HYDRAULIC CONDUCTIVITY OF PARTIALLY PREHYDRATED GEOSYNTHETIC CLAY LINERS PERMEATED WITH AQUEOUS CALCIUM CHLORIDE SOLUTIONS

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ABSTRACT: Tests were conducted to determine how prehydration water content affects the hydraulic conductivity of geosynthetic clay liners (GCLs) permeated with calcium chloride ($CaCl_2$) solutions of various concentrations. Results of the tests show that prehydration may not prevent the hydraulic conductivity of GCLs from increasing when permeated with divalent solutions. Hydraulic conductivities generally increased with $CaCl_2$ concentration, regardless of the prehydration water content, with hydraulic conductivities as much as 85,000 times higher than that obtained with deionized water. Application of a light confining stress during prehydration did not consistently result in lower hydraulic conductivities. Hydraulic conductivities much higher than anticipated were obtained when prehydration did not occur uniformly, indicating that prehydration must be carefully implemented in the field if it is to be reliable. Hydraulic conductivity was inversely correlated with void ratio, which is consistent with differences in the swelling of the bentonite granules for fully and partially prehydrated GCLs.

INTRODUCTION

Geosynthetic clay liners (GCLs) are used for lining waste containment systems because they have very low hydraulic conductivity ($\sim 10^{-9}$ cm/s) when permeated with dilute waters (i.e., deionized, distilled, or tap water). Their low hydraulic conductivity is due to constrictions in the pore space that occur when the bentonite swells as the surfaces and interlayer regions of the montmorillonite particles hydrate (Low 1979, Shackelford et al. 2000). An issue of prime concern when using GCLs for waste containment is the potential for adverse chemical interactions with the liquid being contained; i.e., the liquid will prevent swelling and cause the hydraulic conductivity to increase (Petrov and Rowe 1997, Shackelford et al. 2000). One method that has been suggested to prevent alterations in hydraulic conductivity of GCLs and other clay barrier materials is prehydration (Daniel et al.1993, Shackelford 1994, Gleason et al. 1997, Ruhl and Daniel 1997, Stern and Shackelford 1998); i.e., the barrier material is hydrated with deionized (DI) water, distilled (DS) water, or tap water before permeation with the chemical solution (Shan and Daniel 1991, Ruhl and Daniel 1997, Shackelford et al. 2000). Henceforth, the prehydrating fluid is referred to simply as "water."

Prehydration may be imposed (e.g., by spraying) or may occur naturally as the GCL adsorbs water from adjacent soils (Daniel et al. 1993, Bonaparte et al. 1996, Petrov and Rowe 1997). Prehydration may be full or partial. Full prehydration corresponds to saturation of the GCL with water prior to chemical permeation. Partial prehydration corresponds to hydration to a particular water content without saturating the GCL. The water content existing prior to introduction of chemical solution is referred to as the "prehydration water content."

The objectives of this study were to determine if prehydration can preclude increases in hydraulic conductivity caused by permeants where the cations primarily are divalent and to assess how increases in hydraulic conductivity are related to the prehydration water content. Leachates where the inorganic fraction is predominantly divalent are present in some municipal solid waste landfills, mine waste disposal facilities, fly ash landfills, and process water lagoons. Hydraulic conductivity tests were conducted using GCL specimens prehydrated to water contents ranging from approximately 9% (air dry) to 250% (saturated) and aqueous solutions of calcium chloride having various concentrations.

BACKGROUND

Daniel et al. (1993) studied how prehydration affected the hydraulic conductivity of GCLs permeated with five organic liquids (benzene, gasoline, methanol, tertbutylethylether, and trichloroethylene). Specimens were air dry (non prehydrated) or were partially prehydrated to water contents of 50%, 100%, 125%, and 145%. The non-prehydrated and the partially prehydrated specimens were permeated for two months with one of the organic liquids. Non-prehydrated specimens and those prehydrated to a water content of 50% had similar hydraulic conductivities ($\sim 2\times10^{-5}$ cm/s). When the prehydration water content was increased to 100%, the hydraulic conductivity decreased by 3-4 orders of magnitude. Tests on specimens prehydrated to initial water contents of 125% and 145% were not completed. No permeant liquid flowed through these specimens during the two-month test period. Petrov et al. (1997) suggest that chemical equilibrium may not have been established in the specimens that retained low hydraulic conductivity.

Shackelford (1994) describes hydraulic conductivity tests conducted on compacted sand-bentonite mixtures that were permeated with a mine waste solution saturated with calcium. The mixtures contained 16% sodium bentonite by weight and were tested with and without initial permeation with water. The composition of the mine waste solution was not reported. Hydraulic conductivity of the sand-bentonite mixture initially permeated with water and then with mine-waste solution was approximately two orders of magnitude lower than the hydraulic conductivity of the sand-bentonite mixture permeated directly with the mine-waste solution.

Ruhl and Daniel (1997) conducted hydraulic conductivity tests on prehydrated and non-prehydrated GCLs using a simulated municipal solid waste (MSW) leachate designed to represent a worst-case scenario. When the GCLs were permeated directly with the simulated MSW leachate, the GCLs had hydraulic conductivities between $2x10^{-6}$ and $8x10^{-6}$ cm/s. When the GCLs were prehydrated with tap water prior to permeation with simulated MSW leachate, the hydraulic conductivities ranged between $3x10^{-10}$ and $2x10^{-9}$ cm/s. Ruhl and Daniel (1997) indicate that the prehydrated GCLs may not have been in equilibrium, and that the hydraulic conductivity of the GCLs may have increased had the tests been run longer. An analysis by Shackelford et al. (2000) confirms this supposition. They show that the specimens permeated with simulated MSW leachate that retained low hydraulic conductivity were not in pH equilibrium when the tests were terminated, whereas equilibrium had been reached for the specimens that exhibited large increases in hydraulic conductivity.

Gleason et al. (1997) investigated how prehydration affected the hydraulic conductivity of calcium (Ca) bentonite permeated with 0.25 M calcium chloride ($CaCl_2$) solution. The hydraulic conductivity of Ca-bentonite permeated directly with 0.25 M $CaCl_2$ solution was almost an order of magnitude higher than Ca-bentonite permeated initially with tap water and then with 0.25 M $CaCl_2$ solution. Shan and Daniel (1991) report similar findings from testing a sodium bentonite that was permeated first with water and then with 0.25 M $CaCl_2$ solution.

Petrov and Rowe (1997) indicate that, under the same confining stress, GCLs fully prehydrated under greater confining stress have lower void ratio and lower hydraulic conductivity than GCLs fully prehydrated at low confining stress. Specimens fully prehydrated at confining stresses of 3-4 kPa were typically two to four times more permeable than specimens fully prehydrated at confining stresses between 101-108 kPa, regardless of the confining stress applied during permeation. Petrov and Rowe (1997) also suggest that the hydraulic conductivity of a GCL is directly related to its final void ratio.

MATERIALS AND METHODS

Geosynthetic Clay Liner (GCL)

The GCL used in this study consisted of granular sodium bentonite encased between two geotextiles that were needle-punched together. One geotextile was a slit-film monofilament woven geotextile (170 g/m^2). The other was a non-woven staple-fiber geotextile (206 g/m^2). The surface of the geotextiles was heat burnished to retain the needle-punching fibers. The air-dry gravimetric water content of the bentonite was 9% and its specific gravity was 2.66. The mass/area of bentonite was 5 kg/m^2, the initial air dry thickness ranged from 7.5 to 8.5 mm, and the median granule size was 0.25 mm. X-ray diffraction showed that the bentonite in the GCL consisted of 67% sodium montmorillonite, 11% plagioclase feldspar, 10% quartz, and 12% other non-clay minerals (Jo 1999, Vasko 1999).

Permeant Liquids

Various aqueous solutions of $CaCl_2$ (0.005, 0.01, 0.025, 0.1, and 1 M $CaCl_2$) were used as permeant liquids. Solutions were prepared by dissolving anhydrous powdered $CaCl_2$ in deionized (DI) water. Only $CaCl_2$ was used because Jo (1999) found that the hydraulic conductivity of GCLs permeated with solutions having different species of divalent and trivalent cations differed by less than one-half order of magnitude provided the concentration of the permeant liquid was the same. Therefore, the hydraulic conductivities obtained with $CaCl_2$ solutions are believed to be representative of the behavior for other divalent and trivalent salt solutions.

Sample Preparation and Prehydration

Square specimens 150 mm x 150 mm were cut from a roll of GCL using a razor knife. Samples were cut from areas away from the edges of the roll or any other areas that appeared to have lower mass of bentonite in comparison to the rest of the roll. After cutting, the sample was weighed to obtain an initial dry weight.

Most specimens were prehydrated without confinement. The GCL specimen was placed on top of a piece of filter paper laying on a pedestal consisting of PVC tubing and a rigid plastic screen (Figure 1). The pedestal and GCL were then placed in a sealed tank filled with deionized water. The water level in the tank was maintained just below the bottom of the plastic screen.

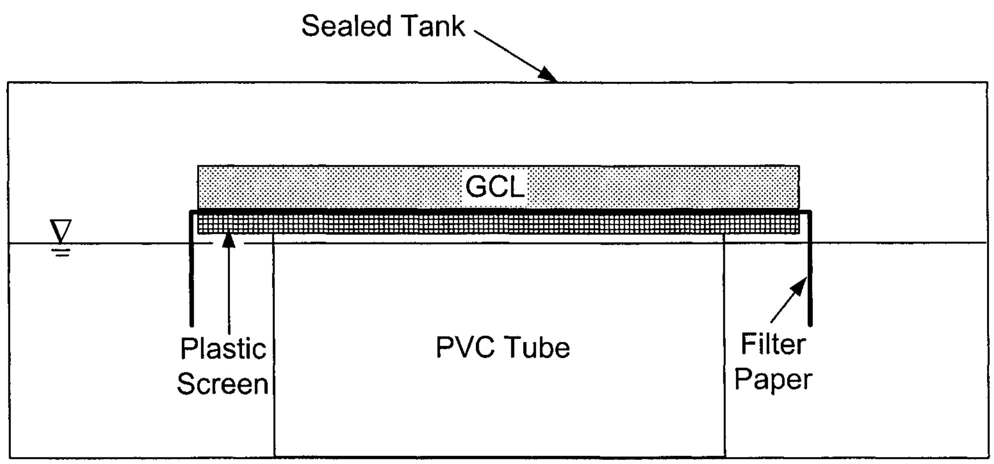

Figure 1. Set-up Used to Prehydrate GCLs.

Prehydration by vapor phase diffusion was attempted initially. However, prehydration water contents obtained by diffusion were limited to about 50%. This finding is consistent with surface hydration studies conducted by Fu et al. (1990), which show that sodium montmorillonites cannot be hydrated beyond 50% by vapor phase diffusion alone. Increases in water content beyond 50% must be achieved through capillary effects or direct application of water. To achieve higher prehydration water contents, the filter paper was made larger so that it would drape over the edge of the plastic screen and into the underlying water (Figure 1). The filter paper wicked water upward and into contact with the bottom (non-woven side) of the GCL. The non-woven side of the GCL was selected for contact based on preliminary comparisons that showed that the water content distribution in the bentonite was more uniform when the non-woven geotextile was in contact with the filter paper. Typical distributions of water content for contact with the non-woven and woven geotextiles are shown in Figure 2.

To monitor water content during hydration, the GCL specimens were regularly removed from the water tank, quickly weighed, and placed back into the tank. When a specimen achieved the target water content, it was removed and trimmed into a circular shape with a diameter of 100 mm. The thickness was measured in 7-10 locations using a caliper, and the specimen was placed in a flexible-wall permeameter for testing.

Specimens prehydrated with light confinement were prepared using the same procedures, with the following exceptions. The specimens were trimmed to a diameter of 100 mm prior to prehydration. Extreme care was used to minimize loss of bentonite during trimming because the specimens would not be trimmed any further after prehydration. Trimmed specimens were placed on the pedestal mentioned previously, and then retained within a stainless steel confining ring 15 mm high. The confining ring prevented lateral squeezing during hydration when the confining stress was applied. Confinement was applied using a cylindrical lead weight that applied an average stress of 8 kPa. This stress was selected to simulate the confining stress provided by a leachate collection layer in an unfilled landfill cell.

Permeation

Falling-head hydraulic conductivity tests with constant tailwater level were conducted on the GCLs using flexible-wall permeameters in general accordance with ASTM D 5084. No backpressure was applied, and the cell and influent pressures were applied using a gravity system. The average effective confining stress was 20 kPa and the average hydraulic gradient was 100. This hydraulic gradient is higher than specified in D 5084, but is typical of hydraulic gradients used for testing GCLs (Shackelford et al. 2000). In addition, Shackelford et al. (2000) show that the higher gradients used for testing GCLs induce the same level of effective stress as the gradients specified in D 5084 since GCLs are much thinner than the soil specimens for which D 5084 was originally developed.

Hydraulic conductivity tests were continued until the hydraulic conductivity data exhibited no trend and varied < 25% for four consecutive values, the ratio of outflow to inflow was between 0.75 and 1.25, the ratio of the pH of the outflow to the pH of the inflow was between 0.9 and 1.1, the ratio of the electrical conductivity (EC) of the outflow to the EC of the inflow was between 0.9 and 1.1, and at least 2 pore volumes of the permeant liquid flowed through the specimen. Shackelford et al. (1999) show that these EC and pH termination criteria ensure that chemical equilibrium is established. At termination, the permeameter was immediately disassembled, the specimen was weighed, the final thickness was measured at 7-10 locations using a caliper, and samples were collected for water content measurements.

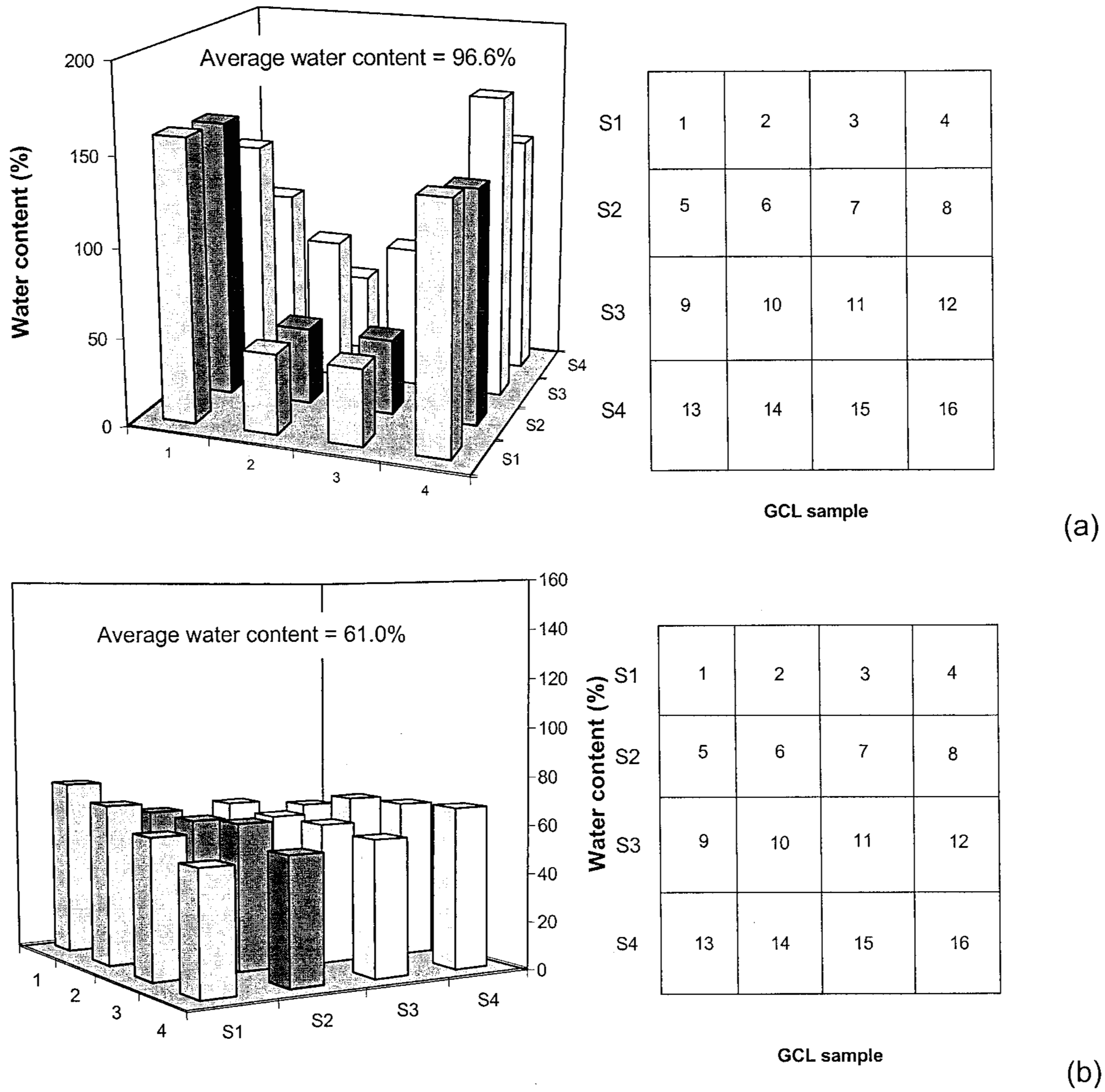

Figure 2. Distribution of Water Content in Prehydrated Specimens with Different Geotextile Contacting the Filter Paper: (a) Woven Geotextile in Contact with Filter Paper, (b) Non-Woven Geotextile in Contact with Filter Paper.

Occasionally the final hydraulic conductivity of a GCL specimen appeared unreasonably high. In such cases, rhodamine WT dye was added to the influent solution after the hydraulic conductivity test was completed to mark the flow paths. Stains left by the dye indicated that most of the flow in such specimens passed through only a portion of the GCL that apparently had much higher hydraulic conductivity than the remainder. No staining was observed along the sidewalls, indicating that sidewall leakage was not responsible for the elevated hydraulic conductivity. Non-uniform hydration was believed to be the cause of these permeable zones and the unexpectedly high hydraulic conductivity of these specimens. Thus, in such cases, the GCL was partitioned into 16 relatively equal sections to measure the spatial distribution of water content. An example of a water content distribution is shown in Figure 3 for a non-uniformly hydrated specimen that had an average prehydration water content of 100% and hydraulic conductivity of 1.0×10^{-4} cm/s to 0.1 M $CaCl_2$. The region with the lowest final water content (location 2 x S2 in Figure 3) was clearly stained by dye and apparently controlled the hydraulic conductivity. The hydraulic conductivity of this specimen is approximately 10 times higher than that of a uniformly hydrated specimen prehydrated to the same average water content and permeated with the same solution (9.6×10^{-6} cm/s). However, the hydraulic conductivity is less than two times higher than that of non-prehydrated GCLs permeated with the same solution (5.7×10^{-5} to 6.4×10^{-5} cm/s).

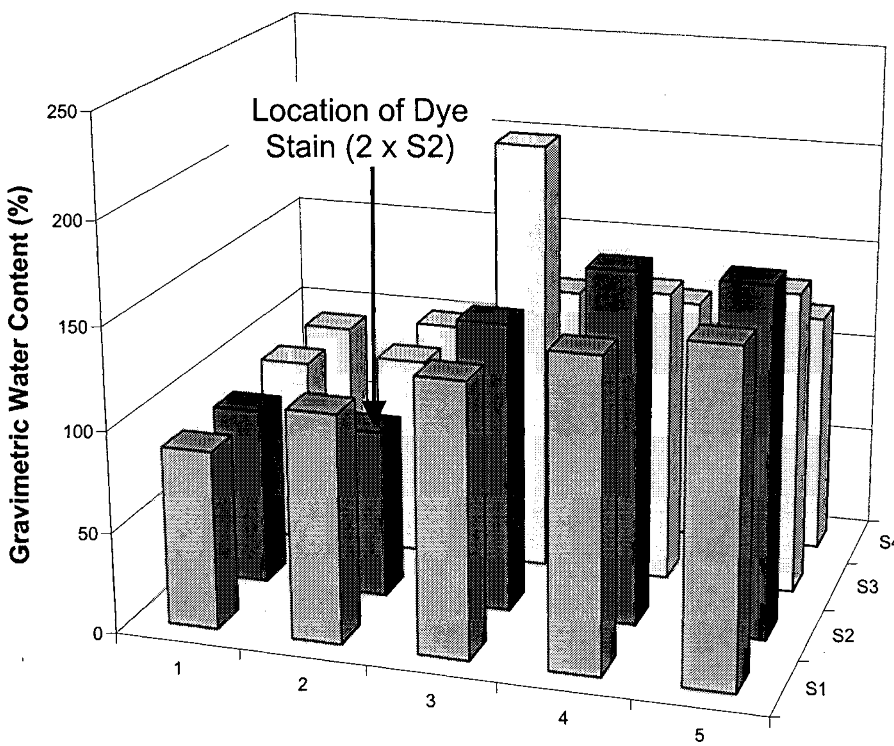

Figure 3. Distribution of Water Content in Non-Uniformly Hydrated Specimen.

RESULTS

Results of all tests on reasonably uniformly hydrated specimens are summarized in Table 1. A summary of all the data is in Vasko (1999).

Table 1. Summary of Hydraulic Conductivity Tests.

$CaCl_2$ Conc. (M)	Prehydration Water Content (%)	Void Ratio After Prehydration	Void Ratio After Permeation	Confined Hydration ?	Hydraulic Conductivity (cm/s)
0.005	9	2.24	5.05	No	$1.3x10^{-9}$
0.01	9	2.33	4.78	No	$1.2x10^{-9}$
0.01	250	6.70	7.20	No	$1.5x10^{-9}$
0.025	9	2.36	2.41	No	$2.7x10^{-7}$
0.025	9	2.27	2.64	No	$5.0x10^{-8}$
0.025	50	2.43	2.57	No	$2.4x10^{-8}$
0.025	50	3.18	3.64	No	$9.0x10^{-9}$
0.025	100	3.61	3.57	No	$4.5x10^{-8}$
0.025	150	5.37	3.89	No	$2.7x10^{-7}$
0.025	277	8.53	6.82	No	$5.9x10^{-8}$
0.1	9	2.41	2.49	No	$6.4x10^{-5}$
0.1	9	2.13	2.28	No	$5.7x10^{-5}$
0.1	50	3.74	4.32	No	$9.7x10^{-5}$
0.1	50	4.38	4.58	No	$1.1x10^{-4}$
0.1	100	3.99	4.07	No	$9.6x10^{-6}$
0.1	133	5.46	4.15	No	$2.5x10^{-6}$
0.1	150	5.16	4.56	No	$7.8x10^{-8}$
0.1	200	6.51	4.75	No	$1.9x10^{-7}$
0.1	258	7.71	6.41	No	$2.0x10^{-7}$
1.0	7	2.16	2.20	No	$4.7x10^{-5}$
1.0	9	2.36	2.41	No	$8.7x10^{-5}$
1.0	9	1.95	2.03	No	$7.4x10^{-5}$
1.0	50	2.61	3.01	No	$7.2x10^{-6}$
1.0	100	4.75	3.13	No	$8.3x10^{-6}$
1.0	150	5.47	5.12	No	$5.2x10^{-6}$
1.0	200	6.50	4.99	No	$4.0x10^{-7}$
1.0	258	8.10	6.96	No	$1.0x10^{-6}$
1.0	277	8.39	6.59	No	$2.9x10^{-7}$
0.1	50	3.31	3.41	Yes	$1.0x10^{-4}$
0.1	100	3.49	3.19	Yes	$5.2x10^{-7}$
0.1	133	4.61	-	Yes	$2.6x10^{-7}$
1.0	50	3.56	3.20	Yes	$8.6x10^{-5}$

Effect of Prehydration Water Content

Hydraulic conductivity vs. prehydration water content is shown in Figure 4 for specimens that were uniformly prehydrated without confinement. The data are segregated into three groups of similar behavior as exhibited by the trend lines: weaker solutions (DI water and 0.01 M $CaCl_2$), intermediate solutions (0.025 M $CaCl_2$), and stronger solutions (0.1 and 1 M $CaCl_2$).

Hydraulic conductivity increases as the concentration of $CaCl_2$ increases, which is most likely due to exchange of Ca^{2+} for Na^+ and the reduced swelling that is associated with the Ca^{2+} ion (Zhang et al. 1995, Jo 1999, Shackelford et al. 2000). Prehydration water content has no apparent effect on hydraulic conductivity for the intermediate and weaker solutions (≤ 0.025 M). For 0.025 M $CaCl_2$, the hydraulic conductivity varies between $1x10^{-8}$ cm/s and $3x10^{-7}$ cm/s, and is approximately $1x10^{-7}$ cm/s on average. For concentrations ≤ 0.01 M $CaCl_2$, the hydraulic conductivity is about that obtained with DI water ($1.2x10^{-9}$ cm/s) and is independent of the prehydration water content. For the stronger solutions (0.1 or 1 M $CaCl_2$), lower hydraulic conductivity is obtained with higher prehydration water content. The hydraulic conductivity decreases from approximately $1x10^{-4}$ cm/s to $3x10^{-7}$ cm/s as the prehydration water content increases from 9% to 150% and then remains approximately constant at $3x10^{-7}$ cm/s as the prehydration water content is increased further.

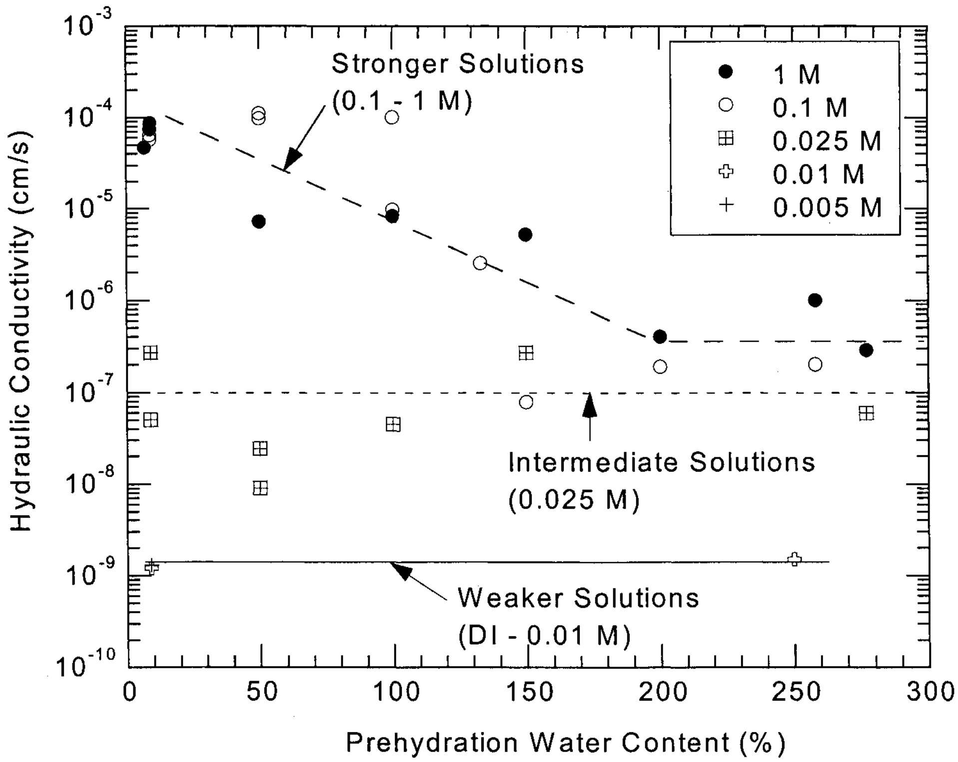

Figure 4. Hydraulic Conductivity vs. Prehydration Water Content for Unconfined Specimens.

The hydraulic conductivities reported here for concentrations ≥ 0.025 M are much higher than those reported by Daniel et al. (1993) for specimens prehydrated to water contents ≥ 100% and permeated with organic chemicals, and are typically above the value considered acceptable for liners (10^{-7} cm/s). Apparently the benefits accrued by hydration with water followed by permeation with a non-wetting organic liquid are not obtained when the permeant liquid is a wetting aqueous solution. One possible explanation for this difference in behavior is that the film of hydration water surrounding particles in a prehydrated GCL prevents the non-wetting and immiscible organic permeant liquid from interacting with the particle surface, and thus prevents a reduction in the volume of adsorbed water. In contrast, when the permeant liquid is an aqueous solution, mixing and exchange can readily occur between the hydration water and the permeant liquid, resulting in a reduced volume of adsorbed water and an increase in hydraulic conductivity. Another viable explanation is that provided by Petrov et al. (1997); i.e., the tests conducted by Daniel et al. (1993) were terminated before equilibrium was established.

Influence of Confinement During Prehydration

A limited number of tests were conducted with confinement during prehydration. Hydraulic conductivities of unconfined and confined specimens prepared and permeated under similar conditions are shown in Table 2. The ratio K_c/K_u in Table 2 corresponds to the hydraulic conductivity of a confined specimen (K_c) relative to that of a similar unconfined specimen (K_u). Hydraulic conductivities of the confined specimens are not consistently lower than those of the unconfined specimens, as was observed by Petrov and Rowe (1997). However, Petrov and Rowe (1997) fully prehydrated their specimens and used NaCl solutions as permeating liquids, whereas the specimens in this study were partially prehydrated and permeated with $CaCl_2$ solutions. By fully prehydrating their specimens, Petrov and Rowe (1997) allowed the bentonite to swell during prehydration with no restriction on the availability of hydration water. When access to hydration water is unlimited, the bentonite granules become soft, resulting in bentonite that appears as a gel. This condition probably results in more uniform pore structure and more well behaved conditions than existed in the partially prehydrated specimens tested in this study. When partially prehydrated, stiffer bentonite granules with larger inter-granule pores are readily visible when a GCL is opened (Vasko 1999).

There is a tendency for lower hydraulic conductivities under confinement when the prehydration water contents are higher (100 and 133%), which may be due to compression of softer bentonite granules that exist at higher prehydration water contents. Lower initial void ratio should correspond to lower hydraulic conductivity. Nevertheless, all of the hydraulic conductivities reported here are above the common maximum value of 10^{-7} cm/s, regardless of the stress applied during prehydration.

Table 2. Hydraulic Conductivity of Unconfined and Confined Specimens.

Prehydration Water Content (%)	Permeant Concentration (M)	Hydraulic Conductivity (cm/s)		K_c/K_u
		Confined Hydration	Unconfined Hydration	
50	0.1	1.0×10^{-4}	9.7×10^{-5}	1.0
50	1.0	8.6×10^{-5}	7.2×10^{-6}	6.3
100	0.1	5.2×10^{-7}	9.6×10^{-6}	0.05
133	0.1	2.6×10^{-7}	2.5×10^{-6}	0.1

Hydraulic Conductivity and Void Ratio

Petrov and Rowe (1997) and Shackelford et al. (2000) show that the hydraulic conductivity of GCLs and bentonites permeated with NaCl solutions is directly related to void ratio, and that a unique relationship between hydraulic conductivity and void ratio exists for each NaCl concentration. The data from this study were graphed in a similar manner to see if partially prehydrated GCLs permeated with $CaCl_2$ solutions follow similar trends. Hydraulic conductivity of the GCLs is shown in Figure 5 as a function of void ratio after prehydration (e_p) (Figure 5a) and void ratio after permeation (e_f) (Figure 5b). For both pre- and post-test conditions, the hydraulic conductivity either is unrelated to void ratio (intermediate or weaker solutions) or decreases with increasing void ratio (stronger solutions). These trends contrast those reported by Petrov and Rowe (1997), and the data exhibit more scatter than they observed. The trends differ because Petrov and Rowe (1997) obtained different void ratios by changing the effective stress on fully prehydrated GCLs, whereas in this study the stress was held constant and the prehydration water content was varied.

The decreasing trends in Figure 5 can be explained in terms of the texture and pore spaces of granular bentonites that are partially prehydrated and then permeated with stronger primarily divalent solutions. When fully prehydrated, bentonite granules disperse into individual particles and form a gel. This gel, while having high void ratio (e.g., e_p = 5-7), typically has low hydraulic conductivity because most of the voids are filled with essentially immobile bound water associated with the montmorillonite particles. When partially prehydrated, inadequate water exists for the bentonite granules to disperse and form a gel. A gel does not form during permeation either, because the Ca^{2+} ions prevent expansion of the interlayer region (Prost et al. 1998). Thus, the void ratio of a partially prehydrated specimen is lower (e_p = 3-5) than that obtained with a fully prehydrated specimen when permeated with the same solution. However, even though the void ratio of partially prehydrated GCLs is lower, the voids between the bentonite granules probably act as larger and more conductive pathways for flow relative to the voids that exist in bentonite in a gel state. Consequently, partially prehydrated GCLs can have higher hydraulic conductivity even though they have lower void ratio than fully prehydrated GCLs.

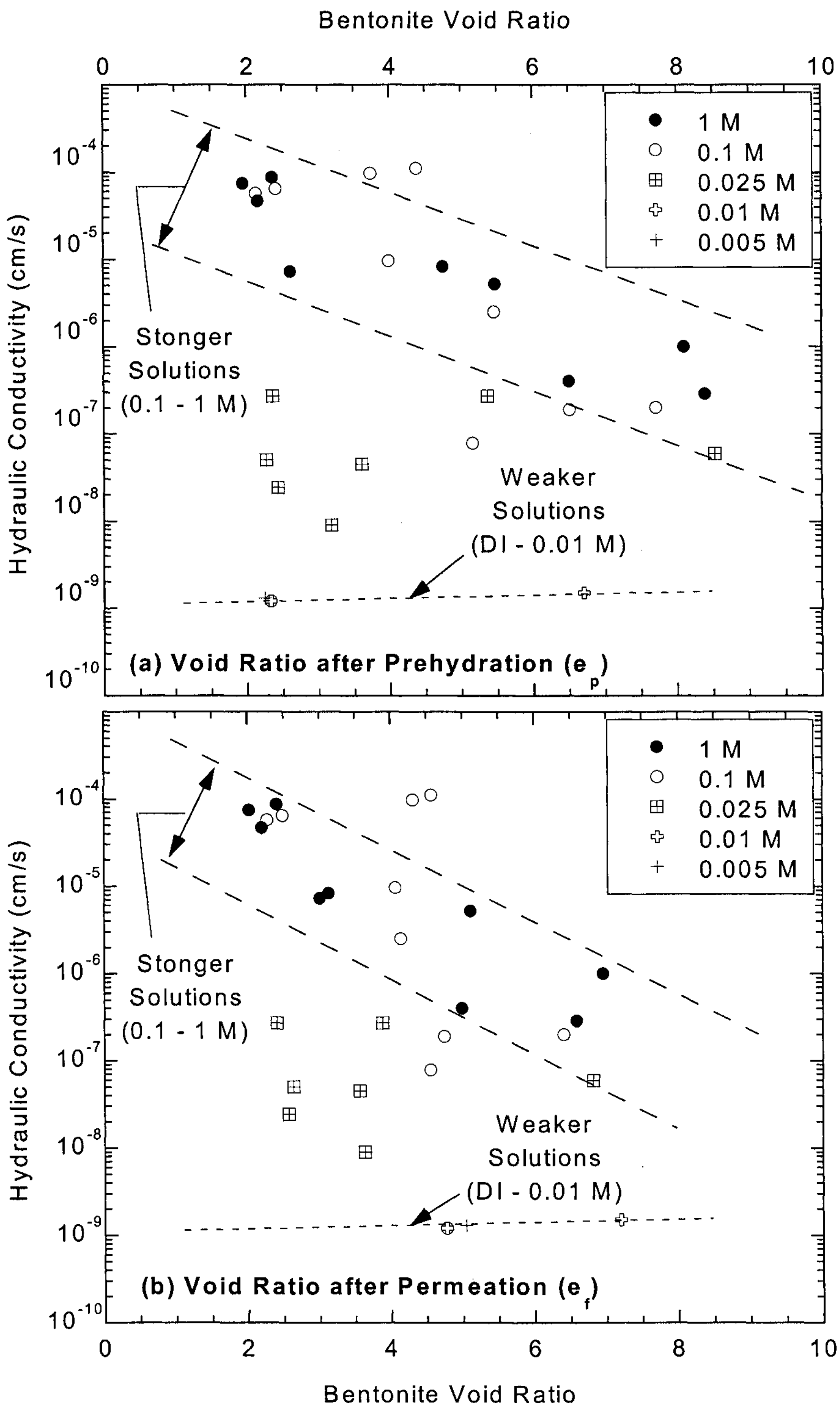

Figure 5. Hydraulic Conductivity vs. Void Ratio: (a) After Prehydration and (b) After Permeation.

The difference in void ratio caused by prehydration is shown in its most exaggerated state in Figure 6, which depicts void ratio after permeation (e_f) as a function of $CaCl_2$ concentration for non-prehydrated and fully prehydrated GCL specimens. The non-prehydrated specimens consistently have lower void ratio than the fully prehydrated specimens for all concentrations, but generally have similar or higher hydraulic conductivity (Figure 4).

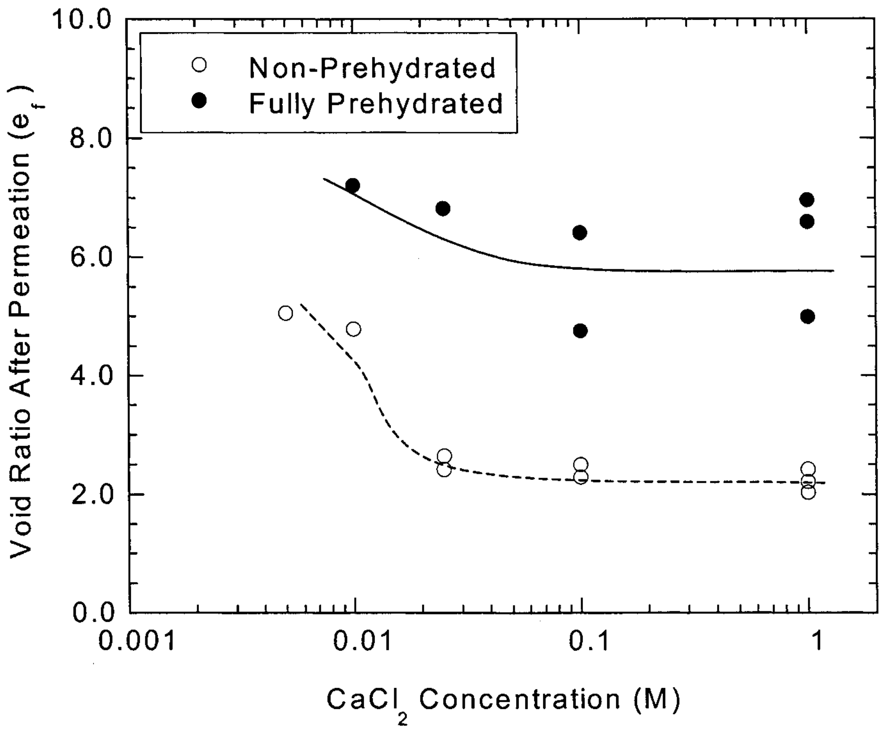

Figure 6. Void Ratio after Permeation (e_f) as a Function of $CaCl_2$ Concentration for Non-Prehydrated and Fully-Prehydrated GCL Specimens.

CONCLUSIONS

The objective of this study was to determine how prehydration water content affects the hydraulic conductivity of GCLs permeated with divalent inorganic chemical solutions of various concentrations. Specimens were prehydrated to differing water contents in a water tank and then permeated with $CaCl_2$ solutions using flexible-wall permeameters. Based on the results shown, the following conclusions are drawn:

- Prehydration with distilled, deionized (DI), or tap water may not prevent the hydraulic conductivity of GCLs permeated with inorganic salt solutions from increasing substantially above the base-line hydraulic conductivities obtained with DI water (~10^{-9} cm/s). Hydraulic conductivities comparable to those with DI water were only obtained for dilute solutions ($\leq$ 0.01 M $CaCl_2$). For the other solutions, the hydraulic conductivity was 10 to 85,000 times higher than that obtained with DI water, with higher hydraulic conductivities being obtained with stronger solutions, and in some cases at lower prehydration water contents.

- Application of a light confining stress during prehydration comparable to that provided by a leachate collection system did not consistently result in lower hydraulic conductivities. In some cases, higher hydraulic conductivities were obtained with confinement. Confinement does appear to result in somewhat lower hydraulic conductivities when the prehydration water content is at least 100%, which is probably due to softening of the bentonite aggregates at higher prehydration water contents. More testing is needed to clearly define the importance of confinement during prehydration.

- Hydraulic conductivities higher than anticipated were obtained when prehydration did not occur uniformly. Thus, if prehydration is to be relied on to provide lower hydraulic conductivity (e.g., for containment of organic liquids), steps must be taken to ensure uniform prehydration exists throughout the GCL. More study is needed to determine conditions that result in uniform prehydration.

- Hydraulic conductivity was uncorrelated or inversely correlated with void ratio for the specimens tested in this study, which were partially prehydrated and then permeated with $CaCl_2$ solutions. This inverse relationship can be explained by the differences in the swelling of bentonite granules and the pore structures obtained at high and low prehydration water contents.

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