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Geotechnical characterization of peat and gyttja by means of different in-situ tests

Caractérisation géotechnique de tourbe et de gyttja au moyen de différents essais in situ

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ABSTRACT The paper comments the usability of classification charts developed for CPTU and DMT tests for the identification of organic soils. The results of the evaluation of shear strength and deformation parameters of organic subsoil by in situ tests were also interpreted. The results of the investigations confirmed the necessity to use different correction factors for estimation of constrained modulus from CPTU and DMT tests. The analyses of the relationship between undrained shear strength from vane test and CPTU proved that N_{kt} factor is strongly dependent on the type of organic soil and variables which define this soil.

RÉSUMÉ Le document commente la facilité d'utilisation des tableaux de classification mis au point pour les tests de CPTU et DMT pour l'identification des sols organiques. Il présente également les résultats de l'évaluation les parametres de résistance et de déformation au cisaillement du sous-sol organique par des essais in situ. Les résultats des enquêtes ont confirmé la nécessité d'utiliser différents facteurs de correction pour l'estimation du module limité de tests de CPTU et DMT. Les analyses de la relation entre résistance au cisaillement de l'essai de l'aube et CPTU prouvé que facteur N_{kt} dépend fortement du type de sol organique et les variables qui définissent ce sol.

1 INTRODUCTION

In the case of subsoil composed of organic soils we face two research problems. The first is to identify the zone and range of these soils in the subsoil, while the next problem is connected with the determination of their mechanical properties. The static penetration method (CPTU) is particularly suitable for the determination of zones of organic soils in subsoil, since characteristics recorded in this test present in a continuous manner changes in properties of the soil medium. When supplemented with dilatometer tests (DMT) and vane tests (VT) CPTU facilitates a comprehensive determination of mechanical parameters of organic subsoil at the geostatic state of stress.

Classification systems developed for CPTU e.g. by Robertson (1990) and for DMT (Marchetti1980) may be used to identify organic soils in the subsoil. Studies conducted by Młynarek (Młynarek et al. 2008) showed that these systems in the case of organic soils and gyttja have to be verified using laboratory analyses, since the diversity and high variability of properties of these soils have a different effect on recorded values of cone resistance in CPTU and measured values of pressure p_0 and p_1 in DMT. The same problem is observed in the determination of mechanical parameters of peats and gyttja if we use empirical relationships established for mineral soils to determine undrained shear strength and constrained modulus. These problems are discussed in this paper.

2 CHARACTERIZATION OF THE STUDY AREA

Tests were conducted in three locations in Poland with organic soils originated from the Holocen. Soils of different types predominated in each of the test sites; in Poznań it was peats, in Stargard Szczeciński - gyttjas, while in the Żuławy area it was mainly organic mud (Fig. 1).

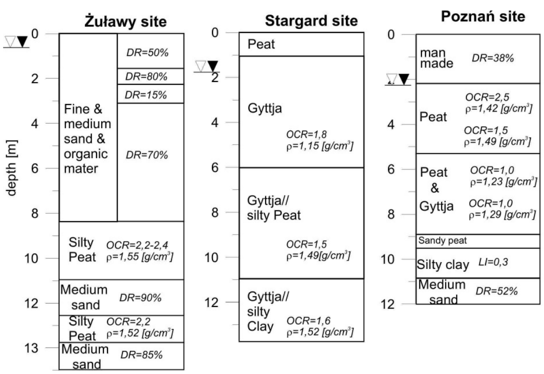

Figure 1. Geotechnical profiles of the test sites.

In each location CPTU, DMT and VT tests were performed and samples with an undisturbed structure were collected for laboratory analyses. Samples were collected using a MOSTAP apparatus by a. p. van den Berg as cores of 1 m in length and 65 mm in diameter. As an example the characteristics from CPTU and DMT for the Stargard location are presented in Fig. 2.

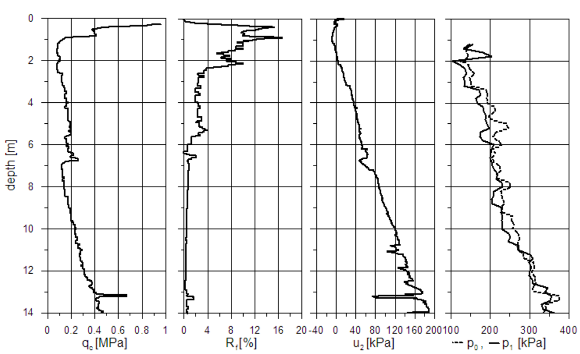

Figure 2. Typical CPTU and DMT characteristics for Stargard Szczeciński test site.

3 IDENTIFICATION OF TESTED SOILS ON CPTU AND DMT CLASSIFICATION SYSTEMS

Robertson (2009) stated that the first step in the interpretation of subsoil properties based on in situ tests should be to use classification systems such as soil behavior charts in order to determine the direction of interpretation for CPTU and identify zones of the soils in subsoil. While in mineral soils such a procedure in most cases makes it possible to determine the general type of soil and its engineering properties (Ramsey 2010), as it is shown by experiences from Poland, in the case of organic soils not all testing methods provide satisfactory results (Młynarek et al. 2008 Lechowicz & Szymański 2002).

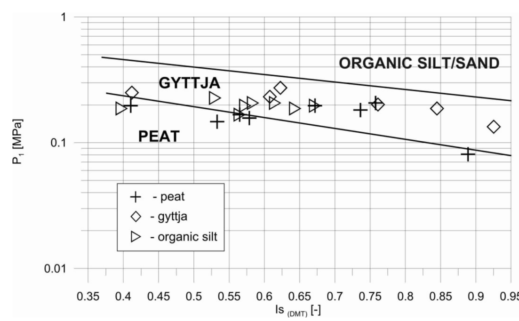

Figure 3. Position of tested soils in the classification diagram by Rabarijoely (2013).

As a rule, a good identification of organic soils is ensured by the presentation of DMT results in the classification diagram proposed by Marchetti and Craps (1981) (Młynarek 2007, 2010). In the case of analyzed soils this observation was partly confirmed. Both tested peats and gyttjas are located in the lower limit zone of soils for mineral soils, in certain cases it was slightly above the limit defined by Marchetti for organic soils. A very good and effective supplementation to this system is provided by the systems developed by Rabarijoely (2013). Those system facilitate more precise separation of soils in the group into gyttjas, peats and organic mud. Such a possibility is also partly confirmed by this study, in which in this diagram gyttjas are relatively well separated from peats (Fig. 3).

In contrast to DMT, in CPTU there are many classification charts available, created within the last several decades (Lunne et al. 1997). They are mostly systems using values of cone resistance and sleeve friction as well as their derivative parameters, such as friction ratio R_f or normalized cone resistance Q_t. One of the latest and at the same time the most frequently applied is the extended diagram by Robertson (2009), which original version dates back to 1990 (Robertson 2010). In the case of typical Holocene organic soils found in Poland, very often these soils are not correctly identified by that system (Młynarek et al. 2008). This observation is also confirmed by the results of the current study. Investigated soils should mostly be classified, in accordance with the Eurocode 7 definition, as low organic (< 20% I_{om}), but they are located away from the area marked for organic soils (Fig. 4).

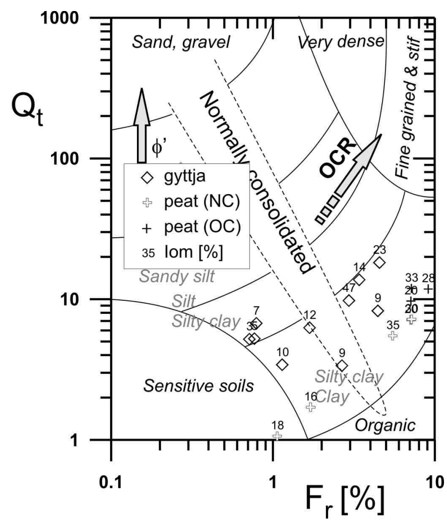

Figure 4. Position of tested organic soils on the soil behavior chart by Robertson (1990) on the background of contents of organic matter I_{om}.

In order to determine factors affecting the position of soils in the soil behavior chart by Robertson, the location of these soils was verified in the chart proposed by Schmertmann (1969). This system does not use normalized values of CPTU parameters, but their original values. In the case of analyzed organic soils the Schmertmann system is definitely more effective (Fig. 5). All soils are located in the zone of weak soils, while a trend may also be observed for the location of data to approach the zone of organic soils with an increase in the contents of organic fractions. The contents of organic fractions were reference data and they were determined in laboratory analyses.

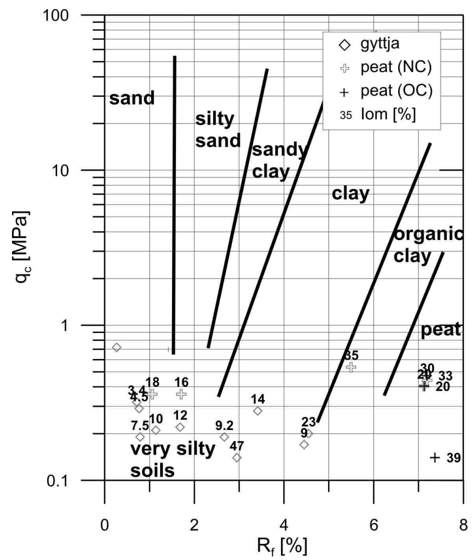

Figure 5. Location of investigated soils in the classification diagram by Schmertmann (1969), numbers denote contents of organic matter I_{om}.

The DMT classification systems and the system proposed by Schmertmann for CPTU make it possible to determine and explain causes for the low effectiveness of the systems using normalized and corrected values of cone resistance (Qt) to identify suborganic soils in the subsoil.

4 CONSTRAINED MODULUS OF ANALYZED SOILS FROM CPTU AND DMT

In the determination of constrained modulus of organic soils from CPTU the relationships developed for mineral soils are typically used (Sanglerat 1972, Mayne 2001), that can be described by general formula :

$$M_0^{CPTU} = \alpha \, (q_t - \sigma_{v0}) \qquad (1)$$

where: q_t – corrected cone resistance, σ_{v0} – overburden stress, α – calibration factor.

In the calculation of the constrained modulus of elasticity, which corresponds to the oedometric modulus, from the given formulas a problem appears in the determination of the index α. It results from data in available literature that the index α changes depending on the type of organic soils within a large range from 0.4 to 1.5 for peats and gyttjas and from 1 to approx. 8 for low organic soils.

Constrained modulus M_0 from DMT is determined using formula proposed by Marchetti (1980) -:

$$M_0^{DMT} = R_M \cdot E_D \quad (2)$$

where E_D – dilatometer modulus.

In the determination of calibrated values the modulus M_0^{DMT} of analyzed organic mud and peats oedometric tests were applied, which were conducted for organic soils from Poznań (Młynarek et al. 2006). Values of pressures p_0 and p_1 in the conducted in-situ tests exhibited large measurement uncertainties. This pertains particularly to gyttjas. In these soils frequently the values of pressures p_0 and p_1 did not differ sufficiently for the interpretation (Fig. 1). This fact prevented determination of values for modulus E_D. For this reason in the analysis of dependencies between moduli from CPTU and DMT a small number of observations was available.

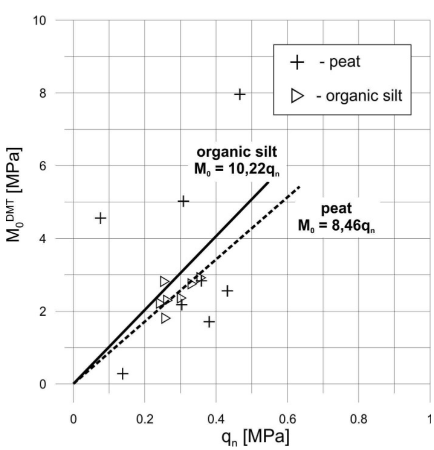

Figure 6. Correlation between constrained moduli M_0 from DMT and q_n value from CPTU.

In order to investigate a relationship between moduli M_0^{CPTU} and M_0^{DMT} a dependence was constructed between the modulus from DMT and net cone resistance q_n (Fig. 6). This dependence makes it possible to formulate a general conclusion, which confirms a pre-formulated opinion that the index α depends clearly on the type of organic soil. Estimated values of this index for peats amount to 10.2, while for organic mud they are 8.5. It also results from Fig. 6 that the investigated dependence has a relatively low statistical evaluation. This fact obviously results from two factors, i.e. measurement uncertainties connected with the determination of q_t, p_0 and p_1 values in these soils, as well as low precision of assessment of values of moduli in oedometric tests due to the anisotropy of structure in the investigated soils.

5 SHEAR STRENGTH OF ANALYZED ORGANIC SOILS FROM CPTU AND VT

Lunne et al. (1997) formulated an opinion that no single undrained shear strength s_u exists. In the case of mineral soils the value of s_u depends on the mode of failure, soil anisotropy, strain role and stress history. In organic soils there are additional variables (Młynarek 1978). In order to determine s_u theoretical solutions are applied, which Lunne et al. (1997) grouped into five classes, while all theories result in relationships between cone resistance and s_u takes the form:

$$q_t = N_{kt}\, s_u + \sigma_{v0} \quad (3)$$

Determination of index N_{kt} requires reference tests (Mayne 2006). In the group of these studies various schemes of laboratory analyses exist for triaxial test or vane test (VT). The values of N_{kt} depending on the reference test are greatly varied (e.g. De Groot & Luteneggar 2003; Mayne 2006).

In order to determine values of s_u the DMT method is also used. In contrast to CPTU, the basis for the establishment of s_u^{DMT} values is provided solely by empirical dependencies, constructed on measured values of pressures p_0 and p_1 (Marchetti 1981; Lechowicz & Szymański 2002).

It results from available literature that the value of N_{kt} for CPTU changes in the range from 12 to 21 (Long & Boylan 2012). Młynarek et al. (2006) showed that the value of this index amounting to 12 corresponds to the maximum shear strength τ_{fu}^{max} from VT, while N_{kt} = 21 for the value of residual strength from this test.

In the conducted analysis undrained shear strength τ_{fu}^{max} from VT was adopted as the reference test for the determination of undrained shear strength from CPTU. The analysis was conducted in two stages. In the first stage the value of net cone resistance q_n was compared with the value of s_u at respective levels of σ_{v0} in individual groups of soils (Fig. 7). This relationship is curvilinear and in the investigated range of quantification for q_n the relationship between q_n and s_u may be described by equations:

- for organic mud: $s_u = 7.3e^{4,11qn} + 7.0$ (4)

- for gyttjas: $s_u = 6.5e^{4,11qn} + 5.5$ (5)

- for peats: $s_u = 11.8e^{4,11qn}$ (6)

where q_n in MPa and s_u in kPa.

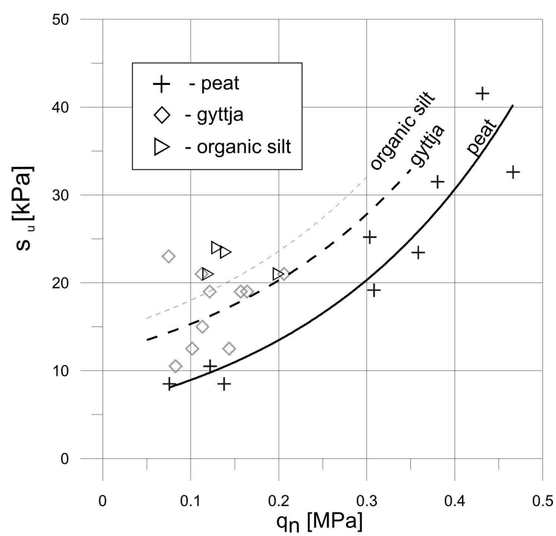

Figure 7. Differences in correlation trends between maximal shear strength s_u from VT and net cone resistance q_n for different soil types.

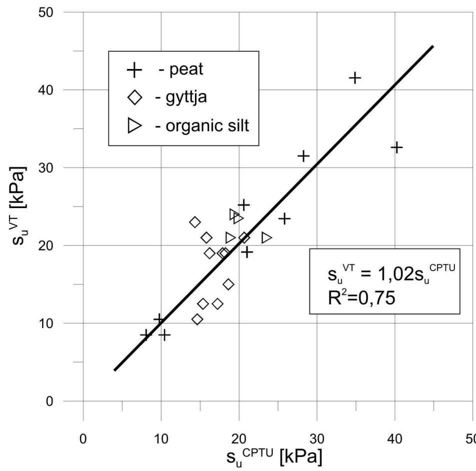

Figure 8. Comparision of undrained shear values derived from vane test s_u^{VT} and from piezocone test s_u^{CPTU} , calculated on the basis of N_{kt} values given bellow.

For practical reasons it is easier to use mean values of the index N_{kt}, which algebraically specify the slope of the straight line describing the relationship between strength s_u and cone resistance q_n. Assuming this, the following N_{kt} values can be adopted: N_{kt} = 7,0 (organic mud), 7,9 (gyttja) and 12,9 (peat).

Obtained values of the index N_{kt} perfectly confirm previously recorded values of N_{kt} for soils from Poland (Młynarek et al. 2006; Lechowicz & Szymański 2002). A statistical assessment of quality of the dependence between undrained shear strength from VT and CPTU is presented in Fig. 8. An analysis was conducted jointly for 3 groups of tested soils. In order to determine values of s_u from CPTU a coefficient calculated from equations 4, 5 and 6 was introduced. The value of the correlation coefficient of 0.75 proves high statistical significance of this relationship.

6 CONCLUDING REMARKS

Analyses of organic subsoil, which were conducted by CPTU and DMT, make it possible to formulate an opinion that identification of the zone and range of organic soils in the subsoil is feasible using classification systems from CPTU and DMT. The effectiveness of the systems varies due to the complex number of factor affecting parameters measured in CPTU (e.g. q_c, f_s) and DMT (p_0, p_1). The greatest consistency with the laboratory assessment of the type of tested peats, gyttjas and organic mud was obtained with the use of the DMT system by Marchetti and the CPTU system by Schmertmann.

Significant observations in the determination of the constrained moduli from CPTU and DMT show that the empirical coefficient α is dependent on the type of organic soil, which is described by several parameters such as organic contents, contents of carbonates and probably the mineral fractions. This conclusion may be formulated if the constrained moduli from DMT are adopted as reference in the determination of constrained modulus from CPTU. Very similar observations may be formulated for the determination of undrained shear strength from CPTU parameters if this strength is referred to strength from the vane test VT τ_{fu}^{max}. The index N_{kt} proved to be strongly dependent on the type of organic soil and the variables, which define this soil.

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