International Journal of Offshore and Polar Engineering
Vol. 13, No. 3, September 2003 (ISSN 1053-5381)

Load-carrying Capacity Enhancement of Skirted Foundation Element by Electrokinetics

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ABSTRACT

The objective of this study is to enhance the load-carrying capacity of skirted foundations embedded in marine deposits by electrokinetics (EK). The focus of improvement is at the interface between the soil and foundation. A series of laboratory tests was performed in an EK-cell to determine the optimal configuration of the electrical field surrounding a skirted foundation. Two soils were tested: Yulchon clay (a natural marine sediment) and Welland sediment (a river sediment mixed with artificially prepared seawater). In each test, a steel plate was embedded in the soil to represent an element of a skirted foundation. Electrodes were installed in the vicinity of the steel plate and a voltage, either constant or intermittent, was applied over a period of time. The load-carrying capacity of the steel plates and the undrained shear strength of the adjacent soil were measured after electrokinetic treatment. The effect of the electrode layout and voltage application was evaluated through a comprehensive experimental program. It is shown that, by optimizing the electrode arrangement and implementing the polarity reversal, the load-carrying capacity of the steel plates increased up to 4 times, and that soil shear strength increased up to 3 times after sustained application of a DC voltage of 5.2 V for 14 days. The results obtained in this study lead to a large-scale laboratory study and will have the potential to be applied in offshore engineering practice.

INTRODUCTION

Skirted foundations and anchors are used extensively in offshore engineering for carrying structural loads in a wide range of fixed and floating offshore platforms (Andersen and Jostad, 1999). Engineers often face the challenge of designing skirted foundations in cases where a soft, highly compressive marine deposit is encountered in such a way as to satisfy bearing-capacity requirements while minimizing the embedment depth and dimensions of the foundation due to cost considerations.

Skirted foundations and anchors are large, hollow, cylindrical foundation elements usually made of steel. They are installed by penetrating the skirts into the seabed, first partially under self weight, and then by creating an underpressure inside the cylinder (Andersen and Jostad, 1999). A thin zone of soil along the skirts will be remoulded during installation. The shear strength of the soil increases with time after penetration, due to dissipation of excess pore pressure and increased horizontal normal effective stress. However, this shear strength increase differs along the skirt because different soil displacement behaviour occurs during the installation, i.e., during the self-weight penetration the soil replaced by the skirt wall moves outside the skirt wall, while during the underpressure penetration the soil replaced by the skirts moves into the skirt compartment. Andersen and Jostad (1999) report that, for the part of the skirt penetrated by underpressure, the shear strength at the outside interface between the skirts and the soil, after full setup has occurred, might be smaller than the initial shear strength. This is attributed to the smaller increase in total horizontal stress and arching caused by the compression of the remoulded clay along the skirt. The shear strength at the soil-skirt interface certainly influences the load-carrying capacity of skirted foundations and anchors. Strengthening the soil around the skirted foundations by electrokinetics (EK) is one of the possible solutions to overcoming these foundation problems.

When an electrical field is applied through saturated clayey soil, it induces consolidation and strengthening effects (Casagrande, 1949, 1983; Bjerrum et al., 1967; Lo et al., 1991). Previous investigations (Spangler and King, 1949; Soderman and Milligan, 1961; Butterfield and Johnston, 1980) have demonstrated that the load capacity of a metallic friction pile driven into clayey soil of low salinity (below 2 g NaCl/*l*) could be increased significantly by EK. Spangler and King (1949) applied an electrical potential to aluminium friction piles embedded in a clay and reported that, by making the piles anodic or cathodic for a period of time, their load capacity can be increased quite markedly. The effect was attributed to electrochemical "hardening" of the clay surrounding the pile. 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 over 40 years ago. It was reported that the shaft resistance increased from less than 300 kN to over 600 kN. Load tests were carried out on the same piles 33 years later, and the results demonstrated convincingly that the axial capacity of the piles remained unchanged (Milligan, 1994), and that the increase in the axial capacity of steel piles after electrokinetic treatment is permanent. The investigation of Butterfield and Johnston (1980) showed that the application of a voltage from 30 to 90 V across the electrode system at 1.5-m spacing increased the shaft load capacity of an anodic steel pile by a factor of about 2 and reduced that of a cathodic pile by as much as 5 times. There are limited data in the literature with respect to the effect of EK around foundation elements embedded in clays of high salinity such as seabed sediments. Shang and Dunlap (1996, 1998) studied the effects of high-voltage electrokinetic treatment via insulated electrodes on a marine sediment from the Texas Gulf Coast. The study demonstrated that the pullout resistance of embedded ground anchors

Received September 10, 2002; revised manuscript received by the editors April 9, 2003. The original version (prior to the final revised manuscript) was presented at the 12th International Offshore and Polar Engineering Conference (ISOPE-2002), Kyushu, Japan, May 26–31, 2002.
KEY WORDS: Electrokinetics, skirted foundations, soft marine clay, load-carrying capacity, soil improvement.