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Voltage optimization in expansive soil improvement with saline solution on swelling and shear strength

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Voltage optimization in expansive soil improvement with saline solution on swelling and shear strength

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Abstract. One of the problems in the construction of the road network is the presence of expansive clay and loose soil. In Java, expansive clays are generally the result of weathering rock formations including shale and clay, while soft soils are derived from unconsolidated sedimentation. In situ stabilization of clay with chemical solutions will bedifficult due to the very low permeability of the soil. Some researchers exploit the phenomenon of electrodynamics, the nature of the electric and hydraulic coupling to reform clay. This paper examines the experimental results of clay reclamation in the laboratory. The study was carried out on clay from Karawang, West Java province, Indonesia, which was injected with saline solution and used different voltages of 12V, 15V, 18V, and 24V. The success of this experiment will be seen by comparing the mechanical properties of the soil before and after electrochemical spraying. The test resultsshow that electrochemical injection with calcium chloride salt solution and a voltage of 15Vcan reduce swelling characteristics and increase optimal shear strength.

1. Introduction

The distribution of soft and expansive soils in Indonesia is almost 60% of which 20% is in Java Island, one of the areas is Karawang, based on the geological map of West Java. However, this type of soil has several weaknesses. The weaknesses of soft and expansive soils are low soil permeability and a large potential for shrinkage which can affect the shear strength of the soil. Infrastructure development that continues to be carried out cannot avoid soft soils and expansive clays that are spread throughout Indonesia. Soft soil and expansive clay are classified as problematic soil types. For this reason, it is necessary to carry out a soil improvement method so that it can be used and support infrastructure development. The current problem is the need for a method to improve in situ soft and expansive soils. Electrokinetic is a method that uses electric current to improve soft soil. This method was first introduced by Reuss (1809) and has been applied by Casagrande (1935) in soil improvement for railroad tracks. The use of direct electric current (DC) for fine-grained soil stabilization has been noticed by geotechnical experts and has begun to be applied to slope stabilization, chemical changes in clay stabilization, remediation of polluted soils, consolidation, and enhancement of pile friction capacity [1–5]. Expansive clay has montmorillonite with a 2:1 mineralogy structure between silica (SiO_2) and alumina ($Al2O_3$), has a positive charge (cation) between the mineralogy sheets which results in easy exchange capacity [6–8]. Divalent cations bind more strongly to the clay surface than monovalent cations, following a typical exchange sequence such as $Na^+ < Li^+ < K^+ < Rb^+ < Cs^+ < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{3+} < Th^{4+}$ [2,9-10]. The saline solution used for electrokinetics is known that better consolidation efficiency can be achieved by using $CaCl_2$ Because the exchange capacity in the double electric layer and hydration capability of cations is different, $CaCl_2$ is able to provide a greater enhancement of electroosmotic consolidation than KCl and NaCl [6–9].

Electrokinetic injection has the ability to change the physical and mechanical properties of the soil by reducing the LL, PL, and IP values, swelling potential, and changing the shear angle and cohesion values of the soil [9–11]. In addition, the mineralogy of the soil also changes due to the chemical injection process [12]. Changes in the cohesion and shear angle of the soil can affect the shear strength of the soil. There was a soil shear-strength increase in the expansive soil that had been injected with $CaCl_2$ at the anode [6]. Electrokinetic with $CaCl_2$ injection reduced the LL, PL, and IP values and had an effect on the swelling potential of the soil [9–13]. The electroosmosis process causes the movement of water from the anode to the cathode, and $CaCl_2$ is simultaneously injected, hence, there is a change in physical and mechanical properties, mineralogy of the soil, and a decrease in each certain distance.

2. Methods

The soil for the electrochemical injection test came from an industrial area, in Karawang, West Java. Testing of the physical properties of the natural soil was carried out to determine the type of soil and its development potential. Table 1 shows the standard of the physical properties test.

Table 1. Physical properties test.

Soil Test	Indonesian National Standard (SNI)
Sieve Analysis	03-3423-1994
Specific Gravity	03-1964-1990
Liquid Limit	03-1967-1990
Plastic Limit	03-1966-1990
Shrinkage Limit	03-3422-1994

The injection was carried out based on the phenomenon of electroosmosis (Figure 1). Soil samples were soil that passed sieve 4 with a weight of 9 kg for each box. Then the soil is mixed with water until its LL. Fiberglass box and install 2 copper plates measuring 15 cm x 15 cm which function as anode and cathode. Put the soil sample into the fiberglass box that has been prepared and then level it so that the surface of the soil under study is clearly visible. A clearly visible soil surface is important cause it is necessary to measure the subsidence that occurs during the electrochemical injection process. Install the copper in a linear position in the center of the sample and the distance between the coppers is 5 cm. DC current will flow to a 15x50x15cm plexiglass box through an adapter that has converted AC electric current into DC. copper electrodes with 15x15 cm and a thickness of 2mm were installed as anode and cathode. The calcium chloride solution was placed near the anode.

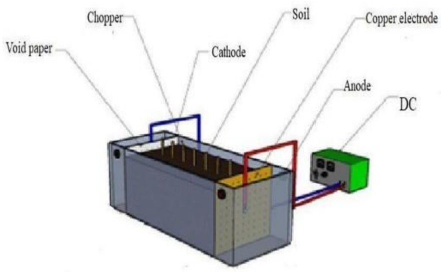

Figure 1. Electroosmosis by injection.

Saturated soil was inserted into the box and given DC electricity with voltage variations of 12V, 15V, 18V, and 24V. Electricity was given for 7 days with a duration of reading every 1 hour for the first two days, then 2 hours after, and the water that comes out will be measured every day. Mechanical tests with triaxial were carried out after the injected soil sample had finished. These points were taken near the anode, in the middle, and near the cathode. Then, an analysis was carried out by comparing the shear strength of the soil and the potential for soil development before and after injection. The method of testing the mechanical properties of the soil carried out is in accordance with Table 2.

Table 2. Soil mechanical test.

Testing	Indonesian National Standard (SNI)
Vane shear	03-2487-1991
Swelling Test	03-6795-2002
Triaxial for cohesive soil (UU)	03-4813-1998
One Dimensional Consolidation (Oedometer)	03-2812-2011

3. Results and Discussions

3.1. Soil classification

The results (Figure 2) of the natural soil physical test i.e., specific gravity (Gs), plastic limit (PL), liquid limit (LL), plasticity index (PI), and shrinkage limits (SL) were 2.625, 65.07%, 30.98%, 34.09%, and 28.18%, respectively. The natural soil was classified according to the USCS classification, so the natural soil is clay with high plasticity (CH).

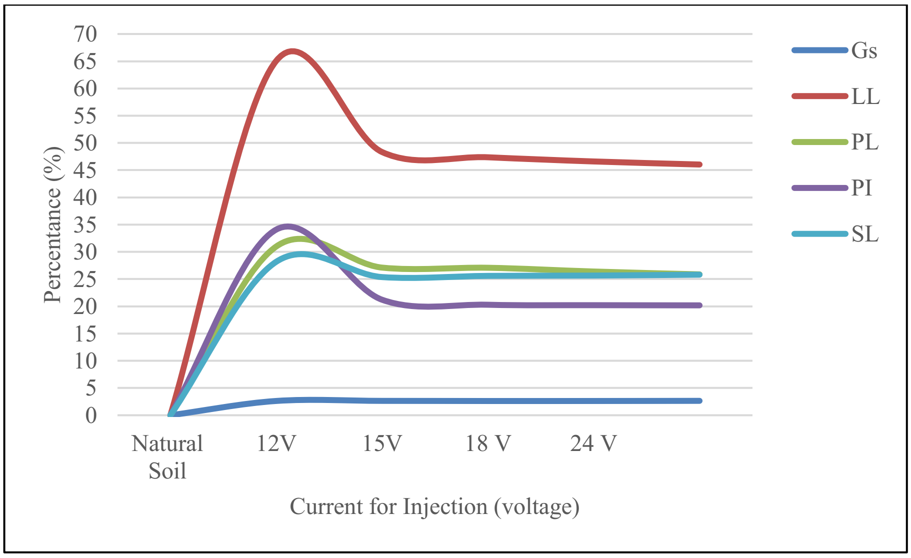

Figure 2. Properties index after injection.

After the injection, the physical properties of the soil were tested again with the results shown in Figure 2. Of the four large voltages given, there was a change in the value of soil density (GS), liquid limit (LL), plastic limit (PL), plasticity index (PI), and shrinkage limit (SL). Injection with $CaCl_2$ caused a decrease in LL, PL, and PI values [10]. The injected soil with a voltage of 12V, 15V,18V, and 24V is classified by USCS are clay with moderate plasticity (CL). From the results of testing the physical properties of the soil, it is found that the injection process can change the basic physical properties of the expansive soil of Karawang.

3.2. Mineralogy

Expansive soil containing montmorillonite has a high ability to absorb water. The analysis was carried out by looking at the differences in the shape and size of montmorillonite from samples obtained from soil testing using the Scan Electron Microscopy (SEM) method [14]. Figure 3 shows the structure of mineral sheets that accumulate and form a solid mineral. After the injection, there is a change in the mineralogy structure of the soil where the stacked and exposed soil sheets become closed and there is no mineral buildup.

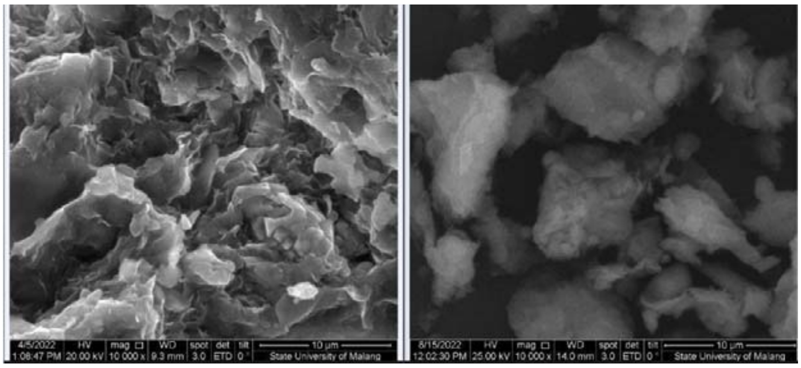

Figure 3. SEM clay before and after injection.

3.3. Electroosmotic permeability

Electroosmosis flow can be determined by the value of the flow associated with the hydraulic gradient i.e., the flow of water in the electroosmosis process to the time of water flow. This phenomenon is called the coefficient of permeability [15]. The coefficient of electroosmotic permeability (k_e) is the ability of the soil to drain water due to an electric potential difference (Equation 1). The difference with the hydraulic permeability coefficient is that its constant value is not affected by the pore size. The value of ke is obtained from the calculation of permeability where qA is the amount of water flow in unit time through an area of land (A) which is electrified by electric potential and with a certain length (L) of flow and potential difference (V).ss

$$qA = k_e \cdot ie \cdot A = k_e \cdot V/L \cdot A \quad (1)$$

The use of $CaCl_2$ electrokinetic phenomena can affect the permeability value of the soil but cannot change the soil structure [22].

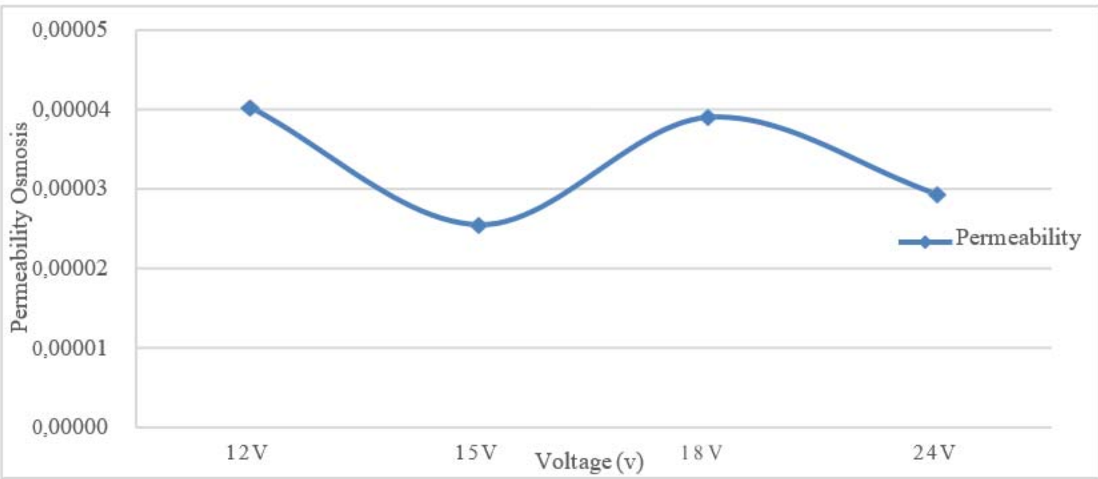

Figure 4. Electroosmosis permeability.

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Electroosmosis permeability can be seen in Figure 4, the largest occurs at a voltage of 12V, which is 4.0234E-05 cm^2/second.volt. While the smallest occurs at a voltage of 15V, which is 2.5463E-05 cm2/sec.volt. From the test results, it is found that the magnitude of the voltage can affect the value of the electroosmosis coefficient, although the magnitude of ke that occurs between the 4 voltages given is not very significant. The phenomenon of electroosmosis by injection of a chemical solution with a certain voltage can be carried out and has an effect on the magnitude of ke [1 4, 1 6]. The resulting ke value shows that Karawang soil is categorized as Na-montmorillonite [14].

3.4. Soil shear strength

The success of the electrochemical injection process can be seen from the comparison of the mechanical properties of the soil before and after injection. The results of the injection can be seen in Figure 5.

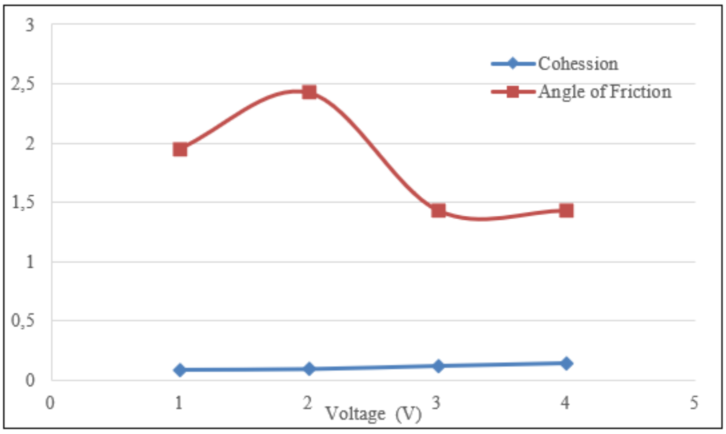

Figure 5. Relationship between voltage with cohesion and soil shear angle.

Triaxial test results showed that there was a change in the cohesion value and internal shear angle. The largest internal shear angle occurred in the injected soil with a voltage of 15 volts. Figure 6. shows that the largest cohesion value occurs at a voltage of 24V with a magnitude of 0.141 kg/cm2. The increase in the cohesion value occurred along with the increase in the applied voltage. The triaxial test results showed an increase in stress and strain values for all given voltages.

The decreased cohesion value was caused by the mineralogy of the clay being covered by the mineralogy of $CaCl_2$ while the injection process caused water to flow from the anode to the cathode which was then filled with an injection solution that would react to form a cement solution that closed the soil pores.

3.5. Swelling

The development potential of the soil before and after injection can be determined from the consolidation test. A dimensional consolidation test with an Oedometer is the parameter used in this study. The resulting compression index (Cc) can be seen in Figure 6.

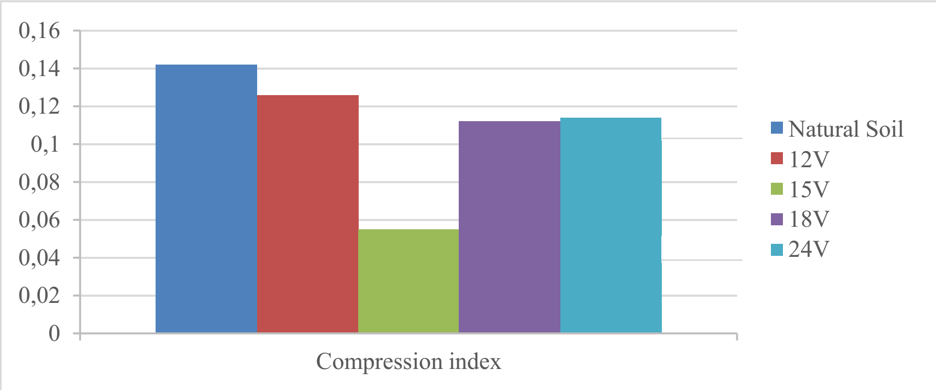

Figure 6. Compression index for every variant current.

There was a decrease in the Cc value of the soil before and after injection. From the four given voltages, there was a decrease in the value of Cc where the smallest value of Cc was found at a voltage of 15V, which was 0.055. This occurs because of the Ca bonding of the $CaCl_2$ solution in the soil, which causes the mineralogical composition of the soil to change, and the ability of the soil to absorb water decreases. This condition makes the potential for land development to be small.

Soil shrinkage will decrease by electrochemical injection method Stabilization of changes in soil volume after electrokinetic is very significant. This method is effective and efficient. Soil to changefrom CH to CL, b). Electrochemical injection with $CaCl_2$ creates new mineralogy forms that can be seen in the SEM results, c). The voltage and current that occur in the electrokinetic process decrease along with the increase in the distance of chubber between the cathode to the anode, d). The decrease in soil surface also occurs and increases with increasing distance between cathode to anode, e). Soil permeability that occurs after the electrochemical injection percentage decreases and changes. This process can be said to be effective and efficient, f). There is an increase in shear strength at the addition of $CaCl_2$ which can be seen from the increasing Cu value based on the vane shear test results s, and g). The increase in the angle of friction and cohesion of the four different voltages applied where the best result was at 15V.

4. Conclusion

This paper examines the experimental results of clay improvement in the laboratory by $CaCl_2$ Electrochemical Injection. The test results show the findings, namely: a). There was a change in the characteristics of the soil, namely the values of Gs, LL, PL, PI, and SL, which decreased along with the increase in voltage, which caused the soil to change from CH to CL, b). Electrochemical injection with $CaCl_2$ creates new mineralogy forms that can be seen in the SEM results, c). The voltage and current that occur in the electrokinetic process decrease along with the increase in the distance of chubber between the cathode to the anode, d). The decrease in soil surface also occurs and increases with increasing distance between cathode to anode, e). Soil permeability that occurs after the electrochemical injection percentage decreases and changes. This process can be said to be effective and efficient, f). There is an increase in shear strength at the addition of 10% $CaCl_2$ which can be seen from the increasing Cu value, and g). The increase in the angle of friction and cohesion of the four different voltages applied where the best result was at 15V.

Acknowledgments

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