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Research paper

A study of the effects of electrode spacing on the cementation region for electro-osmotic chemical treatment

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ABSTRACT

Previous laboratory studies have shown that injection of the calcium chloride solution can cause soil to be cemented near the cathode during electro-osmosis. In order to predict the size of the cementation region, a series of electro-osmotic chemical tests was conducted using different electrode sizes, electric voltages, and electrode spacing. After the tests, the concentration of calcium ions and pH values over the entire sample were analyzed and the cementation near the cathodes was inspected. Results show that the contours of the Ca^{2+} concentration, contours of the pH values and the cementation region were consistent to each other. Cementation often occurs near the cathode in an alkaline environment where the pH values are higher than 8.3 to 8.7. The cementation region was highly related to the applied voltage and electrode spacing but slightly related to the size and shape of the cathodes. When the electric field intensity was amplified by N times, the radius of the cementation region was increased by $\sqrt{N}$ times. This relationship can be used to predict the cementation region around the cathode and to design a rational spacing between two cathodes for multiple pairs of electrodes.

1. Introduction

Electroosmosis can be used to improve the mechanical strength of soft clay. The main result of electroosmosis is dewatering, which leads to consolidation and a subsequent increase in the strength of the soil (Mitchell, 1993). To enhance the effect of electro-osmotic improvement, chemical solutions are injected into the soil during electroosmosis. The technique sometimes is termed as the electro-osmotic chemical treatment (ECT). Studies of electro-osmotic chemical treatment have been done on various types of soil with different voltage levels, electric currents, chemical solutions, and different consolidation stress in the laboratory to examine the complex mechanism (Lefebvre and Burnotte, 2002; Alshawabkeh et al., 2004; Burnotte et al., 2004; Asavadorndeja and Glawe, 2005; Paczkowska, 2005; Abdullah and Al-Abadi, 2010; Moayedi et al., 2011; Ahmad Tajudin, 2012). Laboratory studies have shown that although a substantial strength increase can be gained by chemical reactions in the soil matrix including cation exchange, cementation, and precipitation other than consolidation, most of the cementation occurs in a region near the anode or cathode. This may be attributed to the fact that acidic and alkaline conditions are developed in an area around the anode and cathode, respectively, due to electrolysis. The chemical reaction between injecting chemical solutions and soil preferably occurs under the acidic or alkaline environment, which in turns produces cementing agents, leading to cementation between soil particles near the anode or cathode (Mitchell, 1993; Asavadorndeja and Glawe, 2005). The author and his coworkers have found through laboratory experiments that injection of the calcium chloride solution followed by the injection of the sodium silicate solution during electroosmosis can cause the soil cemented near the cathode and anode, respectively (e.g., Ou et al., 2009b; Chang et al., 2010; Chien et al., 2010, 2011, 2012; Ou et al., 2013). However, the degree of alkalinity and acidity relating to cementation, size of cementation region and its influence factors has not been studied yet.

Moreover, the pipe type of electrodes is often used in the field and its influence is very different from the plate type of electrodes, normally adopted in the laboratory due to limited dimensions in experimental cells (Mitchell, 1993; Ou et al., 2009a; Chien et al., 2012). To obtain the cementation covering the entire area in the field, it is necessary to have a rational way to predict cementation size and to determine the spacing between electrodes.

The objective of this study is to investigate the cementation region around the cathode and to establish a rational way to determine the spacing between two adjacent cathodes. The calcium chloride solution was adopted as the injection chemical solution during electro-osmosis. The laboratory tests were performed using different electrode sizes, voltages, and different electrode spacing. Chemical analyses including calcium concentration and pH were performed to examine the properties and composition of the treated soils.

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2. Materials and methods

A standard experimental cell, with two platinum (Pt) coated titanium (Ti) meshed plates, 350 mm in span, serving as the anode and cathode was used for the ECT test in this study. As shown in Fig. 1, a chamber connected to the anode, 20 mm wide and 150 mm long, was used to store a very small amount of injected chemical solutions, allowing the chemical solutions to be uniformly injected into the soil under the electric field. The other chamber, also 20 mm wide and 150 mm long, connected to the cathode was used to store drained water and then discharged through a drained tube. The top plate also served as a bearing plate, on which air pressure acted to provide a designated consolidation pressure. The use of platinum (Pt) coated titanium (Ti) mesh as the anode was for prohibiting oxidization of the anode during electro-osmosis. For investigating the scaling effect of the cementation, a smaller experimental cell with a 200 mm span was also used. The direct current was applied during electro-osmosis.

Kaolinite, with basic properties as listed in Table 1, was used in this study. The kaolinite powder was thoroughly mixed with a sufficient amount of distilled deionized water using a mechanical mixer so that its water content was 60%. The soil or slime was placed in the experimental cell in layers. After putting the soil in the cell, it was covered with a filter paper, and then the electrodes were attached. The 30 kPa vertical pressure was applied to the soil in increments to generate a normally consolidated condition. The water content after consolidation was equal to 51%.

Table 1
Chemical and physical properties of kaolinite.

Items of analysis	Mean percent by weight
Silicon dioxide (SiO_2)	45.5%
Aluminum oxide (Al_2O_3)	38.00%
Titanium dioxide (TiO_2)	1.65%
Iron oxide (Fe_2O_3)	0.90%
Calcium oxide (CaO)	0.25%
Magnesium oxide (MgO)	0.03%
Potassium oxide (K_2O)	0.23%
Sodium oxide (Na_2O)	0.04%
Loss on Ignition (L.O.I)	13.40%
Liquid limit (%)	46
Plastic limit (%)	25
Plastic index (%)	21
Specific gravity	2.61

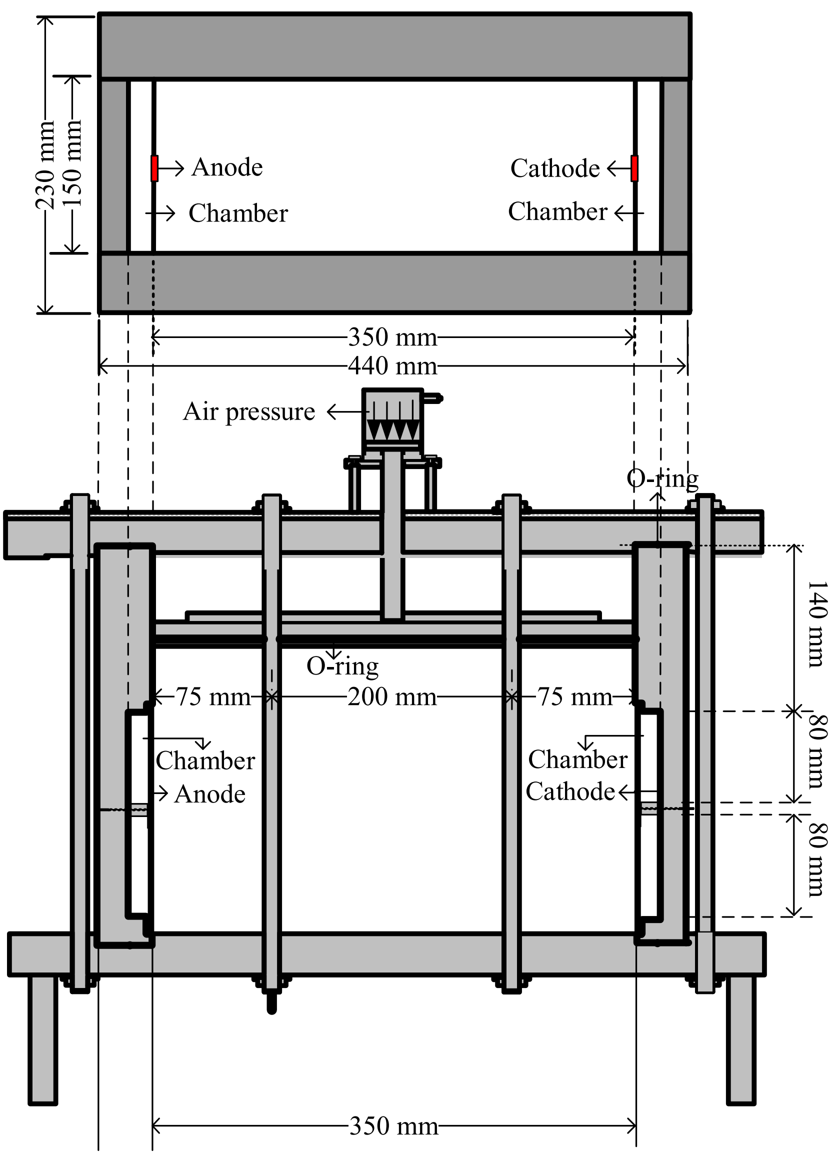

Fig. 1. Schematic configuration of the electroosmotic cell (top view and side view).