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Assessing appropriate stiffness levels for spudcan foundations on dense sand

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ABSTRACT

Before a jack-up can operate at a given location, a site-specific assessment of its ability to withstand a design storm during operation must be performed. During this assessment, the complex state of stress and strain under a spudcan is usually simplified to a value of foundation stiffness that is integrated as a boundary condition into the structural analysis. Soil stiffness is a critical parameter affecting the foundation and structural load distribution and displacements, and the jack-up natural period and dynamic response. The level of spudcan stiffness is an area of intense interest and debate. This paper assesses appropriate stiffness levels for numerical simulation. Utilising results from a detailed "pushover" experiment of a three-legged model jack-up on dense sand, the paper compares the experimental pushover loads and displacements on the hull and spudcans to numerical simulations using different assumptions of spudcan stiffness. These include pinned and encastré footings, linear springs and a force-resultant model based on displacement-hardening plasticity theory. Constant stiffness levels are shown to be inadequate in simulating the experimental pushover test. The non-linear degradation of stiffness associated with the latter force-resultant model is critical.

1. Introduction

Most jack-up rigs use inverted conical footings known as spudcans as their foundations. Within the offshore industry, there is considerable interest in determining the level of moment restraint they

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provide, as this level of fixity is often a vital component in the site-specific assessment of a jack-up unit. This is because inclusion of rotational restraint tends to reduce critical assessment criteria such as member stresses at the leg/hull connection and the lateral hull deflection. If fixity is assumed within current site-assessment guidelines SNAME [1] initial rotational stiffness levels have been derived from recommendations based on monitored offshore data [1–3]. During a numerical analysis these initial values degrade as the combined loading on the foundation approach the defined failure envelope [1].

The level of spudcan fixity, as well as the overall pushover capacity of a jack-up, is explored in this paper. A 1:250 scale model jack-up is used to experimentally measure the spudcan and hull load and displacements during a pushover event on dense silica sand. The experiment reported here furthers the extensive testing of Vlahos [4] and Vlahos et al. [5,6] which explored the pushover behaviour of jack-ups on over-consolidated clay. It was performed at 1-g on the laboratory floor as part of a series of six experiments that studied the effect of different spudcan configurations on both the degree of fixity and the overall pushover capacity of a model jack-up sitting on dense sand (the programme included a conical spudcan with spigot, a flat plate, two skirted caissons with different skirt length to diameter ratios and a spudcan with three prongs [7]). Fig. 1 shows the dimensions of the spudcan used in the experiment discussed in this paper.

The experiment is used to back calculate stiffness levels of the spudcan and jack-up system. However, it also provides relevant data to evaluate the performance of numerical analysis techniques. Therefore, the pushover experiment has been retrospectively simulated using a plane-frame structural finite element program. Numerical assumptions for the spudcan response have included (i) pinned and encastré footings, where infinite stiffness is assumed in the vertical and horizontal direction and zero and infinite in the rotational degree of freedom respectively, (ii) linear springs with stiffness levels as assumed in the SNAME document [1], and (iii) by using a plasticity modelling approach (see for example Refs. [8–11]).

2. Model jack-up experiments

2.1. Model jack-up

The model rig used in the experiment was a 1:250 scaled version of jack-ups used offshore. The prototype leg length was assumed at 150 m, with the remainder of the parameters being average values of five large jack-ups designed by the Houston-based company Friede & Goldman Ltd (see Vlahos et al. [5] for more details). As shown in Figs. 1 and 2 and detailed in Table 1, the leg length of the model jack-up was 600 mm and the spudcan diameter 72 mm. Variations between the true 1:250 scale

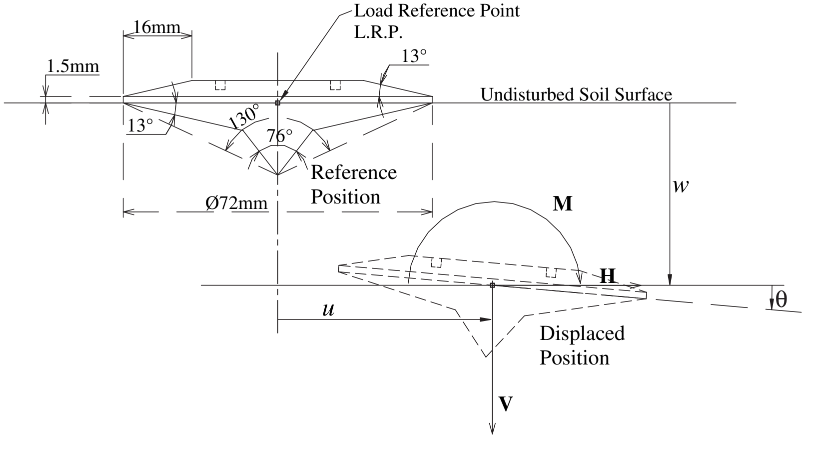

Fig. 1. Spudcan used in experiments, including the sign convention for spudcan loads (V, M, H) and displacements (w, θ, u) at the load reference point (LRP) assumed.