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Full Length Research Paper

Electroosmosis ground improvement efficiency by non-metallic electrodes

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The purpose of this study was to compare the ground improvement efficiency driven by electroosmosis for different electrode materials. Many studies have examined the ground improvement efficiency with respect to ground characteristics, grouting, pH, and salt concentration. However, few studies based on electrodes types have been reported. In this study, metallic (steel and aluminum) and non-metallic (nanocoated-plastic drain board (Nano-PDB)) electrodes have been used to determine the ground improvement efficiency for each type of electrode materials. For this purpose, a small model box was made for the tests in which Kaolin clay was used to form the ground. The various tests were conducted over 24 h with different voltages and inter-electrodes distances in order to analyze settlement, consolidation drainage, water content and shear strength. The results showed that the ground improvement efficiency was greatly increased when the distance between the electrodes was decreased while the voltage was increased. Furthermore, ground improvement efficiency was significantly enhanced by the Nano-PDB electrode. The ground improvement efficiency varied greatly depending on the electrode material.

Key words: Ground improvement efficiency, electroosmosis, nanocoated-plastic drain board, steel bar, aluminum bar, electrode.

INTRODUCTION

Although, the electroosmosis method that can apply both physical and chemical method (Kazemian et al., 2011) has been used in a variety of field tests, such as, measuring soil contamination, improving the soil of soft ground by electroosmosis has only recently been applied to small areas without the disturbance or replacement of existing ground soil. Since it was first discovered by Reuss in 1807, the phenomenon of electroosmosis has been studied by many other researchers with all using a water-clay-electrolyte system. Factors that affect the efficiency of electroosmosis include soil type, the amount and concentration of dissolved solids in the pore water (electrolyte), distance between the electrodes, voltage, and electrode material. With regards to the electrode material, most studies have been conducted with high conductivity metallic electrodes such as platinum, silver, copper, brass, or steel. In particular, steels are commonly used due to economic reasons. However, there are few studies comparing various electrode types.

Studies using electroosmosis for soft ground improvement have widely relied on metallic electrodes. Lo et al. (1991) used copper electrodes to increase the shear strength of sensitive Leda clay that spread at the site. Milligan (1994) inserted a H-shaped steel pile as an electrode in order to improve the shear strength of the

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Abbreviations: LVDT, linear variable differential transformer; **PDB**, plastic drain board.

Table 1. Physical properties of Kaolin clay.

Properties	Quantity
Specific gravity, G_S	2.5
Liquid limit, *LL* (%)	64.2
Plastic limit, *PL* (%)	47.1
Plasticity index, *PI* (%)	22.9
Initial Water Content (%)	100
Passage through a #200 sieve (%)	100
USCS (Unified Soil Classification System)	MH

ground at the work site. In addition, Micic et al. (2003) inserted a steel panel in marine clay that imitated the surrounding ground in order to increase the strength of the soil. DeFlaun and Condee (1997) used stainless steel as an electrode material to study decontamination using electroosmosis remediation by bacterial transfer within the ground. Zhou (2006) also studied electroosmosis remediation soil decontamination (copper contamination) using stainless steel electrodes.

Lee and Lee (1998) studied the improvement in electroosmosis efficiency of marine clay by using a steel bar as an electrode. In that study, electrophoresis using a high voltage (1500 V/m) did not appear to affect the ground improvement and electroosmosis using a low voltage (3–6.6 V/m) also did not appear to increase the ground improvement by more than would be expected from a loading test. Kim et al. (1999) also studied electroosmotic consolidation behavior based on the concentration of the electrolyte by using a carbon electrode. Kim et al. (2007) further studied the shear strength improvement of marine clay induced by electroosmosis cementation.

Many researchers have reported agreement between metallic electrodes but a consequence of long term use is cementation due to corrosion and this leads to decreased water permeability. Electroosmosis using metallic electrodes has been limited to testing small areas for soft ground improvement due to difficulty in construction and economic efficiency on a large construction site.

An electrode which avoids this corrosion issue is the geosynthetic nanocoated-plastic drain board (Nano-PDB). This electrode is suitable for large construction areas due to the simplicity of the construction process. Additionally, the electrodes can be operated at low voltages (3–7 V/m) thus reducing power consumption costs. Two main studies were conducted in this research. First, a comparison of the ground improvement efficiency for three electrode types: steel bar, aluminum bar, and Nano-PDB electrodes, was undertaken. Second, an assessment of the electroosmosis efficiency at low voltage (3–7 V/m) was performed to examine economic factors.

MATERIALS AND METHODS

Soil used for tests

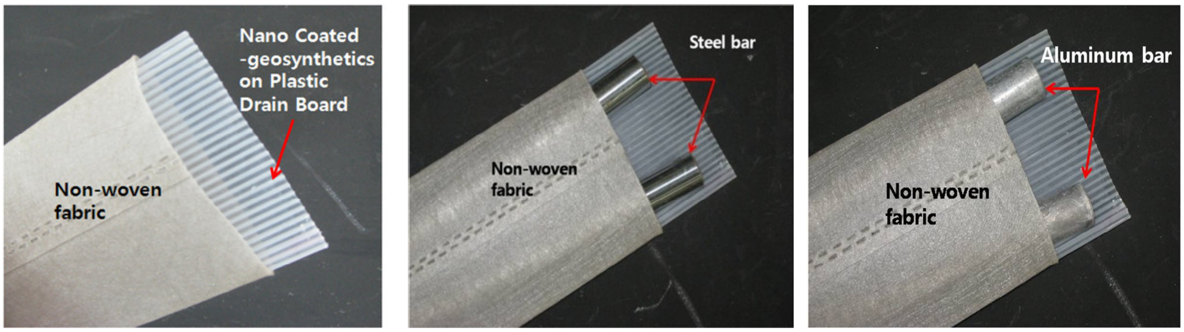
Kaolin clay was used for the model test because it is less active and expansive than normal clay and will retain its consistency. Table 1 shows the physical properties of Kaolin clay obtained from a physical properties test.

Electrode types

Figure 1 shows a picture of each electrode: the Nano-PDB, steel bar and aluminum bar electrodes. The Nano-PDB electrode shown in Figure 1a was developed specifically for this study and was treated with conducting macromolecules by a flow coating method. The Nano-PDB and steel bars used for electroosmosis have similar electrical currents and resistances. However, the advantage of using the Nano-PDB is to avoid chemical reaction with the ground soil. The steel and aluminum bars are inserted into a non-woven fabric for this study. The specifications for each electrode are shown in Tables 2 and 3.

Test method

A total of 28 experiments were conducted as shown in Table 4 in order to compare the ground improvement efficiency of the different electrode types. The electroosmosis tests were conducted for various inter-electrode distances (250, 220 and 200 mm) and various voltages (0, 3, 5 and 7 V/m) over a period of 24 h. Only a general PDB was used for the test without applying a voltage. A linear variable differential transformer (LVDT) was installed on the top of the model box (W(300)xD(200)xH(260) mm, material of acrylic) in the center, as shown in Figure 2, in order to measure settlement and holes on the bottom of the box allowed the pore water to drain. Consolidation drainage outflow produced during the tests was measured by drainage valves located below the box. In order to prevent evaporation of the drainage overflow, floating oil was used in a mass cylinder to measure the discharge. Moreover, a surfactant was also used to reduce the lateral friction that affects settlement. The change in the shear strength of the clay before and after the tests was measured by a laboratory vane test. The change in water content was measured from samples collected from the center and both sides of the electrodes. The changes in the amount of settlement and ground improvement were compared by adjusting the distance between PDBs inserted on both sides of the box. Figure 3 shows the electroosmosis test device.



(A) Nano-PDB (B) Steel bar (C) Aluminum bar

Figure 1. Electrodes used in the tests.

Table 2. Nano-PDB specifications.

Total transmittance (%)	≥75
Sheet resistance (Ω/sq)	1×10^{7}
Uniformity (%)	≦10
Thermostability	0.8-1.2
Hardness	≥3
ITO adhesion	100/100

Table 3. Steel bar and aluminum bar specifications.

	Steel bar	Aluminum bar
Diameter (mm)	20	20
Length (mm)	250	250
Resistance (Ω/cm)	0.0993×10^{6}	0.377×10^{6}
Specific gravity	7.87	2.702

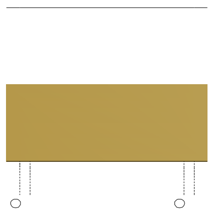
Table 4. Number of tests conducted for each condition.

Test no.	Electrodes	Inter-electrode distance settings	Voltage settings	Total
Test 1	General PDB	1	-	1
Test 2–10	Nano-PDB	3	3	9
Test 11–19	Steel bar	3	3	9
Test 20–28	Aluminum bar	3	3	9

RESULTS AND ANALYSIS

Consolidation settlement amount

The LVDT measured the amount of consolidation settlement as a function of elapsed time, voltage, and inter-electrode distance. Figure 4 shows the consolidation settlement measured at 30 min intervals. The results show that the initial consolidation settlement increases as the distance between the electrodes decreases and the voltage increases. Comparing each electrode based on the consolidation settlement for the general PDB with



```
ERROR: rangecheck
OFFENDING COMMAND: .buildcmap

STACK:

-dictionary-
/WinCharSetFFFF-V2TT9BF4ACCAt
/CMap
-dictionary-
/WinCharSetFFFF-V2TT9BF4ACCAt
```