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# VALIDATION OF SOIL TYPE INTERPRETATION AND DETERMINATION FROM CPT AND DMT TESTS

Simon Rabarijoely✉

Institute of Civil Engineering, Warsaw University of Life Sciences – SGGW, Warsaw, Poland

**ABSTRACT**

This paper consists of three parts. The first part presents the methodology of *in situ* tests using a CPT probe and methods of soil type determination that are based on them. The second part lays out the methodology of field tests with Marchetti's dilatometer (DMT) and methods of soil type determination on their basis. In the third part, the process of validation of CPT and DMT tests with borehole test methods is carried out based on the analysis of *in situ* investigations in the Warsaw University of Life Sciences (SGGW) Campus sites compared to the results obtained from laboratory tests. Validation of the CPT method using Marr's nomogram was successful. The DMT method using Marchetti's nomogram chart should be also considered as satisfactory.

**Key words:** validation, *in situ* investigations, CPT, DMT, borehole tests

## INTRODUCTION

When designing an engineering structure, many factors must be taken into account, including safety considerations, without which it is impossible to carry out even the most ambitious plan. The engineer's task is to gather various types of data to enable, among other things, verification whether the soil is suitable for the designed building and allows for the construction of solid foundations. Soil type and geotechnical parameters needed for designing are obtained in soil tests (Schneider, 1997; Orr, 2000; Bond & Harris, 2008; Młynarek, 2008; Wierzbicki, 2010; Młynarek, Stefaniak & Wierzbicki, 2012; Tarnawski et al., 2020). Soil investigations are thus indispensable here. They can be subdivided into field and laboratory tests. Laboratory tests have a number of advantages, including accuracy, a well-defined stress state or the ability to control drainage conditions (Gryczmański, 1995; Pisarczyk, 2014; Cichy, Lechowicz & Garbulewski, 2017). *In situ* tests, which are the subject of this article, are used for testing soil parameters directly in the field. Based to them it is possible to determine the geotechnical parameters of soils in their natural state. These measurements, owing to modern investigation methods, are in the forefront of soil classification because of the large array of available nomogram charts, which can be used to determine characteristic soil parameters in a simple way for a given type of probing and then to interpret the results of this probing. The most common *in situ* soundings include the cone penetration test (CPT) and the Marchetti's dilatometer test (DMT) (Schmertmann, 1978; Marchetti, 1980; Lunne, Robertson & Powell, 1997; Fellenius & Eslami, 2000; Młynarek, Gogolik & Marchetti, 2006; Młynarek, Wierzbicki & Wołyński, 2007; Bałachowski & Kurek, 2008; Tankiewicz & Bagińska, 2021). They are also often used to supplement borehole data. This paper does not describe the construction of dilatometer and cone penetration tests, as this information can be found

Simon Rabarijoely https://orcid.org/0000-0002-4409-223X
✉simon_rabarijoely@sggw.edu.pl

in the archives of the journal (Bajda, Skutnik, Lech & Rabarijoely, 2018; Rabarijoely, 2018). Analysis of the accuracy of the subsoil layer identification methods and their comparison with samples taken for laboratory tests was carried out. The research was conducted on the Warsaw University of Life Sciences (SGGW) Campus. The aim of this publication is to verify the accuracy of selected soil identification methods based on *in situ* tests with CPT and DMT analyses. It also supplies data on the application of Marr's and Marchetti's nomogram charts in the interpretation of CPT and DMT test results, respectively, from the SGGW Campus. The article is also focused on the validation of methods for soil type determination and the application of nomograms for soil type determination in the SGGW Campus subsoil.

## *IN SITU* METHODS FOR SOIL TYPE DETERMINATION

Cone penetration and Marchetti's dilatometer tests (CPT and DMT respectively), and later also piezocone penetration test (CPTu) were initially considered more reliable in the assessment of geotechnical conditions in the designed building structure. Currently, despite significant differences in test methodology, CPTu and seismic dilatometer Marchetti's test (SDMT) soundings are considered equivalent.

One of the simplest CPT nomograms was developed in 1981. The classification on Figure 1 presents the dependence of cone resistance ($q_c$) on sleeve friction ($f_s$). The classification nomogram is subdivided into seven areas, each representing a different soil

a

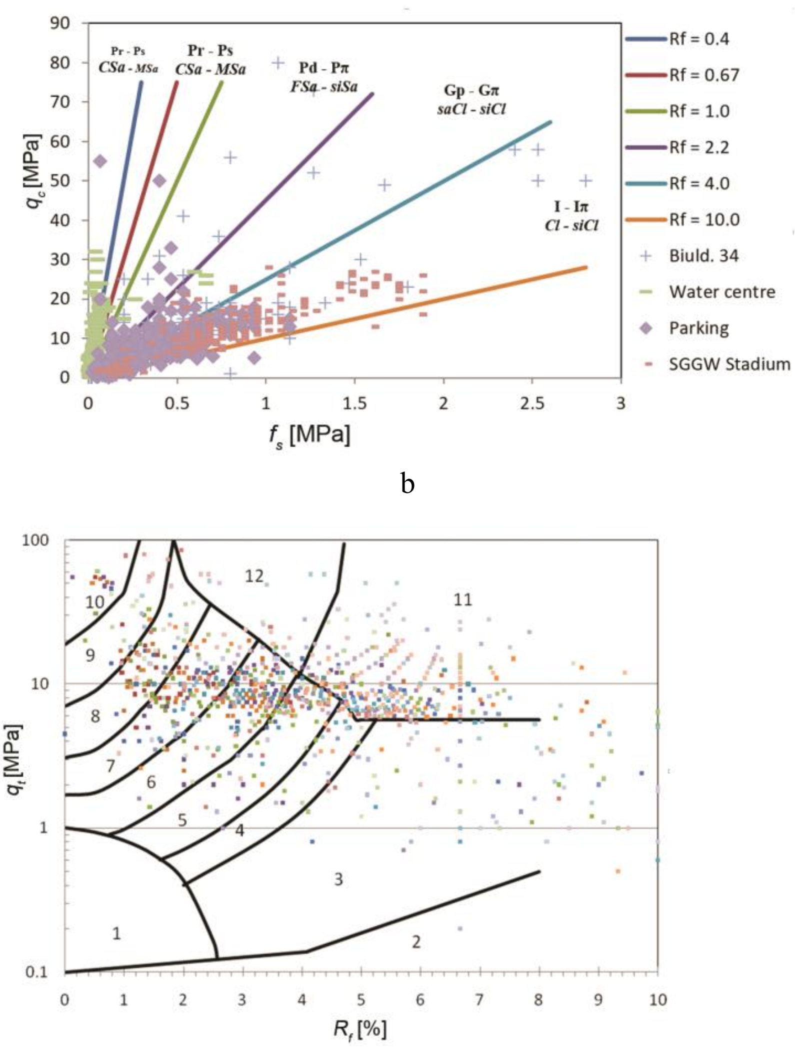


**Fig. 1.** The CPT test results from the SGGW Campus: a – the Marr's nomogram (Begemann, 1965); b – Robertson's nomogram (Robertson, Campanella, Gillespie & Grieg, 1986)

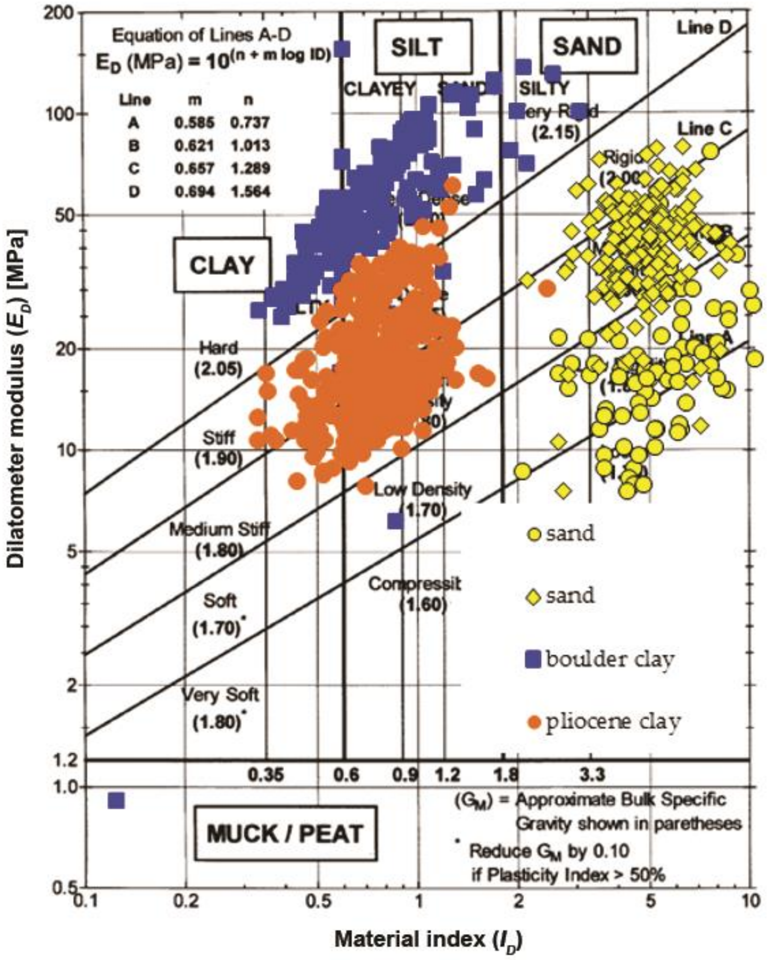


**Fig. 2.** Marchetti's nomogram chart with DMT test results from the SGGW Campus

**Table 1.** Soil classification depending on the value of the material index ($I_D$) (Marchetti, 1980) along with an additional soil range presented in this paper

<table>
<tr><th colspan="6">Material index ($I_D$)</th></tr>
<tr><td colspan="6">Clay (Cl)</td></tr>
<tr><td>silty clay<br>(siCl)</td><td>clay<br>(Cl)</td><td>sandy clay<br>(siCl/saCl)</td><td>silty clay with sand<br>(siCl)</td><td>sandy and silty clay<br>(sasiCl)</td><td>sandy clay with silt<br>(saCl)</td></tr>
<tr><td>0.1–0.27</td><td>0.27–0.33</td><td>0.33–0.57</td><td>0.57–0.58</td><td>0.58–0.59</td><td>0.59–0.61</td></tr>
<tr><td colspan="6">Silt (Si)</td></tr>
<tr><td>clayey silt<br>(saclSi)</td><td>clayey and sandy silt<br>(sasiCl)</td><td>clayey sand<br>(saCl/clSa)</td><td>silt<br>(Si)</td><td>sandy silt<br>(clSi)</td><td>slightly clayey sand<br>(clSa)</td></tr>
<tr><td>0.61–0.78</td><td>0.78–0.79</td><td>0.79–0.81</td><td>0.81–1.17</td><td>1.17–1.74</td><td>1.74–1.8</td></tr>
<tr><td colspan="6">Sand (Sa)</td></tr>
<tr><td>silty sand<br>(siSa)</td><td colspan="2">fine sand<br>(FSa)</td><td>medium sand<br>(MSa)</td><td colspan="2">coarse sand<br>(CSa)</td></tr>
<tr><td>1.8–3.3</td><td colspan="2">3.3–4.5</td><td>4.5–6.5</td><td colspan="2">6.5–10</td></tr>
</table>

type, and each straight line represents a boundary for the value of friction coefficient ($R_f$).

Marchetti (1980), Cruz, Devincenzi and Viana da Fonseca (2006), Cruz (2009), and Cruz (2010), when presenting Marchetti's dilatometer, an innovative research device, proposed a soil subdivision based on the material index ($I_D$). This parameter is a close connection between the material index and grain-size distribution (Marchetti, 1980; Fig. 2). Marchetti observed that in the case of clays, the material index ($I_D$) reaches similar values, whereas for sands these values diverge significantly. On this basis, the subsoil was divided into types depending on the value of the material index ($I_D$) – Table 1.

## MATERIAL AND METHODS

The SGGW Campus area is located on a post-glacial plateau. It is a flat area that developed in the Neogene, located in the Mazovian basin (Fig. 3). According to archival data, the basin bottom is composed of marls, siliceous limestones and gaizes. The thickness of Paleogene and Neogene deposits exceeds 200 m. The upper part of the Neogene is represented by Pliocene sediments, which consist mainly of motley clays with lenses and layers of sand and silt with a thickness of about 105 m. The erosive activity of waters in the periglacial and later periods, as well as glacitectonic deformation resulted in a varied surface of Pliocene clays. Quaternary sediments with a thickness of 26–49 m occur above the clay layers. These deposits were formed as a result of glacial, fluvioglacial and fluvial accumulation. At the base of the Quaternary occur ice-dammed clay-silt deposits with silt interbeds.

This paper presents the test results of mineral subsoils obtained from the SGGW Campus with the Department of Geotechnical Engineering of the SGGW sites located in Warsaw, where a laboratory and field testing program was carried out. The geological characteristics of grounds in the buildings designed in the frame of SGGW Campus development were recognised by the interpretation of boring data (102 boreholes), CPT and DMT tests (69 and 41 profiles, respectively) and comprehensive laboratory investigations (Fig. 4a). Analysis of data collected in the


**Fig. 3.** Location of the SGGW Campus site

ground investigation report (GIR) allowed to identify five geotechnical layers in the SGGW Campus test site (Fig. 4b–c), including a layer of brown glacial boulder clay referred to in this paper as Layer III (according to the geotechnical classification: sandy clay – saCl and sasiCl) from the Wartanian glaciation (gQpW), for which the liquidity index ($I_L$) values varies from 0.0 to 0.11, and a layer of grey glacial boulder clay from the Odranian glaciation (gQpO), as well as sandy clay with boulders, referred to as Layer IV, for which the liquidity index ($I_L$) values varies from 0.0 to 0.12. Layers III and IV were indicated as layers with relevant geotechnical conditions for the foundation of the Campus buildings (Fig. 4b–c). The SGGW Campus in Ursynów was founded on a moraine plateau (Katedra Geotechniki Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie, 2000––2005). In order to create a 3D model of geotechnical layer distribution in the tested ground, Surfer v. 8.0 software was applied. Each geotechnical layer was drawn by the program separately and then all layers were joined together (Fig. 4d). The grain-size distribution curve obtained from the laboratory tests for mineral soils from the described sites is presented in Figure 5. The basic properties of the Miocene and Pliocene clays are presented in Table 2.

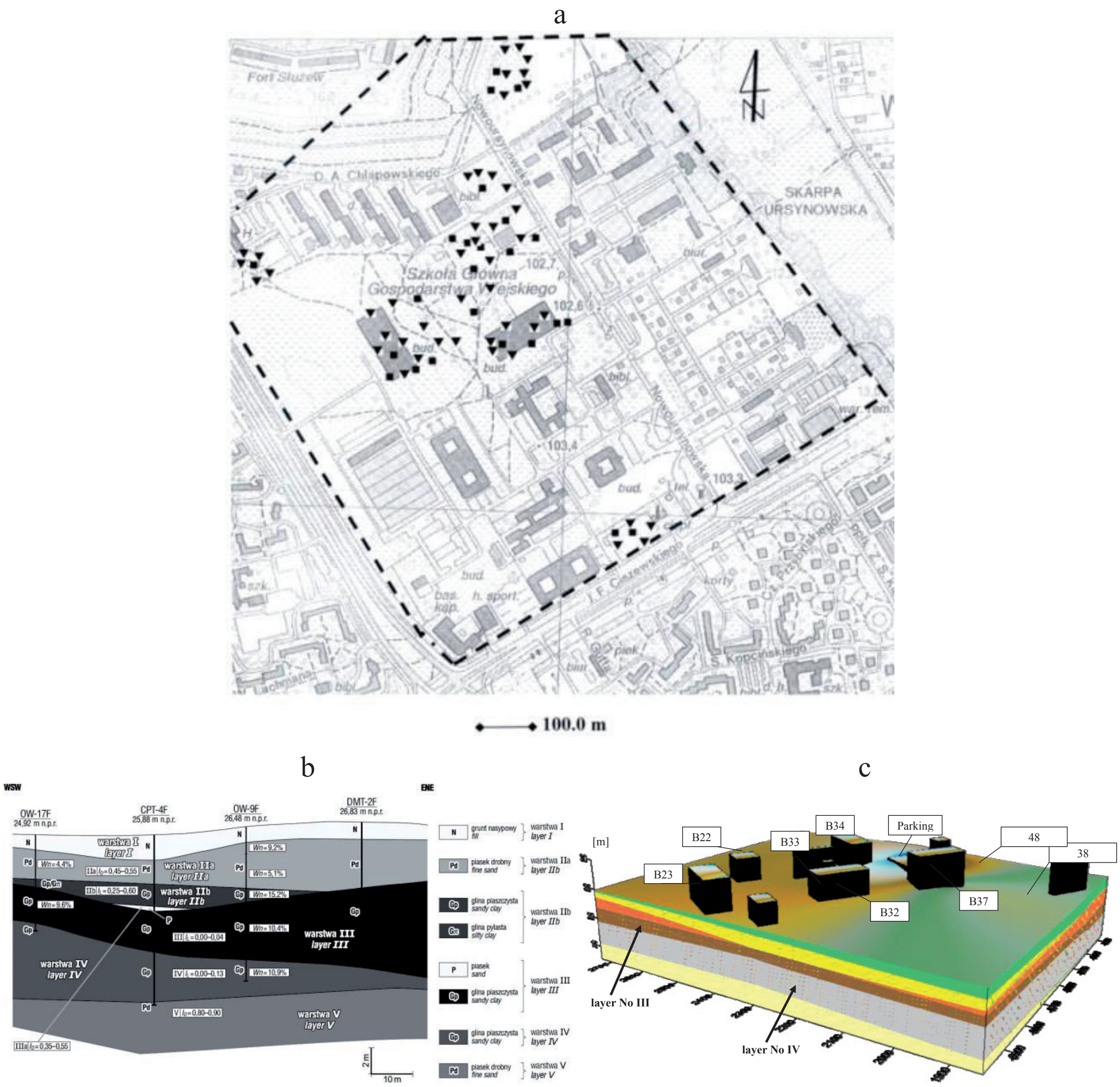


**Fig. 4.** The SGGW Campus site: a – locations of CPT (▼) and DMT (■) test sites; b – typical geotechnical cross-section; $w_n$ – moisture content, $I_D$ – relative density, $I_L$ – liquidity index, m n.p.r. – meters above Vistula 0 level; c – 3D geotechnical model

**Table 2.** Properties of the tested Warsaw clays

| Site | Grain size by soil type[a] [%] | | | | Density unit weight ($\rho$) [t·m$^{-3}$] | Specific density ($\rho_s$) [t·m$^{-3}$] | Preconsolidation ratio (*OCR*) [-] | Plasticity limit ($w_P$) [%] | Liquidity limit ($w_L$) [%] |
|---|---|---|---|---|---|---|---|---|---|
| | gravel | sand | silt | clay | | | | | |
| SGGW Campus (boulder clay) | 2 | 61–70 | 18–26 | 10–13 | 2.0–2.2 | 2.72 | 2–5 | 11.67–13.08 | 21.9–26.5 |
| SGGW Campus (Pliocene clay) | 0 | 3–8 | 40–64 | 32–56 | 2.1–2.2 | 2.72 | 2–3 | 24.97–31.16 | 67.60–88.11 |

[a]According to EN ISO 14688-1 standard (International Organization for Standardization [ISO], 2018).

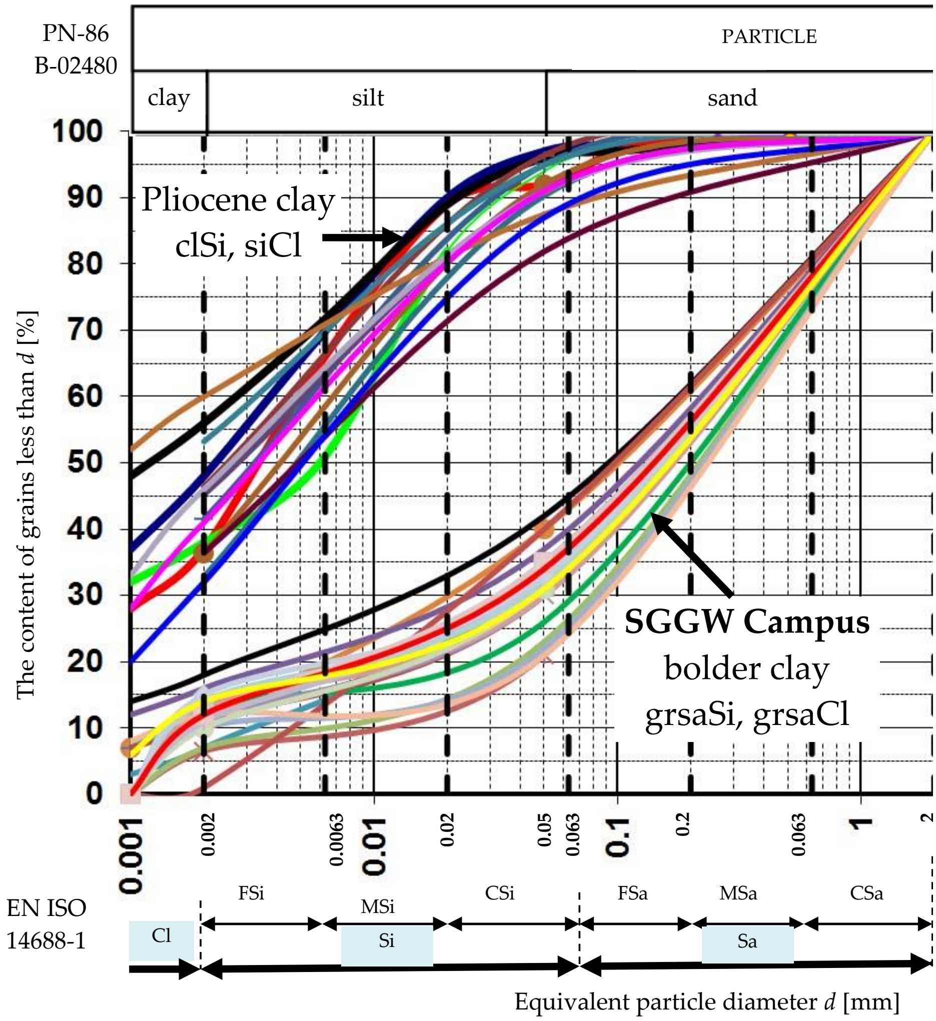


**Fig. 5.** Grain-size distribution of clay from the test sites

## RESULTS

### Soil soundings on the SGGW Campus

The CPT soundings on the SGGW Campus were performed for the future Building 34 (Fig. 6), underground parking lot (Fig. 7), the SGGW Water Centre (Fig. 8) and SGGW Sport Stadium (Fig. 9). The results are presented as graphs of the measured $q_c$, $f_s$ and $R_f$ parameters.

Validation of methods for soil type determination – application of nomograms for the determination of soil type in the subsoil of the SGGW Campus.

Marr's nomogram was chosen to determine the soil type from CPT tests in this paper (Eslami & Fellenius, 2004). Polish standards do not contain detailed guidelines for the interpretation of CPT soil type determination, therefore selected criteria, most commonly used in international practice, were used for the identification. In this study the guidelines of the field investigations standard PN-B-04452 (Polski Komitet Normalizacyjny [PKN], 2002) were used. The results of soil probing from the SGGW Campus were plotted on the nomogram (Fig. 1). The nomogram enables to determine the soil type. The foundations of Building 34,

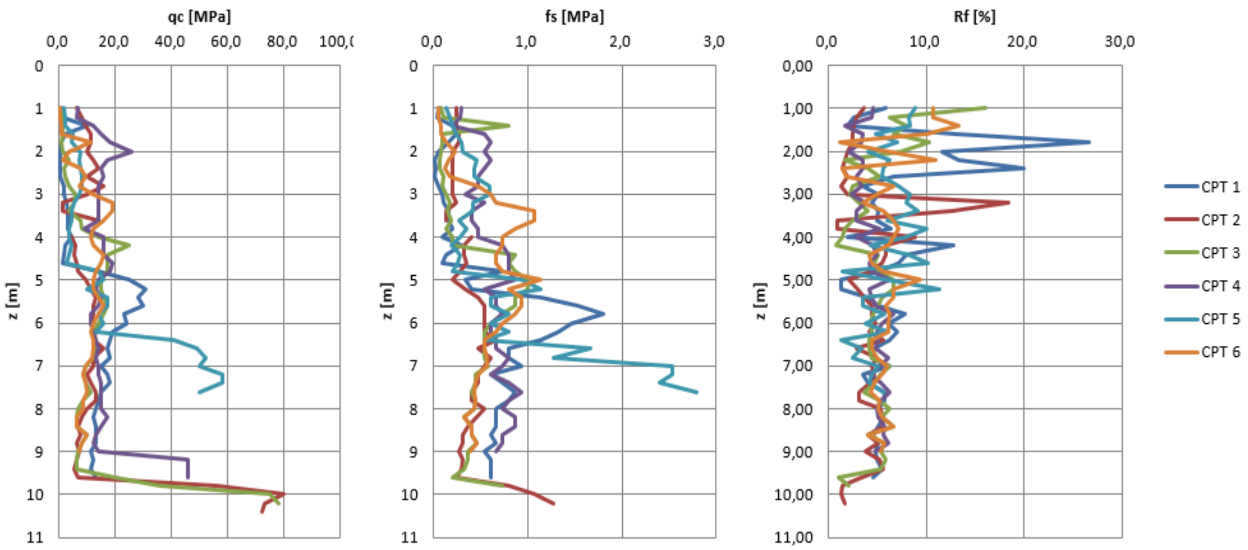


**Fig. 6.** Profiles of $q_c$, $f_s$ and $R_f$ of CPT sounding results for future Building 34 on the SGGW Campus

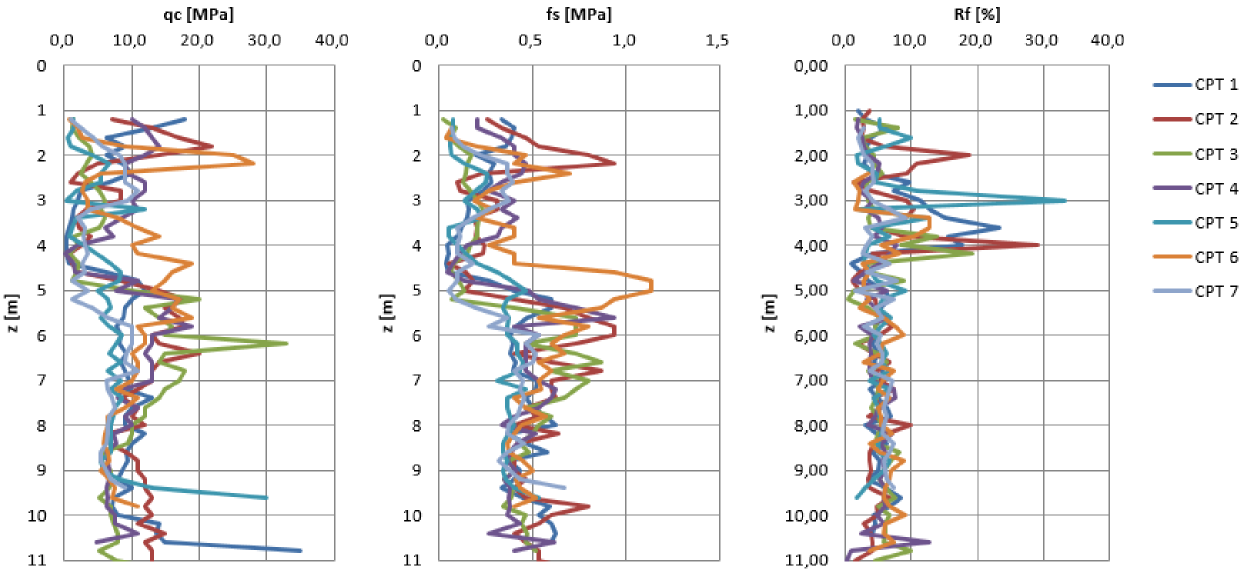


**Fig. 7.** Profiles of $q_c$, $f_s$ and $R_f$ of CPT sounding results for the underground parking lot in the SGGW Campus

the underground parking lot and the SGGW Sport Stadium are characterised by similar soils, mostly clays and silts, whereas the foundation of the SGGW Water Centre is composed mainly of sands within the analysed depth interval. Marchetti's nomogram charts were chosen for the DMT study. The results of soundings from the SGGW Campus were plotted on this nomogram. It shows also that their subsoil is composed mainly of silts and clays (Fig. 2).

Validation is the process of confirming in a documented way whether the results obtained by a certain method are reliable and consistent with the actual state. It involves checking the method validity. Validation may also refer to equipment, materials, opera-

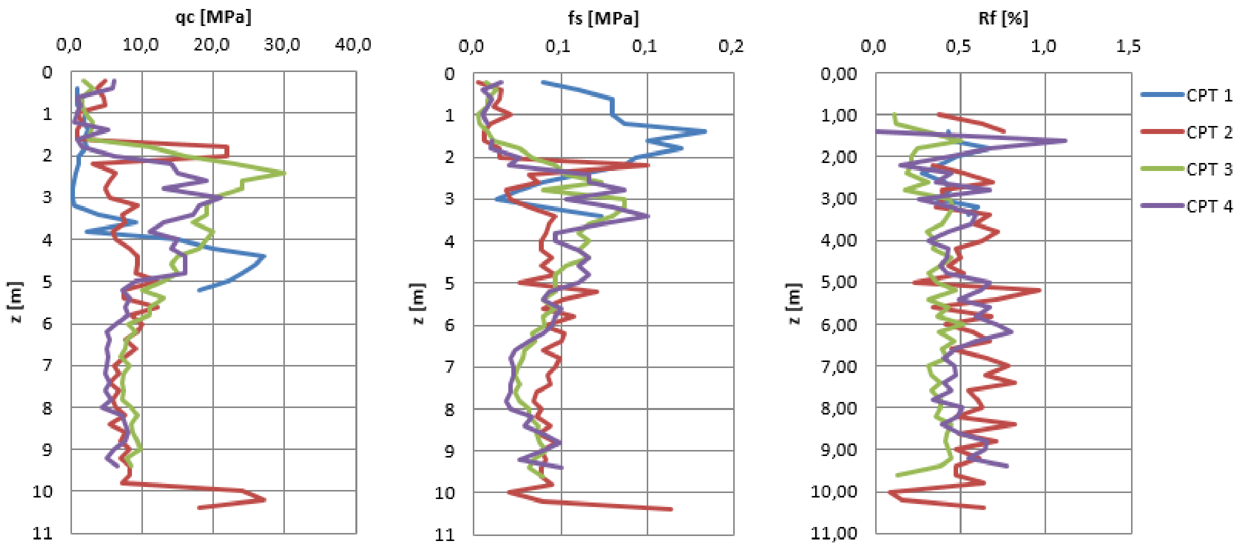


**Fig. 8.** Profiles of $q_c$, $f_s$ and $R_f$ of CPT sounding results for the SGGW Water Centre

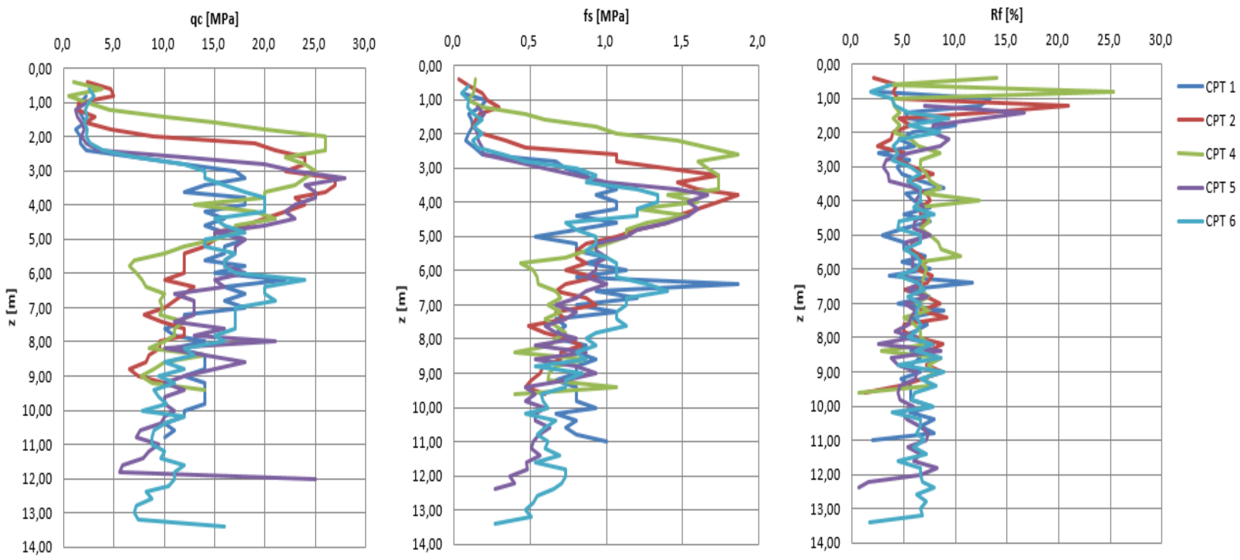


**Fig. 9.** Profiles of $q_c$, $f_s$ and $R_f$ of CPT sounding results for the SGGW Sport Stadium

tions, or procedures. Marr's nomogram was selected to determine the soil type from CPT and CPTU tests. Cone probe tests and boreholes were performed on the SGGW Campus to determine the foundation conditions of the structures. The investigations were performed under the future buildings, Building 34, the SGGW Sport Stadium, the SGGW Water Centre and underground parking lot. Samples for laboratory tests were taken from the boreholes. These tests determined the soil type at the sampling depths. The results of laboratory tests are considered reference data for the field test results. The $q_c$ and $f_s$ parameters obtained from the CPT test were plotted on Marr's nomogram (Fig. 1a) and then the layer types found in particular points were determined. The next step was a comparison of the results from the CPT survey with the nearest borehole in a tabular form. The soil names were adjusted to the new EN ISO 14688-1 standard.

The Marchetti and Crapps nomogram from 1981 was chosen to determine the soil type from the DMT tests. The dilatometer tests were conducted for the future buildings, Building 34, SGGW Water Centre, underground parking lot, and the SGGW Sport Stadium. The results of laboratory tests are considered a reference for *in situ* test results. The $E_D$ and $I_D$ parameters obtained from the DMT test were plotted on Marchetti's nomogram (Fig. 2), then the layer types located in the following points were determined. The next step was to compare the results from the DMT survey with the nearest borehole. The soil names were adjusted to the new EN ISO 14688-1 standard. In the area intended for the foundation of Building 34, where the Faculty of Forestry and Wood Technology is located, 16 boreholes (OW), 5 DMT and 6 CPT soundings tests were made. The validation results are presented in Tables 3–6. In the area designated for the SGGW Water Centre (CW) foundation, 11 borings (OW) and 4 CPT soundings were performed. Validation results are presented in Table 7. In the area designated for the foundation of the underground parking (SGGW

**Table 3.** Summary of CPT 1 with DMT 1 and OW – 27 Building 34 results

| Depth [m] | OW – 27/B34 | | | CPT 1/B34 | | | DMT 1/B34 | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil symbol[b] | soil type[b] |
| 2.0 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | clayey silt | clayey silt | saclSi |
| 7.0 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand – clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | sandy clay – lightly clayey sand | sandy clay – lightly clayey sand | saCl/clSa |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard (PKN, 1986); [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 4.** Summary of CPT 2 with DMT 1 and OW – 27 Building 34 results

| Depth [m] | OW – 27/B34 | | | CPT 2/B34 | | | DMT 1/B34 | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 2.0 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand – clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | clay | clayey silt | saclSi |
| 7.0 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand – clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | sandy clayey silt | sandy clay – lightly clayey sand | saCl/clSa |
| 10.0 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | fine sand – silty sand | **fine sand – silty sand** | Fsa-siSa | sandy clayey silt | clayey silt | saclSi |
| 11.5 | fine sand | **fine sand** | FSa | fine sand – silty sand | fine sand – silty sand | Fsa-siSa | clayey silt | **clay lightly clayey – sandy clay** | siCl/saCl |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 5.** Summary of CPT 5 with DMT 1 and OW – 27 Building 34 results

| Depth [m] | OW – 27/B34 | | | CPT 5/B34 | | | DMT1/B34 | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 2.0 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | clay | clayey silt | saclSi |
| 7.0 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand – clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | sandy clayey silt | sandy clay –lightly clayey sand | saCl/clSa |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 6.** Summary of CPT 6 with DMT 2 and OW – 40 Building 34 results

| Depth [m] | OW – 40/B34 | | | CPT 6/B34 | | | DMT 2/B34 | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 0.8–2.3 | clay | clay | Cl | clay – silty clay | clay – silty clay | Cl-siCl | silt | silt | Si |
| 2.8–3.5 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | sandy clayey silt | clayey silt | saclSi |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 7.** Summary of CPT 1 with DMT 2 and OW – 3 SGGW Water Centre results

| Depth [m] | OW – 3/CW | | | CPT 1/CW | | | DMT 2/CW | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 2.3 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | sandy silt | silty sand | clSa |
| 3.3 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand - clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | sandy clayey silt | clayey silt | saclSi |
| 6.0 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clayey sand – clayey silt | lightly clayey sand – clay lightly clayey | saCl-siCl | sandy clayey silt | clayey silt | saclSi |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

Parking), 10 borings (OW) and 7 CPT soundings were performed. Validation results are presented in Tables 8 and 9. Within the area designated for the construction of the university sports facility (SGGW Sport Stadium), 14 boreholes (OW) and 5 CPT soundings were performed. Validation results are presented in Table 10.

The soil types obtained from laboratory tests and CPT soundings were in agreement in 28 cases out of 48, giving an efficiency of 58.3%. Considering that sandy clay and silty clay have very similar characteristics when comparing the tests, one could assume that it is the same type of soil. Then the results of both

**Table 8.** Summary of CPT 1 with DMT 1 and OW – 1 SGGW Parking results

| Depth [m] | OW – 1/ SGGW Parking | | | CPT 1/SGGW Parking | | | DMT 1/SGGW Parking | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 2.5 | fine sand | **fine sand** | FSa | clayey sand – clayey silt | **lightly clayey sand – clay lightly clayey** | saCl-siCl | fine sand | FSa | fine sand |
| 4.5 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | silty sand | siSa | silty sand |
| 6.0 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | sandy clay – lightly clayey sand | saCl/clSa | sandy clay –lightly clayey sand |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 9.** Summary of CPT 2 with DMT 2 and OW – 12 SGGW Parking results

| Depth [m] | OW – 12/SGGW Parking | | | CPT 2/SGGW Parking | | | DMT 2/SGGW Parking | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 4.5 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | sandy silt | **sandy silt** | clSi |
| 6.0 | clayey sand | **sandy clay – lightly clayey sand** | saCl/clSa | clay – silty clay | **clay – silty clay** | Cl-siCl | silt | **silt** | Si |

Places where the soils differ from each other are marked in bold.

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

**Table 10.** Summary of CPT 1 with DMT 6 and OW – 9 SGGW Stadium results

| Depth [m] | OW – 9/SGGW Stadium | | | CPT 1/SGGW Stadium | | | DMT 6/SGGW Stadium | | |
|---|---|---|---|---|---|---|---|---|---|
| | soil type[a] | soil type[b] | soil symbol[b] | soil type[c] | soil type[b] | soil symbol[b] | soil type[d] | soil type[b] | soil symbol[b] |
| 4 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clay – silty clay | clay – silty clay | Cl-siCl | sandy clayey silt | sandy silty clay | sasiCl |
| 8 | clayey sand | sandy clay – lightly clayey sand | saCl/clSa | clay – silty clay | clay – silty clay | Cl-siCl | silty sand | silty sand | clSa |

[a]According to: PN-B-02480 standard; [b]EN ISO 14688-1 standard; [c]Marr's nomogram chart; [d]Marchetti's nomogram chart.

tests would agree in 83.3%. It should also be noted that the test sites were far away from each other, which in consequence could cause differences in the test results. This is especially evident in the comparison of the surveys from the SGGW Water Centre site, where in three positions show no point agreed.

For DMT tests, an efficiency of 74.7% was obtained. Considering that sandy clay and lightly clayey sand have very similar material index ($I_D$) values when comparing the surveys, one could assume that it is the same type of soil. Then the results of both tests would agree in 86.4%. It should also be noted that the test sites were far away from each other, which in consequence could cause differences in the test results.

## CONCLUSIONS

Cone penetration tests (CPT) and Marchetti's dilatometer tests (DMT) allow for an almost continuous measurement of soil parameters. They require specialised equipment, at the same time offering fast and easy testing under *in situ* conditions. Interpretation of the results using nomograms is also relatively simple and fast to perform, but it is necessary to take samples for laboratory tests in order to properly identify soil and geotechnical parameters. Laboratory analysis helps to increase the reliability of the results obtained and to avoid errors. Experience in conducting this type of analysis is also useful.

Validation of the CPT method using Marr's nomogram was successful. Despite being developed many years ago, the nomogram works well. Data for the compared sites agreed with each other in 83.3%. It must be taken into account that the differences may have arisen because the sites were not located directly near one another. A variable terrain may cause the same layers to occur at different levels.

The validation of the DMT method using Marchetti's nomogram chart should be considered as satisfactory. The compared sites agree at 86.4%, similarly as in the CPT study. Similarly, terrain variability also influences the results. Furthermore, it should be noted that the principles presented by Marchetti in his first publication for interpreting dilatometer results are still valid and applicable.

The CPT and DMT tests are very useful in obtaining soil data. The results are primarily reproducible and allow for the calculation of important soil parameters used in construction and environmental engineering. In order to increase the reliability of the results, laboratory analysis of the soil samples should be applied.

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## WALIDACJA METOD INTERPRETACJI I WYZNACZANIA RODZAJÓW GRUNTÓW NA PODSTAWIE SONDOWAŃ GEOTECHNICZNYCH CPT I DMT


### STRESZCZENIE

W pierwszej części artykułu przedstawiono metodykę badań *in situ* sondą (CPT) oraz metody określania na ich podstawie rodzaju gruntu. W następnej części zaprezentowano metodykę badań terenowych testami dylatometrycznymi Marchettiego (DMT) oraz metody określania rodzaju gruntu na ich podstawie. Na koniec przeanalizowano proces walidacji sondowań CPT i DMT z metodami badań wierceń na przykładzie obiektów kampusu Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. W tym celu porównano wyniki badań laboratoryjnych z terenowymi. Walidacja rezultatów sondowań CPT z zastosowaniem nomogramu Marra wypadła pomyślnie. Metodykę badań DMT z wykorzystaniem nomogramu Marchettiego należy uznać za zadowalającą.


**Słowa kluczowe:** walidacja, badania *in situ*, CPT, DMT, wiercenie