ABSTRACT

The paper reports results of finite element analyses undertaken to provide insight into spudcan foundation behaviour during undrained vertical penetration through a thin stronger clay layer into weaker material, varying the thickness of the upper crust layer relative to the spudcan diameter between 0.17 and 0.5, the strength ratio between 0.2 and 0.6 and the normalised strength gradient of the lower layer between 0 and 1. The analysis was carried out using a large deformation finite element (LDFE) approach, modifying the simple elastic-perfectly plastic Tresca soil model to allow strain softening, and incorporate strain rate dependency of the shear strength. Attention was focused on relatively thin layers, extending previous work that has looked at thicker layers. Discussion focuses chiefly on the effect of (thin) crust thickness ratio, strength ratio and strength non-homogeneity on the soil deformation mechanisms and the form of the penetration resistance profile, with emphasis on the likelihood and severity of punch-through failure. The potential for punch-through was demonstrated by a local maximum in penetration resistance followed by some reduction. The degree of bearing capacity reduction with penetration, that is the severity of punch-through, increased with increasing crust layer thickness and decreasing strength ratio between lower and upper soil layer, but decreased with increasing strength gradient of the lower layer. The LDFE results were shown to be consistent with results from centrifuge tests. While the recently developed mechanism based design approaches provided excellent prediction, the approaches suggested in offshore design guidelines was shown to underestimate the penetration resistance significantly and give poor estimate of the likelihood and severity of spudcan punch-through.

KEY WORDS: Spudcan foundations; layered clays; punch-through; large deformation FE analyses; strain softening; soil flow mechanisms; bearing capacity.

NOMENCLATURE

$q_{\text{net}}$ net bearing pressure
$s_{\text{bli}}$ intact undrained shear strength of bottom layer soil
$s_{\text{blhi}}$ bottom layer intact strength intercept at the layer boundary
$s_{\text{uti}}$ intact undrained shear strength of top layer soil
$t$ thickness of top layer
$z$ depth below the soil surface
$\gamma^\prime_b$ effective unit weight of bottom layer soil
$\gamma^\prime_t$ effective unit weight of top layer soil

INTRODUCTION

Installing and preloading an independent three leg jack-up rig in stratified deposits, where a strong layer overlays weaker soil, remains a challenge for the offshore industry, with the potential for severe ‘punch-through’ failure under the load-controlled conditions. Uncontrolled rapid leg penetration may lead to buckling of the leg, effectively decommissioning the platform, or may even result in toppling of the unit.

Fig. 1 Noble David Tinsley and Sapphire Driller after the respective punch-through failure

The punch-through of jack-up units is regrettably still prevalent (Aust, 1997; MSL, 2004; Jack et al., 2007). Two recent examples are the failure of the Noble David Tinsley off the coast of Qatar in May and of the Sapphire Driller off the coast of Ivory Coast in October 2009 (see Fig. 1). The more frequent use of jack-ups in geological conditions where a clay crust is underlain by a soft clay layer, such as on the Sunda Shelf in Southeast Asia (Castleberry II and Prebaharan, 1985;