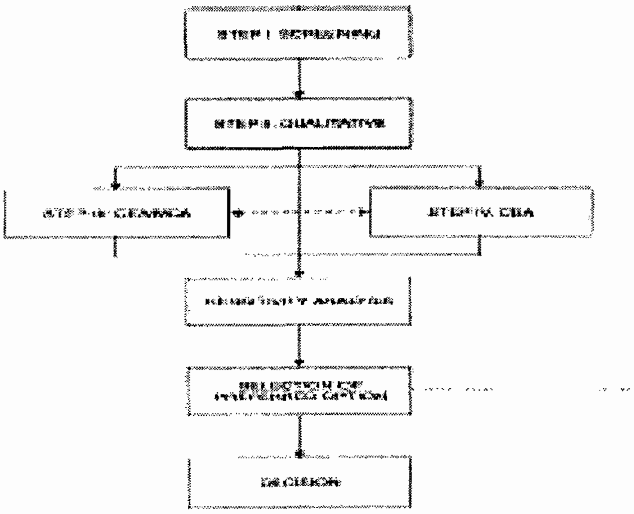
- Benefits (in monetary terms) calculated relative to costs
- Advantage: single value calculated as measurement of value of project, with units consistent throughout
- Disadvantages: some aspects (e.g. changes in biodiversity) cannot be measured in monetary terms, hence incomplete analysis
  Overcome by combining with a more general multi-criteria analysis (MCA)
- Method commonly applied commercially to determine the best remediation technique for contaminated land remediation projects

Multi-criteria analysis:

- Scores are determined for a range of indices:
  directly: by measurement (e.g. amount of soil going to landfill)
  indirectly: by subjective analysis (e.g. stakeholder concerns)
- Information is transposed to a common scale using scores
- Weighting is then applied to each score depending upon the importance of the particular indicator in that particular case – amended scores then summed
- Used in government decision making
- Disadvantage: potential subjectivity inherent in outcome
- Overcome by use of expert judgement & maximum use of measurable data

(ii) Stages of the EA CBA: 25%

- Screening: remove obviously unsuitable methods
- Qualitative Appraisal: observation of potential impacts without estimating impacts
- Multi-criteria/cost-benefit analysis: scoring & weighting following criteria: before, during and after remediation:
  Risks to site users/public — Emissions to air, dust, odour
  Impacts on quality/quantity of controlled waters — Habitat/ecology
  Site/surrounding land use/value — Stakeholder confidence/acceptability
  Remediation costs and consequential losses
- Cost-benefit analysis: analysis of as much information in financial terms as possible
- Sensitivity analysis: assessing sensitivity to variations in scoring/weighting



3D6 Environmental Geotechnics

Answers

Q1b) ii) 1083.6 m^3
1c) FoS =1.6

Q2 c) $K = 1.88 \times 10^{-10}$ m/s
2 d) 27 days

Q 3a) i) 11.86 years