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Centrifuge and Numerical Modelling of Horizontally Loaded Suction Piles

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ABSTRACT

A test programme was carried out in the small geotechnical centrifuge of the University of Delft to investigate the horizontal bearing capacity of suction piles in sand and clay. Thanks to the small size of the samples, the soil density could be accurately reproduced, so that slight differences in design could be made visible. The influence of several parameters was tested, such as the height/diameter ratio, the attachment point of the cable and loading angle. In some typical cases the failure mechanism was visualized in a 3-dimensional test. The test results were compared with the API standard and with 3-dimensional finite element calculations. It appeared that the optimum bearing capacity was achieved with the attachment point of the cable at 2/5 of the pile height. The API calculations yield rather conservative values for the horizontal loads. The finite element calculations appeared to be in good agreement with the measured tendencies of the test results. It is believed that a combination of numerical calculations and tests in a small centrifuge yields a powerful design tool.

INTRODUCTION

In recent years, suction piles have been increasingly applied in offshore engineering (Wang et al., 1978; Senpere et al., 1982). Suction piles are attractive because of the convenient method of installation. A pile with a diameter of 9 m and a height of 10 m can be installed in a few hours, by using a pump only. In a previous test programme (Allersma et al., 1997) the installation process was investigated by means of a centrifuge test. A linear relationship was found between the pressure and parameters such as height, diameter and wall thickness.

In this test programme the attention is focused on the static horizontal bearing capacity. In practice suction piles are used for several different loading conditions. The horizontal loading condition is significant when suction piles are used for the anchoring of floating offshore systems. Since prototype tests are very expensive and time-consuming, the investigation of the bearing capacity of real-scale devices under different circumstances is of limited practicality. In small-scale tests it is much easier to change parameters. The soil type can be varied, as can the dimensions of the suction pile and other process parameters. In a small-scale test, however, problems arise concerning the stress-dependent behaviour of soil. Further, the measured loads are so low that measurements are not accurate enough to visualize differences in design. These restrictions can be overcome by performing the tests in a geotechnical centrifuge, where the soil stresses over a similar depth are the same as in the prototype situation. At 150 times earth's gravity a suction pile with a height of 10 m and a diameter of 9 m can be simulated with a can 67 mm high and 60 mm in diameter. It is possible to measure loads and displacements during the tests. Centrifuge and model tests on suction piles are reported in the literature, e.g. by El-Gharbawy et al., 1998; Fuglsang et al., 1991; Renzi et al., 1991; and Helfrig et al., 1976. The focus of these tests, however, was mainly on the vertical bearing capacity, and the suction tests were performed on clay. Some information about horizontal bearing capacity was reported by Sparrevik (1998). However, the paper did not contain details about the influence of the most significant parameters.

At the University of Delft a test technique has been developed in the centrifuge in order to simulate the horizontal loading of the suction piles in sand and clay in a reproducible way. The aim of this study was to examine the influence of several parameters, such as attachment point, attachment angle, H/D-ratio and soil parameters, on the bearing capacity of suction piles in dry sand and clay. The test results are compared with the American Petroleum Institute (API, 1991) recommendations and the finite element program Plaxis. The used version of Plaxis is capable of performing real 3-dimensional calculations. This option allows a more realistic comparison of experimental tests with numerical calculations.

PRINCIPLE OF SUCTION PILE

A suction pile is a large-diameter steel cylinder closed at the top either by a dome formed section or by a flat stiffened plate. The pile is open at the bottom. Pump inlets and relief valves are installed at the top as well as the lug to connect the pile chain.

The pile, which can be launched from an installation vessel or from the aft deck of a supply boat, must be landed softly on the sea floor. The cylinder is lowered to the sea floor with open valves so that the enclosed air can escape rapidly.

Once the pile has penetrated the seafloor by its own weight, the relief valves are closed. To avoid piping when pumps are started, additional weights are usually needed in cohesionless soils like sands to penetrate the skirt into the soil sufficiently.

Pumping the trapped water out of the pile by means of pumps mounted on the top causes a pressure difference between the external hydrostatic water pressure and the water pressure inside the pile. The pressure difference generates the driving force for

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