Effect of Loading Rate on the Uplift Capacity of Plate Anchors

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ABSTRACT

The plate anchor is a relatively new offshore foundation to moor large floating structures in deep water. The behaviour of strip plate anchors for various loading rates is studied using a large deformation finite element method for coupled geotechnical problems. The normally consolidated clay in the seabed is described with the modified Cam-clay constitutive model. The procedure of large deformation analysis developed avoids severe distortion of soil elements, therefore, it can derive the uplift capacity and distribution of excess pore pressures against the significant displacement of anchors. It is found the mobilised capacity may decrease with increasing moving velocity of anchors until the velocity approaches a critical value. This critical velocity represents the undrained condition. Compared with total stress analyses, the uplift capacity factor from coupled analyses is a little higher due to plastic hardening of soil above the plate.

KEY WORDS: Large deformation, plate anchor, offshore foundation, finite elements, pore pressure, clay

INTRODUCTION

Offshore oil and gas exploration is moving towards deep and ultra-deep waters, which requires the development of reliable anchoring foundation systems to moor large floating platforms. Suction caissons and suction piles have been widely used in the Gulf of Mexico, North Sea and West Africa during the last 2 decades (Andersen et al., 2005). The plate anchor is a relatively new type of offshore foundation, characterized by benefits of low cost, accurate positioning and short installation times. The plate anchor is generally installed vertically by attaching into a suction caisson. The suction caisson is retrieved after penetrating to the designed depth, with the plate anchor being left in the seabed. The plate anchor is then rotated by loading eccentrically until the plate becomes normal to the mooring chain.

Previous studies of plate anchors, including model tests, plastic limit analyses and finite element (FE) methods, were mainly focused on the uplift capacity of anchors subjected to short-term loadings. When a plate anchor embedded horizontally in clay is pulled up rapidly, the soil remains attached to the anchor base at deep embedment, due partly to the high overburden pressure on the anchor and partly to suction (Rowe and Davis, 1982). Loading of the anchor induces differential excess pore pressures on the plate top and base, as shown in Fig. 1. The development of suction (in reality under-pressure relative to high hydrostatic water pressure) is a function of the soil properties, loading rate and anchor embedment, which is not easy to predict. Most researchers have tended to neglect the suction and simplify this complex process into two cases: no breakaway (soil remains attached to the anchor base) and immediate breakaway (soil separates from the anchor base once the pulling force is applied). A series of 1g small-scale model tests were performed to derive the capacity factors in weightless soil under immediate breakaway conditions (Das, 1978; Das and Singh, 1994). The uplift capacity was then computed as the sum of overburden pressure and the corresponding capacity in weightless soil. Merifield et al. (2001, 2003) presented upper bound and lower bound solutions of immediate breakaway cases, and noticed the breakout capacity cannot increase indefinitely with the overburden pressure. In fact, a limiting capacity is ultimately approached since a local flow mechanism forms around deep anchors, with the anchor capacity being always equal to or less than that under no breakaway conditions. This conclusion has been verified by centrifuge tests (Song et al., 2006; Gaudin et al., 2006) and large deformation FE methods (Wang et al., 2006; 2007). Both previous limit analyses and FE simulations belong to total stress analysis, in which the seabed clay was regarded as an ideal plastic or elasto-perfectly plastic material obeying the Tresca yield criterion. It was found the capacity factor of anchors under undrained conditions depends on the geometry, roughness and embedment depth of anchors. However, little effort has been directed at the behaviour of anchors to long-term loading, where the accumulation and dissipation of excess pore pressures must be considered.

Although conventional small strain FE methods based on total or updated Lagrangian formulation have been implemented to determine anchor capacities, the accuracy of these approaches is uncertain since anchors may undergo large displacements to mobilise the ultimate capacity. During the uplift process, the distortion of soil elements becomes increasingly significant, especially in the vicinity of the anchor. A simple practical approach to avoid mesh distortion, Remeshing and Interpolation Technique with Small Strain (RITSS), was proposed by Hu and Randolph (1998). Much of the early application of RITSS in geomechanics was built around the locally developed finite element code, AFENA (Carter and Balaam, 1990; Hu