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Electrokinetic Cementation of Calcareous Sand for Offshore Foundations

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A large-scale experimental study was conducted on electrokinetic cementation of calcareous sand for offshore foundations. A steel tube, 200 mm in diameter and 400 mm in length, was used as a model caisson. Calcareous sand and seawater from the coastline of Western Australia were used in the study. The cementation treatment consisted of 2 phases: the treatment after caisson installation (phase A) and the remediation treatment after pullout failure (phase B). Twelve electrodes made of perforated steel pipes were installed around the caisson. A DC voltage of 6 volts with current intermittence and polarity reversal was applied with the caisson serving as 1 electrode and 6 of the 12 electrodes serving as the second electrode in phase A, and the other 6 electrodes and the caisson in phase B of the treatment. A control test with identical configurations was also set to provide baseline data. The results showed that the pullout resistance of the foundation model increased by 119% in phase A, and by 214% in phase B, as compared with the control.

INTRODUCTION

Calcareous sediments with more than 30% calcium carbonate cover approximately 34% of the Earth's surface (Sverdrup et al., 1942). Many oil reserves, such as those in Saudi Arabia, India, Australia and the Caribbean, are located under calcareous soils (Murff, 1987; King and Lodge, 1988). Calcareous soils in general are highly compressible and prone to crushing, compared to siliceous particles at similar stress levels.

Exploration of oil and gas fields in offshore sites around the world and expansion of recent projects of wind farms have resulted in the construction of many oil platforms and farm towers on calcareous soils of grain sizes ranging from sand to clay. Installation of traditional structural foundations in calcareous soils disturbs the soil in the close vicinity of the foundation and destroys any existing cementation between the soil particles, resulting in a low skin friction (Poulos, 1999). Dolwin et al. (1988) reported that the skin friction of piles installed in calcareous soil in the North-West Shelf of Australia decreased from 15 kPa to 5 kPa during the installation with no significant increase in the pile capacity after several months of installation. As a result, a US$250 million remediation project was undertaken (King and Lodge, 1988).

Electrokinetic treatment is a soil improvement technique that has been used over the last 5 decades mostly for fine-grained soils such as silts and clays (Casagrande, 1952). For example, electrokinetics has been successfully applied to improve the load capacity of foundations and increase the shear strength of soft clayey soils (e.g. Bjerrum et al., 1967; Lo et al., 1991), stabilize slopes and control pore water during excavation (e.g. Perry, 1963; Fetzer, 1967). The long-term effectiveness of electrokinetic treatment was reported by Milligan (1995), who performed pile load tests 30 years after electrokinetic treatment on piles installed in a soft varved clay and found that the load capacity of the piles remains the same. Shang et al. (2004) had successfully used electrokinetics assisted with calcium chloride ($CaCl_2$) to increase the shear strength properties of a calcareous silt in a bench-scale study. Recently, the authors have investigated the use of electrokinetics assisted with $CaCl_2$ to increase the pullout resistance of a model caisson embedded in a calcareous sand in a laboratory floor study (Mohamedelhassan et al., 2005; Mohamedelhassan et al., 2008). The pullout resistance of the caisson after the treatment increased by 140% to 304%, and significant cementation in the soil surrounding the model and electrodes was observed. Rittirong et al. (2007) further studied the effect of electric field intensity on electrocementation between the model caisson and the calcareous sand.

The goal of this study is to explore the use of electrokinetic treatment to increase the load capacity of a suction caisson as an example of a foundation system in a calcareous soil. Specifically, this paper focuses on improving the pullout resistance of a model caisson embedded in calcareous sand. The specific objectives of the study are:

- to determine the increase in the pullout resistance of the model caisson after electrokinetic treatment;
- to study the potential use of electrokinetic treatment to recover the pullout resistance of the caisson after failure;
- to study the relationship between the electric parameters and cementation effects; and
- to investigate the physical, chemical and mineralogical changes in the soil and water after the treatment.

The main considerations in the design of the experimental setup of the study were minimizing disturbance to the calcareous soil during the electrokinetic treatment, and focusing the treatment on the soil-caisson interface. The treatment was conducted in two phases: Phase A investigated the initial increase in the pullout resistance of the model caisson by electrokinetic treatment, and phase B investigated the effect of the treatment on the pullout capacity of the model after it had undergone pullout failure. In addition to simulating post-failure recovery, the soil condition at the beginning of phase B was similar to the condition after a driven pile or caisson installation in an offshore foundation

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KEY WORDS: Calcareous sand, electrokinetic treatment, offshore foundations, load capacity, soil improvement.