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Soil Resistivity Measurements to Predict Moisture Content and Density in Loose and Dense Soil

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Abstract. In the past, most of the soil electrical resistivity charts were developed based on stand-alone geomaterial classification with minimal contribution to its relationship to some of geotechnical parameters. Furthermore, the values cited a very wide range of resistivity with sometimes overlapping values and having little significance to specific soil condition. As a result, it created some ambiguities during the interpretation of observations which were traditionally based on qualitative anomaly judgments of experts and experienced people. Hence, this study presents soil resistivity values based on laboratory experiment with a view to predict the soil moisture content and density in loose and dense soils. This study used a soil box and a resistivity meter to test a clayey silt soil, increasing its water usage from 1-3% based on 1500 gram of dry soil. All the moisture contents and density data were observed concurrently with 25 electrical soil resistance observations being made on the soil. All testing and formula used were in accordance with that specified in BS1377 (1990). It was apparent that the soil resistivity value was different under loose (L) and compact (C) condition with moisture content (w) and density (ρ_{bulk}) correlations being established as follows; $\rho_{bulk\,(C)} = 2.5991\rho^{-0.037}$, $\rho_{bulk\,(L)} = -0.111\ \ln(\rho) + 1.7605$, $w_{(L)} = 109.98\rho^{-0.268}$, and $w_{(C)} = 121.88\rho^{-0.363}$ with determination coefficients, R^2 that ranged between 0.69 – 0.89. This research therefore contributes a means of predicting these geotechnical parameters by related persons such as geophysicist, engineers and geologist who use these resistivity techniques in ground exploration.

Introduction

Ground investigation (GI) is a process involving exploration, sampling and testing within the realms of Site Investigation (SI). Conventional ground investigation is performed by drilling exploration and some problems are faced when working at difficult construction sites. With the increasingly limited land availability, construction industry is urged to develop many structures in difficult sites such as those with hilly terrain area or conversely swampy area. As a consequence, some problems arise such as mobilization of equipment and their operation due to them being bulky and heavy machinery as those commonly used for ground exploration purposes. As reported by [1], conventional SI experiences difficulties in steep and hilly terrain, swampy areas, coastal regions and complex geomaterial areas which need to be investigated.

Geophysical methods are increasingly being used in ground investigation due to its ability to reduce cost, time and provide additional data which cover a greater area of investigation compared to the traditional method. Geophysical methods can be implemented more quickly and less expensively and can cover greater areas more thoroughly [1,2,3,4]. This technique is used to define an earth structure using basic properties in physics such as electrical resistance, seismic velocity, density, magnetic susceptibility, etc. The equipment and technology so developed are employed to measure those physical properties viz; electrical resistivity, seismic refraction and reflection, gravity, magnetic, etc. The standard performance of individual geophysical method always depends on fundamental physical constraints, e.g. penetration, resolution, and signal to-noise ratio [5]. Traditionally, most of the data measured from field will be analyzed using utility software with an anomaly contrast. Finally, this anomaly contrast will be interpreted subjectively based on past references and expert experience.

A critical problem that is always raised during the anomaly judgment and interpretation stage due to a weak verification and most of anomaly justification was given subjectively using qualitative point of view, and such problems cause it to be considered as a black box between an expert with different background knowledge obtained from specialist experts such as geophysicist, geologist and engineers. Most interpretations of investigations obtained with geophysical techniques are controlled by physicists and geologist with considerable expertise in their respective fields, but posses less ideas of construction constraints within civil and construction interest and necessity [6]. Moreover, some experts as geophysicists attempt to hide their expertise from others due to the business reasons. As a result, some of geophysical results and conclusions are difficult to deliver in a sound and definitive ways as they are always subjected to the famous established expert and experienced people who are commonly too obsessed with an anomaly outcome. In the worst scenario, different conclusions will often comeout from a different interpreter for the same particular anomaly outcome investigated. Geophysical methods are insufficient to stand alone in order to provide solutions to any particular problem [7,8]. Past geophysical reference standards give a general classification with a wide range and overlapping values with minimal contribution for geotechnical properties determination or prediction.

Professionally, there is no argument that the geophysical data acquisition and processing was championed by an expert in geophysics. However the interpretation stages solicit a multidisciplinary knowledge and field especially from sciences and engineering. Moreover, the interest of the related people involved in site investigation works must be always related to their background of knowledge and expertise. For example, a geotechnical engineer will demand to relate the geophysical method to assist their conventional exploration method more than its traditional anomaly detection such as a contribution to soil properties determination which enables the prediction and support the existing information for design and construction purposes. Geophysicists still possess little appreciation to the engineer's point of view and lack the knowledge of the science in soil mechanics [6].

Studies which relate the geophysical data to geotechnical properties are rare and less known [4]. Furthermore, geotechnical properties quantification was an important factor for geophysical method used in engineering application [9]. However recently, researchers have begun to collaborate and relate the geophysical parameter to geotechnical properties [9,10,11,1,12,13,14,4,15]. Geophysical method has a good prospect in order to solve some of the problems related to the conventional site investigation methods [6]. Hence, to ease some of the black box and gap from related experts, this study proposed to establish a comparison of laboratory electrical resistivity correlation specifically under loose and compaction effort with additional relationship to predict soil moisture content and density statistically. Quantification of geotechnical properties has become an important factor for rigorous application of resistivity imaging in engineering applications [9].

MATERIAL AND METHODS

Disturbed soil samples were used to perform 25 number of laboratory resistivity test for loose and compacted samples. Sieve analysis test was conducted to classify the type of soil based on grading characteristics [16]. Nilsson soil box resistance meter was used to test the soil resistivity value under loose and compact condition based on 1500 gram of origin dry soil with additional percentage (%) of water from 1-3% (% of water used was based on 1500 g of soil used: 1% = 15 ml, 2% = 30 ml and 3% = 45 ml). Each experiment was performed separately according to % of water and condition (loose or compact) for a total of 25 numbers of data. Continuous % of water was added and tested until 25 number of test for each experiment. Soil moisture content and density was determined immediately after each number of resistivity test being performed to develop a series of data specifically according to 1-3% of water used and under loose and compaction effort. Moisture content test was determined for two samples from each soil box test for final averaging purposes. During the loose condition test, soil sample was poured inside the box in a free fall condition while a hammer was used to compact the soil for each three layer under a consistent of 27 numbers of impact. Before the hammer was used to hit and compact the soil, a flat wood with a same total area of box was fitted placed on the top of the soil and being impacted in consistent forced (27 number of impact) in order to control the consistency of the soil compaction effort. All results obtained from the experiments were analyzed using a statistical regression method. The following Eq. 1 – 3 were used to calculate the resistivity value, bulk density and moisture content [16].

$$\rho = RA / L \tag{1}$$

where A is the cross-sectional area of the sample, *L* is the length of the sample between the electrodes and R is the mean resistance of the soil sample ($R=V/I$)

$$\rho_{bulk} = m / V \tag{2}$$

where m is the mass of the soil specimen (solids + water) and *V* is the volume of the test specimen (total volume)

$$w = ((m_2 - m_3)/(m_3 - m_1)) \times 100 \tag{3}$$

where m_1 is the mass of container, m_2 is the mass of container and wet soil and m_3 is the mass of container and dry soil

RESULT AND DISCUSSIONS

Based on sieve analysis results as shown in Fig. 1, it was found that the soil tested was classified as Clayey SILT as the particle was dominantly from silt (54.08%) and clay (24.82%) followed by sand (16.51%) and gravel (4.59%) respectively. Hence, it was proved that the soil tested was fine grain soils results a low resistivity value especially in wet condition. According to [17], a quantitative proportion of water and geomaterial particle fractions were observed to be very sensitive to influencing soil resistivity data. Furthermore, resistivity data exhibits a low value for a fine soil such as clay and silt while the coarser soil such as sand and gravel will produce a higher resistivity value [18]. It was found that the relationship between bulk density and resistivity is strongly correlated based on the R^2 value obtained which is 0.6 (loose state) and 0.73 (pack state). Furthermore, the relationship of moisture content and resistivity was very strongly correlated since its R^2 value was found at 0.8927 (loose state) and 0.8853 (pack state). Hence, the value of soil bulk density and moisture content of Clayey SILT was applicable to be predicted based on the statistical regression equation established as given in Fig. 2 and 3. This equation was developed to predict the field soil moisture content and density using resistivity value input which can be determine during the field resistivity survey at the site studied. Hence it can contribute to the ease of basic geotechnical properties determination which able to reduce the number of soil sampling and lab test which traditionally used in practice.

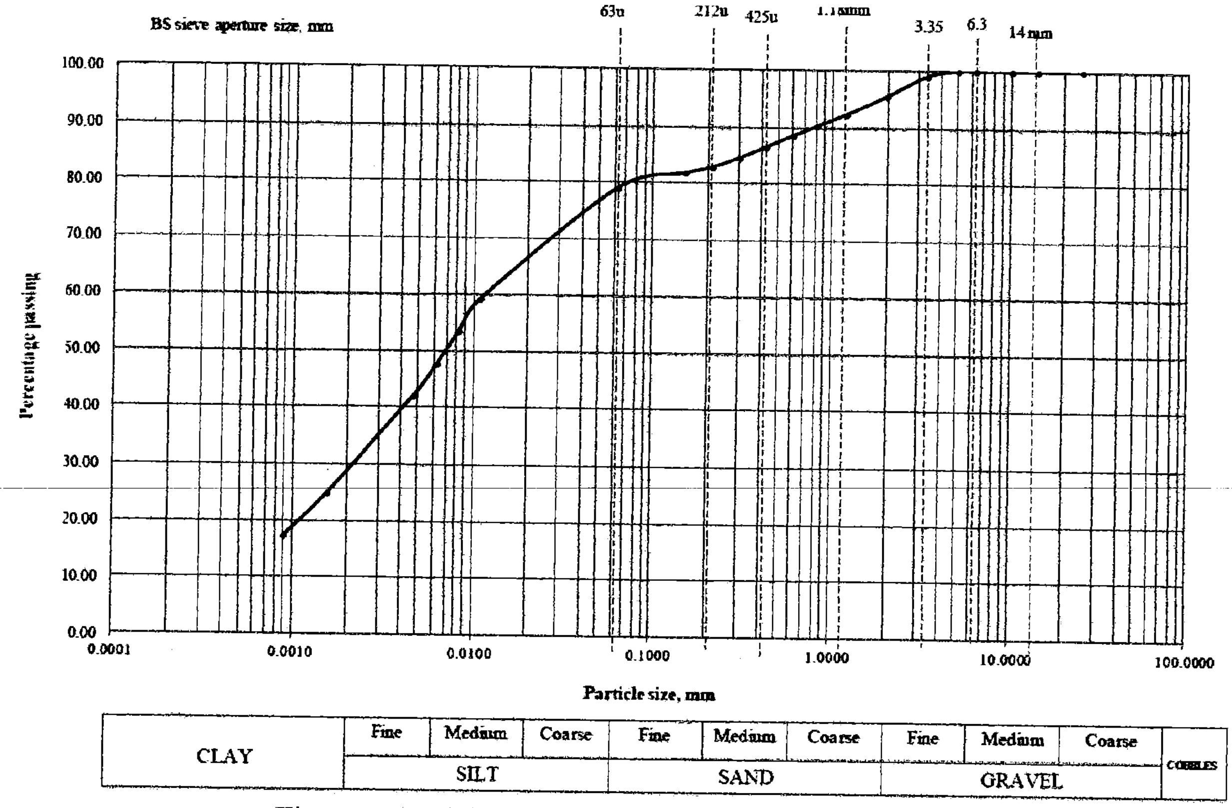

Figure 1. Particle size distribution curve for soil studied

The soil density value of compact condition was higher than loose condition since the soil quantity of compact condition require more than loose condition. During the compaction effort, volume of air contained in pore was decreased and thus require an additional soil added and compacted for three layers until it fully fit inside the box volume. Hence, the amount of soil used was higher compared to the loose conditions which contribute to a greater value of bulk density. Under loose condition, soil consist higher of voids which dominantly filled by air and water thus contribute to a lower weight which relative to the lower bulk density value measured. It was found that the moisture content value for the compact condition was less than loose condition due to the least amount of moisture contained in a compacted soil. During dense and compact state, soil will reduced its pore thus effecting to a lower moisture content amount. However in loose stated, lots of pore was filled by water which increase the soil moisture content value.

Generally, the resistivity value was greatly influenced by basic soil characteristics variation such as quantity of solid, air and water. According to [19,20], resistivity value was highly influenced by pore fluid and grain matrix of geomaterials. In compact condition, it was found that the statistical plot was highly concentrated at a lower resistivity value due to the ease of current propagation in soil. The volumes of pore in compact condition were reduced and cause the current to propagate easily especially during the existing of water. However, pore which contained an air in dry state will produced a higher soil resistivity value. According to [21], air filled void posses a higher resistivity value compared to water filled void. The resistivity value in loose state was decreased gradually during the moist to saturated state thus producing a continuous statistical plot compared to the compact condition. Different statistical distribution plot representing loose and compact condition for resistivity data was given in Fig. 2 and 3. The comparison of soil arrangement which caused the resistivity value variations was illustrated in Fig. 4.

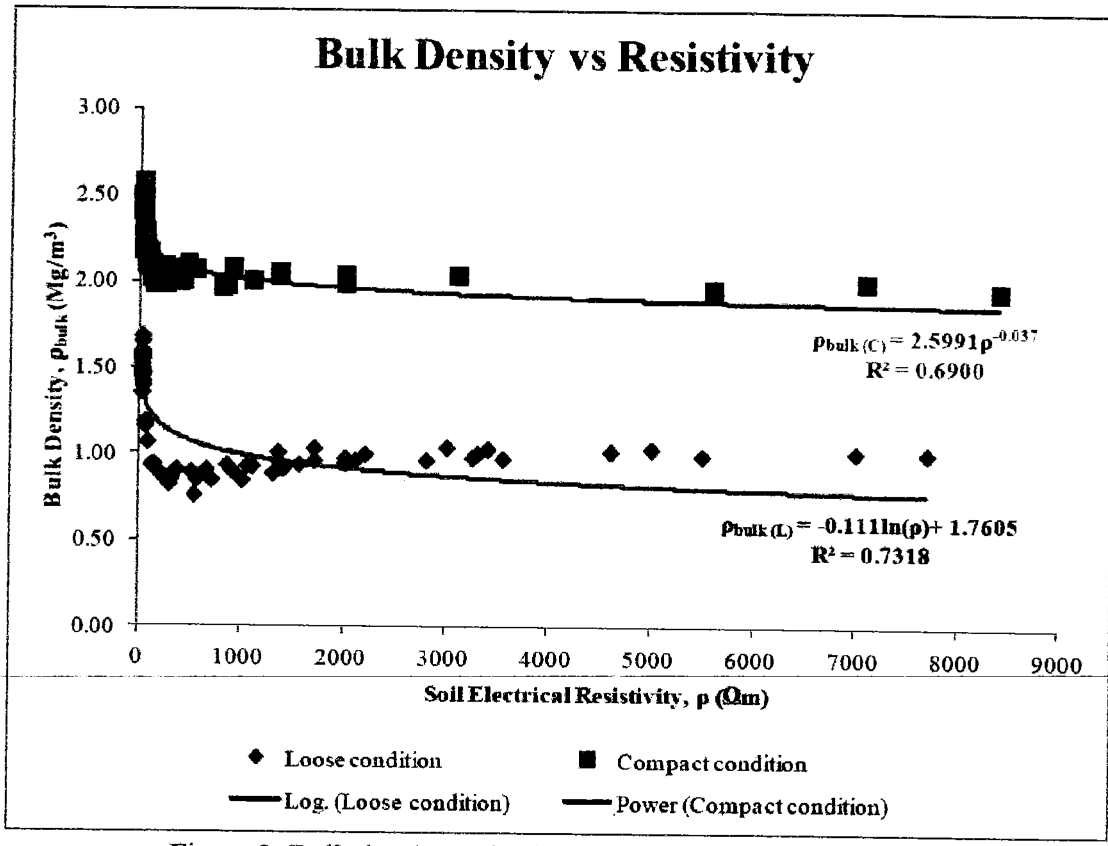

Figure 2. Bulk density and soil electrical resistivity correlation

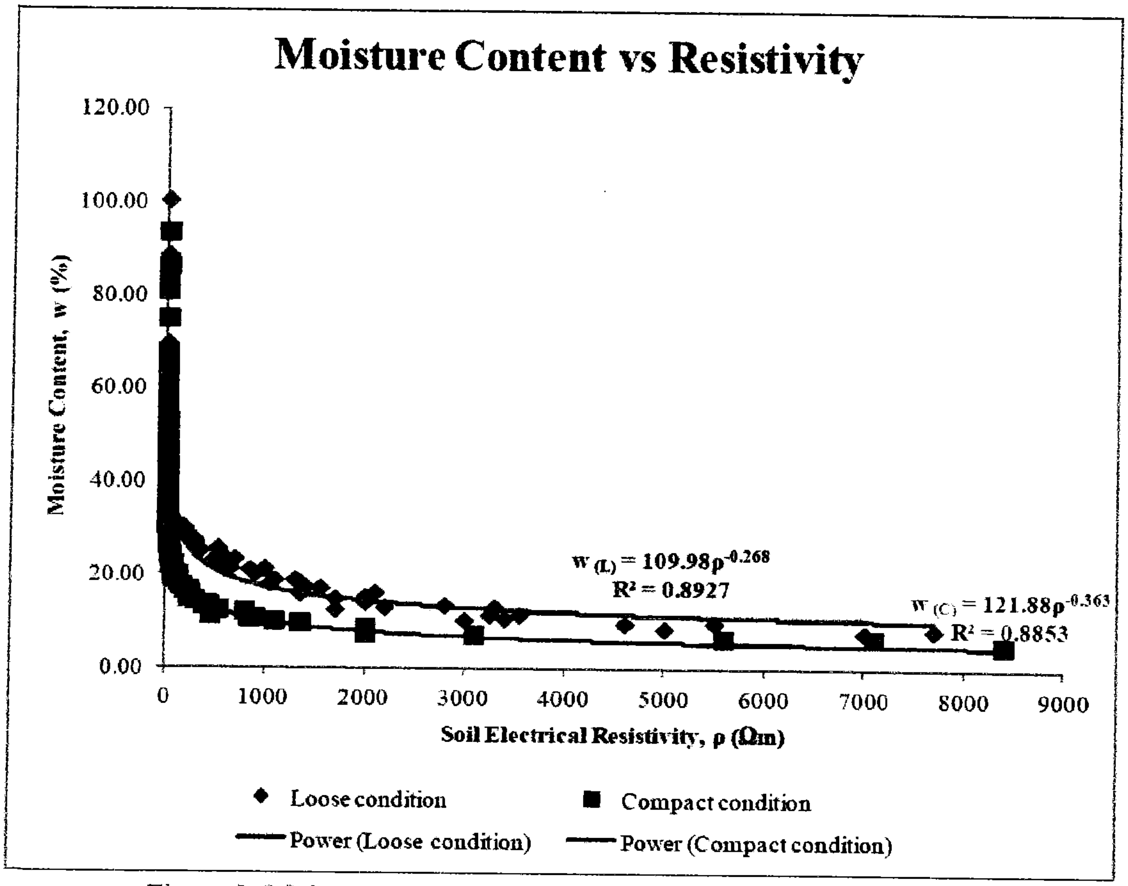

Figure 3. Moisture content and soil electrical resistivity correlation

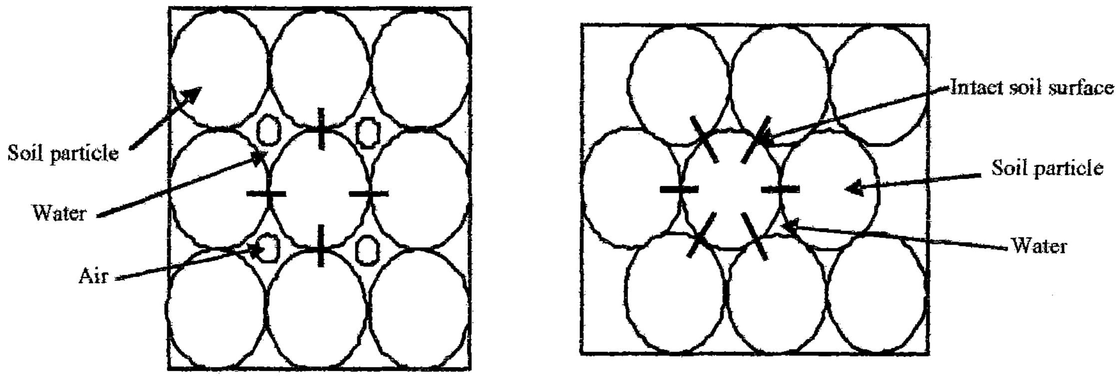

Figure 4. Diagram of soil particles and air with water before (left) and after (right) compaction effort

CONCLUSION

The laboratory experiment of soil box resistivity test under loose and compaction effort was successfully being performed specifically on Clayey SILT soil. The soil electrical resistivity was greatly influenced by the presence of water and porosity which related to the loose and compaction condition. The correlation of soil electrical resistivity to moisture content and density was established. The establishment of laboratory geophysical and geotechnical tests was strongly applicable to predict the basic geotechnical properties with particular reference to moisture content and density.

Acknowledgements

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