Evaluation of consolidation parameters from piezocone penetration tests

Evaluation des paramètres de consolidation des sols à partir d'essais au piézocône

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ABSTRACT: This paper is aimed at evaluating the consolidation parameters of cohesive soils needed to estimate the total and rate of settlement of cohesive soils, utilizing the piezocone penetration test (PCPT) and piezocone dissipation test data. Two sites in southern Louisiana were selected and used for this study. In each site, in-situ piezocone penetration tests were performed and soundings of cone tip resistance, q_c, sleeve friction, f_s, and excess pore pressures at different locations (u_1, u_2 and u_3) were recorded. Dissipation tests were also conducted at different penetration depths. Shelby tube samples were collected close to the PCPT tests and used to carry out a comprehensive laboratory-testing program including oedometer and triaxial tests. The coefficient of consolidation, c_v, and the tangent constrained modulus, M, predicted using different interpretation methods were compared with the reference values determined from the laboratory oedometer tests. Results of this study showed that the consolidation parameters can be reasonably predicted from the piezocone penetration and dissipation tests and hence provide a continuous profile of these parameters with depth.

RÉSUMÉ : L'objectif de cette communication est de présenter une méthode d'évaluation des paramètres de consolidation des sols cohérents, nécessaires pour estimer l'amplitude et le temps de tassement de ce type de sol, basée sur les résultats d'essais de pénétration au piézocône (PCPT) ainsi que d'essais de dissipation des surpressions interstitielles. Deux sites ont été sélectionnés en Louisiane du sud et utilisés pour cette étude. Sur chaque site, des essais au piézocône ont été réalisés, avec mesure de la résistance en pointe q_c, du frottement latéral f_s et de la surpression interstitielle mesurée à différents niveaux sur la pointe (u_1, u_2 et u_3). Des essais de dissipation de la surpression interstitielle ont aussi été effectués à différentes profondeurs de pénétration. Des échantillons ont aussi été prélevés au carrotier près des emplacements des essais au piézocône et ont été utilisés pour réaliser un programme d'essais de laboratoire complet comprenant en particulier des essais à l'appareil triaxial et à l'oedomètre. Le coefficient de consolidation, c_v, et le module de compressibilité oedométrique, M, évalués à partir de différentes méthodes d'interprétation, ont été comparés avec les valeurs de référence déterminées à partir des essais oedométriques . Les résultats de cette étude ont montré que les paramètres de consolidation peuvent être raisonnablement bien estimés à partir des essais de pénétration et de dissipation réalisés au piézocône et fournir ainsi un profil continu de ces paramètres en fonction de la profondeur.

1 INTRODUCTION

Saturated fine-grained soils can undergo large settlements over a long period of time. Therefore, the estimation of total and rate of settlement of cohesive soils under field loading is essential for geotechnical engineering design and analysis. The total settlement can be estimated from deformation moduli such as the tangent constrained modulus, M. The time rate of settlement is predicted using the coefficient of consolidation, cv.

The consolidation characteristics of cohesive soils can be estimated from either laboratory or in-situ testing. The laboratory tests such as the oedometer consolidation test are usually conducted on small presumably undisturbed samples. Almost all recovered samples have a certain degree of disturbance, which makes the laboratory- derived parameters not entirely representative of in-situ conditions. In-situ field tests can provide more accurate and reliable results than laboratory tests in assessing the actual in-situ consolidation performance. Conventional field tests are expensive, time-consuming, and require high skill and experience and hence it is not always possible to perform enough tests to achieve satisfactory results. The piezocone penetration testing (PCPT) has gained a wide popularity and acknowledgement as a preferred device for subsurface investigation, soil characterization and the evaluation of design soil parameters. The PCPT is robust, simple, fast and economical test that provides continuous soundings of subsurface soil. Different interpretation methods have been proposed to estimate the consolidation parameters of cohesive soils utilizing the piezocone penetration test (PCPT) and piezocone dissipation test data.

2 LABORATORY TESTS

Two sites in southern Louisiana (Lafourche and New Iberia) were chosen for this study. Boreholes were drilled in each site and highly quality Shelby tube samples were taken from the field for laboratory testing. The laboratory test program includes basic soil characterization tests such as water content, unit weight, atterberg limits, grain size distribution, and specific gravity. The oedometer consolidation test is conducted in both the vertical and horizontal direction to evaluate the reference consolidation properties of the soil such as the vertical and horizontal coefficient of consolidation, c_v and c_h, the tangent constrained modulus, M, and the compression indices, c_c, c_r. The k_o consolidated triaxial test was also performed to estimate the undrained shear strength, s_u, and the shear modulus, G, of the soil.

3 IN-SITU TESTS

Several in-situ piezocone penetration tests (PCPT) were performed at each site around the boreholes using the 10 and 15 cm^2 piezocone penetrometers. The 10 cm^2 piezocone has a porous element located 5 mm behind the base (U_2 configuration), while the 15 cm^2 piezocone has two porous elements located on the cone face and behind the sleeve (U_1 and U_3 configuration). The schematic of the 10 and 15 cm^2 piezocone penetrometers are depicted in Figure 1. The penetration of the piezocone was stopped at the same depth the samples were taken to perform dissipation tests. Two state-of-the-art cone penetration systems are available at Louisiana Transportation Research Center (LTRC). These systems are the 20-ton Research Vehicle for Geotechnical In-situ Testing and Support (REVEGITS) and the Continuous Intrusion Miniature Cone Penetration Test (CIMCPT) system (Tumay, 1994). Figure 2 presents a photograph of REVEGITS and CIMCPT systems. The 20-ton cone truck is used in this study for in-situ piezocone penetration and dissipation testing.

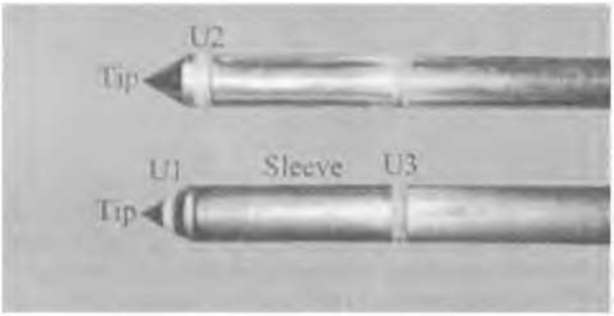

Figure 1. 10 and 15 cm^2 piezocone penetrometers.

Figure 2. Louisiana cone penetration systems: REVEGITS cone truck on the left and CIMCPT cone truck on the right.

The obtained PCPT profiles for the Lafourche and New Iberia sites are presented in Figures 3 and 4 respectively. Column 1 presents the corrected tip resistance, q_t, and friction ratio, Rf, profiles. Column 2 presents the pore pressure profiles, U_1 and U_2. Column 3 presents the soil classification profile using the probabilistic region estimation method proposed by Zhang & Tumay (1999). This method estimates the probability of each soil constituents (clay, silt and sand).

The dissipation test results performed at different depths for Lafourche and New Iberia sites are presented in Figures 5 and 6 respectively.

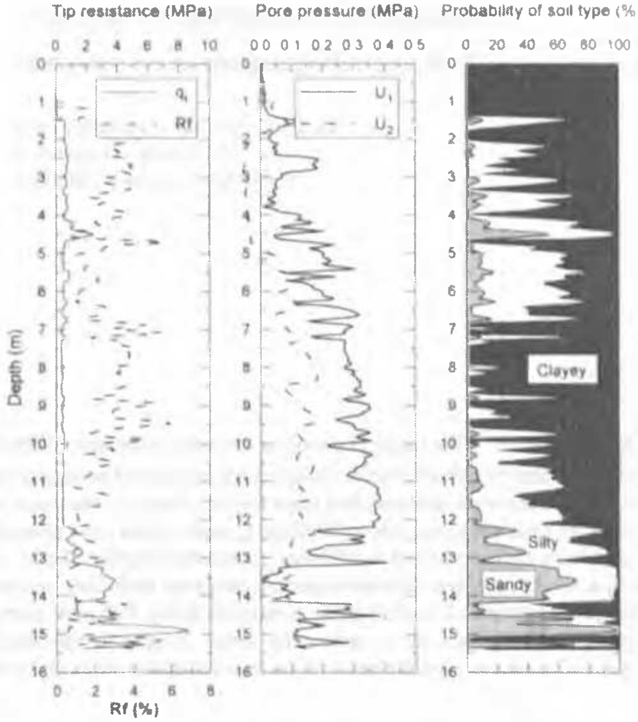

Figure 3. PCPT profile and soil classification for Lafourche site.

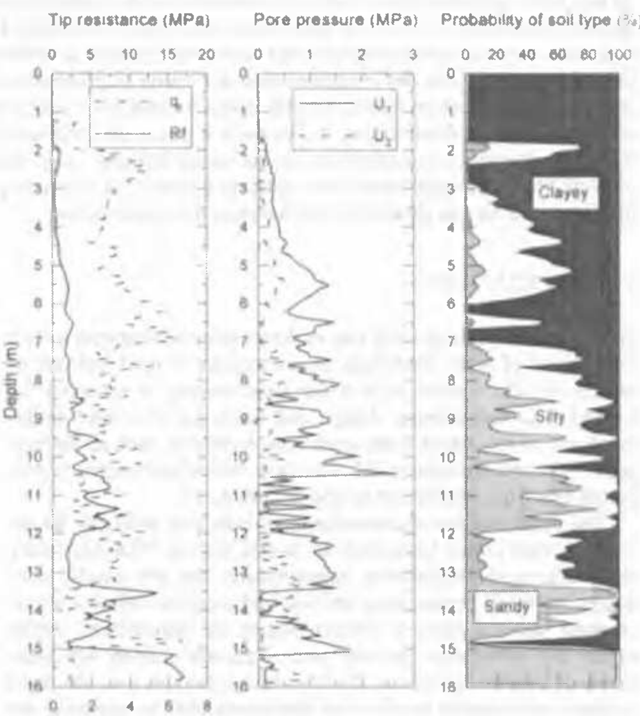

Figure 4. PCPT profile and soil classification for New Iberia site.

4 INTERPRETATION

The total settlement of fine-grained soils can be predicted utilizing the piezocone penetration test data through the evaluation of the constrained modulus, M. Correlation has been developed to relate the laboratory measured constrained modulus, M, to the cone tip resistance, q_c. For South African alluvial clay, Jones & Rust (1995) found the following relation for M:

$$M = \alpha_m \cdot q_c \qquad (1)$$

where $\alpha_m = 2.75 \pm 0.55$. Kulhawy & Mayne (1990) suggested the following relation:

$$M = 8.25 \cdot (q_t - \sigma_{vo}) \qquad (2)$$

where q_t is the corrected cone tip resistance, and σ_{vo} is the total overburden stress.

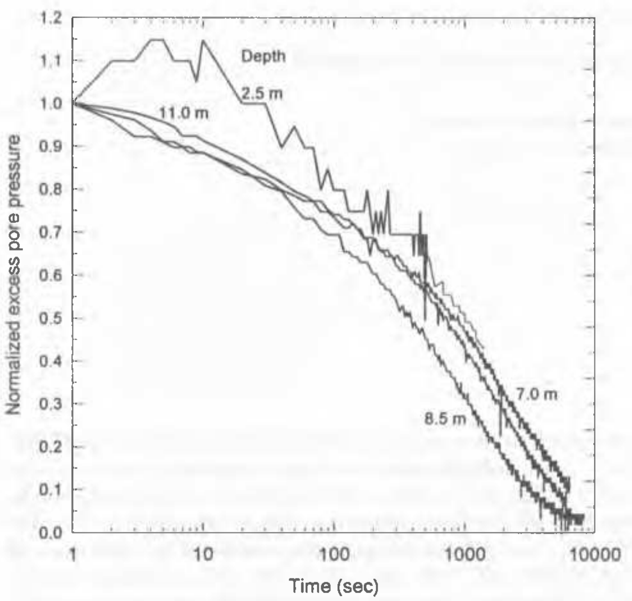

Figure 5. Dissipation test results for Lafourche site.

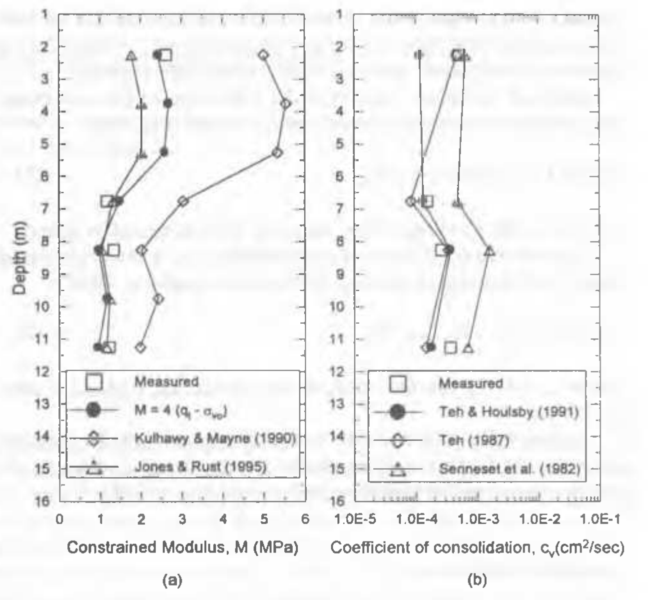

Figure 7. Comparison between measured and predicted values for Lafourche site

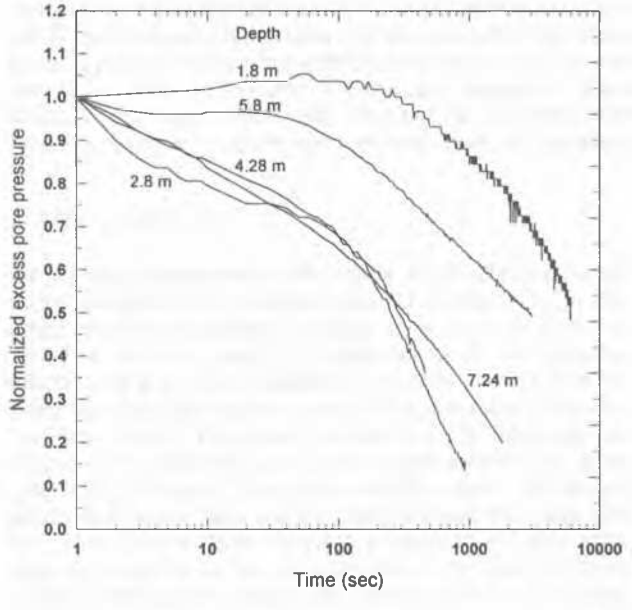

Figure 6. Dissipation test results for New Iberia site.

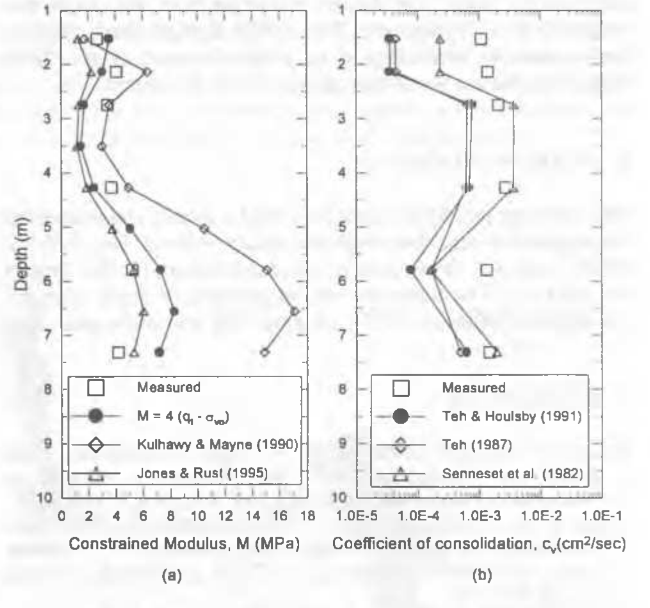

Figure 8. Comparison between measured and predicted values for New Iberia site

Based on the current study, The following relation is proposed to predict M from q_t:

$$M= 4 \cdot (q_t - \sigma_{vo}) \quad (3)$$

Figures 7a and 8a present comparison between measured and predicted constrained modulus from equations 1 through 3.

Several empirical, semi-empirical, and analytical interpretation methods have been proposed to assess the coefficient of consolidation, c_v, that is used to calculate the rate of settlement of soils, from the piezocone dissipation test data

Teh and Houlsby (1991) proposed the following expression to predict of the horizontal coefficient of consolidation, c_h(piezo):

$$c_h(\text{piezo}) = (T^*_{50} r_o^2 \sqrt{I_r}) / t_{50} \quad (4)$$

where T^*_{50} is a modified time factor at 50% dissipation, t_{50} is the time for 50% dissipation, r_o is piezocone radius, $I_r= G/s_u$ is the rigidity index, G is the shear modulus, and s_u is the undrained shear strength.

Teh (1987) proposed a method to interpret c_h from the plot of pore pressure dissipation on square-root time as follows:

$$c_h(\text{piezo}) = (m / M_G)^2 . \sqrt{I_r} . r_o^2 \quad (5)$$

where m is the gradient of the initial linear dissipation, M_G is a gradient of dissipation curve for a given penetrometer geometry and filter location (M=1.63 for U_1 and 1.15 for U_2).

Senneset et al. (1982) suggest an equation to predict c_h(piezo) from the dissipation rate diagram as follows:

$$c_h(\text{piezo}) = \lambda_c r_o^2 \left| \Delta\dot{u} / \Delta u_c \right| \quad (6)$$

where λ_c is the rate factor obtained as a function of the ratio of pore pressure dissipation, $\Delta u/\Delta u_c$ (Senneset et al., 1982), $\Delta \dot{u}$ is the rate of dissipation, and Δu_c is the excess pore pressure.

Baligh & Levadoux proposed the following relation to transfer c_h(piezo) to normally consolidated condition c_h(NC)

$$c_h(NC) = c_h(piezo).(c_r / c_c) \qquad (7)$$

where c_r is the swelling index, and c_c is the compression index.

The vertical coefficient of consolidation, c_v is then calculated using the following expression (Baligh & Levadoux, 1986):

$$c_v(NC) = (k_v / k_h)\, c_h(NC) \qquad (8)$$

where k_v and k_h are the vertical and horizontal hydraulic conductivities.

A comparison between the measure and predicted c_v values using the above-discussed methods are presented in Figures 7b and 8b for Lafourche and New Iberia sites respectively.

5 CONCLUSIONS

Results of this study showed that the consolidation parameters can be reasonably predicted from the piezocone penetration and dissipation tests and hence provide a continuous profile of these parameters with depth. The proposed expression for the constrained modulus gives better prediction than the other two methods. In Lafourche site, Teh (1987) method shows the best performance in predicting of c_v, while Senneset et al. (1992) method shows the best performance in New Iberia site.

6 ACKNOWLEDGMENT

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