Electrokinetic Strengthening of Marine Clay Adjacent to Offshore Foundations

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ABSTRACT

The present study originates from a common problem that faces offshore engineering practice. It focuses on electrokinetic strengthening of soft marine clays adjacent to skirted foundations. A series of laboratory electrokinetic experiments was conducted in a natural marine clay. A steel plate was embedded in the soil during the electrokinetic treatment to simulate part of a skirted foundation, and the design, execution and results of the electrokinetic tests are reported. The results show that the undrained shear strength of the soil around the embedded steel plate increased considerably after the electrokinetic treatment. It is also shown that the soil's shear strength further increased with time after the electric field was withdrawn, which is attributable to electrokinetics-induced soil-particle cementation during post-treatment ionic diffusion. The effects of polarity reversal and current intermittence under a constant applied voltage were also investigated in order to obtain a uniform strength increase between the electrodes, to reduce energy consumption and to prolong the electrodes' service life.

INTRODUCTION

The use of skirted foundations is increasing worldwide as an attractive and effective foundation solution in various types of soils, ranging from soft clays (Colliat et al., 1996) to dense sands (Tjelta, 1995). Skirted foundations have been used for floaters, tension leg platforms, gravity platform jackets, jackup rings, subsea systems and other protection structures (Anderson and Jostad, 1999). Skirted structures also have the potential for use for other purposes, such as pipeline pull-in anchors or standby moorings (Lacasse, 1999). Deep skirted foundations have actually been successfully used in water depths ranging from 70 m, as for the Draupner E heavy jacket in the North Sea (Tjelta, 1995) to about 1000 m, as for the semisubmersible platform at Marlim Field offshore Brazil (Mello et al., 1998).

Skirted foundations are normally cylindrical units made of steel or concrete. The basic functions of the skirts are mainly to confine any soft surface layers, to carry structural loads, to effectively prevent lateral loads from sliding, and to provide uplift resistance. The capacity to carry loads depends on factors such as depth of skirt penetration, cylinder diameter, soil strength and the combination of horizontal, vertical and moment loads. When soft soils are encountered in a site, however, the bearing capacity is governed by an undrained shear failure in the soil. Hence, the soil's undrained strength becomes one of the major concerns in the design of skirted foundations. Marine clay deposits in many offshore areas are often characterized by low shear strength and high compressibility. The poor engineering properties of these deposits pose foundation problems for offshore structures. There are 2 alternatives to overcoming these problems: Increasing the size of skirted foundations, and improving the soil. Electrokinetics may be used to strengthen the soil when the latter alternative is considered in design and construction.

The application of direct or alternating electric fields in clayey soils generates electrokinetic processes, including electro-osmosis (transport of pore water toward the cathode), electrophoresis (transport of negatively charged particles toward the anode) and ionic migration (transport of ions toward electrodes). Upon application of an electric field to clays and silts, consolidation and strengthening occur if the method of application is properly designed, and the physical and chemical properties of the soil satisfy certain requirements. The earliest application of the electrokinetic method is electro-osmosis used in silts and clays (Casagrande, 1949, 1983; Bjerrum et al., 1967; Lo et al., 1991a). Bjerrum et al. (1967) employed electro-osmosis to stabilize an excavation in a very soft Norwegian quick clay near Oslo and reported that the average undrained shear strength was 4 times greater. More recently, Lo et al. (1991b) demonstrated in a pilot field test that pumping at the cathode was eliminated by the appropriate design of electrodes and polarity reversal, and that both the effective stress parameters and preconsolidation pressure increased (Lo and Ho, 1991). In the past, some investigators (Soderman and Milligan, 1961; Butterfield and Johnson, 1980) found that the shaft resistance of steel friction piles driven into a clay stratum could be increased significantly by the application of electrokinetics. Soderman and Milligan (1961) conducted a series of electro-osmotic tests on 16.5-m-long steel H-piles installed in a soft varved clay. It was reported that the shaft resistance increased from below 300 kN to over 600 kN. Load tests were carried out again on the same piles 33 years after the electro-osmotic treatment, and the results demonstrated that the ultimate bearing capacity of the piles remained unchanged (Milligan, 1994)—a convincing demonstration that the increase in bearing capacity of steel piles by electrokinetic treatment is permanent.