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Deep Penetration of Rectangular Spudcan into Single-Layer Clay

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Rectangular foundations are employed as an emerging solution to support jack-up platforms, where the impact of changes in foundation shape and size compared to traditional circular foundations needs to be explicitly considered. However, few recent studies have addressed this topic. Therefore, this paper reports the deep penetration behavior of rectangular foundations in kaolin and silty clays based on centrifuge experiments and particle image velocimetry (PIV) techniques. The flow back of the soil is found to be complicated by the nonaxisymmetric characteristic of the rectangular spudcan. Sensitivity is the most critical factor affecting the flow state and bearing capacity response of different clays, and some discrepancies exist between the experimental bearing capacity results and the predicted values of the classical methods.

INTRODUCTION

Jack-up platforms are widely used for offshore operations in water depths of approximately 120 m to provide various services such as drilling and exploration, etc. Typically, these platforms contain three vertically retractable independent legs, each with a spudcan attached below. The spudcan is ballasted to a certain depth by static vertical preload, and the reaction force provided by the soil supports the entire platform to meet the operational requirements and ensure that the platform is stable enough during possible storm loads (Young et al., 1984). Offshore soil is usually stratified and may be interbedded with clay or sand layers, or the shear strength of the clay variates strongly. This paper is confined to relatively uniform clays where the shear strength increases linearly with depth, expressed as

$$s_u = s_u m + kz \tag{1}$$

where s_{um} and k are undrained shear strength at the mudline and the gradient of increase in s_u along with depth, and z is the depth below the soil surface.

Therefore, it is extremely critical to accurately predict the penetration bearing capacity of the spudcan foundation so that it can be seated in the intended position. However, the bearing capacity problem of foundations is extremely complex and is affected by various factors, such as soil strength characteristics, soil flow during penetration, foundation shape, etc. Skempton (1951) modified the bearing capacity factor of the strip foundation on the soil surface by a semi-empirical method to predict the bearing capacity of different shapes of spudcans at different locations, and this method is used in offshore design guidelines to this day (ISO, 2016; SNAME, 2008). Various methods have subsequently emerged, with differences intended to cover different application ranges reflected in the bearing capacity factor N_c, representative s_u, etc. For instance, Martin and Randolph (2001) proposed the N_c factor for flat-bottomed skirted foundations based on the upper and lower bound analysis. Wang and Carter (2002) proposed the value of the bearing capacity factor N_c applicable to homogeneous clays based on two-dimensional conditions.

With the development of centrifuge technology and large deformation finite element methods, more details of the penetration process of spudcans have been discovered and reported. Hossain, Hu, and Randolph (2004), Hossain, Mehryar, et al. (2004), and Hossain et al. (2005) reported that the surface soil is the first to heave after the circular foundation penetrates the clay; the soil then flows back to the top surface of the spudcan and forms a stable open cavity resembling an inverted cone; the depth of the cavity does not change after the beginning of the flow back. Based on the experimental and numerical results, Hossain et al. (2006) and Hossain and Randolph (2009a) proposed an equation to predict the cavity depth and an N_c value that considers the effect of the complicated changes of the soil strength during the penetration process. However, the above studies and existing standards are based on axisymmetric conditions and applied to fully circular foundations.

The application of rectangular foundations as shallow foundations on the soil surface has been much studied. Gourvenec et al. (2006) investigated the ultimate bearing capacity of rectangular foundations on the clay surface with homogeneous strength by finite element analysis. Osman (2019) performed a limit analysis on smooth rectangular foundations and obtained a strict upper limit solution for the bearing capacity of the foundation on the noncohesive soil surface. Gupta et al. (2017) established the ultimate bearing capacity equation for a rectangular foundation on the layered soil.

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KEY WORDS: Rectangular spudcan, centrifuge experiment, PIV, clay, bearing capacity, sensitivity.