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EVALUATION OF SOIL CPT PROGRAM TO ESTIMATE HETEROGENITY OF SOIL USING SONDIR DATA

Budhi Setiawan [1] and Ambiyar Setiojati [2]

ABSTRACT: Since on soft soil, large settlement might be occur under loaded foundation without actual shear failure occurring, the soil profile based on soil investigation in soft soil areas e.g. Palembang is become important. Among the different in situ tests, sondir is a simple, quick, and economical test that provides reliable in situ continuous soundings of subsurface soil. In Indonesia, sondir is considered the most frequently used method for characterization of geomedia. This research focused on site characterization of soil properties based on sondir data. This procedure is very important due to management data of soil field test is still conventional and unstructured.

Keywords: Soil CPT Program, Sondir, Soil Classification, Soft Soil.

INTRODUCTION

Investigation on a soil classification and a description of soil layers can be carried out by various ways in appropriate to the need of use. A usual method is to apply a field penetration test using a drilling technique, where based on the result of the drilling test the soil sample will be obtained. The analysis of sample soil is done by a laboratory test, so technical and physical properties will be found out as the main bases of determining the soil classification. Other method is to apply the Cone Penetration Tests (CPT) of finding out soil behavior until the depth of solid layers. The weakness of CPT is that soil sample is not obtained, so finding out the technical and physical properties of soil and the soil profile in an accurate manner couldn't be done.

Following the weakness of the CPT test, the Loussiana Department of Transportation and Development (LADOT) is developed a software such as the Soil CPT program to implement the CPT-based technology. Results of the software processing are the kind of soil layers/profiles compared with the most easily ones, without having to do soil sampling (drilling test) and laboratory test.

The Soil CPT software is one developed on the base of five different soil classification methods, i.e. Probability Region Estimation Method (1999), Fuzzy Logic Method (1999), Scherthmann's Method (1978), Robertson's Method (1986) and Douglas Olsen's Method (1981). All the five soil classification methods are those studied and developed on the base of data from the CPT test in United State (American soil). Based on the result, the research was conducted to evaluate the accuracy rate of the software using data of Sondir Test (Dutch Cone Penetration Tests—DCPT) much used in Indonesia (tropical soil).

FIVE SOIL CLASSIFICATION METHODS OF THE CPT PROGRAM

The SOIL CPT Program used one developed by the Lousiana Departement of Transportasion and Development (LADOT) as software for soil classification developed on the base of CPT-based technology. Five soil classification methods in the software result in data output such as estimation of the kinds of soil layer.

The Soil CPT software contains five soil classification methods. All five methods of grouping the soil are: Zhang and Tumay (1999), developing the method consisting of two methods, i.e.: the Probability Method and Fuzzy Logic Method; Schmertmann, developing the Schmertmann's Method (1978); Robertson, developing the Robertson's Method (1986); and Douglas Olsen, developing the Douglas Olsen's Method (1981). These method were developed based on comparison/correlation between CPT/PCPT (cone tip resistance (*qt*) and friction ratio (*Rf*) as input parameters) profiles and soil type data bases collected/evaluated from extensive soil boring.

Schmertmann's Method (1978)

Schmertmann's method is one developed on the base of data obtained by CPT (mechanical cone data) in the areas of North Central Florida (California, Oklahoma, Utah, Arizona and Nevada) through conversing the data into those of drilling test, and based on the result of such correlation the division into four zones for each of the soil types occurred (Figure 1).

[1] Lecturer, Civil Engineering Department, Sriwijaya University, INDONESIA
[2] Student, Civil Engineering Department, Sriwijaya University, INDONESIA

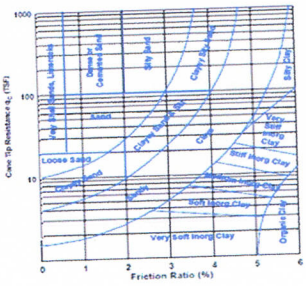


Fig.1 Schmertmann soil classification charts

Douglas Olsen's Method (1981)

Douglas Olsen's classification method shows soil classification based on correlation between USCS classification and data of CPT (electrical cone penetrometer) collected from many testing regions in the western areas of the United States. Douglas Olsen classified soil into three arching lines in vertical direction, representing coarse-grained soil and four horizontally arching lines to differentiate many regions of sandy zones (metasable sands) and of sensitive zone (mixed soil and clay soil).

The weakness of the method is that it cannot provide accurate prediction to find out the kind of soil on the base of soil composition (grain size distribution), but serves as guide of determining the behavior of soil type.

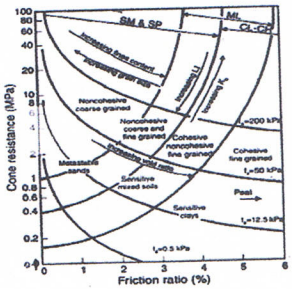
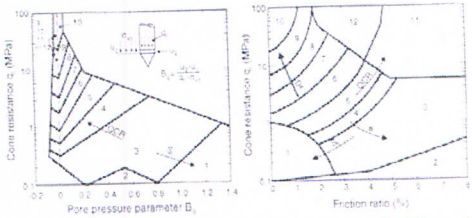


Fig.2 Douglas Olsen (1981) soil classification charts

Robertson's Method (1986)

Robertson et al. (1986) developed a soil behavior type classification method derived from PCPT data (*qc*, *fs*, *u*). They proposed two charts, one chart uses corrected tip resistance (*qt*) and friction ratio (*Rf*) as input data; while the other chart uses *qt* and pore pressure parameter ($Bq = (u2 - uo)/(qt - \sigma vo)$) as input data. They identified twelve different soil behavior types. Incase a soil falls within two different zones in respective charts, engineering judgment is required toclassify the soil behavior correctly.



1. Sensitive fine grained, 2. Organic material, 3. Clay, 4. Silty clay to clay, 5. Clayey silt to silty clay,
6. Sandy silt to clayey silt, 7. Silty sand to sandy silt, 8. Sand to silty sand, 9. Sand,
10. Gravelly sand to sand, 11. Very stiff fine grained, 12. Sand to clayey sand.

Fig.3 Robertson et al. (1986) soil classification charts

Region Estimation Method and Fuzzy Logic Method (1999)

The Probability Region Estimasion Method is one similar with classic soil classification method, namely, method developed on the base of grain size distribution. It identifies soil based on three kinds of soil, namely, clay, silty and sandy soil. It results in output such as the percentage of soil composition (grain size distribution). The probability region estimasion method determined the probability of each soil constituents (clay, silt, sand) at a certain depth.

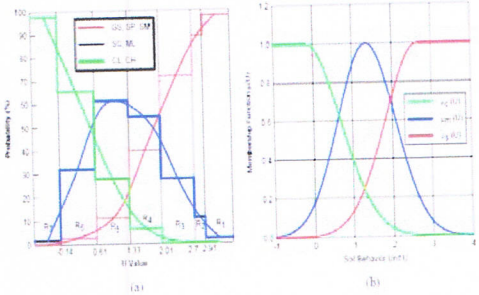


Fig.4a Region's boundaries and the corresponding probabilities of each soil group
Fig.4b CPT fuzzy soil classification chart

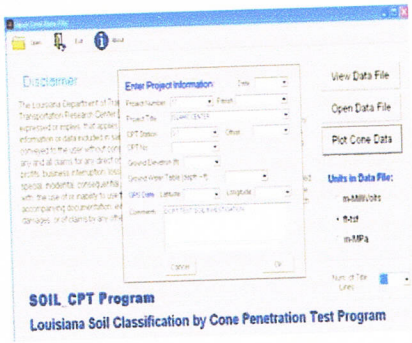
Fuzzy Logic Method is one developed based on the Probability Region Estimasion Method, but in fact output of the fuzzy logic method did not result in soil composition (grain size distribution), but classify the soil only based on the behavior of soil types. It divides the soil classification into there kinds, i.e.: High Probable Sand (HPS), High Probable Mixed (HPM), and High Probable Clay (HPC).

THE DATA PROCESSING OF SOIL CPT PROGRAM

A visual basic soil engineering classification program, Louisiana Soil Classification by Cone Penetration Test Program (LSC-CPT) (Figure 7), was

developed utilizing the CPT data to provide geotechnical engineers with a user friendly methodology. Five CPT soil classification methods were implemented in this program. These include the probabilistic region estimation method and fuzzy classification method, both developed by Zhang and Tumay (1999), the Schmertmann (1978) method, the Douglas and Olsen (1981) method, and the Robertson et al. (1986) classification method. These methods use the cone tip resistance (*qc* or *qt*) and friction ratio (*Rf*) as input parameters.

The program is capable of reading CPT input data files of different units (SI, English, or millivolts raw data). Before running the program, the user can view the data file. The first step for the user is to input the project information. The program then plots the profiles of cone tip resistance, sleeve friction and friction ratio with depth. The user has the option to select the classification method and the corresponding display charts for output (graph and/or text). If the user selected a text chart for soil profile, the user can always change the layers manually. The program (Soil-CPT 4.0) is available for free download from the LTRC Web site (www.ltrc.lsu.edu/ downloads.html). Figure 5 describes the general features of the soil classification program, sampel data from the Development Project of Islamic Center (Sondir 1 Bore I).



(a) Data and Information Input Screen

(b) CPT Profiles and Main Menu Screen

(c) Schmertmann Classification Method

(d) Douglas Olsan Classification Method

(e) Robertson et al. Classification Method

(f) Probabilistic Region Estimation Classification Method

(g) Fuzzy Classification Method

Fig.5 Islamic Center Project by Cone Penetration Test Program

ANALYSIS ON A RATIO OF OUTPUT OF SOIL CPT PROGRAM TO THAT THE USCS CLASSIFICATION

Data collection

Data collected and used to analyze the accuracy of Soil CPT Program were obtained from the relevant parties in the existing planning of building in Palembang City (20 location). The data needed in the research were those of the DCPT, the data of laboratory test were the USCS soil classification obtained by a sample of bore log test.

Data Analysis

Initial data processing is carried out by processing the data of DCPT using the Soil CPT Program. Data input required to process the data are such as the depth value, the cone resistance value (qc) and friction ratio (fs). Output of the processing program is five models of soil layer profile on the base of five soil classification methods. The sampel data used are from the Development Project of Islamic Center (Sondir 1 Bore I).

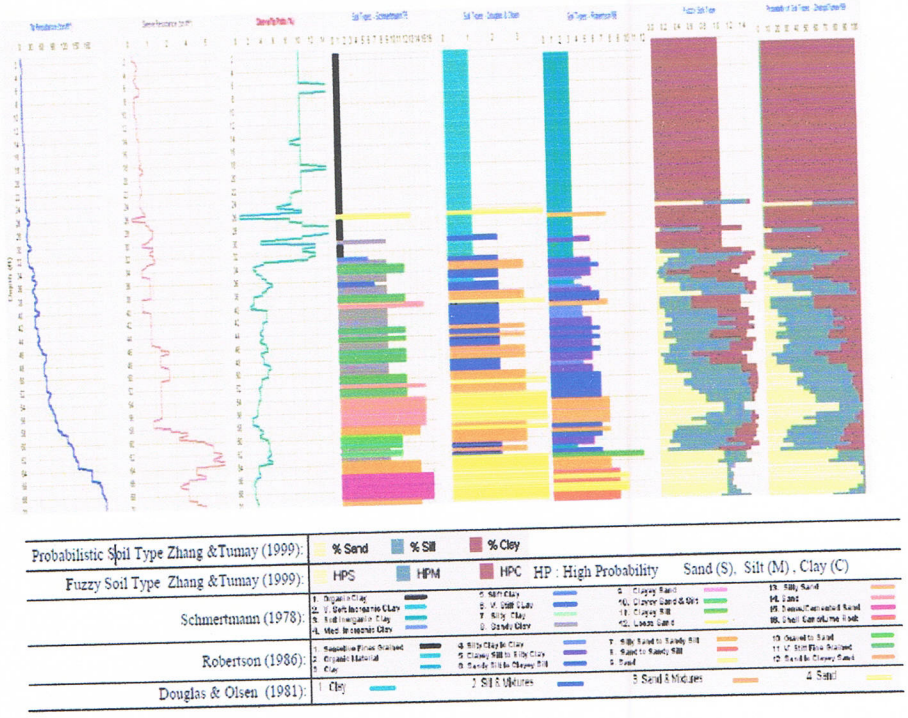


Fig.6 Site Soil Classification of Islamic Center Project (Sondir 1 Bor I).

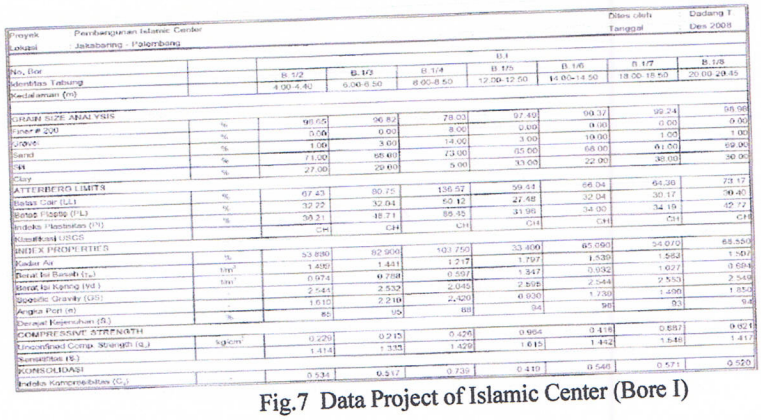


Fig.7 Data Project of Islamic Center (Bore I)

Output of the five models of soil profile from the Soil CPT Program is analyzed by compared the depths of output of the five models of soil profile of each method based on the depth of soil sample (bore log), and followed by the laboratory test (based on USCS classification). After recapitulation of program output and the data of laboratory test on the base of USCS classification, the next stage is to compare recapitulation (result of software output above for each classification method) to the result of data on the soil sample of laboratory test, i.e. USCS soil classification, by using USDA and USCS classification approaches. The process of data analysis is done by looking at result of output from running the program by using a result of the laboratory test such as the USCS classification. The following is the analysis of data as output running.

Table 1-5 were the example of the analysis comparison output program with USCS soil classification, Development Project of Islamic Center (Sondir 1 Bore I).

Table 1. Analysis Data of Schmertmann Classification Method

Sampel Point	Depth	Laboratory data (USCS)	Output Running Program	Analysis USCS Classification
B.2	4 m - 4.4 m (13.124 ft - 14.4364 ft)	CH	Organic Clay	Clay (OH)
B.3	6 m - 6.5 m (19.686 ft - 21.3265 ft)	CH	Organic Clay	Clay (OH)
B.4	8 m - 8.5 m (26.248 ft - 27.8885 ft)	CH	Organic Clay	Clay (OH)
B.5	12 m - 12.5 m (39.372 ft - 41.0125 ft)	CH	Sandy Clay	Clay (CL)
B.6	14 m - 14.5 m (45.934 ft - 47.5745 ft)	CH	Silty Clay with layers of Sandy Clay	Clay (CL)
B.7	18 m - 18.5 m (59.058 ft - 60.6985 ft)	CH	Clayey Sand and Silt	Sand (SM) and Silt (ML)
B.8	20 m - 20.45 m (65.62 ft - 67.0965 ft)	CH	Dense/Cemented Sand	-

Analysis on data for Schmertmann's Method with the output of program such as Organic Clay (sampel point B.2 to B.4), and output of USCS classification such as CH. According to USCS classification, analysis of data indicates that output of organic clay is OH. From the comparison between the two outputs, it can be concluded that both soils have similarity in soil types, i.e. clay where the one is CH (clay hight plasticity) and the other is OH (organic clay). From sampel point B.5 to B.8 output of program are Sandy Clay, Silty Clay with layers of Sandy Clay, Clayey Sand and Silt and Dense/Semented Sand and output of USCS classification is Clay (CH). According to USCS, analysis of sampel data indicates that all output (sampel point B.5-B.8) are different and from the all comparison between the two outputs, it can be colculded that all soil not have similarity in soil type, where all the results output program indicates to silt and sand, and the output USCS classification is CH (clay hight plasticity).

Table 2. Analysis Data of Robertson et al. Classification Method

Sampel Point	Depth	Laboratory data (USCS)	Output Running Program	Analysis USCS Classification
B.2	4 m - 4.4 m (13.124 ft - 14.4364 ft)	CH	Clay	Clay (CH)
B.3	6 m - 6.5 m (19.686 ft - 21.3265 ft)	CH	Clay	Clay (CH)
B.4	8 m - 8.5 m (26.248 ft - 27.8885 ft)	CH	Clay	Clay (CH)
B.5	12 m - 12.5 m (39.372 ft - 41.0125 ft)	CH	Silty Clay to Clay	Clay (CL)
B.6	14 m - 14.5 m (45.934 ft - 47.5745 ft)	CH	Clay with layers of Clayey Silt	Clay (CH)
B.7	18 m - 18.5 m (59.058 ft - 60.6985 ft)	CH	Sandy Silt to Clayey Silt	Silt (ML)
B.8	20 m - 20.45 m (65.62 ft - 67.0965 ft)	CH	Sand with layer of Sandy Silt	Sand (SM), Silt (ML)

Table 3.Analysis Data Douglas Olsen Classification Method

Sampel Point	Depth	Laboratory data (USCS)	Output Running Program	Analysis USCS Classification
B.2	4 m - 4.4 m (13.124 ft - 14.4364 ft)	CH	Clay	Clay (CL-CH)
B.3	6 m - 6.5 m (19.686 ft -21.3265 ft)	CH	Clay	Clay (CL-CH)
B.4	8 m-8.5 m (26.248 ft - 27.8885 ft)	CH	Clay	Clay (CL-CH)
B.5	12 m - 12.5 m (39.372 ft - 41.0125 ft)	CH	Silt and Mixtures	Silt (ML-CL)
B.6	14 m - 14.5 m (45.934 ft - 47.5745 ft)	CH	Clay with layers of Silt and Mixtures	Clay (CL-CH), Silt (ML-CL)
B.7	18 m - 18.5 m (59.058 ft - 60.6985 ft)	CH	Sand and Mixtures	Sand (SM-ML)
B.8	20 m - 20.45 m (65.62 ft - 67.0965 ft)	CH	Sand	Sand (SW-SP)

Analysis on data for Robertson's Method compare with USCS laboratory test classification of the depth 4 m. - 4 .4, 6 m – 6.5 m, and 8 m - 8.5 m (13.124 ft - 14.4364 ft , 19,686 ft – 21,3265 ft, and 26.248 ft - 27.8885 ft). is CH, whereas output running the program is clay. The analysis could be towards the two data's concluded that both soils have similarity in soil types for classification of the Robertson's Method of can determine classification of the soil is base on USCS, that is clay that has the level of the high plasticity (CH).

Other example is analysis on data for Douglas Olsen's Classification Method with the output of program such as clay, and output of USCS classification such as CH. According to USCS classification, analysis of data indicates that output of Clay is CL-CH. From the comparison between the two outputs, it can be concluded that both soils have similarity in soil types, i.e. clay where the one is CH (clay hight plasticity) and the other is Clay (clay low probabilty to clay hight probability).

From sampel point B.5 to B.8 outputs of program are Silt and Mixtures, Clay with layers of Silt and Mixtures, sand and mixtutes, sand. Output of USCS classification is clay (CH). According to USCS, analysis of sampel data indicates that all output (sampel point B.5-B.8) are different and from the all comparison betwen the two outputs it can be colculded that all soil not have similarity in soil type. Where all the results output program indicates to silt and sand, and the output USCS classification is CH (clay high plasticity).

Table 4. Analysis Data of Probability Region Estimation Method

Sampel Point	Depth	Laboratory data (USCS)	Output Running Program (%)			Analysis USCS Classification
			Sand	Silt	Clay	
B.2	4 m - 4.4 m (13.124 ft - 14.4364 ft)	CH	0	2	98	Clay (CL-CH)
B.3	6 m - 6.5 m (19.686 ft - 21.3265 ft)	CH	0	2	98	Clay (CL-CH)
B.4	8 m - 8.5 m (26.248 ft - 27.8885 ft)	CH	0	2	98	Clay (CL-CH)
B.5	12 m - 12.5 m (39.372 ft - 41.0125 ft)	CH	7	49	43	Silty Clay (CL-ML)
B.6	14 m - 14.5 m (45.934 ft - 47.5745 ft)	CH	5	41	54	Clay (CL-CH)
B.7	18 m - 18.5 m (59.058 ft - 60.6985 ft)	CH	24	60	16	Sandy Silt (ML)
B.8	20 m - 20.45 m (65.62 ft - 67.0965 ft)	CH	98	2	0	Sand (SM-SP)

Table 5. Analysis Data of Fuzzy Classification Method

Sampel Point	Depth	Laboratory data (USCS)	Output Running Program (%)			Analysis USCS Classification
			Sand	Silt	Clay	
B.2	4 m - 4.4 m (13.124 ft - 14.4364 ft)	CH	-	-	100	Clay (CL-CH)
B.3	6 m - 6.5 m (19.686 ft -21.3265 ft)	CH	-	-	100	Clay (CL-CH)
B.4	8 m - 8.5 m (26.248 ft - 27.8885 ft)	CH	-	-	100	Clay (CL-CH)
B.5	12 m - 12.5 m (39.372 ft - 41.0125 ft)	CH	7	49	43	Silty Clay (CL-ML)
B.6	14 m - 14.5 m (45.934 ft - 47.5745 ft)	CH	5	41	54	Clay (CL-CH)
B.7	18 m - 18.5 m (59.058 ft - 60.6985 ft)	CH	24	60	16	Sandy Silt (ML)
B.8	20 m - 20.45 m (65.62 ft - 67.0965 ft)	CH	98	2	0	Sand (SM-SP)

For Probability Estimation and Fuzzy Logic Methods, analysis on the data of initial soil is done by analyzing the output of running program based on USDA classification, followed by comparing the data with result of USCS soil classification. Output of Probability Estimation Method is obtained, including a soil composition of sand, silt and clay of 5%, 41%, 54%, respectively, so based on USDA classification (grain size distribution) the soil is stated as the silty clay. According to USCS classification, the silty clay is included in the soil group of CL, and can be concluded that the two soils have a similarity in soil type, i.e. clay, but have the different level of plasticity.

Final Analysis

The following is a table of the percentage of accuracy level of Soil CPT Program based on five soil classification methods by using the input of data from bore log the DCPT compared with that based on result of (USCS classification) at 20 locations of development planning.

Table 6. The Recapitulation of Processing Data Five Soil Classification Methods

Number	Project	Schmertmann	Douglas Olsen	Robertson	Probability Region Estimation	Fuzzy Logic
P1	The Insurance building Wahanan (KM5)	100	66,67	100	100	100
P2	Tower (Anton Bambang Utoyo)	66,67	66,67	66,67	66,67	66,67
P3	Tower (Dwikora)	100	100	100	100	100
P4	Tower (Sei Selincah)	100	100	100	100	100
P5	Tower (Jl Swadaya Lr. Masjid Srijaya)	100	100	100	100	100
P6	Tower (2 Ilir/ Lorong Kenangan)	100	100	100	100	100
P7	JM-Plaza (JL Prabu Mangkunegara- Patal)	100	100	100	100	100
P8	PLTG (PLTG Kertapati)	66,67	66,67	66,67	66,67	66,67
P9	Show Room (Jl Jendral Sudirman)	100	100	100	100	100
P10	Telkomsel Building (JL Veteran)	100	100	100	100	100
P11	The Workshop (Sukabangun II)	83,33	50	66,67	50	50
P12	GOR Jakabaring	94,44	94,44	94,44	94,44	94,44
P13	Show Room (Kol H. Burlian (KM-8)	100	100	100	100	100
P14	PLTG (Kalidoni)	100	100	100	100	100
P15	Hotel (7 Ulu)	65	62,5	67,5	77,5	77,5
P16	Turap quay and Beton Bridge in the Musi River(Pasar 16 Ilir)	89	71,5	86,5	87	87
P17	Islamic Center (Jakabaring)	79,65	73,87	81,78	82,15	82,15
P18	Rubber Factory Hoktong (Keramasan)	83,33	70,17	75,167	82,15	82,15
P19	2 floors of PDC Auto 2000 (Tanjung Api-Api, Sukarame)	37,5	29,17	37,5	37,5	37,5
P20	Turap 9-10 Ulu	100	100	100	100	100
	Rate	88,28	82,58	87,14	87,2	87,2

Based on results of tabulation of the analysis of the percentage five classification methods, could be seen that the level of the truth each method more than 80%, and could be concluded that Soil CPT Program with five soil classification methods (Schmertmann Method, Douglas Olsen Method, Robertson Method , Probability Reion Estimation Method , and the Fuzzy Logic Method) could be used by using the test data sondir (DCPT).

CONCLUSION

1. The Soil CPT Program is based on five soil classification methods, namely Schmertmann's Method, Douglas Olsen' Method, Robertson's Method, Fuzzy Logic Method, and Probability Region Estimation Method.
2. The Soil CPT Program is developed only based on soil grain sizes (sand, silt, clay) using the five soil classification methods, and did not refer to the parameters of plasticity index as available in USCS soil classification.
3. Based on the comparison of running the Soil CPT software with data of the DCPT to those of bore log based on USCS soil classification, it can be known that the accuracy level of each classification was between 80-85%, with the most accurate level being the Schmertmann's Method.
4. Based on result of the analysis on the profile of soil from the output of the Soil CPT Program, it can be concluded as follows:
    - The probability Region Estimation and Fuzzy Logic Methods can be used to find out the thickness of soil layer.
    - The Schmertmann's, Robertson's, and Douglas Olsen's Methods can be used to find out the kinds of soil in detail at each interval.
5. The Soil CPT Program with five soil classification methods can be used as an initial information of the classification, profile and depth of soil by the requiring parties such as users of construction service, considering that the software is faster and more efficient for the soil classification in general (sand, silt, clay).

SUGGESTION

1. The Soil CPT Program with five soil classification method still needs the completion of applying data based on the DCPT.
2. The research is necessary to complete by adding a number of data sample in the penetration test for more increasing the accuracy of obtained result.

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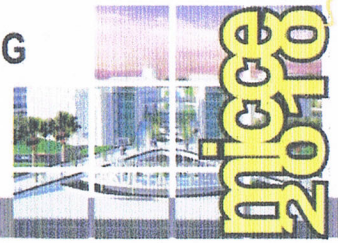

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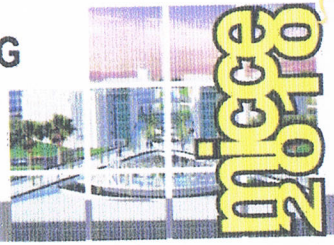

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