GCL HYDRAULIC PERFORMANCE: A DISCUSSION OF FLUX, PERMEABILITY, AND DESIGN APPLICATIONS OF THESE CONCEPTS

Introduction

This information is offered to assist engineers and regulators in understanding the basic hydraulic performance parameters for geosynthetic clay liners (GCLs) and how they would be applied to evaluate product performance for a given design.

Definitions

Permeability. A mathematical constant (k) determined by measuring water flow through a soil or other layer under a prescribed set of conditions. For soils, permeability is measured using flexible-wall permeameters in accordance with ASTM D 5084. The GCL flux test method (ASTM D 5887) also contains procedures for calculating permeability. Permeability is essentially synonymous with *hydraulic conductivity,* although this term may be more strictly interpreted as correct only if water is the permeant.

Flow. The total quantity of leakage through a soil or barrier layer in a given time, expressed in units of volume/time.

Flux. The rate of flow per unit area per unit time through a soil or barrier layer, typically expressed in $m^3/m^2/sec$. It may also be expressed in L/Ha/day or other more intuitively helpful units.

Discussion

It is important to recognize that permeability data only gives a relative indication of the performance of a barrier layer such as a clay soil or a GCL. Permeability is not a direct measure of leakage, nor of the velocity of water as it penetrates through the barrier layer. If the expected *performance* of a product is to be determined, total leakage is the best parameter to evaluate. Comparing total leakage between two types of liner systems allows the designer to make informed decisions as to which system might be expected to offer superior performance.

Total leakage may either be measured directly or calculated using Darcy's Law, Q = kiA, where:

Q = Total leakage, m^3/sec
k = permeability, m/sec, determined from testing
i = hydraulic gradient, dimensionless (m/m)
= (hydraulic head + barrier thickness) / barrier thickness
A = area over which leakage occurs, m^2

Because most GCL applications involve replacing a compacted clay liner (CCL) of specified thickness and permeability, the above equation can be used to quantify the theoretical performance of the CCL such that a design comparison can be made.

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"Q" This is total flow, the parameter that theoretically tells how much leakage is occurring. If the test conditions are reasonably close to the site conditions, then this parameter should also reflect the performance at the site, not including, of course, installation-related factors, which cannot be duplicated in a laboratory test.

"k" This is the permeability, as determined by laboratory testing. **Note that k is a calculated value, not a directly measured value, and that a laboratory "permeability test" actually is a flow test (i.e., a "Q" test) from which we obtain "Q" and solve Darcy's Law for "k."**

"i" This is the hydraulic gradient, an indicator of the amount of hydraulic driving force on the barrier layer. It is determined by the height of water above the barrier and the thickness of the barrier itself. This means that thick barriers have lower gradients than thinner ones.

"A" This is the area through which flow occurs. For the sake of simplicity, it can be assumed that the area is just one square meter, so that a "Q" value is expressed on a 'per unit area' basis.

A designer needs to determine the expected flow through the liner under specific site conditions. These conditions are probably not similar to the test conditions used by the GCL manufacturer to report their specified properties. Most permeability/flux data reported by a manufacturer is obtained for MQC purposes under test conditions specified in ASTM D 5887 of permeating distilled/deionized water at 5 psi (35 kPa) confining pressure and 2 psi (14 kPa) head pressure. It is usually a mistake to apply a standard permeability or flux figure taken from a tech data sheet for use as a design value, *unless* the designer has a site where the liquid being contained has low ionic strength and there will be approximately 5 psi (35 kPa) confining pressure and 2 psi (14 kPa) head pressure. Otherwise, the hydraulic conductivity value of $k = 5 \times 10^{-11}$ m/sec and flux or 1×10^{-8} $m^3/m^2/s$ are not applicable.

Another reason why ASTM D5887 test data may not represent site performance is because we often cannot perform a routine test under the most common site conditions. For example, landfill cap landfill and liner systems are usually designed with a maximum hydraulic head of 300 mm. In reality, this is a miniscule driving force for a laboratory to reproduce without some specialized, expensive and non-standard equipment. It is not possible to consistently apply a 300 mm driving head (equivalent to just 0.43 psi or 3 kPa) using standard flexible-wall permeameters. The random fluctuation in the pressurization system for the permeameters is about 1 psi or 7 kPa, so setting a head pressure at 3 kPa could result in a *negative* pressure some of the time during the test. The pressure parameters of the ASTM flux test are within the limits of generally available equipment in order to ensure reproducibility and repeatability.

Suppose an MQC test report shows a permeability result of 1×10^{-11} m/sec. It's an MQC report, so the test conditions were 35 kPa confining pressure and 14 kPa head pressure as per ASTM D 5887. What does this mean in terms of performance? Is it applicable to site conditions? Here's a 3-step procedure to answer these questions:

1. **Compare head pressures**
   The ASTM standard requires a head pressure of 2 psi or 14 kPa. 14 kPa is the same as 14 kN/m^2. Since this is water pressure, we can describe it in terms of the height of a column of water that exerts a force of 14 kN over one square meter. Because the density of water is approximately equal to 9.81 kN/m^3, the hydraulic head is (14 kN/m^3) / (9.81 kN/m^3) = 1.42 m. This is the first

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parameter to check against site conditions. Is the hydraulic head at the site less than or greater than 1.42 m? If greater, then the test has not accurately modeled site conditions and the test will yield a lower flux than what will occur at the site.

2. **Compare confining stresses**
The confining stress is the compressive force on the sample, and in the ASTM test, it is required to be 5 psi or 35kPa, which is equal to 35 kN/m^2. Assuming a "typical" soil density of 1,500 kg/m^3, and recognizing that 1 kN = 102 kg, we can convert to an equivalent depth of soil as follows: equivalent soil depth = (35 kN/m^2)(102 kg/kN) / (1,500 kg/m^3) = 2.38 m. For landfill bottom liners, it is possible to divide by an assumed density for waste, say 1,000 kg/m^3, obtaining an equivalent refuse height of 3.57 m. This is the second parameter to check against site conditions. Is the typical soil burial depth or height of waste at the site similar to the test conditions? If the height of waste is less than the confining pressure, the testing will give lower flow values than what would actually occur in situ. If the height of waste is greater than the test confining pressure, the testing will give greater flow than what would actually occur in situ. Petrov et al 1997 estimate that GCL hydraulic conductivity and confining pressure when permeated with distilled water are related by the following expression:

$$\text{Log } k_{DI} = -8.0068 - 0.5429 \text{ Log } \sigma$$

Where k_{DI} is in cm/s and σ is in kPa.

3. **Compare hydraulic gradients**
The hydraulic gradient "i" is calculated as (head + thickness) / thickness. Experience tells us that the average thickness of a bentonite liner under these stress conditions is about 0.24 inches or 0.0061 m. Then i = (1.42 m + 0.0061 m) / 0.0061 m = 234. The gradient for site conditions would be calculated based on the design head pressure and the bentonite thickness at the design confining pressure. Generally, bentonite barrier thicknesses will range from 5-10 mm. An increase in gradient will result in an increase in flux.

4. **Compare ionic strength and RMD**
The hydraulic conductivity is affected by the relative prevalence of divalent and monovalent cations. TR-254 discussed the predicted GCL hydraulic conductivity based upon ionic strength and ratio of monovalent to divalent cations (RMD).

We can use all of the above information to calculate leakage as Q = (1 x 10^{-11} m/sec) (230) (1 m^2) = 2.3 x 10^{-9} m^3/m^{2}sec. This number is difficult to understand, but it can be converted to liters per square meter per day by multiplying by 86,400 sec/day and then by 1,000 L/m^3. Doing so results in a leakage rate of 0.2 liters/m^2/day.

Ultimately, the real question is, what is the significance of this number? What is "acceptable?" What is "unacceptable?" To CETCO's knowledge, these questions have no definite technical answer except that bentonite-based liners are often compared to traditional compacted clay liners. So Darcy's Law can be used to determine leakage through the GCL under similar conditions to make a statement as to whether the GCL is equivalent. Such comparisons are found in CETCO's TR-303 or in the Koerner and Daniel paper on "technical equivalency" found in the Proceedings of the 7th GRI

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Seminar, 1994. In most cases, GCLs are found to outperform compacted clay liners, although this may not be the case in the presence of high head pressures or high ionic strength.

References:

Petrov, R.J., Rowe, R.K., and Quigley, R.M., “Selected Factors Influencing GCL Hydraulic Conductivity”, *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, Vol. 123, No. 8, August 1997, pp. 683-695.

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