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Controlled installation of spudcan foundations on loose sand overlying weak clay

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A B S T R A C T

Offshore jack-up rigs are often used for site exploration and oil well drilling. The footings of jack-up rigs are known as spudcan foundations. The risk of rapid uncontrolled penetration of spudcan in seabed ("punch-through") exposes jack-ups to significant risk during installation in strong over weak layered seabeds. An example for this is a thin loose sand layer overlying a weaker stratum of clay. To prevent spudcans from "punch-through", an in-situ measurement concept is suggested in this paper to control the installation process of spudcan foundations. First, three-dimensional finite element studies using a Coupled Eulerian–Lagrangian method are carried out to simulate the penetration process. The numerical results have been validated with existing analytical solutions and centrifuge model test data. Furthermore, parametric studies are carried out to quantify the influences of the sand thickness and shear strength of the clay on the bearing capacity of spudcans. Based on the numerical studies an idea for the development of an in-situ measurement concept is suggested to control the spudcan penetration process in-situ.

1. Introduction

Jack-up rigs are a type of mobile platforms which are disembarked on the seabed and used for site exploration as well as oil well drilling. Sometimes the soil conditions are difficult when a thin sand layer overlies a weaker clay stratum. The bearing capacity of the soil may be overestimated, and rapid

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uncontrolled penetration ("punch-through") can occur. This may lead to severe damages or even loss of the jack-up rig. Therefore, it is necessary to predict the bearing capacity of the spudcan footing accurately.

In Meyerhof [1,2] or Hanna and Meyerhof [3] an analytical method and design charts are introduced to predict the bearing capacity of a footing on sand overlying clay. Further investigations using centrifuge tests are presented in Craig and Chua [4], Teh et al. [5,6] and Lee [7]. Most of the centrifuge tests focused more on medium and dense sand, where dramatic punch-through can occur, than on loose sand. Through a serial of centrifuge tests Teh et al. [6] revealed that the ratio of upper sand layer thickness over spudcan diameter and the ratio of bearing resistance between the upper sand and underlying clay affect the development of the spudcan bearing resistance and the existing design methods fail to predict the spudcan q_{nom}-d profile in sand overlying clay. The original q_{nom}-d profile is simplified with three key characteristic bearing resistances [6]: q_0 (spudcan bearing resistance at $d = 0$), q_{peak} (peak spudcan bearing resistance) and q_{int} (spudcan bearing resistance at the sand–clay interface). Two new design frameworks for estimating the characteristic bearing resistances have been developed by Teh et al. [8] and Lee et al. [9]. Nowadays, the use of numerical methods may be a helpful tool to predict the bearing capacity of spudcan foundations [10–13]. First numerical calculations using a Coupled Eulerian–Lagrangian approach (CEL) to model spudcan penetration can be found in Tho et al. [14]. Tho et al. [15] investigated spudcan penetration into different soil profiles using the CEL method. Applications of the CEL method for the analysis of spudcan penetration into sand over clay were carried out by Qiu et al. [16] and Henke and Qiu [17], in which a hypoplastic constitutive model was used to describe the sand.

In the present paper the CEL method is used to simulate the spudcan penetration into uniform clay and sand or into layered soil with a sand layer overlying weaker clay layer respectively. The numerical results are validated in comparison with analytical solutions and centrifuge tests [4,5]. This is done to show that the numerical simulations are suited to capture the behavior of spudcan penetration into uniform or layered seabed.

2. Numerical model

A three-dimensional finite element model using the Coupled Eulerian–Lagrangian method is presented to investigate the installation process of spudcans. The usage of classic FE-codes often leads to contact problems and distortion of the mesh. To deal with these problems the finite element calculations are carried out using the Coupled Eulerian–Lagrangian method (CEL) implemented in the commercial program Abaqus [18]. For general geotechnical problems, a Lagrangian mesh is used to discretize structures, whereas an Eulerian mesh is used to discretize the subsoil. The interface between structure and subsoil can be represented using the boundary of the Lagrangian domain. The Eulerian mesh, which represents the soil that may experience large deformations, is able to overcome problems like mesh and element distortions in finite element simulations.

Several benchmark calculations in Qiu et al. [19] reveal that the CEL approach is well suited to solve numerical problems involving large deformations which cannot be solved satisfactorily using the classical finite element method.

2.1. Geometry and mesh

The soil is modeled as an Eulerian domain. 3D Eulerian elements with reduced integration (element typ: *EC3D8R*), which are the only available Eulerian elements in Abaqus, are used to discretize the soil. Thus, the axisymmetric boundary value problem must be simulated in a 3D model. Due to the symmetry, only one fourth of the whole model is considered in the three-dimensional analysis. Two numerical models are generated to investigate the penetration process of a spudcan into both uniform (see Fig. 1(a)) and stratified deposits (see Fig. 1(b)). The geometry of the spudcans, which are used in centrifuge tests from Craig and Chua [4] (Fig. 1(c)) and Teh et al. [5] (Fig. 1(d)), is shown in Fig. 1. In this paper, the spudcan is modeled as discrete rigid body. The penetration of a spudcan into the soil is simulated displacement controlled with a constant penetration velocity. The depth of penetration d is defined as zero after the cone completely penetrated into the soil (see Fig. 1(c) and (d)).