OTC 19907

New Mechanism-Based Design Approach for Spudcan Foundations on Stiff-Over-Soft Clay

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This paper was prepared for presentation at the 2009 Offshore Technology Conference held in Houston, Texas, USA, 4–7 May 2009.

Abstract

The paper reports an improved mechanism-based design approach for assessing spudcan penetration response on stiff-over-soft clay, where potential for punch-through exists. The method has evolved through a combination of centrifuge modeling and large deformation finite element (LDFE) analysis. The model tests included half-spudcan tests against a transparent window, allowing visualization of the soil flow, and full-spudcan tests to measure the penetration resistance. The LDFE analyses simulated continuous penetration from the surface, providing complete profiles of penetration resistance and revealing the evolving soil flow patterns. The analyses were undertaken with and without taking strain softening and rate dependency into account. The LDFE results were first validated against centrifuge observations and then extended for a range of layer geometries and soil strength profiles encompassing almost all cases of practical interest. The design method currently recommended in the SNAME guidelines was found to underestimate the maximum penetration resistance significantly in most cases and to exaggerate the post-peak reduction in resistance. A new design approach based on the study is presented in both graphical and equation form to facilitate use for practical design problems, and is applied to a case study from the field. Comparison between recorded field data, predictions from the new design method and corresponding results from LDFE analyses show that the design method provides accurate estimate of the depth at which punch-through occurred and its severity, and also a close approximation to the full load-penetration response.

Spudcan on Stiff-Over-Soft Clay: Potential for Punch-Through

Installing and preloading a jack-up 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 (usually experienced by only one leg) may lead to buckling of the leg, effectively decommissioning the platform, or may even result in toppling of the unit. Punch-through failures have occurred throughout the world in locations ranging from off the Australian coast to the Gulf of Mexico (Aust, 1997; Jack et al., 2001, 2007; MSL, 2004). In particular, the Sunda Shelf, Southeast Asia has been identified as the most punch-through-sensitive location in the Asia Pacific region (Osborne & Paisley, 2002; Paisley & Chan, 2006). Exploration jack-up drilling units frequently encounter punch-through hazards due to the geological conditions, where a clay crust is underlain by a soft clay layer. Three recent examples of punch-through events in Southeast Asian waters have been reported by Maung & Ahmad (2000), Brennan et al. (2006) and Kostelnik et al. (2007). A summary of punch-through incidents collating almost all the reported failures may be found in the doctoral thesis of the first author (Hossain, 2008).

In recent years, the number of jack-ups operating around the world has increased considerably and there has also been a significant increase in the number of rig moves per year due to reduced time spent at each location. Although the potential hazard of strong crustal features is well documented, this increase in jack-up operations has tripled the number of punch-through incidents when statistics between 1998 and 2006 are compared (Jack et al., 2007). With jack-up punch-through now the most frequent hazard, there is an urgent need:

1. to improve understanding of the mechanisms of soil flow around spudcan foundations undergoing continuous large penetration;
2. to improve the design approach for punch-through conditions and hence to assess accurately the likelihood of a sudden penetration of a spudcan and its degree of severity; and
3. to find an effective solution for mitigating punch-through that will allow jack-up rigs to be installed safely at hazardous locations.