Interrelationship between deformation moduli from CPTU and SDMT tests for overconsolidated soils

La corrélation entre le module de déformation de CPTU et de tests SDMT pour les sols surconsolidés

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ABSTRACT: At the area of Poland glaciations caused overconsolidation in deep layers of the subsoil. It is imperative to take into account this fact to calculate the differential settlements of structures subjected to great moments, such as wind turbines. Paper presents the results obtained from the deformation characteristics estimated from CPTU and SDMT tests in clays Vistula and Riss glaciations with interbedded layers of fluvioglacial sands.

RÉSUMÉ : En Pologne les glaciers ont provoqué la surconsolidation des couches profondes. Il est impératif de tenir compte de ce fait pour calculer les tassements différentiels des structures soumises à des moments importants telles que les eoliennes. On présente les résultats obtenus à partir des caractéristiques de compressibilité évaluées à partir des essais classiques CPTU et SDMT dans des argiles de Vistula et Riss avec intercalations de couches de sables fluvioglacieres.

KEYWORDS: deformation modulus of overconsolidated soils, CPTU, SDMT

1 INTRODUCTION

Determination of representative values of constrained moduli and deformation moduli of soils found in the subsoil is a topical research problem. It is generally known that deformation and strength parameters may be determined using laboratory and in situ tests. In the laboratory method the key element in the evaluation of quality in case of e.g. an oedometric test is connected with the quality of samples collected for analyses (Młynarek 2003, Tanaka 2007). This problem is particularly evident in overconsolidated deposits. This fact indicated that soil deformation parameters need to be determined in situ using DMT, CPTU or SDMT method. Static penetration plays a particularly important role in forecasting values of deformation modulus of soils, as with the use of this method we may obtain a continuous picture of changes in moduli in the subsoil in a 1-D or 3-D system (Młynarek et al. 2007). The other testing techniques determine values of moduli pointwise. In CPTU the constrained deformation modulus is determined from correlation relationships. For this reason calibration or assessment of quality of the identification of this modulus using SDMT is of considerable practical importance (Marchetti 1999). This paper discusses this problem together with an assessment of interrelationships between modulus G_0 from CPTU and SDMT tests.

2 INVESTIGATIONS OBJECTS

Subsoil structure in Poland is highly complicated in terms of their stratigraphy and lithology. The contact zone of the building structure with the subsoil is comprised primarily of deposits from the two last glaciations, as well as different forms of glacilacustrine deposits.

Figure. 1 Location of investigated plots in the region of Poland

The subsoil of the investigated area (Fig. 1) comprises glacial tills of the Riss and Vistula glaciations, Quaternary and Pleistocene soils and also Holocene fluvial deposits. The effect of diversification in terms of the genesis and lithology of soils in the discussed locations is shown in CPTU classification systems (Lunne et al. 1997) (Fig.2). In turn, Figure 3 presents examples of geotechnical profiles and results of CPTU and DMT. CPTU tests were performed using a Hyson 200 kN static probe by ap van den Berg, while dilatometer tests were performed with an original seismic dilatometer by Marchetti.

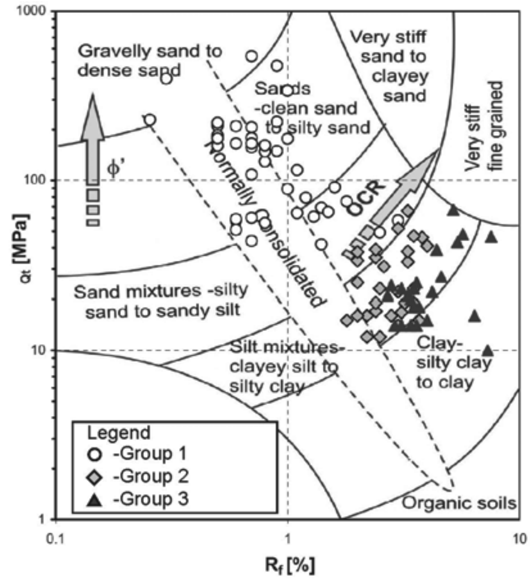

Figure 2. CPTU Soil classification chart (Lunne et al. 1997).

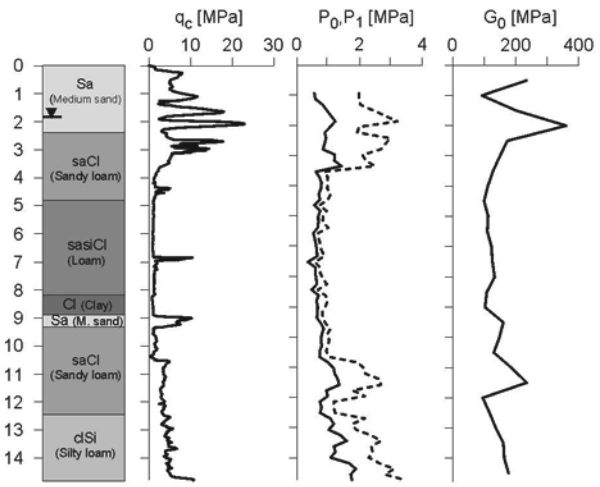

Figure 3. Geotechnical profile with CPTU and SDMT characteristics.

3 CONCEPT FOR THE IDENTIFICATION OF THE SOIL PRECONSOLIDATION EFFECT IN SUBSOIL

Identification of the relationship between the genesis of subsoil and a measure determining the overconsolidation rate, eg. overconsolidation ratio OCR, is a complex problem. Of the two discussed methods, CPTU and SDMT, the chance to determine reliable OCR values is greater for SDMT, since the effect of preconsolidation is strongly related with the geostatic stress σ_{ho}. For this reason in order to obtain a continuous picture of changes in OCR of the subsoil in the examined locations calibration was performed for OCR values determined using cone resistance Q_t, applying OCR values determined by SDMT. In the approach three groups were identified for the discussed locations: with complete drainage – sands (group I), intermediate soils (group II) and clays (group III) (Fig. 2). The groups of intermediate soils and clays were identified based on the content of the clay fraction and the plasticity index I_p.

The values of OCR from dilatometer testing for soils of groups II and III were calculated from the relationship (Marchetti (1999):

$$OCR = 0.5\ (K_D)^{1,56} \qquad (1)$$

where: K_D – horizontal stress index

The value of OCR for soils in CPTU testing was determined using the nomogram proposed by Wierzbicki (2010), in which OCR values are established on the basis of cone resistance Q_t and the plasticity index of soil I_p is considered. In the case of non-cohesive soils OCR values were also assessed applying a diagram proposed by Wierzbicki (2010). This diagram uses both tests, i.e. CPTU and DMT, as it is constructed on the basis of the formula proposed by Mayne (2000).

$$OCR = 5.04\ K_0^{1,54} \qquad (2)$$

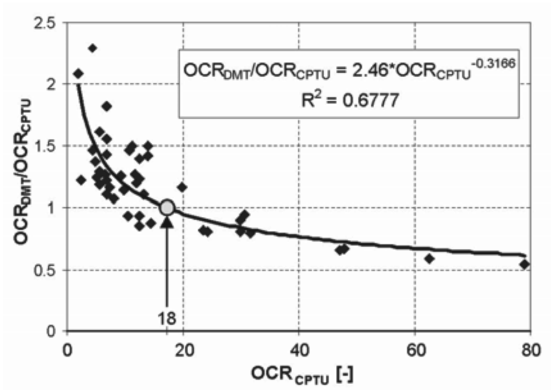

Figure 4. Relaationship between coefficient OCR_{DMT}/OCR_{CPTU} and coefficient OCR_{CPTU} (group II and III).

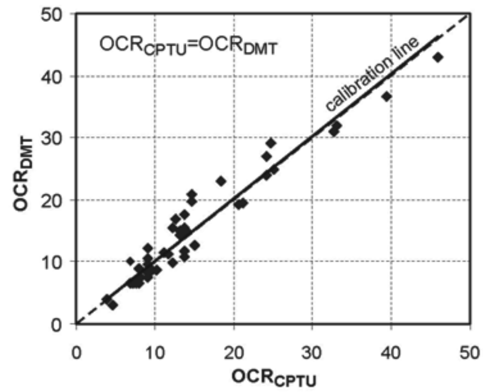

Figure 5. Relationship between OCR_{DMT} and OCR_{CPTU} after calibration (group II and III)

It results from Figs. 4 and 5 that the relationship between OCR values from both tests has a high statistical evaluation. This fact makes it possible to construct a direct dependence between cone resistance Q_t and OCR from SDMT (Fig. 6). Values of OCR determined from this dependence were used to supplement data for statistical analysis and next in the profiles at different levels σ_{v0}, where SDMT testing was not performed.

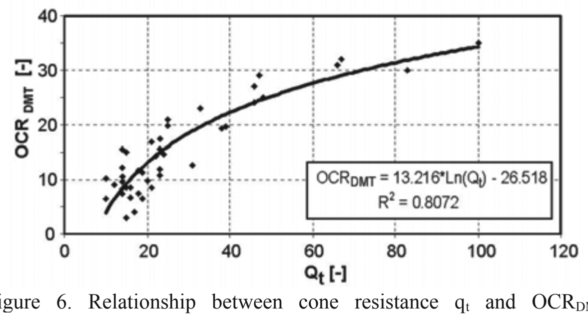

Figure 6. Relationship between cone resistance q_t and OCR_{DMT} coefficient.

4 THE RELATIONSHIP BETWEEN DEFORMATION MODULI AND SHEAR MODULI FROM CPTU AND SDMT

4.1 *Constrained deformation modulus – M*

Concepts for the determination of modulus M from CPTU and SDMT differ fundamentally. This results from the different techniques of parameter measurements, which are introduced to the relationship between the measured parameter and modulus M. Another factor is connected with the different location of CPTU and SDMT on the characteristics shear modulus σ_0 – shear strain (Mayne 2000). In the case of CPTU modulus M is determined from the relationship (Sanglerat 1972, Mayne 2000)

$$M_{CPTU} = \alpha_1 (q_t - \sigma_{v0}) \qquad (3)$$

In DMT the dilatometer modulus E_D is the starting point for the determination of modulus M_{DMT} (Marchetti 1999)

$$M_{DMT} = f(E_D, K_D, I_D) \qquad (4)$$

where K_D – horizontal stress index according to Marchetti (1999)

A modified original formula according to Marchetti for the determination of R_M for preconsolidated glacial tills was given by Lechowicz et al. (2011).

4.2 *Shear modulus G_0*

A function which describes the relationship between modulus G_0 or G from SDMT or SCPTU and variables which describe parameters of the soil medium was given by Lee and Stokes (1986), Jamiolkowski et al. (1995)

$$G_0 = f(\sigma'_{v0}, e_0, OCR, S_r, C, K, T) \qquad (5)$$

where: (σ'_{v0} – geostatic effective vertical stress, e_0 – initial void ratio, OCR – overconsolidation ratio, S_r – degree of saturation, C- grain characteristics, K – soil structure, T- temperature.

This relationship may be used to forecast values of modulus G_0 directly on the basis of cone resistance Q_t.

4.3 *Analysis of results*

4.3.1 *Constrained moduli M_{CPTU}, M_{DMT}*

To calibrate the relationship between moduli M_{CPTU} and M_{DMT} individual moduli were determined from the following formulas. For the CPTU test according to Mayne (2000) (eq. no. 3).

This formula was verified by oedometric tests. The analysis showed that for the tested loams and clays the mean value of coefficient α_i was close to 8.25.

Modulus M_{CPTU} for non-cohesive soils was calculated from dependencies supplied by Lunne et al. (1997) depending on values q_c and including the degree of preconsolidation in these deposits.

Moduli M_{DMT} were calculated prior to calibration from original formulas proposed by Marchetti et al. (1999).

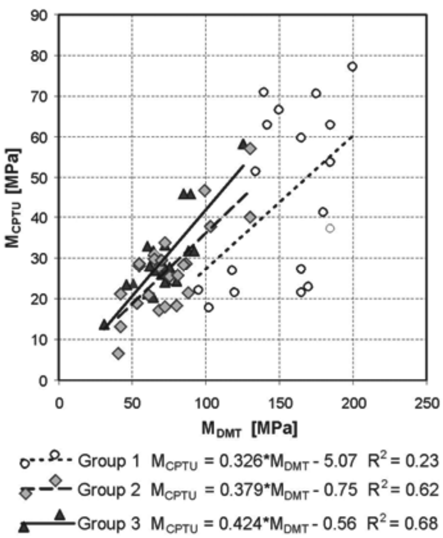

Figure 7. Relationship between constrained modulus M_0^{CPTU} and M_0^{DMT}.

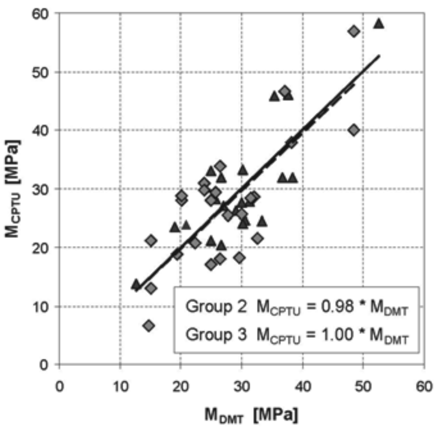

Figure 8. Relationship between constrained modules M_0^{CPTU} and M_{DMT} after calibration.

For preconsolidated deposits the moduli determined by SDMT are higher than those from CPTU (Fig. 7). Obtained relationships fully confirm the opinion by Marchetti et al. (1999) on this subject.

Calibration of both moduli in order to describe their changes in the subsoil with changes in σ_{v0} is presented in Figs. 8. It was assumed in the calibration process that modulus M_{CPTU} is the reference point.

4.3.2 *Shear moduli G_0^{DMT}, G_0^{CPTU}*

The determination of shear modulus from CPTU – G_0^{CPTU} was based on empirical dependencies

- for non-cohesive soils (group 1) (after Hegazy, Mayne 1995)

$$V_s = 12{,}02 \cdot q_t^{0{,}319} \cdot f_s^{-0{,}0466} \qquad (6)$$

$$G_0 = \rho \cdot V_s^2 \qquad (7)$$

- for cohesive soils (groups 2 and 3) relationship determined using multi linear regression

Group 2

$$G_0 = 41{,}44 \cdot q_t + 0{,}31 \cdot G_{v0} + OCR - 1{,}71 \qquad (8)$$

Group 3

$$G_0 = 41{,}20 \cdot q_t + 0{,}37 \cdot G_{v0} + 0{,}88\ OCR - 28{,}53 \qquad (9)$$

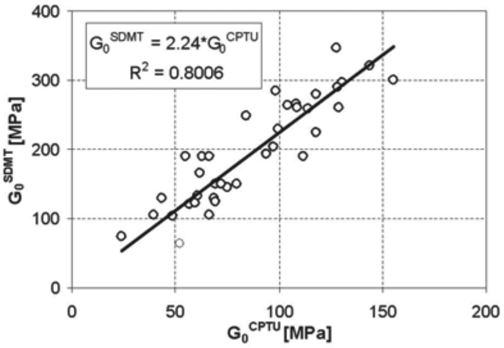

Figure. 9. Relationship between shear modulus G_0^{DMT} and G_0^{CPTU}

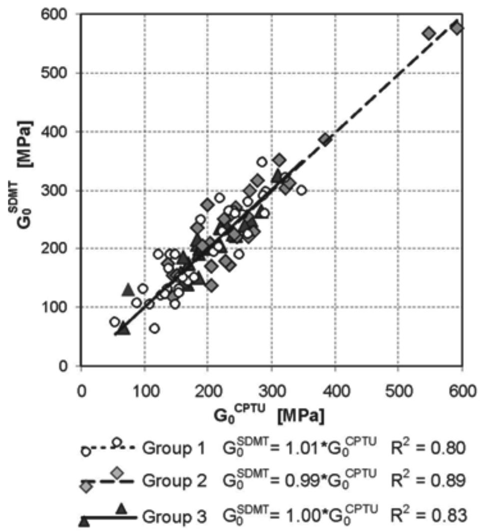

Figure 10. Relationship between measured G_0^{DMT} and G_0^{CPTU} after the calibration.

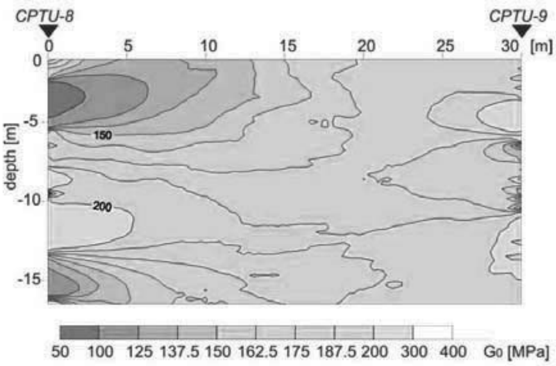

Figure 11. The model of subsoil stiffness calculated on the G_0 values from CPTU, calibrated by SDMT results.

In order to obtain a continuous picture of changes in the shear modulus G_0 the dependence of G_0^{CPTU} was calibrated using measured values of G_0^{DMT} (Fig. 10). Moduli G_0^{CPTU} determined from this relationship may be used in the construction of a model of rigidity for the subsoil composed of soils of varied genesis. An example of such a model for the foundation of a wind turbine is presented in Fig. 11. The model was constructed using Inverse Distance Weighting Method (IDW) according to Młynarek et al. (2007).

5 CONCLUDING REMARKS

On the basis of the conducted investigations it may be concluded that the simultaneous use of CPTU and SDMT provides a continuous picture of changes in rigidity of subsoil composed of soils with diverse genesis. The effectiveness of these methods is emphasized by the high statistical evaluation for the dependence between deformation and shear strength moduli from both tests. However, to determine this dependence it is necessary to apply a calibration function. The calibration function needs to be specified for the soils, which should be grouped depending on their grain size, since this variable also influences relationships between parameters measured in CPTU and SDMT.

After calibration this relationship may be a useful tool in the construction of a model for rigidity of subsoil based on shear strength moduli G_0 or M_0 moduli.

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