Effect of NaCl and CaCl2 solutions on the liquid limit, plastic limit, and plasticity index of clay

IOP Conf. Series: Materials Science and Engineering **508** (2019) 012045 doi:10.1088/1757-899X/508/1/012045

Effect of NaCl and CaCl2 solutions on the liquid limit, plastic limit, and plasticity index of clay

B Widjaja*, K M Setianto

Civil Engineering Department, Faculty of Engineering Parahyangan Catholic University

*widjaja@unpar.ac.id

Abstract. This study aims to investigate the effect of NaCl and CaCl2 solutions on the liquid limit, plastic limit, and plasticity index of soil samples. The liquid and plastic limits of soil samples were obtained using Casagrande's method and the fall cone penetrometer test. Results showed that the liquid and plastic limits of the soils decreased with increasing NaCl and CaCl2 concentration. The plasticity index of the soil samples also changed with the liquid limit. Whereas bentonite was the most sensitive sample, kaolinite was the least sensitive sample to salt. The behavior of the Pasir Panjang clay sample fell between those of bentonite and kaolinite. CaCl2 solution was more effective than NaCl solution in decreasing the liquid and plastic limits of the soil samples.

1. Introduction

As soil is a natural material, its behavior according to its source. For example, the behavior of soil varies when water is permeated through it, especially in fine-grained soil, because the presence of water exerts a significant effect on the characteristics of granular soil [1]. Under the same water content, some clay samples can liquidize, whereas others remain hard. Unfortunately, variations in clay behavior cannot be quantified in terms of water content. Only qualitative descriptions of soil behavior could be obtained until Atterberg proposed a new system known as the Atterberg limits.

The Atterberg limits are the boundaries of a clay sample's condition when water or another liquid is permeated through it. Four clay conditions, namely, solid, semi-solid, plastic, and liquid, have been defined and each condition is further described by Atterberg limits. Solid and semi-solid conditions are separated by shrinkage limit, semi-solid and plastic conditions are separated by plastic limit, and plastic and liquid conditions are separated by liquid limit. Initially, Atterberg limits were only used for soil classification; today, however, these limits are also applied to geotechnical engineering to describe the shear strength of soil and geotechnical problems, especially in expansive soil.

The Atterberg limits are affected by several factors. This study focuses on the effect of NaCl and CaCl2 solutions on the liquid limit, plastic limit, and plasticity index of several soil samples and evaluates the effects of the presence of excess Cl^- and Na^+ and Ca^{2+} from the salts. These solutions were selected because of their homogeneity. Various concentrations of solutions were prepared and expressed in terms of molarity, a common unit of concentration in chemistry [2].

2. Materials and Method

2.1 Materials

Samples of mono-mineral clay and poly-mineral natural clay were obtained for this study. Bentonite and kaolinite were selected as mono-mineral clay samples as they represent extreme types of clay minerals [3]. Bentonite primarily consists of montmorillonite. Bentonite and kaolinite differ in terms of activity, plasticity, swelling, and shrinkage behavior [1]; specifically, bentonite has a higher activity, plasticity, and swelling behavior than kaolinite.

The poly-mineral clay sample was obtained from a landslide deposition in Pasir Panjang Village, Brebes District, Central Java, Indonesia. The behavior of this poly-mineral clay sample was compared with those of bentonite and kaolinite.

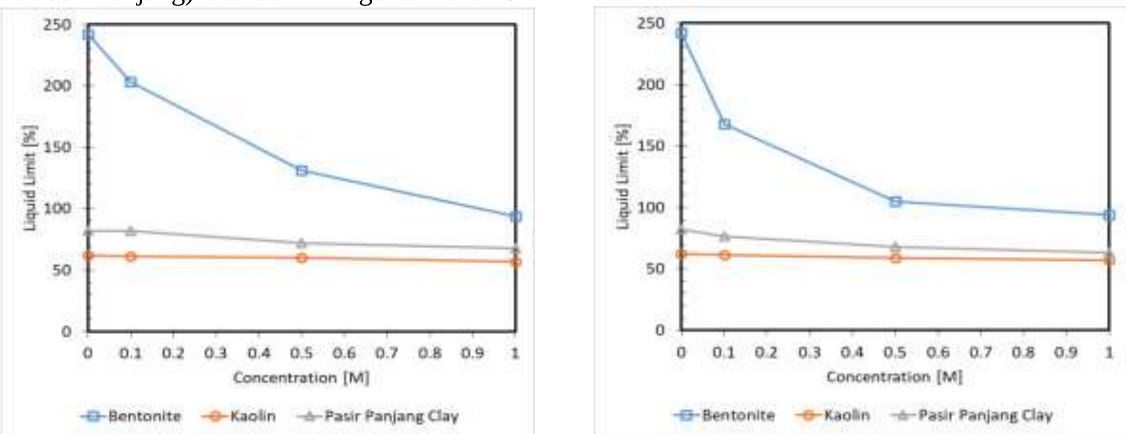
2.2 Method

Salt solutions of 0.1, 0.5, and 1 M were prepared by dissolving the appropriate amounts of NaCl or $CaCl_2$ in 0.5 L of deionized (DI) water. A 0 M solution, representing the absence of NaCl or $CaCl_2$, was also prepared. The liquid and plastic limits of the soil samples in the presence of the salt solutions were determined by Casagrande's method according to ASTM D4318 [4] and the fall cone penetrometer test according to BS 1377-2:1990 [5][6][3]. These two methods were used to check the consistency of the soil sample behavior. If Casagrande's method shows a decrease in liquid limit, the fall cone penetrometer test should also show the same result. Otherwise, a mistake may have occurred. The plasticity index of the soil samples is the difference between their liquid and plastic limits.

3. Result and Discussion

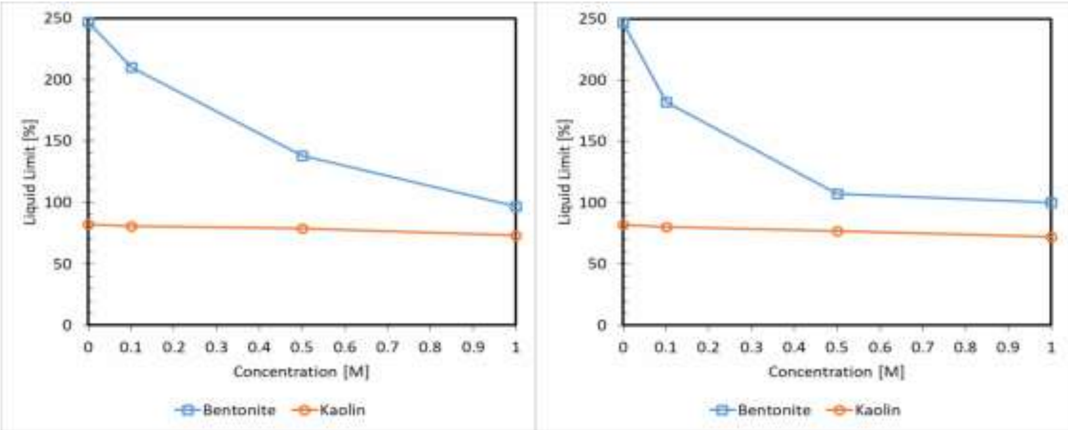
3.1 Liquid limit

The effect of NaCl and $CaCl_2$ solutions on the liquid limits of the soil samples (i.e., bentonite, kaolin, and Pasir Panjang) is shown in Figures 1 and 2.



(a) NaCl Solution (b) $CaCl_2$ Solution

Figure 1. Effect of NaCl and $CaCl_2$ solutions on the liquid limits of the soil samples Casagrande's Method

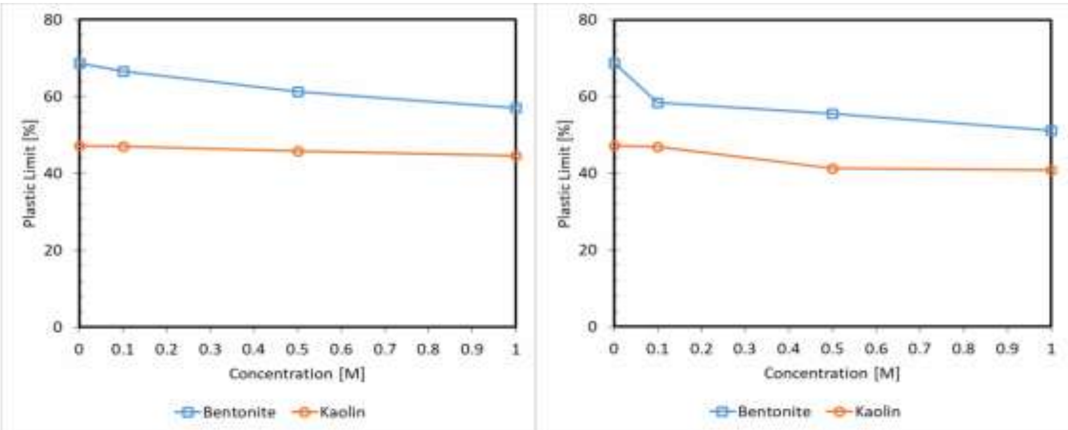


(a) NaCl Solution (b) $CaCl_2$ Solution

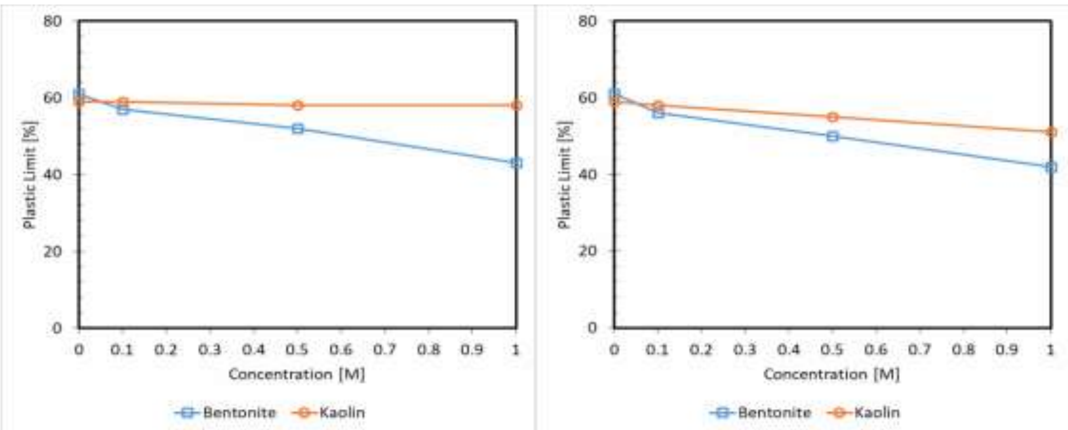
Figure 2. Effect of NaCl and $CaCl_2$ solutions on the liquid limits of the soil samples Fall Cone Penetrometer

3.2 Plastic limit

The effect of NaCl and CaCl2 solutions on the plastic limits of the soil samples is shown in Figure 3.



(a) NaCl Solution – Casagrande's Method (b) $CaCl_2$ Solution – Casagrande's Method

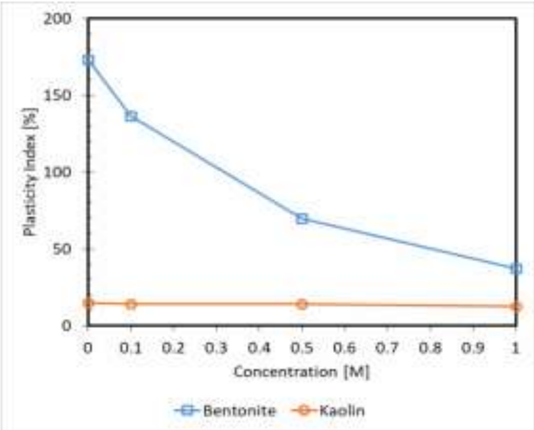


(c) NaCl Solution – Fall Cone Penetrometer (d) $CaCl_2$ Solution – Fall Cone Penetrometer

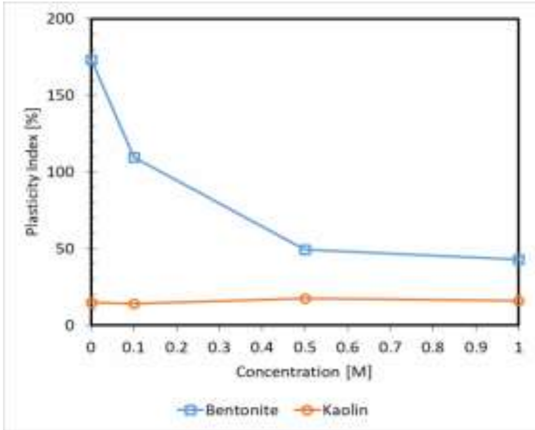
Figure 3. Effect of NaCl and $CaCl_2$ solution on the plastic limits of the soil samples

3.3 Plasticity Index

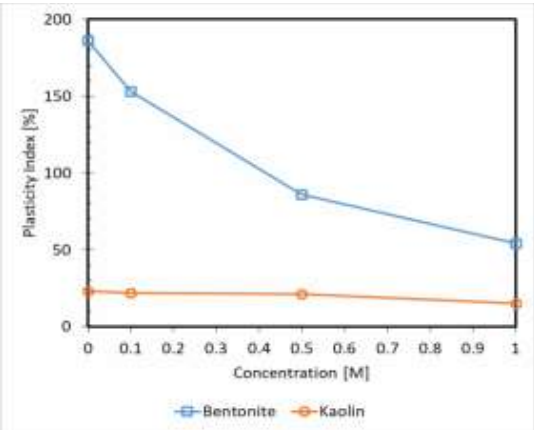
The effect of NaCl and $CaCl_2$ solutions on the plasticity indices of the soil samples is shown in Figure 4.



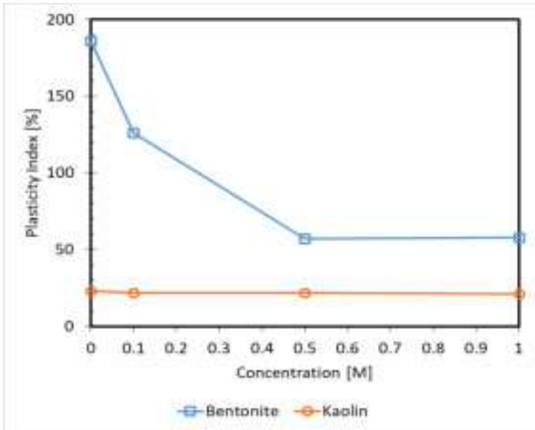
(a) NaCl Solution – Casagrande's Method



(b) $CaCl_2$ Solution – Casagrande's Method



(c) NaCl Solution – Fall Cone Penetrometer



(d) $CaCl_2$ Solution – Fall Cone Penetrometer

Figure 4. Effect of NaCl and $CaCl_2$ solutions on the plasticity indices of the soil samples

3.4 Discussion

Figures 1 and 2 show that the liquid limit of bentonite decreased with increasing salt concentration. In the presence of 0–0.5 M $CaCl_2$, the gradient became steeper, indicating that the decrease in the liquid limit of bentonite was more substantial over this concentration range than over the range of 0.5–1 M $CaCl_2$. However, in the presence of NaCl solution, the decrease in liquid limit of bentonite was nearly proportional to the increase in solution concentration. The liquid limit of kaolinite did not show any substantial change in the presence of the NaCl and $CaCl_2$ solutions. For Pasir Panjang clay, the decrease in liquid limit was not substantial. The decrease in liquid limit determined by the fall cone penetrometer test revealed the same trends obtained from Casagrande's method, although some differences could be observed.

Figure 3 shows that the plastic limit of bentonite decreased with increasing salt concentration by approximately 8%. This change was much smaller than the change in its liquid limit. The plastic limit of kaolinite did not substantially change in the presence of NaCl solution. In the presence of $CaCl_2$ solution, the plastic limit of kaolin decreased by ±4%, but this decrease was not substantial.

Figure 4 shows that the change trends of the plasticity index and liquid limit of bentonite are similar. By contrast, the plasticity index of kaolinite did not change substantially because the change in its plastic limit was similar to the change in its liquid limit.

Considering the same thickness of absorbed water molecules but different sizes of bentonite and kaolinite particles, the behavior of these clay samples can be expected to differ when water is permeated through them. As montmorillonite crystals are smaller than kaolinite crystals, the plasticity and activity of the former are higher than those of the latter [1].

The change in the liquid limit of clay is primarily controlled by shearing resistance at the particle level and the thickness of the diffuse double layer. When the thickness of the diffuse double layer decreases, the liquid limit of soil is reduced [3]. The diffuse double layer is a region consisting of two layer: the partial/charge surface and the diffuse layer of cations [1][7]. The thickness of the diffuse double layer is expressed using the following formula from Gouy Chapman theory:

$$\frac{1}{k} = (\frac{\varepsilon_0 DkT}{2n0e2v2})^2 \quad (1)$$

where k is the Boltzmann constant, ε is the unit electronic charge, $n0$ is the electrolyte concentration, T is the temperature, v is the effect of cation valency, and D is the effect of dielectric constant.

The electrolyte concentration greatly affects the thickness of the diffuse double layer. Increases in electrolyte concentration reduce the surface potential under the condition of a constant surface charge, the thickness of the diffuse double layer decreases (Mitchell et al., 2005), and the liquid limit of clay is reduced.

Figures 1 and 2 show that the decay in the liquid limit of the soil samples in the presence of $CaCl_2$ solution was greater than that in the presence of NaCl solution, likely because CaCl2 has a greater cation valency than NaCl. Na+ is a monovalent cation, while Ca2+ is a divalent cation. Considering that $1/K \propto 1/v$, a divalent cation reduces the thickness of the diffuse double layer more extensively than a monovalent cation does.

The dielectric constant of water decreases with increasing in salt concentration in water [8]. From Equation (1), $1/K \propto D$. Hence, with increasing NaCl or CaCl2 concentration, the thickness of the diffuse double layer is reduced.

Especially for high-swelling clays such as bentonite, the dominant interparticle force is repulsion, which affects the distance of clay particles. With increasing NaCl or CaCl2 concentration, the repulsive force decreases, the particles are able to move easily, and the liquid limit of bentonite decreases [9].

4. Conclusion

The following conclusions were obtained from this study:

(a) The decay in liquid limit of soil samples in the presence of NaCl and $CaCl_2$ solutions depends on the type of soil. Soil samples with high plasticity and activity, such as bentonite, showed a more substantial decrease in liquid limit than other samples, such as kaolinite. The liquid limit of Pasir Panjang clay fell between those of bentonite and kaolinite.

(b) $CaCl_2$ reduced the liquid limit of soil samples more substantially than did NaCl.

(c) Plastic limits did not show a substantial change in the presence of NaCl and $CaCl_2$ solutions.

(d) The change trend of plasticity index was similar to the change trend of liquid limit.

5. References

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