Profiling In-Situ Stresses in Clays Using Penetrometer Test Results

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In this paper, a penetrometer-based methodology for characterizing in-situ stresses in clays is proposed. For this purpose, a correlation model between the effective stress and the penetration resistance is established. Piezocone and T-bar penetrometers, both of which are commonly used in practice, are introduced into the proposed method. The proposed correlation model is given as a function of the penetration resistance, penetration resistance factor and strength increase ratio, considering that the penetration resistance and undrained shear strength are both governed by the effective stress. To check the validity of the proposed method, case examples are selected and used to compare measured and predicted in-situ effective stress profiles. It is observed that the predicted stress profiles agree well with the measured profiles for both piezocone penetration test (PCPT) and T-bar test cases. The effect of soil constitution on the effective stress for the proposed method is also examined.

INTRODUCTION

The effective stress is the key state soil variable that controls geotechnical and mechanical behavior of soils. In routine projects, the depth profile of the effective stress is commonly determined using soil unit weights that are identified from undisturbed soil samples at different depths. The undisturbed soil sampling is subjected to various uncertainties, which tend to be more pronounced as target depth increases or when offshore soil conditions are involved (Hight et al., 1992; Santagata and Germaine, 2002). While various in-situ testing methods have been adopted and used to characterize field soil conditions, no specific way has been addressed for the assessment of the effective stress directly from in-situ test results. Rather, the effective stress is often regarded as a known input variable, which is then used to estimate and evaluate other geotechnical parameters.

The piezocone penetration test (PCPT) has been widely used for the purpose of soil exploration. PCPT is regarded as particularly effective for clayey soils, as it allows the estimation of both strength and compressibility properties (Vesic, 1972; Teh and Houlsby, 1991; Yu and Mitchell, 1998; Lee et al., 2010). Full-flow penetrometers, such as T-bar and ball penetrometers, are also increasingly used for the characterization of clayey soils (Stewart and Randolph, 1994). In current practice, PCPT and T-bar test results are mainly used for soil classification, strength or stiffness estimation, and foundation design. In relation to in-situ stresses, the application has been focused on the estimation of overconsolidation ratio (OCR) and preconsolidation pressure (σ’<sub>0</sub>) (Sully et al., 1988; Mayne, 1991; Larsson and Mulabdic, 1991; Lunne et al., 1997). For example, Larsson and Mulabdic (1991) proposed a correlation chart that utilizes PCPT results to estimate soil unit weights and in-situ stresses. However, it was recommended that this method be used for the preliminary investigation, because the calculation requires overburden stresses and iterative procedure to obtain the net cone resistance (Lunne et al., 1997).

For offshore projects, such as offshore wind turbines and mobile jack-up rigs, in-situ penetrometers have been effectively used for the soil exploration and design of substructures that are to be embedded in seabeds (Lee and Randolph, 2011). However, uncertainties associated with in-situ effective stresses still exist and the test results without addressing in-situ stresses may lead to misinterpretation of geotechnical parameters, and thus overall reliability of target structures could be reduced. Therefore, a methodology that can improve and optimize soil profiling and characterization is particularly important and certainly desirable for offshore engineering and geotechnical characterization of seabed soils.

In this paper, a methodology for profiling in-situ stresses in clays using penetrometer test results is explored. For this purpose, a correlation between the effective stress and the penetration resistances is introduced in terms of the penetration resistance factor. Different penetrometers of piezocone and T-bar are employed in this investigation. Various case examples are used to check the validity of the proposed method. The application of the proposed method for different soil constitutions and multi-layered conditions is also examined and correction procedure is presented.

APPLICATION OF IN-SITU PENETRATION TESTS

Piezocone Penetrometer

The piezocone penetration test (PCPT) is a common in-situ testing method in practice for the purpose of soil characterization and foundation design. It is quasi-statically conducted and gives various measurements including the cone penetration resistance, sleeve friction and pore pressure. This has meant that PCPT is particularly effective for clays where the undrained shear strength and consolidation properties are regarded as key design parameters. The undrained shear strength from PCPT is usually obtained using the following relationship:

\[
s_u = \frac{q_t - \sigma'_0}{N_k}
\]

where \(s_u\) = undrained shear strength, \(q_t\) = cone resistance, \(\sigma'_0\) = overburden total stress, and \(N_k\) = cone factor. Note that other types...