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Effect of Salt Solution in Electrochemical Stabilization with Variation of Potential Difference on Clay's Shear Strength

(Pengaruh Larutan Garam pada Stabilisasi Elektrokimia terhadap Kuat Geser Tanah Lempung dengan Variasi Beda Potensial)

Lydia Darmiyanti [1], Ujang Wiharja[2]

[1] Teknik Sipil, Fakultas Teknik, Universitas Krisnadwipayana - Jl. Kampus Unkris Jakarta, Indonesia
[2] Teknik Elektro, Fakultas Teknik, Universitas Krisnadwipayana - Jl. Kampus Unkris Jakarta, Indonesia

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***e-mail the corresponding author :**
lydiadarmiyanti@unkris.ac.id

PENERBIT :
UNITRI PRESS
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ABSTRACT

Clay is one of the problematic soils in Indonesia, with a distribution in Java of close to 20% of surface pedology. The biggest problem with clay soil is its ability to swell when it absorbs water and shrink when the water content decreases. Indonesia's tropical climate, where only the rainy and dry seasons, significantly affects clay's swelling potential, hindering the soil's mechanical properties. The significant expansion potential causes the soil to have a slight shear angle, which affects its bearing capacity. This condition underlies the urgency of clay soil improvement to increase the shear strength of the soil. Electrochemical stabilization is one of the effective methods for soils with low permeability. This study aimed to determine the most optimum voltage in electrochemical stabilization using a salt solution. The electrochemical process is used in soil stabilization. This method is used to improve soils with low permeability and high plasticity index (>18%), which results in increased bearing capacity and decreased soil development. This study was conducted with four different stress scenarios, and from the results of testing the mechanical properties of the soil, it was found that the greatest shear strength occurred at a stress of 12V. Stabilization of clay soil by electrochemistry can be inferred from the research to increase the value of soil shear strength and affect the increase in soil bearing capacity.

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1. INTRODUCTION

The history of soil formation, based on the geological map of the West Java region, shows that the soil material on the earth's surface is the result of young alluvial sediments that tend to have problems. Sedimentary soils undergo weathering and mineralogical changes due to the influence of pressure and temperature changes so that clay soils are formed. Clay soils have low permeability and high plasticity index values, and their potential for development is a significant concern for geotechnical engineers. Clay soil becomes very hard in the dry season and slurry in the rainy season. This condition risks structural failure in road construction or road shoulders that collapse and experience longitudinal cracks on the Cipularang toll road due to its clay subgrade.

Developing soil strength or bearing capacity requires improvement efforts to increase soil shear strength, decrease swelling index, and thus improve soil bearing capacity. The high content of ions and mineralogy such as monmorillonite, smectite, bentonite, beidellite, vermiculite, atapulgite, nontronite, illite, chlorite, and some sulfate salts in clay soil results in the soil having a considerable shrinkage-swelling ability [1]–[3]. Soil conditions that swell during the rainy season and shrink during the dry season result in decreased bearing capacity and structural failure.

Figure 1. Clay soil in the dry season

Structures above clay become unstable and even collapse. Given Indonesia's rainy and dry climate, some areas are also at risk of landslides. Therefore, an effective soil improvement is necessary. Clay soils have a high montmorillonite content. Clay minerals comprise three-layer sheets, one octahedral sheet between 1 silica sheet. There are fragile van deer walls between the clay minerals. These weak bonds allow water to enter and be trapped there, resulting in swelling. This clay mineral content damages the road structure in the rainy season; the soil will absorb water and shrink in the dry season because the soil releases water. The type of subgrade soil primarily influences road structure damage. Clay soil used as a subgrade will have a high potential for road structure damage.

The characteristics of clay mineralogy that easily absorb water are a problem in and of itself. Therefore, it is necessary to conduct a study that can improve the properties and characteristics of clay soil. The electrochemical injection method that uses the potential difference in direct electric current is one of the alternatives to clay soil stabilization [1]–[4]

Clay soil has a negative ion, which, when it meets the positive ion that water has, the water will be trapped and bound in the clay minerals, and then the clay soil will swell. Therefore, it is necessary to consider an effort to stabilize the clay minerals.

Stabilization of clay soils has been done by adding certain materials with characteristics that allow negative ions to bind in clay soils. Electrochemistry is one of the methods used for clay stabilization. The method was first introduced in 1807 by Reus and continues to be developed today. Due to its charge-bonding properties, the technique is used for the consolidation process from soft and saturated clay soils. Electrokinetics is a technique that consolidates and reinforces soft and saturated clay soils [5]–[10]. When a DC voltage is applied to the soil between the electrodes, the soil pore water is attracted to the negative terminal (cathode) due to the interaction between the electric field and the ions in the pore water and soil particles [11], [12]

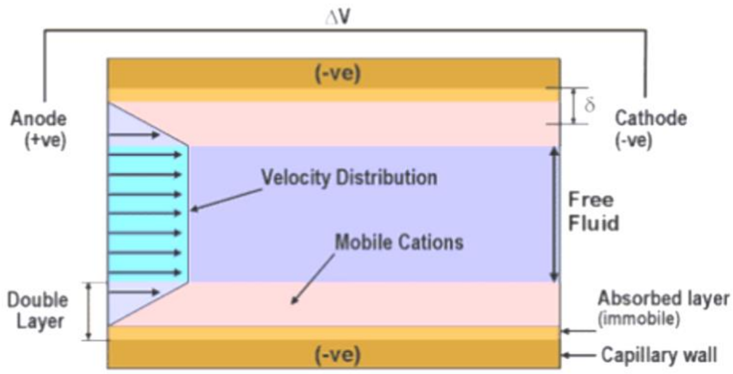


Figure 2. Electroosmosis Helmholtz-Smoluchowski Theory

The zeta potential that occurs is a response to the movement of colloidal particles between the fixed and moving parts of the electric double layer. The zeta potential is also influenced by ion exchange capacity, radius size, and layer thickness. The movement of water in porous media under an electric field is influenced by the cations (negative charge) in the water layer. When electricity is applied to the soil, the particles will remain, and the diffusion layer will move with the solution.

A direct electrical gradient is applied to the soil; the surface water or particles remain, but the diffusion layer moves and carries the solution. The solution will decompose as the direct current is applied, whereas solutions that are acidic, wet, or other compounds can be used for this method.

The ability of DC voltage to attract water in clay soil is one solution because clay is very water-binding. (Fig. 2.)[13] However, the main problem of shrinkage of clay soil cannot be solved by removing the water content by electroosmosis. Therefore, a substance is needed to stabilize the clay soil and reduce the clay's ability to swell.

Lime (CaO) is a widely used material for soil stabilization. Stabilization of clay soils using lime has been widely carried out, and soil mechanical values, such as CBR, soil shear strength, and suppressed swelling values, have increased [14]–[18]. CaO is used for road subgrade stabilization by placing it on the soil and then compacting it with heavy equipment. This stabilization process is carried out before the structure is erected.

Soil stabilization with electrochemical methods is applied to soil improvement for structures erected by applying direct voltage using electrodes that function as electrical conductors. The amount of voltage applied will affect the speed of water flow from the anode to the cathode. Lime-based solution $Ca(OH)_2$ is used for stabilization by utilizing the phenomenon of electroosmosis. The solution is injected into the soil, where it flows from the anode to the cathode, increasing the shear strength of the soil. [5]–[7]

The application of voltage in the electrochemical process affects the speed of the solution moving from the anode to the cathode [17]. Soil characteristics also influence flow solutions. Therefore, it is necessary to conduct electrochemical stabilization research using voltage variations.

When conducting soil stabilization by electrochemical, selecting the type of electrode used must be considered so as not to cause environmental impacts because some electrodes are very easy to corrode. Clay soils with kaolinite, illite, and montmorillonite mineralogy cause water to enter and bond in the soil quickly.

The question of this research is how voltage affects electrochemical stabilization with $Ca(OH)_2$ solution. This research's novelty is obtaining the optimum voltage in the electrochemical process on clay soil, as seen from the results of soil shear strength testing after stabilization.

2. RESEARCH METHOD

Experimental testing was conducted in this study. The clay soil was taken from Bekasi, West Java. The clay was taken in a disturbed state with a depth of 2 m. From the soil physical properties test data, the soil has an OMC of 22% and a specific gravity of 2.62 kg/m3. The tests conducted on the original soil were microstructure, soil physical properties, and mechanical tests. These three tests were performed to provide preliminary data that the soil is problematic and needs stabilization. The tests conducted can be seen in Table 1.

Table 1. Standard Test

Testing	Standard Nasional Indonesia
Water content	03-1971-1990
Attemberg limit	03-1966-1990
Grandsize	03-3423-1994
Hydrometer	03-6874-2002
Specific gravity	03-1964-1990
Vane shear	03-2487-1991

The research stages can be seen in the flowchart in Figure 3.

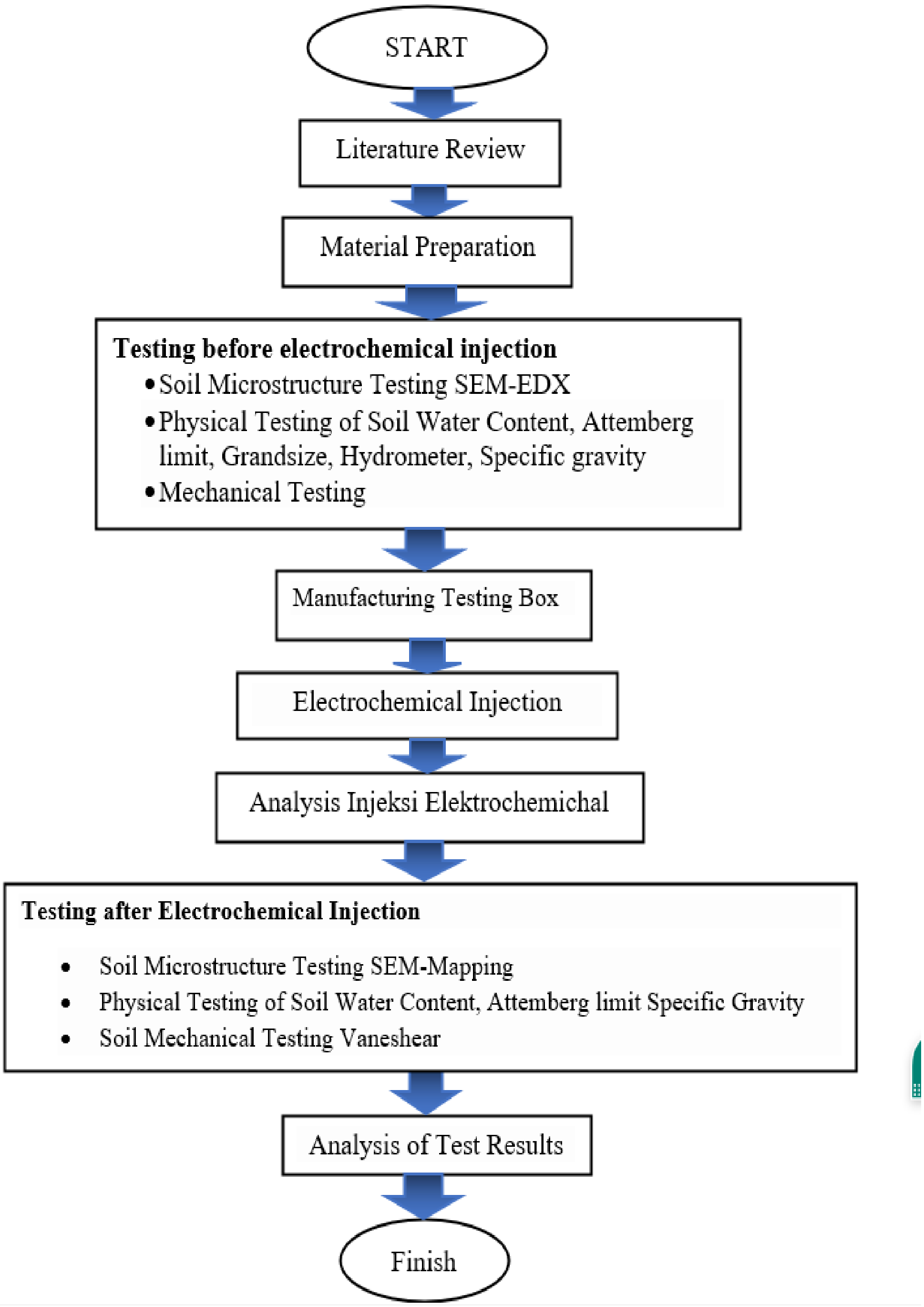


Figure 3. Flowchart

The results of the original soil testing before electrochemical obtained soil microstructure and physical and mechanical properties of the soil. Soil samples were treated with electrochemical stabilization using a salt solution, namely calcium dioxide with a concentration of 5% $Ca(OH)_2$ dissolved with pure distilled water, then placed in the electrochemical testing box. The tested soil is saturated with saturation value, reaching its liquid limit value. After electrochemical stabilization, soil microstructure and physical and mechanical tests were retested. The results were analyzed to conclude. The experimental method of electrochemical soil stabilization in this study can be seen in Figure 4.

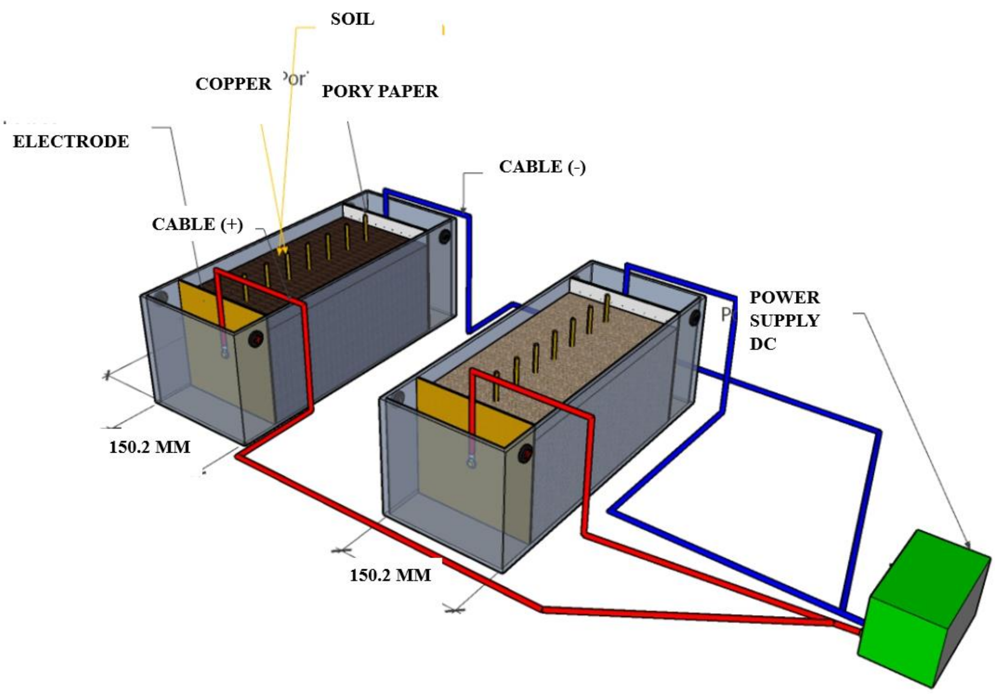


Figure 4. Electrochemical testing

The acrylic box measures 150.2 x 500.2 x 150.2 mm. The electricity supply was direct current with 12V, 15V, 18V and 24V voltages. The voltage was applied for seven days within 24 hours. Voltage measurements were taken hourly for the first two days and measured every 2 hours for the next four days. Voltage and current were measured every 50mm from the anode to the cathode. A salt solution was placed at the end of the box, and a positive voltage was applied. A positive voltage was applied to the anode and a positive voltage to the cathode. The electrical conductive material used is graphite in the form of sheets. Graphite is cut with a size of 150x150 mm thick 3 mm and given a hole diameter of 1mm with a distance between holes 15mm. Copper wire is placed in the center of the test box at a distance of 50mm. Copper wire is installed to help measure the amount of voltage and current at that point. Voltage and current readings are measured with a multimeter.

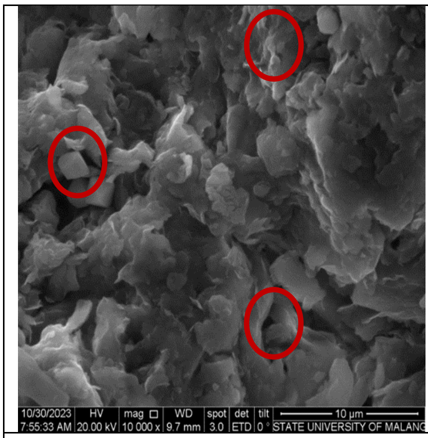
The variants voltage makes the salt solution flow from the anode to the cathode. Where Ca^{2+} will enter the soil while the water will come out through the cathode, the amount of water coming out through the cathode will be measured daily during the electrochemical stabilization process.

After seven days of the electrochemical process, the soil was curring for one day, three days, seven days, and ten days. Soil subjected to electrochemical stabilization and curing was then sampled for microstructural, physical, and mechanical tests. A microstructure test was conducted using scanning electron microscopy (SEM-EDS-mapping). SEM-EDS-Mapping is a test that takes pictures with object magnification reaching 100,000x of the original object, where EDS (energy dispersive X) mapping functions to determine the distribution of elements in soil samples. Physical tests were conducted using the Attemberg limit, and mechanical tests were performed using vane shear testing.

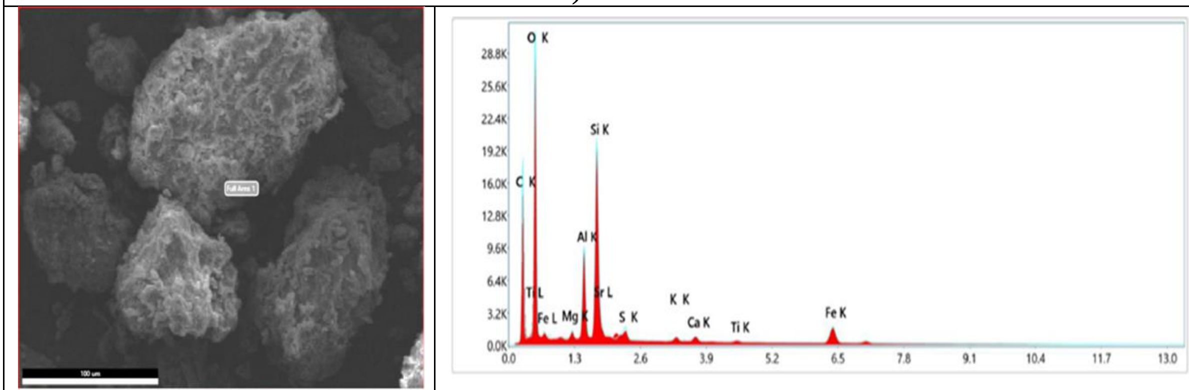
3. RESULTS AND DISCUSSION

3.1 Microstructure Testing

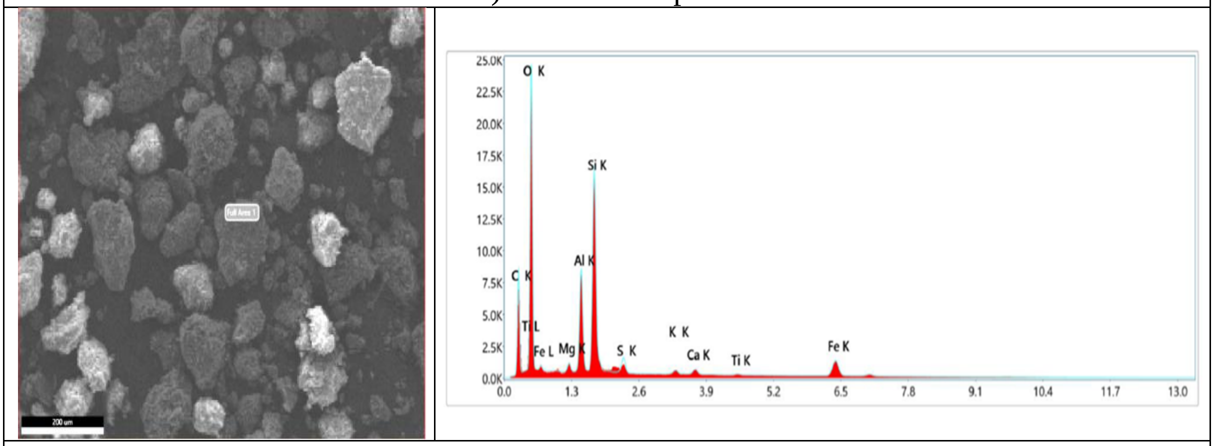
The original soil before stabilization is a clay soil that has clay mineralogy. The mineralogy of the native soil is known from the SEM-EDS-Mapping test in Figure 5. It is a photo of the soil microstructure with an image magnification of up to 20,000x.



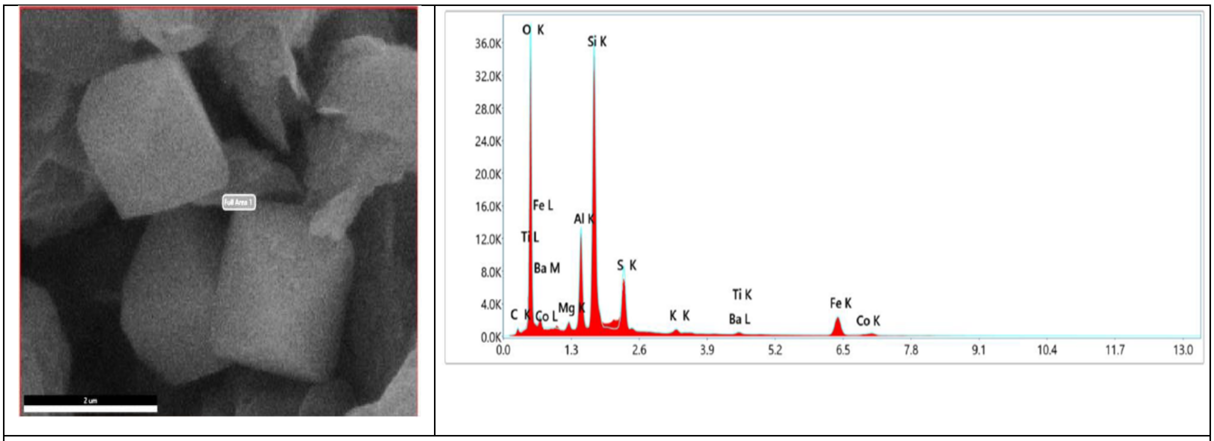
a) SEM



b) SEM-EDX spot 1



c) SEM-EDX spot 2



d) SEM-EDX spot 3

Figure 5. SEM-EDS-Mapping natural soil

Based on the SEM analysis of the original soil in Figure 5, a summary of the soil elements contained therein was obtained. The soil elements are in Table 2.

Table 2. Component in soil

Element	Weight (%)		
	spot 1	spot 2	spot 3
C	48,7	41,1	8,5
O	40,2	44,9	53,1
Mg	0,2	0,4	0,6
Al	2,3	3,4	6,6
Si	4,7	6,3	18,3
S	0,4	0,6	5,5
K	0,2	0,3	0,5
Ca	0,3	0,4	-
Ti	0,1	0,1	0,4
Fe	2,2	2,7	6,2
Sr	0,7	-	-
Co	-	-	0,4

The natural soil test results provide information on the various elements contained in the soil. Aluminum, magnesium, and silica are elements contained in montmorillonite mineralogy. Montmorillonite is a mineralogy in expansive clay soils. Montmorillonite is the most influential mineralogy in the shrinkage of clay soil. SEM-EDS-mapping test was conducted on the stabilized soil. SEM-EDS-mapping results can be seen in Figure 6.0.

The stabilized soil contains Carbon (C) 16.05%, Oxygen (O) 42.76%, Sodium (Na) 0.24%, Magnesium (Mg) 1.13%, Aluminum 7.3%, Silica (Si) 17.61%, Sulphate (S) 1.04%, Calcium (Ca) 0.75%, Titanium (Ti) 0.35%, Iron (Fe) 7.87%, Copper (Cu) 1.05%, Zinc (Zn) 0.95%, and Sr 1.62%. (Figure 6)

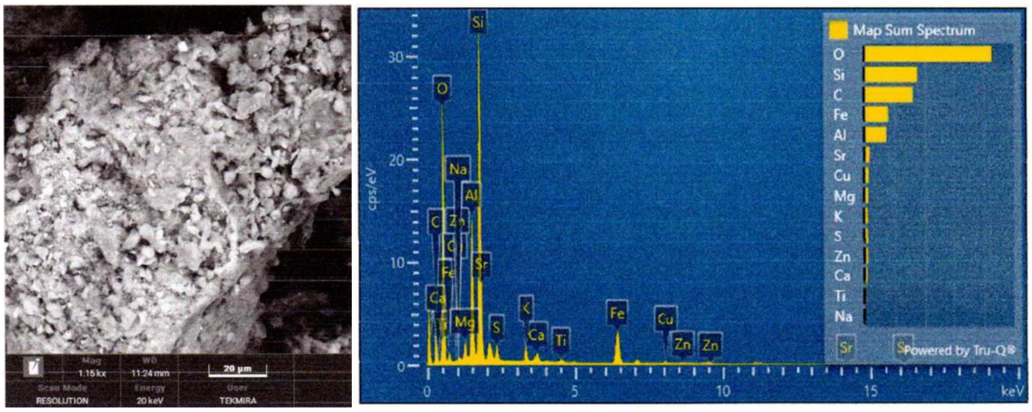


Figure 6. SEM-EDS-mapping after electrochemical

SEM-EDS-Mapping testing before and after electrochemical stabilization has changed some of the chemical elements contained in the soil. The salt solution introduced by electrochemistry to the soil includes calcium. From the SEM-EDS-mapping results, it can be seen that there is a change in the weight (%) of calcium in the soil. Calcium in the original soil of 0.3 - 0.4% increased to 0.75%. This increase in calcium proves that the calcium element is bound to the clay soil.

3.2. Shear strength

Soil shear strength testing was done using vane shear testing in the laboratory. Tests were conducted on soil after electrochemical stabilization with calcium dioxide. Tests were carried out with a curing period of 1 day, three days, seven days, 10 days, and 14 days. Compressive strength testing was carried out in the cathode area, the middle area, and the area near the anode. The shear strength results of each stress can be seen from Figure 7 to Figure 10.

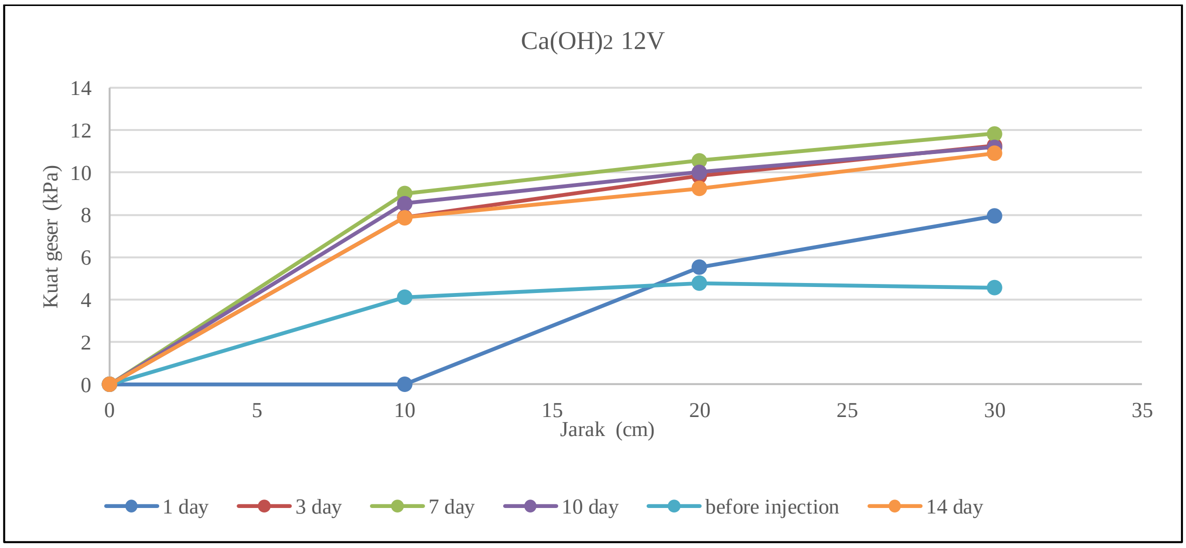


Figure 7. Shear strength at 12V

Figure 7 above shows the amount of soil shear strength in the soil before stabilization and after stabilization. The lowest shear strength is found in the soil before electrochemical stabilization, where the anode area obtained a reading of 4.12 MPa in the middle of 4.78 MPa and at the cathode of 4.56 Mpa. After stabilization using $Ca(OH)_2$ solution with 12V and five curing times, it is known that the most considerable shear strength value is found in soil that has been cured for seven days. The shear strength in the anode area is 9.008 MPa, the center is 10.56 MPa, and the cathode is 11.83 MPa, and there is a decrease at ten days and 14 days. The soil shear strength at ten days in the cathode area is 11.19 MPa, while the soil shear strength at 14 days in the cathode area is 11.09 MPa. The results of soil shear strength in 15 V $Ca(OH)_2$ stabilized soil are shown in Figure 8.

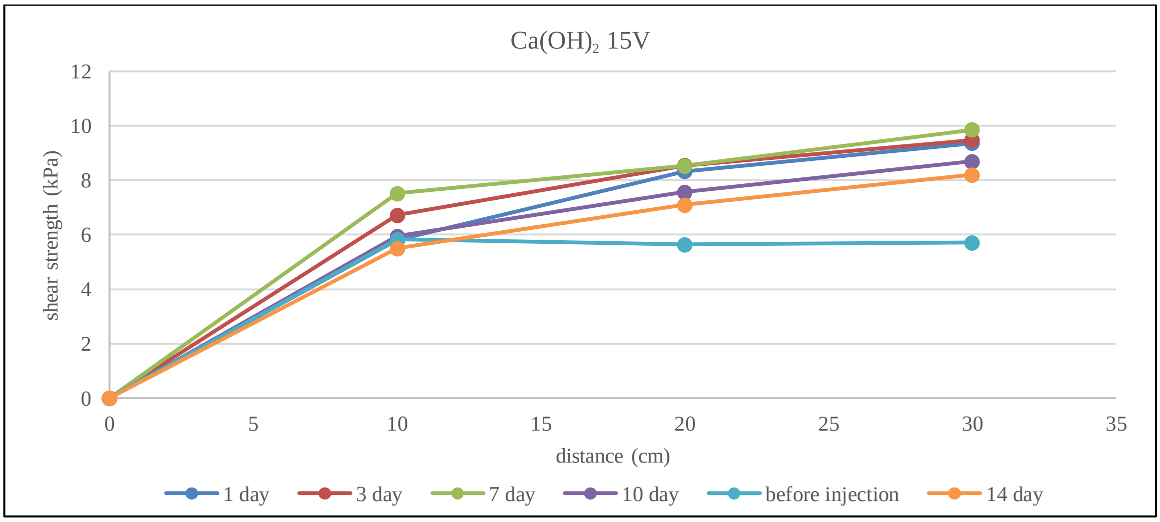


Figure 8. Shear strength at 15V

The shear strength resulting from the electrochemical stabilization of $Ca(OH)_2$ with a voltage of 15V for soil curing times of 1 day to 14 days showed changes. The shear strength of the soil increases as the curing time increases, but there is a decrease in the curing time after seven days. The amount of soil shear strength for 18V $Ca(OH)_2$ stabilization can be seen in Figure 9.

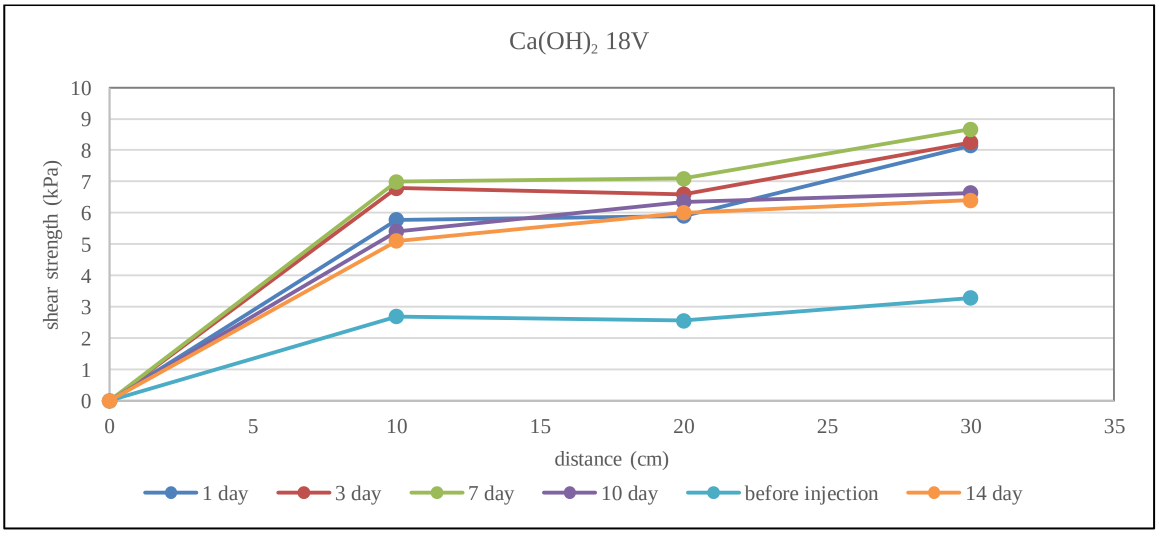


Figure 9. Shear strength at 18V

The shear strength resulting from the electrochemical stabilization of $Ca(OH)_2$ with a voltage of 15V for soil curing times of 1 day to 14 days showed changes. The shear strength of the soil increases as the curing time increases, but there is a decrease in the curing time after seven days. The amount of soil shear strength for 18V $Ca(OH)_2$ stabilization can be seen in Figure 9.

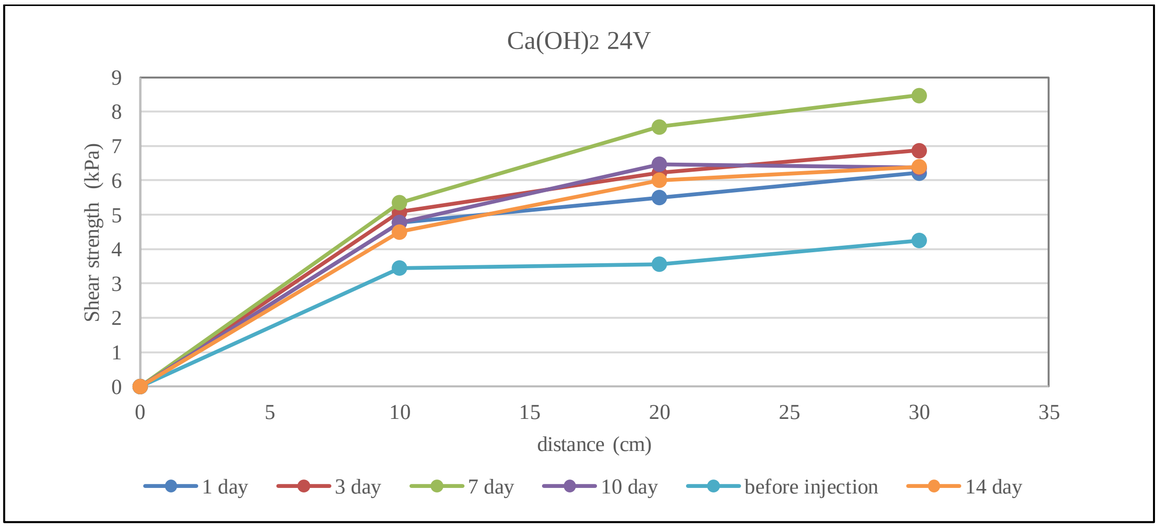


Figure 10. Shear strength at 24V

Figure 10 shows the increase in shear strength of $Ca(OH)_2$ 24V electrochemical stabilized soil. From the four voltages applied to the electrochemical stabilization of $Ca(OH)_2$, it is known that there is an increase in soil shear strength. The shear strength of the soil increased with the rise of soil curing time. The shear strength of the soil started to decrease after the soil was cured for more than seven days. However, the decrease is not significant and is considered to be constant.

The shear strength that occurs appears to increase in all test specimens with different stresses. An increase in shear strength occurs from the anode to the cathode area. From Figure 7 to Figure 10 shows a significant increase. This increased shear strength value is due to the solution flowing from the anode to the cathode, so that the cathode area will have a greater calcium content than the anode. Due to the nature of clay which easily captures other positively charged minerals, Ca which has a 2+ charge enters the mineralogy of the soil and is bound within it. This occurs due to the exchange capacity of ions such as Na+, K+, Ca2+ and Mg2+, attracted by the negatively charged surface of the interlayer in clay particles.

The shear strength increases in all test specimens with different stresses. The increase in shear strength occurs from the anode to the cathode area. From Figure 7 to Figure 10 shows a significant increase. The increased shear strength value is due to the solution flowing from the anode to the cathode, giving the cathode area a greater calcium content than the anode. Due to the nature of clay soil that easily captures other positively charged minerals, Ca, which has a 2+ charge, enters the soil mineralogy and is bound therein. This occurs due to the exchange capacity of ions, such as Na^+, K^+, Ca^{2+}, and Mg^{2+}, attracted by the negatively charged surface of the interlayer in clay particles.[10]–[12]

This condition makes the clay soil more stable because the absorbed water cannot be reabsorbed into the clay structure, so the shear strength of the soil does not decrease. The four different voltages applied, the optimum voltage occurs in the stabilized soil at 12 V, which is 11.82 MPa. Increasing the shear strength of clay soil in electrochemical stabilization is an effective method for soils with low permeability, and further research needs to be done for other types of soil [8], [13], [19], [20].

4. CONCLUSION

The $Ca(OH)_2$ solution injected in the electrochemical stabilization process proved effective and gave results. This can be seen from the results of SEM analysis. SEM EDS-mapping of stabilized soil showed increased calcium element from 0.3-0.4% to 0.75%. This proves the entry of Ca element into the soil due to the ion capacity exchangeability of the clay soil. Soil stabilization with electrochemical $Ca(OH)_2$ increases soil shear strength. The results of mechanical testing show an increase in soil shear strength. The study found that 12V was the optimum voltage of the four different voltages given. The closer to the cathode, the shear strength of the soil will increase. The increase in soil shear strength is influenced by the amount of voltage applied.

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