International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 20, No. 4, December 2010, pp. 313–320

http://www.isope.org/publications

Numerical Modeling of Suction Pile Installation in Caspian Sea Clay with Effective and Total Stress Analyses

Kazem Fakharian* and Amin Iraji
Department of Civil & Environmental Engineering, Amirkabir University of Technology
Tehran, Iran

This paper presents numerical modeling of a suction pile installation in clayey soils, such as those in the southern Caspian Sea area. An axisymmetric finite difference numerical model has been adopted to simulate the suction pile installation, using both total stress and effective stress analyses. The effective stress analysis has shown there is a substantial increase in effective stress adjacent to the inside soil wall due to pore pressure decrease during suction insertion, while a cylindrical core of about 2/3 of the suction pile diameter within the pile is experiencing higher pore pressures and hence lower effective stresses. The critical and required suction pressures with depth are presented for different aspect ratios. Finally, the results are used to obtain the inverse end bearing factor, N_c, for different pile aspect ratios in Caspian Sea soil conditions. It is indicated that N_c increases with suction pile embedment depth, whose rate decreases with the decrease in the pile's aspect ratio.

INTRODUCTION

Suction pile installation is among the challenging operations in offshore engineering. Three methods have been studied—including limit equilibrium analysis, physical modeling and numerical modeling—by different researchers for the installation process. Olson et al. (2003) carried out experiments on suction pile installation in clay on 17 small-scale models. Soil resistance to installation, pore pressure distribution and inside soil plug upheave during installation were investigated.

Maniar and Tassoulas (2003) developed a numerical model using the finite element method for suction pile installation. The Mohr-Coulomb model was used for the pile-soil interface, and a new mesh was generated for the gradual installation of the suction pile. Fakharian and Soltanmohammadlou (2005) presented a finite element method for suction pile installation in Caspian Sea clay. Behavior of the Mohr-Coulomb type was assumed for both soil and soil-pile surface. A total stress condition was assigned to clay throughout the step-by-step installation process, and at each step, the required suction was estimated.

Because of clay's low permeability, no apparent seepage is visualized during the suction application, as opposed to sand. However, due to suction pressure on the pile top inside plug, a pressure decrease is expected within the interior soil adjacent to the inside side wall of the pile, significantly affecting the response to penetration as a result of increase in frictional resistance. It is then essential to consider the pore pressure redistribution within the soil media during suction insertion.

The main objective of this paper is the suction pile installation's numerical modeling with the effective stress method. Laminaria FPSO (Floating Production Storage Offloading), launched in 1999 in the Timor Sea off Australia's Northern Territory, is selected for calibration of the numerical model, for which 9 suction piles were installed (Ebrich and Hefer, 2002).

The numerical model has been assembled on the basis of a finite difference scheme specifically developed for soil and soil-structure systems. The self-weight penetration and the required suction for insertion at different depths are predicted and compared with the field measurements. Both total stress and effective stress analyses are performed making use of the applicable shear strength and deformation parameters. Pore pressure variations and their effect on the installation process, in particular at the soil-pile interface and at the suction pile tip, are investigated. The required insertion suction for both total and effective stress conditions is calculated and compared with field measurements.

The analysis method is then used for the Caspian Sea soil conditions. The self-weight penetration depth, the required suction for installation, and the critical suction at different depths for 5 model piles with different aspect ratios are predicted and discussed.

In addition to the suction pile's installation requirements, the results are also used to calculate the so-called N_c-factor for pull-out capacity during service, which is in fact equivalent to the critical suction during installation. Laboratory and centrifuge tests have been conducted to determine the N_c-factor (e.g. Fuglsang and Steensen-Bach, 1991; Randolph and House, 2002). The N_c-factor is calculated for the 5 model piles of Caspian Sea soil conditions, and the results are compared with the available magnitudes reported in the literature.

NUMERICAL MODEL

The numerical model has been developed using FLAC-2D, a finite difference code. Elasto-perfectly plastic behavior with the Mohr-Coulomb failure criterion is assumed both for the soil material and soil-pile interface. The axisymmetric option is considered, as it is adequately applicable to the geometry, material and installation process of the cylindrical suction pile. Adequate estimates of frictional resistance at the suction pile's wall surface and soil inside and outside the suction pile, during self-weight and suction penetrations, play an important role in the suction pile's installation design. In fine-grained soils such as clay, it is possible to assume either total stress or effective stress conditions during self-weight and suction insertions, and it would be interesting

---

*ISOPE Member.
Received January 23, 2008; revised manuscript received by the editors August 25, 2010. The original version was submitted directly to the Journal.
KEY WORDS: Suction pile, finite difference method, nonlinear numerical analysis, effective stress, installation, clay, inverse end bearing factor.