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Piezocone penetration test (CPTU) based correlation of soil parameters for fluvio swamp soil deposits

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ABSTRACT: Site investigation is a key step of the Geo-structures design and analysis, that require the collection of soil stratigraphy information and soil layering and soil parameters. The piezocone penetration test (CPTU) offers an efficient way to collect up to three independent measured soil behavior based on a single test (q_t, f_s, u_2). This paper discusses the collected soil samples, laboratory tests, in situ vane shear tests, and a large data base piezocone penetration test (CPTU) performed at Bouregreg valley heterogeneous soil deposits. First, a statistical analysis is conducted to deduce site specific correlation between physical parameters and CPTU data. A benchmarking procedure was conducted for Bouregreg valley soil character correlations with some globally available data, that was verified and compared with existing recommendations worldwide.

KEYWORDS: Piezocones penetration test (CPTU), compressibility, plio-quaternary, site characterization, compressibility.

1 INTRODUCTION

In geotechnical practice, the determination of compressibility and hydraulic conductivity parameters is primarily important for defining consolidation time and soil deformations (Müller and Larsson 2012) beneath structural foundations. These geotechnical parameters of soft soils are mainly determined based on laboratory tests such as the oedometer test. However, the direct use of these parameters to accurately describe time-dependent soil behavior is difficult to achieve precisely. This is primarily attributed to scale effects, anisotropy, and soil heterogeneity. In certain cases, the selection of non-representative soil samples with more clayey or silty zones from drilling cores for laboratory testing may provide abnormal values of compressibility and hydraulic conductivity, thereby overestimating or underestimating in-situ consolidation time and subsoil deformations.

Recently, most developments in soil parameter acquisition and soil characterization have progressively benefited from in-situ testing (Mantaras et al. 2015). The piezocone (CPTU) is a well-known in-situ tool that enables continuous identification of soil profiles as well as efficient estimation of a variety of soil properties (Mayne & Benoît 2020). The CPTU provides three different readings during the cone penetration process: tip resistance (qc), sleeve friction (fs), and pore water pressure (u). To measure hydraulic conductivity, piezocone dissipation tests (CPTU) have traditionally been performed at predetermined depths, resulting in rather discontinuous measurements with long acquisition times. Researchers such as Chai et al. (2011) have developed direct approaches to determine hydraulic conductivity continuously based on CPTU-measured parameters.

Furthermore, geotechnical practitioners and researchers regularly use natural water content (wn), liquid limit (LL), and initial void ratio (e0) to estimate the primary compression index (Cc) (McCabe et al., 2014). Others have developed equations to estimate the secondary compression index (Cα) based on initial porosity correlations. Although numerous empirical equations for both compression indices (Cc, Cα) from many regions worldwide have been related to various physical properties (McCabe et al., 2014), the equations that have been developed are site-specific. Moreover, these empirical equations contain discontinuous information regarding the evolution of compressibility parameters with depth. For this reason, using empirical correlations of compressibility indices based on continuous parameters such as those obtained from CPTU can be very valuable, particularly when soils are highly heterogeneous. Thus, combining discontinuous compressibility data from oedometer tests with continuously measured CPTU parameters can be an appropriate means of efficiently estimating compressibility for reliable soil deformation predictions. To this end, this article aims to evaluate a combined approach for reliably estimating soil hydraulic conductivity and compressibility in a continuous manner.

2 PROBLEMATIQUE

The necessity for a detailed soil investigation program to properly characterize subsurface conditions is a critical step in any project. This step is primarily governed by the client's/project manager's spending capacity rather than what is actually required for a particular project. To achieve appropriate borehole spacing and sufficient frequency of in-situ and laboratory testing for a very extensive project footprint, this objective can be costly and impractical in certain cases. For this reason, numerous researchers have studied spatial variability and uncertainty based on probabilistic methods (Phoon and Kullan 1999, Baecher and Christian 2005). They concluded that the sources of spatial variability characteristics can be classified into two main categories. The first is "aleatory," which is associated with natural variability and geological processes, and the second is "epistemic," which is due to lack of knowledge.

To assess this variability, numerous statistical techniques (Jaksa et al. 2004) and probabilistic methods have been developed. However, the application of geostatistics has proven its strength for large geotechnical projects. Conversely, the use of these methods for the Bouregreg Valley has been very general and difficult to apply for deriving precisely estimated parameters at specific points, as Figure 1 demonstrates. For this reason, a method based on correlation between CPTU parameters and oedometer database has shown promising results.

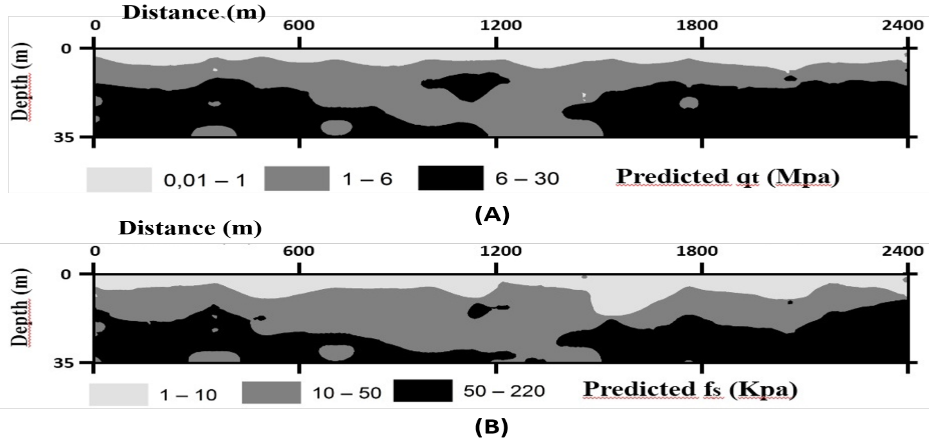


Figure 1. Variability of Deposits beneath the Second Ring Road Rabat-Salé

3 METHODOLOGY

The derivation of empirical correlations between continuous piezocone measured parameters (qc, fs) and discontinuous compression values from oedometer tests (Cc, Cα) in soil is a favorable aspect as long as a good coefficient of determination R² is achieved through an adequate procedure. In order to fill the gaps in compressibility parameters along the heterogeneous soil profile, several correlations are developed for the soft soils of the Bouregreg Valley. These correlations are produced to evaluate oedometer test results and provide guidance for future engineering practices in the study area. Additionally, the approach of Chai et al. (2011) is combined with the subsequent correlation to estimate soil hydraulic conductivity based on piezocone testing.

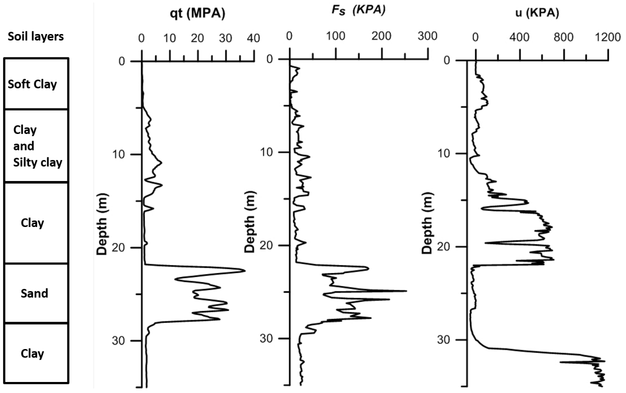


Figure 2. Representative Piezocone

4 RESULTATS ET DISCUSSIONS

In order to study the relationships between compression indices (Cc, Cα) and measured cone resistance parameters (qc, fs), numerous types of plots were performed during regression analysis. Consequently, Log-Log type plots provide improved data distribution. A total of 56 oedometer tests were deemed appropriate to be selected within the framework of this study.

The figures present the primary compression (Cc) and secondary compression (Cα) subsequently calculated, compared to those measured. As can be observed in Figures 3a and 3b, the calculated values of Cc, Cα show a similar trend variation compared to the oedometer laboratory data.

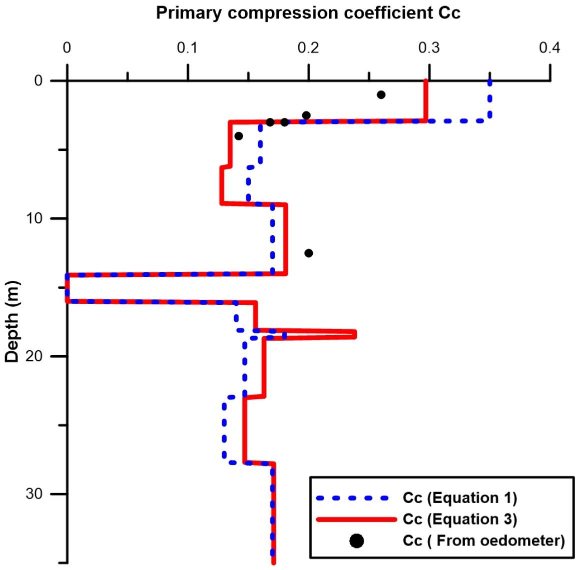
The calculated values of Cc and Cα based on corrected cone resistance qt produced higher values in the upper organic layers and slightly lower values in the deeper intermediate layers of sandy soil. Although the oedometer test data did not cover all soil layers in the selected area, those used follow the estimated compression indices, based on equations 1, 2, 3, and 4 below:

$$C_c = 0.209.\left(\frac{q_t}{P_a}\right)^{-0.24} \tag{1}$$

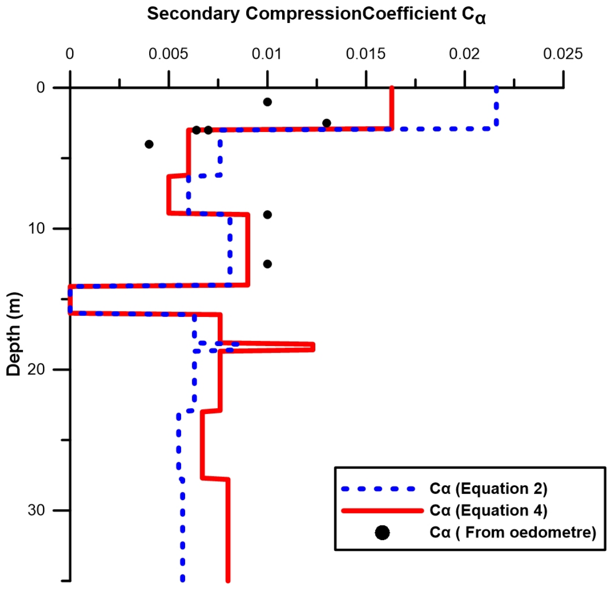
$$C_c = 0.470.\left(Q_{t_n}\right)^{-0.34} \tag{2}$$

$$C_c = 0010.\left(\frac{q_t}{P_a}\right)^{-0.31} \tag{3}$$

$$C_c = 0.029.\left(Q_{t_n}\right)^{-0.43} \tag{4}$$



a)



b)

Figure 3. a) Primary compression coefficient, b) Creep coefficient

Despite some scatter, the measured compression indices (Cc and Cα) are generally more likely to match the estimated compression values that are based on normalized cone resistance Qtn (equations 2 and 4), particularly when soils tend to have high clay content, namely the soils in the upper 3 m in this case.

As previously mentioned, the piezocone measurement from Figure 2 shows the intensity of the heterogeneous aspect in the Bouregreg Valley soils presented through the strong variability of CPTU parameters. Consequently, hydraulic conductivity is no exception. Chai et al. (2011) has proven to be an appropriate approach to use in heterogeneous estuarine soils with normally and/or slightly overconsolidated soft deposits by numerous researchers. As shown in Figure 4, hydraulic conductivity is calculated using the Chai et al. (2011) method based on CPTU testing, then compared to vertical and horizontal permeability values from oedometer tests and in-situ dissipation tests, respectively. According to Figure 4, the hydraulic conductivity values determined by the Chai et al. (2011) method are higher than those measured from oedometer tests in the first 3 meters and slightly lower at the 5-meter mark.

However, the hydraulic conductivity calculated from the proposed method matches perfectly with the in-situ dissipation test. It is known that in-situ hydraulic conductivity in the horizontal direction is generally higher than that in the vertical direction from oedometer tests. This explains the deviations observed at the first measured point during laboratory testing (at 3 m depth). Despite the minor deviations, the general variation of hydraulic conductivity corresponds well to the values from laboratory tests and dissipation testing.

We can conclude that by combining the compression index correlation results, the estimated hydraulic conductivity based on the Chai et al. (2011) method, and using the normalized soil behavior type option, the results correspond to soil behavior in an effective manner.

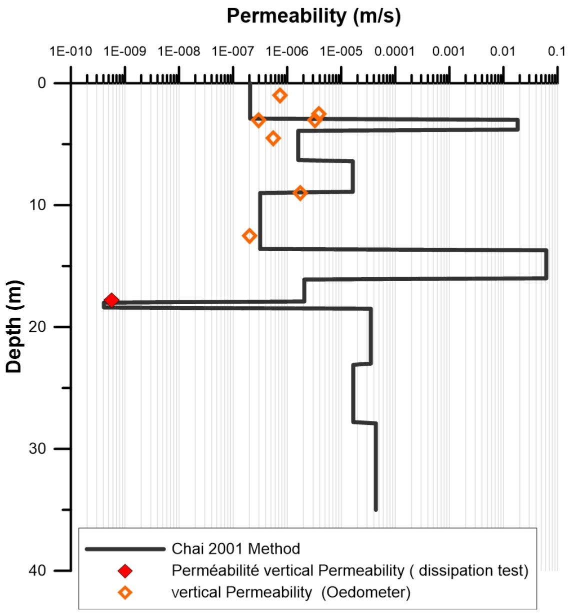


Figure 4. Perméabilité verticale

5 CONCULIONS

- The alluvial deposits of the Bouregreg exhibit a highly heterogeneous character in both vertical and horizontal directions, and thus the parameter selection process can be a difficult task when using only laboratory data.
- The established correlation between discontinuous compression parameter values Cc and Cα with continuous recordings qt and Qtn produced a reliable empirical correlation and guidance tool for evaluating compression characteristics in the Bouregreg Valley deposits.
- The correlations between compression indices Cc, Cα and normalized cone resistance Qtn presented the best coefficients of determination, $R^2 = 0.749$ and $R^2 = 0.775$, respectively.
- The evaluation of hydraulic conductivity based on the Chai et al. (2011) method proved to be accurate compared to in-situ dissipation testing and laboratory-measured testing.

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