

Electrocementation of a Marine Clay Induced by Electrokinetics

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ABSTRACT

This study is directed to using electrokinetic processes for strengthening marine sediments in order to enhance the performance of skirted foundations. This paper studies the electrocementation that occurs during the electrokinetic treatment of a highly saline marine clay. The influence of electrokinetics on the soil structure is characterized by changes in the pore size distributions determined by mercury intrusion porosimetry. The porosity of the treated soil samples was significantly lower, and the pore diameters were significantly smaller than in of the untreated soil samples. The plasticity characteristics of treated soil were also changed after electrokinetic treatment; this is attributable to the electrokinetically enhanced grouping of clay particles into aggregates due to the presence of cementing agents and changes in type and concentration of ions in the soil pore water. The amounts of iron oxide and calcium carbonate, both well-known cementing agents in soil, increased after electrokinetic treatment; this increase contributes to the increase in soil shear strength and decrease in soil pore size. The results of CEC and glycol retention tests indicated that the surface charge of clay particles at the anode sides was reduced after electrokinetic treatment, leading to stronger interparticle bonds.

INTRODUCTION

If voltage is applied across 2 electrodes placed in a saturated clay soil, electrokinetic processes are generated: electro-osmosis (transport of pore fluid from the anode toward the cathode), electrophoresis (transport of negatively charged soil particles toward the anode) and electromigration (transport of ions in soil pore fluid). These processes have been used successfully to improve the geotechnical properties of fine-grained soils by dewatering and consolidation (Casagrande, 1949; Soderman and Milligan, 1961; Bjerrum et al., 1967; Lo et al., 1991). All of these successful applications of electrokinetics involved soils with fresh pore water (salinity less than 2 g NaCl/l). For marine soils with a pore fluid composition similar to that of seawater (salinity around 30 g NaCl/l), no comprehensive study had been performed until recently (Lo et al., 2000; Micic et al., 2001).

If the electrodes are installed close to a metallic object embedded in soil such as a skirted foundation made of steel, the surface of the object becomes the contour of the constant electric potential in the generated electric field. Depending on induced charges that accumulate on the surface of the metallic object, the soil particles can be attracted or repulsed, as they are usually electrically charged. The sustained application of a properly designed electric field can enhance the bonding between the metallic object and the soil. The effects can be experimentally evaluated through the changes in the soil shear strength and skin friction of the foundation element (Shang and Dunlap, 1998; Micic et al., 2002).

Electrochemical effects are always associated with electrokinetics in soil-water-electrolyte systems. Spangler and King (1949) attributed the increase in the load capacity of a metallic pile after electrokinetic treatment to electrochemical hardening of the clay

surrounding the pile. After an extensive field test, Bjerrum et al. (1967) reported that electro-osmotic dewatering or consolidation alone could not explain the increase in the shear strength of a quick clay after electrokinetic treatment. Gray and Schlocker (1969) demonstrated experimentally that the composition and physical properties of the soil were altered by introducing aluminum under an electrochemical gradient. Lo et al. (1994), Shang and Dunlap (1998) and Lo et al. (2000) also noticed that the increases in the soil shear strength and modulus after electrokinetic treatment cannot be attributed solely to consolidation.

It has been known that the application of an electric field induces precipitation of amorphous compounds such as iron oxides and carbonates. In general, the precipitation of these compounds is aided by an increase in the alkalinity of the soil pore water (Krauskopf and Bird, 1995). The precipitated iron oxides and carbonates can act as cementing agents, which strengthen soil interparticle bonds (Quigley, 1980; Mitchell, 1993). It is also well known that the application of an electric field to a soil generates pH and other ionic concentration gradients between an anode and cathode (Acar et al., 1990). The pore water of the soil around the anode becomes quite acidic (pH~2), while the pore water at the cathode becomes alkaline (pH~12). These changes in the pore water pH along the soil profile between electrodes may further cause changes in the clay's surface chemistry and the electro-osmotic flow rate (Eykholt and Daniel, 1994). The ionic diffusion is associated with an electrokinetic process during and after the treatment. The migration of ionic species under the concentration gradients takes place long after the electric field is withdrawn, making electrokinetics a progressive process with time (Lo et al., 2000; Micic et al., 2002). Thus, the precipitation of iron oxides as well as carbonates and ionic diffusion during and after electrokinetic treatment generate cementation in marine soils.

Micic et al. (2002) recently performed a series of electrokinetic tests on a natural marine clay with a steel plate embedded in the soil to simulate a part of a skirted foundation. The objective was to strengthen the soil around the plate, thus enhancing the load-carrying capacity of the plate. Results showed that the undrained shear strength of the soil around the embedded

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