University of California, Berkeley
CE176 Environmental Geotechnics

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March 18, 2009

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MIDTERM

Provide support for your answers. Be organized, concise and neat. Calculations must be clearly presented to obtain partial credit. (100 points)

Part A: TRUE/ FALSE QUESTIONS (2.5 pt each, total=10 pts)

1. The double layer of a clay particle, t, will decrease with decreasing dielectric constant, with increasing cation concentration and increasing valence of exchangeable cation. (T) ✓ F
2. To obtain the lowest hydraulic conductivity for a compacted clay liner you must compact the soil with a water content higher than the optimum water content (wet side of the line of optima) in order to obtain a "dispersed structure" (T) ✓ F
3. In general, as you decrease the hydraulic conductivity of compacted clay liners, the main mechanism of contaminant migration changes from advection-dispersion to constrained molecular diffusion (T) ✓ F
4. A material is considered hazardous when it contains a material listed as hazardous by the USEPA, displays hazardous characteristics (i.e., ignitability, corrosivity, reactivity or toxicity) and/or causes environmental or health damage (T) ✓ F

Part B: Respond briefly to the following questions (5 pts each, total = 30 pts)

1. Describe (**very briefly**) some of the difficulties encountered in determining waste properties such as unit weight, strength and compressibility.

- lack of data due to heterogeneous nature of waste, societal behavior
- waste varies in different locations
- difficult to test ✓

2. List (at least three) processes affecting the movement and change in concentration of a contaminant in groundwater and how would you reduce the risk associated with those processes in a waste containment system

- advection + mechanical dispersion → minimize k to reduce seepage velocity
- diffusion → force a minimum thickness of material/liner
- absorption + adsorption (sorption) → engineer liner to absorb contaminants or destroy them (i.e. reactive barrier) ✓

Excellent.

3. Describe briefly what is chemical compatibility testing and what is the main testing difference between low hydraulic conductivity soils (e.g., clays) vs. high hydraulic conductivity soils (e.g., sands).

chemical compatibility testing is performing k test for water then compare/use to test w/ contaminants expected in the field in order to assess long term k. Volume to use when testing is when k of soil stabilizes over time. For clay, this is usually 2-4 pore volumes for sands, it is much less so we immerse the sands in leachate for 2-3 months and then test them.

4. List the procedure to select a soil-bentonite backfill mixture for hydraulic barrier applications

- add fines (clay) to optimize dry density
- add min amount of bentonite to meet K requirements
- perform compatibility testing w/ contaminants expected in the field in order to assess long term k.

5. List three key elements of the Sealed Double Ring Infiltrometer used for field testing of hydraulic conductivity for clays.

- measures low k
- large volume of soil is permeated
- finds k in the vertical direction

not what I asked

6. List one advantage and one disadvantage for laboratory hydraulic conductivity testing for compacted clays

Advantage of Laboratory Testing	Disadvantage of Laboratory Testing
boundary conditions are known	application of result to real situation is not always accurate

Part C: SIMPLE QUESTIONS/ MULTIPLE CHOICE: Provide support for your answer (10 points each)

1. A 0.60m thick drainage blanket constructed with gravely sand, k ≈5 cm/sec was specified in the design phase of your project. This material is not available in sufficient quantities (at reasonable cost) and you suggested to your supervisor to inquire on several geonets available in the market. As a result, the following data is given to you to assess the equivalency of these systems for in-plane flow. The flow reported in the table for manufactured products at a confining pressure of 100 kPa (similar to that expected in the field).

Geonet number	Name	Manufacturer	Transmissivity (m^3/sec per meter)
1	Enkanet 4015	Akzo Nobel Geosynthetics Co.	0.039 x 0.7
2	CE 3	Terrax Corp.	0.018 x 0.7
3	TerraNet 200	WEBTEC Inc.	0.026 x 0.7

A reduction of 30% in the Transmissivity of the geosynthetic product is expected in the long term. Based on your analysis, the geonets satisfying or exceeding the performance of the original drainage blanket are:

a. only #1 b. only # 1 and # 3 c. all of them d. none of them

.005 x 0.60

($Q_{sand,best}$ = k_{sand} A)

k_{sand} = 5cm/s = 0.05 m/s

1 2 3

θ = $k_T t$ .. for same thickness (t = 60cm) over time $k_T = \frac{.700}{t}$ = 0.046 m²/sec·m 0.021 0.030

drainage ⇒ want large k_T

None of the k_T's are larger than k_{sand} for same thickness of material

2. A field hydraulic conductivity test is performed in a compacted clay liner with a Boutwell permeameter, with dimensions, d= 1 cm, D = 10 cms. For the initial stage (a), the initial height H was 100 cm, and the head drop in 10 hr was 5 cm. For the second stage (b), and a factor L/D=1 a head drop of 5 cm was observed in 3 hrs, from an initial height of 100 cm. Determine the values of vertical and horizontal hydraulic conductivity in cm/sec.

$k_1 = \frac{\pi d^2}{11 D \Delta t} \ln\left(\frac{H_1}{H_2}\right)$ d=1cm D=10cm, Δt=10hr H₁=100cm, H₂=95cm

$k_1 = 4.07(10^{-8})$ cm/s

$k_2 = \frac{A}{B} \ln\left(\frac{H_1}{H_2}\right)$ d=1cm L/D=1 Δt=3hr, H₁=100cm H₂=95cm

$A = d^2 \ln\left(\frac{L}{D} + \sqrt{1+\left(\frac{L}{D}\right)^2}\right) = 0.88014 cm^2$

$B = 8D\left(\frac{L}{D}\right)\Delta t\left(1 - 0.562\exp\left(-1.57\left(\frac{L}{D}\right)\right)\right)$
$= 7.6298(10^5)$ cm·sec

$k_2 = \frac{0.88014 cm^2}{7.6298(10^5) cm \cdot sec} \ln\left(\frac{100cm}{95cm}\right) = 5.93(10^{-8})$ cm/s

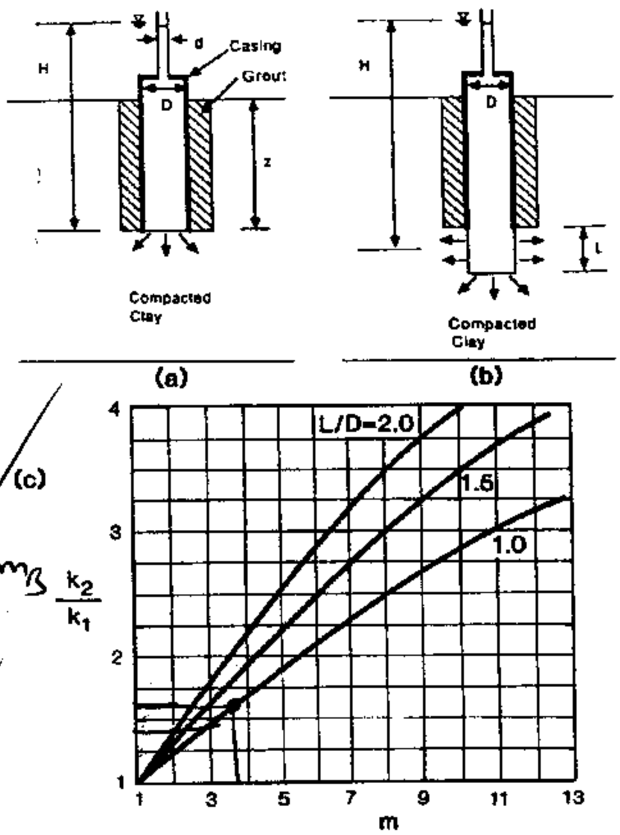
$k_2/k_1 = 1.45$

approximated

from graph, m ≅ 3.8

$k_v = \frac{k_1}{m} = \frac{4.07(10^{-8})cm/s}{3.8} = 1.07(10^{-8})$ cm/s

$k_h = k_1 \cdot m = (4.07(10^{-8})cm/s)3.8 = 1.55(10^{-7})$ cm/s



Boutwell Permeameter: a) first stage, b) second stage. c) k_2/k_1 required for the analysis (after Daniel, 1989)

3. A field hydraulic conductivity test on a compacted clay liner is performed using a Sealed Double Ring Infiltrometer. The inner ring is 30 cms in diameter and a volume of 50 cm³ is measured to have gone into the soil at the time the tensiometer at a depth of 2 cms marks zero suction. This occurred at the end of exactly 1 day. The elevation of water above ground level inside the ring is 30 cms. The likely hydraulic conductivity of the compacted clay liner is:

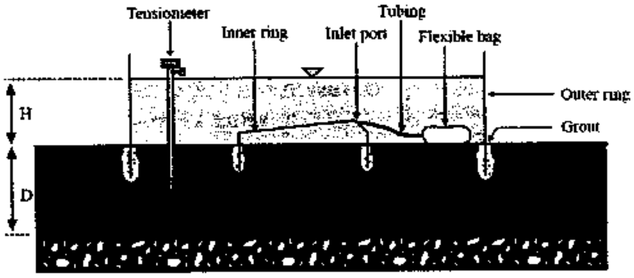
a) 5x 10⁻⁷ cm/s   b) 5x10⁻⁸ cm/s   c) 5x10⁻⁶ cm/s   d) too pervious for a compacted clay liner.

d = 30 cm
V = 50cm³
Δt = 1day
Lf = 2cm
H = 30cm

$k = \frac{V}{A \Delta t\, i}$; $i = \frac{H + L_f}{L_f}$

$i = \frac{30cm + 2cm}{2cm} = 16$

$k = \frac{50cm^3}{\frac{\pi}{4}(30cm)^2 \cdot 1day \cdot 16} \cdot \frac{1day}{24hrs} \cdot \frac{1hr}{3600sec}$
$= 5.12(10^{-8})$



Bonus Question: Identify the following geosynthetic specimen, its primary function in a waste containment system and main properties (do not list all properties, but the 1-2 most relevant) (2 pt/each)

Specimen	Geosynthetic Type	Potential Functions	Main Properties of Interest
	geo grid	reinforcement	strong in tension when force applied along primary axis

Table for Complementary Error Function

B	erfc (B)
0.00	1.00000
0.05	0.94363
0.10	0.88754
0.15	0.83200
0.20	0.77730
0.25	0.72367
0.30	0.67137
0.35	0.62062
0.40	0.57161
0.45	0.52452
0.50	0.47950
0.55	0.43668
0.60	0.39614
0.65	0.35797
0.70	0.32220
0.75	0.28884
0.80	0.25790
0.85	0.22933
0.90	0.20309
0.95	0.17911
1.00	0.15730
1.05	0.13756
1.10	0.11979
1.15	0.10388
1.20	0.08969
1.25	0.07710
1.30	0.06599
1.35	0.05624
1.40	0.04772
1.45	0.04031
1.50	0.03390
1.55	0.02838
1.60	0.02365
1.65	0.01962
1.70	0.01621
1.75	0.01333
1.80	0.01091
1.85	0.00889
1.90	0.00721
1.95	0.00582
2.00	0.00468
2.05	0.00374
2.10	0.00298
2.15	0.00236
2.20	0.00186
2.25	0.00146
2.30	0.00114
2.35	0.00089
2.40	0.00069
2.45	0.00053
2.50	0.00041
2.55	0.00031
2.60	0.00024
2.65	0.00018
2.70	0.00013
2.75	0.00010
2.80	0.00008
2.85	0.00006
2.90	0.00004
2.95	0.00003

The Equation for 1-D transport with Advection, Diffusion/Dispersion & Retardation is given by:

$$\frac{C}{C_0} = \frac{1}{2}\left\{ \operatorname{erfc}\left(\frac{R.z - V_s\, t}{2\sqrt{D.R.t}}\right) + \exp\left(\frac{V_s.\, z}{D}\right) \operatorname{erfc}\left(\frac{R.z + V_s\, t}{2\sqrt{D.R.t}}\right)\right\}$$

For the case of no seepage velocity ($V_s = 0$), the previous equation simplifies to:

$$\frac{C}{C_0} = \operatorname{erfc}\left(\frac{R.z}{2\sqrt{D.R.t}}\right)$$

4. A clay liner 90 cms (~ 3ft) thick with a hydraulic conductivity of 10^{-8} cm/s and an effective porosity of 0.333 is constructed at the base of a landfill. Assuming that the maximum elevation of the leachate at the top of the liner would be only 30 cm (~1ft) and the pore pressure below the liner is assumed atmospheric, the time required for the leachate to appear at the bottom of the liner considering only advection would be most likely:

a. ~ 7 years b. ~ 14 years c. ~ 25 years d. 70 years

$z = 90$ cm, $k = 10^{-8}$ cm/s, $n = 0.333$, $\Delta h_L = 30$ cm
only advection → $\alpha = 0$, $D = 0$, $D^* = 0$ → only controlled by v_s
$v_s = \frac{v_d}{n} = \frac{ki}{n} = \frac{k}{n}\left(\frac{\Delta h_L + z}{z}\right) = \frac{z}{\Delta t}$
$\Delta t = \frac{n z^2}{k(\Delta h_L + z)} = \frac{0.333(90\text{cm})^2}{10^{-8}\text{cm/s}(30\text{cm}+90\text{cm})} = 7\text{yrs}$ × conversion

5. The concentration of a particular chemical in the leachate of a landfill is 1000 ppb (parts per billion). The constrained molecular diffusion for this chemical is $D^* = 5 \times 10^{-6}$ cm²/sec. Assume for this part of the problem that the contaminant is not adsorbed into the liner (R=1). If the initial background concentration is zero and that transport results only from molecular diffusion, the concentration of this chemical at the bottom of a clay liner (thickness ~ 90 cms) at the end of 5 years is approximately:

a. 20-25 ppb b. 200-250 ppb c. 2-5 ppb d. ~1000ppb

$C_0 = 1000$, $D^* = 5(10^{-6})$ cm²/sec, $R = 1$, $z = 90$ cm, $\Delta t = 5$ yrs
$C = C_0 \operatorname{erfc}\left(\frac{Rz}{2\sqrt{D^* R \Delta t}}\right) = 1000 \operatorname{erfc}\left(\frac{1 \cdot 90\text{cm}}{2\sqrt{5(10^{-6})\text{cm}^2/\text{sec} \cdot 1 \cdot 5\text{yrs}; \text{conver}}}\right)$
$= 1000 \operatorname{erfc}(1.603) = 1000 \cdot 0.02365 = 23.65$

6. While discussing with your colleagues the suitability of this liner you suggest mixing "zeolites" with your clay material before compacting the liner. You know that the contaminant will be adsorbed into the zeolite particles as it travels through the liner and preliminary tests suggest a retardation factor of 2 (R=2). All the other parameters remain the same. It is presumed that the addition of zeolites will not change the hydraulic conductivity, the constrained molecular diffusion or the dispersivity. The longitudinal dispersivity for this liner is 1 cm. With this new design the concentration of the above chemical (i.e., C_0= 1000 ppb) at the bottom of a clay liner (thickness ~ 90 cms) at the end of 5 years, based on advection, dispersion and diffusion is approximately:

a. same as before b. 200-250 ppb c. 20-50 ppb d. 1-2 ppb

$R = 2$, $\alpha_L = 1$ cm, $D_L = D^* + \alpha_L v_s$
$v_s = \frac{k}{n}\left(\frac{\Delta h_L + z}{z}\right) = \frac{10^{-8}\text{cm/s}}{0.333}\left(\frac{30\text{cm}+90\text{cm}}{90\text{cm}}\right) = 4.004(10^{-8})$
$D_L = 5(10^{-6})\text{cm}^2/\text{s} + 1\text{cm} \cdot 4(10^{-8})\text{cm/s} = 5.04(10)^{-6}\text{cm}^2/\text{s}$

$\frac{v_s z}{D} = \frac{4(10^{-8})\text{cm/s} \cdot 90\text{cm}}{5.04(10^{-6})\text{cm}^2/\text{sec}} = 0.7 < 1$ → diffusion dominates!

$C = C_0 \operatorname{erfc}\left(\frac{Rz}{2\sqrt{D^* R \Delta t}}\right) = 1000 \operatorname{erfc}\left(\frac{2 \cdot 90\text{cm}}{2\sqrt{5(10^{-6})\text{cm}^2/\text{s} \cdot 2 \cdot 5\text{yrs} \cdot \text{conversions}}}\right) = 1000 \operatorname{erfc}(2.504) = 1.46$ ppb

lower concentration due to organics/retardation