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EXPERIMENTAL INVESTIGATIONS

EMPIRICAL CORRELATION BETWEEN ELECTRICAL RESISTIVITY AND ENGINEERING PROPERTIES OF SOILS

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Soil's electrical properties are the parameters of natural and artificially created electrical fields in soil and are influenced by distribution of mobile electrical charges, mostly inorganic ions. We aim to determine practically-applicable relations with which to determine soil moisture content and void ratio based on electrical resistivity measurements taken from two different sites in Penang Island. In this study, analysis was conducted to determine the relationship between soil electrical resistivity, moisture content, and void ratio. Moreover, an initial analysis was conducted to determine the variation between the coefficient of gradation with moisture content and void ratio for all data. The developed empirical correlation found in this study can be used as an initial guideline for the further study of tropical soil.

Introduction

Natural geomaterials that form a load-bearing structure consist of various solid mineral particles with diverse sizes, shapes, and arrangements, and multiple phases of pore fluids fill the voids between the particles including air, water, and solutions [1]. Many kinds of electrical fields and potentials have been observed simultaneously in natural soil and therefore it is difficult to identify the mechanism responsible for their formation. The electrical conductivity and resistivity of soils have been investigated in a large number of studies, which can be divided into three groups. The first group includes laboratory studies of electrical conductivity and the dielectric constant of different dispersed media (including soils) with electromagnetic waves [2] and [3]. These studies help to develop the relationship between electrical parameters and the quantitative and qualitative compositions of electrolytic solutions [4]. Our understanding of these relationships was enhanced by studies of soil electrical parameters under a constant electrical field [5]. For some diluted soil solutions and groundwater, methods have been developed to calculate electrical conductivity based on the solution compositions. Electrical conductivity of the extracted soil solutions have been studied in detail [6-8]. The second group of studies is devoted to laboratory measurements of surface electrical conductivity. The surface electrical conductivity is a major parameter describing the structure of the electric double layer and its ionic composition. However, there is limited research involving experimental measurements of the surface electrical conductivity in soils [9]. The third group of studies includes measurements of the electrical conductivity of soils, rocks, and sediments in situ based on various geophysical methods [10, 11, 12].

In a general engineering sense, soils are defined as the uncemented aggregate of mineral grains and decayed organic matter (solid particles) along with the liquid and gas that occupy the empty space

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between the solid particles. Soil is used as a construction material in various engineering projects and it supports structural foundations [13]. Therefore, civil engineers must study the properties of soil, including its origin, grain-size distribution, ability to drain water, shear strength, and compressibility. The in situ behavior of soils is complex because it is heavily dependent upon numerous factors. To obtain an appropriate level of understanding, it is necessary to analyze soils not only based on geophysics and geotechnical engineering skills but also through other associated disciplines like geology, geomorphology, climatology, and other earth and atmospheric sciences. It is generally understood that geotechnical problems with socio-economic impacts like landslides can be addressed within a framework that accounts for behavioral features in natural soils. Research is actively taking place in many countries, each focusing on natural deposits of local importance, and a unified framework that can account for all important effects is still being developed [14]. The development of this unified framework requires a huge and joint effort from as many sources as possible, applying exceptional academic and technical skills and using the best possible equipment. In this context, this paper attempts to summarize some soil index properties and electrical resistivity of tropical residual soils of Penang Island, Malaysia, and discusses the important correlations and facts that emerged from the analysis.

The objective of this study was to generate empirical correlation models between soil electrical resistivity and the moisture content and void ratio in the context of electrical properties of coarse-grained clayey sand soils. We aim to determine practically-applicable relations with which to determine soil moisture content and void ratio based on electrical resistivity measurements taken from two different sites in Penang Island. In this study, analysis was conducted to determine the relationship between soil electrical resistivity, moisture content, and void ratio. Moreover, an initial analysis was conducted to determine the variation between the coefficient of gradation with moisture content and void ratio for all data. The developed empirical correlation found in this study can be used as an initial guideline for the further study of tropical soil.

Geography and geology of Penang Island

Penang Island is situated in the northern region of Malaysia. The climate is tropical with an average mean daily temperature of approximately 27°C and mean daily maximum and minimum temperature of 31.4°C and 23.5°C, respectively. The mean daily humidity varies between 60.9% and 96.8%. The major portion of Penang Island is underlain by igneous rocks. All igneous rocks are granites according to the Streckeisen classification [15]. These granites can be classified on the basis of proportions of alkali feldspar to total feldspars. This analysis indicates that granites of Penang Island may be further divided into the North Pluton and the South Pluton [15].

Research method

In geophysics, the electrical resistivity of any material is defined as the electrical resistance of a soil sample with a cross section of unit area and with unit length. In most earth materials, porosity and the chemical content of water filling the pore spaces are more important in governing resistivity than the conductivity of the mineral grains that comprise the material itself [16]. In this study, the electrical resistivity was measured using soil's box for 20 soil samples from two different areas of Penang Island using the sample core IP tester (SCIP). We determined the electrical resistivity value for each sample

$$R = \rho(L/A),$$

where R is the resistance (Ω), ρ is the resistivity (Ωm) of the conductor material, L is the length of the conductor (m), and A is the cross-sectional area (m^2).

In addition, water content determination is a routine laboratory test in geotechnical engineering to determine the amount of water present in a quantity of soil in terms of its dry mass [14, 17, 18]. We determined the water content value for each sample

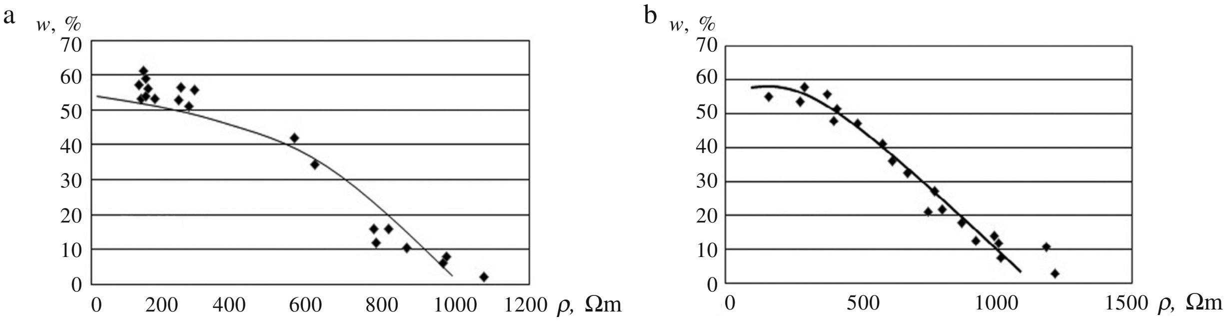

Fig. 1. Relationship between soil electrical resistivity and water content for: a) Batu Uban area, and b) Balik Pulau area.

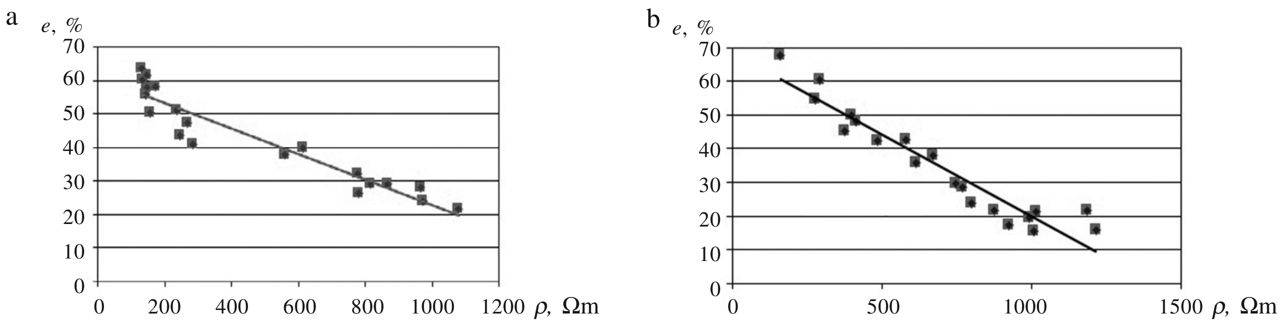

Fig. 2. Relationship between soil electrical resistivity and void rato for: a) Batu Uban area, and b) Balik Pulau area.

$$w = (M_w / M_s)100\%,$$

where M_w is the mass of natural sample, and M_s is the mass of sample in dry condition (kg).

Results and discussion

The electrical properties of soils represent parameters of natural and artificially created electrical fields in soils and are influenced by the distribution of mobile electrical charges, mainly represented by the water content. Based on the laboratory test data and by selecting the appropriate relationship, empirical correlation models that may be used to provide an estimation of soil water content from electrical resistivity data of soils have been developed for the study areas. Applications of the electrical resistivity measurements for studying soil moisture content and void ratio provides a useful tool for geotechnical engineering studies, especially in soil mechanics and foundation engineering perspectives.

Laboratory tests were performed for 20 clayey sand soil samples collected from each of the Batu Uban area and Balik Pulau study areas. The soil samples showed resistivity values of between 129 Ωm and 1215 Ωm, water content between 2% and 62%, and void ratio of between 15% and 68%. In Batu Uban the relationship between resistivity and moisture content of soils was identified as $w = 0.629e^{-0.0007175\rho}$. The regression coefficient R^2 for this relationship was approximately 0.964. The relationship between resistivity and void ratio for Batu Uban was identified as $e = -0.038\rho + 61.09$, and $R^2 \approx 0.901$. In Balik Pulau $w = 1.81e^{-0.003113\rho}$, $R^2 \approx 0.949$. Moreover, $e = -0.048\rho + 68.37$, $R^2 \approx 0.911$. For all data from both study areas $w = 1.46e^{-0.003865\rho}$ with $R^2 \approx 0.934$, and $e = -0.042\rho + 63.54$ with $R^2 \approx 0.900$ (Figs. 1-3).

The empirical correlation models developed in this study provide a useful tool to relate electrical resistivity with moisture content and void ratio of a soil serving as a reference to describe its fluid

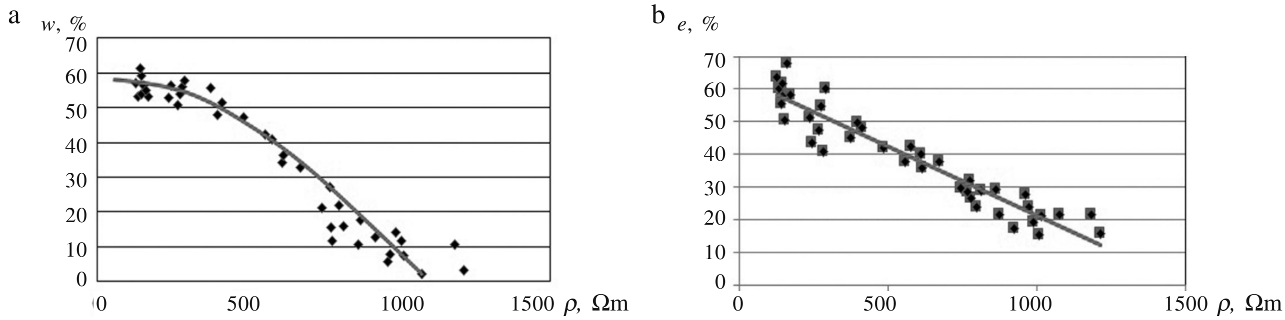

Fig. 3. Relationship between soil's water content (a) and void ratio (b) with electrical resistivity for all data.

behavior. As pointed out by [19-21], solid soil components are generally electrical insulators; the conduction of electrical current is associated with the contents of the soil pore spaces only. Volume conduction is controlled by the electrolyte concentration in water and the geometrical characteristics of the macropore network. This study has shown that the obtained models have the capability of investigating the effects of water content and void ratio on the electrical resistivity of a soil.

Conclusion

In this study, we successfully generated empirical correlation models between soil electrical resistivity and moisture content or void ratio in the context of electrical properties of coarse-grained clayey sand soils from two different sites in Penang Island. Therefore, the study is achieved with successfully. The data obtained from this study allow us to estimate the effects of moisture content and void ratio on soil electrical resistivity. The variation between coefficient of gradation with moisture content and void ratio for all data was initially determined in this study. The determination of these empirical correlation models may be of use in future studies of electrical properties of clayey sand soils in relation to the water content and void ratio parameters from an engineering perspective.

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