

Spudcan Punch-Through in Thin Clay Crust Overlying Soft Clay

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ABSTRACT

The presence of clay crust overlying soft clay in parts of Southeast Asian Sunda Shelf may result in punch-through hazard during jack-up spudcan installation due to the potential for reduced (or softening) bearing resistance upon failure of the crust layer. In view of the above, a series of centrifuge model tests have been undertaken on circular spudcans with prototype diameter of 10 m on layered clay samples. The thicknesses of the upper crust layer adopted in the tests ranged from about 0.16 to 0.71 spudcan diameter while the strength ratio of the lower layer to the upper layer is 0.2. This paper presents experimental results obtained in terms of 1) the development of bearing resistance upon spudcan penetration in the layered clay samples, and 2) the development of soil deformation and failure mechanisms upon spudcan penetration. The shape of bearing resistance versus penetration curves changes from ductile (non-softening) to brittle (softening) profiles as the crust thickness increases. The observed soil deformations show punching-shear failure in the upper layer, followed by the formation of a rigid crust block beneath the spudcan. The test results and the practical implications of the findings are discussed in this paper.

KEY WORDS: Spudcan foundation; centrifuge modelling; deep penetration; punch-through; post-peak softening resistance; layered clay; artificially cemented clay.

INTRODUCTION

Today's jack-up rig foundation consists of three independently-installed legs each supported at the base by a spudcan, which is a steel footing of conical wedge configuration having diameter ranging from 10 m to slightly over 20 m. Spudcans are installed by penetration to some depth below the seabed surface under incremental preloading, which is usually provided by a combination of self weight and water ballast. SNAME (2002) recommended the total preload to be larger, by a factor of safety, than the maximum expected working load of the leg under extreme conditions. Given the considerable amount of preloading pressure required, typically in excess of 300 kPa, the penetration depths of spudcans may vary from several meters for cases with stiff granular seabed to as much as several tens of meters for soft clay seabed.

During the preloading process, the load applied to a spudcan has to be reacted by the bearing resistance from the soil in order to maintain static equilibrium. In soil conditions showing increasing bearing resistance with depth, this process sets the spudcan deeper at a rate controlled by the load increments. On the other hand, in conditions consisting of a strong soil layer overlying a weak layer, the bearing resistance may decrease with depth at some point during the process, leading to temporary loss of static equilibrium. This results in rapid uncontrolled spudcan penetration, or punch-through, before resting at a final depth where the bearing resistance is sufficient to overcome the preload and the dynamic forces associated with the spudcan motion. During the operational period of the rig, punch-through may also occasionally occur due to storm overload (McClelland et al., 1981; Baglioni et al., 1982).

Punch-through of one of the jack-up legs temporarily loses the stability of the rig as the hull tends to tilt and sway, resulting in large bending moments generated in the legs and the leg-hull connections. This often results in severe buckling of the legs and hence the consequent costly repair and delay in the rig's operation. The uncontrolled rig's motion may also put human lives at risk as given by the fact that a total of 19 fatalities had been caused by such failures worldwide as at 2003 (Dier et al. 2004). Punch-through incidents in South-East Asia resulting in both rig damage and lost drilling time amounting to economic cost between US\$1 and 10 million occurred at a rate of one per annum (Osbourne and Paisley, 2002). A recent incident in the Natuna Sea offshore Indonesia in 2004 was recorded in great detail by Brennan et al. (2006).

Hard clay crust overlying softer clay is one of the soil conditions favourable to punch-through occurrence (McClelland et al., 1981; Dier et al., 2004). Such layered soil conditions is hereafter referred to as 'layered clay' profile. This profile is the most common cause of punch-through in the waters of Southeast Asia for its extensive presence in the Sunda Shelf (Fig. 1; Castleberry and Prebaharan, 1985). The crust layers in this Shelf have maximum and average thicknesses of 10 and 3 m, respectively, from 69 borings' data (Castleberry and Prebaharan, 1985). Comparing the crust layer thickness H with the spudcan diameter B , the ratio H/B typically encountered in the Sunda Shelf is less than 1. Besides the Southeast Asian region, clay crust overlying