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Spudcan Foundations on Multi-Layered Soils with Interbedded Sand and Stiff Clay Layers

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The spudcan foundations for mobile drilling rigs continue to exhibit a high failure rate in the offshore oil and gas industry. Contributing to this is the more frequent use of larger jackups in regions with highly stratified seabeds and continual exploration in deeper and untested environments. This paper reports centrifuge modelling of spudcan foundations penetrating through multi-layered soils with interbedded stronger layers. The soil conditions tested simulate offshore strength profiles that have reported punch-through failures. The effect of soil type (hence drainage conditions) in the critical strong layer on the likelihood of punch-through is discussed. The experimental results show that the failure was less severe for a carbonate sand layer sandwiched by soft clay layers compared to that for a silica sand layer, in spite of the higher critical state friction angle of the carbonate sand.

NOMENCLATURE

A = spudcan plan area at largest section
d = penetration depth of spudcan base
D = foundation diameter at largest section
I_D = relative density of sand
q_u = ultimate bearing pressure
s_u = undrained shear strength of clay
t = thickness of a layer
z = depth below the soil surface (mudline)
ϕ'_{crit} = critical state friction angle
ϕ'_p = peak friction angle

INTRODUCTION

Progression of Drilling Rigs

Most offshore drilling in shallow to moderate water depths throughout the world is performed from independent 3-leg jackup rigs with proven flexibility, mobility and cost-effectiveness. Depletion of known reserves in the traditional regions and in shallow waters is resulting in exploration in deeper, unexplored and undeveloped environments with more complex seabed soil conditions. In emerging provinces and fields, highly layered soils are prevalent (Fig. 1). Over 75% of the case study data sets forming the basis for the InSafeJIP (Osborne et al., 2009) involve stratified seabed profiles, with interbedded layers of clay and sand evincing strong variations in shear strength. The Sunda Shelf, offshore Malaysia, Australia's Bass Strait and North-West Shelf, offshore India and the Arabian Gulf are particularly problematic in terms of stratigraphy and soil types. The seabed sediments offshore Australia and the Arabian Gulf comprise layered carbonate sediments that range from relatively permeable calcareous sands to fine-grained muds, and with varying degrees of intergranular cementation; an example is shown in Fig. 1a (Erbrich, 2005; Watson and Humpheson, 2005). Layered soil profiles result from various geological processes, including previous crustal desiccation, sand channelling and evolving depositional environments associated with changing sea level (Castleberry II and Prebaharan, 1985; Paisley and Chan, 2006).

Increasing Punch-Through Incidents

Installing and preloading a mobile offshore drilling (jackup) rig in stratified deposits, where an interbedded strong layer overlays a weak layer (Fig. 1), remains a challenge for the offshore industry, with the potential for severe punchthrough 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 (Aust, 1997; Maung and Ahmad, 2000; Brennan et al., 2006; Kostelnik et al., 2007; Chan et al., 2008).

The number of mobile jackup rigs operating has increased considerably over the last decade as their use has gradually extended into deeper water (now approaching 150 m). There has also been a significant increase in the number of rig moves per year due to reduced time spent at each location (Osborne and Paisley, 2002; www.rigzone.com). In turn, this has led to an increasing frequency of unpredicted penetration incidents (MSL, 2004; Jack et al., 2007), partly resulting from economic pressures that restrict the quality of site investigation data from which to assess spudcan performance. Although the potential hazard of strong crustal features is well documented (SNAME, 2008), jackup rigs frequently undergo punch-through failure around the world. Two recent examples are the failures of the *Noble David Tinsley*, with reported severe damage to the jackup and its 3 legs, in May 2009 off the coast of Qatar; and the *Sapphire Driller*, with reported minor damage to the bracings of 1 leg, in October 2009 off Ivory Coast (see Fig. 2). Punch-through events result in both rig damage and lost drilling time, and sometimes loss of lives. Even temporary loss of serviceability of a rig has major financial implications, considering that a modern jack-up costs over US$300 million and is hired out at over US$150,000 per day. The consequential cost to the industry is estimated to be between US$10 and US$30 million per incident.

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