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Prototype testing for the partial removal and re-penetration of the mooring dolphin platform with multi-bucket foundations

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ABSTRACT

The partial removal, adjusting, and re-penetrating tests were carried out on a mooring dolphin platform with three-bucket foundations after a seven-year service. When the bucket foundations were penetrated by internal and external pressure differential, the soil shear strength around the bucket skirt was different from that of the intact soil after installation. The side shear strength along the skirt may be increased with time due to the set-up effect. The shear strength factor α is an important time-varying factor to determine the skin friction of the foundation during installation and removal operations. The shear strength factors obtained by prototype records and theoretical methods in cohesive soils are compared, from total stress to effective stress methods. In addition, the prototype tests show that the foundations will be able to resist removal forces that are significantly larger than penetration forces due to the set-up effect after a long working time. The results show an 85% increase in the soil resistance after seven years for the three-bucket foundations with diameters of 6 m and penetration depths of 8.5 m. Meanwhile, the construction procedure and operation of the three-bucket foundations and the analysis of the extraction forces are also given for the partial removal. The test results support the successful removal by a reasonable overpressure without soil plug failure inside the buckets by controlling the pump discharge inside the buckets and reutilizing the structure with multi-bucket foundations after an initial service period of seven years.

1. Introduction

Bucket foundations are a promising cost-effective type of foundation for ocean engineering [1–6]. Among the costs of geotechnical investigation, material, fabrication and installation, the most significant savings are from installation due to self-installed technology. No complex installation equipment and expensive large crane barges are required. The installation time, which is normally within 24 h, is greatly shortened compared with the several days required for a conventional platform foundation. First, the bucket foundation partially penetrates the soils under its dead weight. Then, the differential pressure across the top of the foundation, between the hydrostatic water pressure outside of the bucket and the reduced water pressure inside the bucket, created by pumping out the water trapped inside the bucket chamber from the top of the bucket, in addition to the weight, can trigger further penetration of the foundation to the desired depth. Bucket foundations also have significant bearing capacity, high positioning accuracy, and mobility, which have been successfully applied as effective solutions for anchoring in deep water and have also been applied as the

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Fig. 1. MDP and other structures at Bohai Sea site.

foundations of jacket structures, jack-up rigs, mooring structure and offshore wind turbines [7–12]. Meanwhile, relocatable structures with bucket foundations can be reused at different sites, and the removal of the structure also provides a clean site after exploitation which accommodates environment-friendly concerns.

Two mooring dolphin platforms (MDP1 and MDP2) with multi-bucket foundations were installed in the JZ9-3 field of the Bohai Sea in 1999 [13,14]. They are located on two sides of the drilling & accommodation wellhead platform (DRPW) and storage loading platform (SLPW). As shown in Fig. 1, MDP1 and MDP2 are connected to the main platforms by the trestles. The mooring dolphin platforms have been in operation for many years, and the removal process of the three-bucket foundation platform had not undergone prototype testing until 2006. An illustration of the prototype test processing and the analysis of the removal forces observed in the test are provided in the paper. The results have certain implications on how to guide the construction procedure and further studies on removal forces. The prototype tests provide an enhancement of the bearing capacity due to an increase of side friction resistance on the bucket skirts during the seven years. In fact, self-weight penetration is similar to the installation of open-ended piles, with significant amounts of the soils replaced by the skirt wall moving outside the skirt wall. When underpressure is applied, the soils replaced by the skirts will mainly move into the skirt compartment. A thin zone of soils along the skirts will be remolded in both phase, and the shear strength along the skirts will be reduced to the remolded shear strength. There will be a set-up effect, with the shear strength increasing with time due to the dissipation of excess pore pressure after penetration, increased horizontal normal effective stress and thixotropy (gain in shear strength with time with no change in volume) [15].

The penetration resistance is made up of the side friction resistance along the skirt walls and the bearing resistance at the skirt tip. When the bucket foundations are penetrated by suction or underpressure, soil shear strength around the skirt is different from that of the intact soil after installation. The suction pressure inside the bucket foundations may induce seepage flows around and inside the buckets, which will result in a reduction of penetration resistance at the skirt tip and along the inner skirts. This characteristic in sandy soils with high permeability can more evidently promote the installation of bucket foundation than in clayey soils with low permeability. The lower permeability soils need more time and suction to set up seepage flows to lower the soil resistance during the penetration phase or larger water pressure inside the bucket foundations during the removal phase. The reduction in resistance by seepage should be considered in the calculation. As a contingency during installation or if the foundation will be removed after an operation, recovery can be achieved by pumping water into the confined compartment, thus creating an overpressure that will drive the foundation out of the ground [15–21]. The same equations used for the penetration analysis are employed for the removal analysis. The side shear along the skirt may be higher than during penetration due to "set-up" with time. The relative importance factor during the operation in clay is the shear strength factor α varying with time. Typical α values have been found to increase from installation to extraction after limited consolidation (a minimum of 10 days at prototype scale) [22,30]. This paper mainly concentrates on the shear strength factor α in penetration and removal analyses.

2. Site characteristics and testing procedures

The mooring dolphin platform consists of three-bucket foundations, a mooring dolphin, and a truss structure. As illustrated in Fig. 2, each bucket foundation is 6 m in outside diameter and 9 m in height. The distance between the center lines of the bucket foundations is 15 m. The diameter of the mooring dolphin is 1.5 m. The mooring dolphin platform is located at a mean water depth of 7.4 m in the Bohai Sea area of China. And the total weight of the platform structure is 2228 kN [13,14].

The seabed soils properties were determined by laboratory testing on undisturbed soil samples acquired from three geotechnical investigation drilling boreholes. The soil conditions at the sites were relatively uniform and composed of organic silt, silty clay and clay, which indicated a typical Bohai sea soil profile with a normal unit weight (the average of unit weight was 18.1 kN/m^3 for 0–5 m soil and 19.3 kN/m^3 for 5–15 m). The undrained shear strength profile increased nearly linearly in the depth (z) range of 0–10 m, which was expressed as $s_u = 7 + 1.49z$ (kPa). The liquid limit of the soils ranged from 22% to 47%, and the plasticity index was