International Journal of Offshore and Polar Engineering (ISSN 1053-5381)
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Vol. 17, No. 1, March 2007, pp. 74–79

Effect of Electric Field Intensity on Electro-cementation of Caissons in Calcareous Sand

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Effects of the electric field intensity on electro-cementation of offshore calcareous sand are studied via large-scale model tests and electric field analyses. In the experiments, the model caissons were embedded in noncemented calcareous sand recovered from the Western Australia coast, and a DC intermittent electric field was applied via a central electrode placed inside the caisson. The development of cementation in soil during electrokinetic treatment was monitored through soil shear wave measurements. After 7 days of electrokinetic treatment, the pullout resistances of the caisson model embedded in calcareous sand increased up to 105%. Significant soil cementation was observed in the vicinity of soil-caisson interfaces, which was confirmed by electro-microscopic images. The results of the performed electric field analyses show that the formation of cementing constituents in soil is directly related to the intensity of the applied electric field.

INTRODUCTION

Calcareous soils are encountered in many offshore oil reserves and pose challenges to offshore foundations throughout the world, in Australia, India, Saudi Arabia and the Caribbean (Murff, 1987; King and Lodge, 1988). Calcareous soils typically consist of over 50% calcium carbonate, derived from skeletal remains of marine organisms. They are normally highly compressible and naturally cemented. The installation of offshore foundations generates disturbance to the soil, destroys the cementation bonds, and results in low skin friction between the soil and foundation elements.

Suction caissons have been used as anchors for floating platforms in many sites, including the North Sea, Brazil, Gulf of Mexico, Timor Sea, West Africa and west of the Shetlands (Ehlers et al., 2004). The suction caisson typically comprises a steel cylinder with a sealed top and open bottom. A major advantage of suction caissons is their high uplift capacity relative to their weight. Further, the suction caissons can be precisely installed at specific locations.

Electrokinetics has been successfully applied to the stabilization of slopes, excavations, embankments, and pile foundations (Casagrande, 1952; Wade, 1976; Milligan, 1994). Recently, Mohamedelhassan et al. (2005) used calcium chloride for the electrochemical stabilization of a model caisson embedded in calcareous sand. Six pairs of electrode poles were installed surrounding the caisson model. A DC voltage of 6 V was applied between the caisson and electrodes for 7 days. The pullout capacity was increased by 140% due to soil cementation generated by the applied voltage.

In offshore operations' deep water, the electrode configuration used in the Mohamedelhassan et al. study (2005) is difficult to implement because the electrodes must be installed close to but not in contact with the caisson. In order to improve the applicability of the electrokinetic treatment, a series of experiments was carried out in another electrode configuration, i.e., a central electrode placed inside the model caisson. This study investigates the effects of the electric field intensity on the electro-cementation in this configuration, and the results are analyzed and compared with the electric field distribution in the electrokinetic treatment.

THEORETICAL BACKGROUND

The electrokinetic process leads to the electro-cementation of soils containing carbonate compounds such as $FeCO_3$ and $CaCO_3$ (Mohamedelhassan et al., 2005; Rittirong et al., 2005). Ferric and ferrous compounds (e.g., $Fe(OH)_2$, FeOOH, and Fe_2O_3) can also serve as cementation agents (Cundy and Hopkinson, 2005; Mohamedelhassan et al., 2005). Some techniques have been used to enhance the treatment efficiency, such as current intermittence and polarity reversal (Gray and Somogyi, 1977).

The electric field analysis is an important step in the design of the electrokinetic stabilization. The distribution and intensity of the electric field in soil, generated by a direct current (DC) power supply through electrodes, are key parameters in the electrokinetic treatment. The electric field intensity vector, **E** (V/m), is defined as:

$$\mathbf{E} = -\nabla\phi \tag{1}$$

where ϕ is the electric potential (V). Under steady state conditions, the electric field distribution satisfies the following condition:

$$\nabla^2\phi = 0 \tag{2}$$

EXPERIMENTS

Offshore Calcareous Soil and Seawater

Noncemented calcareous sand and seawater recovered from the coastline some 100 km north of Perth, Western Australia, were

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Received July 14, 2006; revised manuscript received by the editors December 9, 2006. The original version (prior to the final revised manuscript) was presented at the 16th International Offshore and Polar Engineering Conference (ISOPE-2006), San Francisco, May 28–June 2, 2006.

KEY WORDS: Caissons, soil stabilization, calcareous soil, electrokinetics, offshore foundations, electro-cementation.