

DESIGN CONSIDERATIONS FOR GCL COVER SYSTEMS

INTRODUCTION

Compacted clay liners (CCLs) in cap applications are difficult to construct and are subject to deterioration from differential settlement and freeze-thaw. In an EPA field study Rogowski (1990) found that CCL field permeabilities were up to several orders of magnitude higher than expected by laboratory permeability tests. LaPlante and Zimmie (1992) found CCL hydraulic conductivity increased two orders of magnitude from freeze-thaw cycles. LaGatta et al. (1997) state that CCLs fail at only 0.1-4% tensile strain whereas GCLs can withstand up to 12% strain. Geosynthetic clay liners (GCLs) have been increasingly utilized in lieu of CCLs to overcome these problems, but certain design considerations must be made in GCL cap applications. The sodium bentonite component of GCLs is affected by confining pressure, ion exchange and desiccation.

FACTORS AFFECTING GCL PERFORMANCE

Confining Pressure

The permeability of sodium bentonite is inversely proportional to confining pressure. Petrov and Rowe (1997) determined that there is an increase in hydraulic conductivity of GCLs subjected to low confining pressure compared to the standard 5 psi confining pressure used in ASTM D5887. From their equation, there is an estimated 85% increase in hydraulic conductivity at 1.7 psi confining pressure (equivalent to 2 feet of 120 pcf soil) and an estimated 50% increase in hydraulic conductivity at 2.5 psi confining pressure (equivalent to 3 feet of 120 pcf soil).

Ion Exchange

Recent laboratory and field research indicated that the sodium bentonite component of GCLs is subject to changes from ion exchange and desiccation. Ion exchange occurs when divalent ions, primarily calcium, replace the sodium ions attracted to the surface of the clay platelets. Ion exchange is a concern because naturally occurring calcium bentonite has a hydraulic conductivity of $\sim 10^{-5}$ cm/s.

Jo et al. (2001) reported laboratory studies that indicated that the effect of inorganic chemicals on nonprehydrated sodium bentonite is related to both valence and concentration. Kolstad et al. (2004) built upon this work and developed a relationship between ionic strength and relative abundance of monovalent to divalent cations (RMD) to nonprehydrated GCL hydraulic conductivity (see TR-254).

Egloffstein (2000) presents a theory on prehydration of sodium bentonite. Sodium bentonite undergoes an initial osmotic swelling which results in colloidal dispersion. Naturally occurring calcium bentonite does not undergo dispersion due to its higher valence and electrostatic attraction (see Figure 1). This dispersed platelet structure of sodium bentonite in part contributes to its low hydraulic conductivity by creating a tortuous pathway for free water molecules to flow.

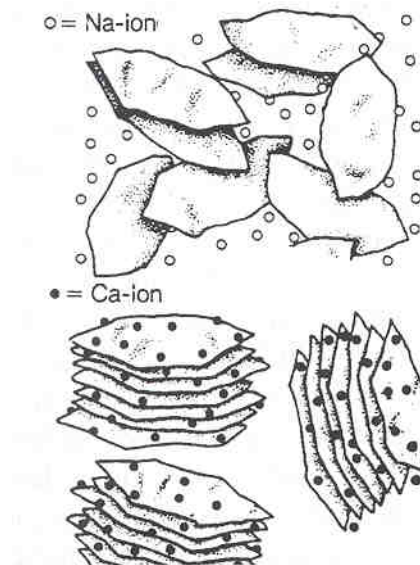


Figure 1. Dispersion of sodium montmorillonite platelets compared to naturally occurring calcium montmorillonite (Jasmund & Lagaly 1993)

This dispersed orientation can be maintained after swelling even if the pore water divalent concentration increases. An ion exchange of the sodium with divalent cations can take place over one to several years. The exchange continues until there is an equilibrium balance between the ion distribution on the surface of the bentonite and the ionic concentration in the pore water. Although the divalent cations cause a certain reduction in volume, some of the dispersed micro-structure is maintained as long as there is sufficient confining pressure. Thus, the resulting hydraulic conductivity is lower than that of naturally occurring calcium bentonite. Egloffstein estimated an increase in permeability of 3-5 times after ion exchange. Figure 2 compares the microstructure of virgin sodium bentonite, ion exchanged sodium bentonite, and calcium bentonite. The photo in Figure 2a is natural sodium bentonite with its dispersed honey-combed structure. The photo in Figure 2b is the sodium bentonite after permeation with a 0.3M CaCl_2 solution. The honeycombed structure remains, however, somewhat thicker. Figure 2c is bentonite from an excavated GCL sample. It is quite similar to Figure 2b. Figure 2d is a naturally occurring calcium bentonite with a thick flat aggregate structure.

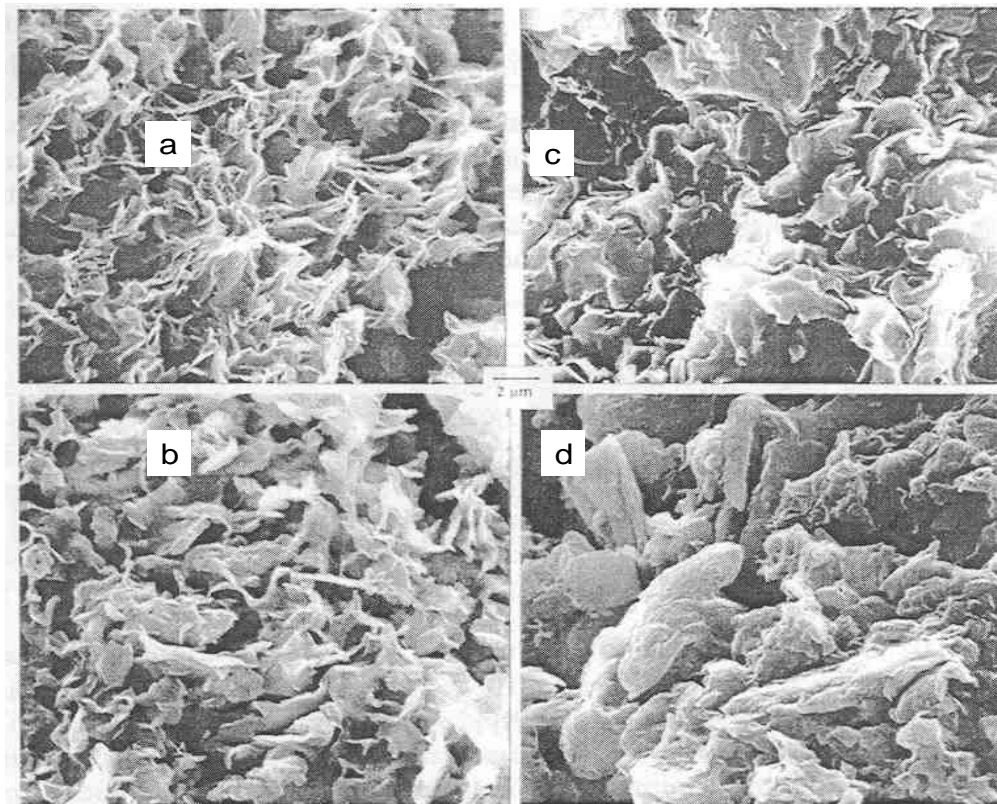


Figure 2. Comparison of montmorillonite micro structures using electron scan microscope pictures (Egloffstein 2000)

However, Lin and Benson (2000) performed laboratory work that suggests that desiccation can negate the beneficial effects of prehydration. Tests alternated permeation under 2.5 psi confining pressure and air drying under zero confining pressure. When a GCL was initially hydrated with deionized water, and then subjected to multiple wet-dry cycles with permeation with a 0.0125M CaCl_2 solution, the hydraulic conductivity increased to $>10^{-6}$ cm/s after 8 wet-dry cycles.

Field study data provide some good examples of what can be expected with varying confining pressure. Melchior (1997) tested a sodium bentonite GCL under 1 foot of cover at a landfill site in Germany. Shortly after one year, the GCL produced high leakage rates up to 1×10^{-7} m³/m²/s, an order of magnitude greater than typical GCL certified index flux at 4.6 foot head pressure. Desiccation cracking was observed in exhumed samples.

GCL samples were exhumed from two landfill cover systems in the Southeast U.S. (Mackey and Olsta, 2003). Original laboratory tests for the lots of GCL material installed indicated hydraulic conductivities of 1.2 to 2.3×10^{-9} cm/s at 2 psi confining pressure.

Chemistry tests of the exhumed samples revealed that they had undergone significant ion exchange. Permeameter tests conducted at 2 psi confining pressure indicated a decreasing hydraulic conductivity with increasing depth (see Figure 3), but the hydraulic conductivity at 34 inches cover was still 2 to 4 times the initial hydraulic conductivity.

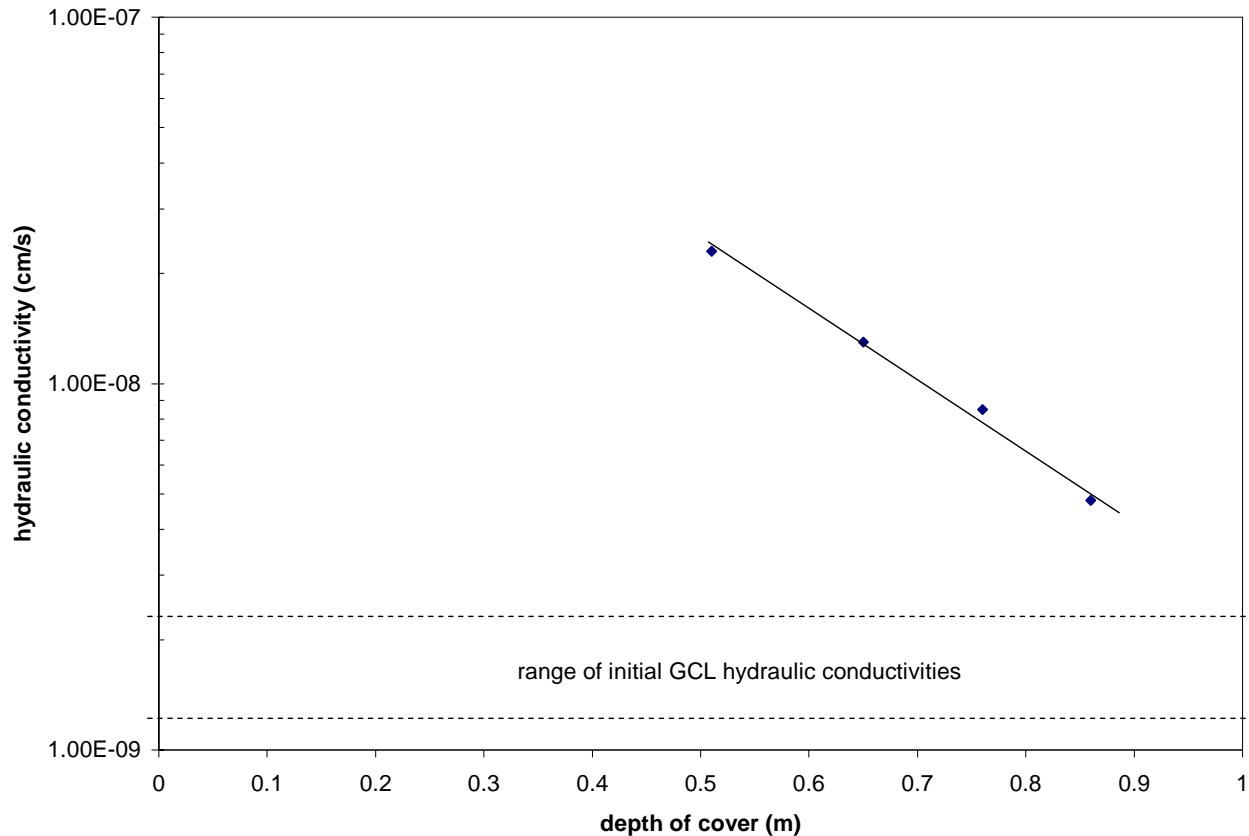


Figure 3. Hydraulic conductivity of exhumed GCL samples versus depth of cover soil.

GUIDELINES

So what permeability can be expected in a typical cover application? It will depend on pore water soil chemistry the cover soil confining pressure and whether the GCL is protected from desiccation. The aqueous solubility of calcite (limestone) is quite low, 0.0006M Ca^{+2} , while gypsum has aqueous solubility of 0.015M Ca^{+2} . However, the solubility increases dramatically with lower pH. At pH 5, typical of acid rain, the solubility of free calcium from calcite is 0.2M Ca^{+2} . Thus, if the GCL is in contact with high ionic strength soil then ion exchange of the bentonite can be expected to occur during hydration. This would result in a significant increase in hydraulic conductivity.

CETCO suggests the following guidelines when designing a GCL cap:

- Avoid high ionic strength pore water soils in direct contact with the GCL. This will allow for proper prehydration of the GCL bentonite that creates the dispersed platelet structure needed for low permeability.
- Assume a higher hydraulic conductivity than the ASTM D5887 certified hydraulic conductivity due to the lower confining pressure. For example, at 2.5 psi confining pressure, assume a 50% increase in hydraulic conductivity.
- The use of membrane-laminated GCLs or composite cap systems including both GCL and an overlying geomembrane should be considered in landfill final cover applications. Membrane-laminated GCLs, such as Bentomat CL, Bentomat CLT and Claymax 600CL can be economical alternatives for use in cap applications.

Using the previous referenced literature and Darcy's Law, $Q/A = k \cdot i$, it is possible to estimate the following hydraulic conductivity comparisons for CCL and GCL covers with 1 foot of head:

Compacted Clay

Initial hydraulic conductivity	1×10^{-7} cm/s
Increase in hydraulic conductivity	100
Long-term hydraulic conductivity	1×10^{-5} cm/s

Geosynthetic Clay Liner w/ 36" of cover

Initial hydraulic conductivity	5×10^{-9} cm/s
Increase in permeability due to confining pressure	1.5
Increase in permeability due to ion exchange	3
Long-term hydraulic conductivity	2.2×10^{-8} cm/s

Giroud (1997) developed empirical equations for leakage through defects in composite systems. In the equations, the leakage is controlled by the hydraulic conductivity of the underlying soil or GCL. Thus, a GM/GCL composite cap would be expected to outperform a GM/CCL composite cap.

CONCLUSIONS

Compacted clay liners have been shown to be difficult to construct and can undergo significant (several orders of magnitude) increases in permeability due to desiccation, freeze-thaw and differential settlement. For these reasons, GCLs have become increasingly used in cap design. Nevertheless, designers need to be aware of the effect of low confining pressure, ion exchange and desiccation on the long-term performance of GCLs. However, a well designed GM/GCL cap is still expected to outperform a GM/CCL cap.

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