Laboratory study on the effect of leachate type to swelling behavior of bentonite

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Abstract. Bentonite is well known as highly plastic, swelling clay material, the product of volcanic ash. An experimental test of the effect of leachate type on swelling behavior of bentonite has been conducted. Four types of liquids, tap water, 10 g/l of NaCl solution, 11.1 g/l of CaCl₂ solution, and 100 ml/l of ethanol solution were used in the tests. Liquid limit, plastic limit, free swelling index, and swelling pressure tests were carried out to evaluate the relative swelling ability of bentonite when interacted with different leachate types. The result of free swelling tests indicated bentonite swelled higher when interacted with tap water and ethanol solution compare with NaCl solution and CaCl₂ solution as a liquid. The value of liquid limit and plastic limit of bentonite for ethanol solution and CaCl₂ solution were highest and lowest among liquid tested, respectively. The result also showed that bentonite has the highest swelling pressure when contacted with tap water but opposite for NaCl solution.

1. Introduction

Bentonite is known as a highly plastic, swelling clay material, the product of volcanic ash. Bentonite has low hydraulic conductivity to water. For industrial purposes, commonly bentonite is divided into sodium bentonite and calcium bentonite. Bentonite content Montmorillonite, normally ranging from 65 to 90 % [1]. It also contains quartz, feldspars, mica, cristobalite, carbonates material, and some other minerals. A large specific area (about 800 m²/g), high charge deficiency (80-150 meq/100 gr), and the ability for interlayer swelling of montmorillonite are believed as the factors contributed to high swelling capacity and low hydraulic conductivity of bentonite when contacted with water (Shackelford et al.2000). When the volume of a bonded molecule of water increases, the fraction of the pore space contains freely bulk water decreases, and pathways for water flow become smaller and more serpentine. So increase in the volume of water bounded is manifested as an increased in swell volume and a decrease of hydraulic conductivity [2].

2. Materials and properties

2.1. Bentonite

Bentonite tested was a granular type which part of Geosynthetic Clay Liner (GCL). Chemical composition is listed in table 1.
Table 1. Chemical composition of bentonite (X-ray semi-quantitative analysis, data provided by manufacturer).

| Chemical composition       | Colony* | Lovell* |
|----------------------------|---------|---------|
| Si as SiO₂                 | 66.32   | 64.06   |
| Al as Al₂O₃                | 21.26   | 20.56   |
| Ca as CaO                  | 0.80    | 1.08    |
| Na as Na₂O                 | 2.09    | 2.52    |
| Mg as MgO                  | 2.59    | 2.27    |
| Fe as Fe₂O₃                | 1.73    | 1.87    |
| K as K₂O                  | 0.29    | 0.30    |
| Cr as Cr₂O₃                | 0.01    | 0.03    |
| Mn as MnO                  | 0.08    | 0.04    |
| Ti as TiO₂                 | 0.12    | 0.18    |
| V as V₂O₅                  | 0.05    | 0.02    |
| Quartz                    | 5       | 2       |
| Potassium feldspar       | Trace   | ------  |
| Plagioclase feldspar     | Trace   | 4      |
| Calcite                   | ----    | Trace   |
| Opal                      | 2       | 5       |
| Clinoptilolite            | ----    | Trace   |
| Dioctahedralsmectite      | 91      | 85      |
| Illite                     | 2       | 4       |

2.2. Liquids
Tap water, 10 g/l of NaCl solution, 100 ml/l of ethanol solution and 11.1 g/l of CaCl₂ solution were used as liquids in the tests, pH and electric conductivity of the liquids are given in table 2. The device for measuring the pH of liquid tested was shown in figure 1, while for measuring Electric Conductivity (Ec), conductivity meter was used (table 2).

Table 2. Properties of liquids.

| Liquids    | pH  | Ec(µS/cm) |
|------------|-----|-----------|
| Tap water  | 7.02| 105       |
| Ethanol    | 7.46| 85        |
| NaCl       | 7.24| 17600     |
| CaCl₂      | 7.60| 199       |

3. Experimental tests and results

3.1. Liquid Limit and plastic limit test
Liquid limit (wₐ) and plastic limit (wₚ) of the bentonite with the four liquids were tested using Atterberg devices [3] shown in table 3. The result of the tests indicated bentonite has 560% of wₐ and 67.4% of wₚ if contacted with an ethanol solution, which is the highest among liquid tested. The solution of NaCl and CaCl₂ gave 58% - 70% lower than wₐ and wₚ of ethanol solution. Similar to the ethanol solution, tap water gave high value that is 537 % of wₐ and 45.8% of wₚ.

Table 3. Value of liquid limit and plastic limit.

| Liquids    | wₐ (%) | wₚ (%) |
|------------|--------|--------|
| Tap water  | 537    | 45.8   |
| Ethanol    | 560    | 67.4   |
| NaCl       | 235    | 46.3   |
| CaCl₂      | 165    | NA     |
3.2. Free swelling index test

In the free swelling index test (figure 1), granular bentonite was ground to 100 % passing a 100 mesh U.S standard sieve and a minimum of 65% passing a 200 mesh U.S standard sieve with a ceramic mortar [4]. The bentonite was placed in an oven at 105 ±5°C for 24 hours. Then weigh 2.00 ± 0.01 gr of dried bentonite and put on a weighing paper. Add 90 ml liquid tested to clean 100 ml graduated cylinder. Grab ± 0.1 gr increment of bentonite powder with a spoon from weighing paper and carefully dust it over the entire surface of the water in the graduated cylinder over a period of approximately 30 seconds. After wet bentonite hydrate and settle to the bottom of the graduated cylinder for a minimum period of 10 minutes, the additional increment of bentonite powder is added by following the procedure mentioned above until the entire 2.0 gr bentonite has been added.

Rinse any adhering particles from sides of the cylinder into the water column carefully after the final increment has settled. Add the water into 100 ml in a graduated cylinder. Then measure the temperature of water carefully without disturbing the settled bentonite and record the temperature to ± 0.5°C. The cylinder is placed undisturbed for a minimum of 16 hours from the last incremental addition. Check the hydrating bentonite column for trapped air or water separation after 2 hours from the last additional bentonite powder. Tip the cylinder at 45°C angle gently and roll slowly to homogenize the settled bentonite.

Figure 1. Free swelling index test.

Figure 2. The device of swelling pressure.
Finally, record the volume of hydrated bentonite and its temperature after the cylinder was allowed undisturbed for a minimum of 16 hours. Record the volume level in millimeters at the top of the settled bentonite to the nearest 0.5 ml. Check the distinct change in appearance at the upper surface of the settled bentonite. It has ignored low density flocculated material (sometimes lighter in coloration to white) for measurement.

Results of the test showed volume level at the top of settled bentonite was 21.5 ml/2 gr for tap water as liquid. The swelling index of bentonite gave 40% higher when contacted with ethanol solution compared to tap water. However, the top-level of hydrated bentonite indicated 23% and 58% lower for NaCl and CaCl₂ solution as a liquid, respectively.

The different behavior of bentonite swelling depends on the diffuse double layer. It showed the higher concentration of cation the less thickness of the diffuse double layer and results in less expansion of bentonite. In geotechnical references, the volume of bond water and interaction between particles has been described in the term of a diffuse double layer (DDL) [5]. The thickness \( 1/K \) of DDL is related to the square root of dielectric constant, \( D \), and \( D \) is reversely related to electric conductivity, \( E_c \), of the solution, and then:

\[
\frac{1}{K} \propto \frac{1}{E_c^{1/2}}
\]  

The \( E_c \) value of NaCl and CaCl₂ solution tested are more than 2 orders higher and two times than that of the tap water and the ethanol solution (table 2), which will have a thinner double layer around the surface of the bentonite particles. In addition, cation concentration and valence of cation also influence \( 1/K \) value, and the qualitatively NaCl and CaCl₂ cases tend to result in a smaller \( 1/K \) value in terms of cation concentration and valence for CaCl₂ case.

A direct indication of \( 1/K \) value maybe the free swelling index in table 3-6, in which the value for the saltwater and CaCl₂ solution are 16.5 ml/2 gr and 9 ml/2 gr, which is about 75 % and 40 % of the value for the tap water case. The thinner double layer means that under a given condition, the bentonite will expand less.

![Figure 3. Swelling pressure versus water content.](image)

3.3. Swelling Pressure test
Swelling pressure is known as pressure which expansive soil exert if the soil prevents to swell or change the volume. Swelling pressures of bentonite were tested using an Oedometer device (figure 2) and basically following the procedure of Method-C of [6]. Firstly, the initial water content of the bentonite was adjusted to about 30% - 100% and put into a mould 0.060 m in diameter 0.02 m in height. Then apply a vertical pressure of 300 kPa for 2 hours to compress the sample. The resulting sample had a dry density of 760 kg/m³ – 1020 kg/m³. Then cut the sample into 0.005 m in thickness...
and reset it into the equipment for swelling pressure test. The tests were conducted with constant volume conditions, and fluids were supplied until there was no more pressure change.

Then the final pressure was recorded, and the water content of the specimen was measured. The swelling pressure versus the final water content curve for using liquid tested is given in figure 3. The result shows that the tap-water and the ethanol solution have about the same swelling pressure, but the salty water (NaCl solution) has much lower swelling pressure at the same water content condition. Result of these tests similar to the result in the free swelling index above.

4. Conclusions
Effect of leachate type on swelling behavior of bentonite has been investigated by several tests that are, Atterberg limit, free swelling index, and swelling pressure. From the following test, it can be concluded leachate type strongly influenced the expansion of bentonite. The behavior of swelling depends on the thickness of the forming of a diffuse double layer (DDL) around bentonite particles. The thicker the DDL, the more expansion bentonite. The liquid which contained high cation concentration produced less DDL. The thinner DDL means less swelling of bentonite.

5. References
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