A LABORATORY STUDY OF ELECTRICAL RESISTIVITY AND CONSOLIDATION PROPERTIES OF KUANTAN BAUXITE DEPOSITS

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ABSTRAK

Di Pahang, bauksit menjadi bencana ekologi yang bermula dari tahun 2015 hingga sekarang. Keluaran tahunan bijih bauksit Malaysia telah meningkat daripada lebih 200,000 tan pada tahun 2013 kepada hampir 20 juta tan pada tahun 2015, menjadi pengeluar utama dunia dan menyumbang hampir separuh daripada bekalan kepada industri aluminium besar China. Impak potensi dijangka melampaui persekitaran fizikal dan penyakit fizikal jika keadaan tidak terkawal. Penyatuan tanah dilaporkan secara meluas oleh arus perdana dan media sosial. Isu kejuruteraan asas atau masalah bangunan sedia ada di tanah lembut menjadi lebih dahsyat Konsolidasi tanah berlaku apabila volum perubahan dalam tanah tepu disebabkan oleh pengusiran air liang dari pemuatan. Menurut Karl Terzaghi penyatuan adalah sebarang proses yang melibatkan pengurangan kandungan air tanah tepu tanpa penggantian air melalui udara. Penyelidikan ini akan menjalankan ujian makmal tentang sifat rintangan dan penyatuan elektrik dari deposit bauksit Kuantan. Lokasi sampel bauksit untuk ujian diambil dari Bukit Goh, Indera Mahkota dan Semambu. Dari setiap lokasi, lima sampel diambil untuk diuji. Ini bermakna sebanyak lima puluh sampel dari semua lokasi dinyatakan.

ABSTRACT

In Pahang, bauxite become an ecological disaster which start from 2015 until now. Malaysia annual output of bauxite ore has increased from over 200,000 tonnes in 2013 to nearly 20 million tonnes in 2015, becoming the world's top producer and accounting for nearly half of the supply to China's massive aluminium industry. Potential impacts are expected to go beyond physical environment and physical illness if the situation is not controlled. Consolidation of soil was widely reported by mainstream and social media. The issue of foundation engineering or the problem of existing buildings on soft ground become more terrible Consolidation of soil occurs when volume changes in saturated soil caused by the expulsion of pore water from loading. According to Karl Terzaghi consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air. This research will carry out laboratory test about electrical resistivity and consolidation properties of Kuantan bauxite deposits. The location of the bauxite sample for testing is taken from Bukit Goh, Indera Mahkota and Semambu. From each location, five samples are taken to be tested. This means that total of fifty samples from all location stated.

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(KΩ)	Kilo ohm
Ω.m	Ohm meter

CHAPTER 1

INTRODUCTION

1.1   Background of Study

The existence of bauxite in the Kuantan area, Peninsular Malaysia was first recognized by the Geological Survey in 1937 (Fitch, 1952). The area of interest lies in the neighbourhood of Kuantan in the states of Pahang and Terengganu. It is easily accessible via the highway to Kuala Terengganu, the new Kuantan bypass, and roads to Sungai Lembing, Bukit Goh Estate and Jabor Valley Estate.

Bauxite is a weathered rock containing two forms of hydrated Aluminum oxide. These oxides are either predominantly monohydrate or trihydrate, and the bauxite will usually have additional Fe_2O_3 as the main impurity. They are often disposed in nearby dumps, not adhering to environmental regulations. In the building industry, recycling of waste materials is environmentally friendly. It is because they re-use them as starting materials for engineering applications.

Red Mud is a solid by product in the production of alumina by alkaline leaching process called Bayer process. Many researchers had found various applications of Red Mud and some of them are, special cement preparation, iron powder recovery, clay liners stabilizers and construction grade brick.

In both cities and the countryside, selection of sites with the best soil is an important engineering decision in the building process. Whether live in a house, condo, or apartment, our home is connected to the soil. School, the building where we work, the stores we shop in all of them are built on soil, and often with it.

1.2   Problem Statement

In Pahang, bauxite become an ecological disaster which start from 2015 until now. Malaysia annual output of bauxite ore has increased from over 200,000 tonnes in 2013 to nearly 20 million tonnes in 2015, becoming the world's top producer and accounting for nearly half of the supply to China's massive aluminium industry.

Potential impacts are expected to go beyond physical environment and physical illness if the situation is not controlled. Consolidation of soil was widely reported by mainstream and social media. The issue of foundation engineering or the problem of existing buildings on soft ground become more terrible.

Consolidation of soil occurs when volume changes in saturated soil caused by the expulsion of pore water from loading. According to Karl Terzaghi consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air.

In general, it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume.
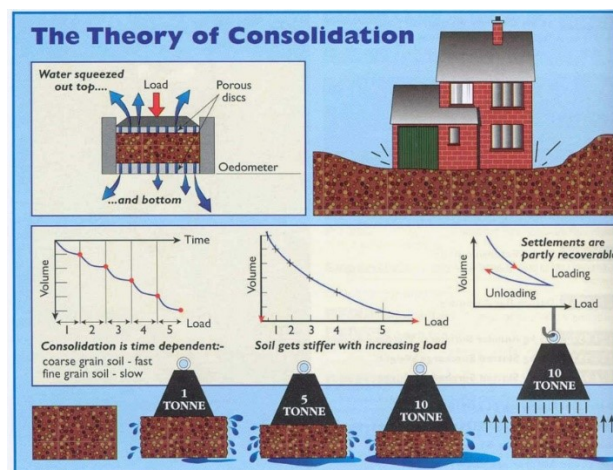
Figure 1.1: Theory of consolidation.

1.3   Objective of Study

The objectives of this study is to determine the electrical resistivity and consolidation properties of Kuantan bauxite . Furthermore, this study was conducted to determine the relationships between electrical resistivity and consolidation properties of bauxite possible source and processing effects on bauxite residue behaviour.

1.4   Scope of Study

This research will carry out laboratory test about electrical resistivity and consolidation properties of Kuantan bauxite deposits. The location of the bauxite sample for testing is taken from Bukit Goh, Indera Mahkota and Semambu. From each location, five samples are taken to be tested. This means that total of fifty samples from all location stated.
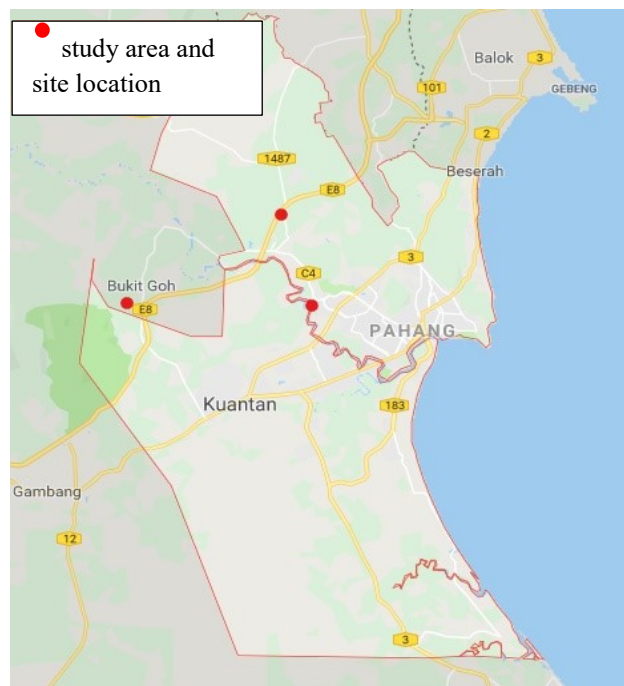
Figure 1.2: Location of bauxite.

The sample of bauxite was tested according to the test below:

   i.   Soil consolidation test

  ii.   Electrical resistivity test

1.5   Significant of Study

The importance of this study is to prevent soil consolidation or reduce the effect of soil consolidation that may effects the building on the bauxite. The consolidation properties of bauxite can be determined during the laboratory test.

The soil consolidation test to control the density and moisture content of soil fill to reduce settlement, ensure flexibility in earthfill dams, improve bearing capacity and insure uniformity in an earthfill.

Significant of electrical or direct current methods to determine the bulk resistivity of subsurface of bauxite to determine geologic structure subsurface of bauxite. An electrical current is introduced directly into the ground through an evenly spaced string of current electrodes. Soundings can be used to determine the depth and thickness of subsurface layers, depth to the water table, and bedrock.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

The information about bauxite and previous studies that related to this research topic will be explained in detailed in this chapter. Besides that, the consolidation properties and electrical resistivity were also reviewed in this chapter.

2.1   Bauxite

Bauxite, which is known as the chief ore of aluminium, can be said is the main aluminium source in the world (Brown et al, 2015). Basically, bauxite can be practically be described as typically soft (Mohs Hardness: 1-3), white to grey to reddish brown of combination in colour, clay- material and low specific gravity. It is discovered that the presence of iron materials in bauxite contributes to its reddish brown colour. Normally, a concentric structure will be shown in the particular ore that occurs in rounded grains or in pisolitic which normally range 1-2mm to more than 2cm in size. Bauxite is a rock that forms from leached silica laterite soil and another compound in a humid tropical or subtropical climate and not a mineral.

Based on (Hind et al, 1999), bauxite is said to be the ore which aids the production of alumina and aluminium. The conversion of bauxite using the Bayer process which was first patented and developed by Carl Josef Bayer in 1888. The

bauxite will be refined before being converted to smelting grade alumina which is the precursor to aluminium in Bayer process (Hind et al 1999). It will then be followed by the digestion process of bauxite with sodium hydroxide in the Bayer process which will then yields red mud as its product.

Basically, red mud is mainly composing of fine particles that involves the mixture of silica, aluminium, calcium, iron, titanium and hydroxides together with other minor components which includes the iron impurities that are responsible for the brick red colour of the mud (Hudson, 1982). However, bauxite is relatively danger due to its high contains of calcium and sodium hydroxide and can cause serious pollution hazard (Hind et al, 1999).

Generally, bauxite is found in abundance at many places around the world which comprises the location of those major commercial deposits are found. This includes countries such as Australia, China and Brazil (Brown et al, 2015).
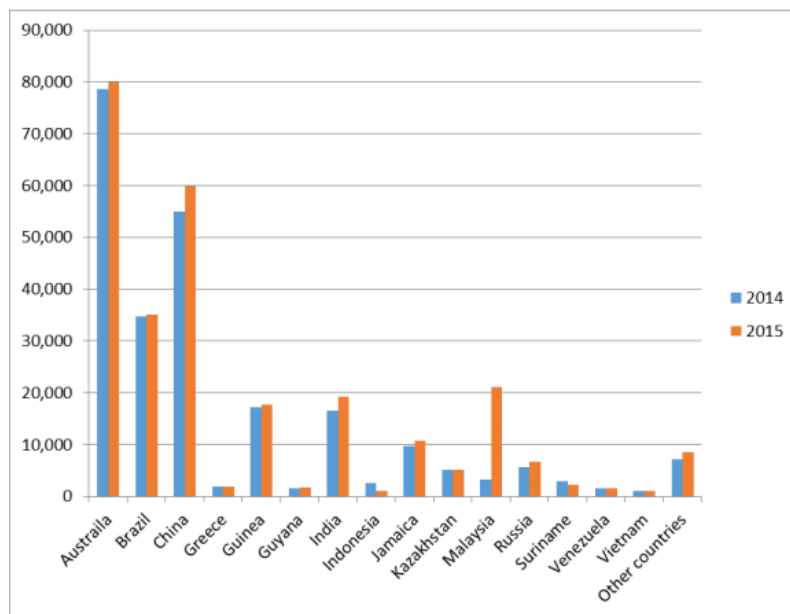
Figure 2.1: Amount of bauxite produced by country in 2014 and 2015.

2.1.1 Bauxite Production

As we know nowadays, bauxite is produced by mining process. The process of mining was existed since thousands years ago. These processes have been started in many areas. Usually, a type of mineral which is known as flint, were easily be made into weapons and equipment to be used in the mining of bauxite process. Long time ago, the extraction process of minerals and mining process took places by using traditional methods. Then, it was improvised to get a higher outcome. The mining process had become the creation stage of the fund chain for most all products produced by bauxite and the minerals that obtained through mining process are then be used in the manufacture of everything from stapler to superstructure. Currently, mining has grown exceedingly into a massive industry, and thus producing abundance of people a job opportunity to feed themselves. This gives a big advantage in advertise economic growth in countries rich in natural resources (Topstad & Karlsen, 2015).

In 2009, Australia becomes the top producer of bauxite with approximately one-third of the world's production. It was being followed by China, Brazil, India and Guinea. Most of the world's aluminium today is mined from lateritic bauxite deposits (Bell, 2001; Buultjens et al., 2010). Other countries with large reserves include Vietnam, Guinea and Jamaica (Brown et al, 2015) Compared to other types of bauxite ore.

A new report issued by BMI research states that global bauxite production growth will accelerate over the coming years as new projects come online in Australia, India's production ramps up, and Indonesia re-enters the market following the end of the mineral ore export ban. According to the firm, Indonesia is bound to become a big player as it reclaims its share of bauxite exports to China. BMI says that the relaxation of the ban on bauxite exports has allowed companies to step back into the market with a stronger foot. In July 2017, the government allowed PT Dinamika Sejahtera Mandiri to export 2.4mnt of bauxite, and in September 2017 PT Laman Mining received an annual export quota of 2.9mnt of bauxite.

2.1.2 Bauxite Process

The Bayer process is the principal industrial means of refining bauxite to produce alumina. Bauxite, the most important ore of aluminium, contains only 30–60% aluminium oxide ($A1_2O_3$), the rest being a mixture of silica, various iron oxides, and titanium dioxide. In the late 1888, Karl Josef Bayer had developed and patented a process. This process has become a new discovery of the world aluminium production industry that we have nowadays. Typically around 1.9 to 3 tonnes of bauxite is required to yields 1 tonne of alumina depending on the quality of the ore itself.

In Bayer process, the bauxite will be refined before being converted to smelting grade aluminium (Hind et al, 1999). It will then be followed by the digestion process of crushed bauxite in concentrated sodium hydroxide solution at temperature up to 27 Celsius. This allow most of the aluminium containing element in the ore will be dissolved and thus leaving an insoluble residue which is known as red mud as its end product. Basically, red mud is mainly composing of fine particles that include the mixture of aluminium, calcium, silica, iron and titanium and hydroxide together with iron (Hudson, 1982). Red mud will then be extracted by settling or filtration process. Gibbsite will be precipitated after solids separation process by cooling the solution and seeding it with gibbsite. The extraction depends on the chemical processes that occur at the solids/ aqueous interface. All the process above can be summarized as shown in figure 2.
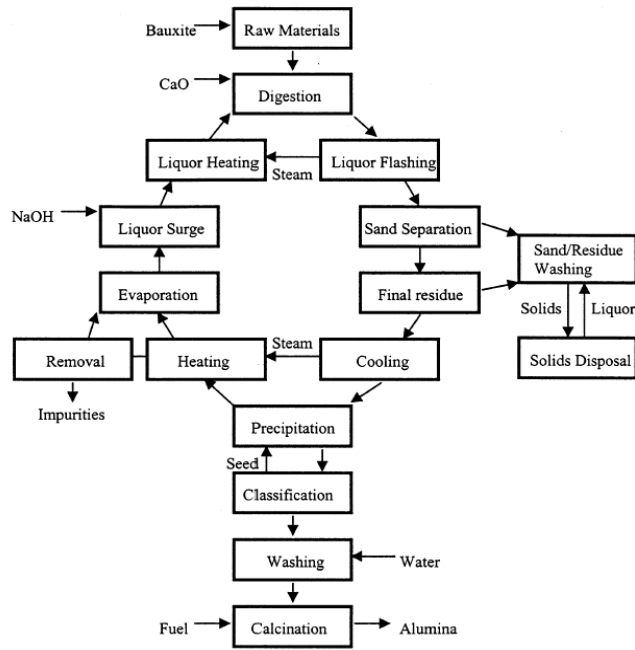
Figure 2.2: The representation of Bayer process.

However, there are some major distinctive negative effects found in Bayer process during the gibbsite precipitation stage as shown in figure 3 below. If it left uncontrollable, the oxalate in Bayer liquor will accumulate to the level of supersaturation before being crystallised in an acicular.

2.2   Consolidation

When fine grained soil mass subjected to compressive stress, it exhibits compression in a number of ways which include rearrangement of soil particles, extrusion of pore water (Das, 2013). The arrangement of soil particles under compressive loading is known as compaction which occurs in both coarse–grained and fine grained soils. Through compaction, the fine grained soil reduces its voids through pore water dissipation under compressive loads and settles with time. This is known as consolidation which is a time-dependent phenomenon in fine-grained specifically in the clayey soil. Usually, when compressive loads are applied in saturated clay, excess pore water develops due to the low permeability of the clayey soil. With time, pore water from the soil voids starts to dissipate. As a result, the void space of the soil reduces and cause soil settlement. Traditionally, the consolidation of the clay soil is determined using the odometer testing, after collecting soil samples from the site location. However, collecting soil samples from the field and testing it in the laboratory involves significant time and cost. On the other hand, developing an alternative technique using geophysical testing to investigate the consolidation properties may provide preliminary consolidation properties and help to reduce the testing time and cost.

Researcher such as Barden and Sides (1970) modified a conventional odometer and conducted consolidation tests on soil samples under different suctions. They used the axis translation technique to create the desired suction in the sample. In this test, the lateral deformation of the sample was confined and the volume change was obtained only in vertical direction (AR Estarbragh et al, 2017). In isotropic consolidation the sample is compressed isotropically to a normally consolidated condition by increasing the mean net stress. The increasing mean net stress (applied load) is usually carried out by step loading or ramp loading. Cui and Delage(1996).

2.3   Factors Affecting the Rate of Consolidation

The first factor that can cause consolidation of soil is its permeability. An increase in permeability of the consolidating soil would lead to an increase in the rate of seepage flow, other factors remaining constant. With the greater rate of expulsion of water from the soil the pore pressures will dissipate more rapidly. This means that a more rapid rate of consolidation occurs (Barron, R.A., 1948)

Furthermore, a greater compressibility leads to a greater decrease in the void space of the soil for a particular stress change. This means that a greater volume of water must be expelled from the soil and this will require a longer time (Barron, R.A., 1948). Consequently, a lower rate of consolidation will result. Moreover, an increase in the layer thickness leads to a decrease in the total head gradient during the stage of pore water expulsion. It also means an increase in the volume of water to be expelled and both of these effects lead to a lower rate of consolidation (Biot, M.A., 1941)

The presence of drainage boundaries through which water may be expelled has a significant effect on the rate of consolidation. If drainage layers exist on both sides of a consolidating layer (doubly drained) the rate of expulsion of water will be greater than in the case where one drainage layer only exists, the other side being an impermeable layer (singly drained). Consequently, a consolidating layer which is doubly drained will consolidate at a faster rate than one which is singly drained (Das, B.M., 1985).

2.4   Determination Coefficient of Consolidation

When it is required to predict the time rate of settlement of soil in the field, it is necessary to know the coefficient of consolidation, CV and the appropriate boundary conditions. The oedometer test with vertical flow of water only is applicable to one dimensional consolidation problems which are encountered in situations where a wide surface load is placed over a relatively thin compressible stratum. There are two commonly used methods for the determination of the coefficient of consolidation from oedometer data. These are known as the logarithm of time fitting method and the square root of time fitting method. With these methods the experimental deflection - time plots are fitted to the theoretical degree of consolidation - time factor curves.

Firstly, with log-time method the experimental data for a particular load increment is presented on a deflection - log (time) plot. The theoretical degree of consolidation - time factor curve is plotted in a similar pattern. With the theoretical curve the initial and final points are known but this cannot be said for the experimental curve.

Once the ordinates corresponding to U = 0.0 and U = 1.0 are known, intermediate values may be determined. The U = 0.5 (or 50%) point on the curve is normally selected for the calculation of coefficient of consolidation. The time factor T50 corresponding to 50% consolidation is 0.197. The actual time t50 corresponding to 50% consolidation may be read. The coefficient of consolidation CV, may then be calculated from the equation defining the time factor.

2.5   Electrical Resistivity

Electric resistivity is a measure of how strong a material opposes the flow of electric current (Boykov, 2006). Electrical current flows through the earth material, by either or both electrolytic conduction and electronic conduction methods (Telford et al, 1990). In electronic conduction methods, the current flow takes place via free electrons and is dependent on the rock's mineral composition. The presence of conductive minerals such as metal sulphides and graphite is rarely insufficient concentration to have a considerable effect on the electrical properties of host rock.

Electrical resistivity is known to have the widest range of values among all the physical properties of rock. In some cases, the values vary by several orders of magnitude in the same rock type (Grant and West, 1965). The wide range of rock's resistivity parameter has always presented a challenge to uniquely identify a subsurface rock type, if no other information on the geology of the area is available. The engineering behavior of rocks depends on intrinsic properties such as mineralogical composition, cementing material, grain size and shape, texture, and porosity (Behrestaghi et al., 1996). In addition, rock electrical properties are sensitive to the nature and amount of pore saturant, pressure, alteration, and temperature. The amount of the pore saturant and its nature and microstructural properties are the most significant factors (Boykov, 2006).

The pore structure of the rock also significantly influences its behavior in terms of its strength. (Choi et al.2006) investigated the effect of rock mass parameters such as joint thickness, joint condition, joint spacing, intact rock strength, and RQD on the resistivity. They compared analytical and experimental test results and found a strong correlation between resistivity and rock mass classification. Brace et al. (1965) and Brace and Orange (1968) tested electrical resistivity of several igneous rocks and limestone. They showed that resistivity increases sharply as confining stress is increased with increasing pressure. Other studies indicate that electrical effects could be manipulated in order to reduce the wear on the cutting tool by reversing the flow of electricity from the work to the tool (Bobrovski, 1966).

2.6   Resistivity measurements

The resistivity of rocks varies tremendously from one material to another. For example, the resistivity of a good conductor such as copper is in the order of 10^{-8} Ω m, and the resistivity of poor conductors such as sandstone is ~ 108 Ω m. Due to this great variation, measuring the resistivity of an unknown material has the potential for being very useful in identifying that material (Herman, 2001). Electrical resistivity is used to determine the depth of groundwater, the presence of mineral deposits and cavities, and numerous environmental and engineering applications.

There is also a large variability in measuring the electrical resistivity of intact rocks, since it is sensitive to properties such as porosity, the amount of pore saturant, temperature, and pressure surface conduction (Roberts et al., 2001). DC and AC methods with a four point probe,i.e. Wenner measurements, are widely applied to measure the surface and volume resistance of rocks (Le et al., 2011). Similar site testing conditions can also be obtained in the laboratory by taking into consideration the few conditions.

In order to reliably determine the electrical properties of rocks in laboratory, the points listed below should be considered. Core or block shaped samples could be used for the tests. However, the dimension of the samples should be selected in appropriate sizes. The length of the sample could be the same as the core diameter. However, as the length of the sample is increased, the magnitude of the current should also be increased.

2.7   Factors Affecting Electrical Resistivity

Electrical resistivity of soil is affected by several factors such as moisture content, mineral content, soil types, sizes, fluid contents, porosity, temperature and many more.

2.8   Determination of Soil Electrical Resistivity

In Geotechnical investigations in situ (Mondelli et al., 2012) and in laboratory (Adli et al., 2010) the electrical resistivity method has been extensively applied. This means that electrical resistivity laboratory test comprises with the consolidation test in laboratory. According to (G.Kibria etc al., 2018) by tradition, the consolidation of clay soil in laboratory involves more time and cost. However, an alternative technique were developed using geophysical testing to determine the consolidation properties and help to decrease the time and cost.

Based on (Sahadat Hossain etc al., 2018) electrical resistivity is an indirect method, which can be used to categorize pore structure of geo physical. The advantages of using this method are easier sample preparation, non insentivity, and representation of bulk samples (McCarter and Desmazes 1997). Furthermore, electrical resistivity also provides important information about consolidation properties of the soil.

2.9 Electrical Resistivity Measurements at Different Consolidation Stages

According to (G.Kibria et al.,2018) electrical resistivity at various consolidation stages was measured using the Super Sting R8/IP equipment. In this method, the electrodes were placed in the cell. And the annular pores were sealed to prevent loss of water. The inside wall of the modified oedometer was lubricated to reduce friction loss during consolidation. A dial gauge was attached to monitor the settlement of the soil specimen during the consolidation tests.

Four undisturbed soil samples were tested. The soil samples were trimmed at a dimension 25mm (height) x 63.5mm (diameter). Three days were needed for the soil specimen to be saturated before starting the consolidation tests. The loading range of 200-800 kPa was set to conduct the consolidation test in the air valve, with an increment of 100kPa. The induced load should be mentioned in the soil sample. The electrical resistivity was not change significantly before adding to the cell and after drainage.

The results showed that the kaolinite as a dominant mineral in which 1:1 layers are electrically neutral and contain less surface charge (Meunier, 2005). Therefore, it was predicted that the voltage drop in electrode was the same to the soil specimen. It is because during consolidation and current measurement the specimen was in contact with the electrodes. The process shown in Figure 3
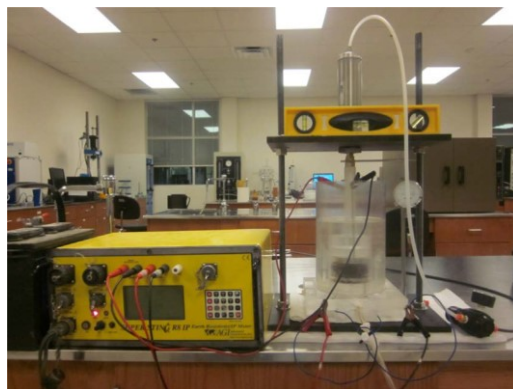
Figure 2.3: Laboratory set up for electrical resistivity at different consolidation stages

2.10   Gap of study

From the literature review, it is seen that the researchers had used same concept of electrical resistivity and consolidation properties of soil. The researchers also highlight the relationship between electrical resistivity and consolidation at different stages. The difficulty of the tests has been clarified earlier in previous section. In this gap of research section, the variations between these researches with the previous research are being underlined. Equipment called the Precision LCR Meter is used in determining the soil profile of the soil sample. While for consolidation Odometer is used in determining the rate of settlement of the soil.

From the table 2., the gap of study between the previous researches and this research is that the previous study focussed on the consolidation using traditional method only while this study emphasise on the consolidation properties of soil using electrical resistivity test. The previous researches mostly correlated with the environmental problems. Different with the current study that investigate the bauxite deposit use for engineering purposes such as a foundation soil therefore this study on consolidation and electrical resistivity is important to be conducted.

Table 2.1: Summary of previous researches

Author	Year	Title	Remarks
Golam Kibria., Sahadat Hossain., Mohammad Sadik Khan.	2018	Determination of consolidation properties using electrical resistivity	The relationship between consolidation and electric resistivity was determined
Adli, Z. H., Musa, M.H. and Arifin, M.N.K.	2010	Electrical Resistivity of Subsurface: Field and Laboratory Assesment	The electrical resistivity method in field and laboratory
Okan Su., Moe Momayez.	2017	Indirect estimation of electrical resistivity by abrasion and physico-	To know the properties of rock and soil using electrical resistivity

		mechanical properties of rocks	
A.R. Estabragh., M. Moghadas., M. Moradi., A.A. Javadi.	2016	Consolidation behavior of an unsaturated silty soil during drying and wetting	Know the consolidation behaviour of the soil

CHAPTER 3

RESEARCH METHODOLGY

3.1   Introduction

The soil samples were tested for its essential soil properties and electrical resistivity. The samples were taken from three different places. Figure 3.1 below are summarization of the research
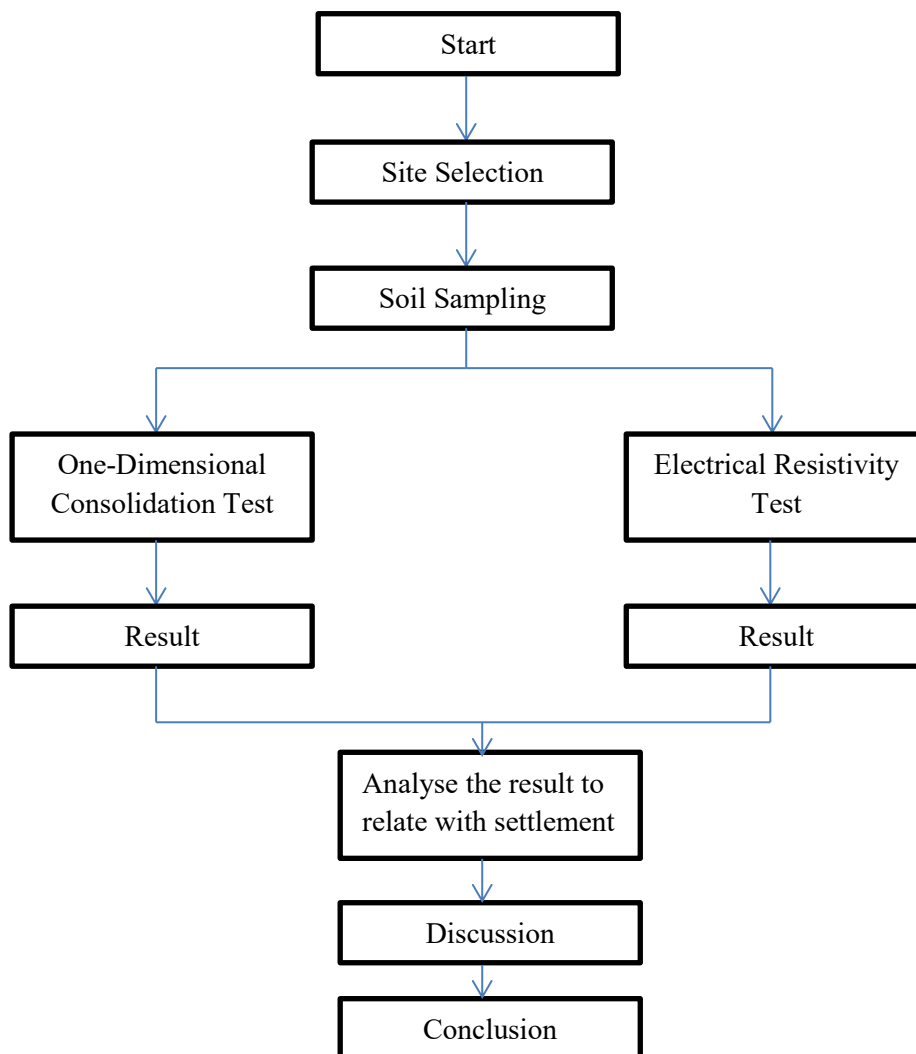
Figure 3.1: The methodology research flow chart.

3.2   Soil sampling

Soil sampling was taken as disturbed and disturbed sample. The disturbed sample was used for basic soil properties laboratory test while the undisturbed soil will be used for the laboratory soil electrical resistivity test.

3.2.1   Disturbed Soil Sample

In this research, disturbed sample was obtained by digging the soil at a point using a scoope. Disturbed soil samples do not retain the in-situ properties of the soil during the collection process. Generally, disturbed samples are mainly required for soil type and texture, moisture content, and nutrient and contaminant analysis, among other evaluations. The sample dug as mentioned above then were placed and sealed into plastic bags.

As stated by BS 5930: 1990 Code of Practice for Site Investigations, a minimum of five kilograms of soil sample are needed but we collected eight kilograms of sample were taken from the site. Figure 3.2 below process of collecting disturbed soil sample:

Figure 3.2: Disturbed soil sampling.

3.2.2   Undisturbed Soil Sample

Undisturbed soil sample for this research were taken using Hollow pipe samplers. The undisturbed soil sampling was done using hammer that used to knock the Hollow pipe until the pipe burden inside the ground. Three points were chosen for the boring process, the same points where the field resistivity measurement is carried out.

Right after the pipe was removed from the ground, each end of them were sealed to maintain the soil samples moisture content. The samples were then taken for laboratory soil electrical resistivity test. Figure 3.3 below shown undisturbed sampling apparatus that were used.

Figure 3.3: Undisturbed soil sampling.

3.4   One Dimensional Consolidation Laboratory Test

The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation

settlement of a structure or an earth fill. Estimation of this type is of key importance in the design of engineered structures and the evaluation of their performance.

Figure 3.4: Equipment used for consolidation test.

First, the empty consolidation ring was weighed together with glass plate. The height of the ring and its inside diameter also measured. The soil sample was extruded from the sampler, generally thin-walled Shelby tube. The initial moisture content and the specific gravity of the soil were determined.

A three- inch long sample was cut. The sample was placed on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring. The ring and pare of excess soil were rotated by means of the cutting tool so that the sample is reduced to the same inside diameter of the ring. It is important to keep the cutting tool in the correct horizontal position during this process.

As the trimming progresses, the sample gently pressed into the ring and continues until the sample protrudes a short distance through the bottom of the ring. Trimming process must be done carefully to ensure that there is no void space between the sample and the ring.

Figure 3.5: loading / unloading process.

The ring was turned carefully, and the portion of the soil was removed protruding above the ring. Metal straight edge was used to cut the soil surface flush with the surface of the ring. The final portion was removed with extreme care. The previously weighed glass plate was placed on the freshly cut surface. The ring was turned over again and cut carefully on the other end in a similar manner.

The specimen plus ring plus glass plate were weighed. The ring with specimen from the glass plate was carefully removed. The porous stones that have been soaking were centered on the top and bottom surfaces of the test specimen. The filter papers were placed between porous stones and soil specimen. To make sure the stones adhere to the sample it was presses very lightly. The assembly was lowered carefully into the base of the water reservoir. The water reservoir was filled with water until the specimen is completely covered and saturated.

To prevent movement of the ring and porous stones we must be very careful, the load plate was placed centrally on the upper porous stone and the loading device was adjusted. The dial gauge was adjusted to a zero reading. With the toggle switch closed position, the pressure gauge dial was set to result in an applied pressure of 0.5 tsf. Next, open the valve simultaneously open and the timing clock started.

The consolidation dial readings at the elapsed times given on the data sheet were recorded. The steps were repeated for different preselected pressures. The final

consolidation dial reading and time was recorded at the last elapsed time reading. The load was released and the consolidation device was quickly disassembled and the specimen was removed. Carefully blot the surfaces dry with paper toweling. The specimen and ring on the glass were placed and weighed them together once again.

Figure 3.6: Samples was placed in oven.

Empty large moisture can and lid was weighed. The specimen from the consolidation ring was carefully removed, soil was making sure it not loses too much and the specimen was placed in the previously weighed moisture can. The moisture can containing the specimen was placed in the oven and dried about 12 to 18 hours. The dry specimen in the moisture can was weighed.

3.5   Laboratory Soil Electrical Resistivity

The laboratory soil resistivity test was conducted by using the Precision LCR Meter (DER13520). The precision LCR Meter is electronic equipment used to measure the inductance (L), capacitance (C), and resistance (R) of a component or material.

To conduct this test, the undisturbed soil samples obtained was extracted first using horizontal extruder into a PVC pipe. The picture of Precision LCR Meter shown as follows in figure 3.7 below:

Figure 3.7**:** Precision LCR Meter.

The PVC pipe provided has the same diameter as the sampling tube, which is 5.8 cm with length of double of its diameter, 11.6 cm. After the soil was extracted, the sample was ready to be tested with the precision LCR Meter. Figure 3.8 below are the pictures of the Precision LCR Meter together with the apparatus and sample set.

Figure 3.8: Setting up of apparatus.

Based on Figure, the PVC pipe which contained with the undisturbed soil sample was attached with copper plates at each end. The copper plates have the same diameter with the PVC pipe. It was then being attached to the plywood plate to avoid direct contact with the pipe holder and it should be held tightly by the pipe holder. Next, the connection clips which were connected to the Precision LCR Meter and clipped at both of the copper plate on each end of the PVC pipe.

Right after the setting up of the apparatus and soil sample, the Precision LCR Meter was set up. As referred to Figure, it was first switched on using the "POWER" button at its bottom. As the prime purpose of using this meter was to find the resistance of the soil, the resistance mode, was chosen. Following that, the Frequency and the Current were set to the maximum value that the Precision LCR Meter can provide which were "200 kHz" and "1.0V" respectively.

To increase the precision of the reading, the speed was set to "MEDIUM" option and to obtain the value of the resistance, the display mode was set to "VALUE". Not to mention, lastly the circuit type was set to "SERIES" before the whole experiment was ready to be carried on. The resistance reading was then obtained by pressing the "START" button. The resistance reading for a soil sample was displayed at the area.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result of Consolidation Test

Bukit Goh

Table 4.1: m_v and c_v value of Bukit Goh after Loading and Unloading stages

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
22.2 kPa	2.74 m^2/MN	458.73 m^2/yr
44.4 kPa	1.25 m^2/MN	405.07 m^2/yr
88.8 kPa	0.53 m^2/MN	377.72 m^2/yr
177.6 kPa	0.47 m^2/MN	359.63 m^2/yr
44.4 kPa	0.04 m^2/MN	---------
11.1 kPa	0.21 m^2/MN	---------

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Based on the Table 4.1 using consolidation apparatus the reading shows the coefficient of Volume of Compressibility (mv) of this sample from site Bukit Goh

decreasing when loading stages. The initial mv value is 2.74 m^2/MN and the final mv value is 0.47 m^2/MN. For unloading stages, the initial mv is 0.04 m^2/MN and the final reading is 0.21 m^2/MN.

Coefficient of Consolidation (c_v) for this sample site shows initial reading 458.73 m^2/yr however for the final reading it shows 359.63 m^2/yr. For unloading stages, the result not shown because we removed the load stage by stage.

Indera Mahkota

Table 4.2: m_v and c_v value of Indera Mahkota after Loading and Unloading stages

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
22.2 kPa	3.08 m^2/MN	412.35 m^2/yr
44.4 kPa	1.29 m^2/MN	407.57 m^2/yr
88.8 kPa	0.88 m^2/MN	383.83 m^2/yr
177.6 kPa	0.59 m^2/MN	352.37 m^2/yr
44.4 kPa	0.03 m^2/MN	---------
11.1 kPa	0.12 m^2/MN	---------

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Based on the Table 4.2 using consolidation apparatus the reading shows the coefficient of Volume of Compressibility (mv) of this sample from site Bukit Goh decreasing when loading stages. The initial mv value is 3.08 m^2/MN and the final mv value is 0.59 m^2/MN. For unloading stages, the initial mv is 0.03 m^2/MN and the final reading is 0.12 m^2/MN.

Coefficient of Consolidation (c_v) for this sample site shows initial reading 412.35 m^2/yr however for the final reading it shows 352.37 m^2/yr. For unloading stages, the result not shown because we removed the load stage by stage.

Semambu

Table 4.3: m_v and c_v value of Semambu after Loading and Unloading stages.

Pressure (Loading Stages)	Coefficient of Volume Compressibility (m_v)	Coefficient of Consolidation (c_v)
0.00		
22.2 kPa	1.97 m^2/MN	458.07 m^2/yr
44.4 kPa	1.63 m^2/MN	233.97 m^2/yr
88.8 kPa	0.85 m^2/MN	371.21 m^2/yr
177.6 kPa	0.64 m^2/MN	346.30 m^2/yr
44.4 kPa	0.04 m^2/MN	---------
11.1 kPa	0.12 m^2/MN	---------

Based on the Table 4.3 using consolidation apparatus the reading shows the coefficient of Volume of Compressibility (mv) of this sample from site Bukit Goh decreasing when loading stages. The initial mv value is 1.97 m^2/MN and the final mv value is 0.12 m^2/MN. For unloading stages, the initial mv is 0.04 m^2/MN and the final reading is 0.12 m^2/MN.

Coefficient of Consolidation (c_v) for this sample site shows initial reading 458.73 m^2/yr however for the final reading it shows 346.30 m^2/yr. For unloading stages, the result not shown because we removed the load stage by stage.

Electrical Resistivity Test

Bukit Goh

Table 4.4: Laboratory soil electrical resistivity data of Bukit Goh samples

Length of pipe (m)	0.086	Diameter of pipe (m)	0.057		
Cross-section area of pipe (m^2)	0.003				
Point	Frequency (kHz)	Voltage (V)	R$_1$ (kΩ)	R$_1$ (kΩ)	R$_1$ (kΩ)	R Average (KΩ)	Resistivity, p (Ω.m)
1	200	1.0	4.702	4.704	4.705	4.703	163.954
2	200	1.0	6.003	5.903	5.806	5.935	206.861
3	200	1.0	6.502	6.404	6.404	6.457	225.002
Average resistivity, p (Ω.m)							198.603

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Indera Mahkota

Table 4.5: Laboratory soil electrical resistivity data of Indera Mahkota samples.

Length of pipe (m)	0.086		Diameter of pipe (m)		0.057	
Cross-section area of pipe (m²)	0.003					
Point	Frequency (kHz)	Voltage (V)	R_1 (kΩ)	R_1 (kΩ)	R_1 (kΩ)	R Average (KΩ)	Resistivity, p (Ω.m)
1	200	1.0	6.901	6.903	6.808	6.932	241.753
2	200	1.0	7.252	7.245	7.249	7.263	253.264
3	200	1.0	7.705	7.687	7.651	7.681	267.101
Average resistivity, p (Ω.m)							254.045

Semambu

Table 4.6: Laboratory soil electrical resistivity data of Semambu samples

Length of pipe (m)	0.086		Diameter of pipe (m)		0.057	
Cross-section area of pipe (m²)	0.003					
Point	Frequency (kHz)	Voltage (V)	R_1 (kΩ)	R_1 (kΩ)	R_1 (kΩ)	R Average	Resistivity, p (Ω.m)
1	200	1.0	6.803	6.802	6.804	6.801	237.206

2	200	1.0	6.555	6.588	6.505	6.549	228.148
3	200	1.0	7.132	7.151	7.119	7.122	248.374
Average resistivity, p (Ω.m)							237.909

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Table 4.4, Table 4.5 and Table 4.6 shown the result of the laboratory soil electrical resistivity which was carried by the means of Precision LCR meter. From the meter used, only resistance (R) values were obtained. All the undisturbed soil samples were tested at the frequency of 200 kHz and 1 V of voltage. The resistance reading has been taken for each location that has been choose.

The electrical resistivity (p) values of the soil samples were then calculated using the formula from equation (3-6). The results were tabulated as shown in Table 4.4, Table 4.5 and Table 4.6. Based on calculation made, the average soil electrical resistivity, p, for soil sample at Bukit Goh was 198.60 Ω.m whereas soil sample at Indera Mahkota and Semambu had 254.045 Ω.m and 237.909 Ω.m respectively.

4.7 Discussion

Based on the result from one dimensional consolidation test, with reference to the void ratio vs applied pressure graph for all three samples the larger the applied pressure, the larger the reduction in void ratio. The compressive index of unloading is smaller than that of loading. The void ratio follows one curve when compression increases but follows another straight-line during unloading. This phenomenon is acceptable since when the soil is compressed, some voids may be driven off by stress meaning the disappearance of voids. Although there is an unloading after compression, those voids will not fully reform after the unloading. This may explain why voids ratio cannot reach original value during unloading.

It can be observed that the calculated values of final void ratios after rebound of the three soil specimens were different from their corresponding initial void ratios. This means that the volume of specimens did not return to their original values upon unloading. This phenomenon can be explained by the fact that some voids in the specimens were driven off by stress as the specimens were compressed. Although unloading took place at the end of the experiment, those voids might not fully reform. Hence, the values of the final void ratios after rebound of the four samples were smaller than their corresponding initial void ratios.

Based on the result from laboratory assessment of soil electrical resistivity, it is a bit impossible to stimulate the exact same condition as the field, where the sample was originally in the subsurface. This can be the reason that contributed for the different in the soil electrical resistivity. According to Indraratna and Chu (2005), the electrical currents in the field environment and laboratory assessment could not be directly compared because of the difference in volume of tested soil.

To add more, the inhomogeneities effects of the sample might as well the sample size tested should be considered too because it does not represent the entire geological formation. As mentioned before, water content in a soil has a very great effect on soil electrical resistivity. Saturation condition influence the water content of soil. Supposedly, all the soil samples taken from site should have the same moisture content as where they were taken. However, the effects of temperature, and time can possibly affect the soil water content.

For this study, the laboratory test did not being carried out right after the borehole sampling and keeping the soil samples for a period of time before being tested could lead to this matter. Moreover, there was a probability too that the sealed soil samples did not being kept well as there was still air ways or holes that can cause the evaporation and water content loss of the soil sample. Although this problem seems so small, it could greatly affect the electrical resistivity readings.

Furthermore, when the moisture content of soil was lost, and high voltage was used to carry out the test, this might as well could lead to high electrical resistivity readings too. Lastly, another reason that may lead to this matter is density. The density of the soil could contribute to the difference in the values. Relating to the loss moisture content of the soil, the soil became less dense where the voids that used to be filled with water were replaced by air. When there were only air in the soil, the electric current would not had any medium to pass through the soil and this resulting the soil electrical resistivity to increase.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1   Conclusion

According to BS 1377, the oedometer test should be carried out with only one soil sample which is to be loaded, unloaded and reloaded repeatedly. However, this procedure would require a long time to complete and quick results are not possible. Hence, for this study, three samples were used instead, each with a different applied load. As a result, even though the phenomenon of consolidation was studied in this study, the findings might not be accurate enough as the properties of the three samples might not be the same and thus leading to inconsistency errors.

Throughout the analysis and discussion of laboratory soil electrical resistivity assessment by the mean of precision LCR Method, it can be concluded that the objectives to determine the soil electrical resistivity by laboratory assessment were successfully achieved. Not to forget, by laboratory test carried out such as particle size distribution, moisture content, Atterberg limit, and particle density, together with the data, the first objective of this study which was to determine the physical properties of soil was successfully achieved too.

To add more, the results and analysis shows that the laboratory electrical resistivity is a good technique to determine the average resistivity of the soil. However, more and more precise data need to be obtained in describing the subsurface properties, in order to help engineers to come out with a good engineering design. As said by Abidin et al. (2013), a verification of

geophysical interpretation by laboratory is important to show that it can produce enough reliable results.

5.2   Recommendation

Referring to the results obtained, and conclusions made, there are still more improvements and enhancement from this study that could be done in future researches. The recommendations of the improvements are as follows:

i.   Soil electrical resistivity test and consolidation test should be done as borehole samples are obtained to avoid loss of moisture content.

ii. More samples should be taken to increase precision of the laboratory assessment of soil.

iii. Another type of insulator can be used to avoid copper plates from contacting the pipe holder

iv. Increasing the area of study to get more data and analysis so that more data of the place can be explore.

v.   Make a revision about the weather around the study area so that when we take the sample, the moisture content will not be disturbed from rain water.

REFERENCES

Abidin, M. H., Saad, R., Ahmad, F., Wijeyeskera, D. C., & Baharuddin, M. F. (2011). Application of Geophysical Methods in Civil Engineering. *Malaysian TechnicaUniversities International Conference on Engineering and Technology* (2011).

British Standard. (1990). *Code of practice for site investigations*, *BS 5930*. London.

British Standard. (1990). *General requirements and sample preparations, BS 1377-1:1999*. London.

British Standard. (1990*). Methods of test for Soils for civil engineering purposes*-Part 2: *Classification tests, BS 1377-2:1999*. London

Adli, Z., Musa, M., & Arifin, M. (2010). Electrical Resistivity of Subsurface: Field and Laboratory Assessment. *International Journal of Environment, Ecological, Geological and Marine Engineering Volume 4, Number 9*., 45-48.

Benson, R., & Yuhr, L. (2015). *Site Characterization in Karst and Psedokarst Teraains*. New York: Splinger.

Milsom, J., & Erikson, A. (2011). *The Geological Field Guide Series: Field Geophysics, Edition 4*. England: John Wiley and Sons Ltd Publication.

Mondelli, G., Giacheti, H., & Elis, V . (2012). *Geo-Environment Site Investigation for Municipal Solid Waste Disposal Site, Edited by Dr. Xiao-Ying Yu*. Shanghai: InTech.

Smith, K., & Mullins, C. (2005). *Soil and Environment Analysis: Physical Methods, Revised and Expanded, Edition 2*. New York: Marcel Dekker Inc.

Whitlow , R. (2004*). Basic Soil Mechanics, Fourth Edition*. Singapore: Prentice Hall Pearson Education South Asia Pte Ltd.

Griffiths, D., & King, R. (1981). *Applied Geophysics for Geologists and Engineers: The Elements of Geophysical Propecting. Edition 2*. England: Pergamon Press.

ASTM, (2011*). Standard Test Methods for One-dimensional Consolidation Properties of Soils using Incremental Loading. D2435*. West Conshohocken,PA.

Estabragh, A.R., Javadi, A.A., (2008). Critical state for over consolidated silty soil. Can. Geotech. J. 45, 408–420.

Kibria, G., Hossain, M.S., (2012*). Investigation of geotechnical parameters affecting electrical resistivity of compacted clays*. J. Geotech. Geoenviron. 138 (12), 1520–1529.

Kibria, G., (2014)., *Evaluation of Physico-Mechanical Properties of Clayey Soils using Electrical Resistivity Imaging Technique*. Ph.D. dissertation, The University of Texas at Arlington.

Result of moisture content

Semambu

TEST NUMBER	Unit	SM1	SM2	SM3	SM4	SM5
Container weight	Gm	13.84	23.18	24.59	22.97	24.06
Wet soil + container	Gm	48.65	72.58	76.38	75.83	78.59
Wet soil, W_w	Gm	34.81	49.40	51.79	52.86	54.53
Dry soil + container	Gm	39.65	60.89	64.07	62.25	64.53
Dry soil, W_d	Gm	25.81	37.71	39.48	39.28	40.47
Moisture loss, (W_w-W_d)	Gm	9.00	11.69	12.31	13.58	14.06
Moisture content, (W_w-W_d) / W_d	%	34.87	31.00	31.18	34.57	34.74
Range of moisture content	%	31.00 – 34.87				
AVERAGE MOISTURE CONTENT	%	33.27				

Bukit Goh

TEST NUMBER	Unit	BG1	BG2	BG3	BG4	BG5
Container weight	Gm	30.49	23.54	22.69	23.94	23.64
Wet soil + container	Gm	86.04	81.46	74.92	83.22	79.18
Wet soil, W_w	Gm	55.55	57.92	52.23	59.28	55.54
Dry soil + container	Gm	75.02	72.81	63.18	72.79	71.50
Dry soil, W_d	Gm	44.53	49.27	40.49	48.85	47.86
Moisture loss, (W_w-W_d)	Gm	11.02	8.65	11.74	10.43	7.68
Moisture content, (W_w-W_d) / W_d	%	24.75	17.56	29.00	21.35	16.05
Range of moisture content	%	16.05 – 29.00				
AVERAGE MOISTURE CONTENT	%	21.74				

Indera Mahkota

TEST NUMBER	Unit	IM1	IM2	IM3	IM4	IM5
Container weight	Gm	23.50	23.11	24.15	25.53	31.94
Wet soil + container	Gm	85.88	64.81	65.28	77.63	76.99
Wet soil, W_w	Gm	62.38	41.70	41.13	52.1	45.05
Dry soil + container	Gm	78.69	59.91	60.55	71.61	71.83
Dry soil, W_d	Gm	55.19	36.80	36.40	46.08	39.89
Moisture loss, (W_w-W_d)	Gm	7.19	4.9	4.73	6.02	5.16
Moisture content, (W_w-W_d) / W_d	%	13.03	13.32	12.99	13.06	12.94
Range of moisture comtent	%	12.94 – 13.32				
AVERAGE MOISTURE CONTENT	%	13.07				

Result of liquid limit

Semambu

TEST NUMBER	1		2		3	
Cone penetration (mm)	14.40	15.10	21.00	19.80	24.90	24.50
Average penetration (mm)	14.75		20.40		24.70	
CONTAINER NUMBER	A	B	C	D	E	F
Container weight (gm)	13.93	13.76	15.63	14.24	14.42	14.91
Wet soil + container (gm)	20.46	21.96	23.43	22.06	22.76	23.81
Wet soil, W_w (gm)	6.53	8.20	7.80	7.82	8.34	8.90
Dry soil + container (gm)	18.15	19.04	20.68	19.29	19.46	20.30
Dry soil, W_d (gm)	4.22	5.28	5.05	5.05	5.04	5.39
Moisture loss, (W_w-W_d) (gm)	2.31	2.92	2.75	2.77	3.30	3.51
Moisture content, (W_w-W_d) / W_d (%)	54.74	55.30	54.46	54.85	65.48	65.12
AVERAGE MOISTURE CONTENT (%)	55.02		54.66		65.30	

Bukit Goh

TEST NUMBER	1		2		3	
Cone penetration (mm)	15.80	14.30	18.20	18.80	24.80	25.70
Average penetration (mm)	15.05		18.50		25.25	
CONTAINER NUMBER	A	B	C	D	E	F
Container weight (gm)	15.90	15.12	13.98	13.81	14.19	14.89
Wet soil + container (gm)	25.55	26.20	25.82	25.37	24.87	26.11
Wet soil, W_w (gm)	9.65	11.08	11.84	11.56	10.68	11.22
Dry soil + container (gm)	22.57	22.85	22.06	21.73	21.50	22.60
Dry soil, W_d (gm)	6.67	7.73	8.08	7.92	7.31	7.71
Moisture loss, (W_w-W_d) (gm)	2.98	3.35	3.76	3.64	3.37	3.51
Moisture content, (W_w-W_d) / W_d (%)	44.68	43.34	46.53	45.96	46.10	45.53
AVERAGE MOISTURE CONTENT (%)	44.01		46.25		45.82	

Indera Mahkota

TEST NUMBER	1		2		3	
Cone penetration (mm)	14.30	16.00	20.40	21.60	26.00	24.50
Average penetration (mm)	15.15		21		25.25	
CONTAINER NUMBER	A	B	C	D	E	F
Container weight (gm)	14.40	15.07	14.84	15.17	15.12	14.69
Wet soil + container (gm)	25.97	27.84	27.82	28.04	26.37	25.74
Wet soil, W_w (gm)	11.57	12.77	12.98	12.87	11.25	11.05
Dry soil + container (gm)	23.28	24.84	24.71	24.94	23.67	23.05
Dry soil, W_d (gm)	8.88	9.77	9.87	9.77	8.55	8.36
Moisture loss, (W_w-W_d) (gm)	2.69	3.00	3.11	3.10	2.70	2.69
Moisture content, (W_w-W_d) / W_d (%)	30.29	30.70	31.51	31.73	31.58	32.18
AVERAGE MOISTURE CONTENT (%)	30.50		31.62		31.88	

Result of Plastic Limit

Semambu

Container Number	A	B
Container weight (gm)	15.09	15.80
Wet soil + container (gm)	28.28	26.68
Wet soil, W_w (gm)	13.19	10.88
Dry soil + container (gm)	24.09	23.19
Dry soil, W_d (gm)	9.00	7.39
Moisture loss, (W_w-W_d) (gm)	4.19	3.49
Moisture content, $(W_w-W_d) / W_d$ (%)	46.56	47.23
AVERAGE MOISTURE CONTENT (%)	46.90	

Bukit Goh

Container Number	A	B
Container weight (gm)	14.94	14.61
Wet soil + container (gm)	33.77	33.48
Wet soil, W_w (gm)	18.83	18.87
Dry soil + container (gm)	28.57	28.34
Dry soil, W_d (gm)	13.63	13.73
Moisture loss, (W_w-W_d) (gm)	5.20	5.14
Moisture content, $(W_w-W_d) / W_d$ (%)	38.15	37.44
AVERAGE MOISTURE CONTENT (%)	37.80	

Indera Mahkota

Container Number	A	B
Container weight (gm)	14.42	14.66
Wet soil + container (gm)	34.05	31.45
Wet soil, W_w (gm)	19.63	16.79
Dry soil + container (gm)	30.06	28.02
Dry soil, W_d (gm)	15.64	13.36
Moisture loss, (W_w-W_d) (gm)	3.99	3.43
Moisture content, $(W_w-W_d) / W_d$ (%)	25.51	25.67
AVERAGE MOISTURE CONTENT (%)	25.59	

Result of density test

BG2

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	32.65	32.25	36.75
Mass of bottle + stopper + dry soil, m_2	g	44.63	44.22	49.01
Mass of bottle + stopper + soil + water, m_3	g	140.39	139.76	144.32
Mass of bottle + stopper +water, m_4	g	132.41	131.72	136.18
Mass of dry soil, $(m_2 - m_1)$	g	11.98	11.97	12.26
Mass of water in full bottle, $(m_4 - m_1)$	g	99.76	99.47	99.43
Mass of water used, $(m_3 - m_2)$	g	95.76	95.54	95.31
Particle density, ρ_s	mg/m^3	3.00	3.05	2.98
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	3.01		

BG3

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	33.65	32.55	35.93
Mass of bottle + stopper + dry soil, m_2	g	45.60	44.98	48.01
Mass of bottle + stopper + soil + water, m_3	g	141.40	140.67	143.33
Mass of bottle + stopper +water, m_4	g	133.20	132.68	136.09
Mass of dry soil, $(m_2 - m_1)$	g	11.95	12.43	12.08
Mass of water in full bottle, $(m_4 - m_1)$	g	99.55	100.13	100.16
Mass of water used, $(m_3 - m_2)$	g	95.80	95.69	95.32
Particle density, ρ_s	mg/m^3	3.19	2.80	2.50
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.83		

BG4

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	32.37	32.00	32.84
Mass of bottle + stopper + dry soil, m_2	g	44.58	44.03	44.94
Mass of bottle + stopper + soil + water, m_3	g	140.29	140.66	141.79
Mass of bottle + stopper +water, m_4	g	132.20	132.71	133.78
Mass of dry soil, $(m_2 - m_1)$	g	12.21	12.03	12.10
Mass of water in full bottle, $(m_4 - m_1)$	g	99.83	100.71	100.94
Mass of water used, $(m_3 - m_2)$	g	95.71	96.63	96.85
Particle density, ρ_s	mg/m^3	2.96	2.95	2.96
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.96		

IM 2

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	36.70	30.38	31.94
Mass of bottle + stopper + dry soil, m_2	g	48.80	42.47	43.88
Mass of bottle + stopper + soil + water, m_3	g	143.57	138.31	140.24
Mass of bottle + stopper +water, m_4	g	136.14	130.98	132.96
Mass of dry soil, $(m_2 - m_1)$	g	12.10	12.09	11.94
Mass of water in full bottle, $(m_4 - m_1)$	g	99.44	100.60	101.02
Mass of water used, $(m_3 - m_2)$	g	94.77	95.84	96.36
Particle density, ρ_s	mg/m^3	2.59	2.54	2.56
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.56		

IM3

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	31.75	31.64	32.65
Mass of bottle + stopper + dry soil, m_2	g	43.80	43.93	44.94
Mass of bottle + stopper + soil + water, m_3	g	139.01	138.86	140.08
Mass of bottle + stopper +water, m_4	g	131.64	131.24	132.37
Mass of dry soil, $(m_2 - m_1)$	g	12.05	12.29	12.29
Mass of water in full bottle, $(m_4 - m_1)$	g	99.89	99.60	99.72
Mass of water used, $(m_3 - m_2)$	g	95.21	94.93	95.14
Particle density, ρ_s	mg/m^3	2.57	2.63	2.68
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.63		

IM4

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	32.80	32.69	33.70
Mass of bottle + stopper + dry soil, m_2	g	44.85	44.97	45.99
Mass of bottle + stopper + soil + water, m_3	g	140.06	139.91	141.13
Mass of bottle + stopper +water, m_4	g	132.69	132.29	133.42
Mass of dry soil, $(m_2 - m_1)$	g	12.05	12.28	12.29
Mass of water in full bottle, $(m_4 - m_1)$	g	99.89	99.60	99.72
Mass of water used, $(m_3 - m_2)$	g	95.21	94.94	95.14
Particle density, ρ_s	mg/m^3	2.57	2.64	2.68
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.63		

Semambu 2

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	33.72	33.61	34.62
Mass of bottle + stopper + dry soil, m_2	g	45.77	45.90	46.91
Mass of bottle + stopper + soil + water, m_3	g	140.94	140.83	142.05
Mass of bottle + stopper +water, m_4	g	133.61	133.21	134.34
Mass of dry soil, $(m_2 - m_1)$	g	12.05	12.29	12.29
Mass of water in full bottle, $(m_4 - m_1)$	g	99.89	99.60	99.72
Mass of water used, $(m_3 - m_2)$	g	95.17	94.93	95.14
Particle density, ρ_s	mg/m^3	2.55	2.63	2.68
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.62		

Semambu 3

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	31.04	30.67	31.51
Mass of bottle + stopper + dry soil, m_2	g	43.25	42.70	43.63
Mass of bottle + stopper + soil + water, m_3	g	138.96	139.33	139.37
Mass of bottle + stopper +water, m_4	g	130.87	131.38	131.48
Mass of dry soil, $(m_2 - m_1)$	g	12.21	12.03	12.12
Mass of water in full bottle, $(m_4 - m_1)$	g	99.83	100.71	99.97
Mass of water used, $(m_3 - m_2)$	g	95.71	96.63	95.74
Particle density, ρ_s	mg/m^3	2.96	2.95	2.87
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.93		

Semambu 4

Test number	Unit	1	2	3
Mass of bottle + stopper, m_1	g	31.65	31.00	31.48
Mass of bottle + stopper + dry soil, m_2	g	43.94	43.03	43.63
Mass of bottle + stopper + soil + water, m_3	g	139.08	139.66	139.37
Mass of bottle + stopper +water, m_4	g	131.37	131.71	131.48
Mass of dry soil, $(m_2 - m_1)$	g	12.29	12.03	12.15
Mass of water in full bottle, $(m_4 - m_1)$	g	99.72	100.71	100.00
Mass of water used, $(m_3 - m_2)$	g	95.14	96.63	95.74
Particle density, ρ_s	mg/m^3	2.68	2.95	2.85
AVERAGE PARTICLE DENSITY, $\boldsymbol{\rho_s}$	mg/m^3	2.82		

Result of Consolidation Test

Bukit Goh

Test Details			
Standard	BS 1377: Part 5 : 1990 : Clause 3	Particle Density	2.65 Mg/m3
Sample Type	Core sample	Lab Temperature	25.0 deg.C
Sample Depth	3.00 m		
Sample Description	Bauxite		
Variations from Procedure	None		

Specimen Details			
Specimen Reference	B	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	174.28 g	Condition	Natural Moisture
Specimen Height	17.59 mm	Preparation	

Test Apparatus			
Ring Number	1	Ring Diameter	72.80 mm

Ring Height	20.00 mm	Ring Weight	110.13 g
Lever Ratio	10.00 :1		

Voids Ratio Vs Applied Pressure
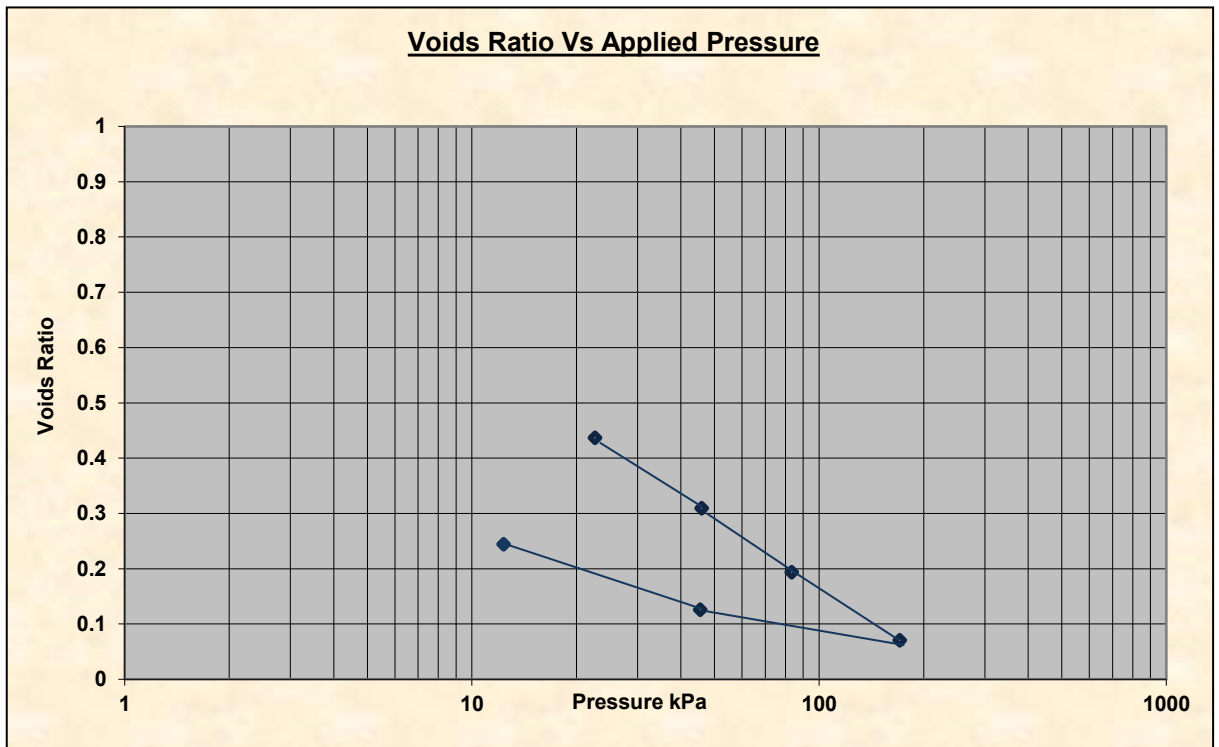
Height of Solid Particles	12.64 mm	Swelling Pressure	0.0 kPa

Initial Moisture Content*	25.0	Final Moisture Content	25.9%
Initial Bulk Density	2.38	Final Bulk Density	2.67 Mg/m3
Initial Dry Density	1.90	Final Dry Density	2.12 Mg/m3
Initial Void Ratio	0.3917	Final Void Ratio	0.2492
Initial Degree of Saturation	169.17%	Final Degree of Saturation	274.94%

Indera Mahkota

Test Details			
Standard	BS 1377: Part 5 : 1990 : Clause 3	Particle Density	2.65 Mg/m3
Sample Type	Core sample	Lab Temperature	25.0 C
Sample Depth	0.00 m		
Sample Description	Bauxite		
Variations from Procedure	None		

Specimen Details			
Specimen Reference	A	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	182.52 g	Condition	Natural Moisture
Specimen Height	19.32 mm	Preparation	
Comments			

Test Apparatus			
Ring Number	1	Ring Diameter	74.52 mm
Ring Height	19.32 mm	Ring Weight	115.28 g
Lever Ratio	10.00 :1		

Voids Ratio Vs Applied Pressure
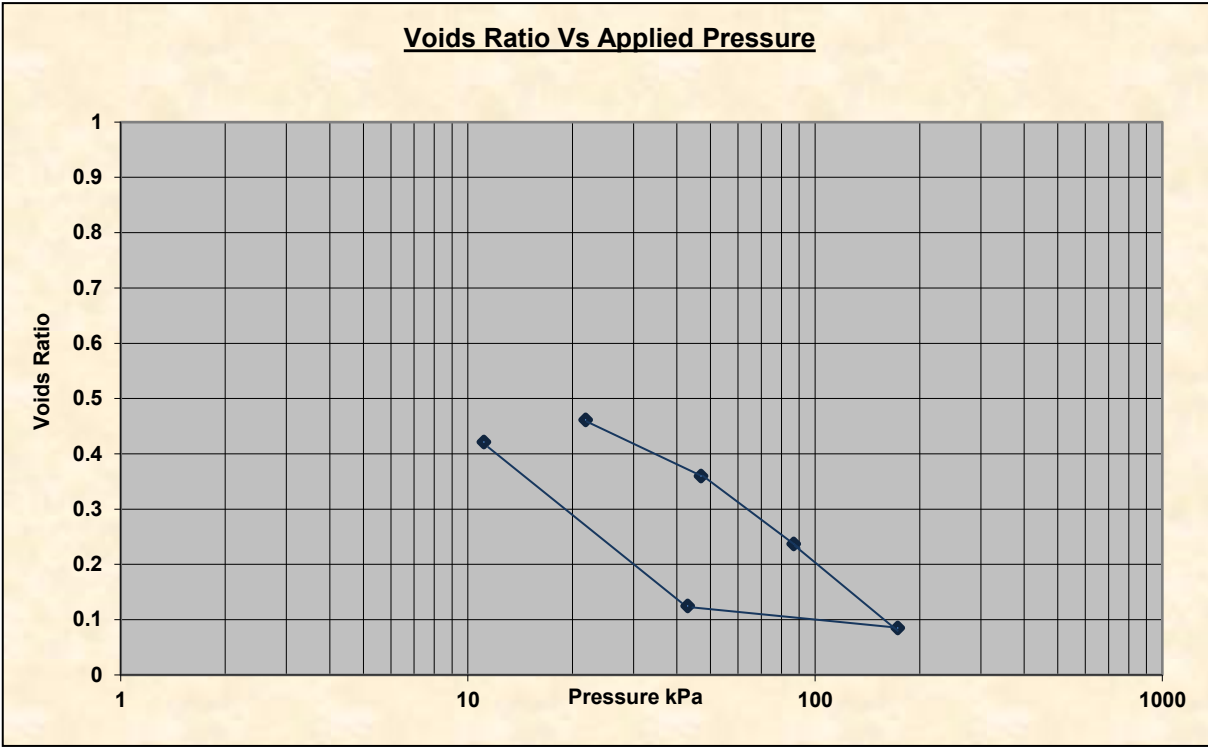
Height of Solid Particles	13.14 mm	Swelling Pressure	0.0 kPa

Initial Moisture Content*	23.0 %	Final Moisture Content	23.0%
Initial Bulk Density	2.17 Mg/m3	Final Bulk Density	2.23Mg/m3
Initial Dry Density	1.76 Mg/m3	Final Dry Density	1.82Mg/m3
Initial Void Ratio	0.4704	Final Void Ratio	0.4253
Initial Degree of Saturation	126.49%	Final Degree of Saturation	139.90%

Semambu

Test Details			
Standard	BS 1377: Part 5 :1990 : Clause 3	Particle Density	2.65 Mg/m3
Sample Type	Core sample	Lab Temperature	25.0 deg.C
Sample Depth	3.00 m		
Sample Description	Bauxite		

Specimen Details			
Specimen Reference	C	Description	
Depth within Sample	0.00mm	Orientation within Sample	
Specimen Mass	175.37 g	Condition	Natural Moisture
Specimen Height	20.00 mm	Preparation	

Test Apparatus			
Ring Number	1	Ring Diameter	72.70 mm
Ring Height	20.00 mm	Ring Weight	110.60 g
Lever Ratio	10.00 :1		

Voids Ratio Vs Applied Pressure
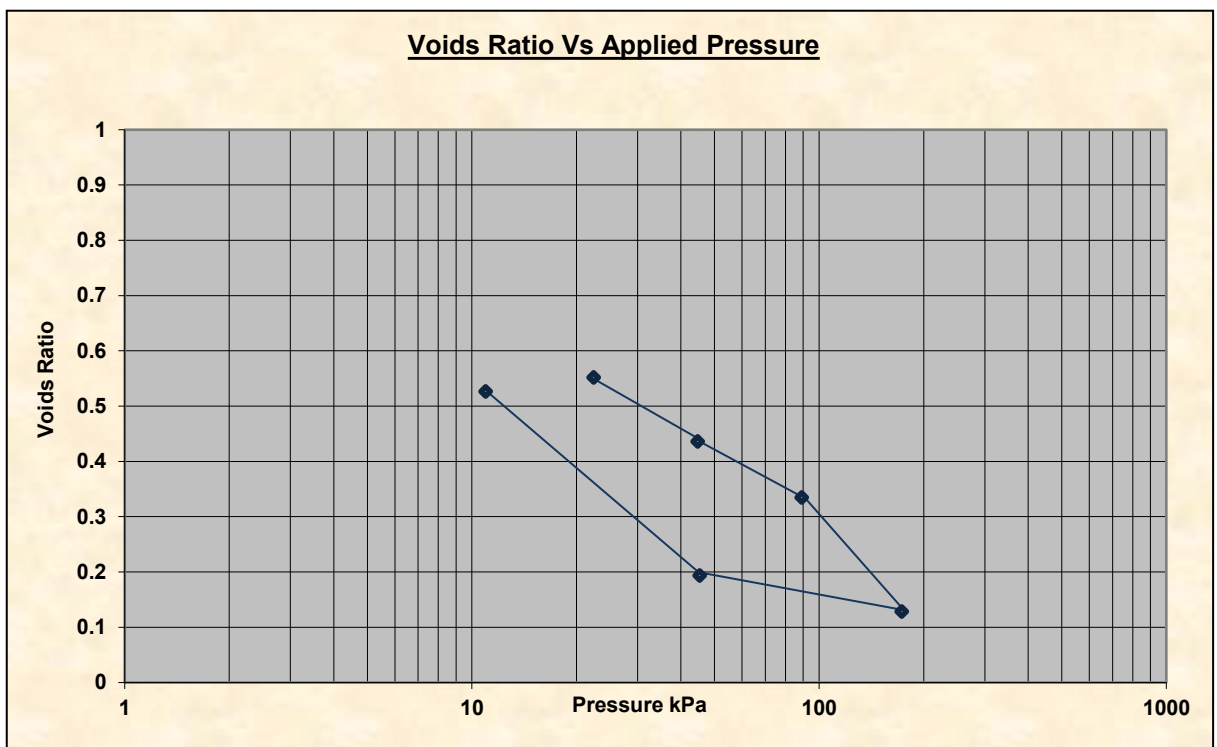
Height of Solid Particles	12.18mm	Swelling Pressure	0.0 kPa

Initial Moisture Content*	22.8%	Final Moisture Content	24.1 %
Initial Bulk Density	2.11Mg/m3	Final Bulk Density	2.17 Mg/m3
Initial Dry Density	1.72Mg/m3	Final Dry Density	1.75 Mg/m3
Initial Void Ratio	0.5524	Final Void Ratio	0.5238

Initial Degree of Saturation	110.28%	Final Degree of Saturation	122.81 %