Effective Stress Analysis of a Dynamically Installed Anchor Penetrating into Rate-Dependent Soil

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ABSTRACT
This paper presents a dynamic large deformation finite element approach based on frequent mesh regeneration within the effective stress framework and investigates the penetration behavior of a dynamically installed anchor in normally consolidated kaolin clay. The strain rate dependency of clayey soil is represented by an elasto-viscoplastic soil model. The numerical model is validated against existing centrifuge testing data. The anchor deceleration profiles and the development of excess pore pressures around the anchor are discussed. A parameteric study is then conducted to explore the effect of impact velocity on the final embedment depth.

KEY WORDS: dynamically installed anchors, large deformation finite element analyses, strain rate dependency, effective stress, pore pressures

INTRODUCTION
Recently introduced dynamically installed anchors (DIAs) have been regarded as a cost-effective anchoring solution for floating structures in deep waters. They are usually rocket shaped equipped with three or four fins at the trailing edge. The DIAs are installed by releasing from a design height above the mudline. The anchor is then penetrated into the seabed via the kinetic energy gained during the free-fall in the water column and the anchor’s submerged self-weight. The quick installation process can be regarded as nearly undrained conditions, especially in clayey sediments, and significant excess pore water pressures are accumulated around the anchor. An anchor installation is generally followed by a set-up period, prior to applying operational loadings, allowing dissipation of the installation induced excess pore water pressures up to some degree.

To date, the dynamic penetration behavior of DIAs have been explored mainly through field trials and centrifuge tests, while a limited number of numerical studies have been conducted. The anchor penetration from the mudline to the final embedment depth was replicated using a computational fluid dynamics method (Raie and Tassoulas, 2009) and large deformation finite element (LDFE) approaches (Nazem et al., 2012; Kim and Hossain, 2015; Kim et al., 2015a, 2015b; Liu et al., 2016). However, almost all previous numerical analyses on DIA installation were within the framework of total stress, in which the development of excess pore pressures during penetration and the subsequent dissipation could not be considered directly. This limitation may lead to an inaccurate prediction of pullout capacities at an operational stage, which is dictated largely by the degree of dissipation or consolidation, unless an artificially increased undrained shear strength of the adjacent soil is considered (Kim and Hossain, 2016, 2017). Therefore, an effective stress analysis is required to gain comprehensive interpretation of the soil response during dynamic installation and to compute accurate capacity under operational loading.

Liu et al. (2014) adopted an effective stress formulation under ideally undrained conditions to explore the excess pore pressures during installation of DIAs. In their study, soil was assumed as rate-independent material with a Mohr-Coulomb yield criteria. More recently, Sabetamal et al. (2016) conducted effective stress analyses using the Modified Cam Clay (MCC) model in which the strain rate dependency was included by adjusting the over-consolidation ratio empirically. An artificially high over-consolidation ratio ‘forms’ a large soil undrained shear strength. A more appropriate way to consider the strain rate effect is to incorporate a general stress-strain-time constitutive model, as suggested by Liingaard et al. (2004).

In this paper, the installation of DIAs in normally consolidated clay is investigated through a dynamic LDFE approach. An undrained effective stress formulation is employed to capture the excess pore pressures in the dynamic analysis. An elasto-viscoplastic soil model, EVP-MCC, established on the basis of the overstress theory (Perzyna, 1966) and the MCC model, is used to describe the rate-dependent behavior of soil. The numerical model developed is validated against existing centrifuge test data and then used to perform parametric analyses.

METHODOLOGY

Dynamic LDFE Procedure

DIA installation was simulated using a LDFE approach termed as