Evaluating effect of electro – osmotic on mechanical properties of soft clay

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ABSTRACT

One of the techniques of stabilization soil is the electrical method. In this method, stabilization of fine-grained soils, especially saturated clay soils, is done by reducing the thickness of the double water layer by establishing an electric current. In this study, to improve and stabilize soft clay soils, the electrokinetic injection method, which The index results of the studies showed that the use of this method increases the unconfined compressive strength from 98 kPa to 223 kPa, decreases the water content from 24 to 15/2 and the plasticity index from 24 to 10 and Soil porosity decreases from 0/675 to 0/443 . The results of chemical analysis confirm the correctness of the physical results in the scanning electron microscope images. According to the water content, Etterberg limits, unconfined compressive strength and consolidation tests, it was determined that the best performance is related to the use of plate aluminum electrode with a voltage of 1/5.

KEYWORDS

Soft clay soil, electro - osmosis, electrod material, electrode shape

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1. Introduction

Electrokinetic stabilization is the application of applying direct current (DC) electric fields through a wet soil mass via a pair of electrodes to promote the migration of stabilizing agents into the soil of electric current to the soils. Electrokinetic stabilization includes electroosmosis, electrolysis, electrophoresis and electro migration. Electro-osmosis involves transport of water through the voids in the soil. One of the methods of improving soft fine-grained soils is the electroosmosis [1, 2]. The improvement of soil during electrokinetic stabilization can occur either due to the electroosmotic consolidation or electrochemical changes such as pozzolanic reactions that lead to soil cementation and mineralogy changes, resulting in strengthening of the soil [3]. The material of the electrode plays a major role in the efficiency of the electrokinetic stabilization method. The electrode used should be cheap, accessible, resistant to the heat generated during electric current, and resistant to corrosion [4]. Electric current is another factor in evaluating the effect of electrical improvement. An increase in electric current causes an increase in electroosmotic flow and, as a result, an improvement in soil resistance [5]. Using a plate electrode instead of a rod electrode will get better results due to its effect on the entire soil complex. While using the plate electrode, electro-osmotic current flows in the entire soil, water drainage towards the cathode electrode increases, and on the other hand, a lot of heat is produced, and as a result, the moisture content of soil is further reduced [6, 7]. The aim of the current study is to observe the effect of electroosmosis method on the mechanical properties of soft clay by considering the influential variables and comparing them using laboratory tests.

2. Methodology

The Soil that is used in this study was a soft clay soil sample collected from Kermanshah Agricultural College. Following the experiments performed on the given soil, it was found that the soil type is fine-grained with low swelling ability. The experiment was carried out in a plexiglass chamber with dimensions of 50 x 30 x 20 cm^3. Electrodes have been used in two mods, rods with dimensions of 15*5 cm^2 or plate with dimensions of 15*30 cm^2. The model used is shown in Figure 1. In this experiment, the voltage gradient of 1 v/cm and 1/5 of the soil mass using two types of aluminum electrodes (Al) and graphite (G) and rod shapes (R) and plates (P) has been applied to the soil sample in a period of 48 hours by connecting the electrodes to the power suply. After the 48-hour the electricity was cut off and the model was prepared for sampling for the intended tests. A total of 25 unconfined compressive strength tests, moisture content and etterberg limits (an untreated specimen, 24 specimens treated with three variables and near the anode, cathode and middle part) were performed and to check the degree of consolidation of clay from 4 samples (an untreated specimen and 3 specimens optimal treated) consolidation test was done based on the standard.

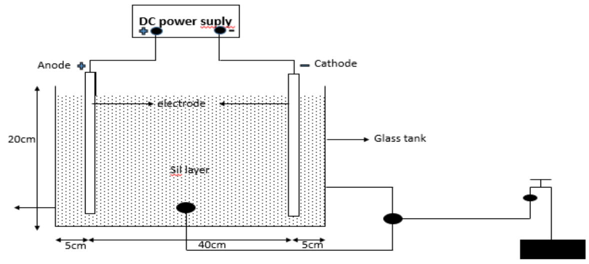

Figure 1. Schematic of the electroosmosis system used in the experiment

3. Discussion and Results

The results of the change moisture content of soil in the case of using aluminum and graphite electrodes in two types of rod and plate in currents of 1 and 1/5 v/cm after 48 hours near the anode, cathode and middle part show that the moisture content decreases from the anode to the cathode because the electroosmotic flow is towards the cathode. Drying due to the heat created during of electric current and natural evaporation of water are also other effective factors in reducing soil moisture content [8]. The results of changes in the etterberg limits of soil samples show that the moisture content is between the plastic limit and the liquid limit. Only in three samples with plate aluminum electrode with voltages of 1 and 1/5 V and with plate graphite electrode with voltage of 1/5 V near the anode, the moisture content is lower than the plastic limit. The result shows that in the case of using a plate electrode at a higher voltage, due to the appropriate effect of this electrode on the soil sample, weakly bound water are not formed in the soil. In general, there is no free water in any of the samples after applying the electroosmotic flow. With the production of H^+ in the anode and due to the mobility 1/8 times higher than OH^- and also the direction of the electroosmotic flow towards the cathode, low pH values occur in a large part of the soil sample, especially in the vicinity of the anode [9, 10]. The negative charge of soil particles has increased and this increases soil PL. Ion exchange during electroosmosis replaces high ions capacity such as Al^{3+} and Fe^{3+} in the hydrated layer around soil particles. This factor reduces the thickness of the double layer and the attraction between particles also reduces the value of PI. Many researchers have reported a reduction in plasticity index when using electroosmotic stabilization [11, 12]. The results of the UCS tests show that the strength of the untreated soil is lower than the treated samples, because with the applying voltage and the movement of water in the soil and its drainage, as well as the generation of heat due to the electric current in the treated soil, the moisture content of soil decreased and this is one of the factors of increasing soil resistance. Dehydration, suction created in the soil, soil consolidation, electrical transfer of ions due to changes in ion concentration, changes in the thickness of the double water layer, cement reactions, natural drying of the soil during electric current, which causes exothermic reactions and as a result, changes in the soil structure. It is another factor that increases soil resistance [13]. The results obtained from the consolidation test show that the settlement values were better for the treated soil sample near the ande. The cations that enter the pore water pressure and move towards the cathode, by displacing the water around them, cause more water to come out and increase the strength. With the release of water by these cations, a negative suction pressure is applied to the voids between the soil and leads to the disappearance or smaller size of the pores. This issue has reduced the void ratio and thus increased the strength of the soil. In order to conduct the SEM test of two samples (an untreated specimen and a specimen treated with an aluminum plate electrode with an applied voltage of 1/5 v/cm) under were tested. Microstructural changes are related to two main mechanisms. First, ion exchange, which reduces the thickness of the double layer, resulting in the compression of silicate plates, and second, the exit of water from the pores of soil. that these two phenomena happen less from the anode to the cathode. Capillarity creates negative pressure in the pores and causes the loss or reduction of the volume of the pores [4]. The results have shown that natural soil samples are composed of separate soil masses. This may be due to water absorption by the clay particles, which become larger masses by absorbing water [10]. On the other hand, ion exchange during electroosmosis replaces high ions capacity such as Al^{3+} and Fe^{3+} in the fixed hydrated layer around soil particles. This factor reduces the thickness of the double layer and also the attraction between particles leads to the closure of the pores, strengthening the soil, and eventually dense soil is created.

4. Conclusions

In this research, the effect of various factors related to electroosmotic improvement conditions on mechanical properties has been investigated and the key results are summarized below:

- According to the the electroosmotic flow from the anode to the cathode and the discharge of water, the moisture content of soil decreases, and with the movement of water and changes in the chemical structure due to the transfer of ions, the plastic index of the soil changes.
- Soil calcium ions and aluminum ions released from the electrode participate in the cementation process and improve soil strength.
- Electro-osmotic flow leads to negative pore pressure and causes soil integrity, this issue reduces porosity and, as a result, increases soil strength.
- The movement of cations which causes the movement of hydrated water around the cations, as well as the ion exchange which causes the replacement of high ions capacity, the thickness of the double layer is reduced and by increasing the attraction between particles, it reduces the value of PI and soil porosity. Therefore, the soil sample stabilized by electrokinetic method has a denser composition.
- The best result is for the soil sample improved with an aluminum plate electrode with a voltage gradient of 1/5 v/cm, which compared to the untreated soil, the values of the plastic index and its void ratio are reduced by 58% and 35%, respectively, and the unconfined compressive strength is 128 % has increased.

5. References

[1] M. Malekzadeh, J. Lovisa, N. Sivakugan, An overview of electrokinetic consolidation of soils, Geotechnical and Geological Engineering, 34 (2016) 759-776.

[2] J.G. Loch, A.T. Lima, P.J. Kleingeld, Geochemical effects of electro-osmosis in clays, Journal of applied Electrochemistry, 40 (2010) 1249-1254.

[3] A. Estabragh, M. Naseh, A. Javadi, Improvement of clay soil by electro-osmosis technique, Applied Clay Science, 95 (2014) 32-36.

[4] T. Askin, D. Turer, Effect of electrode configuration on electrokinetic stabilization of soft clays, Quarterly Journal of Engineering Geology and Hydrogeology, 49(4) (2016) 322-326.

[5] Y.-m. Liu, H.-f. Xu, Experimental study of the electrode material for electro-osmosis in mudflat sludge, in: IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2017, pp. 012093.

[6] H.A.M. Mahalleh, M. Siavoshnia, M. Yazdi, Effects of electro-osmosis on the properties of high plasticity clay soil: chemical and geotechnical investigations, Journal of Electroanalytical Chemistry, 880 (2021) 114890.
[7] A. Alibarootitabar, A. Ardakani, M. Mahmoudipour, Evaluation of the effect of voltage variation on the electro-osmosis dewatering of a silty soil using prefabricated vertical drains, International Journal of Geotechnical Engineering, 15(4) (2021) 512-518.
[8] M.Y. Fattah, Q.G. Majeed, H.H. Joni, Comparison between methods of soil saturation on determination of the soil water characteristic curve of cohesive soils, Arabian Journal of Geosciences, 14(2) (2021) 101.
[9] W. Wen, L. Jia, W. Zhao, H. Feng, D. Cao, J. Xie, T. Xu, M. Cui, W. Zhou, Q. Mei, Study on the effect of electrokinetic methods combined with and solidification/stabilization technique for remediation of Cu2+-contaminated soil under different voltage gradients, International Journal of Electrochemical Science, 17(10) (2022) 221021.
[10] H. Bibak, J. Khazaei, H. Moayedi, Investigating the effect of a new industrial waste on strengthening the soft clayey soil, Geotechnical and Geological Engineering, 38 (2020) 1165-1183.
[11] W. Abdullah, A. Al-Abadi, Cationic–electrokinetic improvement of an expansive soil, Applied Clay Science, 47(3-4) (2010) 343-350.
[12] V. Kumar, The effect of electrokinetic stabilization (EKS) on peat soil properties at Parit Botak area, Batu Pahat, Johor, Malaysia, Indian Journal of Science and Technology, 11 (2018) 44.
[13] H. Wu, L. Hu, Microfabric change of electro-osmotic stabilized bentonite, Applied Clay Science, 101 (2014) 503-509.