Effect of a Thin Strong Middle Layer on Spudcan Penetration into Three-layer Uniform Soils
by LDFE Analysis

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ABSTRACT

Jack-up rigs are a popular offshore structure in medium water depth due to its mobility. Spudcan foundations are commonly used to support each individual jack-up leg. When multi-layered soils are encountered, foundation bearing capacity needs to be predicted by considering the layered soil profiles. In this study, large deformation finite element (LDFE) analyses have been conducted to simulate spudcan continuous penetration into three-layer soils. The Large Deformation FE (LDFE) analysis was carried out using Remeshing and Interpolating Technique with Small Strain (RITSS) model. The LDFE/RITSS results were compared with existing centrifuge test data and numerical results. The effect of a thin strong soil layer sandwiched between two soft uniform clay layers on spudcan penetration responses was studied. The thin strong layer can be either a stiff clay layer or a sand layer. The soil flow mechanisms at various penetration depths are also discussed. It was found that, with a thin relatively strong layer lying in the middle of two soft uniform clay layers, a squeezing mechanism was observed in the top layer, which resulted in a deeper cavity than that in a single uniform clay layer. With increasing top layer thickness, the bearing capacity of the spudcan was increased. At the same time, the potential of punch-through failure was increased as well.

KEY WORDS: Punch-through failure; three-layer soil; spudcan foundation; LDFE.

NOMENCLATURE

\[ d \] penetration depth of spudcan foundation
\[ D \] diameter of spudcan foundation at its largest section
\[ H_t \] thickness of top soft soil layer
\[ H_{mc} \] thickness of middle stiff clay layer
\[ H_{ms} \] thickness of middle sand layer
\[ s_{ut} \] undrained shear strength of top layer soil
\[ s_{um} \] undrained shear strength of middle clay layer
\[ s_{ub} \] undrained shear strength of bottom layer soil

\[ \gamma_c' \] effective unit weight of clay
\[ \gamma_s' \] effective unit weight of sand

INTRODUCTION

Most offshore drilling in moderate water depths throughout the world is performed from independent Jack-up rigs. However the increased number of mobile jack-up rigs operating has led to increasing unpredicted incidents throughout the last decade. Two recent examples are the failures of Noble David Tinsley in May 2009 with severe damage to the legs and rig, and the incident of Sapphire Driller in October 2009 during preloading test. The failure at the foundation level can cause damages to the offshore structure that the foundation supports. It also results in lost drilling time and sometimes loss of lives. Since spudcan foundation can penetrate into soil by up to two times of its diameter in certain soil conditions, spudcan large penetration responses under different layered soil conditions need to be predicted accurately.

Over the last decade, research on spudcan penetration response has been concentrated on soil layers comprising a strong soil layer overlaying a soft soil layer, where the foundation may experience punch-through failure (Teh et al. 2005; Lee K. K. 2009; Yu, et al. 2009; Yu, et al. 2010a; Yu, et al. 2010b). However highly layered soil are prevalent (Kostelnik, et al. 2007) and when soils consist of more than two layers the penetration responses of spudcan foundations can be more difficult to predict. The behavior of spudcan penetrated into sand-clay-sand was investigated by Kellezi and co-workers (Kellezi, et al. 2005; Kellezi, et al. 2008; Kellezi and Stromann 2003), using large deformation FE methods provided by ABAQUS Standard (Hibbitt and Sorensen 2000b) and Explicit (Hibbitt and Sorensen 2000a) and ELFEN FEM programs. Hossain and Randolph (2011) also reported centrifuge modeling of spudcan foundations penetrating through multi-layered soil with interbedded strong layers, showing that patterns of punch-through failure and squeezing on multi-layered soils were identified.