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# Application of Recent Developments in Terrestrial Soft Sediment Characterization Methods to Offshore Environments

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## Abstract

This paper presents results from research directed towards developing more accurate and reliable measures of the intact and remolded undrained shear strength ($s_u$ and $s_{ur}$) of soft sediments. These soil parameters are critical inputs to assessment of certain offshore geohazards, such as submarine landslides, and design of oil and gas production and transportation infrastructure, such a foundation systems and pipelines. The research was conducted at well characterized terrestrial test sites consisting of soft clay deposits. Extensive in situ testing, soil sampling and laboratory testing were conducted for each of the test sites. The in situ testing program was focused on studying the relatively new family of in situ tools known as full-flow penetrometers. Sample collection and subsequent advanced laboratory testing was focused on assessment of sample disturbance and laboratory measurement of high quality reference design parameters for interpretation of the in situ tests. Developments in the application and interpretation of the T-bar and ball full-flow penetrometers for in situ measurement of $s_u$ and $s_{ur}$ are presented. A new non-destructive method of assessing sample quality using shear wave velocity measurements on collected samples is described. The method allows for evaluation of sample quality in the field immediately after sample collection. Application of the full-flow probes for in situ characterization of offshore sediments and the shear wave velocity tool for assessment of sample quality during offshore sampling operations is described.

## Introduction

Both terrestrial and offshore soft sediment site characterization programs for geohazard analysis and infrastructure design ideally combine in situ testing and follow-on laboratory testing on high quality samples. Assessment of sample quality is essential for evaluating the accuracy of laboratory measured mechanical properties. Coupling this with well calibrated results from in situ tests greatly enhances the reliability of site characterization programs. However, terrestrial and offshore site investigation practices have largely developed separately due to the different conditions under which in situ tests are conducted and soil samples are collected. Budgets associated with offshore investigations are generally larger but the challenges and costs are often much greater, especially as investigations continue moving to deeper waters. Ideally both practices benefit from a two-way technology transfer so that developments in sampling and in situ testing equipment and methods can be adopted in either practice. Because of cost and logistical considerations, new tools and practices proposed for offshore site investigations are often proof tested using well characterized terrestrial sites. This paper describes findings from recent research on the characterization of soft terrestrial sediments and the application of these findings to the characterization of soft offshore sediments.

The research was focused on two key components of site characterization programs: 1) in situ testing and 2) evaluation of sample quality. The primary emphasis was on the use of new tools that provide a means for developing accurate measures of the intact and remolded undrained shear strength ($s_u$ and $s_{ur}$) profiles of soft sediments. For such deposits, both $s_u$ and $s_{ur}$ are critical soil design parameters for conducting reliable numerical analyses of offshore geohazards, such as submarine landslides, and infrastructure design such as foundation systems.

The new family of in situ testing probes called full-flow penetrometers was developed (Randolph et al. 1998, Randolph 2004) as an alternative to piezocone (CPTU) and field vane testing for measurement of $s_u$ and $s_{ur}$ of soft sediments. These devices present a number of advantages over more traditional in situ testing tools such as the CPTU. However, test procedures and interpretation of the measured penetration resistance for estimation of $s_u$ and $s_{ur}$ are not yet fully developed. This paper describes results from research conducted on use of the T-bar and ball penetrometers at several well characterized soft clay test sites. Data from monotonic, variable rate and cyclic testing are presented. Factors for conversion of measured resistance to specific reference $s_u$ and $s_{ur}$ values are given.

Closely coupled with the full-flow probe research was development of a new non-destructive means for evaluating