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Electro-Osmotic Consolidation of Soft Bangkok Clay Using Copper and Carbon Electrodes with PVD

ABSTRACT: Electro-osmotic consolidation of Bangkok clay using copper and carbon electrodes with prefabricated vertical drain was studied. A laboratory testing program was conducted on undisturbed and reconstituted samples in a small cylinder cell and a large consolidometer in order to assess the probable effectiveness of electro-osmotic treatment. The tests were performed under the voltage gradients of 60 and 120 V/m with a polarity reversal of every 24 h. The time to achieve 90 % degree of consolidation induced by electro-osmosis ranges from 1.4 to 2.1 and 1.2 to 2.2 times faster than the normal consolidation using PVD only for undisturbed and reconstituted samples, respectively. The faster rate of consolidation and higher magnitude of settlement were achieved at a higher voltage gradient. Higher reduction of water content up to 9 % and increase in shear strength up to 144 % were obtained using electro-osmotic consolidation with PVD compared to using PVD only, especially when using the carbon electrode. The liquid limit, plastic limit, and plasticity index were increased due to increased salinity during electro-osmotic consolidation. With its total dissolved salts of 4050 ppm well below the 6000 ppm limit, the soft Bangkok clay is considered to be suitable for electro-osmotic consolidation.

KEYWORDS: electro-osmosis, consolidation, prefabricated vertical drain, laboratory tests

Due to its high compressibility, clay will consolidate and generate significant settlement when subjected to loading. This consolidation settlement causes detrimental effects on the overlying structures. Furthermore, with its low permeability, the clay takes longer to achieve primary consolidation. To solve this problem, vertical drains are installed with a preloading pressure to shorten the drainage path and, subsequently, to reduce consolidation time. Consequently, water can be discharged much faster through the drain towards the drainage layers.

Recently, prefabricated vertical drains (PVD) have gained popularity because of low price and short installation time. However, although PVD has desirable effects in accelerating the consolidation of soft foundations and thereby increasing soil strength, it was deemed necessary to conceptualize another way as to how PVD can function more efficiently and economically. The development of the use of PVD can be enhanced by the electro-osmosis technique for the transport of water and moving chemical species within fine-grained and low- permeability soil.

Electro-osmotic transport of water through clay is the result of diffuse double-layer cations in the clay pores being attracted to a negatively charged electrode or cathode upon the application of electric fields. Water molecules orient themselves around ions in the pore space as water of hydration. As these cations move through the pore space towards the cathode, they bring with them associated hydration water or water molecules that clump around the cations as a consequence of their dipolar nature. Consolidation results when water is drained at the cathode but not replaced at the anode. It has been proven to be effective in stabilizing and consolidating soils both in the laboratory and in the field (Chappell and Burton 1975; Mitchell and Wan 1977; Shang et al. 1996; Shang and Ho 1998). The electro-osmotic consolidation induced the reduction of moisture content and increase in shear strength (Bjerrum et al. 1967; Lo et al. 1991; Shang and Dunlap 1996). This process can also be used in remediation of contaminated soils and groundwater (Acar et al. 1994).

The purposes of this paper are to evaluate the electro-osmotic effects generated on both undisturbed and reconstituted Bangkok clay using the combination of electrodes with PVD and to compare the efficiency of using copper and carbon as electrodes. The experimental data are obtained from Sasanakul (2000), which is the continuation of the work by Bergado et al. (2000).

Electro-Osmotic Consolidation

If, in a compressible soil, electro-osmosis draws water to a cathode where it is drained away and no water is allowed to enter at the anode, consolidation of the soil between the electrodes occurs in an amount equal to the volume of water removed. As water movement away from the anode causes consolidation in the vicinity of the anode, the effective stress must increase. Because the total stress in the vicinity of the anode remains essentially unchanged, the pore water pressure must decrease. On the other hand, there is no consolidation at the cathode since water flows towards it. This means that there is no change in total, effective, and pore water pressures. As a result, a hydraulic gradient develops that tends to push water back from cathode to anode. Consolidation continues until the hydraulic force that drives water back toward the anode exactly balances the electro-osmotic force driving water toward the cathode (Mitchell 1993).

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According to Esrig (1968), the pore water pressure developed due to electro-osmotic consolidation has been induced from the proportion of the electrically induced velocity of water flow through soil, v_e, the voltage gradient (electric field), $\partial V/\partial x$, and the coefficient of electrokinetic permeability, k_e. Assuming the validity of superposing electrically and hydraulically induced flows through an incompressible soil mass, the governing partial differential equation for electro-osmotic consolidation can be obtained. Using electrically conductive geosynthetics (ECGs), Nettleton et al. (1998) generated negative pore pressures during electro-osmotic (EO) consolidation.

Electro-Chemical Reaction

The application of direct electric current leads to electrolysis reactions at the electrodes, generating an acidic medium at the anode and an alkaline medium at the cathode. The primary chemical reaction equations are as follows:

$$\text{at the anode:} \quad 2H_2O - 4e^- \rightarrow O_2\uparrow + 4H^+ \tag{1}$$

$$\text{at the cathode:} \quad 4H_2O + 4e^- \rightarrow 2H_2\uparrow + 4OH^- \tag{2}$$

As a result of pH gradient and the prevailing chemistry during the process, it is expected to involve dissolution of available salts/clay mineral, adsorption/desorption and complexion reaction, and formation of cementatous products (Acar et al. 1994). The gas formation at the anode causes cavitation, and the generated heat causes desiccation; then cracking may develop at the anode (Mitchell 1993). Polarity reversal is an effective technique in preventing dessication and decreasing electrode corrosion. It promotes a more uniform water content and shear strength distribution due to a more uniform increase in the effective stress and improved development of pore pressure (Gray and Samogyi 1977; Shang et al. 1996).

Experimental Investigation

Small Cylinder and Large Consolidometer

Electro-osmotic consolidation was performed by using a small cylinder cell and a large consolidometer. The schematic diagrams of these experimental apparatuses are depicted in Figs. 1 and 2. Similar to the apparatus used by Abiera et al. (1999), the small cylinder cell (Fig. 1) consisted of a loading piston located on the top of the frame where air pressure was being supplied by a compressor and was adjusted properly by a valve regulator. The small cylinder cell can accommodate a sample up to 300 mm in diameter and 300 mm in height. Two holes, 200 mm apart, at the top and bottom were provided for PVD installation (Fig. 3*a*). Undisturbed and reconstituted samples were tested in this apparatus. In this investigation, the direct measurement of pore pressure distribution was not done, since the research work concentrated mainly on settlement change with time and physical and chemical improvement due to preloading and electro-osmosis. Additional details of this apparatus are given by Bergado et al. (2000).

The large consolidometer (Fig. 2) was made up of a 10-mm-thick transparent PVC sheet 950-mm high with an inner diameter 450 mm placed over a PVC base plate. The loads were applied through a loading piston placed on top of the soil by using rubber balloons connected to a compressor through a special regulator valve. The loading piston has four shafts arranged in a square pattern and that are 200 mm apart in the centers to facilitate PVD installation (Fig 3*b*). A lid placed on top of the PVC tube and tightened by screws holds the apparatus in place. Steel rings are wrapped around the cylinder to prevent bulging. Only a reconstituted sample was tested in this apparatus. More description of the experimental setup is given by Bergado et al. (2000).

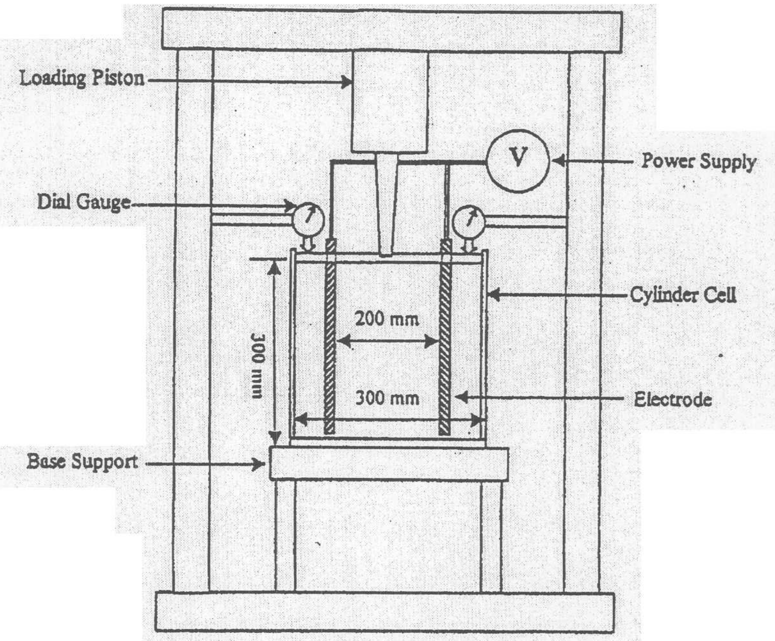


FIG. 1—*Small cylinder electro-osmotic cell.*

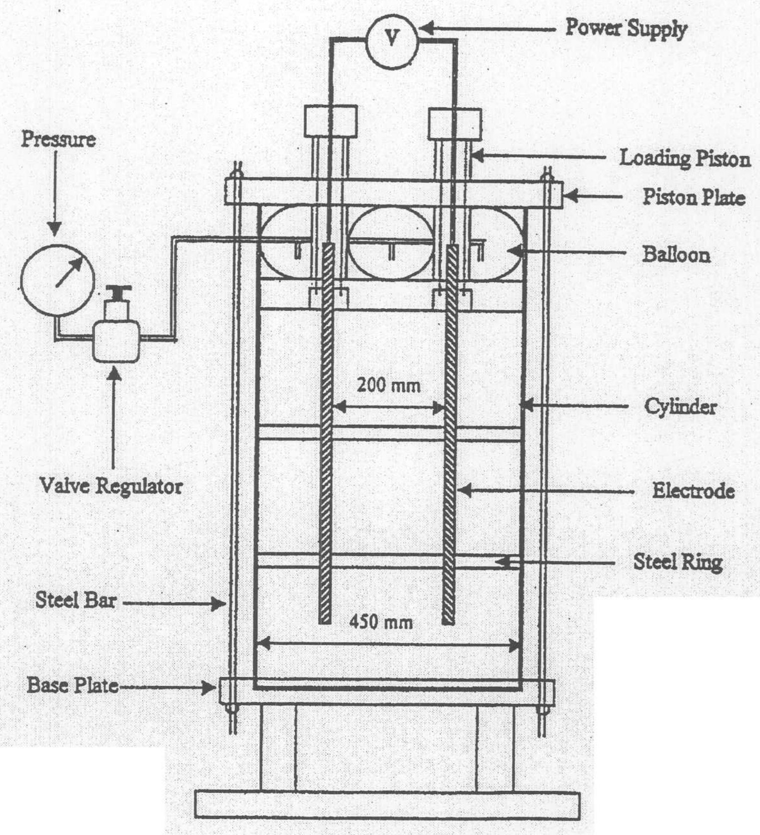


FIG. 2—*Large consolidometer.*

Soft Bangkok Clay Specimen

The soft Bangkok clay used in this study was obtained from a site on the Asian Institute of Technology campus at a depth of 3 to 4 m. The reconstituted sample was prepared by applying a consolidation pressure to the remolded sample. The remolded sample was obtained by adding a sufficient amount of water until its water content was 1.5 times greater than its liquid limit. The sample was then throughly mixed in a mechanical mixer and tranferred in layers into the testing container. The purpose of adding water was to ensure a high degree of saturation. In addition, at this stage (high water content) the flow ability was high, leading to high workability. At each layer, the air bubble was eliminated by using a vibrator. The reconstitution pressures of 5 and 50 kPa were used for the small cylinder cell and large consolidometer, respectively. All reconstituted samples were loaded until 90 % consolidation was achieved using Asaoka's method (Asaoka 1978). The undisturbed samples were taken by extruding them from a 254-mm- diameter piston sampler. Using the extruding machine, the soil with its smooth-trimmed top surface was pushed slowly to the cell. When the top of the soil touched the bottom of the cell, the excess soil at the top was also smoothly trimmed by using a fine wire saw. The trimmed sample was taken to determine the water content. It was found that the degree of saturation is higher than 97 % for all tests due to the fact that the natural water content was higher than the liquid limit. Hence, both the undisturbed and reconstituted samples were considered to be saturated. The undisturbed sample reflects the lightly overconsolidated in-situ condition. Reconstituted samples served to simulate the normally consolidated condition.

Adjusted PVD with Electrodes

The adjusted size of the PVD with an electrode is 20 mm wide and 300 mm and 600 mm long for the small cylinder cell and the large consolidometer, respectively. The copper and carbon electrodes were made by inserting eight copper rods 13.6 mm in diameter and eight carbon fibers, respectively, into the grooves of the drain core (four on each side) and covered by a geotextile filter. This combination of PVD with electrode was inserted into the soil sample together with another drain without electrodes for drainage purposes. Both anode and cathode are allowed to drain since there are two directions of drainage: towards the anode due to the applied vertical load and towards the cathode due to the electro-osmosis. This is different from the previous investigation (Lo et al. 1991; Shang and Ho 1998) that the anode is closed (without drainage) since their investigation studied the effect of electro-osmosis itself on strengthening the soil strength.

Drainage can be controlled at both ends of the consolidometer. The apparatus was designed to dissipate the gas liberated at the electrodes by installing gas vents onto the drainage line at both ends.

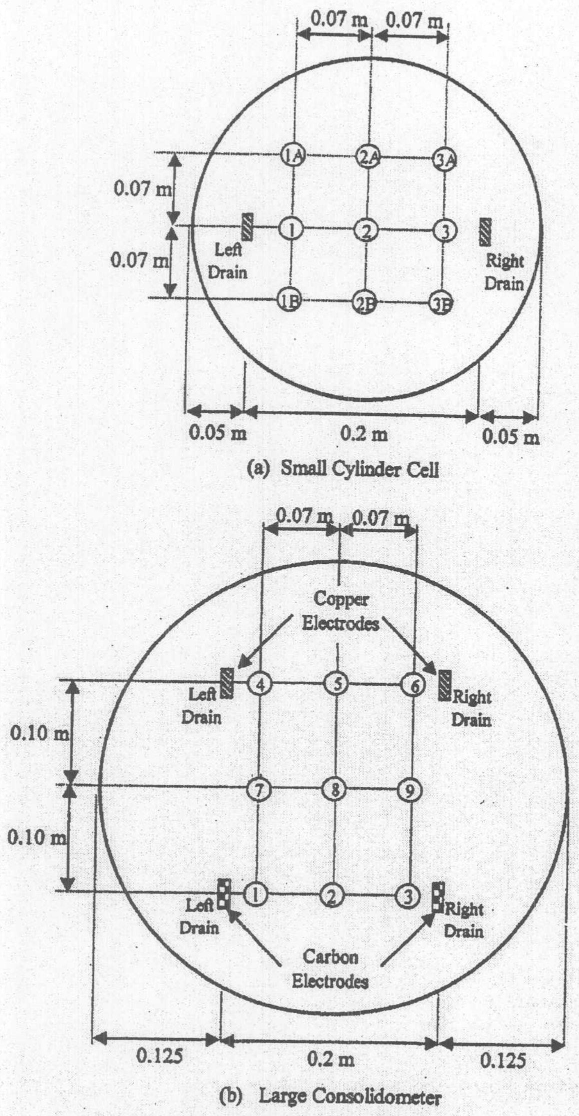


FIG. 3—*Predetermined locations of sampling points.*

Electro-Osmotic Consolidation in Small Cylinder Cell

Electro-osmotic consolidation on a small cylinder cell was conducted under the vertical pressure of 5 kPa with a 24-h polarity reversal. Polarity reversal was carried out every 24 h so as to obtain the uniform shear strength distribution along the sample (Lo et al. 1991). Several tests were carried out on undisturbed and reconstituted samples using variable parameters, namely: electrode type and voltage gradient as tabulated in Table 1. Since this investigation is a pioneering work on soft Bangkok clay that mainly concentrated on the performance of the soil improved by PVD with electrodes and the applicability of this technique in the soft clay rather than the design aspect, the voltage gradient is simply defined as the ratio of the applied voltage to spacing between the anode and the cathode, as termed by Abiera et al. (1999). The amounts of settlement, voltage, current, and temperature were measured across the electrodes during the test at a predetermined time. All tests were stopped once the 90 % degree of consolidation was achieved using Asaoka's method. Moreover, the physical and chemical properties were determined on soil samples taken from different locations as indicated in Fig. 3*a* before and after electro-osmotic consolidation.

Electro-Osmotic Consolidation in Large Consolidometer

For the large consolidometer, five tests were conducted in one setup on a reconstituted specimen. First, the soil sample was reconstituted at 50-kPa consolidation pressure until it reached 90 % degree of consolidation using Asaoka's method. Secondly, PVDs were installed with the load increased up to 75 kPa. The consolidation with the PVD only was investigated. After 90 % degree of consolidation was achieved, a couple of carbon and copper electrodes with PVD, spaced 20 mm apart, were inserted into the sample. The effect of electro-osmosis was then investigated by applying direct current using the voltage gradients of 60 and 120 V/m for both types of electrodes under the maintained pressure of 75 kPa. The soil properties before and after the electro-osmotic test were determined to be similar to the small cylinder cell. The predetermined locations of sampling points are shown in Fig. 3*b*. The summary of the testing program on the large consolidometer is tabulated in Table 2.

Laboratory Vane Shear

Shear strength was measured by using an especially designed laboratory vane shear apparatus (Abiera et al. 1999; Bergado et al. 2000). The vane blade is 20 mm in diameter and 40 mm in height. It is attached to an adjustable rod 5 mm in diameter capable of measuring the shear strength at different locations and depths. The dig-

TABLE 1—*Summary of tests conducted on small cylinder cell.*

Test	Sample Type	Voltage Gradient, V/m	Vertical Pressure, kPa	Polarity Reversal Duration, h	Electrode Type
A	Undisturbed	0	5	24	PVD only
B	Undisturbed	60	5	24	Copper
C	Undisturbed	60	5	24	Carbon
D	Undisturbed	120	5	24	Copper
E	Undisturbed	120	5	24	Carbon
F	Reconstituted	0	5	24	PVD only
G	Reconstituted	60	5	24	Copper
H	Reconstituted	60	5	24	Carbon
I	Reconstituted	120	5	24	Copper
J	Reconstituted	120	5	24	Carbon

TABLE 2—*Summary of tests conducted on large consolidometer.*

Test	Sample Type	Voltage Gradient, V/m	Vertical Pressure, kPa	Polarity Reversal Duration, h	Electrode Type
K	Reconstituted	0	75	24	PVD only
L	Reconstituted	60	75	24	Copper
M	Reconstituted	60	75	24	Carbon
N	Reconstituted	120	75	24	Copper
O	Reconstituted	120	75	24	Carbon

ital data logger took the readings electronically.

Testing Results and Discussions

The soft Bangkok clay used in this study is dark gray with a natural water content of about 120 %. The liquid limit and plastic limit amounted to 96 and 33 %, respectively. The plasticity and liquidity indexes were, respectively, 62 % and 1.1. The soil consists of 79 % clay particles, 19 % silt, and 2 % sand. The dominant clay minerals in the soft Bangkok clay are illites, but kaolinites and montmorillonites are also present. The undrained shear strength obtained from the laboratory vane shear apparatus is 18.6 kPa. The undisturbed soil sample was found to be slightly acidic in nature with a pH of 6.3. The electro-conductivity of the soil is 2230 μS/cm with a salinity of 498 ppm and a total dissolved salt content (TDS) of 4050 ppm. The TDS is well below the maximum limit of 6000 ppm as mentioned by Johnston (1978), wherein electro-osmotic consolidation becomes practically ineffective.

Settlement Versus Time Curves

The soil sample demonstrated the favorable response to electro-osmotically induced consolidation after vertical load and electrical gradient had been applied. The discharge of water was observed at the cathode for about 72 h of the treatment time. In the sample using a copper electrode, the water discharge was greenish, whereas it was dark brown in the case of the carbon electrode due to the corrosion of copper and the disintegration of the carbon electrode, respectively. The shapes of settlement versus time curves are similar for both consolidation with PVD only and electro-osmotic consolidation as shown in Figs. 4*a* and 4*b*, repectively, for the undisturbed sample and the reconstituted sample. For the same initial conditions, faster rates of settlement were achieved using a combination of electrode with PVD than using the PVD only. To achieve 90 % degree of consolidation induced by electro-osmosis, the time periods range from 1.4 to 2.1 and 1.2 to 2.2 times faster than using PVD only for both undisturbed and reconstituted samples in a small cylinder cell, respectively. The settlement attained by using the electro-osmosis generated 39 to 101 % and 27 to 86 % more than the sample using PVD only for the undisturbed and the reconstituted samples, respectively. In order to quantify some benefits from induced consolidation due to electro-osmosis, greater settlement means more vertical stress to achieve such settlement magnitude. Therefore, in this case, a greater surcharge load should have been required using PVD only to achieve the same settlement as was achieved by electro-osmotic consolidation.

The carbon electrode achieved more settlement and a faster rate of consolidation. A highly corrosive effect on the copper electrode was observed due to the oxidation reaction. The corrosion affected the performance of copper electrodes, which reduced the efficiency of electro-osmotic consolidation. The carbon fiber electrodes decomposed with time due to the acidic medium resulting from the electrolysis reactions. However, it was clear that carbon electrodes generated a faster rate of consolidation and achieved greater settlement at the same vertical load and voltage gradient before its efficiency was hindered by its disintegration.

For the electro-osmotic consolidation in the large consolidometer, the 90 % degrees of consolidation in each test were found to be 12.8, 8.8, and 8.2 days with corresponding settlement values of 31.7, 21, and 16.1 mm at the end of the each test, respectively. In this apparatus, the time to reach 90 % degree of consolidation and magnitude of settlement of each test could not be directly compared because the tests were conducted on the same soil sample with different initial conditions.

Effect on Water Content and Shear Strength

The initial water contents of undisturbed and reconstituted samples were 102 and 97 %, respectively. With the PVD only, the water content was reduced for about 3 % at the time when 90 % degree of consolidation was achieved for both sample types. The reduction of water content was about 5 to 9 % for both undisturbed and reconstituted samples in a small cylinder cell, respectively. The variations of water contents across the drains before and after electro-osmotic consolidation is shown in Fig. 5. Electro-osmotic tests using carbon electrode generated higher reductions of water contents for both sample types. A more uniform reduction of water content was observed across the PVD only. The reduction of water content across the drains in the tests of the 120-V/m gradient was higher than in the tests of the 60-V/m gradient at the same location. A higher reduction of water content was achieved with the increasing voltage gradient similar to the observation of Abiera (1999) and Abiera et al. (1999). However, the different change of water content may be due to the different types of soil samples and different initial water content.

The reductions of water content induced the reduction of void ratio. The value of void ratio after treatment was calculated from the amounts of water content reductions and settlements as shown in Fig. 6. The void ratios were correlated to the 45° line. The void ratios from water content reductions generally agreed with the corresponding values obtained from settlements, with slight scatter of the results due to other factors such as evaporation.

The increase of shear strength in the sample with PVD only was about 15 and 26 % for undisturbed and reconstituted samples, respectively. A significant increase was observed on the treated sample by electro-osmotic treatment of about 25 to 63 % and 46 to 144 % for both undisturbed and reconstituted samples, respectively, in a small cylinder cell as shown in Fig. 7. Abiera (1999) and Abiera et al. (1999) also observed the increase of shear strength after treatment but with higher values. Using the sensitive soft Ariake clay in Japan, a higher increase was found by Abiera (1999) and Abiera et al. (1999), especially in the sample with carbon electrodes.

The carbon electrodes achieved lower water content and higher shear strength after treatment compared with the copper electrode under the same voltage gradient for all samples. Therefore, it can be implied that the carbon electrode is the more effective electrode configuration for electro-osmotic consolidation. In these results, a more symmetrical distribution of water content reduction and shear strength increase across the drain was achieved due to the applied polarity reversal.

Effect on Liquid and Plastic Limits

Values of liquid limit and plastic limit are influenced by the drying and preparation procedure of the clay samples. The average value of liquid and plastic limits of the soil were initially 95 and 33 %, respectively. The initial plastic index of the sample was 62 %. Due to the electro-osmotic treatment, the liquid limit, plastic limit, and plasticity index of all clay samples increased from the initial values by about 2 to 7 %, 1 to 6 %, and 2 to 8 %, respectively. Figure 8 shows the variation of liquid and plastic limits.

The liquid limit is influenced by such factors as exchangeable ion, salt concentration and pH of the clay. The increase of salt concentration was also observed after the electro-omotic tests. The

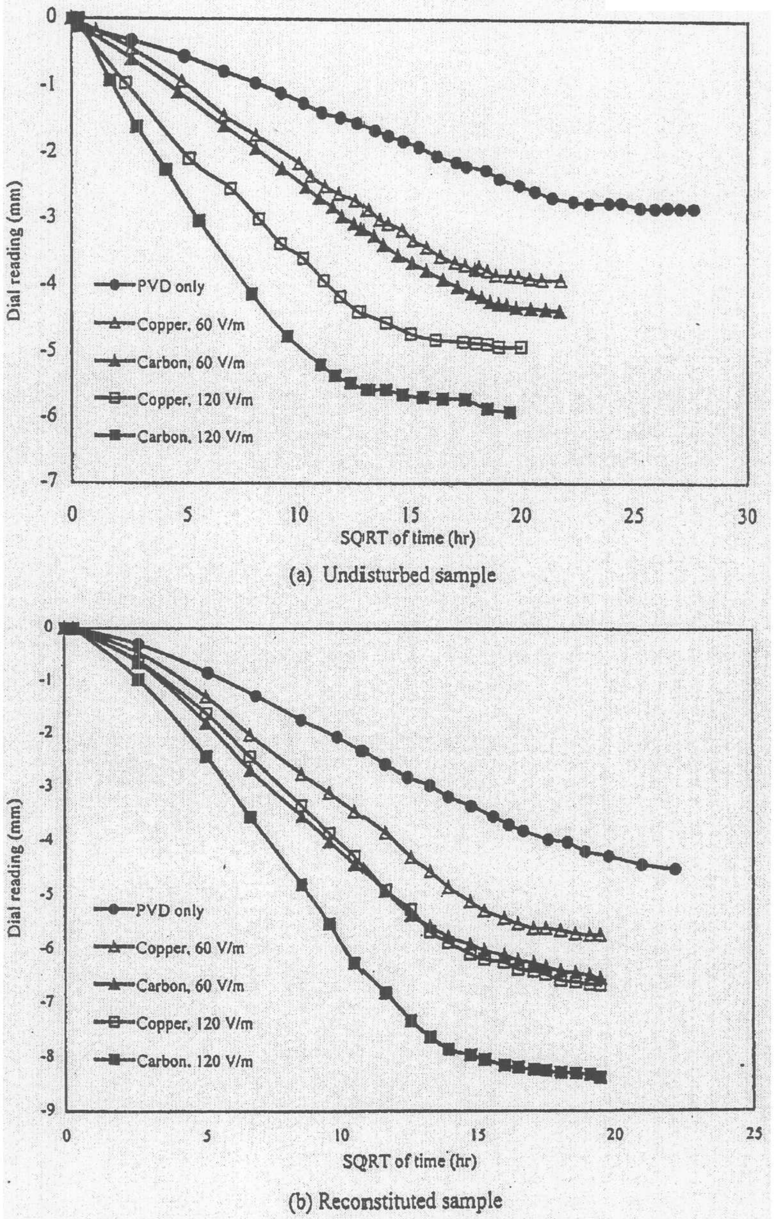


FIG. 4—*Settlement versus time curve.*

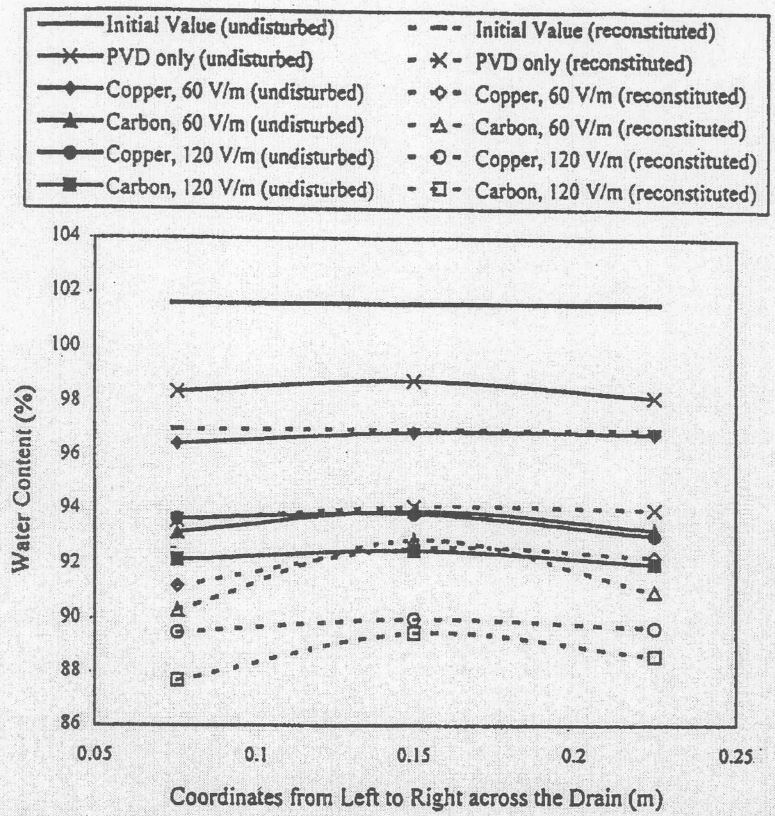


FIG. 5—*Variation of water contents for undisturbed and reconstituted sample before and after consolidation (small cylinder).*

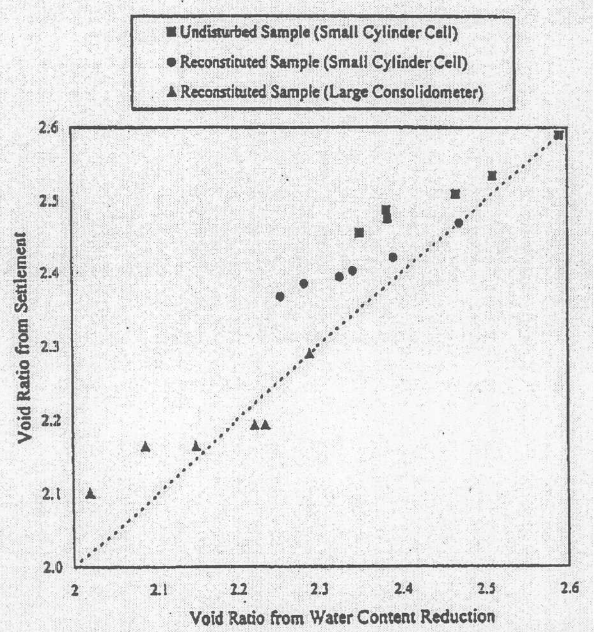


FIG. 6—*Correlation of void ratios from water content reductions and settlements.*

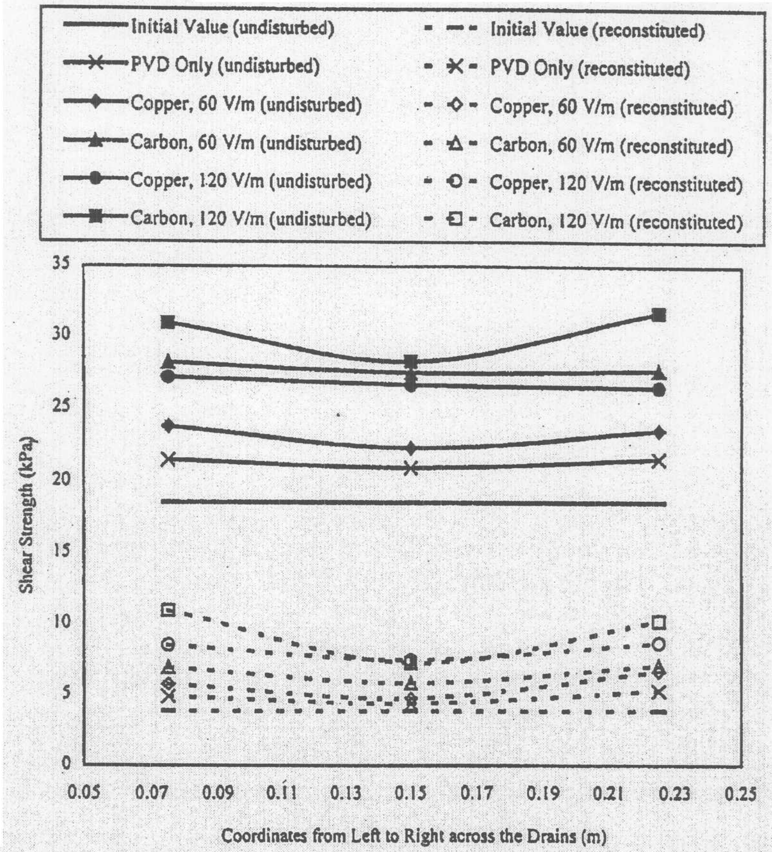


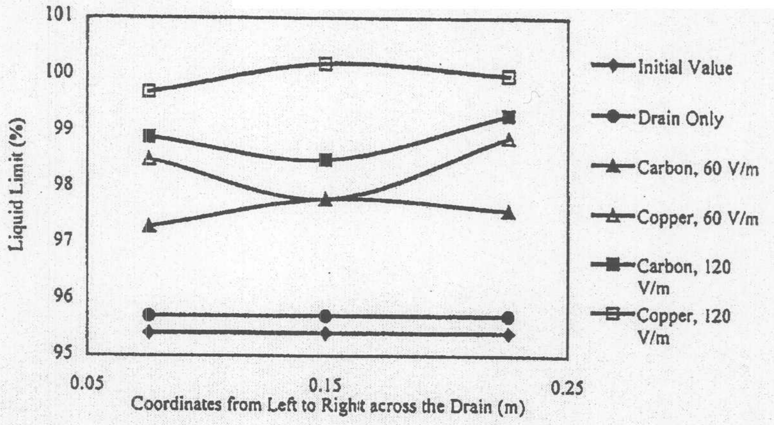
FIG. 7—*Variation of shear strengths for undisturbed and reconstituted sample before and after consolidation (small cylinder).*

experimental results by Abiera et al. (1999) showed that for the low swelling but sensitive smectite Ariake clay in Japan where particle arrangement is the dominant force, the Atterberg limits increased after electro-osmotic treatment due to increased salt concentration. However, it should be noted that the increase in liquid limit for a corresponding increase in salt concentration has some maximum limits (Bjerrum 1954).

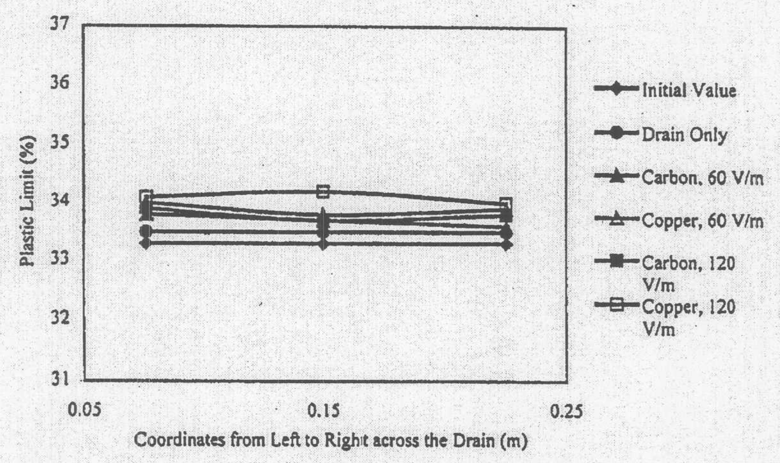
Effect on Chemical Properties

Chemical tests were conducted on the soil sample to determined the pH, electro-conductivity, and salinity before and after treatment. There was a variation of pH values due to the applied electric gradient. The pH values of the reconstituted sample in the small cylinder cell decreased upon completion of the tests. However, for undisturbed samples, the final pH values are higher than the initial pH, especially in the sample using a copper electrode. Higher values of pH were observed in the sample with the 60-V/m gradient. A variation of pH values was also observed in the reconstituted sample of the large consolidometer. The reduction of pH values in the sample using carbon electrode was observed, whereas the pH values in the sample using copper electrodes increased. The variation of pH values due to the applied electric gradient can be explained by electro-chemical reaction (Acar et al. 1994). Predominant electro-chemical effects generated at the vicinity of electrodes yielded acidic and basic fronts at both anodes and cathodes, respectively. However, when polarity was reversed regularly, the pH at both electrodes was almost identical.

A conductivity meter measured the soil electro-conductivity immediately after the applied current was switched off. The method of measurement was explained by Head (1998). The decreasing electro-conductivities were observed after electro-osmotic treatment in all samples, as shown in Fig. 9. Higher reduction was observed at the higher voltage gradient. This reduction may be caused by the reduction of water content. According to Mitchell (1993), the electro-conductivity of soil depends on soil porosity, degree of saturation, pore water composition, mineralogy, soil structure including fabric and cementation, and temperature. Electro-conductivity may increase for a brief period after starting the electro-osmotic test and decrease as the water content reduces and other changes take place in the soil (Casagrande 1983). The rate of decrease depends on the initial



(a) Liquid limit



(b) Plastic limit

FIG. 8—*Variation of liquid and plastic limits for undisturbed sample before and after consolidation (small cylinder).*

liquidity index, the plasticity and permeability of the soil, and the chemistry of the soil-water system.

The value of salinity, which is the presence of total concentration of soluble salts (i.e., Na, Ca, Mg, HCO_3, SO_4 and Cl), increased for all samples as seen in Fig. 10. It was measured by a salt meter in accordance with the Japanese Geotechnical Society (JGS) Test Method and Explanation of Soil Testing (JGS0212-2000) immediately after the applied current was switched off. The increase of salinity was mainly due to the reduction of water content and, consequently, the increased electrolyte concentration (Lo et al. 1992). A higher amount of salinity was observed in the sample with the copper electrode. A higher voltage gradient also produced higher salinity in the soil sample. The change of salinity is the result of an electro-chemical reaction. Abiera (1999) found that in the case of no polarity reversal the range of increase in salt concentration was smaller at the cathode and the range became higher at the anode. As discussed earlier, the liquid limit increased when the salinity was increased because of the change in soil particle arrangement. Torrance (1975) found that the increase of salt concentration also affected the increase in shear strength.

Effect of Current Density

The current was measured during the electro-osmotic treatment. The current density generated on the electrical gradient of 120 V/m is presented in Figs. 11*a* and 11*b*, corresponding to the different types of electrodes. The current density was simply determined as the ratio of current measured by ammeter to the total area of the electrode so as to understand the overall change in current and soil resistance during electro-osmotic consolidation. The current density reduced with time, starting from a higher value when the polarity of the voltage was reversed. The possible explanation for this observation

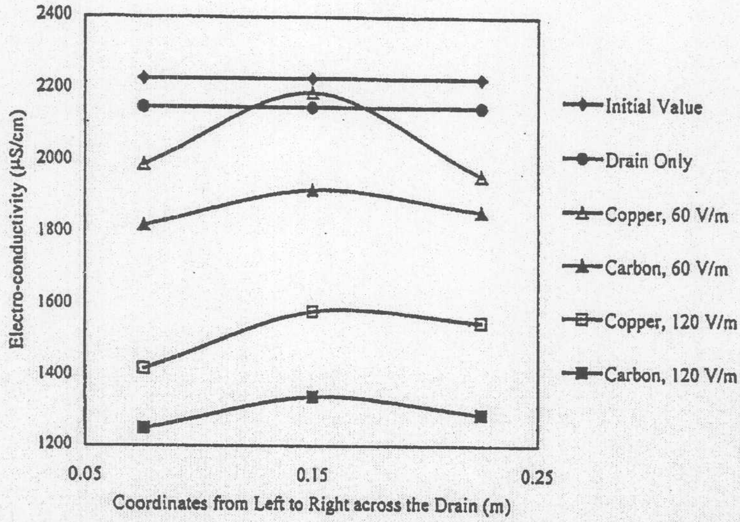


FIG. 9—*Variation of electro-conductivity for undisturbed sample before and after consolidation (small cylinder).*

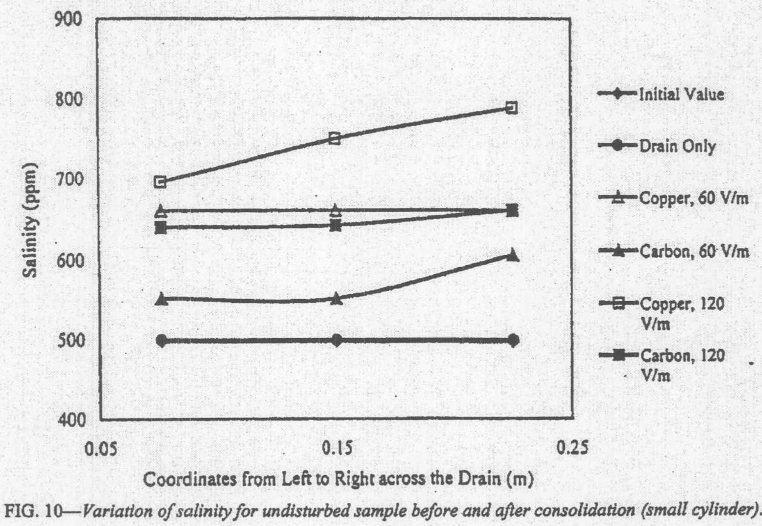


FIG. 10—*Variation of salinity for undisturbed sample before and after consolidation (small cylinder).*

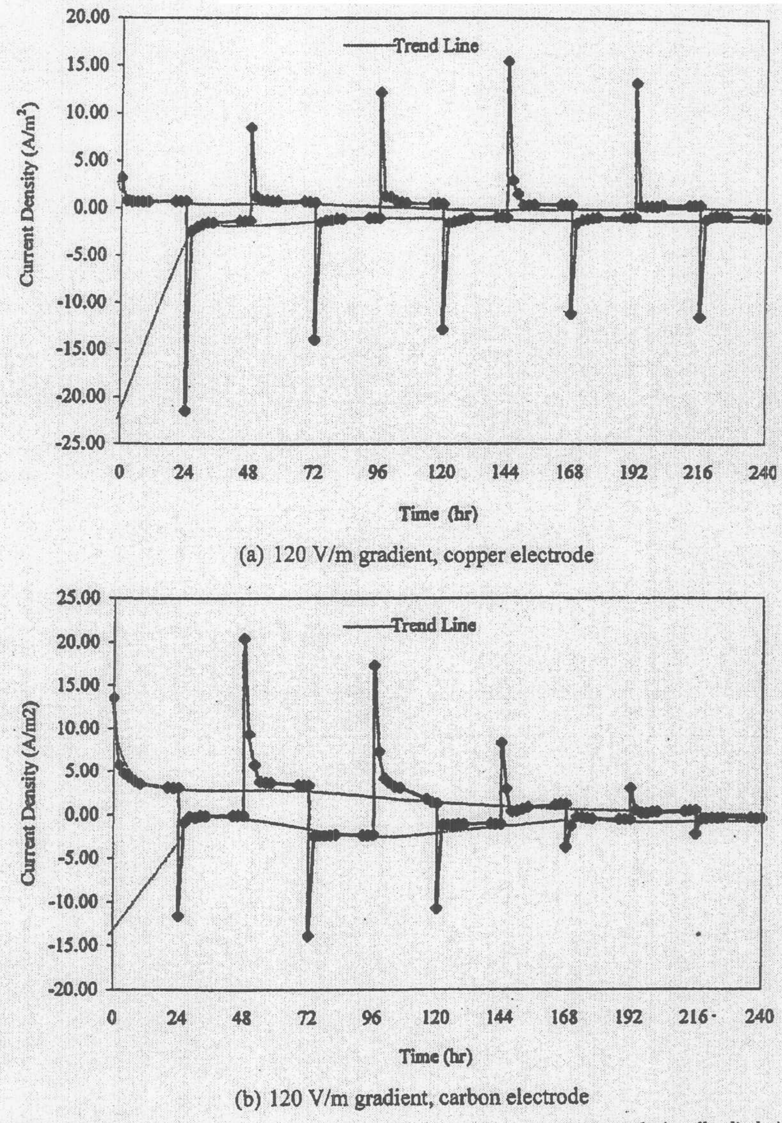


FIG. 11—*Variation of current density during treatment time for undisturbed sample (small cylinder).*

is that the current density is inversely proportional to the soil resistance as observed by Abiera (1999). Correspondingly, the current intensity decreased toward the end of the test. Consequently, the energy consumption decreased. A higher reduction of the current density at the end of the tests was observed in carbon electrodes due to the disintegration of carbon, leading to reduced efficiency of electro-osmotic treatment. Shang et al. (1996) demonstrated that the electric current density is the driving force in electro-osmotic consolidation. The effectiveness of electro-osmotic consolidation can be improved by the increase of the current density in the soil during polarity reversal even though the voltage gradient is constant.

Conclusions

The soft Bangkok clay showed a favorable response to electro-osmotic consolidation using a combination of electrodes with PVD. The following conclusions can be drawn:

1. The rate of electro-osmotic consolidation was achieved 1.4 to 2.1 and 1.2 to 2.2 times faster than using PVD only for undisturbed and reconstituted samples, respectively.
2. At a higher voltage gradient, a faster rate of consolidation and higher magnitudes of settlements were achieved.
3. Although carbon electrodes decompose with time due to the acidic medium, it achieved faster rates of consolidation and more settlements than the copper electrode. With polarity reversal, the carbon electrodes were beneficial in inducing consolidation before its efficiency was hindered by its disintegration. On the other hand, copper electrodes have highly corrosive and toxic products due to oxidation reaction.
4. The reduction of water content is approximately 5 to 9 % due to electro-osmotic consolidation and 3 % for consolidation with the PVD only. The water content reduction was mainly due to the corresponding reduction in the void ratio.
5. A higher increase in shear strength was obtained after electro-osmotic consolidation compared to consolidation with PVD only. The range of significant increase was 25 to 144 % for electro-osmotic–treated soil and 15 to 26 % for the sample with PVD only.
6. All samples indicated an increase in liquid limit up to 7 % from the initial value and an increase in plastic limit of 6 %, and, consequently, the plasticity index increased by 8 % due to the increase of salinity.
7. The current density suddenly increased after polarity was reversed and decreased with time under a constant voltage gradient.
8. The soft Bangkok clay is suitable for electro-osmotic consolidation, having 4050 ppm of total dissolved salts (TDS), which is well below the 6000 ppm limit.

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