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Soil profiling from rheological CPT data

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Abstract

First results of a research are presented indicating that the simple rheological type cone penetration tests can be used for soil profiling. This test can be performed simultaneously with the pore water pressure dissipation test, one more measuring channel is needed.

Keywords: dissipation test, cone penetration test, soil profiling

1. Introduction

The aim of the research is to get more information from the dissipation tests by using mathematically precise evaluation methods. The in situ dissipation tests (except the pore water pressure dissipation test) are not used in the lack of proper evaluation methods (Table 1).

1.1 Types of dissipation tests

The CPT can be used in a logging and a rheological testing mode. Short dissipation tests were made at the technical stops of the steady penetration in the case of the CPT Sz832 equipment. In these stops the time variation of the local side friction and the cone resistance was recorded for a few seconds – minutes. Recently, the dissipation is measured by the MEDUSA DMTA at the technical pause between the stop of the steady penetration and the “standard A reading” up to 30 s elapsed time, where the time variation of the A reading is recorded in the first 30 seconds.

Table 1. Types of dissipation tests made with in situ equipment, only the pore water pressure test of dissipation tests are evaluated in the practice.

Measured variable	Notation	Name
Pore water pressure	CPTu u_2 u_3 etc.	pore water pressure dissipation
Total stress *and pore water pressure	PSL* DMTA DMTC	piezo-lateral stress dissipation A-dissipation C-dissipation
Shaft f_s and tip resistance q_c	CPT f_s CPT q_c	simple f_s dissipation simple q_c test

1.2 Goal of paper

This research was initiated by the facts that the total stress, shaft and tip resistance dissipation tests made by the cone penetration tests (Table 1) can not be evaluated and properly used. In this work the short dissipation tests made at the technical stops of the steady penetration with the CPT Sz832 equipment was analyzed. A radial consolidation model was used to explain the results (see Fig. 1.)

Table 2. Plasticity and void ratio soil parameters of the layers

	*I*p [%]	*e*[-]
Mo	7.4	0.68
Medium clay	20.	0.76
Fat clay	36.3	0.85

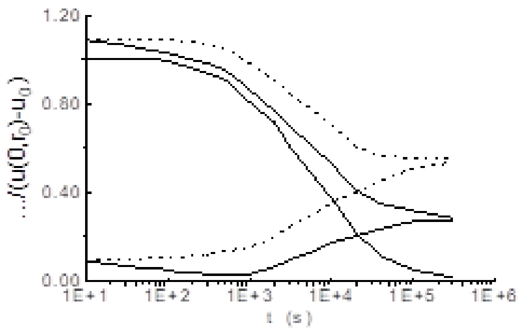

Figure 1. The solution of the joined model (solid lines) and the coupled consolidation model otal stress model (dashed lines) [3, 4]

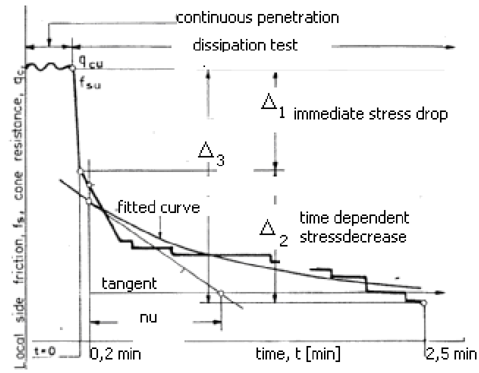

Figure 2. S832 CPT short f_s and q_c dissipation tests, analogue outputs with empirical parameters(from Imre, 1995 [1])

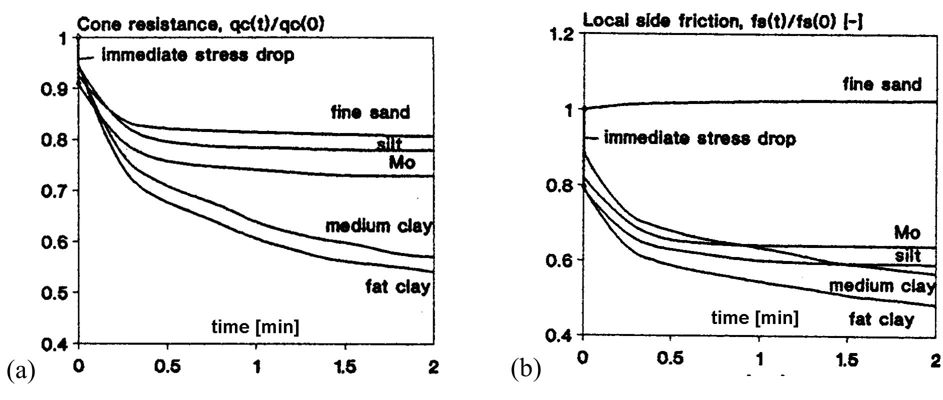

Figure 3. Soil group mean curves in terms of time with approximate time scale [3]. (a)]. Measured mean q_c-time relations (b) Measured mean f_s-time relations. Note the qualitatively different response for sandy and clayey soils.

2. Empirical modeling

2.1 Typical features of mean dissipation curves

A short dissipation test can be performed with the S832 equipment in every 50 cm. This is done in such a way that the steady penetration is stopped due to technical reason, so that the rod is released then re-clamped. During this the local side friction f_s and the cone resistance q_c are continued to be measured. Figure 1 shows the typical S832 CPT short dissipation output which is an analogue record with saw-tooth-like features for both the short f_s and q_c dissipation tests (Imre, 1995, [1]).

The short dissipation output typically consisted of an immediate stress drop and a time dependent stress decrease period. According to our interpretation, this is due to the dynamic – static transition. There is a so called dynamic amplification factor expressing the ratio of the dynamic / static load, the load decreases if loading changes from dynamic to static, different during steady penetration and when penetration stops (Németh-Kocsis, 2013, [2]).

A total of 135 rheological type cone penetration test records associated with the ten boreholes, selected from the data bank of the Geodesical and Geotechnical Institute FTV, were evaluated such that dissipation test groups of soil groups were defined from plasticity index I_p.

The mean dissipation tests of soil groups indicated that the time variation of the local side friction short dissipation curves initially showed an immediate stress drop, then the shaft resistance decreased or increased during the time dependent dissipation period in the first minute for plastic or granular soils, respectively. The mean dissipation tests indicated that the time variation of the cone resistance short dissipation curves showed a time dependency which was controlled by the soil plasticity in intact layers. These results can be used for soil identification (Figs. 2, 3, [1]).

2.2 Empirical parameters

The immediate stress drop Δ_1 was generally left out in the empirical evaluation, the time dependent stress decrease period was characterized by two parameters, the time dependent stress drop Δ_2 and the initial stress variation rate parameter ν. These empirical parameters are used for the characterization of the simple rheological-type cone penetration test records (Imre 1995). One is the cone resistance parameter Δq_{c2} and, local side friction sounding parameter Δf_{s2} (Fig 1) given by :

$$\Delta q_{c2} = q_c(t_i) - q_c(t_i + \Delta t); \text{ and } \Delta f_{s2} = f_s(t_i) - f_s(t_i + t_1); \quad (1)$$

where t_i is the time when the immediate stress drop is ended, and t_1 is a reference time.

An additional sounding parameter ν was defined by fitting the relaxation equation of the Poynting-Thomson model on the stress σ measured during the time dependent period (Fig. 1). The equation:

$$\sigma(t) = \sigma_\infty + (\sigma_0 - \sigma_\infty)\ e^{-\frac{t}{\upsilon}} \quad (2)$$

Factor analysis was made with the in situ and lab test data indicated strong correlations between the empirical parameters, permeability and plasticity index I_p, except at layer boundaries or in the case of secondary structure (if the permeability is larger than expected from soil type).

3. Modelling, parameter analysis

The foregoing results concerning the time dependent stress decrease period were explained by a parameter analysis made with the joined model shown in Figure 1 (ie., the superposition of a coupled consolidation model and an empirical relaxation model, Imre et al. 2010 [3]).

3.1 A coupled consolidation model

The system of equation of the consolidation part-model was developed on the basis of the field equations of the coupled consolidation Analytical solutions were made assuming new boundary conditions for the dissipation test problem [3]. The qualitative features of the analytical solution were determined by the initial condition for the pore water pressure, the total stress solution can be expressed in terms of the pore water pressure solution ([3]). For example, the transient part of the total / effective normal stress on the shaft expressed in terms of the pore water pressure and the space mean pore water pressure:

$$\sigma_r^t(t, r_0) = u_{mean}(t) \tag{3}$$

$$\sigma_r^{t'}(t, r_0) = u_{mean}(t) - u(t, r_0) \tag{4}$$

In the modelling of the total stress changes at r_0 it is assumed that the constitutive equation is time dependent, and a relaxation part-model can be applied as follows:

$$\sigma_r \ (t, r_0) = \sigma_r^c \ (t, r_0) + \Delta\sigma_r^r \ (t, r_0) \tag{5}$$

where superscript c and r indicate consolidation and relaxation, respectively. It is assumed that the relaxation term can be described as follows:

$$\Delta\sigma_r^r \ (t, r_0) = -s \cdot \sigma(0, r_0) \cdot \log\frac{t}{t_1}; t > t_1 \tag{6}$$

where s is the coefficient of relaxation, and t_1 is the delay time. The radial total stress at r_0 decreases with time due to consolidation and also relaxation. The effective stress at r_0 increases due to consolidation and decreases due to relaxation, the net effect depends on the model parameters, the coefficient of consolidation (c) and the coefficient of relaxation (s) both depending on soil type.

3.2 Explaining the empirical parameters

radial effective stress response acting at the shaft-soil interface was simulated with the joined model in such a way that the values of the coefficient of consolidation (c_v) and the coefficient of relaxation (s) were varied ([4]). The time variation of the radial effective stress was a decrease or increase during the first minutes for plastic or granular soils, respectively. Similar to the shaft resistance during short dissipation, the simulated empirical parameters indicated the same dependence on the plasticity index I_p.

The simulated radial normal stress - time functions characterized with two parameters (Δf_{s2}, ν) were defined similarly to the foregoing two sounding parameters (Δf_{s2}, ν). Results are shown in Figures 6, 7. The relations concerning the simulated sounding parameters (Δf_{s2}, ν) - coefficient consolidation (c_v) were compared with the relations concerning the empirical sounding parameters (Δf_{s2}, ν) - plasticity index (I_P). In this way the correlation between sounding parameters and the plasticity index (I_p) shown in Figures 4 to 5 was explained theoretically.

4. Discussion, conclusion

A short dissipation test can be performed with the S832 equipment in every 50 cm. This is done in such a way that when the steady penetration is stopped, the rod is re-clamped, the local side friction f_s and the cone resistance q_c continue to be measured.

According to the results, the time variation of the short dissipation test can be used for soil type and layer boundary identification. The main tendencies were explained by a precise model. The new model allowed the development of evaluation methods [3 to 4].

Recently it was revealed that some similar short dissipation test can be made with DMTA ([5], see Figure 8), can also be explained. The total stress decrease/increase is explained by the dissipation of positive/negative initial excess pore water pressures (see Eq (3)) .

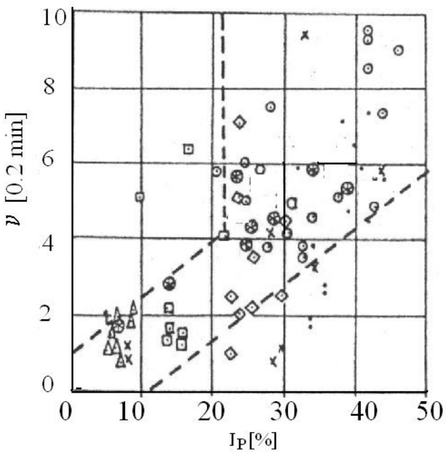

Figure 4. Empirical ν- I_P relation – from measured q_c-time relations

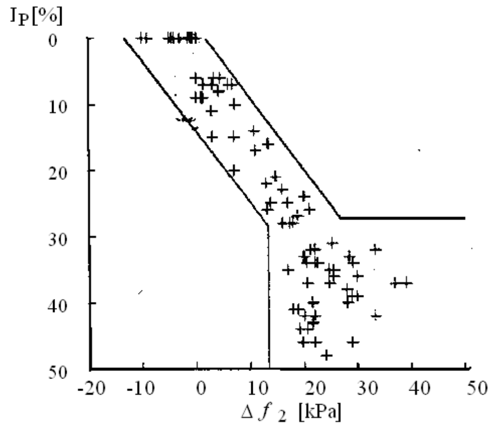

Figure 5. Empirical Δf_{s2}- I_P relation– from measured f_s-time relations

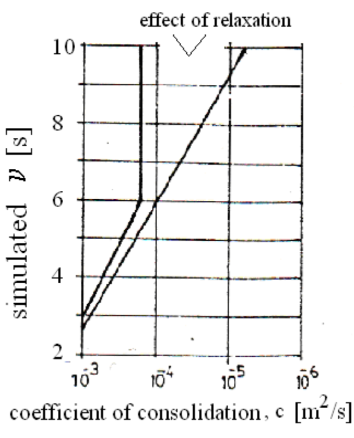

Figure 6. ν- I_P relation determined from simulation.

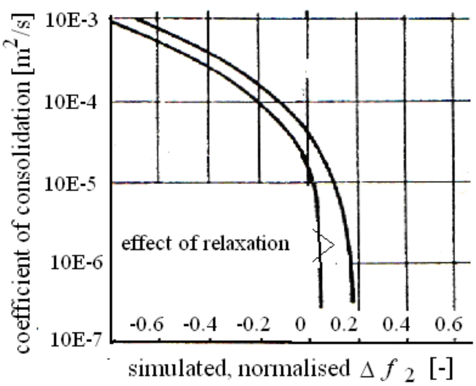

Figure 7. Δf_{s2}- I_P relation determined from simulation.

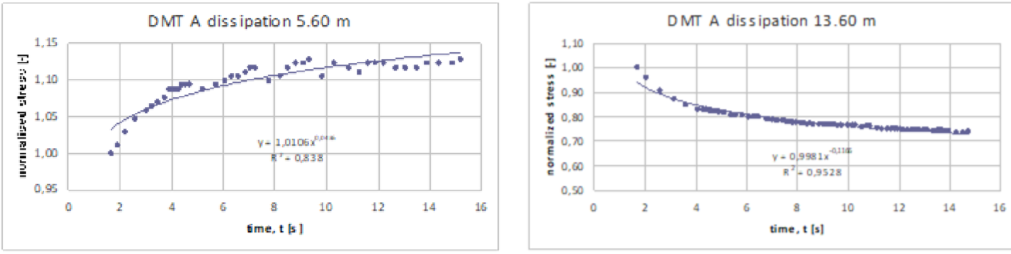

Figure 8. DMTA short dissipation test, (a) sand behaviour, (b) plastic soil behavior [6]

5. References

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