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The Behaviour of Drag Anchors in Layered Soils

M.P. O'Neill, M.F. Randolph and A.R. House
The University of Western Australia
Nedlands, Australia

ABSTRACT

This paper presents the preliminary results of an investigation into the behaviour of drag anchors in soils consisting of normally consolidated clay overlying silica sand. A limit equilibrium approach examines the forces acting on an anchor in a pre-ultimate state. This approach is combined with a kinematic model utilising incremental displacements and energy methods, resulting in a simulation program that predicts anchor behaviour in layered soil profiles. The results of this investigation are compared with the results of a series of centrifuge model anchor tests.

KEY WORDS: Drag anchor, anchor, model testing, ultimate holding capacity.

INTRODUCTION

Floating Production, Storage and Offloading (FPSO) facilities have recently emerged as a favoured method of offshore hydrocarbon extraction compared with traditional fixed platforms. They are well suited to oil and gas fields situated in deep waters, and at the end of the life of the field they can be relocated to another field. This trend has focused much attention on appropriate anchor designs for the moorings. There are a number of anchoring options available, including pile, deadweight and suction anchors, but high capacity drag embedment anchors provide a simple and economical anchoring solution. They require the least installation effort of all anchoring systems, and are easily retrieved and reinstalled. They are also highly weight efficient with anchoring forces exceeding 20 times their dry weight.

Until recently, the lack of accurate prediction methods for the behaviour and holding capacity of drag anchors often led to an overestimation of the required anchor size. Drag anchor design was largely empirical and based primarily on manufacturer's design charts developed from field test data on small anchors. Furthermore, these design charts assumed that the soil was homogeneous, giving little consideration to the soil properties and classifying it broadly as "sand" or "clay". This raises the uncertainty over the behaviour of drag anchors in complex soil stratigraphies like those found in the North Sea, which consist of normally consolidated clay overlying silica sand.

Previous work on the theory of drag anchors in clay was outlined by Stewart (1992). Neubecker and Randolph (1996a) developed this theory further by deriving expressions and solutions for calculating the ultimate efficiency and trajectory of a drag anchor in a cohesive soil with a simple strength profile. Neubecker and Randolph (1996b) also enhanced the theory outlined by LeLievre and Tabatabaee (1979, 1981) that described a force equilibrium model for anchors in sand. They proposed significant modifications to the existing static model and outlined a kinematic model that utilised an incremental displacement and least work approach. Integration of the static and kinematic models led to an analytical simulation program that described the complete embedment history of an anchor in sand.

The static sand model has been modified further in order to account for drag anchor behaviour in sand underlying a clay layer. By introducing a force due to bearing of the shank in the clay layer into the force equilibrium solution, and combining the static and kinematic sand models with the solutions for anchor behaviour in cohesive soil, the simulation program is able to predict anchor embedment in a layered clay/sand soil profile.

A number of model anchor tests have been performed in the geotechnical centrifuge at The University of Western Australia in a saturated soil sample comprised of normally consolidated kaolin clay and dense silica sand. Predictions of anchor behaviour made using the simulation program are compared with the experimental results.

THEORY

Drag Anchors in Clay

Stewart (1992) published methods for performing static and kinematic analyses of drag anchors in cohesive soil. These methods were simplified by Neubecker and Randolph (1996a) who formulated bearing capacity and moment equilibrium calculations utilising 2 fundamental anchor resistance parameters (f and θ_w). They expressed the geotechnical resistance force T_p acting on the anchor parallel to the direction of the flukes, illustrated in Figure 1, as:

$$T_p = f\ A_p N_c s_u \qquad (1)$$