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Comparative analysis of seepage field characteristics in bucket foundation with and without compartments

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A R T I C L E I N F O

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A B S T R A C T

By taking the importance of seepage parameters into account during the suction process, a comparison analysis of seepage field between bucket foundations with (C-BF) and without multiple subdivisions inside (N-BF) is performed in this paper, with the consideration of tilt adjustment as well as the complexity in underwater soil. Scaled model experiments were conducted at first to acquire the excess pore water pressure μ_e, and then the law of three-dimensional heat conduction was used to simulate the seepage field and the parameters of the two models. The results of simulations were compared with those of the model experiment, and it is shown that the computational results agree well with those of experiments; N-BF is more sensitive to the tilting of the bucket body than C-BF; the layered soil can protect the seepage filled with limited hydraulic gradient and seepage flux; basically the seepage field variations with the same internal structure under different working conditions have their own regularities.

1. Introduction

Along with the rapid development of wind industry in recent years, the yield advantage of offshore wind turbines has been a positive factor for constant exploration in this field. Combined with the offshore installations, the demand on transportation and installation techniques has also increased. Bucket foundation has been increasingly used as an effective alternative to provide fixed anchorage in deep water and as foundation for jacket structures, offshore wind turbines and jack-up rigs over the past three decades (Kim et al., 2014; Li et al., 2015; Liu et al., 2015; Senders, 2008; Wang et al., 2017; Y. Zhang et al., 2016). A single bucket foundation without compartment inside (N-BF) is a large cylinder-structure, which is typically made of steel, open at the bottom and closed on the top. Compared with N-BF, the bucket foundation with compartment inside (C-BF) is different, i.e., the bucket wall has a seven-room structure, and these subdivisions divided by steel bulkhead are arranged in a honeycomb structure that can be adjusted individually. Therefore, C-BF can be actually regarded as a multi-bucket foundation which is capable of maintaining the floatation stability to a certain extent under slight disturbances. Moreover, each compartment can control the levelness of bucket foundation during the suction installation, since water can be drained therefrom independently to apply a negative pressure and achieve a sinking depth further (Ding et al., 2013, 2015; Lian et al., 2012, 2014; Zhang et al., 2013, 2015).

In general, the installation of bucket foundations can be divided into two main phases: in the first stage, skirt is partially embedded under the self-weight of the caisson and structure; when the mobilized soil resistance along the caisson wall becomes equal to the submerged weight of the caisson, the second stage begins by reducing the inside water pressure through pumping the water out from the caisson top, thus forces the skirts onto the seafloor. In the clay, the net downward force caused by the pressure difference between the inside and outside of the caisson drives the caisson onto the ground. As a result, there is a relatively high water head outside the bucket foundation, which can drive the water to flow towards the foundation. Then, a seepage field due to this water flow is formed on the sea floor sediments both outside and inside the bucket. A number of studies on the seepage field formation and seepage failures in N-BF were conducted, and it can be concluded that this seepage field may cause certain effects on the suction penetration of bucket foundation (Harireche and Alani, 2014; Feld, 2001; Koteras et al., 2016; Sender, 2008; P. Zhang et al., 2016). Moreover, the calculation procedure used in the analysis for the suction installation in clay was described by Houlsby and Byrne (2005), and the procedure were presented for three parts including the magnitude

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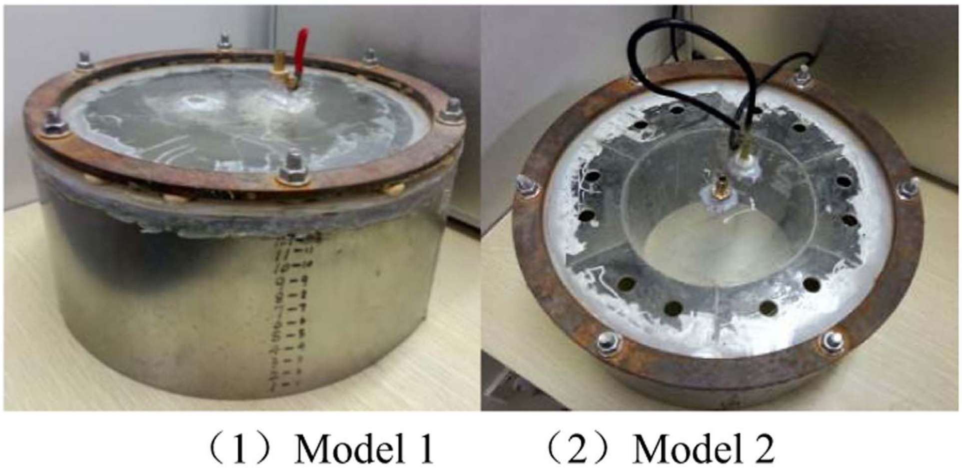

Fig. 1. Laboratory test models.

of the self-weight penetration, the relationship between suction and further penetration, and the limits to penetration that can be achieved by suction. The calculation methods for the penetration resistance and required suction were studied to obtain the experimental formulas, and it was suggested that the overall behavior and the pressure variation with depth were similar for caissons of different sizes and wall thicknesses (Tran and Randolph, 2008). Besides, Tran et al. (2005) indicate that seepage field may increase the effective stress between the surrounding sediment and the bucket wall may hinder the penetration, thus experimental model tests were also conducted. Many researches focused on different soil conditions such as the height differences of soil plug inside the bucket wall in three soil types or the layered soil effect on penetration resistance (Chatzivasileiou, 2014; Romp, 2013; Tran, 2005; Tran et al., 2007; Watson et al., 2006). However, the aforementioned studies mainly focused on N-BF, and few were related with C-BF. Therefore, it is important to perform a comparison analysis of seepage field during the penetration process.

Actually in practice, out-of-verticality (tilt) and misorientation of the foundations is vitally important in the reliability analyses especially for these wide shallow bucket foundations. In addition, the soils in the present and potential sites for offshore wind farms in China are mainly soft clay (or silty clay) and fine sand (or sandy silt), which prominent the value of an elaborate analysis of this two conditions. Given that, in this paper, the out-of-vertical state and layered soil conditions for seepage field of both N-BF and C-BF are studied. The rest is organized as follows: scale model experiments are described in Section 2; numerical simulations are performed in Section 3 to verify the reliability of the proposed method; Section 4 discusses the numerical methods under different working conditions; the conclusions are summarized in Section 5.

2. Experiment

2.1. Experimental models and equipment

To investigate the bucket foundation seepage field characteristic in sand and the impact due to the steel bulkheads arranged inside the bucket foundation, the two forms of bucket foundation adopted in the experiments distinguished from each other in their internal structures, i.e., with or without subdivision. These reduced (1:100) models were based on the prototype of large-scale wide-shallow bucket foundation in Qidong sea area, Jiangsu province, which had a diameter of 30 m and a relatively small bucket wall height of 7 m. However, the final test model had a diameter of 30 cm, a height of 12 cm, and the thickness of skirt-board and bulkhead are 2 mm and 1 mm, respectively. Since the main purpose of the experiment is to observe the suction penetration

Table 1
Model parameters.

Model	Diameter (cm)	Mid-compartment diameter (cm)	Bucket wall thickness (mm)	Bulkhead thickness (mm)	Top cover thickness (mm)	Height (cm)
Model 1	30		2		10	12
Model 2	30	15	2	2	10	12