Effect of Electrokinetic Soil Improvement on CBR Value of Expansive Clay

Lydia Darmiyanti, Ivan Imanuel*, Prihartono

Department of Civil Engineering, Krisnadwipayana University, Bekasi, Indonesia

Department of Civil Engineering, President University, Cikarang, Indonesia

Received 30 March 2025; received in revised form 06 April 2025; accepted 07 April 2025

Abstract

Improvement of low permeability soils with high plasticity index and high shrinkage expansion cannot be done by soil compaction or consolidation. The structure of expansive clays is influenced by the history of soil formation. Expansive soil structure is composed of two tetrahedra with one octahedron. Van der Waals bonds bind them together. Kolinite, illite, and montmorillonite are minerals in expansive soils. Montmorillonite has the weakest bond of the others so that other elements can easily enter the clay structure and bind to it. The ability of clay soil to absorb water or other minerals that come close is due to its cation exchange capacity (CEC). Clay, with its negative ions, will attract positive ions that approach the soil surface. Water with H+ content will easily enter the structure of the clay soil, bond with it, and cause the soil to swell. Electrokinetic soil improvement is effective on clay soils. With the nature and characteristics of clay soil, positively charged stabilizing ions are required. Therefore, this research aims to improve clay soil using the electrokinetic method with a calcium dioxide solution. An increase in the Bearing Capacity Ratio (CBR) value occurred after being improved by electrokinetic using four variations of voltage application. The variation of applied voltage gives different results to the change of soil mechanical properties. The original CBR of 0.093% increased for all stress applications. The optimum CBR value occurred in the soil applied with 15V. The resulting CBR increase reached 200% of the original soil CBR.

Keywords: improvement, electrokinetic, calcium dioxide, montmorillonite, CBR

1. Introduction

In an attempt to balance economic growth, infrastructure construction is still being done. Twenty percent of Indonesia's soils are problematic. Because of its significant shrinkage expansion, expansive clay is a troublesome soil. Clays are highly flexible and have poor permeability [1-2]. Numerous geological, environmental, and historical factors influence the creation of expanding clays. High clay content, soil formation processes, dry to wet climates, and soil drainage characteristics all affect the production of expansive clays [3]. The negative charge on the clay surface causes the approaching positive minerals to be attracted and cation exchange occurs. The ability to exchange cations on clay is the ion exchange capacity (CEC). Expansive clays contain montmorillonite which affects the mechanical properties of the soil so that it has a low bearing capacity, so soil improvement efforts are needed [4-5].

Casagrande was the first to discover electrokinetic ground improvement for railway slope stabilization [6]. For soils with high shrinkage expansion and limited permeability, this technique worked well [7]. The following electrokinetic events take

* Corresponding author. E-mail address: ivan.imanuel@president.ac.id
Tel.: +62(0)21 89109763

place: electrophoresis, which is the movement of dissolved particles through water under an electric field; electroosmosis, which is the movement of water through a solid matrix; flow potential: a tiny electric field produced when water passes through a matrix of soil; A tiny electric field produced when solid particles travel through water or when cations and anions migrate under an electric field is known as the sedimentation or migration potential.

A method of improving soil that makes use of electrochemical principles is called electrokinetic stabilization. Direct electric current (DC) applied to the soil is used in electrokinetic soil improvement. In electrokinetic, a variety of electrical conducting devices have been employed. In electrokinetic stabilization, a direct electric current is supplied to electrodes positioned at the soil's water-saturated edge. Soil consolidation and improvement will come from groundwater moving from the cathode to the anode and out of the soil [8-9]. Carbon's excellent electrical conductivity and lack of corrosion led to its discovery and ongoing development. Water in the soil or from the negatively charged (cathode) to the positively charged (anode) will benefit from this voltage differential.

This water exchange procedure is referred to as electroosmosis. Clay soils are stabilized by this electroosmosis process. Positively charged minerals can readily enter the soil structure due to the mineralogical properties of clays with weak structural connections. Swelling will happen if water with an H2+ charge gets within the clay structure. The clay structure is then penetrated by the stabilizing ion solution, which enhances soil mechanics and structure. Stabilization materials that are positively charged are used in the electrokinetic enhancement of expansive soils [4]. In soft clay soils, electrokinetic stabilization using stabilizing ions K^+, Ca^{2+}, and Na^+ can enhance the soil's mechanical and physical characteristics.

2. Material and Method

The broad clay soil comes from Indonesia's West Java. The soil was sampled in a disturbed state and at a depth of three meters. According to the soil physical test, the soil has a Gs of 2.62 N/m^3 and an OMC of 22%. having a PI (Plasticity Index) value of 31.49% and an LL (Liquid Limit) value of 59.55%. According to the results of the soil mechanical testing, the soil's shear strength is 0.128 kg/cm^2, and its swelling value is 5.8%. The expansive clay soil is categorized as an extremely soft clay soil with a high plasticity clay soil type (CH) based on the initial soil data collected. Seed classifies the swelling value as a high-expansion soil. Calcium dioxide hydrate is the salt solution that is utilized, and its solution percentage is 5% per 1000 grams. Pure water dissolves calcium dioxide. 3 mm thick graphite plate is used in the electrically conductive substance.

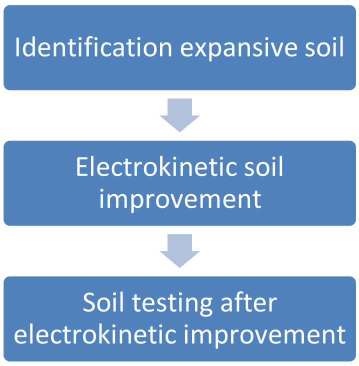

Fig. 1 Research stages

The experimental research was carried out in stages as shown in Fig. 1:

1) Identification of expansive soil.

   To determine the original soil's state, a number of preliminary tests were carried out. Events and structural failures that have taken place in the area serve as the foundation in addition to the history of soil formation in the sampling area. Identification testing was done using ASTM D-1921 for the grain size, ASTM D-4318 for the Atterberg Limit, ASTM D-698 for the compaction, ASTM D-4546 for the swelling, and ASTM D-1183-21 for the CBR.

2) Electrokinetic soil improvement.
   The type and characteristics of the soil are known from the identification process. The soil sample is clay soil that has a high rate of swelling and high plasticity. Therefore, in order to increase the soil's mechanical and physical qualities, soil treatment is necessary.
3) Soil testing after electrokinetic soil
   identification testing was carried out again after Electrokinetic stabilization to determine the changes that occurred after improvement size, Atterberg Limit and CBR.

5% calcium dioxide solution is used for electrokinetic stabilization. After being moistened, the dirt was physically placed in an 11,250 cm³ box. For six days, electrokinetic was conducted using four different potential difference variations. The anode received a positive voltage, while the cathode received a negative voltage. The electrodes that were utilized had holes that were 1 mm in diameter and were spaced 10 mm apart (Fig. 2).

The salt solution will flow from the positive electrode to the negative electrode due to the voltage. When the salt solution ionizes, water will flow to the negative electrode and positive ions will be absorbed into the soil. Every day, water will be collected in a measuring cup after exiting the negative electrode. Following electrokinetic, the soil will be let to stand for a predetermined amount of time before the test is conducted again to see any changes that have taken place. The testing apparatus for electrokinetic stabilization is shown in Fig. 3.

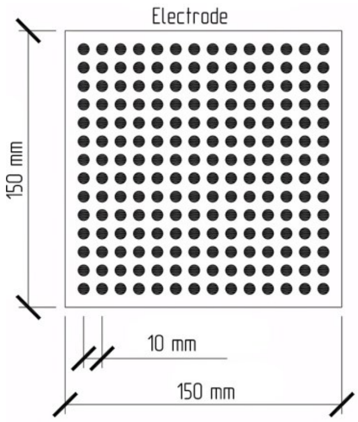

Fig. 2. Electrokinetic improvement: electrode

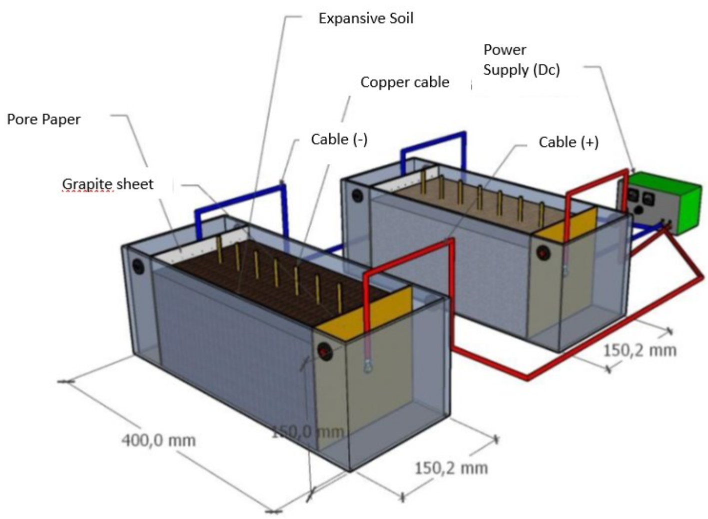

Fig. 3 Electrokinetic improvement: apparatus for electrokinetic clay improvement

One variety of clay underwent several treatments throughout the tests. The electrokinetic process without a chemical solution was contrasted with electrokinetic stabilization using salt solution (EK). Dewatering (XY) is another name for the electrokinetic process that does not involve a saline solution. Table 1 lists the eight variations of soil samples that underwent electrokinetic stabilization.

Table 1 Samples variants

Applied Potential Difference	$Ca(OH)_2$ 5 %	Dewatering
12 V	EK1	XY1
15 V	EK2	XY2
18 V	EK3	XY3
24 V	EK4	XY4

3. Results and Discussion

3.1 Soil physical properties

The original soil and treated soil samples' findings from liquid limit tests revealed differing degrees of efficacy in altering the soil's flexibility. The LL in samples EK1 through EK3 gradually decreased; EK3 had the lowest value at 51.00%, which was 8.55% less than the original soil's value of 59.55%. The liquid limit was continuously lowered after treating EK samples, particularly EK2 and EK3, suggesting that the treatment was successful in lowering soil plasticity. Samples EK4 through XY4, on the other hand, displayed a rising trend in LL, with XY3 (58.38%) nearly reaching the initial soil value [10-11].

Conversely, samples EK4 through XY4 show an increasing trend in LL, with XY3 (58.38%) nearly matching the original soil value. The results from the XY samples are inconsistent and largely ineffective in reducing the plasticity of the soil. The differences in effectiveness between the EK and XY samples highlight the importance of the treatment method used to reduce soil properties. Further research is needed to optimize the treatment formula and understand the underlying mechanisms that drive changes in soil characteristics, in order to achieve the desired soil properties more efficiently and consistently. The LL results are shown in Fig. 3.

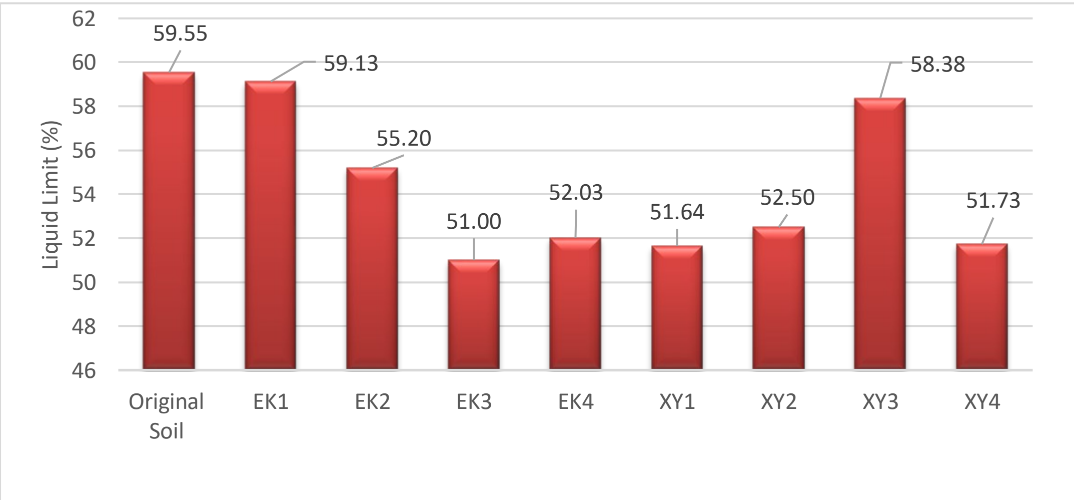

Fig. 3 Liquid limit of clay soil

The results of the PI test show that samples EK1 through EK4 experience a progressive decline in PI, from 27.46% to 19.32%, with EK3 reaching the lowest value of approximately 20.35%. In contrast, samples XY1 through XY4 exhibit a more modest PI range, from 25.52% to 12.3%, indicating varying levels of efficiency in reducing the plasticity of the soil. The difference in effectiveness between the EK and XY samples suggests that the treatment method plays a crucial role in reducing soil plasticity. Therefore, further research is necessary to optimize the treatment formula and better understand the mechanisms that drive changes in soil properties, in order to achieve the desired soil characteristics more efficiently and consistently (Fig. 4).

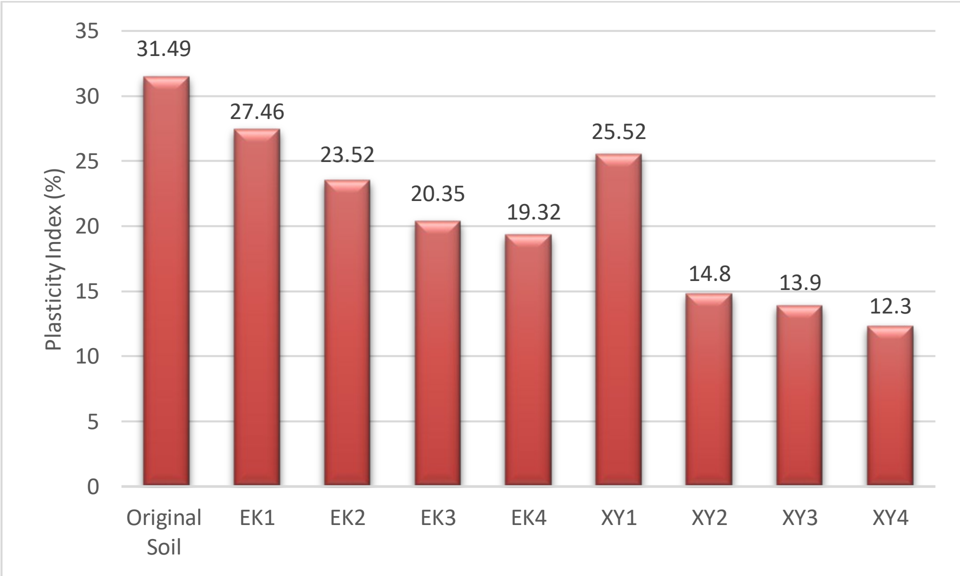

Fig. 4 Plasticity index of soil

3.2 Soil physical properties

Based on the results of the CBR test, the electrokinetic samples (XY1–XY4) show a significant increase in CBR compared to the original soil. Sample XY3 exhibited the highest percentage increase of 22.22%, followed by XY2 (16.67%), XY4 (13.89%), and XY1 (5.56%). This improvement aligns with the findings of previous electrokinetic studies, such as the research conducted by [12], which reported an increase in CBR of up to 25% in clay soil subjected to electrokinetic treatment (Fig. 5).

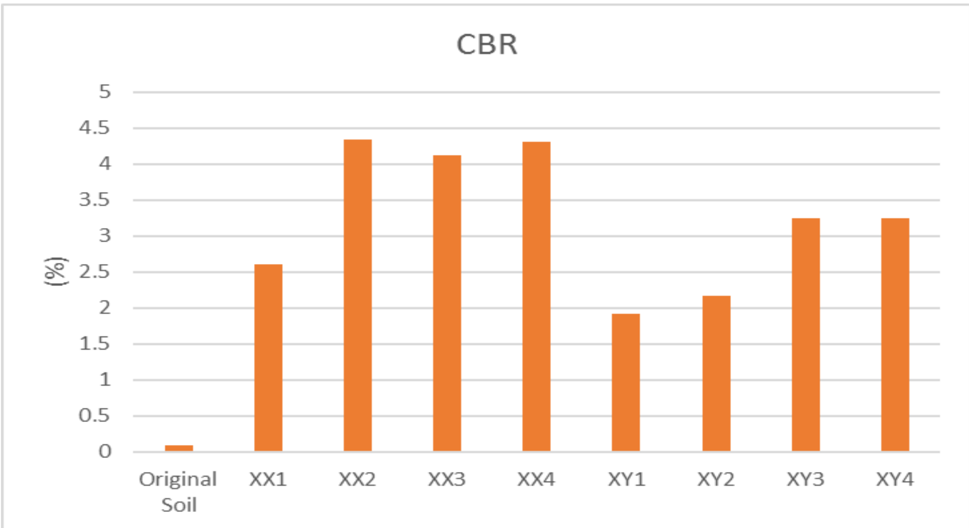

Fig. 5 CBR value of electrokinetic improvement

However, the non-electrokinetic samples (XX1–XX4) show a decline in CBR compared to the original soil. The largest decrease occurred in sample XX3 (50%), followed by XX4 (44.44%), XX2 (41.67%), and XX1 (22%). This finding aligns with research by [13], which suggests that non-electrokinetic processes using additional materials such as lime or cement can increase the CBR of clay soil.

The difference between the results of samples XY and XX highlights the effectiveness of the electrokinetic method in improving the bearing capacity of the soil compared to the non-electrokinetic method used in this study. This can be explained by the electrokinetic mechanism, which facilitates the removal of air from the soil pores, leading to soil consolidation and an increase in strength and bearing capacity [14]. However, the reduction in CBR observed in sample XX may be attributed to factors such as the type of soil, testing conditions, or unintended interactions between the soil and the materials used, which requires further investigation.

4. Conclusions

Based on the results, electrokinetic stabilization with 5% calcium dioxide was effective in improving the physical strength and mechanical development of the soil. The samples resulting from the electrokinetic process (EK1-EK4) showed a steady decrease in the LL and PI indices, with EK3 reaching the lowest level. This indicates that the electrokinetic process is effective in reducing soil plasticity. In contrast, samples obtained from non-electrokinetic experiments (XY1-XY4) showed inconsistent results in terms of reducing soil plasticity.

Mechanical testing of the electrokinetic samples (XY1-XY4) showed a significant increase in CBR when compared to the original, with the highest increase reaching 22.2% in sample XY3. This increase is in line with the findings of previous electrokinetic research. However, the non-electrokinetic samples (XX1-XX4) provided only highlighted a decrease in CBR. The results between samples XY and XX show how effective the electrokinetic method is in improving the bearing capacity of soils when compared to the non-electrokinetic method used in this study. Nonetheless, the decrease in CBR in sample XX requires further research to understand the factors affecting it.

References

[1] B. M. Das, Advanced Soil Mechanics, 2019. doi: 10.1201/9781351215183.

[2] S. Asuri and P. Keshavamurthy, "Expansive Soil Characterisation: An Appraisal," Ind. Lett., vol. 1, no. 1, pp. 29–33, 2016, doi: 10.1007/s41403-016-0001-9.

[3] W. S. Abdullah and A. M. Al-Abadi, "Cationic-Electrokinetic Improvement of an Expansive Soil," 2010. doi: 10.1016/j.clay.2009.11.046.

[4] A. Rachmansyah, L. Darmiyanti, R. Kusumaningrum, and Harimurti, "Expansive Soil Improvement Using Electrochemical Injection," IOP Conf. Ser. Earth Environ. Sci., vol. 1249, no. 1, 2023, doi: 10.1088/1755-1315/1249/1/012039.

[5] H. Afrin, "A Review on Different Types Soil Stabilization Techniques," Int. J. Transp. Eng. Technol., vol. 3, no. 2, p. 19, 2017, doi: 10.11648/j.ijtet.20170302.12.

[6] Y. Liu, X. Xie, L. Zheng, and J. Li, "Electroosmotic Stabilization on Soft Soil: Experimental Studies and Analytical Models (A Historical Review)," Int. J. Electrochem. Sci., vol. 13, no. 9, pp. 9051–9068, 2018, doi: 10.20964/2018.09.40.

[7] J. K. Lee and J. Q. Shang, "Electrical Vertical Drains in Geotechnical Engineering Applications," Geotech. Eng., vol. 44, no. 4, pp. 24–35, 2013, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84892498434&partnerID=40&md5=97a672ea245c2bf5cc3cab5edc6c997b

[8] L. Darmiyanti, A. Munawir, A. Rachmansyah, Y. Zaika, and E. Andi Suryo, "Identification of the Influence of Electrokinetic Soil Improvement on the Microstructure, Physical and Mechanical Properties of Expansive Soil," Eastern-European J. Enterp. Technol., vol. 6, no. 6 (126), pp. 41–50, Dec. 2023, doi: 10.15587/1729-4061.2023.290234.

[9] U. W. Lydia Darmiyanti, "Effect of Salt Solution in Electrochemical Stabilization with Variation of Potential Difference on Clay's Shear Strength," Reka Buana J. Ilm. Tek. Sipil dan Tek. Kim., vol. 9, no. 1, pp. 28–40, 2024, [Online]. Available: https://jurnal.unitri.ac.id/index.php/rekabuana/article/view/5434

[10] W. S. Abdullah and A. M. Al-Abadi, "Cationic–Electrokinetic Improvement of an Expansive Soil," Appl. Clay Sci., vol. 47, no. 3–4, pp. 343–350, 2010, doi: 10.1016/j.clay.2009.11.046.

[11] O. Hamza and J. Ikin, "Electrokinetic Treatment of Desiccated Expansive Clay," Geotechnique, vol. 70, no. 5, pp. 421–431, 2020, doi: 10.1680/jgeot.18.P.266.

[12] K. R. Reddy and R. E. Saichek, "12th International Multidisciplinary Scientific GeoConference and EXPO, SGEM 2012, Volume 4," 12th Int. Multidiscip. Sci. GeoConference EXPO - Mod. Manag. Mine Prod. Geol. Environ. Prot. SGEM 2012, vol. 7, no. 6, pp. 81–104, 2012, doi: 10.1061/(ASCE)0733-9372(2003)129:4(336).

[13] I. Hassan and E. Mohamedelhassan, "Improving the Characteristics of a Lean Clay by Electrokinetic Treatment," Int. J. Civ. Eng., vol. 19, pp. 911–922, 2021, doi: 10.1007/s40999-021-00604-0.

[14] V. A. Korolev and D. S. Nesterov, "Influence of electro-osmosis on physicochemical parameters and microstructure of clay soils," J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng., vol. 54, no. 6, pp. 560–571, 2019, doi: 10.1080/10934529.2019.1571321.