The assessment of variability of CPTU and DMT parameters in organic soils

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ABSTRACT: Organic soils differ from mineral subsoil in terms of physical and strength properties. A characteristic feature of these soils is their non-homogenous macrostructure, anisotropy and considerable deformations. These factors may also have a significant effect on the variation of parameters measured in CPTU and DMT, i.e. tests which are used to assess shear strength and constrained moduli of these soils. The article presents an analysis of variability of CPTU and DMT testing data, concerning layers of peat, gyttja, and marginal lake silty clay. The analysis contains statistical assessment of differences in the variability of tests parameters and the effect of this variability on forecasting undrained shear strength and constrained moduli.

1 INTRODUCTION

The application of empirical relationships to determine shear strength parameters and constrained modulus of soils is presently the most frequently applied method in case of CPTU and DMT (Lunne et al. 1997, Marchetti 1980). Relationships of this type may be used with special efficiency when they are supported by the interpretation, which includes the strength model of the subsoil (Jamiołkowski 2001) and takes into consideration a verification of the solution, which is obtained in tests conducted in calibration chambers (non-cohesive soils). Achievements in this respect in case of CPTU and DMT are considerable, but pertain primarily to mineral subsoil. A key issue in developing a correlation is the introduction of representative measurement data. It is true of both discussed tests. A commonly applied technique to obtain representative parameters is to use filtration methods (Harder and Bloh 1988, Tschuschke and Młynarek 1992, Hagazy and Mayne 2002). The application of these methods in mineral subsoil is well-known. In case of organic subsoil there is limited information on the variability of parameters measured in CPTU and DMT and its effect on forecasted shear strength parameters and constrained moduli. This article discusses this problem.

2 METHODS AND THE OBJECT OF THE STUDY

Cone penetration tests (CPTU), dilatometer and field vane tests were performed in the valley of the Bogdanka River in the city of Poznań. In this area the foundation for a sanitary sewer with the diameter of 1400 mm was planned. Designing the foundation of a collecting pipe requires detailed knowledge about soil bearing capacity and about the magnitude and heterogeneity of the settlements. The soil profile is composed of a surfical layer of embankments, followed by a layer of peats and marginal lake deposits represented by silts, mud and gyttjas, as well as silty clays. These deposits lay on fluvial sands (Fig. 1).

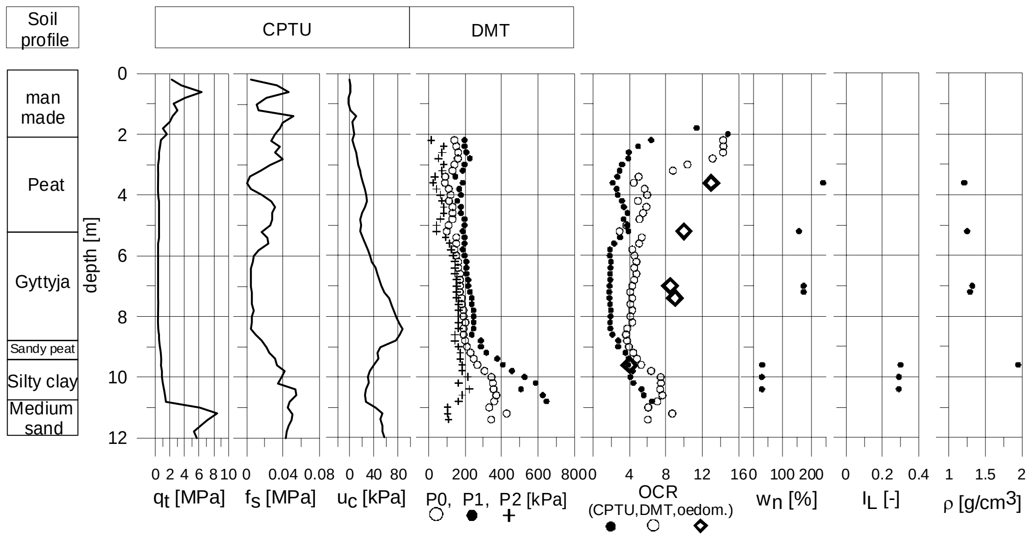

Figure 1. The soil profile at the testing point, based on CPTU, DMT and sampling (after Młynarek et al. 2006).

Piezocone penetration tests were performed using a HYSON 200 kN penetrometer by A. P. van den Berg (Holland). Testing was conducted according to the International Test Procedure for Cone Penetration Test (1999). Dilatometer tests were conducted using an original Marchetti dilatometer. Measurements were recorded according to the International Test Procedure for DMT Test (Monaco et al. 1999). For the field vane a gauging point was applied with the height of 80 mm and width of 40 mm The velocity of the gauging point rotation was 25 rpm. Soil cores for laboratory testing were collected using a Mostap sampler. The procedure of the oedometer test was of the “end of primary” (EOP) type. For each load increment an arbitrary stabilization of sample deformation was assumed at 0.01 mm within 48 hours. On the basis of oedometer tests constrained modulus were determined for the load range from 0.0 to 150 kPa and from 0.0 to σ'_{vo}, and tangential moduli: tan σ'_{vo} and tan $\sigma' = 100$kPa.

3 ASSESSMENT OF VARIABILITY OF CPTU AND DMT PARAMETERS

The F-Snedecor test (Gouri and Johnson 1977) was used to analyze the significance of differences between variability observed in individual testing samples. Data originating from one geotechnical layer were assumed to constitute one testing sample. The analysis covered three groups of samples: a layer of peats, gyttjas and silty clays.

Testing parameters for which differences were studied included: q_n (CPTU) and E_D (DMT), as parameters standardized by subtracting the value of the vertical geostatic stress, and Q_t (CPTU) and K_D (DMT) – as parameters normalized by the division of direct testing results by the vertical geostatic stress. The obtained values of testing probability “p” (defining the probability of no error being committed at the assumption of a zero hypothesis on a lack of differences) are listed in Table 1, along with mean values, standard deviations (σ) and coefficients of variation (CV) for individual parameters.

As shown on the results of Table 1 that in each analyzed case there are statistically significant differences in the variability of recorded parameters. The size of the variability may be inferred on the basis of the determined coefficient of variation. While comparing parameters q_n and E_D, it needs to be stated that in each tested soil lower variability is observed for parameters from CPTU. However, in the case of parameters Q_t and K_D, in gyttjas and firm sandy clays parameters from DMT are more homogenous.

Soil layer	Compared parameters	p	Mean [MPa]	σ [MPa]	CV
Peat	qn	0.000	0.404	0.103	0.255
	ED		2.032	0.570	0.281
	Qt	0.000	10.474	3.038	0.290
	KD		2.357	1.060	0.450
Gyttja	qn	0.000	0.284	0.048	0.169
	ED		1.772	0.398	0.225
	Qt	0.000	5.952	0.714	0.120
	KD		1.478	0.101	0.068
Silty clay	qn	0.000	0.887	0.238	0.268
	ED		6.622	2.074	0.313
	Qt	0.000	14.439	2.835	0.196
	KD		2.170	0.302	0.139

Table 1 Results of statistical analysis of the significance of differences between parameters from DMT and CPTU

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Soil layer	Compared parameters	n	Mean [MPa]	- 95%	+95%	Size of confidence interval as % of mean
Peat	qn	18	0.404	0.356	0.451	23.7
	ED	18	2.032	1.769	2.296	25.9
	Qt	18	10.474	9.070	11.877	26.8
	KD	18	2.357	1.868	2.847	41.6
Gyttja	qn	16	0.284	0.262	0.306	15.5
	ED	16	1.772	1.588	1.956	20.8
	Qt	16	5.952	5.623	6.282	11.1
	KD	16	1.478	1.432	1.525	6.3
Silty clay	qn	8	0.887	0.777	0.997	24.8
	ED	8	6.622	5.664	7.580	28.9
	Qt	8	14.439	13.129	15.748	18.1
	KD	8	2.170	2.030	2.309	12.9

Table 2 95% confidence intervals for parameters q_n, KD, Q_t and ED and their size in relation to the mean value of the parameter

Significant information is also supplied by Table 2. Results presented in this table confirm a considerably lower range of variation in parameters from both tests in the layer of gyttjas and silty clay than it was the case in the layer of peat. The peat layer, apart from its complex macrostructure and anisotropic properties, will thus require a higher number of replications for in situ tests in order to obtain representative data, which would make it possible to assess strength and deformation parameters for this layer. This conclusion is confirmed by the results of studies on the non-homogeneity of a peat deposit by Młynarek and Niedzielski (1983).

4 VARIABILITY AND THE ESTIMATIVE F UNDRAINED SHEAR STRENGTH

Undrained shear strength s_u on individual levels σ_{v0} of CPTU was determined from a formula, in which coefficient N_{kt} was applied (Lunne et al., 1997). Coefficient N_{kt} was corrected on the basis of a field vane test. In the case of DMT shear strength s_u was calculated from relationships given by Marchetti (1980), Larson and Eskilson (1989) and Rabarijoely (1999).

Compressibility modulus of individual soil layers was referred to the constrained and oedometric moduli, while the variation of the moduli with depth for CPTU was obtained by determining the modulus from the Kulhawy and Mayne relationship (1990), assuming coefficients α at 1.3 for peat, 1.6 for gyttja and 8.25 for silty clay, respectively. For DMT compressibility moduli were determined from relationships given by Marchetti (1980) and Rabarijoely (1999). Figure 2 presents changes in undrained shear strength, determined using the above mentioned methods, whereas Fig. 3 shows changes in compressibility moduli along with depth.

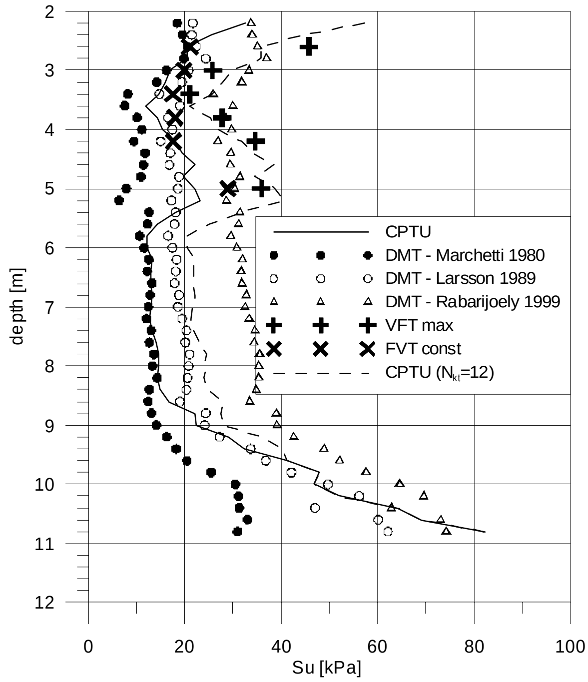

Figure 2. Values of undrained shear strength s_u determined on the basis of different tests.

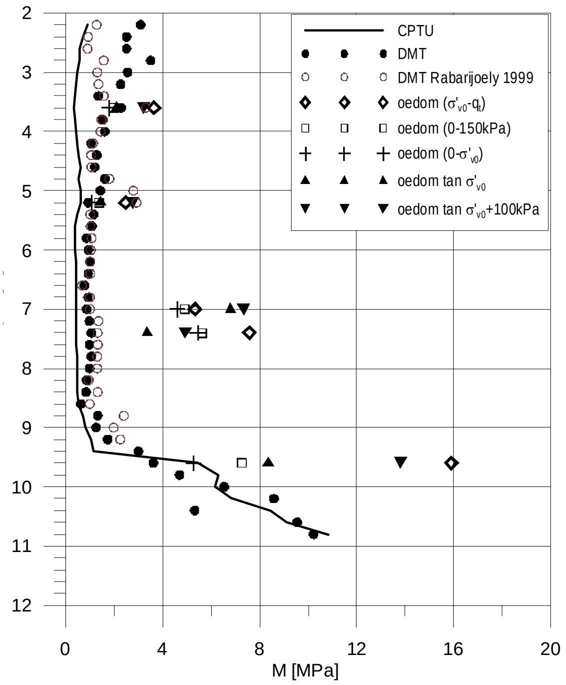

Figure 3. Changes in constrained modulus along with depth, determined using different methods.

The significance of differences between mean values of shear strength s_u was assessed statistically in two stages. In the first stage s_u(CPTU) and s_u(DMT)

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were compared – the latter defined according to the Larsson formula (Larson and Eskilson, 1989). In the second stage differences were analyzed in the values of undrained shear strength defined from CPTU and DMT, as well as FVT. The analysis of results in case of CPTU was conducted both for the originally adopted value N_{kt}=21, and the one corrected on the basis of FVT, i.e. N_{kt}=12. Results of the analysis, supplemented with the analysis of significance of differences between means, are given in Table 3.

Results from Table 3 confirm a known relationship for mineral soils between s_u(CPTU) and $s_{u\ max}$(FVT). The introduced correction of coefficient N_{kt} resulted in the differences in mean strength values for these layers, determined on the basis of both tests, being statistically non-significant. Results based on DMT in turn show a similarity (both in terms of means and variability) to stabilized values of undrained shear strength from FVT.

It may also be observed from Table 3 that discrepancies in the assessment of undrained shear strength between DMT and the field vane test are much larger if they pertain to the maximum value of shear resistance in the field vane test than the determined value. A consequence of the determined dispersion of parameters from CPTU and DMT is the differing probability of the forecast concerning the mean value of undrained shear strength for individual subsoil layers.

Soil layer	Compared parameters	p: For dispe-rsion of data	p: For means	Mean [MPa]	σ [MPa]	CV
Peat	Su(CPTU, Nkt=21)	0.011	0.711	19.21	4.92	0.26
	Su(DMT)			18.73	2.56	0.14
	Su(CPTU, Nkt=21)	0.065	0.000	19.21	4.92	0.26
	Su max(FVT)			31.79	8.79	0.28
	Su(CPTU, Nkt=12)	0.851	0.658	33.63	8.61	0.26
	Su max(FVT)			31.79	8.79	0.28
	Su(DMT)	0.000	0.000	18.73	2.56	0.14
	Su max(FVT)			31.79	8.79	0.28
	Su(DMT)	0.093	0.230	18.73	2.56	0.14
	Su const(FVT)			20.51	4.34	0.21

Table 3 Results of statistical analysis of significance of differences between undrained shear strength s_u from DMT, CPTU and FVT.

Soil layer	Compared parameters	n	Mean [MPa]	- 95%	+95%	Size of confidence interval as % of mean
Peat	Su(CPTU, Nkt=12)	18	33.63	29.65	37.61	23.7
	Su (DMT-Lars.)	18	18.73	17.55	19.91	12.6
Gyttja	Su (CPTU)	16	23.07	22.03	24.11	9.0
	Su (DMT-Lars.)	16	19.47	18.62	20.32	8.7
Silty clay	Su (CPTU)	8	55.41	48.54	62.28	24.8
	Su (DMT-Lars.)	8	48.44	43.57	53.32	20.1

Table 4 95% confidence intervals of undrained shear strength and their size in relation to the mean value of parameter

Table 4 shows that in the peat layer, at the assumed normal distribution for the analyzed data, the 95% range of confidence intervals for the assessment of the mean value determined using the CPTU method is smaller than it is the case in the DMT approach. In contrast, in the gyttja and silty clay layers this assessment is similar.

Variation in compressibility moduli assessed using CPTU and DMT is presented in Table 5, while the forecast of probability for the assessment of mean values of moduli is shown in Table 6.

It may be generally observed from the assessment of variability for compressibility moduli obtained using CPTU and DMT according to the Marchetti formula (Marchetti 1980) that in organic soils the stated differences are statistically significant in contrast to the firm silty clay layer. In the layer of gyttja and silty clay the precision of assessment for the mean value of compressibility modulus using CPTU and DMT is

Soil layer	Compared parameters	p	Mean [MPa]	σ [MPa]	CV
Peat	M(CPTU)	0.000	0.525	0.134	0.255
	M(DMT-March.)		1.832	0.764	0.417
	M(CPTU)	0.000	0.525	0.134	0.255
	M(DMT-Rabar.)		1.551	0.718	0.463
Gyttja	M(CPTU)	0.013	0.454	0.076	0.167
	M(DMT-March.)		0.939	0.149	0.159
	M(CPTU)	0.000	0.454	0.076	0.167
	M(DMT-Rabar.)		1.193	0.373	0.313
Silty clay	M(CPTU)	0.890	6.794	2.897	0.426
	M(DMT-March.)		6.439	2.744	0.426

Table 5 Results of statistical analysis of significance of differences between constrained moduli from DMT and CPTU

Soil layer	compared parameters	n	mean [MPa]	- 95%	+95%	Size of confidence interval as % of mean
peat	M(CPTU)	18	0.525	0.463	0.587	23.7
	M(DMT-March.)	18	1.832	1.479	2.184	38.5
	M(DMT-Rabar.)	18	1.551	1.219	1.883	42.8
gyttja	M(CPTU)	16	0.454	0.419	0.489	15.5
	M(DMT-March.)	16	0.939	0.870	1.008	14.7
	M(DMT-Rabar.)	16	1.193	1.020	1.365	28.9
silty clay	M(CPTU)	8	6.794	5.456	8.132	39.4
	M(DMT-March.)	8	6.439	5.171	7.706	39.4

Table 6 95% confidence intervals of compressibility modulus and their size in relation to the mean value of parameter

similar (coefficients of variation are similar in value and confidence intervals have similar percentage range). In contrast, in the peat layer the accuracy of the assessment for the mean value of compressibility modulus using CPTU is much higher than in case of DMT. However, it needs to be stressed that values of means for compressibility moduli in layers of peats and gyttjas obtained with the use of CPTU and DMT differ statistically, while they are completely consistent in the layer of silty clay. The problem of the assessment of these differences and the consistency of in situ methods with oedometer testing was discussed in a study by Młynarek et al (2006).

5 CONCLUSIONS

On the basis of the conducted analysis several generalizations may be formulated as follows:

- The variability of CPTU and DMT testing data as well as estimated geotechnical soil parameters is significantly dependent from the type of organic soil. Higher variability was observed in peat than in gyttja layers for both CPTU and DMT testing.
- A consequence of this variability in parameters from CPTU and DMT is the different precision of assessment in case of undrained shear strength and tangential constrained modulus obtained using both tests in peat and gyttja.
- Due to the diverse variation in parameters of CPTU and DMT it is highly recommended to use both methods to assess strength and deformation parameters especially for organic soils. Such an approach makes it possible to obtain a continuous picture of changes in geotechnical parameters of the subsoil along with depth and it allows conducting a mutual correction for the assessment of numerical values of these parameters.
- Adaptation on correlations to estimate geotechnical soil parameters commonly used for mineral soils, onto organic subsoil is another aspect that has to be considered for organic soil. The conducted investigations showed that correlations have to be modified considering the differences between peats and gyttjas.

REFERENCES

De Groot D.J, Baecher G.B. (1993). Extimating autocovariance of in situ soil properties. ASCE, Journal of Geotechnical Engineering, Vol. 119, No. 1, pp. 147-167.

Gouri K. Bhattacharyya and Richard A. Johnson (1977). Statistical concepts and methods, John Wiley & Sons.

Harder H., von Bloh G. (1988). Determination of representative CPT-parameters. Proc. of Penetration Testing in U.K., Geotechnology Conference Birmingham, pp. 237-240.

Hegazy Y.A., Mayne P.W. (2002). Objective Site Characterization Using Clustering of Piezocone Data. Journal of Geotechnical and Geoenvironmental Engineering. Vol. 12; s. 986-996.

International Test Procedure for Cone Penetration Test (CPT) and Cone Penetration Test with pore pressure (CPTU) (1999). Report of TC-16, ISSMGE.

Jamiolkowski M. (2001). Evaluation of Relative Density and Shear Strength of Sands from CPT and DMT. Proc. of C.C. Ladd Symposium, October 2001, M.I.T., Cambridge, Mass.

Kulhawy F., Mayne P.W. (1990). Manual on estimating soil properties for foundation design. Electric Power Research Institute, EPRI, August 1990.

Larsson R., Eskilson S. (1989). DMT Investigations in Organic Soils. Swedish Geotechnical Institute, Publ. No. 248. Aug., 1989.

Lunne T., Robertson P.K., Powell J.J.M. (1997). Cone Penetration Testing in geotechnical practice. Reprint by E & FN Spon, London, 1997.

Marchetti S. (1980). In situ tests by flat dilatometer. ASCE, JGED, V. 106, No. GT3, pp. 299-321, 1980.

Młynarek Z., Niedzielski A., Tschuschke W. (1983). Variability of shear strength and physical parameters of peat. Proc. of 7th Danube European Conference on Soil Mechanics and Foundation Engineering, vol. 1.

Młynarek Z., Tschuschke W., Pordzik P. (1983). Variability of cone resistance in the process of static penetration of clay. Proceedings of 4th International Conference on Application of Statistics and Probability in Soil and Structural Engineering. Universita di Firenze

Młynarek Z., Tschuschke W., Wierzbicki J., Marchetti S. (2006). An interrelationship between shear and deformation parameters of gyttja and peat from CPT and

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DMT tests. Proc. of 13th Danube-European Conference on Geotechnical Engineering, Ljubljana.

Monaco P., Marchetti S., Calabrese M., Totani G. (1999). The Flat Dilatometer Test. Draft of the Report to the ISSMGE Committee TC-16.

Mortensen J.K., Hansen G., Sorensen B. (1991). Correlation of CPT and field vane test for clay fills. Danish Geotechnical Society, Bulletin No. 7

Nadim F. (1988). Geotechnical site description using stochastic interpolation. 10th NGM-Conf, Oslo, pp. 158-162.

Rabarijoely S. (1999). Wykorzystanie badań dylatometrycznych do wyznaczania parametrów gruntów organicznych obciążonych nasypem. PhD Thesis, SGGW University of Warsaw.

Tschuschke W., Młynarek Zb., Werno M. (1992). Assessment of subsoil variability with the cone penetration test. Proc. of Conference on Probabilistic Methods in Geotechnical Engineering. Canbera, Australia. Balkema, Rotterdam, pp. 215-220.