CORRELATION OF ELECTRICAL RESISTIVITY WITH UNCONFINED COMPRESSIVE STRENGTH , C_u FOR SANDY SIZE PARTICLES

By

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ABSTRACT

Stability and the integrity of the ground area of many constructed and natural structures have been the key studies of geotechnical engineering. Implementing soil investigation in order to precisely determine the engineering properties of the soil that made up the ground area is crucial for a proper design and successful construction of any structures. Geotechnical investigation, in typical conventionally means would involve borehole sampling and many tedious methods which are costly, time-consuming and invasive to ground area. Alternatively, geophysical method of surveying subsurface rocks in ground area provide more rapid, cost effective, convenient and non-invasive as substitute mechanism. Geoelectrical survey provides attractive mechanism as its shows promising relation with many geotechnical parameters of the soils. In addition to that, we also benefited from its feature which can evaluate spatial and temporal variation of moisture and heterogeneity of subsoil. However, in order to employ such means for geotechnical investigation, study must be done to see the correlation of soil parameter with the soil electrical resistivity, which is the fundamental concept of geoelectrical survey. We can later predict the soils proportion and behaviour based on electrical resistivity parameter. Despite many study done on many geotechnical parameter of the soil with its correspond resistivity value, there are lack of study that determine the correlation soil strength parameter with it resistivity value. This research particularly aimed to establish the correlation of electrical resistivity with unconfined compression strength, c_u. Another essential aim of the research is to study the relationship of other soil geotechnical parameter, such as moisture content, porosity and saturation of sandy size particles with the resistivity value. Soil samples were prepared at certain moisture content and applied with different number of compaction blows. We then tested the soil's electrical resistivity tests and its unconfined compressive strength.. All the pertinent data were collected and analysed. The results of the tests illustrate crude but distinct relationship between electrical resistivity and unconfined compressive strength, c_u of the soils. The increment of soil resistivity shows the similar pattern to the soil unconfined compressive strength. We later observed similar interaction of the selected parameters (moisture content, number of compaction blows, saturation) with the soils resistivity value. Overall results showed as the resistivity in soil increases, the moisture content decrease. The increment in resistivity also shows the increment in saturation rate and compaction blows number.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Stability and the integrity of the ground area of many constructed and natural structures have been the key studies of geotechnical engineering. These structures for example are bridges, dams, building and roads would be whether lies within or made up of significant ground area. The engineering properties of the soil that exist within these ground area principally influence the soundness of these structure's strength or its foundation stability. In this subject matter, Cosenza et al. (2006) mentioned that for the purpose of obtain proper design and successful construction of any structure, it is important to precisely determine the engineering properties of soil. Therefore, in many structures project, site investigation done would include soil investigation where these engineering properties, among other soil properties would be determined.

The conventional method of geotechnical investigation would include the soil boring, in-situ testing, sample acquisition and laboratory testing. As stated by both Pozdnyakov and Pozdnyakova (2002) conventional methods of soil analysis in high sampling density would be costly and time-consuming, which also require disturbing soil, extract the soil sample, test and analyzing the sample in laboratory. In conclusion, the conventional method is not only invasive, both time and cost consuming, but also complicated and tedious. While the importance of soil investigation found to be paramount before project commissioning and already had become a necessary routine, the conventional method however, due to its complexity and expensive nature ,had rarely being adopted for the structure maintenance purpose. On the other hand, it is common knowledge that there are possibilities that soil properties and even the soil proportions could undergo significant change in particular site area, which could jeopardize the structures stability.

In order to make geotechnical investigation to be more convenient, a new mechanism should be proposed and studied its efficiency in predicting the engineering properties of soil, at least.

Geophysical method, in contrary would be handier, cost-effective, non-destructive, and take significant shorter time methods, as it already being used to survey engineering site profile. Geophysical method usually categorize to a few different mechanisms such as geoelectrical survey, ground penetrating radar, seismic refraction analysis and etc.

According to Syed and Farhan (2012) among these various approach, geoelectrical method which use the science of electric (potential difference, resistance, resistivity) shows apromising features which could replace the conventional method of soil investigations. Electrical resistivity survey is one of the basics mechanism in geoelectrical approach, commonly used for the mean of imaging sub-surface structures which would profile the soils and rocks at particular surveyed area. As mentioned by Samouelian et al. (2004) , electrical resistivity survey has been widely applied to do fault investigation, ground table investigation and soil moisture content test ,groundwater exploration, and also landfill and solute transfer delineation. The very basic concept applied is as electrical current flux go through any materials, in which conductor materials like metal would show distinct electrical data reading than insulating materials like air, woods and plastics. This somehow told us that every material would differ to one another due to their discrete electrical properties nature. Soil, which is considered among the insulating material would also show distinctive electrical properties, electrical resistivity for instance in which they depends on both chemical and physical properties.

1.2 Problem Statement

The conventional methods of soil investigation which usually required borehole sampling and laboratory analysis found to be destructive to ground area, costly, time-consuming and tedious. Geophysical method, particularly geoelectrical approach shows potential feature to replace the conventional method. In order to do so, there must be some equations or relationship established between electrical properties with engineering properties of soil. As one of the distinct electrical characteristics used to categorize different material, electrical resistivity was used. On the other hand, sandy soil can be found abundantly anywhere across the world.

In addition, in some occasion it was found that contractors or the public will face some risk if they made significant portion of ground area and also certain types of sandy soil exhibit some harmful properties. Due to the fact that sandy soils posses these mentioned features, the selection sandy soil particle as the soil sample for this project is right and important decision to be made. Consequently we can address some serious issue that happened at big scales due to the abundance and drawback nature of sandy soils.

On the other hand, as one of the engineering properties of the soil, unconfined compressive strength usually determined to derive undrained shear strength of the soil. So, this research were about to find the correlation of electrical resistivity of the sandy soil particle and its relative unconfined compressive strength which were to be analyzed from unconfined compression strength test. In addition to that, the correlation of its electrical resistivity with relative saturation, porosity and under different rate of controlled moisture content was observed to ensure the consistency of the correlations.

1.3 Objectives.

This overall project was conducted to determine the relationship of certain geotechnical properties of sandy soil with the electrical resistivity under certain controlled parameters. In order to establish correct relation, pattern of resistivity variation and its relative different geotechnical parameter's must be observed and analysis quantitatively and qualitatively. The specific objectives of the objectives of this project are listed as:

- To determine the correlations between of electrical resistivity and its unconfined compressive strength of soil for sandy size soil particle.
- To study the relationship of electrical resistivity under controlled moisture content and number of compaction blows with other pertinent geotechnical parameters such as porosity and saturation.

1.4 Scope of Project

Project is carried out in order to observe and establish the relationship of geotechnical properties, unconfined compressive strength particularly, beside others, of sandy soil with its relative electrical resistivity. The sandy soil samples (L2B20) were procured from Kaolin Malaysia Sdn. Bhd. in Kuala Lumpur. Test sample later prepared using different moisture content (25%, 30%, 35%, and 40%) which later, using Standard Proctor test method and Proctor compaction machine , different number of compaction blows (15, 25, 35, and 45) applied to the soil sample. Then the soil sample will be extruded in order to obtain the soil specimen, which later would tested to determine it unconfined compressive strength using unconfined compression strength. During the overall procedure, the steps to obtain the soil sample porosity and saturation also taken.

1.5 The Relevancy of the Project

The purpose of this project is to determine and establish the correlations between electrical resistivity and sandy soil's strength parameter, which is unconfined compressive strength. Study of the correlation of geotechnical parameter with the relative soil's electrical resistivity is not new but there are yet very few studies which specifically focus on soil strength properties. These mentioned strength properties would later determine bearing capacity and factor of safety of ground area which are the key features that determine soil strength and stability. Anticipating the soil strength properties may help us prevent geotechnical failure which commonly led to tragic disaster such as landslide due to slope failure and the collapse of building due to sinkhole or settlement of ground level.

Replacing the conventional method with rapid and cost effective geoelectrical survey could contribute significantly in this subject matter. This is why it is important to determine and establish this mentioned correlation of electrical resistivity with relative geotechnical strength parameter if the geolectrical method were to be used as an alternative to conventional geotechnical surveying methods.

Hence, understanding and establishment of the correlation between electrical resistivity of soil which is a basic mechanism in geoelectrical survey, and its pertinent geotechnical properties, soil strength properties specifically is remarkably significant. In depth understanding of this correlation, further studies could establish a correct mechanism and accurate procedure to predict soils properties and soil proportions with its corresponding electrical resistivity. Therefore, with this project we would one step closer to utilize electrical resistivity survey as an alternative to conventional method in order to carry out geotechnical survey.

1.6 Feasibility of the Project within the Scope and Time Frame

This project began by collecting reading material such as books and journals, for more insight on the study of the subject matter, which is electrical resistivity survey and test, geotechnical properties of soil priority to strength parameter of soil, sandy size soil particle , unconfined compressive strength and the relevant correlation of these . It was expected that for Final Year Project (FYP) 1, author should be able to grasp the gist of the said matters and come out with a comprehensive methodology and approach to establish stated correlation. Preliminary laboratory sessions also were carried out during these periods to give author the general idea and deeper understanding about the project study. Meanwhile for FYP 2, the project focused on conducting the laboratory test and analyzing the data in order to establish the mentioned correlation of electrical resistivity with the unconfined compressive strength of sandy soil particle.

CHAPTER 2

LITERATURE REVIEW

2.1 Geotechnical Investigation

In common practice for any structure construction project, site investigation would regularly necessary and carried out before the commencement of design and construction of the project. Site investigation specifically briefed as investigation of the physical characteristics of the site which usually include site documentary and information studies, site surveys and ground investigation. One important element in ground investigation is which the composition, index and engineering properties of soil in particular soil area were to be determined. As mention by Cosenza et al., (2006) accurate finding of soil engineering properties would result in well designed and proper undertaking of construction project. In similar subject matter Moh (2004) remarked that geotechnical failures which occurred due to defect in ground investigation would sometimes led to cataclysmic disaster and imposed serious threat to public safety.

Conventional geotechnical ground investigation typically would require borehole sampling, soil sample acquisition, in-situ testing and laboratory analysis. The typical disadvantages associated with these typical procedures are it really tedious; time consuming, expensive and complicated. This is indirectly actually could lead to geotechnical failure of the project.

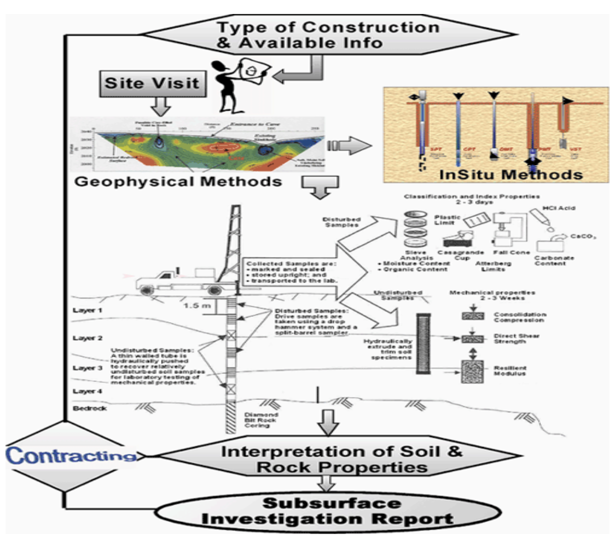


Figure 2.1.1 Common methodology of Rock and Soil Investigation

Figure 2.1.2 Common Borehole Sampling Procedure

Correct mechanism of soil investigation is crucial in order to gain information which crucial for designing the structures. Due to the expensive nature and its other disadvantages, conventional geotechnical investigation technique indirectly contributes to geotechnical failure. In this subject matter, Baars (2011) had remarked in his study of major geotechnical disaster, the principal reason led to such geotechnical failure as quoted that “lack of available knowledge or willingness (incompetence) at the designing part of the construction management” in which he stated there are lack of time and money as common example. In order to verify his reason, he mentioned 10 major geotechnical disasters all over the world. In addition to that, Moh (2004) also pointed out that the cost have become decisive factor for many contractor in appointing soil investigator. In his case study which specifically focused on construction in Singapore, Malaysia and Hong Kong, the pattern shows that majority of the consultant would hire SI contractor and geotechnical consultant on the basis of cheaper cost.

Singapore metro tunnel collapse

Train station building pit collapse, Köln

Peat dike failure, Wilnis

Collapse water defense system of New Orleans

Figure 2.1.3 Major Geotechnical Disasters All Over the World. ***Baars (2011)***

2.2 Electrical Resistivity

Both A. Pozdynakova and L. Pozdynakova (2002) mentioned that electrical geophysical test would allow rapid measurement of soil electrical properties contrary to conventional soil method analysis which are costly and time-consuming. One of paramount mechanism in electrical geophysical is the usage of electrical resistivity indication of rocks and soils. Syed and Fahad (2011) briefed that electrical resistivity is the measure of soil resistance to the current flux flow that pass through it when potential difference or voltage applied to the soil strata. Samouellian et al. (2004) remarked that the very reason why electrical resistivity survey and test were preferred among many of geophysical method of soil testing is that the fact which the electrical resistivity properties shown promising correlation with soil properties. They also specifically mention that because the ever-changing nature of soil in certain areas, it is vital to adopt periodical soil testing to identify its characteristics so we can quantified the harm it posses at certain relative time. So, we can directly conclude that making the soil testing feasible is undeniably crucial.

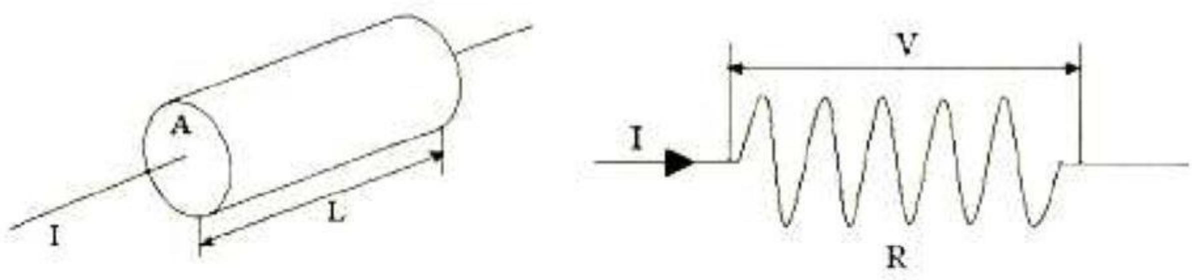


Figure 2.2.1 The schematics of cylindrical section and flow of current

Different composition of soil and soil types which structures built on or consist of typically required different approach in the design. The needs for soil strengthening and drainage also may be differing and varies. Yamamoto et, al. (2009) had studied that different type of soil would required different type of foundation. They also explicitly state that both loose sand and dense sand required distinct type of foundation. In addition to that, different ground area even the one that have same composition but different density would posses different strength-related characteristics (bearing capacity, failure mechanisms).

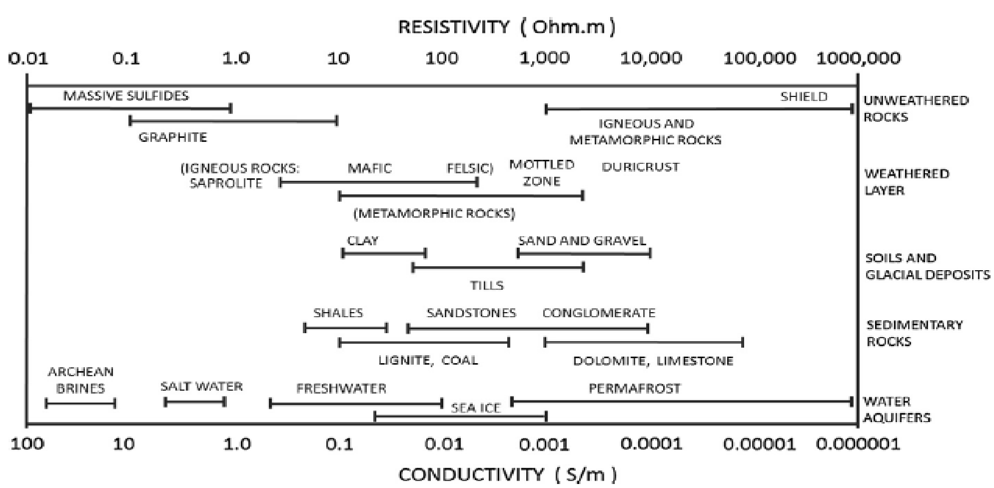


Figure 2.2 2 Typical range of electrical resistivity value of soil

Consequently it is only right to assume that every characteristic of ground area must be accurately derived to enable well design structure. So, with the establishment of new method which lies in foundation of electrical resistivity, the soil testing method could be carried on easier and rapidly which later would appeal the responsible parties to adopt a correct practice of soil investigation and reduce the geotechnical failure occurrence.

Previously, there were quite a number of extensive study had being done to correlate electrical resistivity of soil with its properties. Yoon and Park (2001) described that electrical resistivity of sandy soil depend largely on water content and electrical water properties of pore water rather than its unit weight and types of soil. Other than that there were studies which determine the hydraulic conductivity of compacted clay liners using electrical resistivity method (McCarter, 1984 and Abu-Hassanein et al., 1996), and also structural heterogeneity of soil (Seger et al., 2009).

Despite notable number of studies being done and even a few, succeed to correlate the soil characteristics and some geotechnical parameters with its pertinent electrical resistivity, Syed and Siddiqui (2010) point out that none of these research done to study its relations to soil strength properties. Due to direct relation of the soil strength parameters (cohesion, internal angle of friction) with its bearing capacity and factor of safety which strongly linked to ground stability ,it is important for researchers to start the studies on the correlation of electrical resistivity test with these strength parameters.

2.3 Factors Affecting Electrical Resistivity of Soils.

2.3.1` Soils Particle Arrangement, Chemical and Physical Constituents.

Before commencing with the laboratory testing , collecting and analyzing pertinent data to our project, it was paramount for us to understand how many features and factors that exhibited by the soil could affect the magnitude of soil’s electrical resistivity. In addition, another vital information that we should take note into is that all these soil components influence the electrical resistivity of certain soil portion at different degree, some peculiarly at greater degree compared to the others. Another concern that may somehow affect our project is that the fact that certain parameter that we controlled in the project could still demonstrate variance, and also the fact that these parameters influence one another could make it more complicated for us to establish a different unique independence correlation of electrical resistivity with particular soil parameter. For instance, rate of compaction blows theoretically would reduce soil's void ratio which somehow could affect the porosity and the soil's strength parameter, but the degree of these parameter's influence are varied; either towards the soil's resistivity value or towards each other (soil parameters).

Among these soil parameters that contain some relevant effect towards electrical resistivity of the soils are the moisture content of the soil, mineralogy, particle size distribution, voids arrangement, conductivity and even the electrical resistivity of the fluid that filled in the soil's void. Particle size distribution and the voids arrangement can dictate the porosity and the pore size distribution of the sandy soils, which later, theoretically could influence the resistivity of the sandy soil. Generally, if the air filled the void ratio, the resistivity of the soils would be higher (compared to be more compacted soils or the void filled with water). This tend to occurred due to fact that air dominantly known as insulator medium, at which the electrical charges will face difficulty to flow across the medium. Previously, there were numerous study that being done to correlate these mentioned parameters with the soil's relative electrical resistivity value.

2.3.2 Electrical Resistivity with Soil's Moisture Content

One of the major findings in this particular matter is that how the soil's electrical resistivity had primarily influenced by the water content in the soil. The success of such study had allowed to establishment of ground water detection mechanism utilizing ground penetrating radar methods. Gunn et al. clearly stated that, both soil heterogeneity and moisture content contribute significantly to the electrical resistivity of particular ground area. In their research, where they mainly utilized electrical resistivity tomography to do resistivity imaging in particular ground area, they been able to construct volumetric water movement and moisture content changes over the ground area. Specifically, the particular ground electrical resistivity value is influenced by the amount of moisture stored within the pore space and the ionic distribution across the soil grain surfaces. This is due to the fact these two soils feature that made up the ground area predominantly affect the ability of electrical charges to flow across the ground media. We can expect for the sands and gravels, that the electric current would flows across the non-conducting grains through ionic migration within the saturating fluid that filled the voids between soils.. A clear relationship has been established between resistivity in sands and gravels and various other factors so an accurate measure of resistivity can lead to the calculation of key soil parameters, particularly pore water saturation, and therefore moisture content.

2.4 Unconfined Compressive Strength

Unconfined compressive strength commonly derived using unconfined compressive test. Unconfined compression test basically is an unconsolidated undrained (UU) test where there is no lateral confining pressure (atmospheric pressure) would be exerted to soil specimen. It is chosen due to the fact that this test is by far the most frequent method used to determine soil shear strength parameter. This is maybe because the nature of the test which is fastest and cheapest methods in order to derive soil shear strength. Typically the testing method would primarily used saturated, cohesive soils recovered from thin-walled sampling tubes. It is not wise if the sample were to be used are dry sands or crumbly clays because the materials would fall apart without some land of lateral confinement.

These are among the many of significant reasons why unconfined compressive strength (UCS) used as the parameter that to be correlated with electrical resistivity of soil:

- UCS derived from unconfined compression test which is quickest test to obtain the shear strength parameters of cohesive (fine grained) soils in both undisturbed and remolded state.
- UCS determined from strain controlled test in which the soil sample is loaded rapidly, the pore pressures undergo changes that the water do not have enough time to dissipate
- UCS is representative of soils strength behavior in construction sites where the rate of construction is very rapid that the pore waters do not have enough time to dissipate
- UCS provide an estimate of the relative consistency of the soil

• UCS is important parameter in most geotechnical engineering designs (eg. design and stability analysis of foundations, retaining walls, slopes and embankments) due to the fact it give rough estimate of the soil strength and viable construction techniques

• UCS is vitally important to determine Undrained Shear Strength or Undrained Cohesion (Su or Cu) = qu/2.

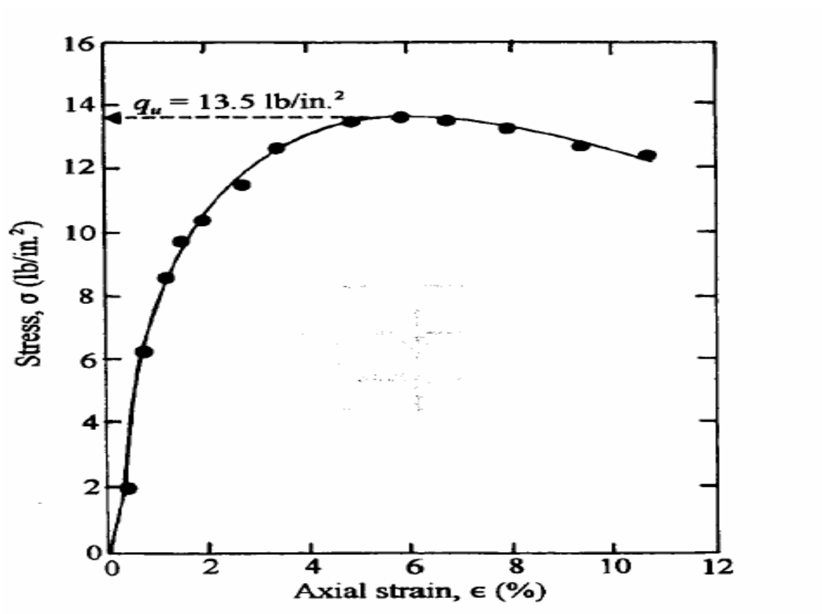


Figure 2.4 Typical stress vs strain plot from unconfined compression test

2.5 Sandy Size Soil Particle

As for the type of soil size sample that we would tested, sandy soil particle type were chosen as we can found abundantly in any ground area anywhere in the world. Identify the sandy soil proportion would be crucial to analyze and design the most suitable foundation were to be chosen and if soil strengthening would be necessary if the sandy soil proportion or its peculiar characteristics (ground water table, moisture content) contain significant risk to structure's stability. As the characteristics of sandy soil, both chemical and physical properties of sandy soil particle are also varies widely, it is crucial to anticipate the problem it may contained. Both coastal and desert area, for instance, are the areas which constituents of sand are highly significant, and also where the foundation problem commonly occurred. This problem may arise due to the ever-changing nature of sandy soils in these particular areas which exposed greatly to weather influence.

Both Gordon (2012) and Stipho (1984) respectively mentioned ,in each coastal and desert area where sand dunes can be found frequently, particular area brought serious hazard to foundation if exposed to significant weather effects. Sand dunes are a general features in both coastal and desert areas which generally consist of unconsolidated or poorly consolidated sand. In addition to that, these mentioned fact are still not accounted for the effect of sandy soil proportion in ground area at cliff ,slopes and hilly areas which may also contains serious risk to pertinent structure.

CHAPTER 3

METHODOLOGY

As the project concern principally on studying and establish the correlation of unconfined compressive strength of sandy soil with its pertinent electrical resistivity at very basic level, there are many factors shall be accounted and also some foundation of geotechnical engineering and soil behavior knowledge must be considered. Other than that, in order to establish the correlation, the consistency of the soil sample shall be established first as omission of such element could led to error in data analysis and correlation derivation. The soil which contain distinct characteristic (moisture content, porosity) would be tested for its electrical resistivity value and then its unconfined compressive strength and these both parameters dependency of its other soil parameter, moisture content, for instance, should be observed and studied. Method of preparation of soil sample in laboratory rather than in-situ retained soil sample is adopted to increase the consistency of the methodology and reduce the disambiguity.

3.1 Project Flows

Objective of this project is to observe and establish the correlation between unconfined compressive strength of sandy soil and its other geotechnical properties with electrical resistivity. Sandy soil samples were bought from the supplier. Laboratory testing on the soil sample which prepared according to certain moisture content, were conducted to determine unconfined compressive strength optimum dry unit weight porosity and saturation. Electrical resistivity testing was conducted after the soil compacted and prior to other laboratory testing to determine the correlation of geotechnical properties with the soil resistivity. In general, the research methodology is shown as below.

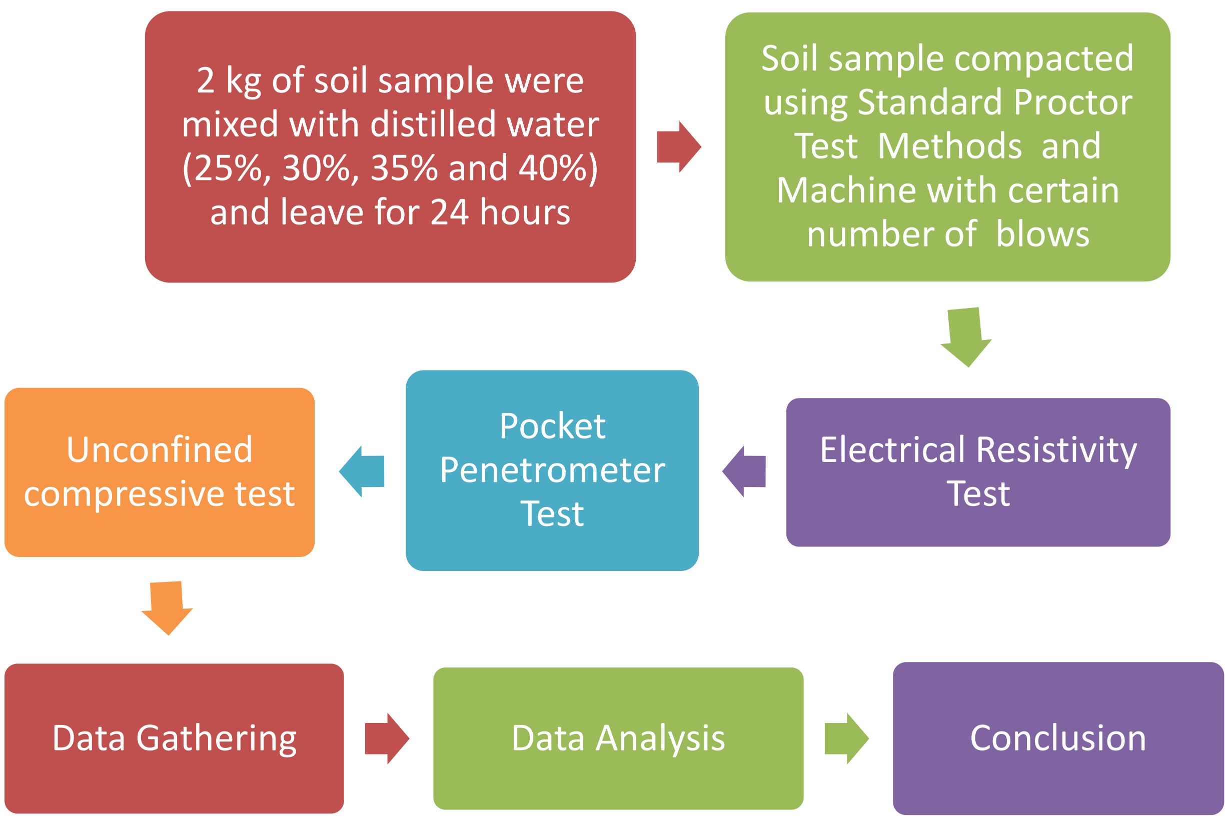


Figure 3.1 Research methodology

3.2 Soil Sample Preparation

1. 2 kg of soil sample were put into mixer bowl.
2. For 25 % soil moisture content , using measuring cylinder, distilled water in mass of 25 % of soil mass (500 g) is poured to mixer bowl.
3. Roughly mixed the sandy soil with the distilled water using trowel.
4. Mixer bowl putted into soil mixer machine, the soil sample mixed thoroughly using the machine.
5. Mixer bowl properly covered with plastic sheet, which then left for 24 hours.
6. After 24 hours, soil sample were to be compacted using Standard Proctor Compaction method

Figure 3.2 Soil Mixer

3.3 Standard Proctor Test Compaction Procedure:

Apparatus

- Proctor mould with a detachable collar assembly and base plate.
- Standard Proctor Machine.
- Sample Extruder.
- A sensitive balance.
- Drying Oven

Procedure

i. Determine the weight of empty proctor mould without the base plate and the collar.
ii. Measure the dimension of the mould (diameter and length)
iii. Fix the collar and base plate. Line the mould with plastic sheet.
iv. Place the first portion of the soil in the Proctor mould and compact the layer applying 25 blows.
v. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent.
vi. Place the second portion of the soil in the Proctor mould and compact the layer using the machine applying 25 blows.
vii. Place the third layer of the soil in the Proctor mould which at least up to half level of the collar mould.
viii. Compact the soil with Proctor machine up to 25 blows.
ix. The final layer should ensure that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
x. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil leveling to the mould.
xi. Determine the weight of the mould with the moist soil .

3.4 Electrical Resistivity Test Procedure:

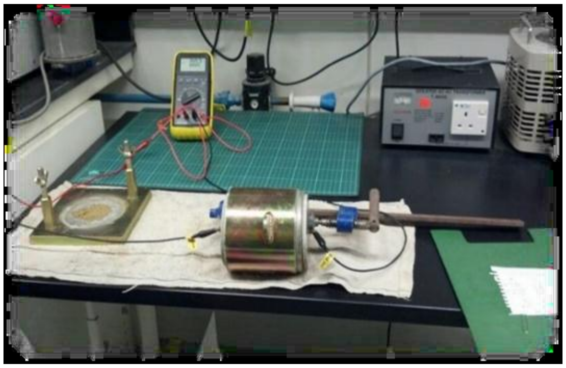


Figure 3.4 Laboratory Set Up for Soil Resistivity

i. The mould together with the soil specimen in it was to be tested for electrical resistivity test using disc electrode method.
ii. Soil in the mould was placed between two circular aluminum electrodes.
iii. The specimens then along with aluminum disc were connected to both positive and negative terminals of a DC power supply and also connected to a multimeter .
iv. Disconnect the wire first, DC power supply then would be adjusted to 30 Volt potential difference. The power supply then switched off.
v. Complete the circuit with connecting the wire according to its correct terminal.
vi. Switch on the power supply,
vii. The immediate resulting current value in milliampere were then recorded.
viii. Repeat the test for 60 Volt and 90 Volt Potential Difference
ix. The electrical resistant and resistivity of the samples were calculated using formula

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

$V = Voltage\ , Volt$

$I = Current\ reading, Ampere$

$R = Resistance\ , \Omega$

$$\rho = R \times \frac{A}{L}$$

$\rho = Electrical\ resistivity\ value$

$R = Resistance$

$A = Cross\ Section\ Area\ of\ Soils$

$L = Length\ of\ the\ Mould\ or\ Soil\ Sample$

3.5 Unconfined Compression Test Procedure:

i. Extrude the soil sample from the mould from previous experiment. Cut a soil specimen so that the ratio (L/d) is approximately between 2 and 2.5.Where L and d are the length and diameter of soil specimen, respectively.

ii. Measure the exact diameter of the top of the specimen and also the exact length of the specimen.

iii. Weigh the sample and record the mass on the data sheet.

iv. Carefully place the specimen in the compression device and center it on the bottom plate. Adjust the device so that the upper plate just makes contact with the specimen and set the load and deformation dials to zero.

v. Apply the load so that the device produces an axial strain at a rate of 0.5% to 2.0% per minute, and then record the load and deformation dial readings on the data sheet at every 20 divisions on deformation the dial.

vi. Keep applying the load until (either one first)

    a. the load (load dial) decreases on the specimen significantly
    b. the load holds constant for at least 3 deformation dial readings

vii. Take photo to show the sample failure.

viii. Remove the sample from the compression device and obtain a sample for water content

Gantt Chart (FYP II)

Activities Week	**Week No/ Date**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Laboratory Session and Data Acquisition															
Data Analysis															
Submission of Progress Report								**9/7**							
Data Validation with Previous Research															
Pre-SEDEX															
Submission of Draft Report															
Submission of Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation															
Submission of Project Dissertation (Hard Bound)															

Current Progress

Table 3.6 Gantt Chart

Chapter 4

Results and Discussion

For all the laboratory session, data acquisition must be carried out through the means of laboratory analysis, only later the data analysis can be performed. Consequently, correct establishment of correlation of sandy soil sample's electrical resistivity and its pertinent unconfined compressive strength can be proposed. In addition, author also can carry out data validation to verify the reliability of the data attained. Following are the overall data from all the laboratory tests.

:

Moisture Content (%)	**No. of Compaction Blows**	**Porosity, n**	**Saturation, S (%)**	**Resistivity, ρ (Ωm)**	**Unconfined Compressive Strength, (kN/m^2)**
15	15	0.41	58.32	97.92	35.74
	25	0.44	86.94	74.56	28.77
	35	0.49	98.94	81.43	30.79
	45	0.57	100.00	90.44	26.08
20	15	0.40	79.80	49.68	91.79
	25	0.44	68.08	82.15	88.33
	35	0.45	68.08	95.33	89.76
	45	0.49	65.23	94.53	87.98
25	15	0.43	90.13	64.70	78.19
	25	0.42	93.22	35.22	32.03
	35	0.41	96.67	52.75	51.89
	45	0.40	100.00	62.47	49.90
30	15	0.44	84.23	14.57	21.66
	25	0.46	95.99	19.84	12.55
	35	0.46	93.01	48.55	14.63
	45	0.47	90.50	51.97	9.87
35	15	0.49	97.60	31.06	5.12
	25	0.50	92.19	39.97	3.73
	35	0.48	99.94	43.85	6.07
	45	0.48	100.00	40.26	4.55

Table 4.1 Overall Data

This project primarily aimed in establishing the correlation of sandy soil resistivity with its pertinent shear strength parameter, specifically unconfined compression strength. In addition to that, the research also purposed to see the relationship of the soil's resistivity with other sandy soil parameters too. One should bear in mind, as the project would involved multiple variable, both controlled and manipulated, the best manner to observe and analyze the relationship is to represent the data in certain unique way. Authors had chose to maintain one or a few of the variable at constant value while synthesize the desired correlation of different parameters. For instance, if the author were to observe the dependency of electrical resistivity towards number of compaction blows, the moisture content should be kept at the same value.

Thus, the correspondence change to the sandy soil resistivity value as the compaction blows number varied can be effectively determined. However, for the sake of deeper understanding the research objective, where the author want to determine whether the similar pattern of can be traced at different moisture content, the numerous correlations that unique to particular moisture content would be represented in one graph. Another important aspect of this research that one should bear in mind is that all these parameters studied are not entirely independent to one another, so while we try to determine the trend of the correlation of the certain intended parameters, other parameter may limited or greatly dictate the interaction pattern (though control measures have been adopted). This case obviously demonstrated when the author try to determine some of the correlation (saturation with electrical resistivity for instance) but the moisture content had greatly affected the sandy soil resistivity value.

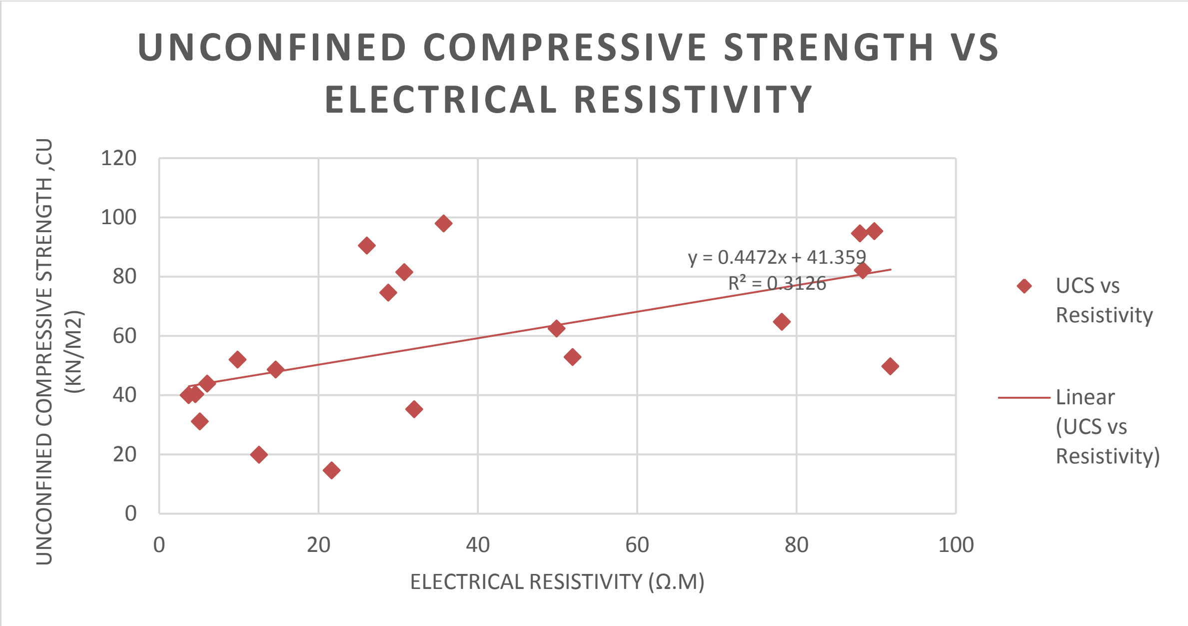


Figure 4.1: Graph of Unconfined Compressive Strength vs Electrical Resistivity

As described briefly in the project title and the project objectives, this overall research project was primarily purpose to study and establish the correlation of unconfined compressive strength of sandy soil particle with the soil's electrical resistivity value. From the graph we can see direct but crude relations between the sandy soils electrical resistivity value with its pertinent unconfined compressive strength. All the different soils data are accounted ,which the soils are prepared for various moisture content of the soils and different compaction blows applied to the soils, which later help diversify the soil's unconfined compression strength . The trend line of the data shows that the resistivity values of the sandy soils are linearly increased as the unconfined compressive strength increase. Regression value have been calculated for this particular interaction and recorded at 0.3126, which subsequently tell us that the correlation is particularly crude but shows direct rise for both c_u and its relative electrical resistivity value.

Another important point to take note are the data that closely fit to the trend line can be observe mostly when the electrical resistivity value are between 0 to 17 Ω where the unconfined compressive strength ,c_u recorded at range of 25 to 55 kN/m^2 . As the trend line climbing for the consequent increment of the data, the exact data fall in scatter pattern, inconsistent and a little far from the trend line. The consistency of the data can later be observed in higher data distribution where the c_u falls within range of 80 to 100 kN/m^{2,} while the resistivity observed at value of 88 to 92Ω. These important features of the correlation should be address for further and deeper study. In addition to that, another laboratory methodology to test the soil's electrical resistivity could be implemented foe subsequent study and to test the data consistency and reliability.

Following are the similar chart, but the correlation is now defined uniquely to certain particular moisture content. This method of interpreting the graph cold helps us to see how different moisture content could affect the correlation. We later may figure out, at which extend that the moisture content govern the interaction of unconfined compressive strength, c_u with the sandy soil electrical resistivity.

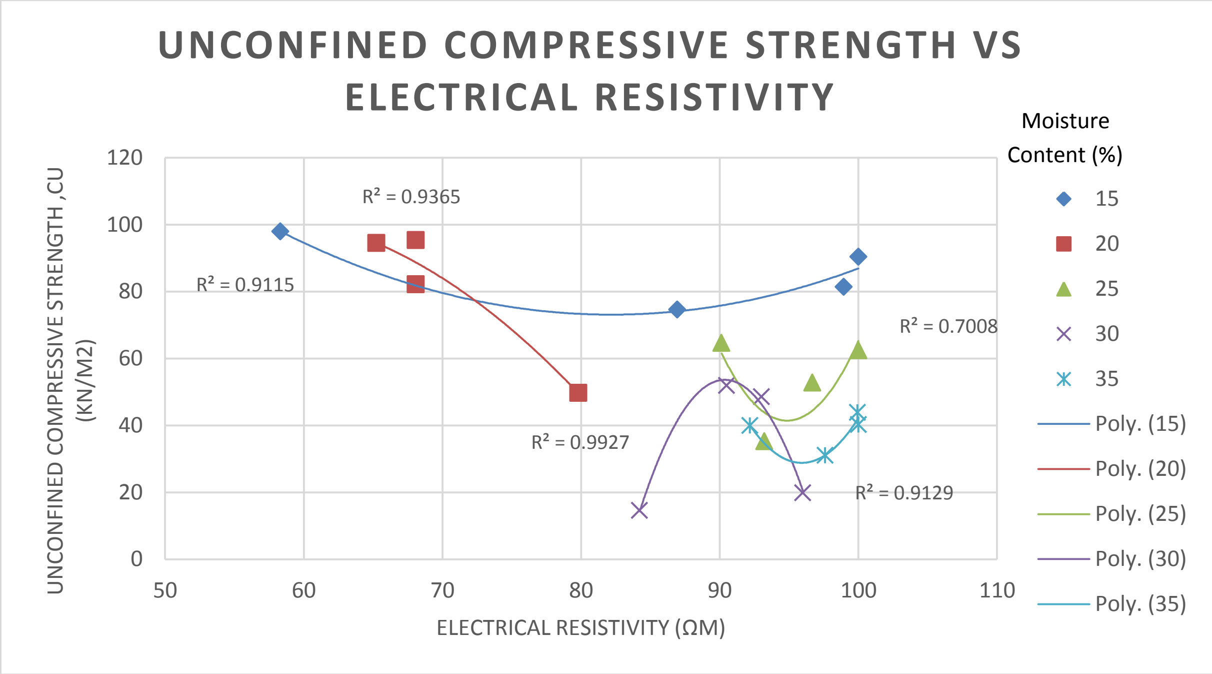


Figure 4.2: Graph of Unconfined Compressive Strength vs Electrical Resistivity Unique to Certain

From this graph, we may derive that at different moisture content, the strength of the relationship of unconfined compressive strength with its relative soil electrical resistivity likely to be varied. Sandy soil which prepared at 35 % moisture content, highest percentage of moisture content shows most inconsistence in the correlation. In addition to how low the electrical resistivity value of the sandy soil prepared at this moisture content, the increment pattern also very crude. This is somehow proving our theory that the moisture content is the most governing factor of the soil's electrical resistivity. The regression value found to be 0.1, significantly less than other correlation. (Note: Defined, direct correlation would produce the regression value 1 and stronger the correlation closer the regression value to 1)

Other than that, we can also recognize that the consequent weak correlation is illustrated by the trend line of sandy soil that prepared at 15 % moisture content. So, the correlation also found to be very irregular if the sandy soils found to be very dry. One conclusion that we could recognize is the fact that the sandy soil that too wet or too dry may subjected to discrepancies if we were to predict the soil strength parameter utilizing any electrical resistivity mechanism. Besides, this outcome of the research contain large potential for further studies and development if we want employ the electrical-resistivity-based survey to predict sandy soil strength behavior.

Another essential observation that illustrate by the numerous correlation in the graph is that for the soils that contain medium percentage of moisture content, not too wet or dry, shows more reliable correlation The sandy soils with 25% moisture content posses highest regression value at 0.6952 shows strongest interaction between the sandy soil's $c_{u,}$ strength parameter with its relative electrical resistivity value. While the sandy soil samples that prepared at both 20 % and 30% moisture content shows quite reliable relationship of the two parameters, demonstrate the regression value at 0.6573 and 0.4361 respectively.

Another parameter that we want to determine the correlation that it posses with the sandy soil electrical resistivity parameter, is the moisture content of sandy soil. Following is the chart:

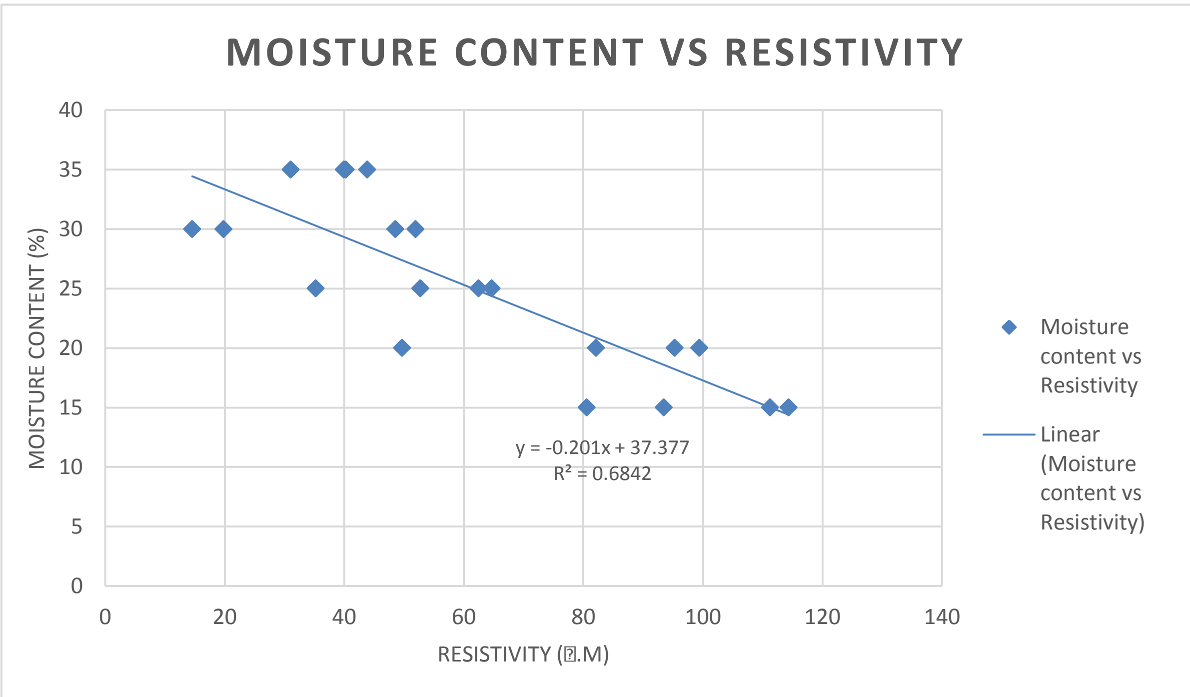


Figure 4.3: Graph of **Moisture content vs Resistivity**

The graph shows the correlation between the moisture content at which sandy soil sample were prepared and its corresponding electrical resistivity value. The graph somehow portrays the similar trend with many of the previous research which stated that the increment of moisture content could particularly decrease the soil's resistivity value. Generally, the fluid that usually filled the pore spaces in the soils medium, despite the soil particle size, would have distinct lower resistivity value than the soils itself. So, the increment of moisture content in the soil, which also means the increment of the fluid in the soils, would enable the electrical current to flow comparably easier across any soil portion. The correlation also calculated at significantly high regression value, 0.68 which tell us that the relationship between these two parameters is peculiarly strong. Other important derivation that we can point out from the graph is that the distribution of the data is relatively consistent across various soil resistivity values. This could supported the idea that moisture content is the major factor that rules the soil resistivity value, as this graph shows no clear distraction and limitation of data distribution.

While we already analyzed how the electrical resistivity of the sandy soils sample behave with the respect of different moisture content in the soil prepared, we now would interpret the similar correlation ,but now the interaction is characterized to different compaction blows.

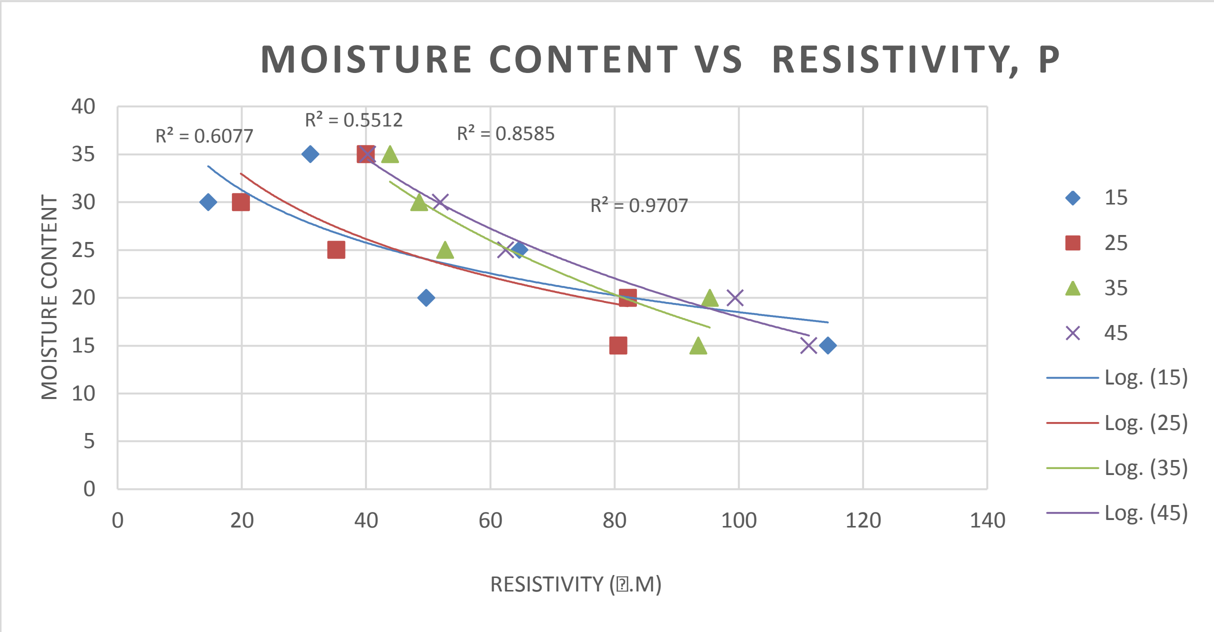


Figure 4.4: Graph of **Moisture content vs Resistivity Uniquely to Different Moisture Content**

As per the graph above, we can learnt that the soils that prepared at 35 %, despite applied with different number of compaction blows, is notably have consistent data distribution. So, we could conclude that, even for sandy soils, at certain extend (which moisture content significantly high) , the moisture content could be the only dictating parameter that influence the soil's resistivity behaviour. Subsequently, as the moisture content uniformly decrease to 30 %, we can see the resistivity value temporary decrease for both 15 and 25 compaction blows but increase for both 35 and 45 compaction blows. The pattern however changed for consecutive decrease of the soils moisture content, the soils were all shows increment in electrical resistivity as the moisture content decrease, confirm many of the established theories from previous research.

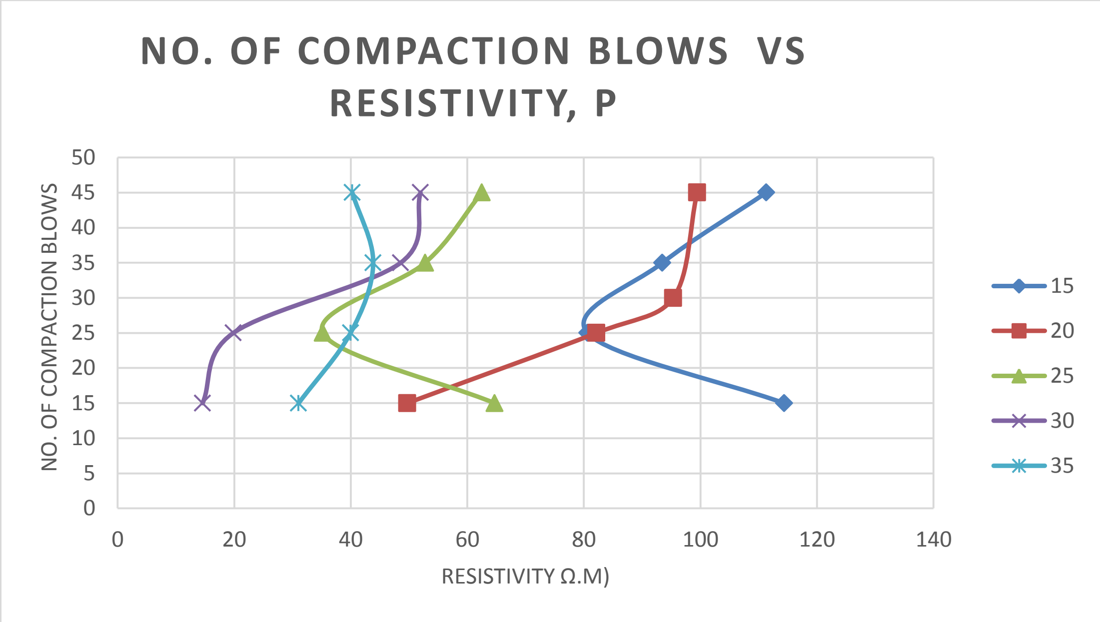


Figure 4.5: Graph of **No. of Compaction Blows vs Resistivity, ρ**

The above graph, on the other hand, shows more irregularities in the data distribution and also the correlation between the number of compaction blows and the electrical resistivity of the soils is cruder. Theoretically, as the number of compaction blows increase, the voids between the soils would decrease and resulted in consequent increase to soils resistivity value. This graph would shows such trend, if we were to put exception to soil resistivity value for 15 number of compaction blows, where the resistivity value found to be distribute in very wide range. For, 15 and 25 moisture content, the soils resistivity value at 15 compaction blows found to be higher than it supposed to. Such cases may happen due to the moisture content still dictated the resistivity reading of the soils, and the compaction may still exhibit minimal influence to soil resistivity value.

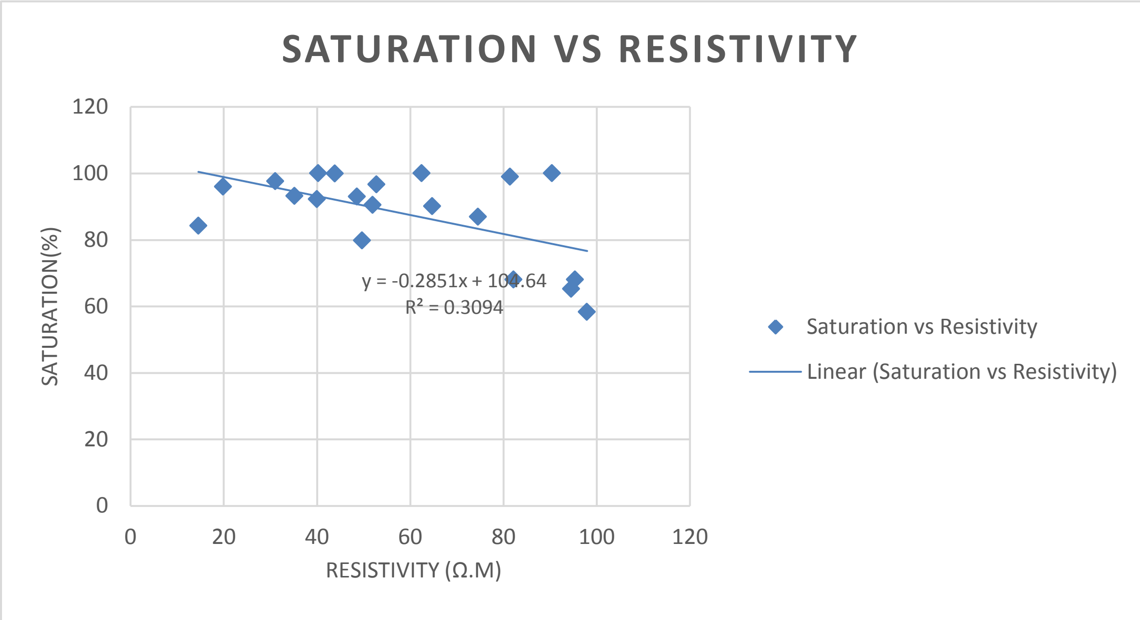


Figure 4.6: Graph of Saturation vs Resistivity

Other vital geotechnical parameter of the soils that we need to determine its correlation with electrical resistivity across the soil sample is the sandy soil saturation. From the graph that we can see the correlation is exist, though the regression value is relatively low, calculated at 0.3094.

The pattern shows that the electrical resistivity of the soils shows decrement for soils with higher saturation. Another important detail of the chart that we need to take note is the data shows irregularities for higher saturation data distribution.

This phenomenon likely to happen due to the fact that the soil saturation percentage tends to rise as the moisture content of the sandy soils increase. As we already point out, the soil moisture content would tend to reduce the resistivity of the sandy soils if the moisture content found to be higher. The data discrepancies for high value of resistivity may happen due to the fact that the numbers of compaction blows also tend to influence the resistivity value of the soils.

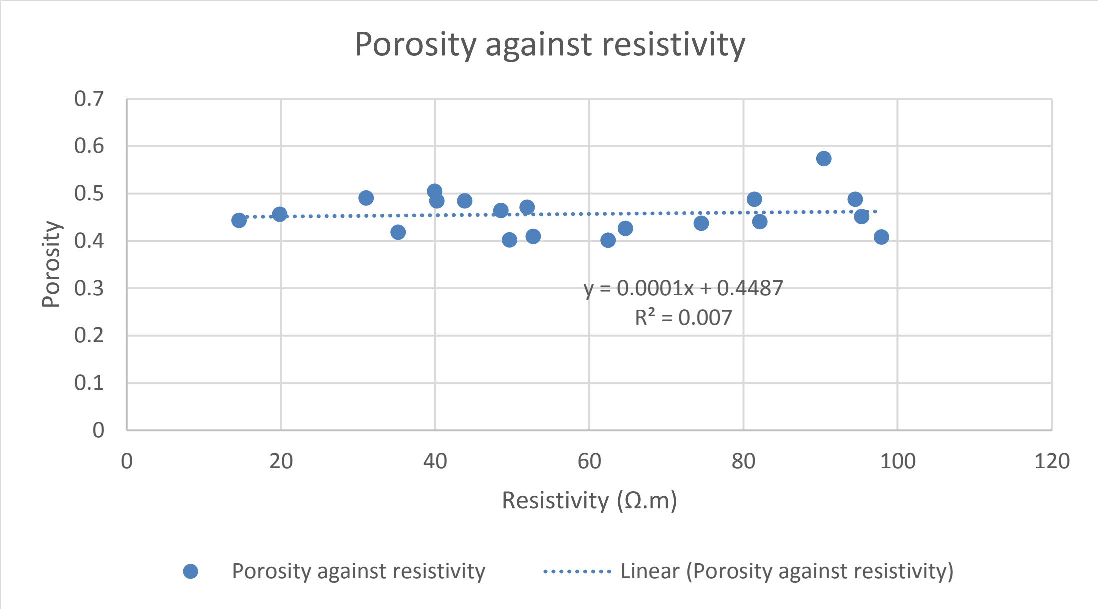
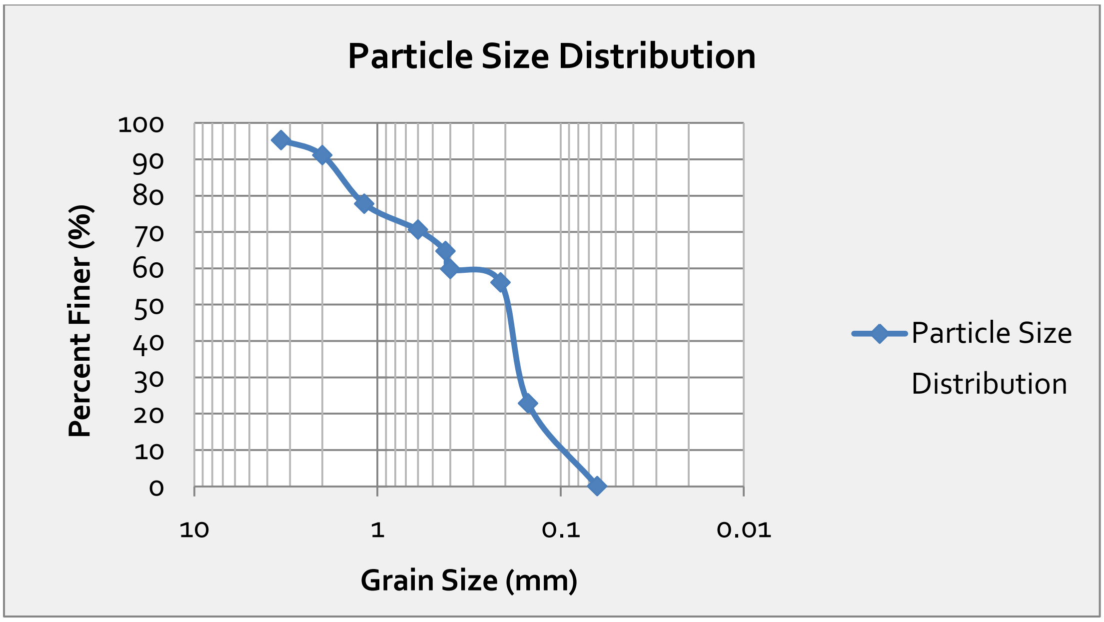


Figure 4.7: Graph of **Porosity against Resistivity**

Last but not least, we try to find out the correlation that sandy soil porosity parameter posses with its respective soils resistivity value. The correlation of both of these parameters established from this research project found to be remarkably weak. The regression value calculated also found to be significantly low, at 0.007. The porosity of the soil sample is closely related with the space between the soils particles. So, the reduction in porosity supposedly increases the resistivity value of the sandy soils. The trend line shows that the increase was distinctively steep (almost flat pattern). This very occurrence might happen due to there are more dominant parameter that influence the soil resistivity value.

While following are the particle size distribution of the soil sample:



From the PSD graph it was found that more than 90 percent of the soil particle fall in sandy size soil particle distribution category. In addition to that following are the Atterberg's limit of the soil to conform the particle size of the soil.

Plastic Limit = 30.25

Liquid Limit = 48

Plasticity Index =18.25

According to AASHTO, the soil was categorized as A-2-6 Plastic or Slightly Sandy Loam Soil. There are minimal presence of clay soil particle

Following are the porosity and saturation calculation sample of one of the sandy soil sample tested:

Moist Unit Weight, $\gamma = \frac{Weight\ of\ Compacted\ Moist\ Soil}{Volume\ of\ the\ Mould}$

= 1.83 kg / (0.001) m^3

= 18.36 kN/m^3

Porosity, n:

$\gamma_B = G_s \cdot \gamma_w (1-n)(1+w)$

19.12 = (2.68) (9.81) (1-n) (1+0.25)

19.12 = (26.29) (1-n) (1.25)

0.58 = 1-n

n = 0.42

Saturation, S:

$\gamma_B = G_s \cdot \gamma_w (1-n) + nS\ \gamma_w$

19.12 = (2.68)(9.81)(1-0.49) + (0.42)(S)(9.81)

3.87= 4.12S

S = 0.93

Chapter 5

Conclusion

This project introduces the establishment of correlation of electrical resistivity with soil shear strength-related parameter, which is unconfined compressive strength at the fundamental level. In order to achieve reliable data and result, the student had choose to test the sandy soil with standard similar particle size and prepared at controlled moisture content and also compaction blows. These combinations were used to attained different unconfined compressive strength, c_u of the sandy soils. We later attained the corresponding value of the soil resistivity value. Other than that, the porosity and saturation parameter of the soil sample also analyzed and observed for its interaction with the soil resistivity parameter.

As per the data collection and data analyzing in FYP II, the author found out that there were crude but distinct correlation between the unconfined compressive strength of the soils and its corresponding resistivity value. On certain extent, as briefed in result and discussion section, the soils will shows inconsistent correlation if it was too wet or too dry. If this particular aspect of the soils were to be addressed in later studies, clear correlation may be derived. In addition to that author also found out that the resistivity value also decrease if the moisture content were to be increase, confirm many of the findings from previous research. While, as per the interaction of number of compaction blows with its resistivity value, with the exception of 15 compaction blows, the correlation is found to be existed but very weak . Analysis of saturation value also made us discover that the resistivity value also influenced by this parameter, and similarly with other parameters interaction, moisture content fond to be dominant influencing factor.

From the research, we attained crucial data and discover a few important phenomenon of the correlation of many soil parameter, particularly soil's unconfined compressive strength with the soils resistivity value. As described, unconfined compression strength of the soils is important soil strength parameter that help geotechnical engineer to assess the ground condition or/and design required structure foundation. The author hopes that with such effort, we would be one step closer to employ electrical resistivity survey to predict soil strength behavior. Besides, commencement of this study of correlation electrical resistivity with soil strength properties is important to initiate the trend among researchers to do wider and deeper research on this particular subject matter. Another essential point is that with availability of the attained data, it could help largely in enhance extensive research on the fundamental level of soil strength parameter with its relative electrical resistivity. This is later could contribute significantly to realization of geoelectrical survey in being alternative choice to time-consuming and costly conventional soil investigation. Establishment of such correlation could assist the process of predicting the shear strength parameter of soil based on its electrical resistivity profile.

Thus, the project had manage to achieve its objective to determine the correlations between electrical resistivity and its unconfined compressive strength of sandy size soil particle and also study the relationship of electrical resistivity under controlled moisture content and number of compaction blows with other pertinent geotechnical parameters such as porosity and saturation.

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