Bentofix® GCL Resistance to Cation Exchange

Bentofix® GEOSYNTHETIC CLAY LINERS

Bentofix® Hydraulic Performance

Bentofix® consists of a layer of high grade sodium bentonite encapsulated between woven and nonwoven geotextiles and internally reinforced to provide swelling and sealing in many containment applications. The key sealing element of the product consists of sodium bentonite which, when pre-hydrated with a compatible liquid, has proven to perform long-term over a range of different applications. This includes contact with a variety of different chemicals and leachates if protected properly.

When hydrated and permeated with clean rainwater or compatible dipolar liquids (such as typical leachates), the hydraulic conductivity of sodium bentonite based GCLs, including Bentofix, results in the range of values shown in Figure 1 (Thiel et al., 2001). Over a range of normal loads, sodium bentonite GCLs provide excellent hydraulic performance, several orders of magnitude below conventional compacted clay liners (k-values typically ≥ $1x10^{-9}$ m/s). Figure 1, as compiled by Dr. David Daniel, can be used to estimate the design hydraulic conductivity value of a typical sodium bentonite based GCL when exposed to compatible liquids under a given design normal load.

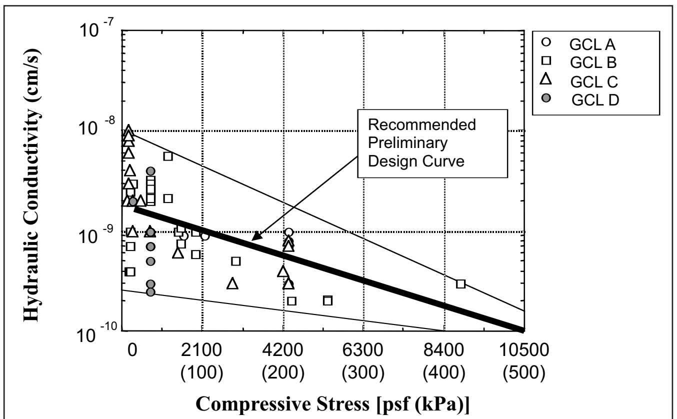

Figure 1. Hydraulic Conductivity of Sodium Bentonite Permeated with Fresh Water as a Function of Normal load. (Thiel et al., 2001).

Sodium Bentonite and Cation Exchange

If a liquid percolates down to and through the GCL containing significant electrolytes [including potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), and aluminum (Al^{+++}) cations], these positively charged cations will preferentially exchange with the sodium (Na^+) cation in the bentonite (referred to as cation exchange). This results in reduced swelling capacity and increased hydraulic conductivity of the bentonite. The higher the charge (or valence) of the cation, the more preferential and readily it will exchange with the Na^+ cations within the bentonite platelet structure.

The extent of the cation exchange is dependent upon the cation exchange capacity (CEC) of the soil, or the amount of cations a soil can hold. But generally, most all soils contain an abundance of salts that contain significant concentrations of K^+, Ca^{++}, Mg^{++}, or Al^{+++}. The least favorable cations with regard to cation exchange of Na^+ in bentonite are the polyvalent cations, which have a charge of +2 or more. Of the cations found in soils, calcium tends to produce by far the most significant adverse effects on bentonite swelling due to its abundance in most all soils (Thiel et al., 2001).

Figure 2 depicts the concept of the micro-structure and the permeability of a Na-bentonite vs. Ca-Bentonite (Egloffstein, 2002). As shown, hydrated Na-bentonite consists of finely dispersed clay particles, or platelets, with lower flow-efficient pore spaces resulting in longer flow paths around the clay particles due to higher water binding capacity. Conversely, the divalent Ca-bentonite particles are subjected to higher surface tensions and tightly bound clay platelets resulting in aggregate clay particles, decreased swelling potential, and increased interstitial flow (Egloffstein, 2002).

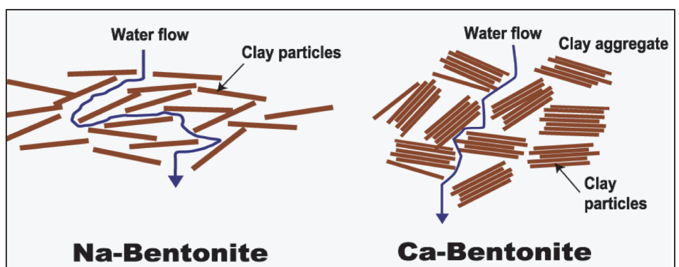

Figure 2. Micro-structure and permeability of bentonite clays. Left: dispersed clay including sodium bentonite. Right: aggregated clay such as course calcium bentonite (Egloffstein, 2002).

The reason sodium bentonite is the preferred clay in most all commercially available GCLs is that with sodium in the bentonite structure, hydraulic conductivity tends to be extremely low as shown in Figure 1. Under low normal loads, if the sodium is replaced by calcium, the hydraulic conductivity of bentonite will increase from one to three orders of magnitude.

- Continued -

Significant cation exchange can occur in unprotected sodium bentonite in most soil environments within several months to several years (Egloffstein, 2002). Thus, a very important factor affecting the hydraulic conductivity of GCLs is the type and valence of the cations within the bentonite platelet structure.

Minimizing Cation Exchange

To minimize cation exchange in Bentofix® and preserve its long-term swelling and sealing ability, the bentonite should be pre-hydrated with a compatible liquid (such as moisture in most subgrade soils) and remain hydrated throughout the design life of the project. This is accomplished by the following three design options:

1. _Utilizing a protective geomembrane_. A geomembrane placed directly above the bentonite layer isolates the bentonite from fluid flux, maintains its moisture content, and effectively minimizes bentonite alteration due to cation exchange (Daniel, 2000; Lin and Benson, 2000). This can be achieved by specifying Bentofix® CNSL which includes a coated flexible polypropylene membrane attached to the carrier geotextile. Alternately, a conventional composite liner (geomembrane-GCL) can be installed by deploying a separate overlying geomembrane above Bentofix® for maximum long-term protection of the bentonite against cation exchange.

2. _Placing an adequate thickness soil cover above Bentofix®._ In cover applications where Bentofix is utilized as the sole liner as a replacement for compacted clay, the compounded problem of cation exchange associated bentonite clay desiccation can increase the permeability of the bentonite by several orders of magnitude (Lin and Benson, 2000). Therefore, the soil cover above Bentofix should be a minimum 3.3 ft (1.0 m) thick (Egloffstein, 2002) and not contain an abnormally high concentration of soluble salts containing K^+, Ca^{++}, or Mg^{++}.

The protective cover thickness insulates the bentonite from surface wet-dry cycles, provides sufficient water storage above the GCL, and ensures the bentonite remains hydrated in most all soil environments. By limiting cation exchange to percolation from overlying soils through hydrated bentonite, this environment limits the increase in bentonite permeability one to two orders of magnitude, depending on site soils. Thus, the design hydraulic conductivity (Figure 1) can be adjusted accordingly for GCL hydraulic analysis.

Cation exchange capacity of the soil and potential increase in bentonite permeability should be evaluated on a project by project basis and subsequently be incorporated into any GCL hydraulic analysis.

3. _Placing a higher normal load on Bentofix®_. In applications where GCLs are used under heavier normal loads, typically ≥8,000 psf (400 kPa), the effect of cation exchange and chemical alterations in sodium bentonite is minimal (Thiel and Criley, 2003). This includes bentonite contact with very harsh liquids. Increasing compressive stress on a GCL decreases the void ratio (or porosity) within the bentonite layer, which lowers its hydraulic conductivity and susceptibility to chemical attack.

Summary

Typical soils contain leachable cations which can exchange with Na^+ in bentonite resulting in an increase in permeability of up to one order of magnitude, depending on site soils and normal load placed on the GCL. To minimize the negative effects of cation exchange, the sodium bentonite in Bentofix® should remain hydrated over the design life of the project. This can be accomplished by (1) placing a minimum 3.3 ft (1.0 m) soil cover thickness on the GCL, (2) placing normal loads generally ≥8,000 psf (400 kPa) on Bentofix®, or (3) placing an overlying protective geomembrane above the bentonite layer.

By minimizing cation exchange, the excellent hydraulic performance of Bentofix® can be preserved over the design life of the project. Cation exchange capacity should be evaluated on a project by project basis and incorporated into any GCL hydraulic analysis.

References:

Daniel, D.E. (2000). "Hydraulic Durability of Geosynthetic Clay Liners," Proceedings of the 14th Annual GRI Conference, Las Vegas, NV, Dec. 2000. Geosynthetic Research Institute, Folsom, PA, pp. 118-135.

Egloffstein, T.A. (2002). "Bentonite as sealing material in geosynthetic clay liners-Influence of the electrolytic concentration, the ion exchange and ion exchange with simultaneous partial desiccation on permeability," Proceedings of the IS Nuremberg 2002 Geosynthetic Clay Barriers Symposium, Nuremberg, Germany, April 2002, pp. 141-153.

Lin, Ling-Chu, and Benson, C.H. (2000). "Effect of Wet-Dry Cycling on Swelling and Hydraulic Conductivity of GCLs," Journal of Geotechnical and Geoenvironmental Engineering, Vol. 126, No.1, pp.40-49.

Thiel, R., and Criley, K. (2003) "Hydraulic Conductivity of a GCL Under Various High Effective Confining Stresses for Three Different Leachates," Geosynthetics International, 2004.

Thiel, R., Daniel, D., Erickson, R., Kavazanjian, E., and Giroud, J.P. (2001). The GSE GundSeal GCL Design Manual, GSE Lining Technology, Inc., Houston, TX, USA, 370 pp.

TN034 R03/16/06

North America	GSE Lining Technology, Inc.	Houston, Texas	800 435 2008	281 443 8564	Fax: 281 230 8650
South America	GSE Lining Technology Chile S.A.	Santiago, Chile		56 2 595 4200	Fax: 56 2 595 4290
Asia Pacific	GSE Lining Technology Company Limited	Bangkok, Thailand		66 2 937 0091	Fax: 66 2 937 0097
Europe & Africa	GSE Lining Technology GmbH	Hamburg, Germany		49 40 767420	Fax: 49 40 7674234
Middle East	GSE Lining Technology-Egypt	The 6th of October City, Egypt		202 2 828 8888	Fax: 202 2 828 8889

www.gseworld.com