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Electrochemical Cementation of Calcareous Sand for Offshore Foundations

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A laboratory-floor experimental study was conducted on the electrochemical cementation of calcareous sand for offshore foundations. A caisson, 200 mm in diameter and 400 mm long, was embedded in a calcareous sand under seawater. The calcareous sand and seawater were recovered from the coast of Western Australia. Installed around the caisson were 12 electrodes, made of perforated steel pipes 14 mm in diameter and 450 mm long and filled with soluble $CaCl_2$ granules as a cementing agent. A *dc* voltage of 8 volts with current intermittence and polarity reversal was applied over a period of 7 days to transport the cementing agent into the pores of the calcareous sand. The results of the treatment were assessed by a pullout resistance test, after which the caisson was pushed back into the soil and the treatment repeated to simulate post-failure recovery. The results showed that the pullout resistance of the foundation model after the electrochemical treatment increased by 140% prior to failure and increased by 255% post-failure, as compared with that of the control test. The cementation generated by the electrochemical treatment was evidenced by the attachment of cemented soil to the electrodes and caisson. The cementation effects were further confirmed by the mineralogical, chemical and XRF analyses, which indicated formation of synthetic calcite, calcium iron chlorate and iron oxide, compounds known as cementation agents in soils.

INTRODUCTION

Calcareous ooze (sediment with more than 30% calcium carbonate) covers approximately 50% of the seafloor on Earth with predominance in tropical and subtropical regions (Sverdrup et al., 1942). Carbonate grains are more compressible and prone to crushing at a lower stress in comparison with siliceous particles.

The exploration of oil and gas fields in offshore sites has resulted in many platforms being erected on calcareous soils with grain sizes ranging from sand to clay. In recent years, many researchers have investigated the geotechnical properties of offshore calcareous soils (Liu et al., 1997; Mao et al., 1999, 2000; Carter et al., 2000; Coop and Airey, 2002; Ismail et al., 2002a). The installation of foundations for offshore structures in calcareous soils, in particular driven piles or caissons, can crush the grains and destroy cementation bonds existing between the soil particles in the close vicinity of the foundation. This may lead to zones of low shear strength around the foundation element and a low load-carrying capacity. The unique challenge surrounding the design of foundations in calcareous soils has been studied by many researchers (e.g. Coop and McAuley, 1993; Watson and Randolph, 1998a, 1998b; Poulos, 1999; Dyson and Randolph, 2001).

Artificial cementation is a common approach to improving the strength of soils, in particular low-plasticity sandy soils. The goal is to generate cementation between the soil particles by mixing the soil with cementing agent(s) or injecting the agent(s) into the soil pores (Aiban, 1994; Kucharski et al., 1996; Huang and Airey, 1998; Ismail et al., 2002a, b). For offshore foundation systems, the second approach has obvious advantages, and it was used in remedial treatment of the pile tips at the North Rankin A platform on the North-West Shelf of Australia (Kenter and Whitehead, 1988). For offshore caisson and pile foundations, the load-carrying capacity is dominated by the frictional resistance along the shaft, and so the stabilization process should focus on the soil-foundation interface.

The strengthening of soft marine clay with high pore fluid salinity by using electrokinetics has been well documented in recent years (e.g. Wrixon and Cooper, 1998; Lo et al., 2000). Micic et al. (2003) reported a significant improvement in the load-carrying capacity of an offshore foundation model in clayey soil by electrokinetics. Further, the parameters that influence the outcome of electrokinetic treatment of soft clayey soils have been identified, including the electric field intensity, current intermittence, polarity reversal, electrode material, soil type, pore fluid chemistry and treatment time (Shang, 2000; Shang and Mohamedelhassan, 2001; Mohamedelhassan and Shang, 2001, 2002).

Various researchers have investigated the use of electrokinetics to inject a chemical solution(s) or compound(s) into a soil mass (electrochemical treatment) to generate cementation (Srinivasaraghavan and Rajasekaran, 1994; Ozkan et al., 1999; Acar and Gale, 1997; Itsekson et al., 2002). Recently, Mohamedelhassan and Shang (2003) have reported successful use of electrokinetics to transport 2 cementing agents into an offshore calcareous soil with a pore fluid similar to seawater. The significant increases in the undrained shear strength, effective cohesion and axial load

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