# GCLs against acid drainage from excavated rocks discharged through construction works

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ABSTRACT: Experimental results of the hydraulic conductivity and free swell tests on a geosynthetic clay liner (GCL) against the leachate from excavated rocks having a potential of acid drainage and leaching of arsenic and lead are presented, to discuss the applicability of the GCL as a barrier material in the embankment in which the excavated rocks are filled. Needle-punched GCL is used in the experiment. Simulated acid leachates (acid solution) and real acid leachates were used as permeant liquid. Real leachates were prepared using a rock shale that had been sampled at a dam construction site in Japan and exhibited strong acid drainage (pH = 3.3) and leaching of arsenic and lead. The experimental results show that the leachates having pH values greater than or equal to 3.0 do not have any adverse impact on the hydraulic conductivity values of the GCL, while the strong simulated acid solution (pH = 1.0) increased the hydraulic conductivity 15 times compared to the hydraulic conductivity value permeated with pure water. Applicability of the GCL in embankments filled with the rocks having a potential of natural contamination is presented.

## 1 INTRODUCTION

Reuse of excavated soils and rocks discharged through construction works has been an important geoenvironmental issue in Japan to reduce the usage of new soil materials as well as to save the limited landfill space to accept the excavated surplus soils for disposal. However, there are various types of soils and rocks that may have a potential of acid drainage and/or leaching of heavy metals (particularly arsenic and lead) due to their mineralogical compositions and sedimentary natures, and countermeasures against the soils and rocks that may have potentials of such natural contaminations have recently been a great issue in geoenvironmental engineering in Japan (e.g., Ohta 2007). These soils and rocks may be used as embankment materials if they are contained properly with the barrier materials such as geomembranes, as shown in Figure 1. Although the "Soil Contamination Countermeasures Law," which was enacted in 2003, actually does not regulate natural contamination but only the contamination that occurs due to artificial reasons such as leakage of contaminants from factories, this law had a trigger to some extent to make clients of these construction works nervous against natural contamination. As a result, excessively expensive measures were sometimes conducted. These expensive measures include the disposal of soils and rocks in landfill sites or containment facility which may have an equivalent performance to waste landfills. Therefore, cost-effective measures should be established.

In this paper, hydraulic conductivity and free swell tests are conducted on geosynthetic clay liners (GCLs) against acid permeants, to propose the use of GCLs to contain the soils and rocks of concern in embankment. Double geomembrane liners have been usually used in this containment system. In this paper, the use of GCLs, instead of geomembranes, is proposed because of ease of installation. There have been many researches on chemical compatibility of GCLs against electrolyte solutions and real or simulated waste leachate. However, researches on the effects of acid solutions are limited (e.g., Jo et al. 2001, Lange et al. 2008 and 2009).

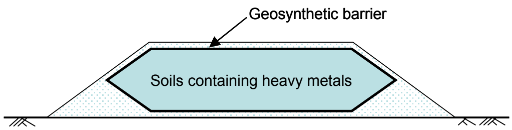


Figure 1. An example of containment of soils with natural contamination in embankment

## 2 MATERIALS AND EXPERIMENTS

Needle-punched geosynthetic clay liner (Bentofix® NSP 4900) was used for the experiment. It contains powdered sodium bentonites sandwiched between woven and non-woven geotextiles. This GCL has a unit mass of bentonite of 4.73 kg/m$^2$. Bentonite contained in this GCL had a water content of approximately 10.0%, a specific gravity of 2.85, and a smectite content of 80%.

Several types of solutions were used for the experiment, including (1) distilled water, (2) $H_2SO_4$ solutions having several pH levels, (3) acid drainage prepared using the rock shale sample, and (4) Pb doped acid drainage.

A rock shale that is distributed at a dam construction site in Japan is considered for this research, and used to prepare the leachate in this research. This rock is known to generate acid drainage, which is an environmental concern during and after construction. Main chemical composition of this rock determined by X-ray fluorescence spectrometer is shown in Table 1. The composition values of lead (Pb) and arsenic (As) determined by energy dispersive X-ray fluorescence spectrometer are 31 mg/kg and 20 mg/kg respectively. In general, the rock which might generate the acid drainage is rich in $SiO_2$ and S, and poor in Ca and Na. This rock contains approximately 5.5% S and very little amount of Ca and Na. These chemical compositions reflect the nature of the rock which might generate acid drainage. The leachate prepared using this rock according to the Japanese Leachate Test No.46 (JLT-46), which is prescribed to judge the soil contamination, was used for the swell and hydraulic conductivity tests. Results of Pb and As leaching and pH based on JLT-46 are shown in Table 2.

Table 1. Main chemical compositions of rock used

| Element | Si | K | Fe | S | Ti | Zn |
|---|---|---|---|---|---|---|
| Composition (%) | 49.2 | 16.4 | 9.70 | 5.30 | 1.95 | 0.02 |

Table 2. JLT46 leaching test results of the rock used

| Item | pH | Pb (mg/L) | As (mg/L) |
|---|---|---|---|
| Value | 3.3 | 0.004 | <0.001 |

A free swell test was performed according to ASTM D 2890 "Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners." The soil material used in this test was the powdered bentonite obtained from the GCL. Two grams of the dry powdered bentonite were dusted into a permeant solution in a 100 mL graduated cylinder filled with 90 mL solution. After these 2 g of bentonite were placed into the graduated cylinder, this cylinder was filled up to 100 mL with the permeant. The graduated cylinder was carefully covered without disturbance. The sample stood for 24 hours before taking a reading. Distilled water, $H_2SO_4$ solutions having pH levels of 1, 2, 3, 4, and 5, acid drainage prepared using rock shale were used as solutions.

The hydraulic conductivity test was conducted according to ASTM D 5084 "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter." The test was performed by using flexible-wall permeameters with a cell pressure of 30 kPa and an average hydraulic gradient of 80 – 90 in a constant temperature room controlled at 20 degrees. For the specimen permeated with chemical solutions and rock drainage, the solutions were directly permeated from the influent port without prehydration with the deionized water. Five types of permeant solutions used for the hydraulic conductivity tests include distilled water (pH = 6.2), $H_2SO_4$ solutions having pH = 1 and 3, acid drainage, and acid drainage doped with 1 mg/L Pb as $Pb(NO_3)_2$. Electrical conductivity and pH of these solutions are tabulated in Table 3. Volumes of influent and effluent, electrical conductivity (EC) and pH of effluent and thickness of GCL were measured during the test.

Typical termination criteria used during compatibility testing include (1) equality of the inflow and outflow rates (~25%), (2) measurement of a steady hydraulic conductivity (four or more consecutive measurements within 25% to 50% of the mean), (3) permeation of a minimum of two pore volumes of flow through the specimen, (4) similarity between the chemical composition of the effluent and the influent, and (5) constant height of the GCL (Shackelford et al. 2000). However, the hydraulic conductivity tests presented in this paper have not yet achieved these termination criteria at this moment, and will be continued.

Table 3. pH and EC values of influents and effluents

| | Influent | | | Effluent | | |
|---|---|---|---|---|---|---|
| | Type | pH | EC (mS/m) | PVF | pH | EC (mS/m) |
| 1 | Distilled water | 6.2 | 0.157 | 2.8 | 9.6 | 273 |
| 2 | $H_2SO_4$ solution (pH = 1.0) | 1.0 | 3470 | 23.2 | 1.8 | 819 |
| 3 | $H_2SO_4$ solution (pH = 3.0) | 3.0 | 35.9 | 2.5 | 9.5 | 319 |
| 4 | Leachate | 3.3 | 56.7 | 2.9 | 9.6 | 255 |
| 5 | Leachate (1 mg/L Pb doped) | 3.0 | 83.0 | 0.9 | - | - |

## 3 RESULTS AND DISCUSSIONS

### 3.1 *Free swell*

Figure 2 indicates the relations between the swell volumes of bentonite in GCL versus pH of the permeants. If the pH value of the solution is equal to or higher than 3.0, the swell volume of benotnite will be approximately 30 mL/2g-solid, which is a value almost similar to the one for distilled water. In contrast, swell volume decreased when the pH value decreased from 2.0, and further decreased to only 15 mL/2g-solid when the permeant is $H_2SO_4$ solution having pH = 1.0. This swell volume is only almost half of the one for distilled water. It is considered that the multi-valent cations are not present in the $H_2SO_4$ solution. The little swell volume might be thus attributed to the dissolution of clay particles by strong acid solution. The results presented herein are consistent with those presented by Jo et al. (2001), who indicated that no adverse effects on swell volume were found for pH ≥ 3 while swell volume was decreased with a decrease in pH if pH < 3.

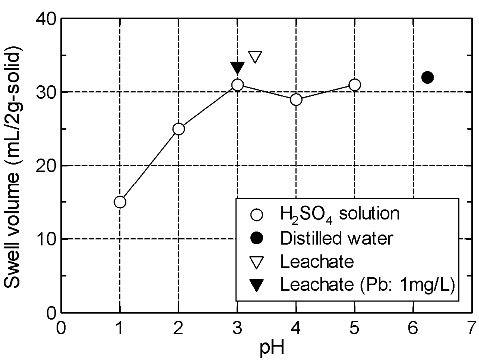


Figure 2. Effect of pH on swelling of bentonite from GCL

As indicated in Table 3, rock shale leachate (acid drainage prepared using rock) exhibited about 1.5 times higher electrical conductivity value than pH = 3.0 $H_2SO_4$ solution (35.9 mS/m for $H_2SO_4$ solution and 56.7 mS/m for acid drainage), although both permeants have similar pH values. These two solutions exhibited almost similar values of swell volumes. It is considered that EC will not be a dominant factor controlling the swell volume under these conditions.

## 3.2 *Hydraulic conductivity*

Temporal changes in hydraulic conductivity values versus pore volumes of flow are indicated in Figures 3, 4, and 5. For the three permeants including distilled water, pH = 3 solution, and acid drainage, the hydraulic conductivity values are around 2.0 x $10^{-9}$ cm/s (Figure 3). If the acid solution or drainage has pH value of 3 or higher, the hydraulic conductivities are almost the same as those for distilled water. These permeants do not have adverse effects on the hydraulic conductivity. For the pH = 1 solution, the hydraulic conductivity is approximately 8.0 x $10^{-9}$ cm/s, which is 4 times higher for PVF = 2 – 12. After PVF exceeds 12, the hydraulic conductivity gradually increased and reached 3.0 x $10^{-8}$ cm/s when PVF is 25.0 (Figure 4). This tendency is similar to the results of free swell test indicated above. pH values lower than 3 have an adverse effect on swell volume of bentonite as well as hydraulic conductivity of GCL. Figure 5 indicates the results of the hydraulic conductivity tests permeated with the acid leachate in which 1 mg/L Pb has been doped. Although the testing duration is not long enough to achieve chemical compatibility and only less than 1 PVF was obtained, the hydraulic conductivity values (2.0 x $10^{-9}$ cm/s) are almost the same as those permeated with the simple acid drainage.

In Table 3, the latest pH and EC values of effluents are also indicated. The pH and EC values of effluents are very different from the values of original permeants for any cases, particularly for the cases using acid solutions and leachate. The pH of the effluent is still 9.5 for the $H_2SO_4$ solution of pH = 3, and 9.6 for the acid leachate that had an original pH of 3.3. From these results, buffering capacity of bentonites in GCL against acid solutions and leachates is evident. However, it is also noted that chemical compatibility has not yet been achieved in these tests because of the significant inequality of chemistry between effluents and influents. Only for the case using $H_2SO_4$ solution (pH = 1), pH value of effluent exhibited a strong acid (pH = 1.8). These hydraulic conductivity tests are planned to be continued until the termination criteria be satisfied to achieve chemical compatibility.

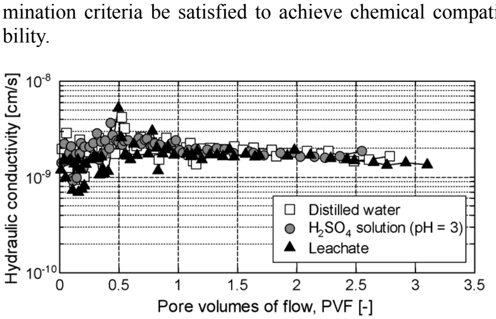

Figure 3. Results of hydraulic conductivity tests permeated with distilled water, $H_2SO_4$ solution (pH = 3), and acid leachate

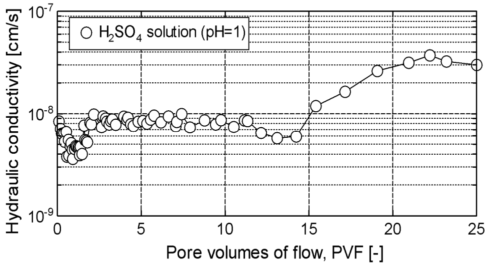

Figure 4. Results of hydraulic conductivity tests permeated with $H_2SO_4$ solution (pH = 1)

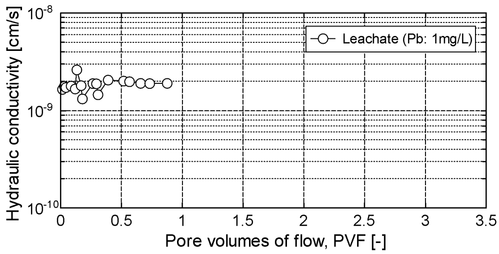

Figure 5. Results of hydraulic conductivity tests permeated with acid leachate doped with 1 mg/L Pb

## 3.3 *Discussion*

Relations between hydraulic conductivity values versus pH of permeants are summarized in Figure 6. Latest hydraulic conductivity values were plotted in this figure. Both distilled water and $H_2SO_4$ solution of pH = 3 exhibited low hydraulic conductivity values (~2.0 x $10^{-9}$ cm/s), while the pH = 1 solution resulted in a 15 times higher hydraulic conductivity (3.0 x $10^{-8}$ cm/s). This result indicated that strong acid solution restricts the swelling of bentonites, as mentioned in 3.1. Jo et al. (2001) conducted hydraulic conductivity tests permeated with several electrolyte solutions including both acid and base solutions using HCl for acid and NaOH for base, and concluded that the solutions having pH values ranging from 2 – 12 did not provide any adverse effect on hydraulic conductivity of a granular benotnite GCL, and ranged 9.1 x $10^{-10}$ - 3.0 x $10^{-9}$ cm/s, while high hydraulic conductivity (1.5 x $10^{-5}$ cm/s) was obtained for pH = 1 solution. The tendency of the results obtained from this research is similar to the one obtained by Jo et al. (2001), except for the magnitude of increase in hydraulic conductivity when pH = 1 solutions are used. There are some differences in the experimental conditions between this research and Jo et al. (2001). This research used $H_2SO_4$ instead of using HCl, because it is intended to simulate the acid drainage from the rock containing the pyrite. Further study is necessary to evaluate the effects of different chemicals (e.g., $H_2SO_4$ and HCl) on the barrier performance of GCL. In addition, Jo et al. (2001) used GCL containing granular bentonites while GCL containing powdered bentonties was used in this research. Katsumi and Fukagawa (2005) indicated that powdered bentonites exhibited lower hydraulic conductivities than granular bentonites for aggressive chemical electrolyte solutions, even if they have almost similar hydraulic conductivity values for distilled water or diluted solutions. However, it is noted that chemical compatibility has not yet been achieved for the tests in this research, and hydraulic conductivity tests are continued until the termination criteria be satisfied.

Hydraulic conductivity values permeated with acid drainage either with or without Pb addition are very similar to the one with pH = 3 $H_2SO_4$ solution, although there might be differences in chemistry between acid drainage and $H_2SO_4$ solution; for example, the acid drainage has a much higher EC (56.7 mS/m without $Pb(NO_3)_2$ addition, and 83.0 mS/m with $Pb(NO_3)_2$ addition) than the $H_2SO_4$ solution (35.9 mS/m). From a practical viewpoint, the concentration levels of Pb and As in the drainage from excavated soils and rocks usually range from values below the environmental standards (0.01 mg/L) to several times higher than the environmental standards. Concentration of doped Pb (1 mg/L) in this experiment is much higher than these natural conditions considerable. In conclusion, compared to the pH values, either electrical conductivity or heavy metals concentrations have minor (or negligible) effects on the hydraulic conductivity.

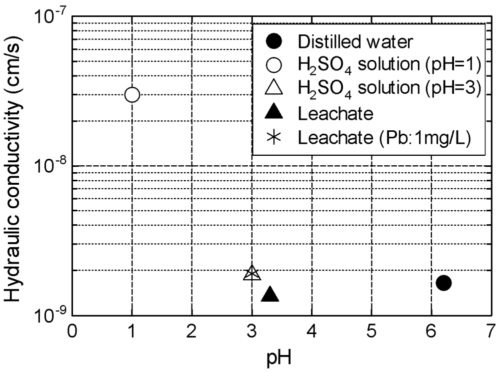


Figure 6. Effect on pH on hydraulic conductivity

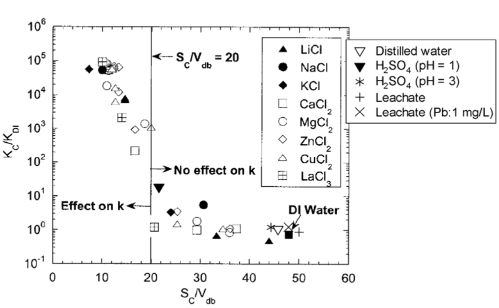


Figure 7. Relationship between hydraulic conductivity ratio and free swell ratio (Jo et al. 2001)

Figure 7 plots free swell ratio versus hydraulic conductivity ratio. In this figure, $S_c/V_{db}$ is the "free swell ratio," which is defined as the free swell volume, $S_c$, in the salt solution divided by the volume of solids in 2 g of air-dry bentonite, $V_{db}$. The hydraulic conductivity ratio, $K_c/K_{DI}$, is the hydraulic conductivity to a salt or acid solution, $K_c$, relative to the hydraulic conductivity to DI water, $K_{DI}$. The data obtained from this research are plotted with the data by Jo et al. (2001). As Jo et al. (2001) indicated that there is a strong correspondence between $K_c/K_{DI}$ and $S_c/V_{db}$. The ratio $K_c/K_{DI}$ ranges between 0.3 and 3 for $S_c/V_{db} \geq 20$, indicating relatively small dependency on $S_c/V_{db}$. However, for $S_c/V_{db} < 20$, the hydraulic conductivity increases significantly with decrease in $S_c/V_{db}$. From this graph, the similarity in the trend for free swell versus hydraulic conductivity was clear between this research and the work conducted by Jo et al. (2001). Katsumi et al. (2007) also found a similar strong correlation between free swell and hydraulic conductivity regardless of the types of peameants (including chemical solutions and waste leachate) and types of bentonites (granular or powdered), except for the cell or confining pressure of permeameter. From this hypothesis, hydraulic conductivity values of GCL against an acid drainage can be predicted even if its detailed chemistry is not well examined.

## 4 CONCLUSIONS

From the experimental results, acid leachates having pH values larger than or equal to 3.0 do not have any adverse impact on hydraulic conductivity of the GCL. GCL has a potential to be applied to a barrier material in the embankment to contain the soil and rock which might generate acid drainage, although further researches including long term hydraulic conductivity tests and effects of the prehydration are necessary.

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