1

ENGINEERING TRIPOS PART IIB 2012
4D14 CONTAMINATED LAND AND WASTE CONTAINMENT
Dr A Al-Tabbaa

1 (a) (i) Any 3 of: Refuelling: petroleum hydrocarbons: benzene, toluene, ethylbenzene, xylene, polycyclic aromatic hydrocarbons, aliphatic hydrocarbons, straight chain hydrocarbons, branched hydrocarbons, diesel. Repair shop: Degreasing bath: TCE, trichloroethylene, PCE, perchloro-ethylene. (ii) TCE, trichloroethylene, PCE, perchloroethylene, (iii) Lead, heavy metals (possibly). [20%]

(b) The most likely to have deep contamination is the dry-cleaning site. This is due to the presence of DNAPLs (chlorinated solvents). These chemicals have a density considerably greater than that of water and therefore sink deeply into the ground, below the water table. The garage site may also have had a degreasing bath containing chlorinated solvents, so this site may also have deep contamination. [10%]

(c) The stage to go through to assess the risk to human health from site contamination:

- Use the EA Contaminated land report 7-10 to help you generally.
- Perform desk study to collate as much information as possible on the history of the site and its contamination to assess location, type and variability of contamination.
- Perform site investigation on site, choose appropriate sampling procedure and number of samples to be taken. Take into account site and contaminant heterogeneity, variation in concentration. Seek guidance from relevant British Standards.
- Carefully consider quality of sampling and sample collection, sample preservation, selection of appropriate analyses method, precision of laboratory testing results and QA applied at all levels.
- Using the contaminant concentration results obtained, perform mean value test and maximum value test. This requires the relevant soil guideline values, which are covered below. Carefully consider any outlier values very carefully and decide whether they are part of the same sample population tested or are part of a localised area of contamination. Decide whether further sampling work is required.
- Use CLEA to assess the compatibility of the site in question to any of the cases considered and in particular the proposed land-use. If quite similar then relevant SGV already obtained can be used. If not similar them CLEA needs to be run for the site specific conditions. The latter is usually likely to be the case.
- The exposure pathways for the relevant end use will need to be identified and hence relevant values of the average daily exposure for the various contaminants will then need to be calculated. The relevant data and figure from CLEA need to be selected and input into the equations which reflect the appropriate exposure pathways.
- Tolerable daily intake and background mean daily intake values need to be obtained for relevant contaminants from CLEA which then determined the tolerable daily soil intake for the individual contaminants or the equivalent Index dose for contaminants without a threshold response. These values would correspond to the SGVs in the soil.
- The average daily exposure calculation needs to be equal or less to the SGV. [70%]

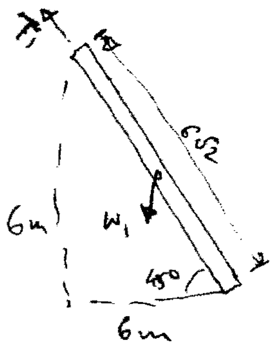
Examiner's comment:

The least popular question and the least well answered. This question tested the candidates on their knowledge of contamination arising from specific sites and on the methodology for assessment the risk to Human health using CLEA model. Most of the students did not get the first part right completely and many only presented part of the solution to the second part.

4D14 Contaminated Land and Waste Containment Systems

Cribs – 2012

Q2 a) Consider the bottom 6 m of the landfill slope. Slope angle = 45°



Weight of geomembrane $= W_1 = 22 \times 1 \times 6\sqrt{2} \times 9.81 = 1.831$ kN

Geomembrane underside friction angle $= 18° = \delta_{under}$.

Frictional resistance $= F_1 = W_1 \cos\alpha \tan\delta_{under}$ $\quad \alpha = 45°$

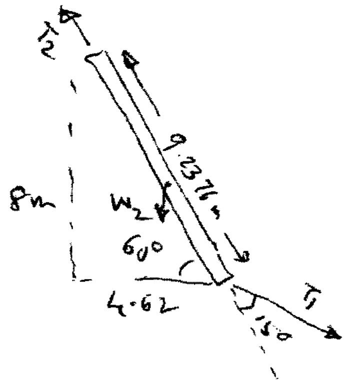
$= 1.831 \times \cos 45 \tan 18 = 0.4207$ kN.

Self weight stress $\sigma_{self,1} = \dfrac{W_1 \sin\alpha - F_1}{t \times 1} = \dfrac{1.831 \sin 45 - 0.4207}{0.008}$

$= 109.25$ kPa or 0.11 MPa.

Tensile force in geomembrane $= T_1 = 109.25 \times 1 \times 0.008 = 0.874$ k

Now consider the upper 8m of the landfill slope.



$W_2 = 22 \times 1 \times 9.2376 \times 9.81 = 1.994$ kN ; $\delta_{under} = 18°$, $\beta = 60°$

$F_2 = W_2 \cos\beta \tan\delta_u = 1.994 \times \cos 60° \tan 18° = 0.324$ kN

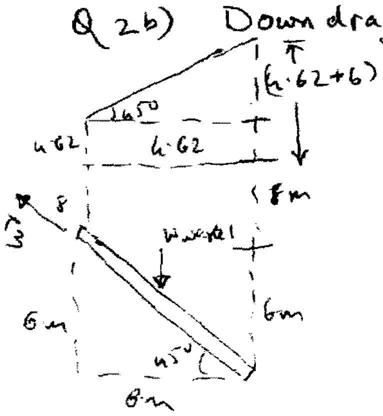
Self weight stress $\sigma_{self\,2} = \dfrac{W_2 \sin\beta - F_2 + T_1 \cos 15°}{0.008 \times 1}$

$= \dfrac{1.994 \sin 60 - 0.324 + 0.874 \cos 15}{0.008} = 280.88$ kPa or 0.281 MPa

∴ The maximum self weight stress = 280.88 kPa [30%]

Tensile force in geomembrane $T_2 = 280.88 \times 1 \times 0.008 = 2.247$ kN

Q 2b) Downdrag stress – Again consider the bottom 6m of the landfill slope.



Weight of waste above liner $= W_{waste\,1} = \frac{1}{2}[12.62 + 24.62]\, 6 \times 650 \times$

$= 712.38$ kN

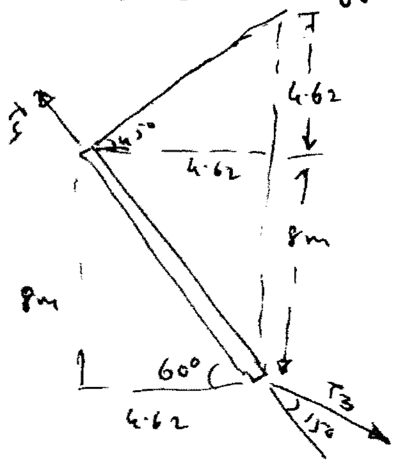
$\sigma_{downdrag\,1} = \dfrac{W_{waste\,1} \cos(90-45) \tan\delta_u}{t \times 1} = \dfrac{712.38 \times \sin 45 \times \tan 5°}{0.008 \times 1}$

$= 5508.8$ kPa or 5.508 MPa.

Tensile force in geomembrane $= T_3 = 5508.8 \times 0.008 \times 1 = 44.07$ kN

Q 2 b) Contd.

Consider the upper 8 m of the landfill slope



Weight of the waste above liner = $W_{waste\,2}$ =

$$= \frac{1}{2}\left[4.62+8\right]\times 4.62\times 650\times 9.81$$

$$= 185.889 \text{ kN}$$

$$\sigma_{downdrag\,2} = \frac{W_{waste\,2}\times \sin 60\ \tan 5 + T_3 \cos 15}{0.008}$$

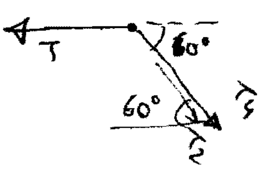
$$= \frac{185.889\ \sin 60\ \tan 5 + 44.07\times \cos 15}{0.008}$$

$$= 7081.58 \text{ kPa or } 7.081 \text{ MPa}$$

∴ Max down drag stress = 7.081.6 kPa < 13.9 MPa OK [30%]

Tensile force T_4 = 7081.6 × 0.008 = 56.65 kN

2 c) Anchor Force T required = $(T_2 + T_4)\cos 60°$



$$T = (2.247 + 56.65)\cos 60°$$

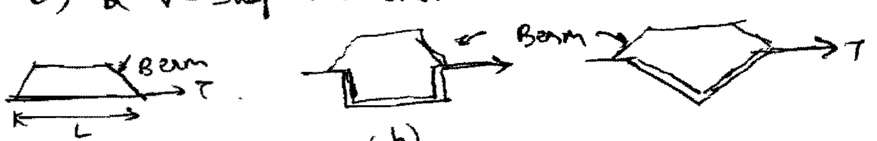
$$= 29.45 \text{ kN}$$

The required anchor force T can be provided by using either

a) Flat bed anchor of sufficient length L

b) Rectangular trench anchor or

c) V-shaped anchor

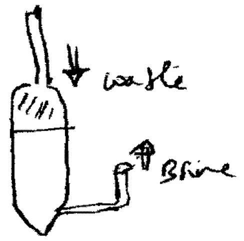


(a) (b) [20%]

2 d) Hazardous waste in liquid form can be disposed off into solution mined caverns. Both toxic and nuclear waste can be disposed in this way. Suitable sites where solution was mined earlier and therefore form suitable receptor must be found

2 d) contd

Brine balanced technique involves floating the liquid waste lighter than brine. The cavern is always full of liquid. When more waste is added, the excess brine is displaced via pipes in the casing and the brine is stored in a holding pond. If waste is removed for processing, the reverse happens.



If the waste is of higher density than brine, then this technique can still be used, but the inlet and outlet point are interchanged.

[20%]

Examiner's comment:

The first part of the question was on calculation of self-weight stress induced in geomembrane liner laid on the side slope of a landfill and the second part was on down drag induced stress due to waste settlement. The third part of the question asked the candidates to calculate the anchor force that is required at the top of the landfill to maintain equilibrium of the geomembrane. The last part of the question was on disposing of liquid waste into solution-mined caverns. Most candidates could answer the final part of the question well. Good candidates could calculate the self-weight induced and down drag induced stresses well, but many candidates made mistakes as they made incorrect assumptions about the problem geometry and assumed that change in slope of the side liner does not make an effect on the geomembrane stresses.

---

3 a) In municipal solid waste that arises from residential and commercial areas, the hazardous waste can be 0.1% to 1% of the total MSW. The hazardous waste can come from household products like aerosols, abrasive scouring powders, chlorine bleach, drain openers, furniture polish, shoe polish, anti-freeze, batteries, paints, thinners, garden insecticides.

Many compounds that are formed from Arsenic, Selenium, Barium, Cadmium, lead, mercury can be found. Organic compounds such as Benzene, Toulene etc can also be found. [20%]

b) The reactions that take place within the waste can change depending on the availability of oxygen.

1) Soon after the top cover of land fill is placed, there will be air in all the pore space. This encourages aerobic reactions to take place with the waste. These reactions take the form of hydrolysis, oxidation & reduction converting waste into liquid form (leachate). Organic matter is initially converted into nitrates, sulphates, CO_2 and water.

3b) Contd

ii) A long time after the top cover is closed, the free air is exhausted due to aerobic reactions and cannot be replaced. Under these conditions anerobic reactions occur within the waste. Organic matter can be converted into Methane, Ammonia, Carbon dioxide & hydrogen Sulphide (H_2S). Other compounds such as alcohols' and carboxylic acids can be produced under these conditions. [20%]

3c) Site dimensions 300 m x 200 m.

Depth allowing for SW above water table = 20 m

Height of waste = 25 m.

we can ignore the side slopes - and the small reduction in volume that cause

$\therefore$ volume = $300 \times 200 \times [20 + 25] = 2700000 \ m^3$.

Density of waste = $825 \ kg/m^3$.

$\therefore$ Total weight of waste that can be placed in this land fill is

= $825 \times 27 \times 10^5$ = 222 7500 tons

Using the data sheets population size can be calculated as

$P_{new} = P \ [1 + r/100]^n$ $\therefore$ $P_0 = 140000$ $P_1 = 14000 \ [1 + 5/100]^* = 147000$

$P_2 = 140000 \ [1 \cdot 05]^2 = 154350$ etc. (See table on next page).

No waste is received in first 2 years - Construction of landfill.

[Candidates will only need to work out first two columns of table]*

4D14 Contaminated Land and Waste Containment Systems

Cribs – 2012

Q3 c)

Density		825	kg/m3				
Current house holds			140000				
Volume=		2700000					
Weight		2227500	tons				
Waste arisings=							
Year	Population	tons	Revenue	Landfill tax	Methane	Energy (kJ)	
1	~~140000~~	147006					
2	154350						
3	162067.5	252825.3	3792379.5	1643364.45	252.8253	14082369	
4	170170.875	265466.57	3981998.48	1725532.67	265.4666	14786488	
5	178679.419	278739.89	4181098.4	1811809.31	278.7399	15525812	
6	167167.322	260781.02	3911715.32	1695076.64	260.781	14525503	
7	172182.341	268604.45	4029066.78	1745928.94	268.6045	14961268	
8	177347.811	276662.59	4149938.79	1798306.81			
9	182668.246	284962.46	4274436.95	1852256.01		73881.44	MJ
10	188148.293	293511.34	4402670.06	1907823.69			
	Total £	2181553.6	32723304.3	14180098.5			

3 c i) The landfill can receive waste for 10 years from now or 8 Years from when it starts to operate and receive 2181553 tons of waste < 2227500 tons [20%]

c(ii) Total revenue generated = £32.723 million
Cost of Construction = £3 mill + £1 mill × 8 = £11 million.
∴ Net profit = £21.723 million [15%]

c(iii) Total landfill tax for local authority = £1.418 million. [10%

c(iv) Total energy output = 73,881.4 M Joules in 5 years [15%]

Examiner's comment:

The first two parts of the question were on hazardous waste in MSW and reactions that occur within MSW under aerobic and anaerobic conditions. The third part was on the estimation of waste arisings allowing for annual changes in population and changes in waste generation due to recycling over years. This year the question asked the candidates the duration of service from a landfill cell. Most students did this part well but a few candidates could not deal with the open ended time duration. This year a final part was included were the candidates had to estimate the energy produced due to gas production from the landfill. Again many candidates could do this part,

4. (a) (i) Low permeability cut-off wall: will isolate the contaminated site from the surrounding environment, usually performed using cement-bentonite slurry mixes. Could be performed using soil mix technology without the need to excavate. This would be ideal for complex and variable site contamination, wide range of contamination although does not lead to any cleaning up of the contaminants, but can be used as an immediate action to prevent river water contamination and be performed with other remedial measure. Suitable for this site given the contaminant and boundary conditions.

(ii) Pump and treat: deals with contaminated groundwater, the contaminated groundwater from the site would be pumped using a series of extraction wells and will need to be treated and then ideally pumped back. This deals with all types of contaminants dissolved in the groundwater and might also pump LNAPLs. Could be quite costly, but quite straight forward with limited environmental impact.

(iii) Dual Phase extraction: This involved one set cf wells to extract organics from the vadose zone as well as contaminated groundwater by applying soil vapour extraction and Air sparging respectively. This will deal with the organic contaminants present above the groundwater, the LNAPLs floating on the groundwater and the organic dissolved phase in the groundwater. Effective but could be costly if extensive are of contamination, environmental impacts can be reduced with capture of the organics gases extracted.

(iv) Permeable reactive barriers. This involves the installation of an in-ground barrier as an appropriate location on the site to intercept the groundwater flow, so somewhere on the site close and parallel to the river boundary. This could be funnel and gate or continuous structure. The wall need to be quayed into the bedrock at 8m depth and must ensure that it catches the whole of the contaminant plume. Suitable reactive material needs to be used which targets the organic contaminants present. Cost effective with minimal environmental impacts as no excavation would be needed if soil mix technology is used.

(v) On-site bioremediation: This is ideal for mainly for soils with organic contamination. The soils can be excavated if the worst of the contamination is on the top soil, and placed elsewhere on the site in windrows where oxygen and nutrients are delivered regularly. This depends on how deep the excavations need to be. Could be very cost effective with minimal environmental impacts.

(vi) In-situ stabilisation/solidification: This involves the addition of a cementitious additive to encapsulate the contaminants. Mainly for contaminated soil, but would also partly deal with groundwater. Works for most contaminants. The binders can be added in-situ. Quite cost effective, with mineral environmental impacts and will enhance soil strength for subsequent construction.

(vii) Monitored natural attenuation: Is a combination of naturally occurring processes that act leading to reduction in contaminant volume, concentration and toxicity without the need for any engineered intervention. Combined processes include dispersion and dilution, sorption, volatilisation, biodegradation, destruction, transformation and chemical and biological stabilisation. Will require significant understanding of the biological, chemical, hydraulic and sorption processes taking place in the soil and continuous monitoring to validate it. This usually works for organic contamination that degrades over time, hence given that the main groundwater contamination is organic, this is suitable for this site. Also given the shallow nature of the contamination and the presence of bedrock at relatively shallow depth, this is generally a feasible option. [70%]

(b) Any offered combinations of the above remediation techniques would be acceptable provided they are adequately justified. This includes:

(i) Low-permeability wall on the river, plus pump and treat to clean up contaminated groundwater plus S/S for made ground. While cut-off wall and S/S are cost effective pump and treat is not. Pumped water will require treatment and would be injected back into the groundwater.

(ii) Cut-off walls and PRB combination system to clean up contaminated groundwater plus S/S for the site above. This is cost effective. Cut-off wall if performed using soil mix technology and S/S will eliminate spoil.

(iii) Dual phase extraction for the organics from both above and below groundwater plus S/S for heavy metals, could be cost effective.

On site bioremediation given the depth of the contamination unlikely to be cost effective. [30%]

9

Examiner's comment:

A popular question and answered well. The students were asked to briefly describe a number of different remediation techniques in the context of a specific contaminated site, and the propose what they consider the most appropriate remedial strategy for this site technical as well as from a cost and environmental impact perspective. Marks were lost when the description of the techniques was general rather than specific to the site and when justification was not given for the chosen remediation strategy in the second part.