The use of dilatometer test for the determination of undrained shear strength in organic soils

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Abstract: *The use of dilatometer test for the determination of undrained shear strength in organic soils*. In engineering practice the empirical correlations or charts are often use to determine soil properties for design calculations. The DMT tests results are analysed on the basis of the empirical formulas proposed by Marchetti (1980). In this paper the new chart to determine the τ_{fu} of organic mud was proposed. The chart presents the relationships between dilatometer readings $(p_o - u_o)$, $(p_1 - u_o)$, σ'_{vo} and τ_{fu}. The chart will be helpful in geotechnical design of embankments constructed on organic subsoil.

Key words: dilatometer test, organic soils, undrained shear strength.

INTRODUCTION

Safe and economic design of the structure on organic subsoil demands the exact recognition of the subsoil properties among them undrained shear strength τ_{fu} (Hartlen and Wolski 1996). In Poland there are many areas covered by very soft deposits, including organic soils characterised with low undrained shear strength and high compressibility. Recently for recognised of the geotechnical condition in organic soils the application of DMT tests are recommended (Lechowicz and Rabarijoely 1996, Młynarek et al. 2006).

Advantage of the DMT test (Marchetti 1980) is the quick and not complicated measurements. Based on the DMT tests results the subsoil profiles and many soil parameters (deformation modulus M_{DMT} and shear strength τ_{fu}), can be determined. The interpretation of organic soil parameters is based on the empirical formulae. In this paper the tests results for organic soils in Nielisz dam foundation are presented. After analysis of the DMT parameters test results new chart for the determination of undrained shear strength for organic muds is proposed.

INTERPRETATION OF DILATOMETER TEST AND TEST RESULTS

The DMT test consists in measurement at given depths during penetration of subsoil the gas pressure on the membrane installed in the DMT blade. Most often two readings A and B are measured. The A reading is equivalent to value of the gas pressure to dislocate of the membrane centre for the contact with surrounding soil (usually 0.05 mm). The second B reading shows the value of the gas pressure obtained at the additional inclination of the centre of the membrane toward of the soil about

1.05 mm (together 1.1 mm). Recently, more and more often after the realization of A and B readings passed is the third C reading – the gas pressure after the return of the membrane to the initial positions (Fig. 1). Values of A, B and C readings are corrected for the influence of the membrane resistance, what lets to the determination of the p_o, p_1 and p_2 pressures (Fig. 1). The detail procedure of DMT tests is presented in many papers (Lutenegger and Kabir 1988, Totani et al. 1998, Marchetti and Crapps 1981, Schmertmann 1986, Briaud and Miran 1992, Marchetti 1999).

The p_o, p_1 and p_2 pressures together with the calculated effective vertical stress σ'_{vo} and water pore pressure u_o of in situ conditions serve to the obtaining of following indexes of the dilatometer (Marchetti 1980, Lutenegger and Kabir 1988):

– Material index I_D

$$I_D = f(A, B, u_o) = \frac{p_1 - p_o}{p_o - u_o} \qquad (1)$$

– Horizontal stress index K_D

$$K_D = f(A, u_o, \sigma'_{vo}, B) = \frac{p_o - u_o}{\sigma'_{vo}} \qquad (2)$$

– Dilatometer modulus E_D

$$E_D = f(A, B) = 34.7(p_1 - p_o) \qquad (3)$$

– Pore pressure index U_D

$$U_D = f(A, C, u_o, B) = \frac{p_2 - u_o}{p_o - u_o} \qquad (4)$$

THE DMT TEST RESULTS AT NIELISZ SITE

The comprehensive field and laboratory tests were performed by the Department of Geotechnical Engineering SGGW at the Nielisz site (the river Wieprz valley) (Lechowicz 1992, Lechowicz and Rabarijoely 1996). The organic subsoils in Nielisz dam foundation are organic mud (Tab. 1). Thickness of the organic mud varies from 3 to 5 m. This soil is lightly preconsolidated with overconsolidation ratio OCR = 2–3. Due to very high compressibility of organic subsoils and its low undrained shear strength values the Nielisz dam was constructed in two
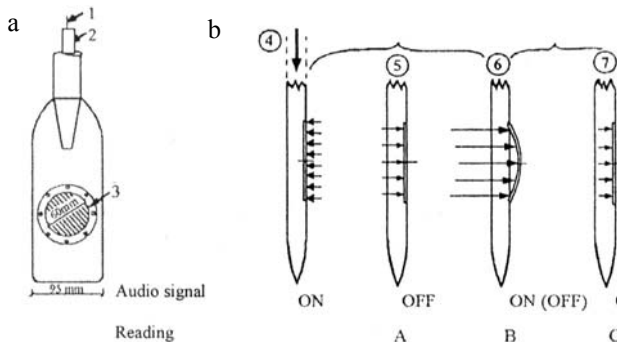

FIGURE 1. Marchetti dilatometer: a – flat blade (1 – electric wire, 2 – pneumatic tubing, 3 – steel membrane), b – test stages (4 – pushing, 5 – contact pressure p_o, 6 – expansion pressure p_1, 7 – pressure p_2)

TABLE 1. Index properties of organic mud at the Nielisz test site

Parameters	Organic content I_{om} [%]	Content $CaCO_3$ [%]	Water content w_n [%]	Liquid limit w_L [%]	Density	
					Unit ρ [t/m^3]	Specific ρ_s [t/m^3]
Values	20–30	–	120–150	130–150	1.25–1.30	2.25–2.3
	10–20	–	105–120	110–130	1.30–1.45	2.30–2.40

stages with surcharge embankment (Lechowicz and Rabarijoely 1997).

The DMT tests results are presented in Figure 2 for virgin subsoil and loaded subsoil by Nielisz dam. The Figure 2 shows the profiles of calculated values as follows: the material index of I_D, the horizontal stress index K_D, the dilatometer modulus E_D and the pore pressure index U_D.

THE DETERMINATION OF UNDRAINED SHEAR STRENGTH – PROPOSED CHART

Recently, many studies have been performed and new correlations improved original ones proposed by Marchetti were introduced in geotechnical practice; the most of them regards only mineral soils (Lutenegger 1988, Campanella and Robertson 1991, Leroueil and Jamiolkowski 1991, Finno 1993). According to Marchetti proposal the undrained shear strength of mineral soils can be obtained using following formulae:

$$\frac{\tau_{fu}}{\sigma_{v'o}} = 0.225 \, (0.5 \cdot K_D)^{1.25} \qquad (5)$$

Hitherto exist results, both laboratory investigations (triaxial test), as and field (field vane test and dilatometer test) (Fig. 3) they show, that the profile of undrained shear strength τ_{fu} of organic mud has non-linear character. Proposed
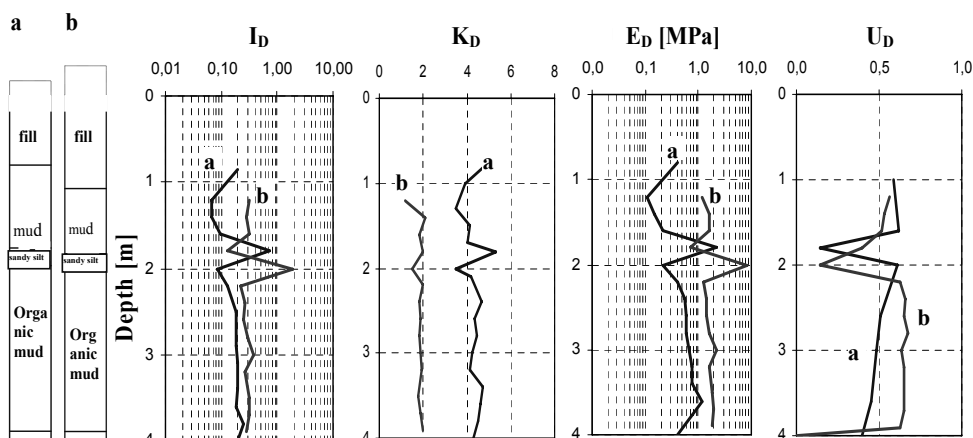

FIGURE 2. Indexes parameters of I_D, K_D, E_D and U_D profiles from dilatometer the test at the Nielisz site: a – virgin soft subsoil; b – under loading

by Marchetti correlation (eq. 5) does not describe τ_{fu} for organic mud got from subsoil under Nielisz dam. With dilatometer test (DMT) it results, that to evaluate the τ_{fu} of organic mud from Nielisz site for help three factors such how: $(p_o - u_o)$, $(p_1 - u_o)$, σ'_{vo} (eq. 6).

For organic soils new equation was proposed (Rabarijoely 2000) as follow:

$$\tau_{fu} = \alpha_o \cdot \sigma_v'^{\alpha_1} \cdot (p_o - u_o)^{\alpha_2} \cdot (p_1 - u_o)^{\alpha_3}$$

(6)

Empirical coefficients to power form of proposed dependence one can so mark on the soil the porosity indexes e from the dependence (eq. 7):

$$\alpha_i = C_i \cdot e + D_i \qquad (7)$$

where: C_i, D_i – coefficients given in the Table 2
– the organic mud ($I_{om} = 20\%$):
$\alpha_o = 0,686$, $\alpha_1 = 0.075$, $\alpha_2 = 0.109$, $\alpha_3 = 0.587$
– the organic mud ($I_{om} = 10\%$):
$\alpha_o = 1.124$, $\alpha_1 = 0.134$, $\alpha_2 = 0.096$, $\alpha_3 = 0.441$

Above mentioned equation was applied for determination of τ_{fu} profiles of in foundation of Nielisz dam (Fig. 3).

Obtained results to analyse for each kinds of organic muds the coefficient of the determination $R^2 > 95\%$ what testifies the strong account among the dependent variable τ_{fu} and with independent variables σ'_{vo}, $p_o - u_o$, $p_1 - u_o$ (Rabarijoely 2000). From the comparison of maximum and average square relative deviations of the appointed undrained shear strength, it results that in the most of chances lower of their value one received for power form.

New chart consists with two parts. The bottom part of chart represents the value of undrained shear strength τ_{fu} (kPa) in dependence for $\sigma'_{vo} = 10$ kPa, $p_0 - u_o$ (kPa) and $p_1 - u_0$ (kPa). It meanwhile the upper part of chart was used for determination of τ_{fu} value for any σ'_{vo} in data profiles (Fig. 4 for organic mud, I_{om} 10%, $e_0 = 2.5$ and Fig. 5 for organic mud, I_{om} 20%, $e_0 = 3.15$).

The undrained shear strength τ_{fu1} appointed (Figs. 4b, 5b) as functions of $p_1 - u_o$ (kPa) and $p_o - u_o$ (kPa). Instead on the Figure the outline 4a these lines top -down'' is presented by exact values τ_{fu1} (kPa) read from the Figure b from which depend values σ'_{vo} (kPa) and τ_{fu} (kPa).

The undrained shear strength of organic mud ($I_{om} = 10 \div 20\%$, $e_0 = 2.5 \div 3.15$) can be obtained using proposed chart presented in Figures 4 and 5 according to the manner:

In order to determine undrained shear strength τ_{fu} (kPa) one marks on the suitable chart following points:
– on the Figure 5b axled of abscissae one qualifies sharp A answering of the value $p_o - u_o$ (kPa),

TABLE 2. Coefficient values α_o, α_1, α_2 and α_3 determined for organic mud from Nielisz

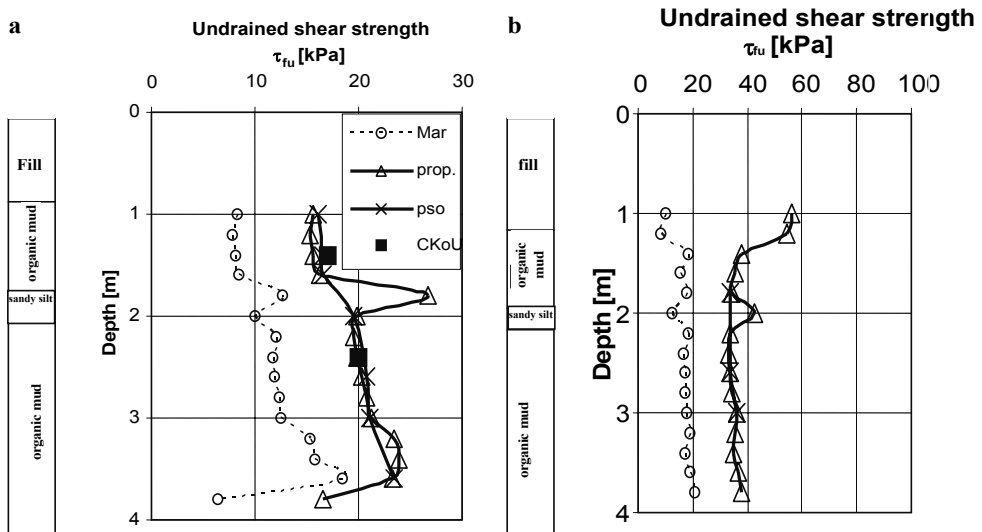| Parameter	e	I_{om}	Value of empirical coefficients			
			α_o	α_1	α_2	α_3
value	2.4	10%	1.124	0.134	0.096	0.441
	3.15	20%	0.686	0.075	0.109	0.587

FIGURE 3. Profiles of undrained shear strength (a): in virgin soft subsoil – (b): under loading, in cross-section hm 4+50: dilatometer test: ──○── Marchetti (5), ──△── proposed eq. (6), ──X── PSO – field vane shear test, ──■── CK_0U triaxial tests

– axled of ordinates one qualifies point B answering of the value $p_1 - u_o$ (kPa),
– straight taken from these points parallel to the coordinate axis will mark local cuts themselves point C,
– curvilinear taken from the point C parallel to the line of the shear strength τ_{fu} (kPa) it will mark on the upper horizontal scale – point D,
– the sloping line taken from the point D on the Figure 4b to the same value τ_{fu} (kPa) on the Figure 5a and will mark point E,
– on the Figure 5a, axled of abscissae one qualifies point F answering of the value σ'_{vo} for which value of the undrained shear strength τ_{fu} (kPa) is a value to finding,
– point cuts himself straight of taken from the point F parallel to the axis of the ordinate and curvilinear from the point E of the parallel to the line of the undrained shear strength τ_{fu1} (kPa) marks point G,

– straight taken from the point G vertically upward will mark in the cut with the upper scale horizontal point F whose the reading will qualify the undrained shear strength value τ_{fu} (kPa).

CONCLUSIONS

Taking into account comprehensive investigation performed by the Department of Geotechnical Engineering SGGW at Nielisz site new chart for determination of undrained shear strength of organic mud was proposed. The new chart (Figs. 4 and 5) will let on the determination of the undrained shear strength τ_{fu} for organic mud (degree of decomposition $I_{om} = 10–20\%$) and lightly preconsolidated (OCR = 2–3). To the use of this chart proper value of the effective vertical stresses σ'_{vo} and the hydrostatical pressure u_o were necessary. Proposed chart is
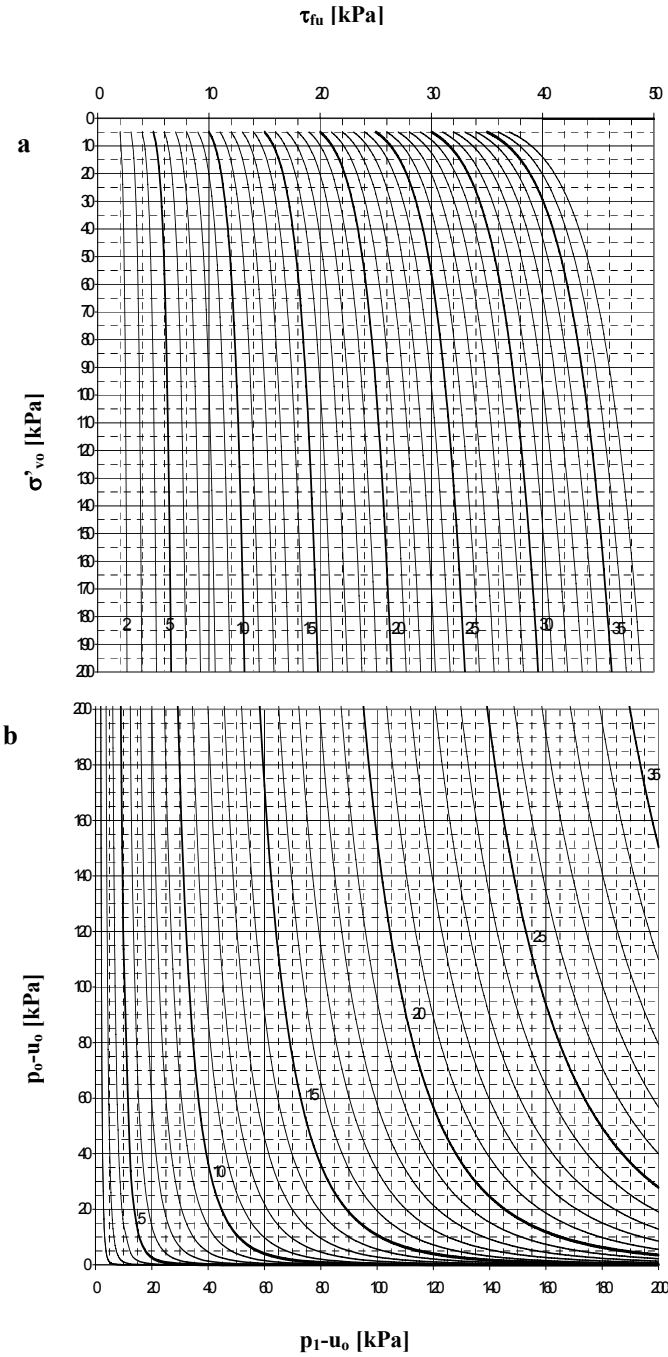
FIGURE 4. The chart for determination of the undrained shear strength τ_{fu} for organic mud (I_{om} 10%, $e_0 = 2.5$) from dilatometer test (Rabarijoely 2000); part of τ_{fu} dependent on: a – (p_o – u_o) and (p_1 – u_o), b – σ'_{vo}
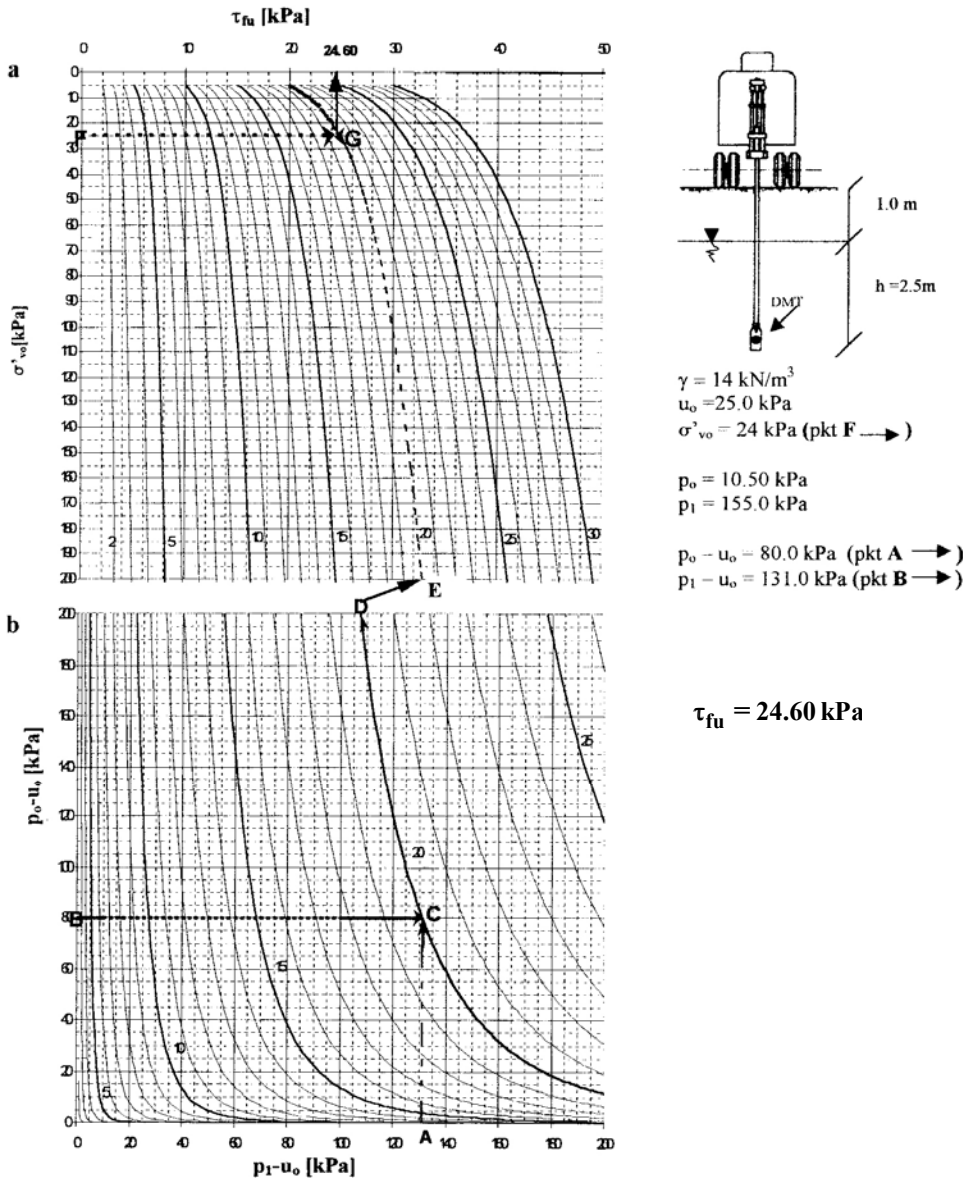
FIGURE 5. Manner of the utilization the chart to determine the undrained shear strength τ_{fu} for organic mud (I_{om} 20%, e_0= 3.15) from dilatometer test (Rabarijoely 2000); part of τ_{fu} dependent on: a – (p_o – u_o) and (p_1 – u_o), b – σ'_{vo}

simple in use and helpful in geotechnical practise for determination of undrained shear strength from DMT tests.

REFERENCES

BRIAUD J., MIRAN J. 1992: The flat dilatometer test, TX, 77843-3136 USA for The Federal Higway Administration.

CAMPANELLA R.G., ROBERTSON P.K. 1991: Use and interpretation of a research dilatometer. Can. Geotech., J., 28: 113–126.

FINNO R.J. 1993: Analytical interpretation of dilatometer penetration through saturated cohesive soils. Géotechnique, 43, No 2, 241–254.

HARTLEN J., WOLSKI W. 1996: Embankments on organic soils. Amsterdam, Elsevier.

LADD C.C., FOOTT R., ISHIHARA K., SCHLOSSER F., POULOS H.G. 1977: Stress-deformation and strength characteristics. Proc. 9th Int. Conf. on Soil Mech. and Foun. Eng., Tokyo, 2; 421–494.

LECHOWICZ Z. 1992: Ocena wzmocnienia gruntów organicznych obciążonych nasypem. [An evaluation of the increase in the shear strength of organic soils under embankment loading]. Treatises and monographs. Wydawnictwo SGGW. [In Polish].

LECHOWICZ Z., RABARIJOELY S. 1996: Wykorzystanie badań in situ w ocenie wzmocnienia słabonośnego podłoża zapory budowanej etapowo [Use of in situ tests in evaluation of soft subsoil strengthening during staged construction]. Mat. na VII Konf. Techn. Kon. Zap., Rytro, 231–240. [In Polish.]

LECHOWICZ Z., RABARIJOELY S. 1997: Use of dilatometer test in evaluation of organic subsoil strengthening. Proc. of Conf. on Rec. Adv. In Soft Soil Eng., Vol. I. Kuching, Sarawak, Malaysia, 185–196.

LEROUEIL S., JAMIOLKOWSKI M. 1991: Exploration of soft soil and determination of design parameters. General Report, Int. Conf. on Geotech. Eng. for Costal Develop. Yokohama.

LUTENEGGER A.J. 1988: Current status of the Marchetti dilatometer test. Proc. Int. Sym. On Penetration Testing ISOPT-1, Orlando, 1: 137–155.

LUTENEGGER A.J., KABIR M.G. 1988: Dilatometer C-reading to help determine stratigraphy. Proc. Int. Sym. on Penetration Testing ISOPT-1, Orlando, 1: 549–553.

MARCHETTI S. 1980: In Situ Tests by Flat Dilatometer. J. Geotech. Eng. Div., ASCE, 106, GT3: 299–321.

MARCHETTI S., CRAPPS D.K. 1981: Flat dilatometer manual. Internal report of GPE.

MARCHETTI S. 1999: On the calibration of the DMT membrane. L'Aquila Univ., Unpublished report.

MŁYNAREK Z., GOGOLIK S. MARCHETTI D. 2006: Suitability of the SDMT method to assess geotechnical parameters of post-flotation sediments. Proc. of the Second International Flat Dilatometer Conference, Washington: 148–153.

RABARIJOELY S. 2000: Wykorzystanie badań dylatometrycznych w wyznaczeniu parametrów gruntów organicznych obciążonych nasypem [The use of dilatometer test for evaluation of organic soil parameters]. Ph. D. Thesis. Warsaw Agricultural University. [In Polish].

SCHMERTMANN J.H. 1986: Suggested method for performing the flat dilatometer test. ASTM Geotechnical testing Journal Vol. 9, No 2, p. 93–101.

TOTANI G., CALABRESE M., MARCHETTI S., MONACO P. 1998: Use of in situ flat dilatometer (DMT) for soil characterization in the stability analysis of slopes. Proc. 14th Int. Conf. on Soil Mech. and Foun. Eng., Hamburg, 1, 607–610.

Streszczenie: *Wykorzystanie badań dylatometrycznych do określenia wytrzymałości na ścinanie gruntów organicznych.* W praktyce inżynierskiej zalecane jest stosowanie nomogramu zarówno w terenie, jak i w biurze projektowym; zarówno do posadowienia bezpośredniego, jak i pośredniego budowli inżynierskich. W nomogramie Marchettiego (1980) nie można bezpośrednio określić wytrzymałości gruntów na ścinanie w warunkach bez odpływu (τ_{fu}) za pomocą wskaźnika K_D. Możliwe jest to jedynie za pomocą wzoru, ale wówczas konieczna jest znajomość współczynnika S, który jest istotnie związany z poszczególnymi warstwami gruntu (rodzaj gruntu). Do zależności potęgowej trzyczynnikowej przy obliczaniu wytrzymałości na ścinanie w warunkach bez odpływu τ_{fu} uwzględniona została historia naprężenia (grunt nieobciążony i podobciążony). Do obliczenia zależności tej wykorzystuje się bezpośrednie pomiary odczyty dylatometryczne, co przyspiesza wykonanie obliczeń.

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