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EVALUATION OF DEFORMATION PARAMETERS OF ORGANIC SUBSOIL BY MEANS OF CPTU, DMT, SDMT

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Abstract

The paper presents a description of deformation parameters of subsoil composed of peat, mud and sand, which intended to be the foundation for the reservoir with a diameter of 30 meters. Performed CPTU, DMT and SDMT tests, allowed to determine the value of G_0 modulus and constrained modulus M. The paper also discusses interrelationships between mechanical parameters presented above. Using statistical methods the influence of factors on these relationships was examined. The IDW method was used for determination of global rigidity subsoil model, used in the final conception in reservoir foundations.

Streszczenie

W artykule przedstawiono opis cech wytrzymałościowych i deformacyjnych gruntów organicznych, pyłów i piasków, które stanowić mają podłoże zbiornika o 30 metrowej średnicy. Wykonane badania CPTU, DMT i SDMT, pozwoliły na określenie wartości początkowego modułu odkształcenia postaciowego G_0 oraz modułu ściśliwości M badanych gruntów. W pracy przedstawiono zależności pomiędzy wspomnianymi parametrami oraz przedyskutowano wpływ różnych czynników na te zależności. Zaprezentowano również model sztywności podłoża, opracowany w oparciu o metodę IDW i wykonany na potrzeby analizy posadowienia zbiornika.

Keywords: **Organic soil; In situ tests; Compressibility.**

1. INTRODUCTION

A characteristic element in the geological structure found in Poland is the occurrence of deposits which are a result of fluvial and lacustrine accumulation. These deposits include normally consolidated non-cohesive deposits in the form of sands, organic soils and silts. Deposits of this type very often constitute subsoil for road structures and large-scale objects. There has been considerable interest in Poland in the last 20 years in static penetration methods such as CPTU, SCPTU and dilatometer testing (DMT). These three types of tests are crucial for the determination of strength and deformation parameters in organic soils and other normally consolidated deposits. An obvious advantage of these tests is the possibility to reduce to the minimum the number of samples for laboratory analyses. Problems with collection of high quality samples from peats, soft silts and sands below water level are commonly known. Key parameters for rational design of road embankments and large structures are soil stratigraphy and spatial variability of constrained modulus. A description of the spatial variation of subsoil deformation may be obtained by constructing a model of subsoil rigidity based on the established constrained modulus [8]. In the construction of the model of rigidity for soft soils, CPTU and SDMT results are very suitable, since they

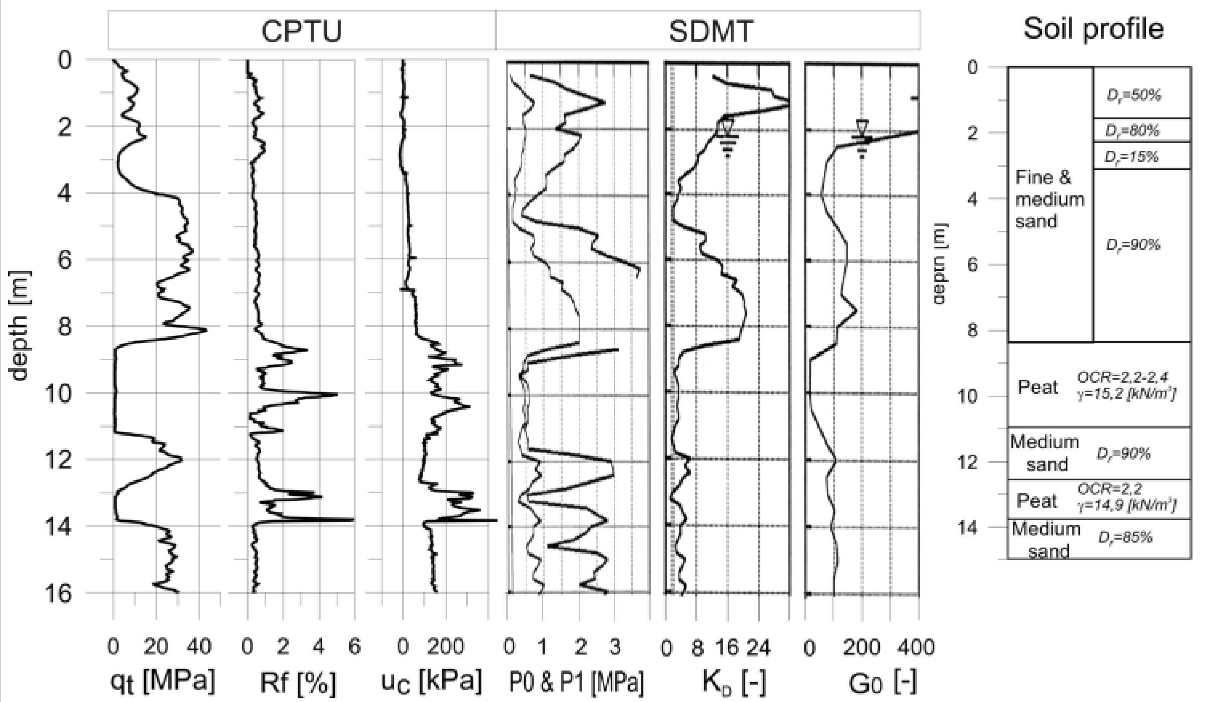

Figure 1.
Typical CPTU and SDMT characteristics of soils in the Wisła delta (test site 1)

provide a large number of measurements and a continuous picture of changes in mechanical parameters of subsoil with depth. On the other hand, the interpretation of characteristics of CPTU and SDMT testing in organic soils and glacilacustrine deposits is still debatable, since a question arises whether relationships known from mineral soils may be adopted for the prediction of soil type and constrained modulus of organic soils and other glacilacustrine deposits.

2. CHARACTERISTICS OF THE TESTING AREA

Tests were performed in two sites with a markedly different genesis of subsoil. The selection of the locations for CPTU and SDMT testing was based on the concept to have subsoils significantly differing in the genesis and lithology of the soil. Site 1 was characterized by the presence of normally consolidated deposits of delta accumulation, while in the other site overconsolidated glacifluvial deposits were found. The site with normally consolidated deposits is located in the delta of the Wisła river. Subsoil structure in this site is determined by the accumulation and erosion processes, typical of delta areas. A characteristic feature of organic layers is their relatively small thickness (approx. 1 m) and the fact that they are found at different depths in the profile. The content of organic matter in these soils ranges from 12 to 27%, while bulk density ranges from 1.3 to 1.6 t/m^3 and natural water content within the range from 54 to 130%.

Overconsolidated soils were found in the valley of the upper course of the Wisła river, between Katowice and Kraków (Site 2) [1]. Fluvial deposits accumulated in this area were overconsolidated by migrating dune fields, active at the end of the Pleistocene and the beginning of the Holocene. The overconsolidation of these soils was also affected by cyclic changes in ground water levels, characteristic of the Wisła valley. The sedimentation profile in that site is monotonous, composed of layers of medium sands and occasionally fine sands.

Typical profiles in CPTU and DMT testing of soils in the first site are presented in Fig. 1. The CPTU and DMT tests were typically spaced about 10m apart. Results of the tests made it possible to evaluate deformation parameters of the subsoil. The CPT constrained modulus, corresponding to the oedometer modulus M_{CPT}, was determined according to the methodology proposed by Sanglerat [17] assuming a cone coefficient α to be between 3 and 4. In case of the interpretation of DMT a standard procedure according to Marchetti (1980) was applied. Values of

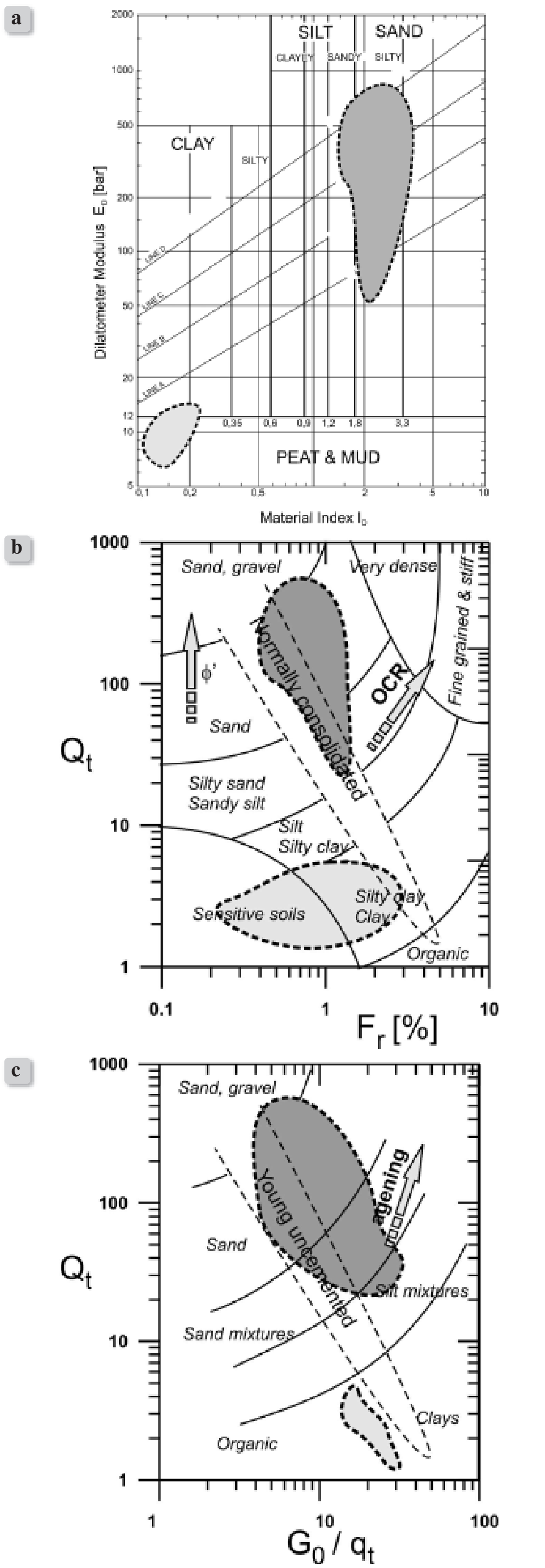

Figure 2.
Locations of tested soils on the DMT classification chart [5] (a) and CPTU classification chart [15] (b) and on the SCPTU classification chart [16] (c)

modulus G_0 were determined based on the measurement of shear wave velocity, according to the assumptions presented by Młynarek et al. [9]. Specific gravity of soil as well as its mineral and grain size distribution were determined on the basis of high quality samples.

3. CPTU AND DMT CLASSIFICATION SYSTEMS FOR IDENTIFICATION OF ORGANIC SUBSOIL

Applicability of commonly applied classification charts for DMT and CPTU testing and their use in the identification of mineral soils found in Poland was assessed in numerous analyses [10]. However, these investigations showed that the identification of organic soils in typical CPTU systems is doubtful. In this paper the location of tested soils was analyzed in the DMT diagram by Marchetti and Crapps [5] and CPTU diagrams by Robertson [15] and SCPT by Robertson et al. [16]. The location of non-cohesive soils found in sites 1 and 2 in the CPTU and DMT classification charts identifies very well the lithology of the subsoil (Fig. 2). Differences in the interpretation appear for the organic soils. Młynarek et al. [8], [9] showed that the DMT diagram very well identifies the structure of organic subsoil (Fig. 2a). In this respect the use of the CPTU diagram leads to an erroneous interpretation of results, since organic soils are located in the zone allocated for silty clays and sensitive soils (Fig. 2b). This fact results from the recording of relatively high values of cone resistance and low values of sleeve friction in the organic soils. Such a situation may be explained by the considerable admixture of the sand fraction in these soils, characteristic of soils of fluvial accumulation. Much better results are provided when the value of G_0 is taken into consideration and the diagram by Robertson [16] is used (Fig. 2c). The application of modulus G_0 in the construction of a CPTU classification chart for the determination of organic soil layers in the subsoil was also pointed to by Long [3].

4. RELATIONSHIP BETWEEN CPTU AND DMT FOR THE DETERMINATION OF CONSTRAINED MODULUS OF SUBSOIL

Modulus, which describe deformability or compressibility of subsoil, are determined based on laboratory tests or estimated from DMT and CPTU tests, using correlations, e.g. [4], [6], [11]. Measurements of the seismic wave, performed in SCPTU and SDMT are used in the determination of the small strain shear modulus G_0. Thus, simultaneous CPTU, DMT and seismic tests make it possible to compare values of both modulus. An example of such an attempt is the correlation proposed by Marchetti et al. [7] for DMT, in which a relationship between a ratio of G_0 to M, and the value of horizontal stress index K_D is suggested. In turn, high consistency between modulus G_0 determined in SCPTU and SDMT was shown for post-floatation deposits by Młynarek et al. [9]. Within the framework of the investigations connected with this paper the applicability of these dependencies was analyzed for the assessment of the constrained modulus of the tested soils. Fig. 3b shows that sands are very well located in the graph by Marchetti et al. [7], which means that this dependence may be used for the indirect determination of modulus G_0 based on DMT results. The relationship for organic soils to a certain degree corresponds with a curve established for clays, although at lower values of G_0/M it approaches the values characteristic of sands. Very similar results were obtained after replacement of modulus M determined from DMT, with the value of the modulus determined from CPTU (Fig. 3a). This statement needs to be considered highly significant, since an analytical notation of the formula makes it possible to determine modulus G_0 on the basis of modulus M from CPTU and observations of changes in this modulus with depth.

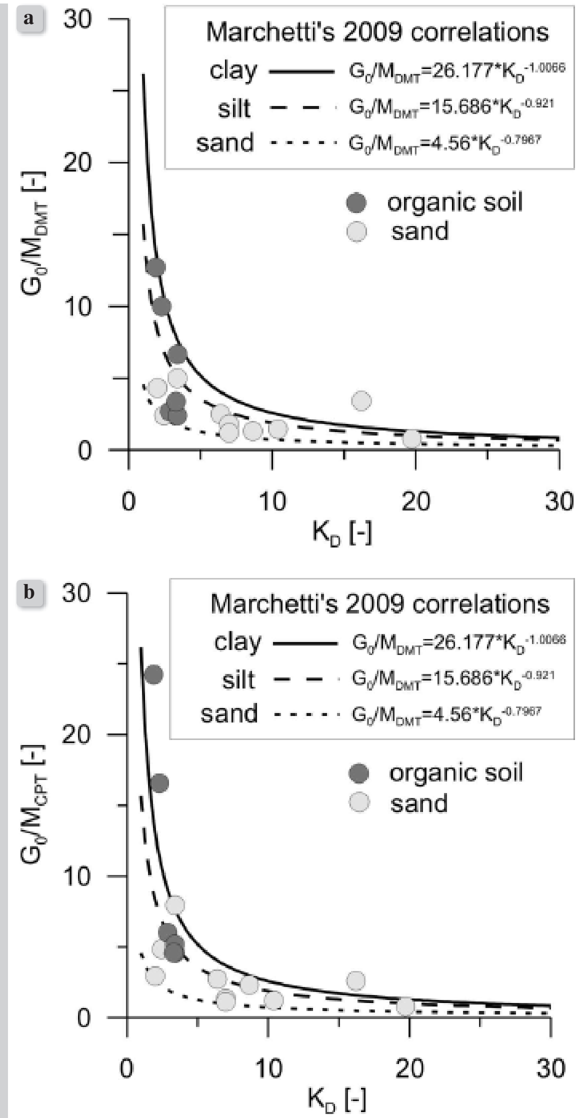

Figure 3.
A relationship between the factor of proportionality of modulus G_0/M from DMT (a) and CPTU (b) and the horizontal stress index KD

It is of interest to consider the relationship between modulus G_0 and M for the organic soils and to determine how this dependence is determined. The analysis of the process of static penetration and the dilatometer test in organic soils conducted by Młynarek et al. [13] showed that there are several factors which affect the course of penetration characteristics and measured parameters in DMT and as a consequence the determined constrained modulus. This analysis showed that the effect of these factors on both tests varies. In the hierarchy of factors, whose effect on cone resistance or values of measurement for pressures p_0 and p_1 is most significant in organic soils, the key positions are taken by overburden stress, OCR and soil moisture content. Due to the complex preconsolidation processes of organic subsoil at site 1, the effect of this factor on the dependence between modulus G_0 and M was analyzed. Values of OCR for peat from different deposition levels in the subsoil were determined on the basis of oedometer laboratory tests and in situ methods [18]. Based on this analysis preconsolidation stress σ'_p was determined and OCR was calculated according to the definition proposed by Casagrande $OCR = \sigma'_p/\sigma'_{v0}$.

It results from Fig. 4 that the effect of OCR on the relationship between modulus G_0 and M is statistically significant and the correlation is described by a high regression coefficient.

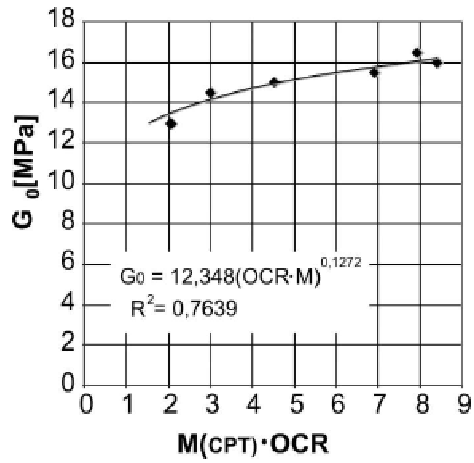

Figure 4.
A relationship between the results of SDMT and CPTU & laboratory tests for organic soils

In geotechnical practice different formulas are used to estimate modulus G_0 on the basis of CPTU results, thus a comparative analysis was conducted for several formulas with values of the modulus provided by the seismic test. Both in case of organic soils and sands a formula given by Rix and Stokoe [14] was used for the calculation of G_0 values on the basis of CPTU results, whose applicability for mineral soils found in Poland was confirmed by Godlewski and Szczepański [2]. Modulus G_0 from DMT was estimated based on formulas given by Marchetti et al. [7]. In case of the organic soils both the formula developed for clays and that for sands were used. Moreover, relationships developed by the authors for CPTU and used are described by the formulas given below:

$$G_0 = 49.97(M_{CPTU}K_D)^{-1.0} \quad \text{for sands} \qquad (1)$$

$$G_0 = 12.35(M_{CPTU}OCR)^{0.13} \text{ for organic soils} \qquad (2)$$

In Fig. 5 line C shows the most statistically significant relationship between modulus G_0 determined from seismic testing as well as DMT and CPTU. It results from this Figure that the formula, which was developed based on the author's studies, makes it possible to forecast modulus G_0 with high accurancy, since points defining the relationship between modulus established from both tests for organic soils are located on line C, while for non-cohesive soils along this line. The other formulas are of little use for the assessment of this parameter in organic subsoil. It is of great practical importance to know this dependence, since DMT is a point test, while a continuous picture of changes in modulus M and G_0 in the subsoil may be obtained from CPTU.

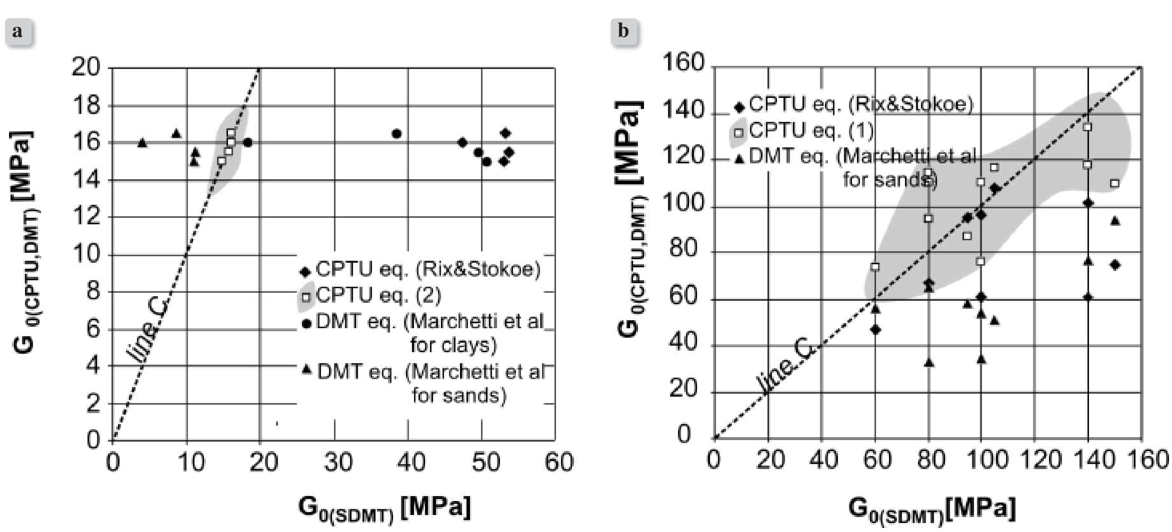

Figure 5.
A comparison of values of modulus G_0 determined from the seismic test and calculated based on CPTU and DMT for organic soils and sands

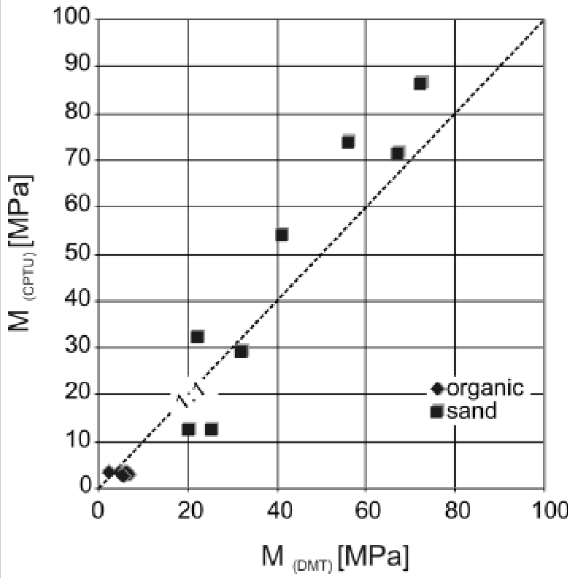

Figure 6.
A comparison between constrained modulus derived from CPTU and DMT

Figure 6 presents a relationship between modulus determined from CPTU and DMT for non-cohesive and organic soils. In case of non-cohesive soils it can be observed high consistency of results from both studies. Absolute differences in values of modulus for organic soils are similar to those for sands; however, taking into consideration relative differences (in relation to the range of the modulus in these soils) it needs to be stated that both methods yield significantly different results. The modulus from CPTU has an almost constant value for organic soils (approx. 3 MPa), while the modulus from DMT changes within a range from 2 to 6 MPa).

5. APPLICATION OF CPTU AND DMT RESULTS FOR THE CONSTRUCTION OF A MODEL OF SUBSOIL RIGIDITY

For the evaluation of stability of a building structure which is to be founded on weak subsoil a crucial issue is to determine the model of rigidity for the subsoil, which will cooperate with the designed object. Having results of testing performed in w specific grid of points, it may be attempted to construct a spatial structure of a model of subsoil rigidity (Fig. 10). Due to the high number of measurements obtained in CPTU, statistical methods may be used for the construction of a model of subsoil rigidity [12]. For the construction of the model it can be used a modified methodology of Inverse Distance Weighting calculations. This method, by assuming specific parameters of the model, facilitates any change of significance of the weight of the distance and elliptical control of the range of interpolation and the number of data measured and considered in the interpolation of traits, based on the formula (3).

$$v_0 = \frac{\sum_{i=1}^{|N(v_0)|} w_i v_i}{\sum_{i=1}^{|N(v_0)|} w_i}, \qquad (3)$$

where: v_0 – interpolated value of parameter, $|N(v_0)|$ denotes the number of included observations from the neighbourhood of v_0, and weight wi. In case of tested soils from the Wisła river delta the application of the above mentioned model made possible a statistically justified isolation of the range of soil layers with reduced rigidity (Fig. 7). A crucial advantage of the constructed model is the fact that it facilitates the determination of the constrained modulus at any point of the subsoil zone which will cooperate with the foundation. This element in turn is required for the calculation of settlement of building structures if advanced rheological models are used in the calculations and calculations for them are going to be conducted by the finite element method.

6. CONCLUSIONS

Results of conducted analyses make it possible to formulate several generalizations and conclusions:

- factors, which affect parameters measured during CPTU and DMT in organic soils differ from those, which have a crucial effect on CPTU and DMT characteristics in mineral soils. This fact limits the applicability of empirical relationships for the assessment of constrained modulus of organic subsoil, which were proposed by many authors for mineral soils. On the other hand, analyses showed that certain groups of factors such as σ'_p (OCR) and the component of the state of stress, similarly as in mineral soils have a statistically significant effect on characteristics of the above mentioned tests in organic soils.
- The classification system proposed by Robertson et al [16] for CPTU, in which modulus G_0 is used, and the system by Marchetti and Craps [5] for DMT seem to be reliable systems for the identifi-

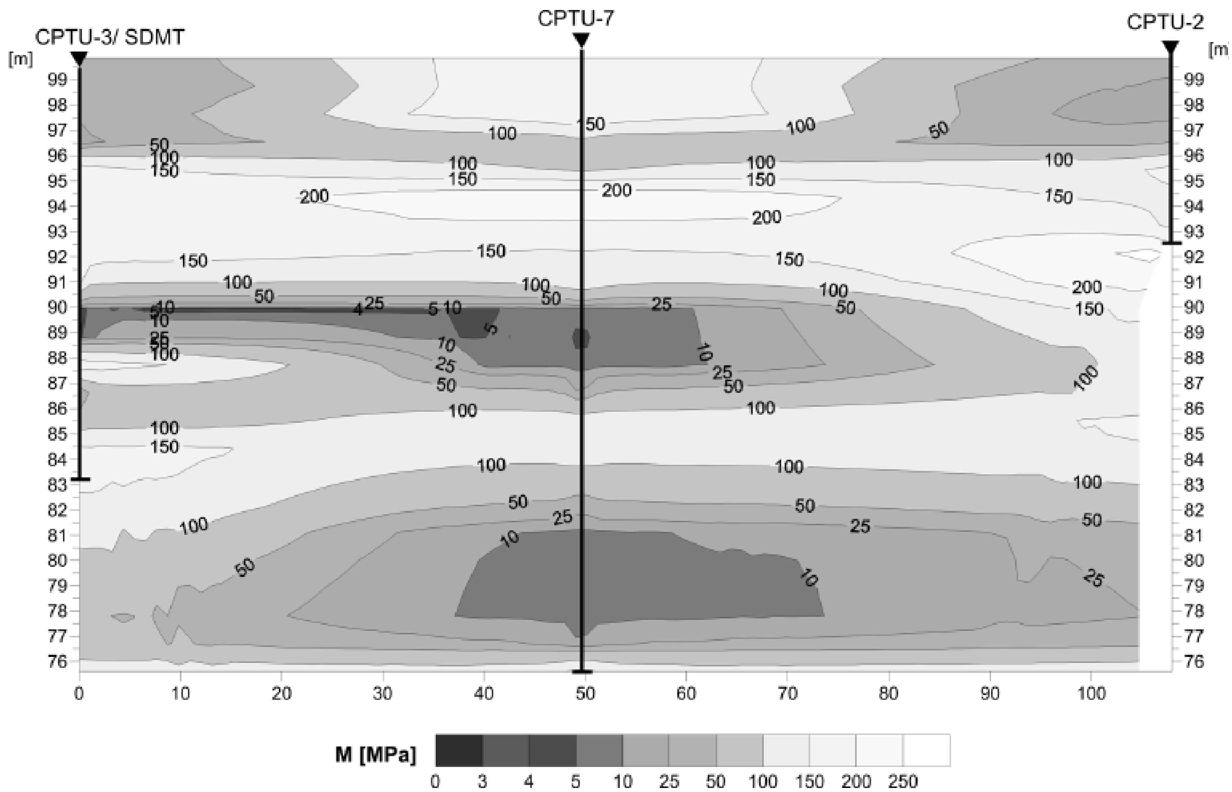

Figure 7.
The rigidity model of test site 1

cation of organic soils in subsoil. The use of these systems may be suitable for the identification of samples for laboratory analyses, and first of all for the determination of the range of layers found in the subsoil.

– Analyses showed that even from such complex subsoil, as the subsoil composed of organic soils, local correlations between CPTU and DMT parameters are described by a statistically significant correlation. Determined relationships facilitate assessment of modulus G_0 and M from both tests. These dependencies are of particular value when in the analyzed area both tests are going to be performed, since from the point assessment of modulus obtained from SDMT it is possible to go to a continuous assessment of changes in these modulus with depth.

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