CPT/PCPT- Based Organic Material Profiling

Matière organique - Le profilage basé sur le CPT/PCPT

Tümay M.T.
Louisiana State University, Baton Rouge, LA, USA and Boğaziçi University, İstanbul, Turkey

Hatipkarasulu Y.
The University of Texas at San Antonio, San Antonio, TX, USA

Marx E.R.
Fugro Consultants, Inc., Baton Rouge, LA, USA

Cotton B.
Fugro Consultants, Inc., Kenner, LA, USA

ABSTRACT: Cone and Piezocone Penetration Test (CPT and PCPT) based analysis and modeling is a popular and handy tool for geotechnical engineers for subsurface investigations and soil characterization. However, effective identification and extent of organic content proves to be a challenge based on traditional CPT and PCPT data and methodologies. This paper presents a comprehensive CPT/PCPT-based organic content identification method using Zhang and Tumay (1999) probabilistic soil classification method. The probabilistic method employs a non-traditional modeling approach that takes the uncertainty of correlation between the soil composition and soil behavior into account. The method is based the conformal mapping of the Douglas and Olsen (1981) classification chart which results in the soil classification index (U) and in-situ behavior index (V). The organic content identification method proposed in this paper uses the in-situ behavior index (V) in combination with the compositional soil classification index (U) to estimate the organic content. A detailed description of the proposed methodology and a discussion of effective applications are included in the paper.

RÉSUMÉ : Le pénétromètre quasi-statique et le piézocône (CPT et PCPT) constituent des outils d'analyse populaires et pratiques pour la reconnaissance géotechnique des sites et la caractérisation des sols. Cependant, l'identification des sols organiques ainsi que l'évaluation de la teneur en matière organique à partir des données classiques obtenues au CPT et au PCPT se sont révélées être un challenge. Cet article présente une méthode d'évaluation complète de la teneur en matière organique basée sur le CPT et la méthode de classification des sols probabiliste de Zhang et Tumay (1999). Cette méthode probabiliste utilise une approche de modélisation non conventionnelle qui prend en compte l'aléa sur la corrélation entre la composition du sol et son comportement mécanique. La méthode est basée sur l'abaque de classification des sols de Douglas et Olsen (1981) qui permet de définir l'indice de classification des sols (U) et l'indice de comportement in situ (V). La méthode d'évaluation du contenu en matière organique proposée dans l'article utilise l'indice de comportement in situ (V) combiné à l'indice de classification (U) pour estimer la teneur en matière organique du sol. Une description détaillée de la méthodologie proposée et une discussion de ses applications sont aussi présentées dans l'article.

KEYWORDS: CPT, PCPT, Cone Penetration, Soil Classification ,Organic Soils

1 INTRODUCTION

Cone and Piezocone Penetration Test (CPT and PCPT) (ASTM D5778-12) based analysis and modeling is a popular and handy tool for geotechnical engineers for subsurface investigations and soil characterization. Since the 1960s, several modeling approaches have been developed for soil classification and evaluation of different soil properties such as the strength and consolidation characteristics of geomedia. However, effective identification and extent of organic content has proved to be a challenge based on traditional CPT and PCPT data and methodologies. Although some models identify organic materials as a separate soil class, they do not provide a continuous profile (for example, Schmertmann, 1978; Robertson et al, 1986; Robertson, 1990). Considering the likelihood of having different levels of organic content in any soil type, a continuous profile will provide additional understanding and evaluation of the subsurface.

This paper presents a comprehensive CPT/PCPT-based organic content identification method using Zhang and Tumay (1999) probabilistic soil classification method. The organic content identification method proposed in this paper uses the Zhang and Tumay method's in-situ behavior index (V) in combination with the compositional soil classification index (U) to estimate the organic content. A detailed description of the proposed methodology and a discussion of effective applications are included in the paper. The paper also presents analyses of two well-documented test sites to illustrate the effectiveness of CPT/PCPT-based profiling and their correlation to laboratory test results.

2 CPT-BASED PROBABILISTIC SOIL CLASSIFICATION

Unlike the traditional chart-based two-dimensional classification methods, the Zhang and Tumay method uses a probabilistic region estimation method to address the uncertainty in misclassifying the soil layers. This statistical based method provides a profile of the probability or the chance of having each soil type (clayey, silty, and sandy) with depth. This method is similar to the classic soil classification methods which are based on soil composition. The probability of incorrectly identifying soil type using the tradition CPT classification charts, especially in transition zones, motivated the development of the probabilistic region estimation method. This CPT classification method addresses the uncertainty of correlation between the soil composition and soil mechanical behavior.

In the Zhang and Tumay probabilistic method, conformal mapping was performed on the Douglas and Olsen (1981) chart to transfer the chart axis from the CPT data (q_c, R_f) to the soil classification index (U) and in-situ behavior index (V). The conformal transformation is accomplished using the following equations:

$$x = 0.1539R_f + 0.8870\log(q_c) - 3.35 \qquad (1)$$

$$y = -0.2957R_f + 0.4617\log(q_c) - 0.37 \qquad (2)$$

The soil classification index (U) and in-situ behavior index (V) are given as:

$$U = -\frac{(a_1x - a_2y + b_1)(c_1x - c_2y + d_1)}{(c_1x - c_2y + d_1)^2 + (c_2x + c_1y + d_2)^2} - \frac{(a_2x + a_1y + b_2)(c_2x + c_1y + d_2)}{(c_1x - c_2y + d_1)^2 + (c_2x + c_1y + d_2)^2} \qquad (3)$$

$$V = 10 + \frac{(c_1x - c_2y + d_1)(a_2x + a_1y + b_2)}{(c_1x - c_2y + d_1)^2 + (c_2x + c_1y + d_2)^2} - \frac{(a_1x - a_2y + b_1)(c_2x + c_1y + d_2)}{(c_1x - c_2y + d_1)^2 + (c_2x + c_1y + d_2)^2} \qquad (4)$$

The coefficients in equations 3 and 4 are defined as: a_1=-11.345, a_2=-3.795, b_1=15.202, b_2=5.085, c_1=-0.269, c_2=-0.759, d_1=-2.960 and d_2=2.477.

A statistical correlation was then established between the U index and the compositional soil type given by the Unified Soil Classification System (USCS) (ASTM D2487-11). A normal distribution of U was established for each reference USCS soil type (GP, SP, SM, SC, ML, CL, and CH). Each U value corresponds to several soil types with different probabilities. Boundary values were used to divide the U axis into seven regions as described in Figure 1.

Soil types were further rearranged into three groups: sandy and gravelly soils (GP, SP, and SM), silty soils (SC and ML) and clayey soils (CL and CH). Figure 1 also gives the probability of having each soil group within each region. The original method gives constant probability of each soil type (represented by the step lines) regardless of the U value within the same region (R1 to R7 in Figure 1). This allows for the sudden drop in the probabilities as the U value crosses the border from one region to another. This method was further modified to allow smooth transition of probability (curved lines) with U values, and hence to provide a continuous profile of the probability of soil constituents with depth.

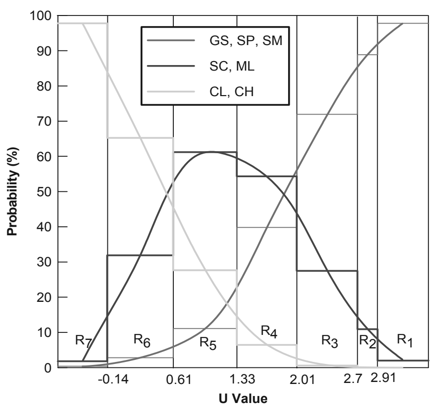

Figure 1. Regional boundaries and the corresponding probabilities of each soil group.

In-situ behavior index (V) provides a profile of soil behavior and, in combination with the compositional soil classification index (U), estimates of soil organic content and of soil rigidity/stiffness (indirectly OCR) can be determined (Tümay et.al, 2012).

3 ORGANIC MATERIAL PROFILING

The proposed profiling method utilizes a combination of the soil classification index and the in-situ behavior index values where the [(V-U) > 3.0] indicates significant organic content. The organic content indicator (V-U) makes it possible to profile the changes in organic content continuously while acknowledging the likelihood of having organic material in any given soil composition.

To illustrate the proposed method, two well documented data sets from the Mississippi River Long Distance Sediment Pipeline study located near Barataria Waterway in Jefferson Parish, Louisiana are considered. Tables 1, 2, and 3 present the laboratory test results for data sets B-7 and B-28 including moisture content percentage (ASTM D2216-10), Atterberg Limits (ASTM D4318-10), and material content finer than No. 200 sieve (ASTM D1140-06). Table 4 presents the organic content percentages (ASTM D2974-07) for the same data sets.

Table 1. Laboratory testing values for B-7 data set.

Depth (m)	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %
1.2	125	133	35	98
3.0	42	38	22	16
4.9	93	99	32	67
9.1	74	85	27	58

Table 2. Laboratory testing values for B-28 data set.

Depth (m)	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %
2.1	72	44	20	24
2.8	81	78	24	54
4.3	80	86	28	58
16.8	50	69	23	46

Table 3. Material passing No. 200 sieve for B-7 and B-28 data sets.

Data Set	Depth (m)	Material Passing No.200 Sieve %
B-7	1.2	89
	9.1	100
B-28	2.1	96
	3.7	27
	4.2	98
	6.1	87
	8.8	27
	10.7	12
	16.5	100

Table 4. Organic content values for B-7 and B-28 data sets.

Data Set	Depth (m)	Ash Content %	Organic Content %
B-7	0.6-0.9	85.42	14.58
	1.8-2.1	96.85	3.15
	3.0-3.4	96.85	3.15
B-28	0.6-1.2	85.95	14.05
	2.4-2.8	84.78	5.22
	3.7-4.0	91.73	8.27
	7.2-7.6	97.10	2.90

Figures 2 and 3 illustrate the CPT sounding values (q_c, f_s and R_f) (ASTM D 5778-12), Zhang and Tumay (1999) probabilistic soil classification soil results with U and V index values, organic content indicator (V-U), and corresponding lithology obtained from the boring logs for B-7 and B-28 data sets.

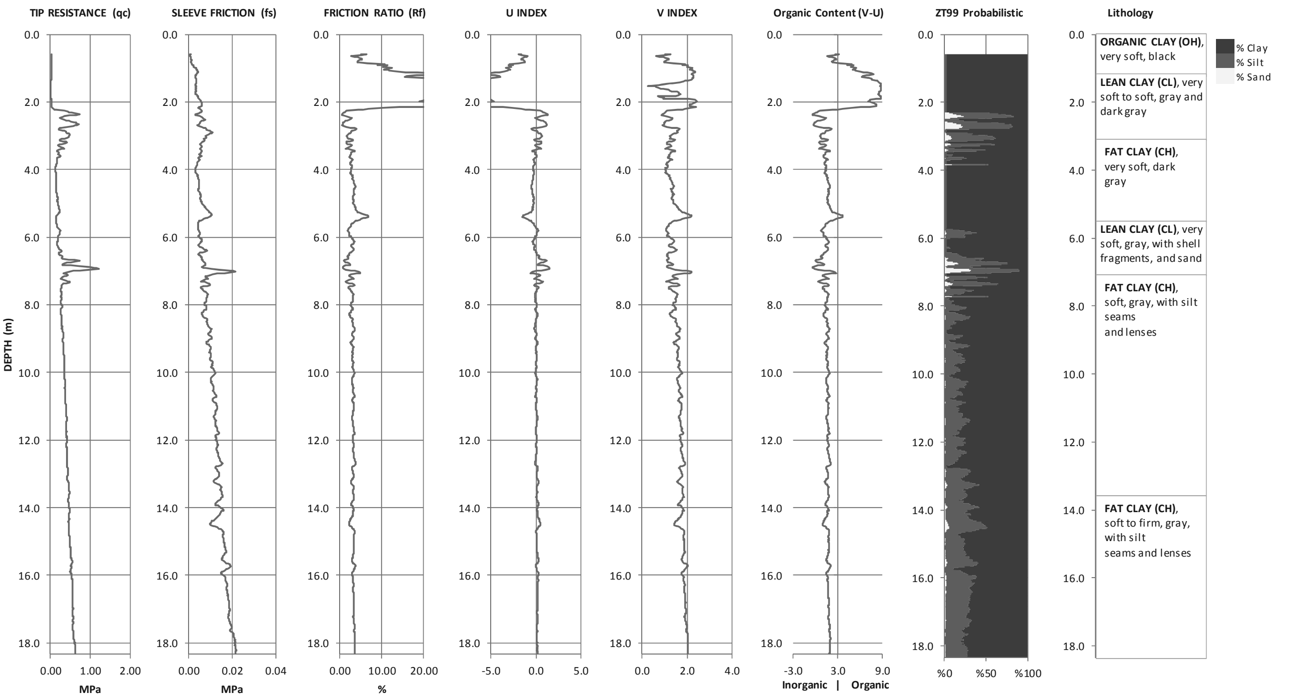

Figure 2. CPT-Based organic material profile and lithology – B-7 Data Set.

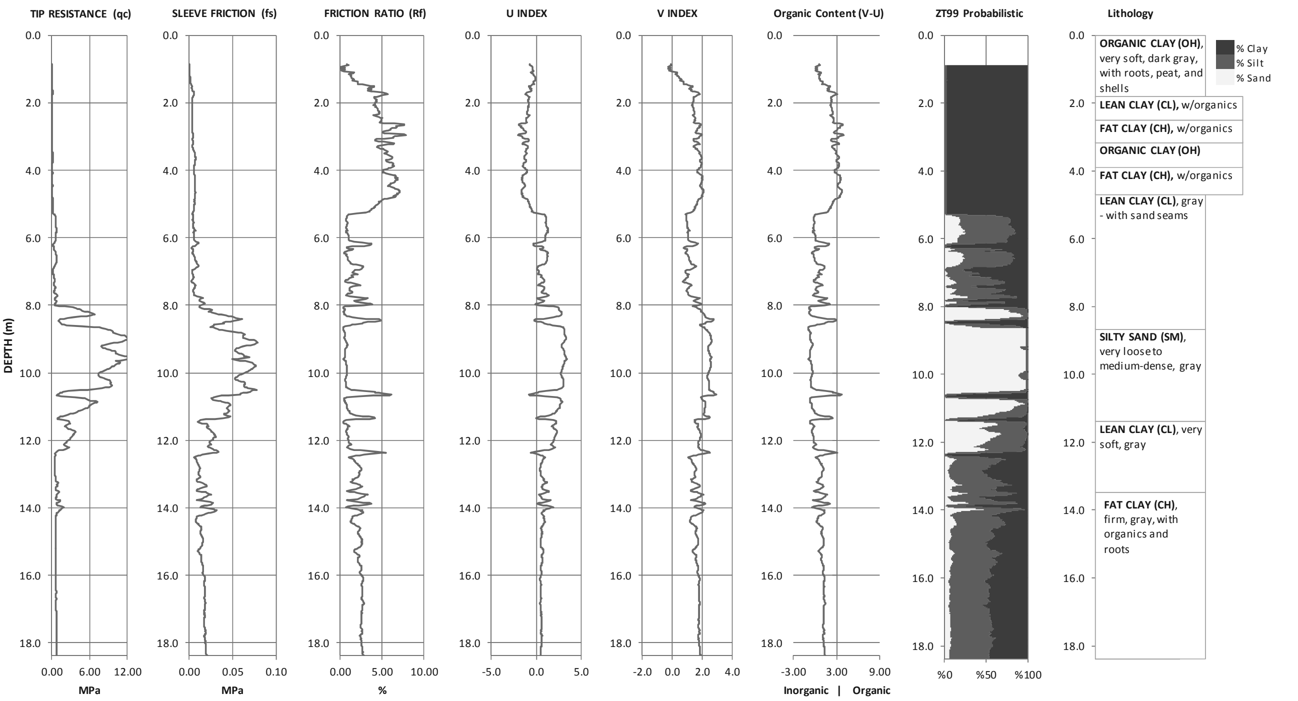

Figure 3. CPT-Based organic material profile and lithology – B-28 Data Set.

As illustrated in Figures 2 and 3, the organic content indicator (*V-U*) identified the significant organic content in the sample data sets while providing a continuous profile. When this information is combined with the CPT-based soil classification, it provides a better understanding of the subsurface conditions. For example, laboratory testing values indicate a fine grained soil with high plasticity index (98%) for the first meter of the B-7 data set where the organic content test resulted in 14.58%. The test values show a significant drop after 2.0 meters for the plasticity index (16%) and the organic content (3.15%). This profile change is clearly illustrated in Figure 2. Similarly, as shown in Figure 3, the test results show organic content over 5% for the B-28 data set between 2.5 and 4.0 meters. This value decreases to 2.90% at 7.2 meters.

The data capture frequency of the CPT soundings (2 cm/sec) also allows for the identification of the thinner seams of sandy and silty sand layers as well as the increases in the organic content. For example, the soil classification of the B-28 data set between 8.0 and 12.0 meters shows thin layers of clayey materials. At these layers, the organic content appears to be higher that the surrounding silty sand.

4 CONCLUSION

Although there are several CPT-based soil classification models effectively used in subsurface investigations, accurate identification of organic materials using CPT soundings provides a challenge. The organic content indicator (*V-U*) proposed in this study offers a continuous profile for the organic content based on the soil classification and in-situ behavior indexes as defined by the Zhang and Tumay's probabilistic method.

For the examples provided in this paper, the organic content indicator shows a strong agreement with the test results and [(*V-U*) > 3.0] indicates an approximate level of 5% organic material. The CPT-based indicator may provide a useful tool considering the importance of identifying organic materials which could lead to problems concerning stability, compaction, compressibility and usability.

Soil classification effectiveness and accuracy of the Zhang Tumay (1999) method has been evaluated with several data sets under different conditions and test sites, and compared with other classification charts, for subsoil stratigraphy (Tümay et. al., 2011), multi model comparison (Hatipkarasulu and Tümay, 2011(1)), tip resistance value correction (Tümay and Hatipkarasulu, 2011), effective area ratio assumption (Hatipkarasulu and Tümay, 2011(2)), and data reduction effects (Tümay and Hatipkarasulu, 2012). The method uses a non-traditional approach which takes into account the probability of having each soil type with depth. The use of soil classification (*U*) and in-situ behavior (*V*) indexes for organic profiling extends the same concept of accounting for the chance of having organic material at any given depth. The organic content indicator (*V-U*) profiling shows reliable performance in clayey materials and its further evaluation is imperative for non-clay organic soils.

5 ACKNOWLEDGEMENTS

This study rests on the interpretations of the field and laboratory investigations conducted for the Mississippi River Long Distance Sediment Pipeline Project designed and undertaken by the Louisiana Department of Transportation and Development (LADOTD). The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein, and do not necessarily indicate official assessments of the agencies, firms and institutions with which the authors are affiliated.

6 REFERENCES

ASTM D5778-12. 2012. *Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils.* ASTM International, West Conshohocken, PA. DOI: 10.1520/D5778-12. http://www.astm.org/Standards/D5778.htm

ASTM D2487. 2011. *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).* ASTM International, West Conshohocken, PA. DOI: 10.1520/D2487-11. http://www.astm.org/Standards/D2487.htm

ASTM D2216-10.2010. *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.* ASTM International, West Conshohocken, PA. DOI: 10.1520/D2216-10. http://www.astm.org/Standards/D2216.htm

ASTM D4318-10. 2010. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA. DOI: 10.1520/D4318-10. http://www.astm.org/Standards/D4318.htm

ASTM D2974-07a. 2007. *Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils.* ASTM International, West Conshohocken, PA. DOI: 10.1520/D2974-07. http://www.astm.org/Standards/D2974.htm

ASTM D1140-00. 2006. *Standard Test Methods for Amount of Material in Soils Finer than No. 200 (75-μm) Sieve.* ASTM International, West Conshohocken, PA. DOI: 10.1520/D1140-06. http://www.astm.org/Standards/D1140.htm

Douglas, J. B., and Olsen, R. S. 1981. *Soil Classification using Electric Cone Penetrometer, Symposium on Cone Penetration Testing and Experience*, Geotechnical Engineering Division, ASCE, St. Louis, MO, USA, (1981), 209-227.

HatipKarasulu, Y. and Tumay, M.T. 2011(1). Practical visual presentation approach for CPT-based soil characterization and modelling. *Proceedings of the ASCE Geo-Frontiers Conference: Advances in Geotechnical Engineering,* Dallas, TX, pp. 2387-2396

Hatipkarasulu, Y. and Tümay. 2011(2). Impact of effective area ratio assumption on PCPT-based soil classification. *Proceedings of the Fourth International Conference on Site Characterization, ISC'4*: Geotechnical and Geophysical Site Characterization, Porto de Galingas – Pernambuko, Brazil. pp. 275-282

Robertson, P. K., Campanella, R. G., Gillespie, D., and Greig, J. 1986. Use of Piezometer Cone Data. *Proceedings of the ASCE Specialty Conference on In Situ'86*: Use of In Situ Tests in Geotechnical Engineering, Blacksburg, Virginia, pp. 1263-1280.

Robertson, P. K. 1990. Soil Classification using the Cone Penetration Test. *Canadian Geotechnical Journal*, Vol. 1, No. 27, pp. 151-158.

Schmertmann, J.H. 1978. *Guidelines for Cone Penetration Test, Performance and Design.* Report No. FHWA-TS-78-209, U.S.

Tümay, M. T. and HatipKarasulu, Y. 2011. Impact of Using Measured v. Corrected Tip Resistance Values in PCPT-Based Soil Characterization and Modeling, *Proceedings, of the ASCE Geo-Frontiers Conference:* Advances in Geotechnical Engineering, ASCE Special Publication No. 211, Dallas, TX, pp. 2544-2553.

Tümay, M. T., HatipKarasulu, Y., Młynarek, Z., and Wierzbicki, J. 2011. Effectiveness of CPT-Based classification methods for identification of subsoil stratigraphy. *Proceedings of the 15th European Conference on Soil Mechanics and Geotechnical Engineering, Athens, Greece, pp.91-98.*

Tümay, M. T. and HatipKarasulu, Y. 2012 Effects of data smoothing and reduction on CPT-based probabilistic soil classification. *Proceedings of the Fourth International Conference on Site Characterization, ISC'4*: Geotechnical and Geophysical Site Characterization, Porto de Galingas – Pernambuko, Brazil. pp. 843-850

Tümay, M.T., Hatipkarasulu, Y., Marx, E.R and Cotton, B. 2012. Multi Model Subsurface Evaluation for Louisiana I-10 Bridge Replacement Using Electronic CPT. *Proceedings of the Fourth International Conference on Site Characterization, ISC'4*: Geotechnical and Geophysical Site Characterization, Porto de Galingas – Pernambuko, Brazil. pp. 1281-1288

Zhang, Z., and Tumay, M.T. 1999. Statistical to Fuzzy Approach toward CPT Soil Classification. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 125, No. 3, pp. 179 186.