Effects of inorganic leachate on polymer treated GCL material

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ABSTRACT: In the United States, the use of geosynthetic Clay Liners (GCL) in waste containment applications is rapidly increasing. In areas were low permeability soils are not readily available, the design engineer may be allowed to substitute the required clayey soils in double liner systems with GCL material as long as the GCL compatibility with the landfill leachate can be demonstrated. GCL material is currently available as treated and untreated. The untreated GCL material consists of sodium bentonite sandwiched between two geotextile fabrics. The treated GCL consists of a bentonite layer that has been synthetically treated by the manufacturer to render it unreactive to most chemicals. Leachate generated from municipal ash landfill contains very high calcium concentrations. In this paper, multiple hydraulic conductivity tests on chemically treated and untreated GCL samples are conducted using synthetic seawater solution containing similar chemical composition as ash leachate. Methods and calculations used to demonstrate the GCL equivalency to natural low-permeability soils to satisfy the local environmental laws and regulations are discussed.

1 INTRODUCTION

Municipal solid waste landfills (MSW) are required to be designed and constructed with a liner system to minimize the potential of groundwater contamination. The U.S. Environmental Protection Agency (EPA) established minimum design criteria that must be met when designing and constructing landfills. These criteria were established in the Code of Federal Regulations (40 CFR 261) under Subtitle D. The minimum design criteria require, among other things, the incorporation of low permeability soils, typically 1 x 10^{-7} cm/sec, in the liner design.

MSW and ash landfills are the two of the most common landfill types in the United States. Municipal solid waste landfills dispose of unprocessed solid waste. Leachate generated from these landfills tends to have a high concentration of organic contaminants. Ash landfills are those that dispose of ash residue generated from the incineration of municipal solid waste. Leachate generated from these landfills contains high concentrations of electrolytes (salts).

In regions where natural low permeability clay deposits are not available, geosynthetic clay liners (GCL) may be used to replace or augment natural clays as long as the selected GCL is chemically compatible with the liquid being contained. The American Standard Test Method (ASTM D4439) defines GCL as follows:

Geosynthetic clay liners are factory manufactured hydraulic barriers typically consisting of bentonite clay or other very low permeability material, supported by geotextile and/or geomembranes, which are held together by needling, stitching, or chemical adhesive.

GCL is available as polymer treated or untreated. The GCL material manufactured in the United States typically contains natural sodium montmorillonite (bentonite). Bentonite is not a clay mineral. It is a rock (or clay deposit) composed largely of the clay mineral montmorillonite. Polymer treated GCL renders the material non-reactive towards most organic and inorganic chemical compounds.

Laboratory results suggest that polymer treated GCL maintain their low permeability when hydrated with liquid containing elevated levels of electrolytes. This paper will discuss and present an experimental laboratory data for polymer treated GCL hydrated for an extended period of time with synthetic solution containing elevated concentrations of electrolytes. Before discussing laboratory results, it is important to understand the characteristics of the bentonite and the factors that can increase its permeability.

2 BENTONITE ORIGIN AND CHARACTERISTSICS

Bentonite forms from the weathering of volcanic ash and occurs as the result of a chemical transformation from acid volcanic ashes, which have been deposited in the sea (Na-montmorillonite) or in fresh water (Ca- montmorillonite). Bentonite achieves its low permeability by swelling and can adsorb water up to seven times its dry weight and swell up to eight times its original size. The swelling capacity of the bentonite depends on many factors including bentonite composition, grain fineness, cation capacity, inorganic and organic chemical concentration in the permeating liquid. These organic and inorganic compounds can limit the swelling capacity of the bentonite, which in turn could cause an increase in permeability. Factors that can negatively affect the permeability of the bentonite during testing include percent type, confining pressure, first wetting liquid and type of testing equipment.

Bentonite permeability may increase as a result of the alterations in its soil fabric stemming from chemical influences on the double layer thickness surrounding the clay particles. Generally speaking, a decrease in the double layer thickness will cause an increase in the soil permeability. It has been found that a reduced-double layer thickness could "*transform a massive, structureless, and slowly permeable clay barrier into an aggregated, structured, and more permeable barrier*" (Anderson and Jones, 1983).

3 TESTING PROGRAM

A laboratory-testing program (program) was setup to determine the long-term reliability of polymer treated GCL when exposed to inorganic solution. Untreated GCL material was also tested for permeability with the inorganic solution for comparison purposes. The permeant used for the program consisted of synthetic seawater at 3.5 percent concentration. The synthetic seawater solution was selected as the permeant because it contains chemical compounds that are similar to what is commonly found in ash leachate. The ions of concerns are calcium and magnesium. These chemical components can negatively impact the permeability of GCL material. Table 1 depicts the concentrations of these chemicals in the synthetic seawater solution:

Table 1. Ion Concentrations in Synthetic Seawater Solution

Ion	Concentration (ppm)
Magnesium	1,317
Calcium	398

3.1 *Sample Preparation and Testing Method*

The program tested multiple samples with time duration varying between 19 and 175 days. The GCL samples used for the program composed of Na-Bentonite and Ca-Bentonite bound between two layers of geotextile fabrics. Each sample had an approximate thickness of 1 cm and was cut from the parent material in a circular pattern. The exposed sample edge was sealed with a bentonite paste made by mixing bentonite granular and water.

The testing program was conducted in general accordance with ASTM D5887, “Standard Test Method for Measurement of Index Flux through Saturated Geosynthetic Clay Liner Using a Flexible Wall Permeameter. For this testing program a flexible wall permeameter with a 10-cm diameter was used for the permeability measurement. Each sample was positioned between two porous filter stones and placed in the permeameter. The sample and the stones were engulfed in a latex membrane and were allowed to hydrate with the synthetic seawater solution for a period of 48-hours prior to the start of the permeability measurements.

3.2 *Confining Pressure*

It has been reported that testing under high confining pressure may cause fine grain soils to have an artificially low permeability value. When Daniel et. Al. (1997) conduct permeability testing on GCL material using a confining pressure between 5-10 kPa, the resulting hydraulic conductivity was 10^{-9} cm/sec. When the hydraulic gradient was increased to 300 kPa, the permeability decreased to 10^{-10} cm/sec.

The ASTM method D5887, specifies a maximum compressive stress value of 35 kPa, however, no minimum value is specified. For this testing program the permeability was measured under a maximum confining pressure of 34.5 kPa.

3.3 *Hydraulic Gradient*

Several studies have been conducted to determine the effect of the hydraulic gradient on the permeability of compacted clays, Oakes (1960), Hansbo (1960), Mitchell and Younger (1967). Due to the low permeability of fine-grained soils, it will take considerable amount of time for the permeant to fully saturate and penetrate the soil layer under a low hydraulic gradient. Therefore, for laboratory measurement, it has been customary to test using high hydraulic gradients to determine the hydraulic conductivity of fine-grained soils. Zimmie (1981) recommended a hydraulic gradient between 5 to 20. Anderson and Brown (1981) conducted permeability measurement using hydraulic gradients as high as 362, Lutz and Kemper (1959) used hydraulic gradient of 900.

The ASTM D5084 standard recommends a maximum hydraulic gradient of 30 when testing low permeability soils. For this testing program a hydraulic gradient of 140 was used in an effort to maximize the pore volume. The use of high hydraulic gradient can shorten the testing duration and can simulate the exposure of GCL to the permeating liquid for extended duration.

4 RESULTS

The permeability for each sample was calculated and recorded. Table 2 summarizes the test results for the Na-Bentonite GCL.

Table 2 – Permeability of Na-Bentonite GCL

Sample	GCL Type	Test Duration (days)	Initial Permeability (cm/s)	Final Permeability (cm/s)
A	Standard	75	1.70×10^{-9}	2.24×10^{-6}
B	Standard	75	1.50×10^{-9}	5.45×10^{-7}
C	Treated	75	1.60×10^{-9}	3.43×10^{-8}
D	Treated	75	1.40×10^{-9}	1.03×10^{-7}
E	Treated	75	3.57×10^{-9}	7.27×10^{-9}

The following charts depict the variation of permeability with time for the above samples.

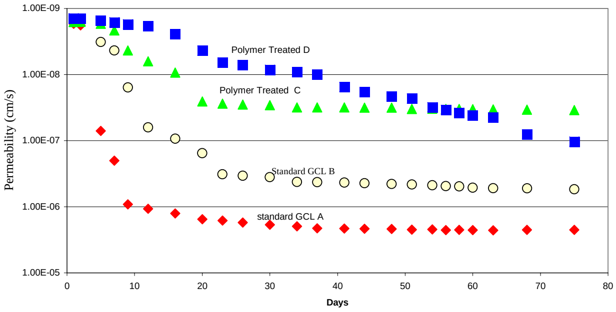

Chart 1
Performance with Time of GCL
Permeated with 3.5% Synthetic Seawater

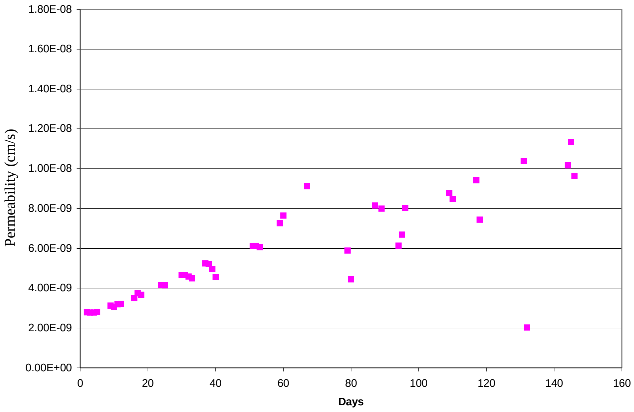

Chart 2
Performance with Time of GCL Sample E
Hydrated with 3.5% Seawater Solution

5 EQUIVALENCY CALCULATIONS

In the United States Certain environmental protection agencies allow the use of double synthetic liners in landfill applications. As a requirement for designing with a double liner system, the designer is required to provide a 15-cm thick soil with hydraulic conductivity of 1 x 10^{-5} cm/sec under the secondary liner. When low permeability soils are not available, the designer may substitute the soil layer with GCL as long as it can be demonstrated that the GCL's laboratory measured permeability is equivalent to the soil layer being replaced. The designer is also required to provide shear strength calculation for the GCL layer to demonstrate stability.

5.1 *Permeability Equivalency Calculation*

To demonstrate permeability equivalency of the GCL with the 15-cm low permeability soil layer; the Darcy's law equation is used:

$$Q=KIA \tag{1}$$

Where:
Q = Flow rate, (m^3/sec)
K = Hydraulic conductivity (cm/sec)
I = Hydraulic gradient = (h_1-h_2)/L (dimensionless)
h_1-h_2 = Difference in hydraulic head (cm)
L = Distance along the flow path between
The points where h_1-h_2 is measured (cm)
A = Cross sectional area (cm^2)

The leachate head above the liner system is assumed to be at the maximum allowable head of 30 cm.

Calculation for the 15-cm soil layer:

Q = Unknown
K = $1x10^{-5}$ cm/sec (required by rules)
(h_1-h_2) = 30 cm
L = 15 cm
I = (h_1-h_2) /L= 2
A = 1 cm^2

Solve for Q= 2 x $10^{-5}$$cm^3$/sec/$cm^2$

Calculation for the GCL layer:

Q = Unknown
K = $3.43x10^{-8}$ cm/sec (Sample C)
(h_1-h_2) = 30 cm
L = 0.5 cm
I = (h_1-h_2)/L = 60
A = 1 cm^2

Solve for Q= $\underline{2.06x10^{-6}}$ cm^3/sec/cm^2

Based on the above calculations, the GCL material permeability is significantly less than the permeability of the 15-cm soil layer since the calculated flow rate through the GCL ($2.06x10^{-6}$

cm^3/sec/cm^2) is less than the calculated flow rate through the 15-cm soil layer (2x10^{-5} cm^3/sec/cm^2). Therefore, it can be concluded that this particular GCL material is suitable for use in place of the 15-cm soil layer.

5.2 *Shear Strength Calculations*

The following is a sample calculation:

Calculate the safety factor for the side slopes using the following equation:

$$F.S. = \frac{\text{Resisting force}}{\text{Driving force}} = \frac{((T/L) + S)}{Z*\gamma*\sin\beta} \qquad (2)$$

Where:

F.S.= Factor of safety
T= Allowable tensile strength = 6.2 kN/m
(supplied by the manufacturer)*
L=Slope length= 4.5 m (from design plans)
S= Shear strength along critical surface
$= z * \gamma * \cos\beta * \tan\theta + C$
γ= Unit weight of soil kN/m^3 = 14.5 kN/m^3
Z= Thickness of cover soil = 0.6 m
β=Slope angle (degrees)= 18.4^o (3:1 slope)
θ= Internal friction angle (degrees) = 5^o
(supplied by the manufacturer)*
C= Cohesion = 21 kPa (supplied by the
manufacturer)*

Results obtained from CETCO's published literature on internal direct shear testing of Bentomat GCL under normal stresses of 96, 480 and 980 kPa.

$$S = (14.5)*(0.6)*(\cos 18.4)*(\tan 5) +21 = 22 \text{ kN/m}^2$$

$$F.S. = \frac{(6.2/4.5) + 22}{(2)*(14.5)*(0.31)} = 5.5$$

Typical F.S. recommended by Geosynthetic Research Institute is 1.4. Therefore, the material is acceptable.

6 GCL ECONOMICAL ADVANTAGES:

The use of GCL in liner applications will provide definite practical and economic advantages to design professionals, landfill owners and operators. Based on actual landfill construction costs, the polymer treated GCL installed cost was $4.50/sq. meter versus $7/sq. meter for natural low permeability clay (10^{-7} cm/sec). The cost differential can be even more dramatic when standard GCL material is used in place of natural clay liners. For an actual landfill liner project, the material and installation cost for standard GCL was $2.50/square meter.

The GCL material can be installed within short time duration. Typically 10,000 m^2 of GCL can be installed on a daily basis. Additionally, the cost of implementing a field quality assurance/quality control program for natural clay installation is substantially higher than that for GCL material. The GCL offers other advantages including, consistent product quality, material manufacturing and shipping is not affected by wet weather periods and has less settlement when compared to thick natural clay liners.

7 CONCLUSION

This experimental testing program demonstrated that the polymer treated GCL can be used in an environment containing liquid of high electrolyte concentration. The results obtained under this program are assuring, however, they can't be generalized. When considering the use of GCL in lining applications, it is recommended that permeability compatibility testing be performed using the actual solution as the permeant. The test results should be evaluated by the design professional to determine application suitability.

Additional studies are still needed to determine the long term effect of actual inorganic solution on polymer treated GCL. Test period of at least one year or greater is still needed

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