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New chart for classification of organic soils from dilatometer tests (DMT) results

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Abstract: *The new chart for classification of organic soils from dilatometer tests (DMT) results*. To identify the type of soils in subsoil profile from the dilatometer (DMT) tests the diagram charts are commonly used. Marchetti (1980), Marchetti and Crapps (1981) proposed the diagram chart based on the values of material index (I_D) and the dilatometer modulus (E_D). This chart is helpful for identifying both mineral (clay, silt and sand) and organic soils. The classification to identify organic soils is not accurate enough. This paper proposes a new classification chart for organic soil identification. It was developed based on the comprehensive investigation of organic sediments performed in the Department of Geotechnical Engineering of Warsaw University of Life Sciences in years 1980–2012.

Key words: *in situ* tests, DMT, organic soils, chart diagram

INTRODUCTION

To date the mineral and organic soils present in the subsoil before the construction design the CPT or DMT tests are traditionally used. In case of the latter, the diagram charts developed by Marchetti (1980) and Marchetti and Crapps (1981) are applicable (Table 1, Figure 1). Marchetti (1980) proposed the classification of soils based on the material index (I_D), obtained from DMT tests (Table 1). According to this, the material index – $I_D < 0.10$ indicates peat or sensitive clays without the distinct distinguishing between them.

TABLE 1. Soil classification based on material index – I_D (Marchetti 1980)

Soil type		Material index I_D
Organic soils	peat / sensitive clays	<0.10
Cohesive soils	clay	0.10–0.35
	silty clay	0.35–0.60
	clayey silt	0.60–0.90
	silt	0.90–1.20
	sandy silt	1.20–1.80
Non-cohesive soils	silty sand	1.80–3.30
	sand	>3.30

Diagram in Figure 1 was developed based mainly on soil mineral tests. It shows the relationship between the material index (I_D) and the dilatometer modulus (E_D) – in the log-log scale. Unit weight of soils (cohesive soils and non-cohesive soils) and their states are also present here. Soils are classified as organic if $I_D < 0.6$ and $E_D < 1.2$ MPa.

The first parts of this paper contains the review of the methods proposed for identification of soil from DMT tests results. Next, the analysis of results from the field test studies in five sites (Lechowicz 1996): an experimental embankment (Antoniny site), embankment dams (Nielisz, Koszyce and Mielimąka) and Metro station in Warsaw named Płocka are presented. Finally, the new diagram

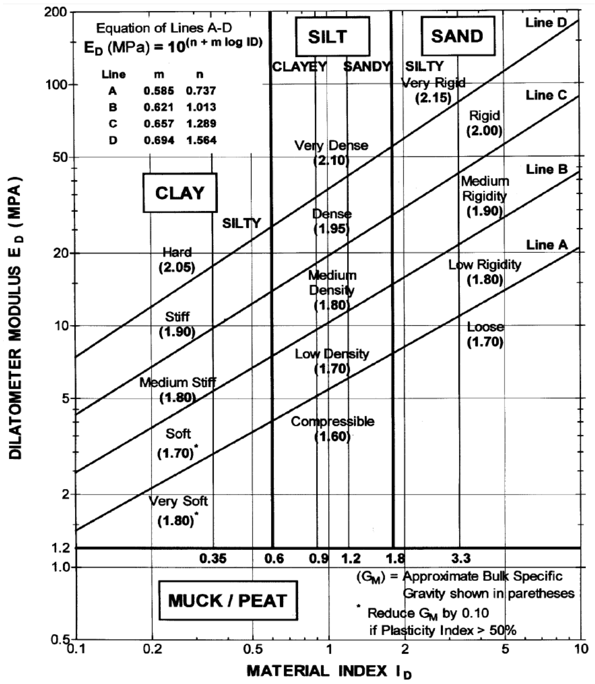

FIGURE 1. Chart for estimating soil type and unit weight for soil – normalized to γ_w (Marchetti 1980, Marchetti and Crapps 1981)

for organic soil identification from DMT tests is demonstrated.

MATERIAL AND METHODS

Description of test sites

The paper presents the test results of organic subsoil obtaining from Antoniny, Koszyce and Mielimąka located in the valley of the River Noteć in Wielkopolska province and Nielisz sites located in the valley of the River Wieprz in Lublin province, where a laboratory and field testing programme of the Department of Geotechnical Engineering WULS-SGGW has been carried out under and outside of the main dam embankment (Wolski et al. 1988, 1989, Lechowicz and Rabarijoely 1996).

Site 1 – Antoniny test embankment

The test embankment at Antoniny was designed and analysed during the cooperation between the Department of Geotechnical Engineering WULS-SGGW and Swedish Geotechnical Institute (SGI). The embankment is located in River Noteć valley on organic sediments and contains two layers: peat of 4.1 m thick and gyttja of 3.7 m thick. Generally, the organic subsoil is composed of amorphous peat with varying carbonate gyttja and variable content of organic matter and calcium carbonate (Table 2). Organic subsoils are preconsolidated with overconsolidated ratio OCR for peat 3–5, and for gyttja 1.5–2.5 (Wolski et al. 1988, 1989, Lechowicz and Rabarijoely 1996).

TABLE 2. Index properties of organic soils at the Antoniny, Koszyce, Nielisz and Płocka station test sites (Wolski et al. 1989, Lechowicz and Rabarijoely 1996, Lechowicz 1997a, 1997b, Lechowicz et al. 2012)

Site		Type of soil	Organic content I_{om} [%]	$CaCO_3$ content [%]	Water content w_n [%]	Liquid limit w_L [%]	Density: Unit weight of soil ρ [t/m^3]	Density: Specific weight of soil ρ_s [t/m^3]
Antoniny		amorphous peat	65–75	10–15	310–340	305–450	1.05–1.10	1.45–1.50
		calcareous gyttja	5–20	65–90	105–140	80–110	1.25–1.40	2.2–2.30
Koszyce		amorphous peat	70–85	5–15	400–550	450	1.05–1.1	1.45–1.50
		calcareous gyttja (G_y)	10–20	65–80	120–160	80–110	1.20–1.35	2.1–2.25
		calcareous gyttja (G_y)	15–20	65–75	180–220	100–110	1.25–1.30	2.2
Nielisz		organic mud (M_{or})	20–30	–	120–150	130–150	1.25–1.30	2.25–2.3
		organic mud (M_{or})	10–20	–	105–120	110–130	1.30–1.45	2.30–2.40
Płocka Station	Vistulian Glactiation (lacustrine deposit)	mud (M)	6–9	–	33–38	45–50	1.65–1.70	2.50–2.55
	Eemian Interglacial (lacustrine deposit)	gyttja (G_y) upper leyer	40–48	–	88–100	135–145	1.40–1.45	1.95–2.00
		organic mud (M_{or})	8–12	–	32–34	50–55	1.60–1.65	2.40–2.50
		gyttja (G_y) lower layer	35–37	–	75–82	115–125	1.50–1.55	2.05–2.10

Site 2 – Koszyce test dam

The test dam was located in the River Ruda valley. In the central part of the dam, a layer of soft organic subsoils was discovered. Such soils are quaternary deposits from the oxbow lake. The thickness of the layer in this region is generally higher than 10 m, locally even above 20 m. Under the organic soils the dense sand is located.

The upper organic subsoils in the test area consist of a 2.5 m thick peat layer on the top of a 10.5 m thick gyttja layer underlain by the sand layer. Values of the index properties tests of organic soils are in Table 2. Based on them, the gyttja layer was divided into three layers, the first one of thickness from 2.5 to 6.3 m, the second with thickness from 6.3 to 10.5 m and the third one below 10.5 m (Wolski et al.

1988, 1989, Lechowicz and Rabarijoely 1996).

The static ground water level is present in the peat layer at the depth of 0.5 m below the surface. The preconsolidation pressure obtained from the oedometer tests is higher than the initial values of effective vertical stresses, showing that organic soils are overconsolidated with an overconsolidation ratio, OCR between 1.5 and 4 (Wolski et al. 1988, 1989, Lechowicz and Rabarijoely 1996).

Site 3 – Nielisz test dam

At the Nielisz site the soft subsoil consists of mineral and organic sediments. Its original thickness varies from 1.0 to 5.0 m. The upper part (about 0.5–1.0 m) mainly consists of the sandy silt or silt. Below there is the layer of mud or organic mud with thickness of 1.0–4.0 m, divided into two layers by the silt layer. Below the sand layer is located. The results of the index properties of organic soils are in Table 2. Outside of the existing embankment under the downstream berm and the upstream slope the overconsolidated soft soils are located with an overconsolidation ratio, OCR, decreasing from 3 to 2 with depth (Lechowicz and Rabarijoely 1996).

Site 4 – Płocka C8 – Metro station

From the geological point of view, the studied area lays within the Warsaw Basin, composed of Upper Cretaceous deposits, developed as marls and marly high plasticity clays. The first subsurface layer in the subsoil tested is formed by fills. They are located at the depth of approximately 4–6 m under the ground surface. They consist of sand and mud deposits of the Vistula Glaciation. These layers cover the continuous layer of gyttja and organic mud of Eemian Interglacial. The top of this layer has been observed from the depth of approximately from 6 to 16 m under the ground surface. Organic soils of Eemian Interglacial are overconsolidated with an overconsolidation ratio OCR varying from 2.5 to 3.5. The grain-size distribution of gyttja relates to silts, silty clays and more plastic silty clays, firm and stiff, with organic matter content from 10 to over 30% (locally even to 50%). Index properties of organic soils are in Table 2 (Lechowicz et al. 2012).

IN SITU TESTS

The dilatometer tests (DMT) were applied to recognize organic subsoils distinguished in the presented test sites. The details of the DMT test operation can be found in Marchetti and Crapps 1981, Młynarek et al. 1983, Schmertmann 1986, Lacasse and Lunne 1988, Briaud and Miran 1992, Marchetti 1980, Lechowicz and Rabarijoely 2000, Młynarek et al. 2006, Młynarek et al. 2008, Młynarek et al. 2010, and Bihs et al. 2010. During the DMT tests A, B and C readings are carried out as it shown in Figure 1b (Lutenegger and Kabir 1988, Totani et al. 1998). They are adjusted due to the inertia impact resistance of the membrane, which allows to determine the readings of pressures: p_0, p_1 and p_2 (Fig. 2).

The latter, together with the calculated value of the vertical effective stress component (σ'_{vo}) and the pore water pressure (u_0), are used to determine the following dilatometer indexes (Marchetti 1980, Lutenegger and Kabir 1988, Lechowicz and Rabarijoely 2000):

– Material index, I_D

$$I_D = \frac{p_1 - p_0}{p_0 - u_0} \tag{1}$$

– Horizontal earth pressure index, K_D

$$K_D = \frac{p_0 - u_0}{\sigma'_{vo}} \tag{2}$$

– Dilatometer modulus, E_D

$$E_D = 34.7(p_1 - p_0) \tag{3}$$

– Water pressure index, U_D

$$U_D = \frac{p_2 - u_0}{p_0 - u_0} \tag{4}$$

where:

p_0 – the A-pressure reading, corrected for Z_m, the ΔA membrane stiffness at 0.05-mm expansion, and the 0.05-mm expansion itself, to estimate the total soil stress acting normal to the membrane immediately before its expansion into the soil (0.00-mm expansion),

p_1 – the B-pressure reading corrected for Z_m and the ΔB membrane stiffness at 1.10-mm expansion to give the total soil stress acting normal to the membrane at 1.10-mm membrane expansion,

p_2 – The C-pressure reading corrected for Z_m and the ΔA membrane stiffness at 0.05-mm expansion and used to estimate pore-water pressure,

σ'_{vo} – vertical effective stress at the center of the membrane before the insertion of the DMT blade,

u_0 – the pore-water pressure acting at the center of the membrane before the insertion of the DMT blade (often assumed as hydrostatic below the water table surface),

Z_m – the gage pressure deviation from zero when vented to atmospheric pressure (an offset used to correct pressure readings to the true gage pressure).

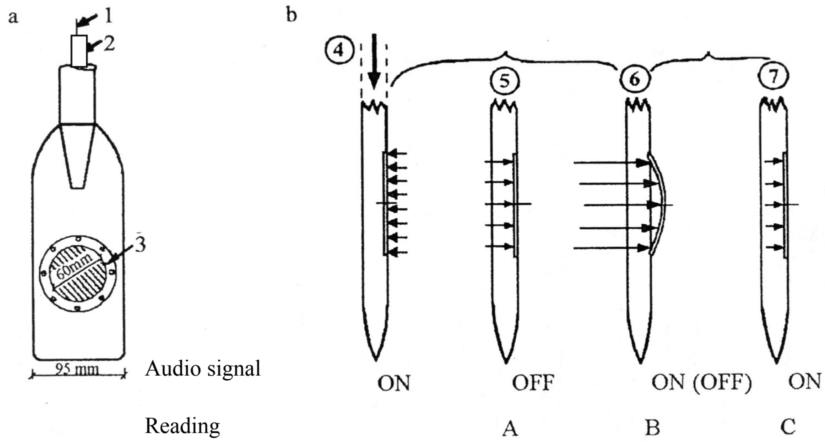

FIGURE 2. Marchetti dilatometer: a – flat blade, 1 – electric wire, 2 – pneumatic tubing, 3 – steel membrane, b – test stages, 4 – pushing, 5 – contact stress, p_0, 6 – expansion stress, p_1, 7 – pressure p_2

RESULTS

Dilatometer tests results

In Figure 3 the test results obtained for selected sites are presented. These tests results were considered in the new classification system of organic soils presented in this paper.

classified as organic when $0.40 < I_{SDMT} \leq$ ≤ 1.0 and $0.01 < p_1 \leq 1.0$ MPa (Table 3). The new diagram contains three areas: 1 – clay/mud, 2 – peat, 3 – gyttja (Fig. 5).

Soil type index:

$$I_{SDMT} = \frac{p_0 - u_0}{p_1} \tag{5}$$

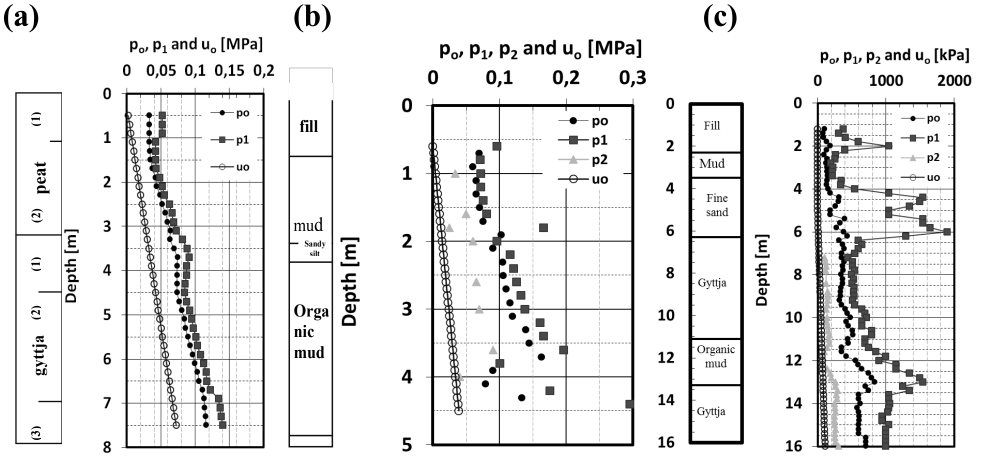

FIGURE 3. Profiles of p_0, p_1 and p_2 from dilatometer (DMT) test and hydrostatic pressure u_0: (a) at the Antoniny site; (b) at the Nielisz subsoil; (c) at the Płocka Station subsoil (Lechowicz et al. 2004, Lechowicz et al. 2012)

Proposed classification chart

The diagram chart developed in this paper is based on the diagram proposed by Marchetti and Crapps (1981) – Figure 4. To recognize the organic subsoils in more detail manner than Marchetti and Crapps (1981), Larsson (1989), the proposed diagram shows the relationship between the second reading p_1 and soil type index – I_{SDMT} (eq. 5). The I_{SDMT} soil type index values can be calculated using the equation (5). Subsoils are

CONCLUSIONS

Considering the analysis presented in this paper the following main conclusions can be drawn.

To date diagrams proposed for soil classification using dilatometer tests results did not include sufficient classification of organic soils.

The classification diagram proposed in this paper allows for specifying the type and the state of the organic soils more accurately than diagrams

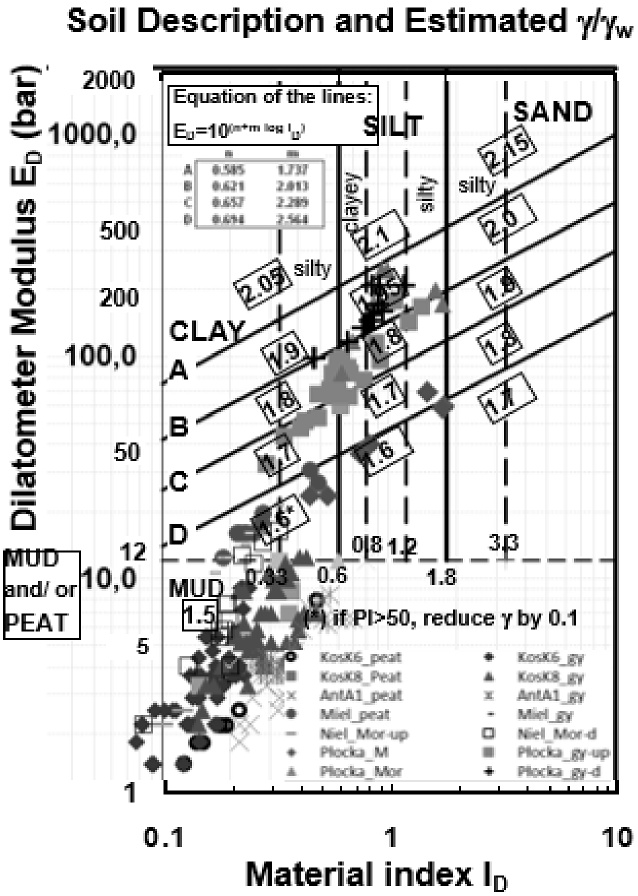

FIGURE 4. Chart for estimating soil type and unit weight – normalized to γ_w (Marchetti and Crapps 1981)

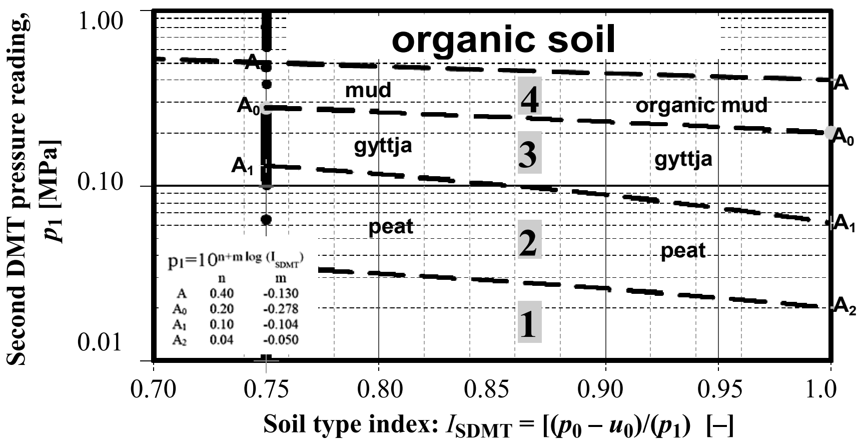

FIGURE 5. Chart for estimating type and state of organic soils

TABLE 3. Proposed soil classification based on I_{SDMT} and p_1 from *in situ* tests

Zone	Description	ρ [t/m^3]	ρ_d [t/m^3]	Porosity index e [-]	Water content w_n [%]	B-pressure reading p_1 [MPa]	Soil type index I_{SDMT} [-]	τ_{fu} [MPa] from FVT
1	peat	1.05÷1.10	0.17÷0.244	4.5÷7.3	350÷500	<0.09	$0.40 < I_{SDMT} \leq 1.0$	<0.0125
2								~0.0125
3	gyttja (Gy)	1.20÷1.40	0.50÷0.60	2.5÷3.2	110÷150	$0.09 \leq p_1 < 0.2$		$0.0125 \leq \tau_{fu} < 0.0255$
4	mud (M)/organic mud (M_{or})	1.25÷1.70	0.54÷0.67	2.6÷3.2	110÷140	$0.2 < p_1 \leq 0.5$		$0.0255 \leq \tau_{fu} < 0.0505$

traditionally applied in the practice. The proposed diagram was established based on the comprehensive investigation of organic deposits distinguished in four tests sites.

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Streszczenie: *Nowy nomogram klasyfikacyjny gruntów organicznych na podstawie badań dylatometrycznych (DMT)*. Głównym zadaniem nomogramu klasyfikacyjnego wyników z badań dylatometrycznych DMT jest ocena rodzaju, stratygrafii i stanu gruntu. Jednym z popularnych metod do wyznaczenia rodzaju gruntu z badań DMT jest nomogram zaproponowany przez Marchettiego (1980) na podstawie wskaźnika materiałowego (I_D) i modułu dylatometrycznego (E_D). Nomogram Marchettiego w sposób niewystarczający uwzględnia grunty organiczne. Niniejszy artykuł zawiera propozycję nowego nomogramu klasyfikacji gruntów organicznych na podstawie ciśnienia (p_1) i wskaźnika rodzaju gruntów (I_{SDMT}). Do określania wskaźnika rodzaju gruntów (I_{SDMT}) wykorzystywane są wartości p_0 i p_1 z badań DMT i u_0 z obserwacji piezometrycznych.

Słowa kluczowe: badanie in situ, DMT, nomogram klasyfikacyjny

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