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Use of SDMT for the evaluation of the geotechnical parameters of organic soils

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Abstract. The paper presents the results of field and laboratory tests performed on organic soils from the "Zoliborz channel" on the route of the II underground line in Warsaw. Seismic Dilatometer Tests (SDMT) were carried out in order to evaluate the geotechnical conditions in one of the most difficult sites in Warsaw. For comparison, results of SCPT test as well as oedometer tests and triaxial tests were analysed. The problem of evaluating the stress history, undrained shear strength and deformation parameters of organic soils from SDMT is discussed.

Key Words: organic soils, Seismic Dilatometer Tests SDMT, stress history, undrained shear strength, deformation parameters.

Introduction

In situ tests allow the investigation of soils in their natural intact state and stress condition, thus giving more accurate quantification of the stress history, shear strength and deformation parameters in soil profiles.

The overconsolidation ratio OCR, undrained shear strength and deformation parameters are the basic parameters for the geotechnical design of the structure. Determination of these parameters using dilatometer tests is usually based on empirical formulae. However, it should be noted that most of these formulae were established in different countries, therefore regional geotechnical conditions could have substantially affected the empirical relationships.

Due to their high compressibility and non-linear behaviour, organic soils require the application of a different description of behaviour and thus other values of coefficients used in the existing formulae for mineral soils. Experience from organic soils indicates that the stress history and current state of effective stress have significant influence on shear strength and deformation parameters (Bihs et al. 2013, Młynarek et al. 2013). This requires modifications of the existing formulae as proposed by Marchetti that could be used during the determination of geotechnical parameters in organic soils.

This paper presents site investigation and geotechnical characteristics of the area for the Plocka C08 Station of the II underground line in Warsaw. In this site occur organic soils, mainly organic muds and gyttja with a thickness reaching up to 10 m. Because of difficulties with the collection of undisturbed soil samples of soft soils, in situ tests, i.e. the Seismic Dilatometer Test (SDMT), were used besides drilling to provide shear wave velocity (V_S) measurements supplementing conventional readings. The use of SDMT was applied mainly to obtain a better interpretation of soil stratification and to provide information on the stress history, shear strength and deformation parameters of the organic soils. Stratigraphy and soil parameters were evaluated from three pressure readings whereas small strain stiffness (G_0) was obtained from in situ V_S profiles. Analysis of the test results have allowed presenting methods of evaluating stress history, undrained shear strength, and deformation parameters of organic soils from SDMT.

Site characteristics

Field investigations using SDMT were performed in the "Zoliborz channel", one of the most difficult sites along the route of the II underground line in Warsaw. The construction of the Plocka C08 Station is planned in this site (Fig. 1). The "Zoliborz channel" is located in the western part of Warsaw; sedimentation of organic soils took place here during the Eemian Interglacial. The channel is about 12 km long and nearly 800 m wide in its central part. In the "Zoliborz channel", the organic soils i.e. organic mud and gyttja, reach a thickness of up to 10 m.

The examined area is located within the Warsaw Basin, composed of Upper Cretaceous deposits, developed as marls and high plasticity marly clays, the top of which lies at approximately 250 m below ground level. The first subsurface layer in the tested subsoil is formed by fills with thickness varying between 0.5 m to 4.0 m. The fills are underlain by sand and mud deposits of the Vistulian Glaciation to the depth of approximately 4–6 m below ground level. The sand and mud layers cover the continuous layer of gyttja and organic mud from the Eemian Interglacial. The top of this layer was noted at the depth of approximately 6 to 16 m below ground level. Organic soils of the Eemian Interglacial are overconsolidated with an overconsolidation ratio OCR varying in the range between 2.0 and 3.5. The grain-size composition of the gyttja points to silts, silty clays and more plastic firm and stiff, silty clays, with the organic matter content from 10% to over 30%, locally even up to 50%. The index properties of organic soils are given in Table 1.

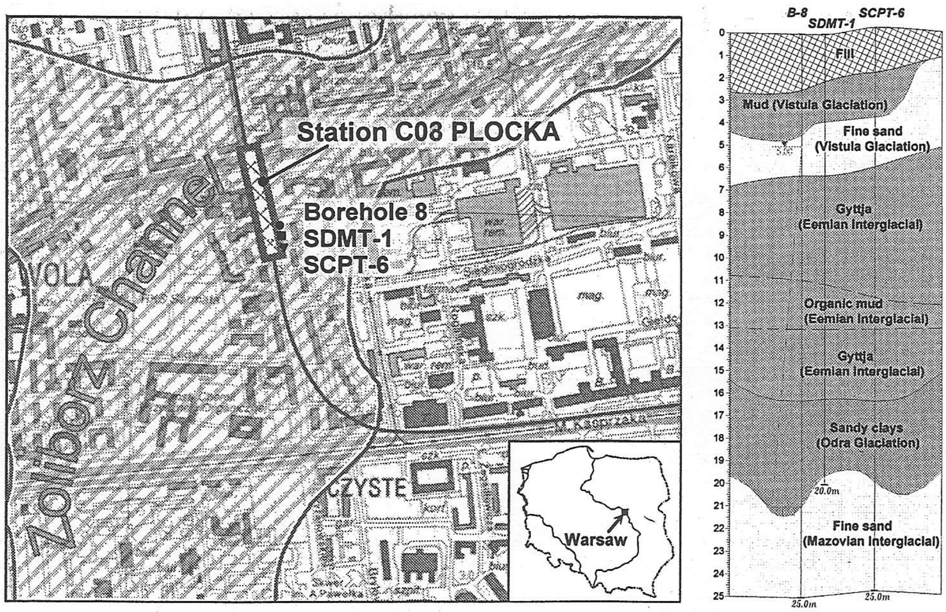

Fig. 1 – Location and typical cross-section of the test site

Tab. 1 – Index properties of the examined organic soils

Properties	Vistulian Glaciation (lacustrine deposits)	Eemian Interglacial (lacustrine deposits)		
	Mud M	Gyttja Gy (upper layer)	Organic mud M_{or}	Gyttja Gy (lower layer)
Water content w_n (%)	33-38	88-100	32-34	75-82
Plastic limit w_P (%)	28-30	80-85	30-32	70-75
Liquid limit w_L(%)	45-50	135-145	50-55	115-125
Plasticity index I_P (%)	17-20	55-60	20-23	45-50
Consistency index I_C (-)	0.60-0.70	0.75-0.85	0.90-0.95	0.85-0.90
Unit density ρ (t/m³)	1.65-1.70	1.40-1.45	1.60-1.65	1.50-1.55
Specific density ρ_s (t/m³)	2.50-2.55	1.95-2.00	2.40-2.50	2.05-2.10
Organic content I_{OM} (%)	6-9	40-48	8-12	35-37

The bottom of the channel is filled with moraine deposits of the Odra Glaciation, mainly comprising sandy clays, underlain by sandy deposits of the Mazovian Interglacial represented by dense, fine, medium and silty sands.

Profiles of data from the SDMT test with two geophones spaced at 0.5 m carried out in the subsoil of the Plocka Station, presented as profiles of the material index I_D, lateral stress index K_D, and dilatometer modulus E_D are shown in Figure 2. Profiles of pore pressure index U_D and shear wave velocity V_s are presented in Figure 3.

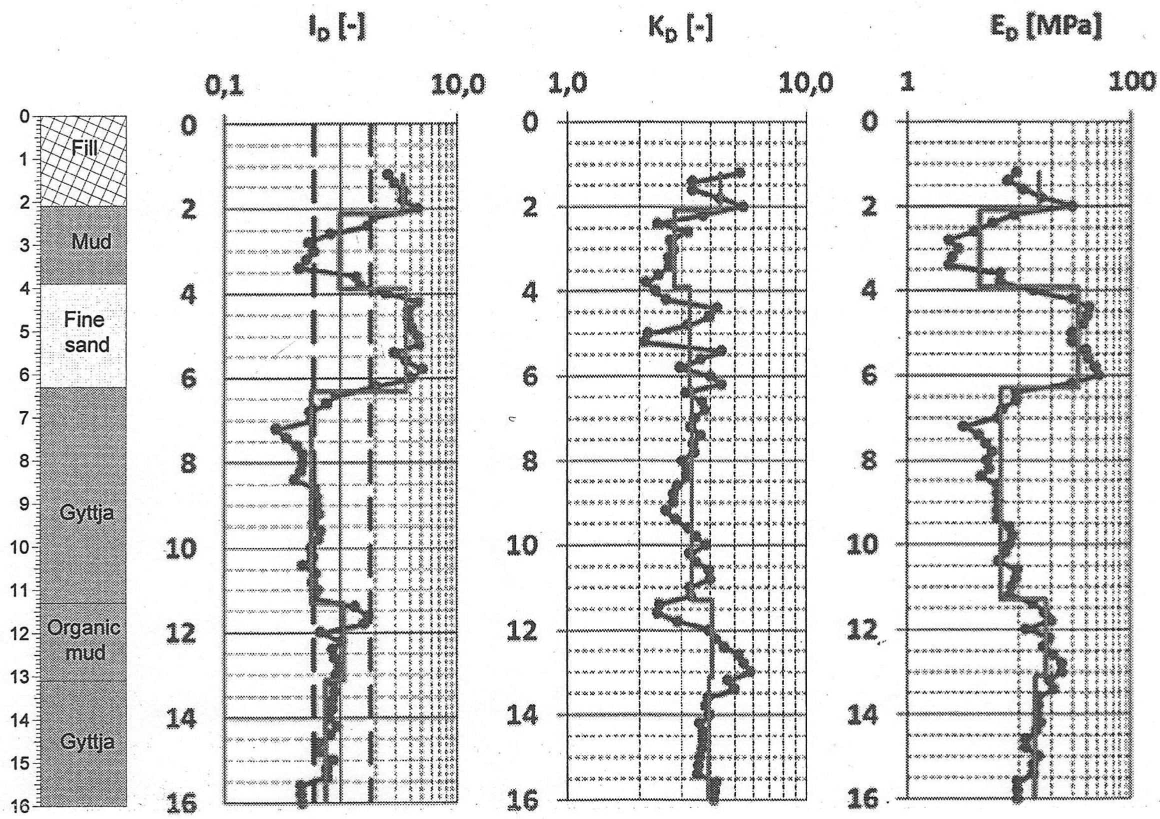

Fig. 2 – Profiles of I_D, K_D and E_D indexes from the SDMT test carried out in the subsoil of the Plocka Station

Lutenegger and Kabir (1988) have shown that in mineral soils the pore pressure index U_D estimated on pressure p_2 is very useful for the evaluation of the pore water pressure conditions. Experience from organic soils indicates that the dilatometer pore pressure index U_D is useful for identifying subsoil stratigraphy and pore water pressure conditions (Lechowicz and Rabarijoely 2000). In case of the subsoil of the Plocka Station, the values of the U_D index indicate that the layers of gyttja are in a preconsolidated state, whereas there is a possibility of horizontal drainage in more permeable interbeddings within the Eemian organic mud.

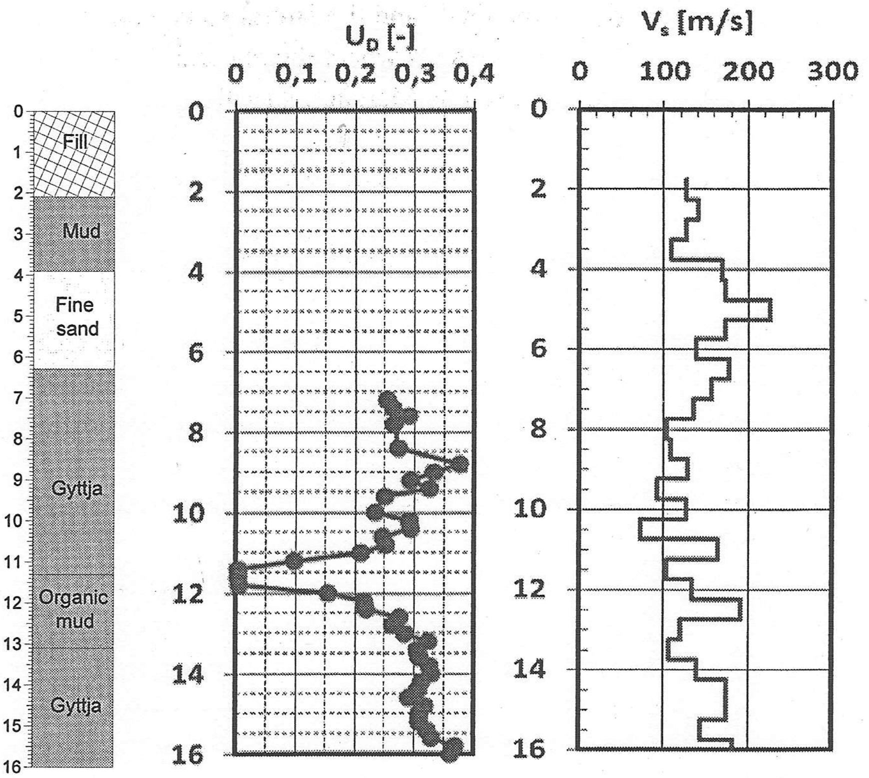

Fig. 3 – Profiles of the U_D index and V_S from the SDMT test carried out in the subsoil of the Plocka Station

Field and laboratory testing programme was carried out to evaluate soil parameters for foundation desing. Oedometer tests as well as CK_0U and CD traixial tests were performed on undisturbed soil samples. In the test site SCPT tests were also carried out.

Determination of the stress history

In practical geotechnical engineering, evaluation of stress history is based on the overconsolidation ratio OCR defined as:

$$OCR = \frac{\sigma'_p}{\sigma'_v} \quad (1)$$

where:
σ'_p – preconsolidation pressure,
σ'_v – vertical effective stress.

The value of the preconsolidation pressure σ'_p is usually determined based on the results of oedometer tests. In situ tests, i.e. dilatometer tests, which can characterize the variation of OCR with depth are valuable tools for geotechnical engineers.

Using the correlation between the OCR and the lateral stress index K_D for soils with the material index $I_D > 2.0$ and for cohesive soils where the material index I_D is smaller than 1.2, the following correlations were proposed by Marchetti (1980):

$$OCR = (0.67 \cdot K_D)^{1.91} \tag{2}$$

$$OCR = (0.5 \cdot K_D)^{1.56} \tag{3}$$

It is important to note that the estimation of the overconsolidation ratio OCR from dilatometer tests depends on empirical and local experience. Many studies have been performed to improve the original correlations proposed by Marchetti, however they were mostly limited to mineral soils (Briaud and Miran 1991, Kamei and Iwasaki 1994).

Experience from organic soils indicates that the relation between the OCR and the lateral stress index K_D is as follows (Lechowicz 1997a):

$$OCR = (0.45 \cdot K_D)^{1.40} \tag{4}$$

Using equation (4), the SDMT profiles, shown as values of the overconsolidation ratio OCR and the preconsolidation pressure σ'_p, were determined in the subsoil of the Plocka Station (Fig. 4).

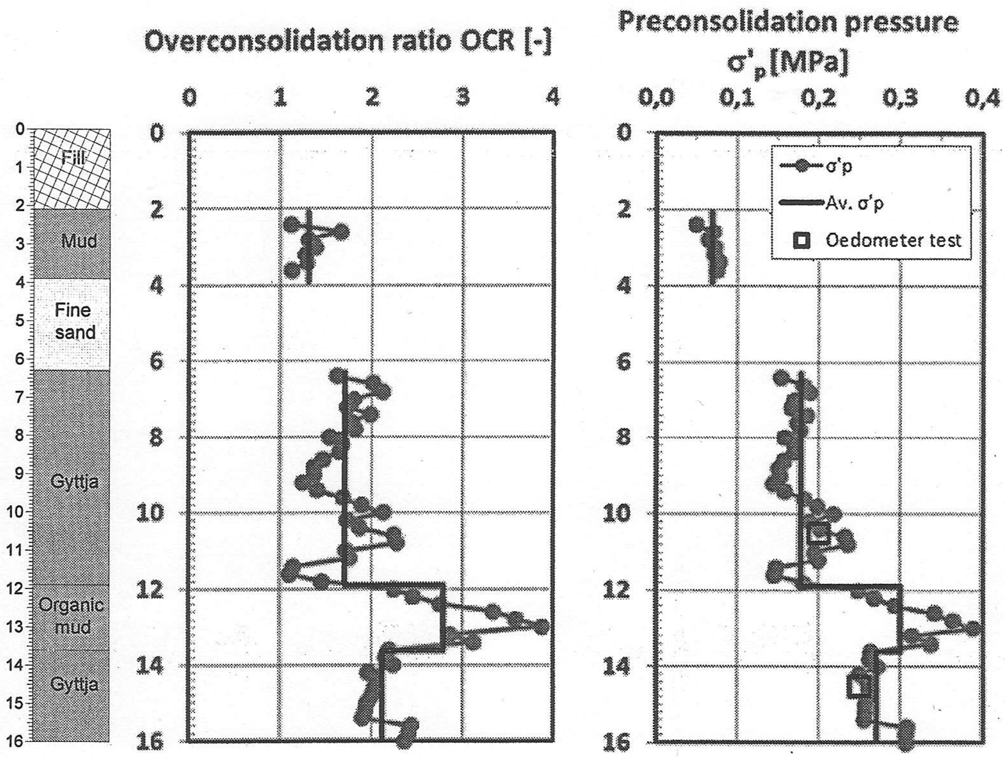

Fig. 4 – Profiles of the overconsolidation ratio OCR and the preconsolidation pressure σ'_p from the SDMT test and values obtained from the oedometer test for the subsoil of the Plocka Station

Undrained shear strength

The methodology of standard DMT and SDMT tests is widely known and a detailed procedure for conducting the test has been presented by Marchetti (1980), Marchetti et al. (2001), Marchetti et al. (2008). Marchetti (1980) proposed the following correlation between normalized undrained shear strength and lateral stress index K_D for cohesive soils ($I_D < 1.2$):

$$\frac{\tau_{fu}}{\sigma'_{v0}} = 0.22 \cdot (0.5 \cdot K_D)^{1.25} \tag{5}$$

where:
σ'_{v0} – in situ vertical effective stress.

The analysis carried out by Lechowicz (1997b) indicates that, particularly for organic soils, the relationship between normalized undrained shear strength and lateral stress index K_D differs from that proposed by Marchetti (1980) and can be modified as follows:

$$\frac{\tau_{fu}}{\sigma'_{v0}} = S \cdot (0.45 \cdot K_D)^{1.20} \tag{6}$$

where:
S – normalized undrained shear strength for a normally consolidated state.

Research on Holocene organic soils indicates that normalized undrained shear strength for the normally consolidated state S for mud and organic mud equals 0.35 and 0.40, whereas for calcareous gyttja, calcareous-organic gyttja and amorphous peat it equals 0.40, 0.45 and 0.50, respectively (Lechowicz 1997b). Analysis of laboratory test results has shown that values of the S coefficient for Eemian organic mud equals 0.30 and for gyttja equals 0.35.

Experience from organic soils indicates that for the evaluation of undrained shear strength from the dilatometer test, the following multifactor formula can be used (Rabarijoely 2000):

$$\tau_{fu} = \alpha_0 \cdot \sigma_{v0}^{\alpha_1} (p_0 - u_0)^{\alpha_2} \cdot (p_1 - u_0)^{\alpha_3} \tag{7}$$

where:
u_0 – in situ pore water pressure,
$\alpha_0, \alpha_1, \alpha_2, \alpha_3$ – empirical coefficients.

Analysis of the test results indicates that the obtained values of empirical coefficients for organic mud from the Plocka Station area are $\alpha_0 = 1.12$, $\alpha_1 = 0.13$, $\alpha_2 = 0.10$, $\alpha_3 = 0.44$, and for gyttja – $\alpha_0 = 1.25$, $\alpha_1 = 0.30$, $\alpha_2 = 0.12$, $\alpha_3 = 0.30$. Figure 5 presents profiles of undrained shear strength evaluated by the modified Marchetti as well as Rabarijoely (2000) formulae.

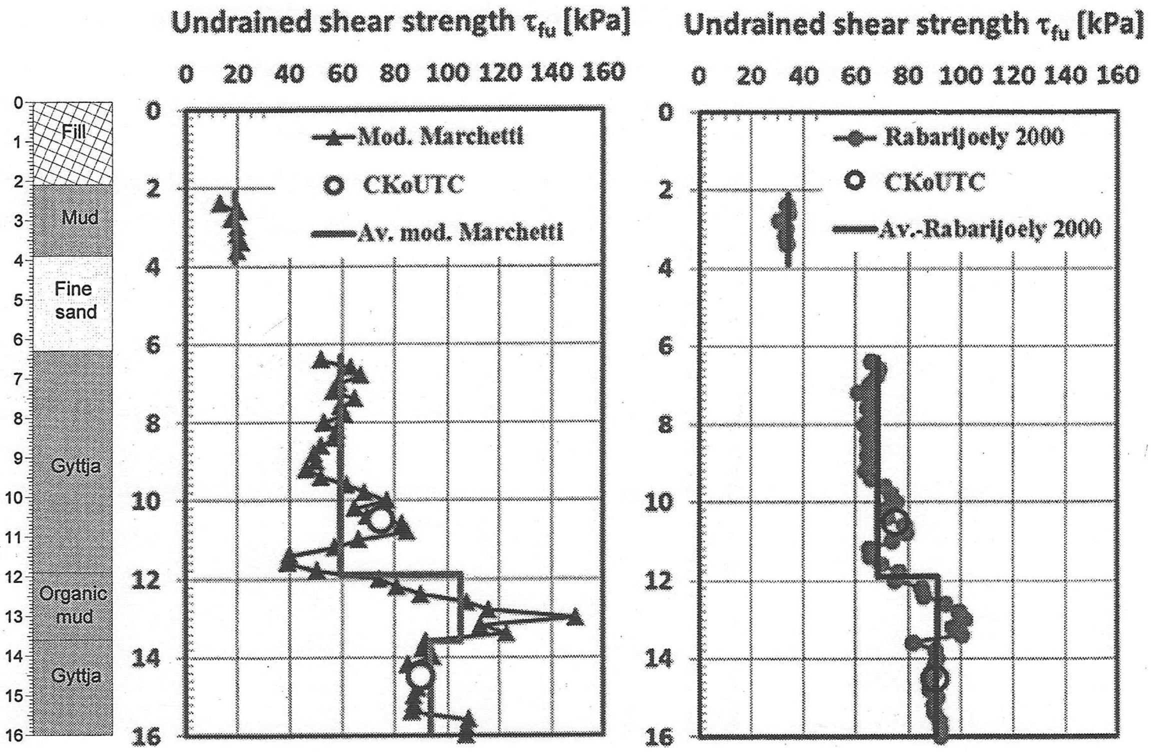

Fig. 5 – Undrained shear strength from the SDMT test and the CK_0U triaxial test for the subsoil of the Plocka Station

Deformation parameters

In 1980, Marchetti proposed a set of empirical correlations from which the constrained modulus M can be obtained by multiplying the dilatometer modulus E_D by the factor RM related to horizontal stress index K_D. For mineral soils formulae were determined that allow evaluating deformation parameters for different soil types. However, there are no such formulae for organic soils. Conducted research (Lechowicz et al. 2012) has allowed to determine the relations for the determination of the constrained modulus M for Eemian organic mud and gyttja:

$$M = R_M \cdot E_D \tag{8}$$

where:
$R_M = 0.14+2.36 \cdot \log K_D$ (for organic mud),
$R_M = 0.12+2.10 \cdot \log K_D$ (for gyttja).

In order to evaluate the deformation modulus $E_{0.1\%}$ at 0.1% of strain, the following relationship was proposed for Eemian organic soils (Lechowicz et al. 2012):

$$E_{0,1\%} = R_E \cdot E_D \tag{9}$$

where:
$R_E = 2.4 + 2.36 \cdot \log K_D$ (for organic mud),
$R_E = 2.15+2.10 \cdot \log K_D$ (for gyttja).

Figure 6 presents profiles of the constrained modulus M and the deformation modulus $E_{0.1\%}$ determined on formulae (8) and (9).

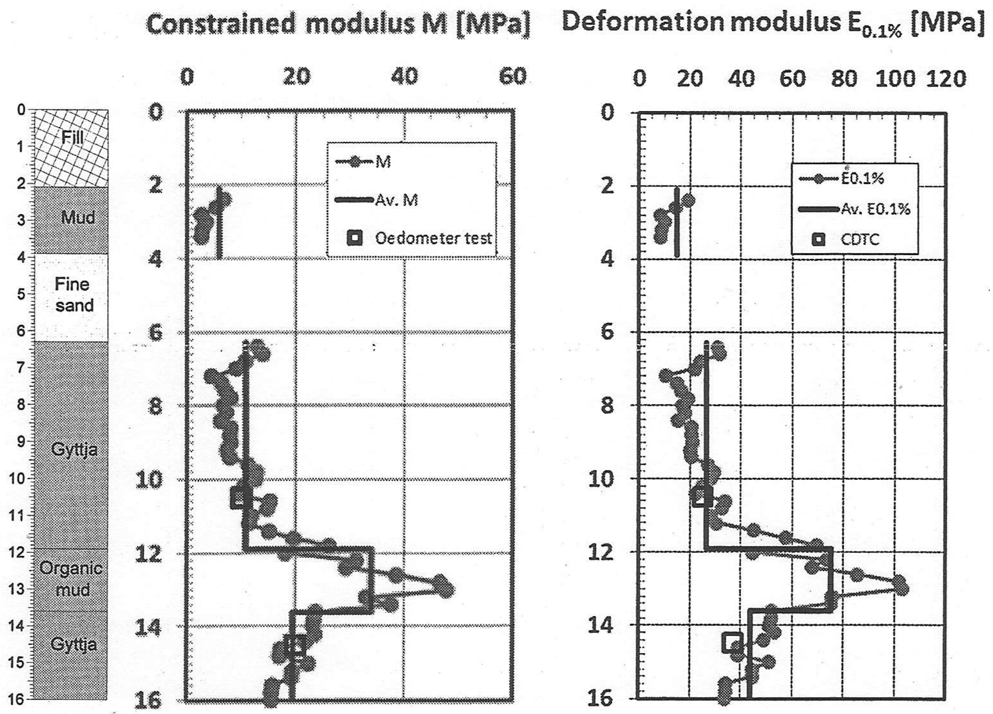

Fig. 6 – Constrained modulus M and deformation modulus E0.1% from the SDMT test and values obtained from the oedometer test and CD triaxial tests for the subsoil of the Plocka Station

The measurement of shear wave velocity gives the possibility to obtain the initial shear modulus of soil G_0 at a strain level less than 0.0001%. The elastic wave theory relates small strain shear modulus G_0 in MPa to shear wave velocity and unit density using the following equation:

$$G_0 = \rho \cdot V_s^2 \tag{10}$$

where:
ρ – soil mass density,
V_s – shear wave velocity.

Figure 7 shows the G_0 moduli obtained from equation (10) using shear wave velocity measurements during the SDMT test. For comparison, values of the G_0 modulus for gyttja obtained from triaxial tests with shear wave velocity measurements and from SCPT test with two geophones spaced 1.0 m are also presented.

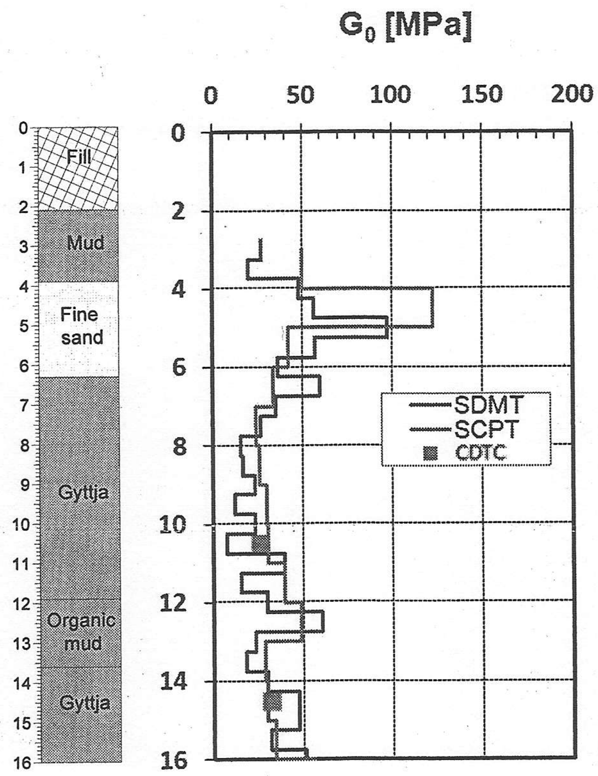

Fig. 7 – G_0 moduli obtained from the SDMT test and the SCPT test as well as the CD triaxial test for the subsoil of the Plocka Station

Conclusions

Based on SDMT tests carried out in one of the most difficult sites of the II underground line in Warsaw, the stress history, undrained shear strength and deformation parameters of Eemian organic soils were evaluated. A comparison between results obtained from SDMT tests and laboratory tests has been made.

On the basis of the presented test results, the formulae used for the interpretation of the dilatometer test to estimate the stress history, undrained shear strength τ_{fu}, constrained modulus M and deformation modulus $E_{0.1\%}$ of gyttja (Eemian Interglacial) were evaluated. The values of initial shear modulus G_0 at small strain obtained from SDMT and SCPT were compared with values evaluated by laboratory tests.

Further studies are necessary in order to verify the proposed correlations in other types of organic soils.

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