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Estimation of Soil Heave Inside a Suction Pile

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The ratio of soil volume driven into a suction pile to total soil displaced by the pile (soil heave ratio) has a direct impact on the external skin resistance and pile length. Recent observations have indicated that the common assumptions of this ratio for self-weight and under-suction installations (50% and 100%, respectively) may overestimate the soil heave inside the pile. In this paper, an equivalent finite element model was used to simulate the fine-grained, normally consolidated sediment behavior adjacent to the pile tip. Afterward a method was proposed to estimate the soil heave ratio considering tip geometry effects. Finally, the method was validated by a field case and other studies.

INTRODUCTION

A suction pile (also called "suction anchor" or "suction caisson"), which is among the most frequently used offshore foundation systems, is an open-ended and closed-top pipe pile. It is partially installed by its own weight followed by insertion to the final depth by applying suction inside the pile. The use of internal and external stiffeners allows the application of relatively high ratios of diameter to wall thickness (d/t) compared with ordinary driven pipe piles (Randolph, 2003).

During installation, a certain amount of soil is displaced by the pile wall. Despite the high diameter-to-wall-thickness ratio (d/t) of suction piles, the amount of displaced soil can be considerable because of the large dimensions of these piles. Hereafter, the ratio of soil volume driven into the pile to the total volume of the displaced soil is called the SHR (soil heave ratio). Andersen and Jostad (2002) indicate that the amount of soil pushed outward from a pipe pile would increase the external skin friction. This alone shows the importance of a correct SHR estimation, as the external wall capacity is approximately 40%–50% of the total transient capacity for a pile with an aspect ratio of approximately 5, and this ratio is even higher when the reversed end-bearing mechanism is not activated and the pullout capacity rules the failure load (Clukey et al., 2004). In addition, as a portion of the displaced soil is pushed inside the pile, the final lengths of the suction piles are always longer than the desired embedment depth imposed by pullout capacity requirements. Therefore, any probable source that can lead to a higher SHR than predicted should be addressed carefully to avoid pile installation failure at the site.

Multiple numerical and experimental research studies have been carried out to investigate SHR during installation. Andersen and Jostad (2002) suggested an SHR equal to 50% during self-weight installation and 100% during installation by suction. However, several field measurements (e.g., Newlin, 2003; Audibert et al., 2003; Lee et al., 2005) showed that in most cases that assumption of SHR may overestimate the soil heave inside the pile. For example, based on real-case monitoring in the Horn Mountain project, Audibert et al. (2003) observed that, in tapered piles, SHR values equal to 30% and 50% in self-weight and under-suction installations, respectively, were in better agreement with measured data from the site.

To achieve a clearer state of understanding, Chen (2005) investigated soil plug behavior through physical modeling. The centrifugal model pile was installed by jacking up to a depth of $2d$ and by applying suction from $2.0d$ to $4.0d$ (d is pile diameter). For complete installation, the reported average SHR was less than 55%.

The main objective of this paper is to develop a method for estimating more realistic values of SHR in fine-grained, normally consolidated sediments. It should be highlighted that the purpose of the current study is not to model the pile installation procedure but just to monitor the response of soil around the pile tip during installation. Andersen and Jostad (2002) indicated that the tip of a cylindrical pile with a high d/t ratio would resemble a buried strip footing. In this study, the response of the equivalent buried strip foundation with unequal surcharge loads inside and outside the pile was investigated by means of the finite element method (FEM).

As shown later, the benefits of this simplification made it possible to propose a new SHR estimation method taking the effects of various pile-tip geometries on SHR into account.

NUMERICAL MODELING AND THE PROPOSED DESIGN METHOD

Figure 1 shows a numerical model developed to calculate a pipe-pile installation force (Mohammadlou, 2004). During self-weight insertion, the downward internal skin friction load on the soil plug causes an increase in total vertical stresses within the soil plug compared with the surrounding soil (Fig. 1a). On the other hand, the reverse effect of the applied suction during installation by suction decreases the total vertical stresses within the soil plug (Fig. 1b). Thus, considering the unequal pressures inside (P_{in}) and outside (P_{out}) the pile, the portion of the displaced soil that

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