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Research Article

Dewatering Efficiency of Electroosmosis: Electrodes Configuration

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ABSTRACT

This research conducted a series of experiments to examine electrokinetic performance on dewatering and settlement in soft clay subjected to two configurations of electrode including; 1) anode and cathode were placed at top and bottom boundaries respectively, and vice versa for the other configuration. These configurations were later labeled as 1AT and 1AB respectively. It was found that the 1AB yielded the best result in term of settlement (27.08 mm). It was concluded that the influence of electrophoresis and gravity played roles to the magnitude of settlement. Due to upward moving of clay particles during settlement (influence of electrophoresis), placing an anode above a cathode would generate cracks which interferes drainage of water, and hence settlement. This study also confirms that soil dewatering is governed by electro-osmosis process rather than effect of temperature. Reduction of water content during the experiment affects the efficiency of electrokinetic technique, including electric current and electrical resistance. As such, this technique is suitable for any problem that requires smaller amount of dewatering within very short time period.

Keywords: Electroosmotic, Water drainage, Electrode arrangement.

INTRODUCTION

Electroosmotic is induced by dragging force from absorbed water layer resulting in moving of hydrated water molecules toward the cathode. In geotechnical engineering, this process has been applied for dewatering [1-2], purification of certain substances [3-6], injection of chemical agent to improve the mechanical properties of soft soil [7-9], and other purposes [10-20] etc. The advantage of this technology is that, under the influence of [electric potential gradient, the rate of water moving through the low permeability medium is much faster than that under the influence of water pressure gradient. However, complex interaction among chemical, electrical, and geotechnical behaviors of this technology draws the attention of geotechnical engineers away from this technology. Crake formation due to extensive drying at the anode and extreme changes in pH at both electrodes also play negatively affect to the performance of the electroosmotic process. In addition, heat induced during the electroosmotic process also promotes the formation of crack near the electrodes. Wu et al. [21] suggested that applying electroosmosis with surcharge load can mitigate the crake formation. Since the propagation of crake usually takes place between the electrode, application of surcharge load will be more effective if the electrodes are placed vertically apart from each other. Due to it inherently supporting the application of surcharge load to mitigate crake formation, the configuration of electrodes that laid horizontally and vertically apart from the other was focused on this study. Two set of the experiment were conducted in this study; the experiment that the anode and cathode were respectively placed at the top end and the bottom end of the soil sample, and the experiment that the anode and cathode were placed at the bottom end and the top end of the soil sample. Results reported in this study might enhance understanding complex behavior of electroosmosis in clayey soil, and hence promote the adoption of this technology to geotechnical engineering application.

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METHODOLOGY

The electroosmotic cell was made from acrylic plates to form a rectangular box of an internal cross section of 110 × 110 mm^2 and a height of 180 mm (Fig. 1). The electrodes were to be laid horizontally and they were to be placed at the bottom and the top end of the soil sample. Five small circular holes of 10 mm were drilled at 25 mm vertically apart from the vicinity holes. These holes were made for installation of potential probes for monitoring real-time effective voltage and electric current during the electroosmotic process. The electrode material used in this study was graphite plate of 100 x 100 mm^2 with thickness of 10 mm. Set of 3 mm diameter holes was drilled on the graphite plates to form perforated graphite electrode as shown in Fig. 1.

The Bangkok Clay having liquid limit of 80%, plasticity index of 50%, and specific gravity of 2.63 was used in this study. The sample was prepared to achieve a homogeneous sample with gravitational water content of 180%. The clay slurry was then poured into the experimental box in five layers, each of 20 mm thick to achieve 100 mm height of the sample. The perforated graphite plate of 100 sq.cm. was used as electrodes and placed at the bottom and top ends of the clay slurry in the experimental box. Thereafter a dead weight of 1 kg was placed at the top end of the experimental box. A vertical displacement gauge was attached on a fixed beam for surface settlement measuring.

Fig. 2 presents schematic diagram of the experiments conducted in this study. The electroosmosis was carried out by applying direct electric current generated from a DC power supply with voltage of 30 Volts, equivalent to 300 Volts/m. Surface settlement, electric current, effective voltage, were continuously recorded during the test. Two experiments were conducted in this study. The first experiment was the test for anode was placed at the top end and cathode was placed at the bottom end and it is later referred as the AT test. For the second experiment, we placed the cathode at the top end and the anode at the bottom end and it is later referred to the AB test.

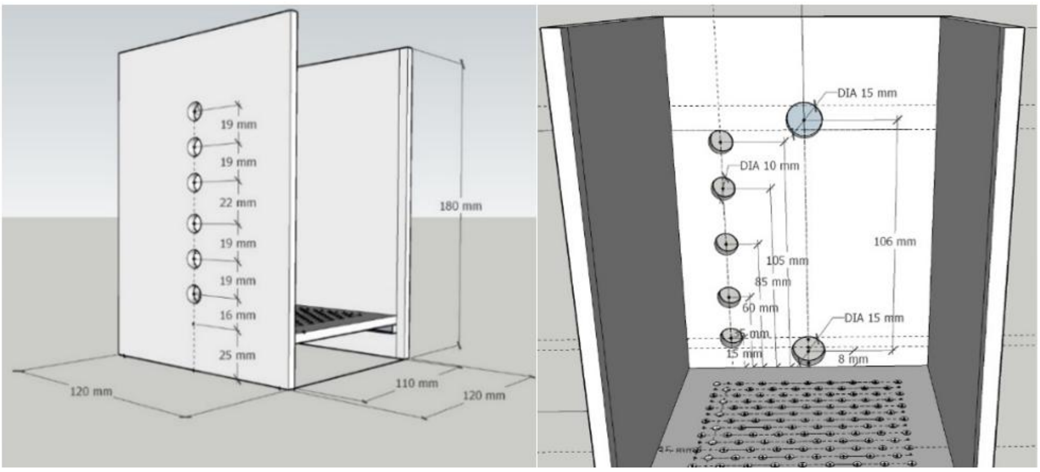

Figure 1. Electroosmotic cell with position of the holes for insertion of potential probes, electrodes and perforated graphite plates.

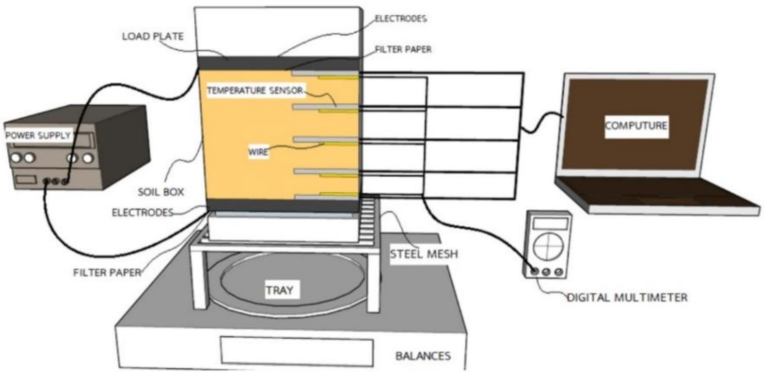

Figure 2. Schematic view of the experiment conducted in this study.

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RESULTS & DISCUSSIONS

Fig. 3 presents surface settlement vs time of the test AT and the test AB. Both tests exhibited fast rate of settlement at the early stage of the process and the settlement rate slowed down afterward. At the early stage, the expelled water mainly came from the soil near the cathode resulting in fast settlement at the early stage. During the process, water further drained, and the thickness of electric double layer reduced resulting in reduction of zeta potential, and hence the reduction of the electric conductivity. The settlement rate took place in AT and AB tests were almost identical at the early stage from 0 min to 50 min. Thereafter from 50 min to 120 min, the settlement rate in the AB test became notably faster than that in the AT test. The total surface settlement of the AB test is about 25% greater than that of the AT test. These results confirm the finding reported in Malekzadeh & Sivagukan [22,23] who conducted one dimensional electrokinetic process in vertical direction with dredged marine slurry having initial water content of 250% and found that the settlement difference between the experiment when the anode was placed at the bottom end and that when the anode was placed at the top end was about 35%.

Fig. 3 also presents the total weight loss of the sample during the AT and AB tests. The similar pattern between drainage water and settlement indicating that drainage of water is the major contributor to the settlement during the test. The zigzag in AB test during 0-100 min. was because of retard of water to be drained at the top end of the model box. Since the amount of water drainage in the AT and AB tests are not notably difference comparing to the settlement presented in this figure, we implied that that, other than the water drainage, other factor would play role to the settlement. For the AB test, the negative charged particles move downward to the anode at the bottom end (electrophoresis) and the pore fluid moves upward to the cathode at the top end. Compared to the case that the anode was placed at the top end (AT test), the negative charged particles were forced by the application of DC current to move upward resulted in deceleration of the negative charged particle settlement. Moreover, this phenomenon of the negative charged particles would result in formation of crakes in the soil which obstructs the electroosmotic process.

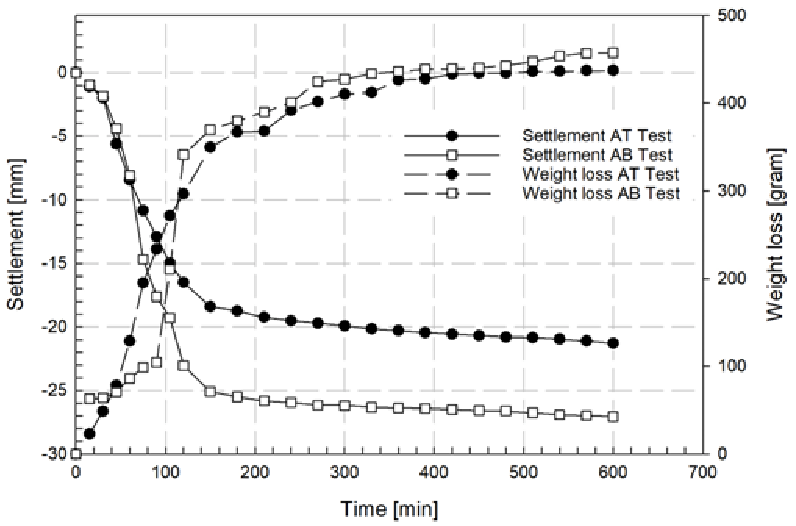

Figure 3. Time series plots for surface settlement and weight loss

Fig. 4 presents electric current measured from both tests. The electric current of each test increased at the early stage but dropped sharply to reach asymptote after 500 min. At the early stage, the low availability of free ions in pore fluid of the soil explains the low value of electric current. Then the desorption and mobilization of the ions in the soil matrix induces an increase in the electric current. Afterward, the rapid drop of electric current was due to the depletion of ions as they moved to the cathode. When there was less water in the soil, electric current also declined, increasing the resistance of cations and water movement. Comparing the electric current measured from the AT and that from the AB test, the electric current measured at the early and middle stages in the AB test was less than that measured in the AT test. However, at the last stage, the electric current in the AT test became lower than that in AB test after 400 min. We implied that the greater resistance was caused by the inner crake generated in the soil during the AT test.

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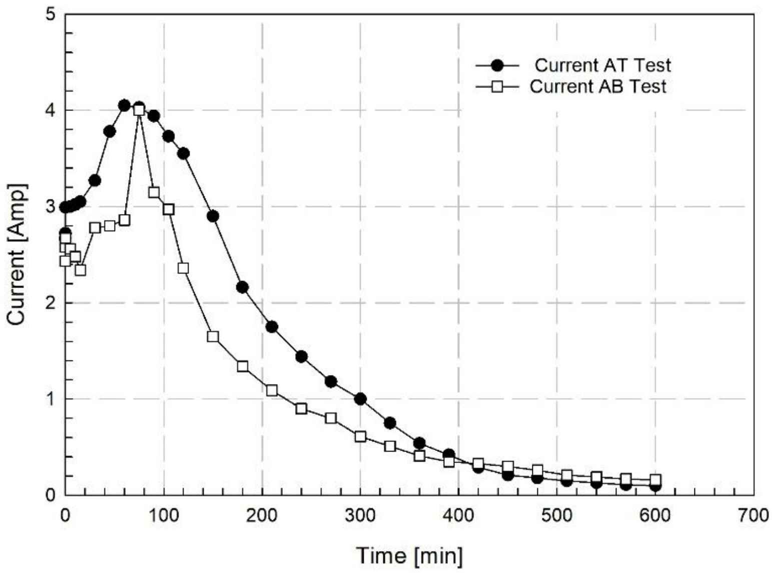

Figure 4. Time series plots of electric current.

Fig. 5 shows variation of the electric resistance during the electroosmotic process. Since the resistance is inverse function of electric current, during the early and the middle stages, the water content in AT test was higher than that in AB test. However, the resistance in AT test became notably greater than that in AB test at the last stage.

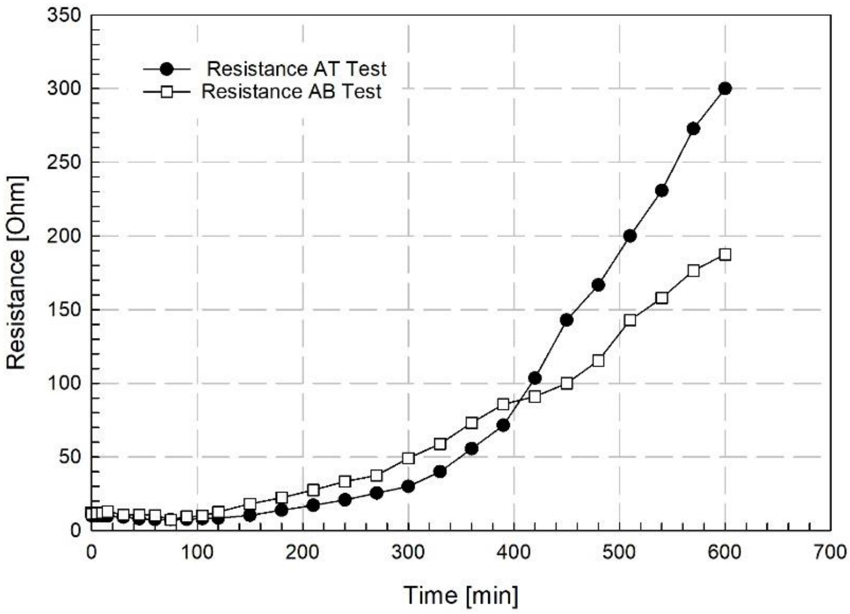

Figure 5. Time series plots of electric resistance.

Fig. 6A, Fig. 6B and Fig. 6C presents XRD of the soil before the test, that of the soil at anode and cathode after the AT test, respectively. New peak was found at 12^o and 29^o (2□) for the soil near the anode indicating presents of $CaSO_4$ after the electrokinetic process. For the soil near the cathode, new peaks were found at 29^o 43^o 48^o and 57^o indicating formation of $CaCO_3$ at this side. Under electric potential, Ca_2^+ ions migrate towards the cathode side while ions migrate toward the anode side in opposite direction. As the process continues, $CaCO_3$ precipitates are produced by a chemical reaction between the Ca_2^+ ions and ions. Since the Ca_2^+ has the higher electric mobility than the does, the $CaCO_3$ was found in the soil near the cathode. Since $CaSO_4$ are resistant to acid dissolution but it do dissolve in alkaline solution, $CaSO_4$ was found only at the soil near the anode.

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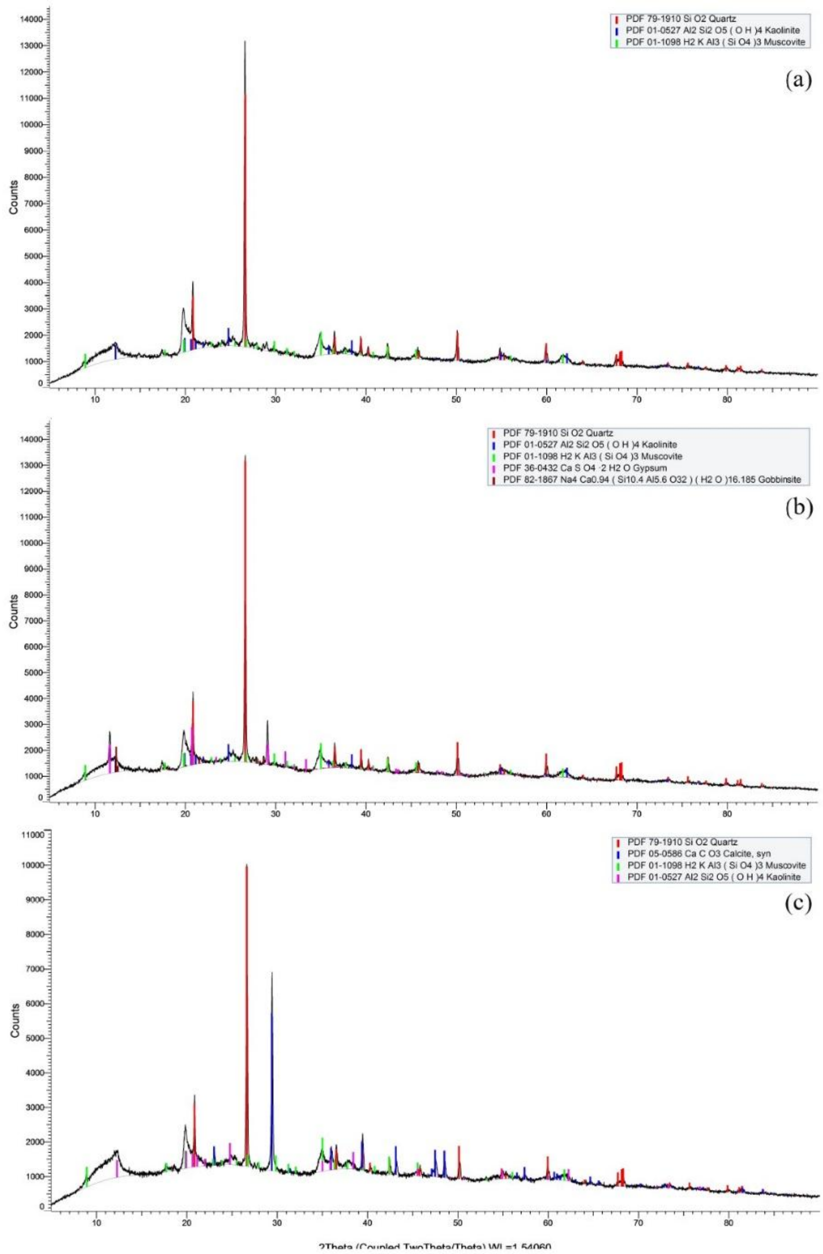

Figure 6. XRD profile of Part A an original clay, Part B a clay at the anodic side after electroosmosis, Part C a clay at the cathodic side after electroosmosis.

CONCLUSION

Due to combination of electrophoresis and gravity, the direction of soil particle movement under the electrophoresis and gravity played a great role to the surface settlement of soil subjected to direct electric current. The adverse directions between the surface particle movement caused by electrophoresis and that caused gravity in the AT test resulted in a formation of internal crake in the soil during electroosmosis. The internal crake formed during electroosmosis in the AT test resulted in the greater final electric resistance in the AT test than that in the AB test.

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