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EXTENDED ABSTRACT

Experimental Investigation on the Behavior of Bucket Foundations Rested on Liquefiable Soils

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1. Introduction

Wind turbines are installed in windy coastal and offshore regions to extract the wind energy with high efficiency (Barari et al. 2017). The construction cost of the foundation of offshore wind turbines is about 30% of the cost of all superstructure and foundations. Therefore, the economic design of the foundation is critically important and many researchers have focused on it. Offshore wind turbines are usually constructed on gravity-based or monopiles. Bucket foundations or skirted foundations are widely used in offshore regions, oil and gas industries. The use of bucket foundations has been increased in offshore regions especially for foundations of wind turbines over the past two decades (Byrne and Houlsby 2004; Eid, 2013). The behavior of tripod and pile foundations in liquefied soils was investigated. But there are limited reports and studies on the behavior of bucket foundation in liquefied soils (Yu et al., 2015). Conducted some centrifuge tests on wind turbine models with suction caisson foundations to study the behavior of bucket foundations in liquefied soils. It was found that increasing the foundation diameter and length of the skirt had the highest impact on the reduction of pore pressure. Moreover, an increase in the skirt length had the highest impact on the reduction of settlement.

The upward seepage can create the soil conditions during the earthquake and liquefaction. In this study, several 1g physical modeling were carried out on shallow and bucket foundations at various levels of excess pore-water pressure. The experiments were designed to evaluate the bearing capacity changes and settlement of shallow and bucket foundations in liquefiable soil. The excess pore-water pressure within the underlying soil was produced through the upward seepage. It can be considered as representative of the pore pressure during the earthquake or static upward seepage.

2. Methodology

2.1. Experimental study

A collection of laboratory apparatus including the testing container, the loading system and the data collection unit in Soil Laboratory of Semnan University were used for physical modeling the behavior of bucket foundation in liquefied graded soils. The schematic view of the experimental setup is shown in Fig. 2. The testing container was employed as a rigid box with dimensions of 120 cm (length), 90cm (height), and 90cm (width). Furthermore, a transparent plexiglass sheet was installed in one side of the testing container to see the soil behavior during the loading.

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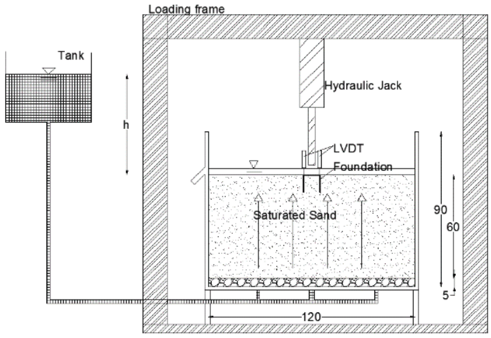

Fig. 1. Schematic view of the experimental setup and upward seepage

Another system was also installed beneath the container to produce the excess pore pressure in the soil mass. This system consisted of the input and output water flow pipes in the testing container, and the water pressure increased by pumping water into the container, and subsequently the pore pressure and upward seepage increased the excess pore pressure ratio (r_u). The test was performed in different levels of the excess pore pressure (r_u) in order to evaluate the impact of pore pressure on the excess settlement of foundation and bearing capacity changes of foundation. Due to the upward water pressure beneath the soil mass, the soil might be scoured and the pressure distribution might not be uniform; hence, a layer of gravel with a thickness of at least 5cm was placed at the bottom of the container and its surface was covered by a reticular rubber with pores for water penetration in order to avoid the scouring phenomenon. The gravel layer and the reticular net above could cross the water, avoid the soil scouring and unify the pore pressure distribution.

The use of upward seepage for representation of earthquake-induced excess pore pressure was employed by previous researchers. For instance, Calvetti et al., (2004) carried out a number of investigations into the post-liquefaction performance of buried pipes in the soil and the pore pressure produced by the controlled upward seepage. In this study, the bearing capacity of shallow and bucket foundations is evaluated in two soil conditions including the saturated soil and complete liquefaction with excess pore-water pressure ratios of 0 and 1. The excess pore water pressure ratio is defined by Equation (1).

$$r_u = \frac{\Delta u}{\sigma'_{v0}} \tag{1}$$

Where, r_u is the excess pore pressure ratio; Δu is the excess pore pressure, and σ'_{v0} is the initial vertical effective stress of soil in the free field.

3. Results and discussion

A relationship was provided as the depth factor by researchers (Barari et al., 2017; Byrne and Houlsby, 1999) in order to estimate the bearing capacity of the bucket foundation. Based on this relationship, the bearing capacity of the foundation is a function of the embedment ratio (d/D) and the capacity of the surface foundation with the same diameter. Equation (2) shows the general form of the formula.

$$\frac{V_{Bucket}}{V_{Surface}} = 1 + n\frac{d}{D} \tag{2}$$

Where, V_{Bucket} is the vertical bearing capacity of the bucket foundation; $V_{Surface}$ is the bearing capacity of the surface foundation, and n is the fitting parameter. Fig 2. Shows the bearing ratio of the bucket to surface foundations in terms of the embedment ratio (d/D). Based on the results of this study, the Equation (2) can be provided for both saturated soil (r_u=0) and the saturated soil with the upward seepage (r_u=1) as Equation (3):

$$\frac{V_{Bucket}}{V_{Surface}} = 1 + 4.32\frac{d}{D} \qquad , r_u = 0$$

$$\frac{V_{Bucket}}{V_{Surface}} = 1 + 5.99\frac{d}{D} \qquad , r_u = 1 \tag{3}$$

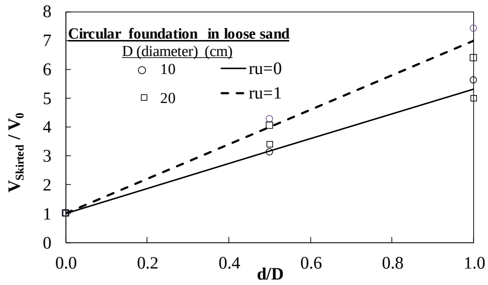

Fig. 2. Bearing capacity factor as a function of embedment ratio

Comparing the curves of Fig. 2. it can be seen that Due to the skirts around the bucket foundation increase the soil strength within the foundation by increasing the confinement pressure, and thus less settlement occurs and the bearing capacity of the bucket foundation will be higher than the shallow foundations.

4. Conclusions

Bucket foundations are the suitable alternatives for foundations of the offshore wind turbines with better performance and bearing capacity against external loads. One of the important advantages of the bucket foundation is its simple installation compared to the pile foundations. The widespread application of such foundations in seismic regions has increased the importance of attention to the performance of such foundations in the liquefied soils. Seismic excitement decreases the soil stiffness and bearing capacity by providing the pore-water pressure .

The present study evaluated the behavior of shallow and bucket foundations in liquefied soils. Results of the present study indicated that the buildup pore-water pressure significantly reduced the bearing capacity of foundations; however, the foundations had the bearing capacity even in the complete soil liquefaction. The bearing capacity of the bucket foundation had a reduction of less than the shallow foundation due to the existence of skirts around the foundation. Equation (3) was presented based on the results of the present study to estimate the bearing capacity of bucket foundations in terms of the shallow foundation bearing and the embedment ratio (d/D). This equation indicated that the bucket foundation had a better performance in liquefied soils compared to the shallow foundations. In other words, the bucket foundation had a higher bearing capacity and better performance in liquefied soils than the shallow foundation due to its internal failure mechanisms and soil confinement around and inside the foundation.

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