Expert Idea on Liquid Limit and Plastic Limit Estimation with Soil Resistivity Profile

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Abstract-This paper presents the idea on determination of liquid limit and plastic limit with soil electrical resistivity in geotechnical investigations. Depending on the moisture contents, the soil behavior is revealed as solid, semisolid, plastic and liquid states in geotechnical engineering and other division of civil engineering. Determination of liquid limit and plastic limit of soil in conventional laboratory test is very tedious, slower and costly for the laboratory testing example as fall cone testing with a lot of collected soil sample. In this work, a method of soil liquid limit and plastic limit determination with electrical resistivity is revealed to define the state of soil as well as the relationship of soil particle distribution in the soil site investigations of geotechnical engineering. In addition, soil resistivity measurements with moisture contents and conventional laboratory test as fall cone test are performed whereas experimental results in laboratory and results from the available literature review are considered. A good correlation of soil electrical resistivity and moisture contents is demonstrated in results to determine the liquid limit, LL and plastic limit, PL in soil behavior. The research is most significant to obtain faster, cost-effective and consistent performance in soil liquid limit and plastic limit determination through electrical signal for a wide range of applications in geotechnical engineering.

Key words: Liquid limit, Plastic limit, Fall cone test, Electrical resistivity profile

Introduction

Observations of soil state behaviors and determinations of soil strength are prerequisite in highway and road engineering including construction of highway embankments, earth dams, geotechnical engineering, and other divisions of civil engineering (Benson and Trast, 1995). The behaviors of soil can be divided into the basic states of solid, semisolid, plastic and liquid depending on the moisture contents. The change from one state to the next is measured with increasing of moisture contents. These smooth transitions are considered for introducing LL, PL in geotechnical investigations. The moisture content between PL and LL is defined as the plasticity index, PI where PI is a measure of the plasticity of soil.

General techniques for the determination of this soil LL and PL were conducted through the laboratory tests, in-situ tests and geophysical methods (Avnimelech et al., 2001; Sridharan and Nagaraj, 2005). The laboratory test is generally conducted to obtain the moisture contents for changing the behaviors of soil states in soil investigations (Elshorbagy and Mohamed, 2000). As an example, in fall cone test, moisture contents are obtained corresponding to the empirical cone penetration to determine LL and PL of soil. Determination of LL and PL in soil is also tedious, slower and costly using conventional laboratory testing based on the procedure of testing. In addition, conventional methods are usually in difficulties during the collecting of dry sample and soil sampling processes, which may change the original value of the testing results.

Determination of soil LL and PL with electrical resistivity shows the important role in the construction of highway embankments, structural engineering and others geotechnical engineering (Osella and Favetto, 2000; Yoon and Park, 2001). The electrical resistivity of the soil is manipulated by soil type, degree of saturation, concentration of ions, water contents and temperature of pore water. Transport properties such as electrical conductivity (Friedman, 2005), soil resistivity (Huang and Fraser, 2002), thermal conductivity, and hydraulic conductivity show associations with the porosity, water saturations, composition, salinity of the pore water, grain size distribution, and particle shape and orientation (Samouelian et al., 2005).

The fall cone test for determination of liquid limit and plastic limit is performed in this work to get the empirical relationship with soil resistivity profile for the collected sample of different type soil. The resistivity of the collected soil is measured with the high resistance meter for each sample of the estimation of LL and PL. The relationship is shown to determine the soil state behaviors with the measurement of soil resistivity corresponding to the different moisture contents in collected soil. Experimental results and study from the available literature are considered to justify the measurements of LL and PL with electrical properties in geotechnical investigations. Background and objective of this study intends the relationships between electrical resistivity and determination of LL and PL in context of electrical properties of collected soils. The aim of the research is to obtain a set of consistent measurements of LL and PL which is used to yield an equivalent model with the electrical performance in geotechnical investigation system.

Methodology

The research work on determination of LL and PL of soil through electrical resistivity is conducted at University Kebangsaan Malaysia with the cooperation of Ministry of Science, Technology and Innovation of Malaysia. The fall cone test for the different type of soil sample is done in the geotechnical laboratory of Civil and Structural Department, UKM. The data collection for soil resistivity measurement is carried out using digital precision multimeter, model 8846A, Fluke at construction site of University Kebangsaan Malaysia (UKM) in Bangi, Selangor, Malaysia shown in Fig. 1. The study on the relationship development between soil electrical resistivity and LL, PL of soil is done and the analysis is performed using MATLAB 2009 in Geotechnical Laboratory, Faculty of Engineering and Built Environment, UKM.

Figure 1.Soil electrical resistivity measurement for soil state determination

Conventionally, LL and PL estimation of soil is estimated with fall cone test as moisture contents of soil corresponding to the cone penetration in soil considering the specifications of penetration depth and size of cone in the test (Sridharan and Gurtug, 2004). As an example, moisture contents corresponding to the 20 mm cone penetration for 0.75 N cone weight reveals the LL of the soil sample in fall cone test.

In the research, soil resistivity is taken considering the increasing of moisture contents to get the soil state behaviors. Decreasing of the resistivity of surface soil is dependable on the increasing of water contents of soil in geotechnical field. Thus, the relation of soil water content with soil resistivity at the time of measurement clearly is major factors contributing to soil EC surveys. The resistance, R in unit of Ohm (Ω) of soil sample is defined with fundamental equation of electrical engineering called as Ohm's law.

$$R = \frac{V}{I} \tag{1}$$

Where V is the potential difference in volt (V) and I is the supplied current in ampere (A) of electrical measurements. The resistivity, ρ of compacted soil is defined from the measured resistance including probe space and area of the soil sample.

$$\rho = \frac{R \times A}{l} \tag{2}$$

Where R is the resistance (Ω) of the material, l is the length of the conductor (m), and A is the cross sectional area (m^2).

When a constant voltage is applied to one of the two probes placed in the soil, the current that flows between the probes is inversely relative with the resistance of the soil (Doolittle et al., 1994; Kelleners et al., 2005). Electrical resistivity shows indeed strong variations that principally depend on variations of water contents in soil (McNeill, 1980; Saarenketo, 1998).The electric current passed through the soil between two steel probes makes an electric field in surface soil investigations. The voltage difference as well as electric field strength in geo-electric field is obtained for soil resistivity measurements. The analog electrical signal is converted into a digital value for getting robust performances using criteria of Analog to Digital Converter (ADC) in soil resistivity observations.

The soil resistivity measurements for determination of LL and PL of soil are done in this work using precision digital multimeter of Fluke Company, model 8846A with accurate measurements and Kilo-Ohm scale for easier reading. The specifications and functions of digital multimeter shown in Table 1 for soil resistivity calculations include 100 µA to 10 A current ranges, with up to 100 pA resolutions for the measurements techniques. High resistance meter with digital and analog configurations are used in our research to measure soil resistance with consistency.

Table 1 Specifications of insulation tester used in soil resistance measurements

	Specifications	Functions
Insulation Resistance Tester-Digital	Test Voltage	1000 V and 600 V
	Measuring ohms Ranges	10 Ω to 1 GΩ with up to 10 μΩ resolution
	Measuring current ranges	100 μA to 10 A current range, with up to 100 pA resolution
	Measurement technique	2 x 4 ohms 4-wire

Results and Discussions

Modern research and innovations in geo-electric and system engineering have improved the ability to collect and process data with manifesting reliable subsurface soil properties of near surface soil profile. Usually, soil LL and PL is determined through the laboratory testing with demonstration of soil moisture contents corresponding to the reading of specified tools (Sridharan and Gurtug, 2004) in geotechnical characterizations. As an example, soil moisture contents corresponding to the specified cone penetration depth in millimeter is considered as LL for particular size of cone for the fall cone test method. PL can be estimated with another size of cone considering the moisture contents for specified cone penetration depth in millimeter. The laboratory tests of different soil sample are also costly and tedious to obtain the criteria of estimation of cone penetration, moisture contents in soil for geotechnical investigations (Sridharan and Nagaraj, 2005). The previous soil LL and PL estimation in laboratory is also time consuming system due to the collecting sample with fall cone test as well as obtaining dry sample of soil.

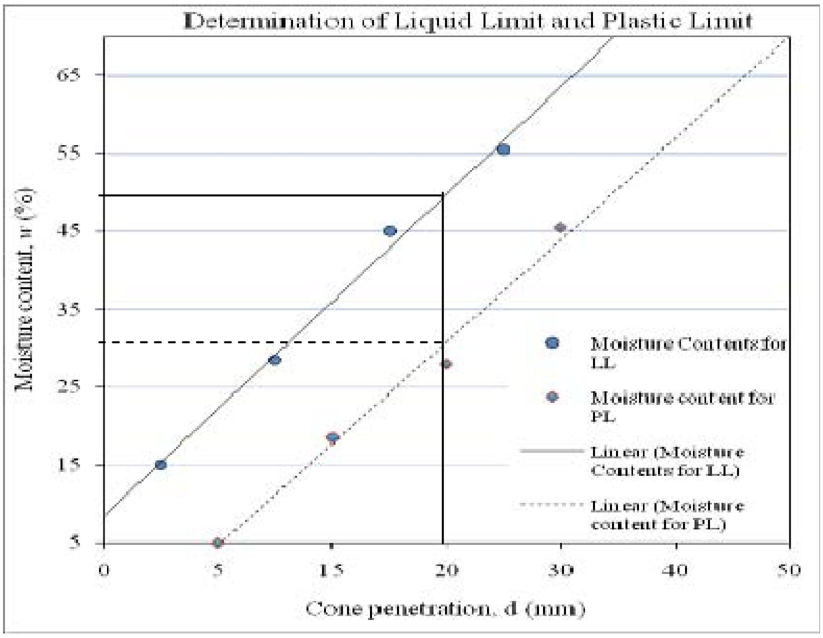

Figure 2. Fall cone test for liquid limit and plastic limit

In this research, fall cone test is performed and cone penetration size is obtained with increasing of water contents for determining LL and PL shown in Fig. 2. The LL of soil is observed using with the weight of cone as 0.75 N whereas the PL of soil is determined with 2.35 N as cone weight in the fall cone test. In both cases, the moisture contents are taken as LL and PL at the empirical cone penetration depth of 20mm. Figure 2 shows that about 49.5 % of moisture contents are considered as LL of soil according to the criteria of fall cone test in the investigated soil sample. Hence, PL is shown as about 30.75 percent moisture contents in soil including cone penetration of 20 mm in the convention laboratory test.

In this study, the resistivity of collected soil sample is determined according to the increasing of moisture contents in soil identifications. Figure 3 shows the soil resistivity decreases exponentially with increasing of moisture content in soil sample. Thus, the resistivity of soil sample is shown about 38 Kilo Ohm-meter (k Ω-m) for 50 percent water contents in soil resistivity estimation.

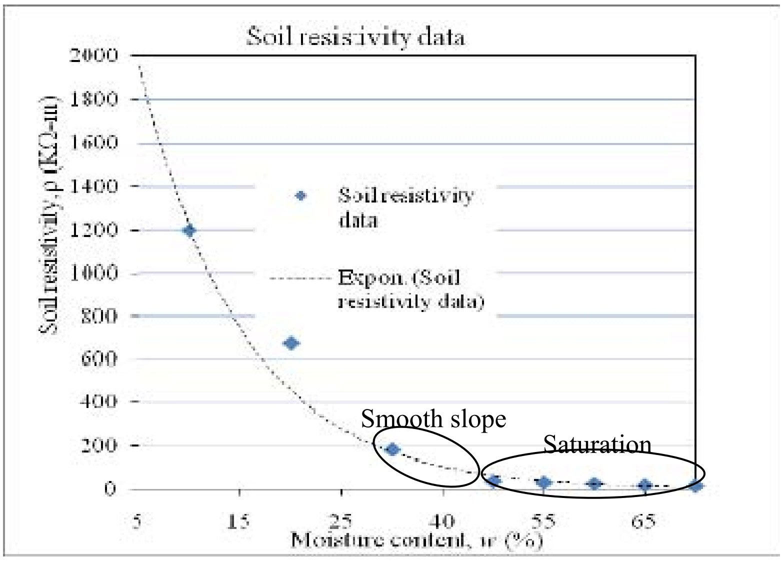

Figure 3. Soil resistivity observations with moisture contents

The resistivity of soil goes into the saturation state with increasing the moisture contents after 50 percent in the soil sample. Moreover, the smooth slope of resistivity data is observed in the range of 30 percent to 50 percent water contents shown in Fig. 3. The moisture content of the starting point of the saturation state is revealed as the LL of soil sample in the research criteria with soil resistivity profile. In addition, the initial moisture content of the smooth slope of soil resistivity data is demonstrated as the PL of soil state behavior observations.

The method of soil LL and PL determination through soil resistivity is faster, easier and more cost-effective than the conventional laboratory test in soil investigations. The soil resistivity measurements manifest better and robust performance in geotechnical monitoring systems. There is no criteria of collecting dry sample with certain temperature in geotechnical laboratory which is tedious, time consuming and labor intensive for soil type identification system. In this study, expert idea of soil LL and PL determination are taken from the measured resistivity data of collected soil sample through high resistance meter. Table 2 shows the data of obtaining empirical relationships of LL and PL with soil resistivity in geotechnical characterizations. This system is also consistent for data acquisition and analysis to estimate soil properties with non-destructive performance for roads and highway engineering, geotechnical and many other engineering structures.

Table 2 Soil LL and PL determination with resistivity profile

Sample No.	Sand (%)	Silt (%)	Clay (%)	Soil LL	Soil PL	Soil resistivity, KΩ-m
A	33.5	38.5	26.0	37.0	20.0	150
B	36.5	58.5	5.0	39.0	26.0	123
C	3.5	56.0	40.5	55.4	31.0	76
D	13.0	35.5	51.5	70.5	35.6	29

Conclusions

A technique of soil LL and PL determination with electrical resistivity is revealed with the aim of achieving better performance in sensing of soil properties for geotechnical engineering. The empirical relationship is demonstrated to get the soil state behaviors through resistivity measurement in soil profile. The saturated state of resistivity with increasing of soil moisture contents is shown as LL of soil whereas the smooth slope in resistivity data before the saturation state is considered as PL of soil in this research work. The resistivity measurement of collected soil sample is able to obtain the better, faster and cost-effective performance in soil type estimation system. The analysis used in this study incorporates collected data with high resistance meter for soil sample in geotechnical characterizations. In addition, laboratory testing also verifies the idea for obtaining soil condition with soil electrical properties as reliable and consistent investigations in geotechnical profile. There will be future studies including more test data for different type of soil on refining this method to estimate earth parameters in particular applications of geotechnical engineering.

Acknowledgements

This research is sponsored by Research Project of Science Fund No. 01-01-02-SF0681 from Ministry of Science, Technology and Innovation of Malaysia.

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