SHALLOW SUBSURFACE LAYER ASSESSMENT USING 2-D RESISTIVITY IMAGING AND GROUND PENETRATING RADAR (GPR) AT COASTAL AREA OF PENANG ISLAND: CASE STUDY AT MINDEN, TELUK KUMBAR AND BALIK PULAU

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by

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LIST OF SYMBOLS

%	Percentage
°	Degree
°C	degree Celsius
c	speed of light
C_c	coefficient of curvature
cm	Centimetre
C_u	coefficient of uniformity
d	Depth
e	void ratio
Hz	Hertz
I_p	plasticity index
km	Kilometre
L	Litre
m	Meter
m/ns	meter per nanosecond
m/s	meter per second
MHz	Megahertz
mL	Millilitre
mm	Millimetre
η	Porosity
ϕ	phi unit
t	Time
v	Velocity
V	Volume
W	moisture content

w_p	plastic limit
w_t	liquid limit
ρ	Density

LIST OF ABBREVIATIONS

1-D	One dimensional
2-D	Two dimensional
3-D	Three dimensional
CWT	Clear Water Team
EM	electromagnetic
ERT	Electrical Resistivity Tomography
GPR	ground penetrating radar
i.e.	that is
TEM	Transient electromagnetic
VES	vertical electrical soundings
VRP	vertical radar profiles

PENILAIAN LAPISAN SUBPERMUKAAN CETEK MENGGUNAKAN PENGIMEJAN KEBERINTANGAN 2-D DAN RADAR PENUSUKAN BUMI (RPB) DI PESISIRAN PANTAI PULAU PINANG: KAJIAN KES DI MINDEN, TELUK KUMBAR DAN BALIK PULAU

ABSTRAK

Penyiasatan mengenai lapisan subpermukaan cetek dijalankan secara meluas di dunia geofizik. Setiap penyelidik menggunakan kaedah yang berbeza untuk menyiasat lapisan subpermukaan bergantung kepada keadaan. Bagi kajian ini, kaedah pengimejan keberintangan 2-D dan radar penusukan bumi (RPB) telah digunakan untuk menyiasat lapisan subpermukaan cetek di kawasan persisiran pantai. Selain itu, analisis tanah di setiap kawasan kajian juga dijalankan untuk meningkatkan ketepatan data yang diperolehi. Objektif utama kajian ini adalah untuk mencirikan stratigrafi tanah dengan menggunakan kaedah geofizik, dan kawasan-kawasan kajian yang dipilih adalah Teluk Kumbar, USM Minden dan Balik Pulau. Kawasan kajian ini telah dipilih kerana lokasinya yang berdekatan dengan laut dan akses mudah untuk menjalankan kajian. Berdasarkan keputusan, trend taburan hujan digunakan untuk menentukan musim kemarau dan hujan bagi tujuan membezakan stratigrafi lapisan subpermukaan cetek semasa musim kemarau dan musim tengkujuh. Bagi keputusan analisis tanah, Teluk Kumbar, keliangan adalah antara 25.37 – 27.54% dan tanah dikelaskan sebagai pasir bergred rendah. Kawasan kajian USM Minden mempunyai keliangan antara 29.58 – 35.06% dan tanah dikelaskan sebagai pasir bergred rendah. Manakala kawasan kajian Balik Pulau mempunyai keliangan 29.70 – 35.77% dan digredkan sebagai tanah kelodak elastik. Kajian ini telah berjaya menunjukkan stratigrafi lapisan subpermukaan cetek di setiap kawasan kajian yang terlibat. Selain itu, dengan bantuan analisis tanah, jenis tanah di setiap kawasan kajian boleh

dikenalpasti dalam ketepatan yang tinggi. Untuk hasil kaedah geofizik, di Teluk Kumbar, lapisan bawah permukaan terdiri daripada batu besar (> 1000 Ωm), tanah yg ditebus (> 600 Ωm), tanah asal (100 – 400 Ωm), batu, dan batuan dasar (> 1000 Ωm) berdasarkan model songsang dan profil radargram. Terdapat juga kewujudan penenggelaman tanah pada jarak 40 – 50 m dengan kedalaman 6 – 16 m. Garis kajian kawasan kajian Teluk Kumbar adalah 100 m panjang dan nilai keberintangan pada jarak 30 m, 45 m dan 70 m pada musim kemarau adalah 4910.80 Ωm, 28.21 Ωm dan 27.05 Ωm. Manakala semasa musim hujan, nilai keberintangan adalah 3948.80 Ωm, 7.75 Ωm dan 19.80 Ωm mengikut jaraknya. Bagi kaedah RPB, halaju gelombang elektromagnet (EM) semasa musim kemarau dan musim hujan adalah 0.125 m/ns dan 0.090 m/ns. Manakala ketelusan dielektrik untuk musim kemarau dan musim hujan adalah 5.76 dan 11.11. Bagi Kawasan kajian USM Minden, berdasarkan hasil penyongsangan dan radargram, lapisan bawah permukaan terdiri daripada tanah masin, batu dasar dan batu-batu kecil. Tanah masin menguasai garis kaji selidik pada jarak 56 – 200 m. Garis kaji selidik kawasan kajian USM Minden adalah 200 m, nilai keberintangan semasa musim kemarau pada jarak 20 m, 60 m, 100 m, 140 m, dan 180 m adalah 383,92 Ωm, 1.74 Ωm, 1.11 Ωm, 0.01 Ωm, dan 0.02 Ωm. Nilai keberintangan pada musim hujan adalah 160.58 Ωm, 18.1 Ωm, 1.35 Ωm, 0.29 Ωm dan 0.72 Ωm. Bagi kaedah RPB, halaju gelombang EM semasa musim kemarau dan musim hujan adalah 0.090 m/ns dan 0.070 m/ns masing-masing. Manakala ketelusan dielektrik untuk musim kemarau dan musim hujan adalah 11.11 dan 18.37. Kawasan kajian Balik Pulau adalah sebuah ladang kelapa sawit dan zon keberintangan rendah meliputi jarak keseluruhan garis kaji selidik. Balik Pulau mempunyai nilai keberintangan daripada 0.07 Ωm, 5.46 Ωm, 2.74 Ωm, 8.59 Ωm dan 3.44 Ωm pada musim kemarau pada jarak 20 m, 60 m, 100 m, 140 m, dan 180 m. Semasa musim hujan, nilai kerintangan pada jarak 20 m, 60 m, 100 m, 140 m, dan 180 m adalah 0.3 Ωm, 6.37 Ωm, 3.58 Ωm, 0.06 Ωm dan 0.73 Ωm. gelombang halaju EM untuk musim kemarau dan musim hujan adalah 0.175 m/ns dan 0,180 m/ns manakala ketelusan dielektrik adalah 10.15 dan 9.26 pada musim kemarau dan musim hujan. Kajian ini telah berjaya mencirikan stratigrafi lapisan subpermukaan cetek di setiap kawasan kajian yang terlibat dengan fakta analisis tanah, jenis tanah di kawasan kajian yang boleh dikenal pasti dengan ketepatan yang tinggi.

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ABSTRACT

Investigation about the shallow subsurface layer is widely conducted in the geophysics world. Every researcher used different methods to investigate the subsurface layer depending on the situation that they were in. For this research, 2-D resistivity imaging and GPR method were used to investigate the shallow subsurface layer at the coastal area. Soil analysis at each of the study area was also conducted to enhance the accuracy of the acquired data. The main objective of this research is to characterise shallow subsurface layer in coastal area using geophysical method at Teluk Kumbar, USM Minden and Balik Pulau. These study areas were selected due to its location that near to the sea and easy access to conduct the research. Rainfall distribution trend was used to determine the dry and wet season by distinguishing the stratigraphy of the shallow subsurface layer during these two seasons. Soil analysis result in Teluk Kumbar shows the porosity is ranging from 25.37 – 27.54 % and the soil is classified as poorly graded sand. USM Minden study area has the porosity ranging from 29.58 – 35.06 % and the soil is classified as poorly graded sand. While Balik Pulau study area has the porosity of 29.70 – 35.77 % and the soil is elastic silt. For geophysical method results, in Teluk Kumbar, the subsurface layer consists of hard layer/boulder (> 1000 Ωm), reclaimed soil (> 600 Ωm), original soil (100 – 400 Ωm) and bedrock (> 1000 Ωm) based on inversion model of resistivity and radargram profile. There is also an existence of soil subsidence at distance 40 – 50 m with the

depth of 6 – 16 m. The survey line of Teluk Kumbar study area is 100 m long and the resistivity value at selected distance of 30 m, 45 m and 70 m during dry season is 4910.80 Ωm, 28.21 Ωm and 27.05 Ωm respectively. Whereas during the wet season, the resistivity value is 3948.80 Ωm, 7.75 Ωm and 19.80 Ωm according to its distance. For GPR method, the velocity of EM wave during dry season and wet season is 0.125 m/ns and 0.090 m/ns respectively. While dielectric permittivity for dry season and wet season is 5.76 and 11.11. As for USM Minden study area, based on inversion and radargram result, the subsurface layer consists of saline soil, bedrock and pebbles. The saline soil dominates the survey line at distance 56 – 200 m. For USM Minden study area, the survey line is 200 m and the resistivity value during dry season at distance is 20 m, 60 m, 100 m, 140 m, and 180 m is 383.92 Ωm, 1.74 Ωm, 1.11 Ωm, 0.01 Ωm, and 0.02 Ωm respectively. The resistivity value during wet season is 160.58 Ωm, 18.1 Ωm, 1.35 Ωm, 0.29 Ωm, and 0.72 Ωm respectively. For GPR method, the velocity of EM wave during dry season and wet season is 0.090 m/ns and 0.070 m/ns respectively. While dielectric permittivity for dry season and wet season is 11.11 and 18.37. Balik Pulau study area is an oil palm plantation and low resistivity zone covered the whole distance of survey line. Balik Pulau have resistivity value of 0.07 Ωm, 5.46 Ωm, 2.74 Ωm, 8.59 Ωm, and 3.44 during dry season at distance 20 m, 60 m, 100 m, 140 m, and 180 m respectively. During the wet season, the resistivity value at distance 20 m, 60 m, 100 m, 140 m, and 180 m is 0.3 Ωm, 6.37 Ωm, 3.58 Ωm, 0.06 Ωm, and 0.73 Ωm. EM wave velocity for the dry season and wet season is 0.175 m/ns and 0.180 m/ns whereas the dielectric permittivity is 10.15 and 9.26 during dry season and wet season. This research has successfully characterised the shallow subsurface layer at each of the study areas involved with the fact of soil analysis, the type of soil in the study area can be identified with high accuracy.

CHAPTER 1

INTRODUCTION

1.0 Background

Subsurface layer study is important in order to know the geological strata beneath the ground. Besides, the geological structures of the ground also can be known. The examples of common geological structures are fault, fracture, fold, bedding, and contact zone. Geological structures such as faults and folds are the architecture of the earth's crust (Dawes and Dawes, 2001). Al-Imam (2015) stated that the raised beach complex composed of marine and continental clastic deposits and reef limestone. Moreover, the area is characterized by complete and high weathering grade facies, where the physical weathering is prevalent.

Geophysical methods used to support and enhance the data for the engineer to interpret the subsurface structure. Besides, geophysical method is cost-effective and can provide the data quickly with high accuracy. The commonly used geophysical methods are 2-D resistivity imaging, ground penetrating radar (GPR), magnetic, gravity, and seismic, and each of the method provide different parameters depending on the objective, budget and accessibility.

In this study, two methods have been chosen which is 2-D resistivity imaging and GPR. Both methods are good in investigating shallow subsurface layer which align with the objective of this research. Detail information about the subsurface layer can be determine such as depth of bedrock, fracture, saltwater intrusion, and fault. 2-D resistivity imaging measures resistivity of the subsurface layer to delineate the structures while GPR method emit electromagnetic (EM) wave into the ground and measure the dielectric permittivity of the soil.

Geophysical methods have their own advantages and limitations. Combination of two methods are crucial in determining the condition of the subsurface layer because it could help to enhance the data interpretation. In other words, correlation of two methods are very effective and could solve interpretation ambiguities (Comina et al., 2002).

1.1 Problem statement

The subsurface layer investigation is important to analyse the engineering and environmental problem of the ground. Aside from that, the geological stratigraphy and geological structure can be determined. There is lack of study regarding coastal area in Penang Island. Hence, by doing this research, the knowledge about the shallow subsurface layer at the Penang Island can be expanded. In Penang Island, developer tend to build a housing area at the coastal area, thus most of the area are reclaimed land. If the reclamation land is not properly executed, in the future, cracks and subsidence might occur. Geophysical study is important to investigate the stability and safety of the reclaimed land. Moreover, engineering problem such as bearing capacity failure or excessive settlement could occur during the settlement process at the soft soil area (Mohamad et al., 2016).

1.2 Objectives

The main objective of this study is:

1. To characterise shallow subsurface layer in coastal area using geophysical methods.

2. To identify the resistivity and GPR response towards different soil types and seasons.
3. To investigate the soil texture at the study area.

1.3 Scope of study

In this study, 2-D resistivity imaging method and GPR method were used to investigate the subsurface layer of the study area. The study area is located in Penang Island, focusing at Teluk Kumbar, USM Minden and Balik Pulau. All of the study areas are considered as coastal area because their location is near to the sea. Geophysical survey was carried out at the survey area to investigate the stratigraphy of the subsurface layer. Furthermore, the soil samples were also taken for observation and laboratory test. The parameter selected for laboratory test are bulk density, porosity and soil texture.

1.4 Thesis layout

The thesis chapters are arranged as follows:

Chapter 1 discussed about the introduction of this research and the content in it which is background, problem statement, objective, scope of study, and lastly the thesis outline.

Chapter 2 is literature review. This chapter explained about the previous study that related to this research. It also discussed about the resistivity value range involved.

Chapter 3 includes the research flowchart of this research. Geological setting and the study area of this research were also mentioned in this chapter. This chapter also explained about the geophysical methods used and the procedures to conduct the experiment. Plus, soil analysis procedure was also explained.

In chapter 4, result and discussion were explained. Correlation between geophysical methods were made to gain the information about this research. Moreover, soil analysis result was also discussed in this chapter and the result show about the soil properties in the study area.

Lastly, chapter 5 is the conclusion and recommendation. The conclusion of this research is made in this chapter and the recommendation for future work was also been suggested.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Many studies have been published to explain about shallow subsurface layer at coastal area. This chapter is divided into three subsection which are previous geophysical studies, previous coastal area studies and resistivity value range.

2.1 Previous geophysical studies

Shukla et al. (2008) said the coastline compose a very sensitive geomorphic domain constantly subjected to dynamic coastal processes. The study was carried out at Modwa beach complex which is between Rawal Pir and Modwa. It is about 10 km east of Madvi on the northern coast of the Gulf of Kachchh. The ground penetrating radar (GPR) survey differentiated variety of the radar surfaces and radar facies which reflects not only large scale sedimentary architecture, but depositional beach complex. Beach ridges, washover, coastal dune and swale are the bounding surface separating the radar facies. From the GPR profiles, the internal sedimentary structures like tangential, parallel, concave and convex upward stratifications can be visualized.

Ground penetrating radar (GPR) and shallow seismic refraction (SSR) are non-invasive geophysical method that enhance studies of shallow subsurface deposits. The method can be used to measure thickness and material properties of subsurface deposits in sensitive alpine areas without harming the environment that can impact future research. GPR and SSR survey along 1.5 km of geophysical lines shows the layer from fine to coarse, blocky deposits of periglacial origin underline alpine slopes in the vicinity of Niwot Ridge, Colorado Front Range. The data from geophysical and drilling has been interpreted and it shows the depth to bedrock range from 4 to > 10 m and is not simply related to local slope. Geophysical interpretations are mainly consistent with data derived from nearby drill cores and corroborate the utility of GPR in combination with SSR for collecting subsurface data required by different landscape models in sensitive alpine environments (Leopold et al., 2008).

A survey using integrated geophysical and geotechnical method was carried out at Magodo Estate, Lagos, Nigeria. The area showing structural instability because the building in the area are either sinking or intensively affected by severe cracks. Oyedele et al. (2015) conduct a survey to characterize the shallow subsurface in order to differentiate features that may cause the structural instability that led to cracking and sinking of the residential building. Resistivity profiling (2-D) using Wenner array and Cone Penetration Test (CPT) was carried out to image the subsurface layer. The data were processed and interpreted integrally to image the shallow geotechnical setting of the site. Integrated interpretation led to delineation of low resistivity, low bearing capacity clay which is identified as the main cause of instability that resulted in potentially dangerous cracking and sinking of residential building.

Electrical resistivity tomography (ERT) method is used to characterize the nature of the shallow subsurface infiltration areas (3 – 18 m) and to understand the connection between water storage transfer and the characteristics of the chalky formation, usually considered as aquitard (non-aquifer). The survey was carried out at Al – Aroub area, West Bank, Palestine to map the electrical distribution by Sirhan et al. (2011). ERT method measured electrical resistivity along a profile, where a series of electrodes are regularly placed. The existence of continuous dominated moderate layer ($90 < \rho_a < 130$ Ωm) accompanied with an upper clayey layer (< 30 Ωm) has been interpreted from two-dimensional (2-D) resistivity sections. The groundwater circulation within the fractures existed in the chalky geological formations and the results are highly correlated with the existed dug wells located at the study area.

To differentiate groundwater and faults elements which are dissecting the north-western part of Gulf of Suez, vertical electrical sounding (VES) and shallow seismic refraction have been used. 35 VES were carried out and inverted through 3-D VES inversion to determine the subsurface stratigraphy, structures and groundwater aquifer potentialities. The results from VES inversion shows that the study area consist of four geoelectrical units interpreted as surficial dry sand and gravel deposits, underlain by freshwater bearing zone (10 – 20 Ωm), saltwater bearing unit (0.1 – 10 Ωm) and limestone layer (20 – 50 Ωm), at the bottom. 3-D VES inversion indicates the area is dissected by normal fault of NE-SW direction. Moreover, 34 shallow seismic refraction indicate that the shallow part of subsurface section consists of three layers, the first soil layer which is dry gravels and sands of the recent deposits underlain by the second soil layer which is sands and gravels of the Pleistocene, while the third layer is the bedrock layer of sandstone and shale belonging to the Middle Miocene (Araffa et al., 2016).

Geophysical investigation of the Sant'Imbenia Roman villa archaeological site in northern Sardinia (Italy) has been made to optimize a non-invasive approach to reconstruct rapidly the geometry of coastal sites. A hitherto unexplored area approximately 700 m^2, adjacent to excavations, was investigated using ground penetrating radar (GPR) and electrical resistivity tomography (ERT) surveys. The villa is close to the shoreline and subject to a very high erosion rate and burial. Comparison between GPR and ERT model have been made and their integrated results are discussed. It shows that the combined geophysical method along with archaeological prospecting has revealed buried buildings north of the excavated part of the archaeological site. ERT survey provide most accurate results in this coastal environment at the deeper wet level of investigations (Testone et al., 2014).

Subsurface layer study is a crucial step to obtain parameters such as density, shear wave velocity (Vs), thickness and damping characteristics. Chandran and Anbazhagan (2017) said most sites response studies at shallow bedrock sites are one-dimensional (1-D) and are usually carried out by using Vs from multi-channel analysis of surface waves (MASW) or a standard penetration test (SPT) for N values with assumptions that soil layer is horizontal, uniform and homogeneous. The assumptions are not completely true if the subsurface layer is heterogeneous. The aim of this study is to develop the actual subsurface profiles in two-dimension at shallow bedrock regions using integrated subsurface investigation testing. There were three study area selected in Bangalore at two different locations which is at Indian Institute of Science (IISc) Campus and Whitefield. Ground penetrating radar (GPR) and 2-D MASW were carried out at the survey lines. Geophysical results are compared and validated with a conventional geotechnical SPT. The soil profile at IISc is obtained from a trench excavated for a pipeline used to compare the geophysical test results. The results from GPR shows that it is very useful to delineate subsurface layer, especially for shallow depth. While, MASW result show variation of Vs values and layer thickness comparatively at deeper depth for both sites.

2.2 Previous coastal area studies

There are various geotechnical studies on soil at the coastal area of Nigeria. The study is to enhance consistency in local soil properties with respect to strength, and consolidation parameters for foundations design strategy. Field testing include 12 cone penetrometer tests (CPT) and 15 number boring in standard penetration test (SPT). Olaonipekun and Tanimola (2017) stated that disturbed and undisturbed soil sampling were done at various depths. Laboratory test including moisture content, Atterberg limit and grain size analysis has been done in accordance to British Standard 1377, BS (1990). Particle size is in order of distribution gravel < clay < silt < sand, with 10% to 30% by weight of fines. The coefficient of permeability is ranging from $1.0 \times 10^{-10} \leq k \leq 4.7 \times 10^{-8}$ m/s which revealed slow water movement with water content ranging from 15% - 25%, and degree of water saturation range of 79% - 94% which confirm partial saturation. Consistency limits showed that the soils have medium to high plasticity index and the further confirm illite and kaolinite as the major clay minerals in the soils.

Natural clay is usually used as a liner material to contain landfill leachate from contaminating the environment and the key characteristics of liner material is its hydraulic conductivity. The recommended value of hydraulic conductivity of the potential material should be 1×10^{-9} m/s or less. The test that has been carried out are consistency index, compaction behaviour, compressibility and hydraulic conductivity. The marine clay was dominated by finer fraction of silt and clay (78% - 88%) followed by sand (12% - 22%). The minerals present in marine clay are montmorillonite, kaolinite and illite as well as quartz, as the non-clay mineral. The consistency index of liquid limit, w_L is 56% - 80.5% and plastic limit, w_P is 36% - 45%. The plastic index, I_p of marine clay samples range from 19% to 37%. Permeability test indicate that the hydraulic conductivity of the samples ranged between 1.10×10^{-9} and 2.44×10^{-9} m/s. This study showed that there are some geotechnical characteristics of the marine clay were in favour of being used to be landfill liner material (Rahman et al., 2013).

Long et al. (2012) state that the effort to map quick clay areas using electrical resistivity measurements has been made. However, lack of understanding about soil parameters that controlled measured resistivity values. Hence, inverted resistivity values from 15 marine clay sites in Norway have been compared to basic geotechnical index properties. Resistivity value is strongly controlled by the salt content of the pure fluid. It showed that the resistivity value decreases when the salt content is increasing. There is also relatively clear trend of decreasing resistivity with increasing clay content and plasticity index. The resistivity value of the soil become very low (≈ 5 Ωm) for high clay content (> 50%), medium to high plasticity ($I_p \approx 20\%$) materials with salt content values greater than 8 g/l. Poor correlation between resistivity and bulk density, and between resistivity and water content. The study showed that the suggested resistivity value for quick clay is from 10 Ωm to 100 Ωm which is consistent with other published limits. A comparison made from 2D ERT and resistivity cone penetration test data for two of the sites and the two sets of data shows similar trends and values irrespective of scale effect.

In North-western Peninsular Malaysia, the sub-soils consist of sedimentary soil deposits which form alternate layers of clay and sand. Oh and Chai (2006) conduct a research about characteristics of marine clay in North-western Peninsular Malaysia and it is investigated based on field and laboratory test data gathered from the ground investigations. Empirical correlations were done between the index properties and compressibility behaviours of marine clay. Other aspect discussed were the role of soil properties and geological conditions which is the natural moisture content of marine clay that is extremely variable and range from 39 % to 129 %. The Atterberg limit test of marine clay sample show the study area is silty clay of high to extremely high plasticity.

2.3 Resistivity value range

There are three ways electric current may be propagated through rocks and minerals which is electronic (ohmic), electrolytic, and electric conduction (Telford et al., 1996). Electronic or ohmic is the normal type of flow in materials containing free electrons such as metals. Moreover, in an electrolyte, the ions carried current at a slow rate. Dielectric conduction takes place in a poor conductors or insulators, which it has less free carriers or none at all. Because of the influence of external varying electric field, the atomic electrons are displaced slightly according to their nuclei. The displacement current is formed from the separation of positive and negative charges also known as dielectric polarization and it produce a current known as the displacement current (Telford et al., 1996).

Igneous and metamorphic rocks usually have high resistivity values and the resistivity value of the rocks depend on the degree of fracturing and the percentage of fractures filled with water (Loke, 2004). These types of rock can give resistivity value between 1000 to 10 million Ωm and it depend on whether it is wet or dry. As for the sedimentary rocks, it is usually porous and have high water content. Typically, this rock gives low resistivity value with the range of 10 to 1000 Ωm. However, salinity of the water content and porosity of the rock affected most to the resistivity value.

Unconsolidated sediments give a low resistivity reading. It could range between 10 to less than 1000 Ωm. Clayey soil usually have low resistivity value than sandy soil and the overlapping of the resistivity value between rocks and soils could happen. This is because resistivity value depends on a number of factors such as the porosity, the degree of saturation and the concentration of dissolved salts (Loke, 2004).

As for the resistivity of the groundwater and saltwater, the resistivity value range of fresh groundwater is from 10 to 100 Ωm and it depend on the concentration of the salts in the groundwater. For the saltwater, resistivity value ranges from 0 to 1 Ωm. The low resistivity value of the saltwater is because of the high concentration of salt content. Table 2.1 shows the resistivity value range of rocks and soils.

Table 2.1: Resistivity value table of rocks and soils (Telford, 1996; Loke, 2004)

Materials	**Resistivity Value (Ωm)**
Granite	> 700.0
Clay	1.0 – 100.0
Alluvium	10.0 – 900.0
Sandstone	10.0 – 5000.0
Shale	30.0 – 2000.0
Fresh groundwater	10.0 – 100.0
Seawater	0.2 – 1.0
Limestone	70.0 – 5000.0
Basalt	1000.0 – 10^7

2.4 Chapter summary

This chapter discussed about previous study related to geophysical method and coastal areas studies in investigating shallow subsurface layer. It focuses on two or more geophysical methods needed to understand about the subsurface layer study and how the methods complement each other in investigating the subsurface layer. Moreover, coastal area studies help to gain knowledge about the stratigraphy of the subsurface layer at the coastal area and the type of soil involves in it.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter discussed about the geophysical method used during the research. The method used are 2-D resistivity imaging method and ground penetrating radar (GPR). Normally, geophysical survey is a cost-effective, non-intrusive and relatively quick way of detecting and assessing subsurface features. Combining both methods can give extra information on the subsurface layer. 2-D resistivity imaging method has ability to distinguish the resistivity value of the subsurface layer. GPR method is suitable for imaging and detecting anomaly of shallow subsurface layer. Moreover, soil analysis has also been conducted to increase the accuracy of the type of soil involves in the subsurface layer. The study area is located in Penang Island which are Teluk Kumbar, USM Minden and Balik Pulau. Figure 3.1 shows the flowchart of this research.

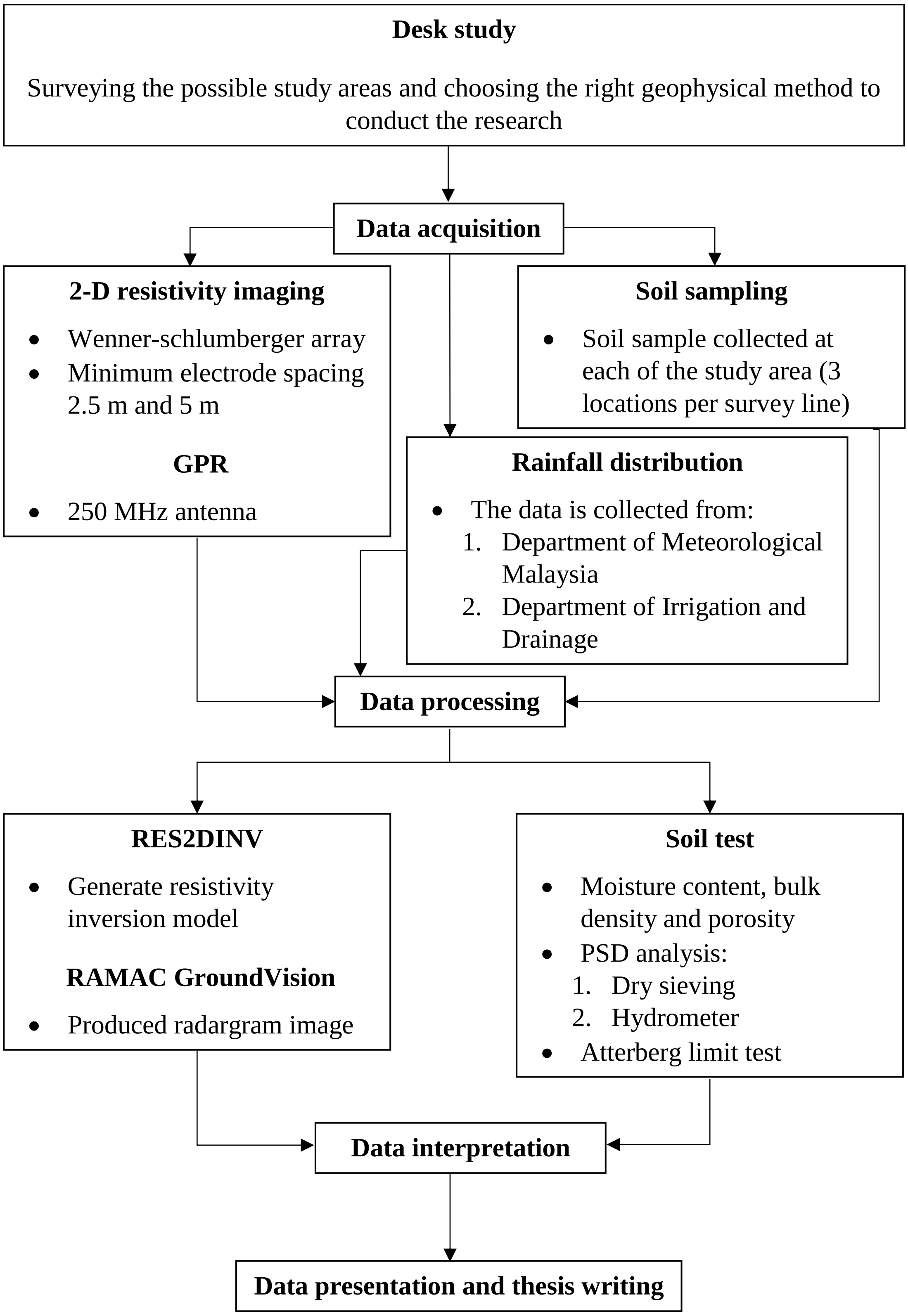

Figure 3.1: Research flowchart

3.1 Geological setting

Most of the Penang Island was covered by granitic rocks. Sedimentary rocks can only be found in Pulau Kendi a small island situated to the south. These sediments can be correlated to the Mahang Formation rocks which occur extensively to the east in the mainland. According to Gan (1977), Lim (1977), Thiruchelvam (1977) and Ng (1978), they described the granites of Pulau Pinang in accordance with Williams et al. (1954) and differentiated several granitic bodies on that basis.

Figure 3.2 shows the spread of various type of granites around Penang Island. Penang Island is divided into two plutons which is North Pinang pluton and South Pinang pluton. North Pinang pluton consist of orthoclase to intermediate microcline granite and its covered 40% of North Pinang pluton area. The granite with xenoliths present, is variable texturally and two phases have been mapped. Numerous veins and dykes traverse the granite. As for the South Pinang pluton area, microcline granite is dominant in the area. Moreover, the granite in Pulau Rimau is also this type. There are likely to be two different phases of the granite that have been mapped, namely Batu Maung granite and the Sungai Ara granite.

Ong (1993) explained the Penang Island in two parts which is northern part and southern part. The northern part of Penang Island which is above the latitude 5° 23’ is fairly rugged. It is appeared to be higher in elevation than the southern part of Penang Island, and Bukit Western which is the highest peak of the northern part is 830 m high above sea level. As for the southern part (below latitude 5° 23’), the elevation seems to be lower and the highest peak is only averaging about 360 m above sea level (Ong, 1993). At the western and eastern part of the Penang Island, there is an existence of two large flat with elevation less than 30 m.

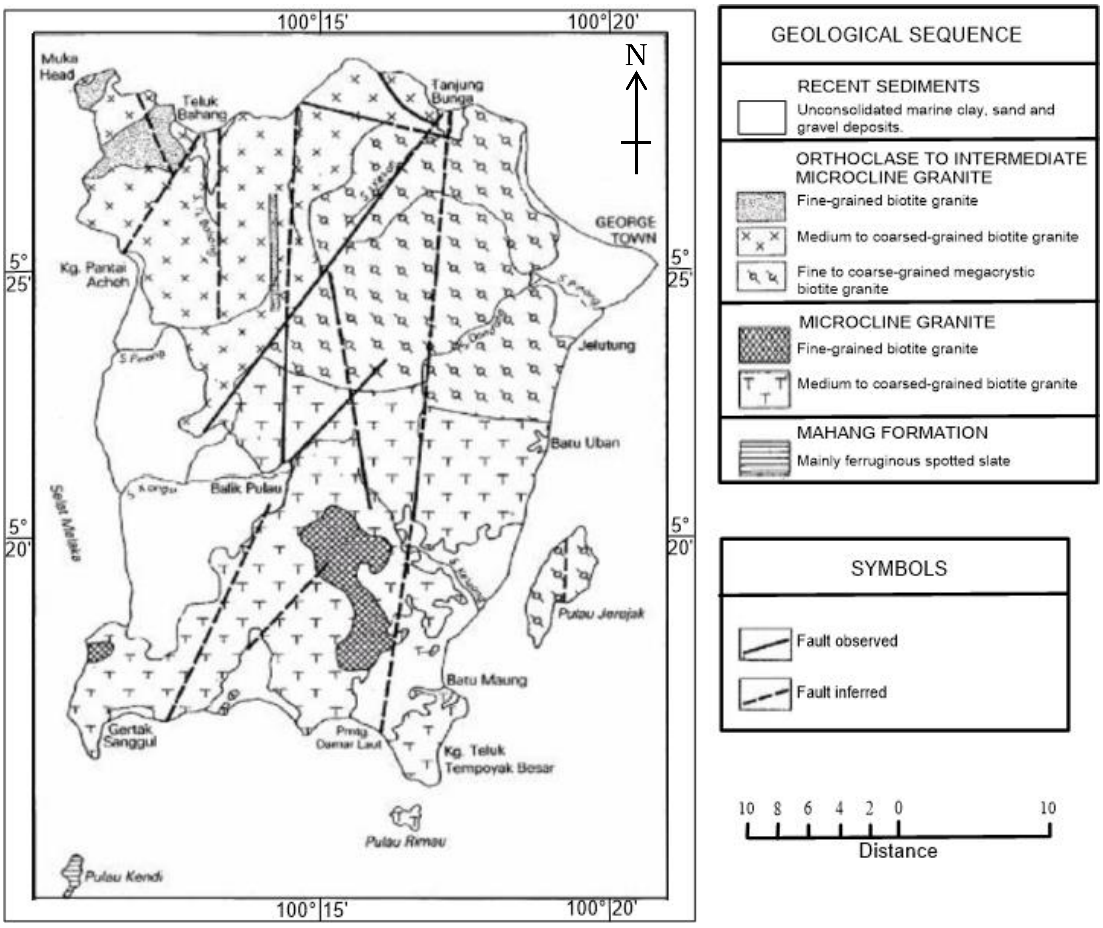

Figure 3.2: Geological map of Penang Island (Ong, 1993)

3.2 Study area

This research was conducted in Penang Island. Three places have been selected as a study area which is Teluk Kumbar, USM Minden and Balik Pulau. These study areas were selected because the location is located at the coastal part of Penang Island.

3.2.1 Teluk Kumbar

The study area is located at Teluk Kumbar and it is surrounded by residential area. The coordinate of the study area is 5° 16’ 56.37” N, 100° 14’ 26.33” E and the distance of the survey line from the sea is 96 m (Figure 3.3). The study area is reported to be a reclamation land and there are small cracks existed at some of the building at the residential area.

Figure 3.3: Aerial view of Teluk Kumbar study area

3.2.2 USM Minden

USM Minden is located at east of Penang Island with the coordinates of 5° 21’ 43.17” N, 100° 18’ 32.47” E; and it is a part of South Pinang pluton. It lies at the large flat area with elevation less than 30 m. The area is underlain with microcline granite and with the present of medium to coarse grain biotite granite. The distance of the survey line to the sea is 590 m (Figure 3.4). The study area is plain and made for football field.

Figure 3.4: Aerial view of USM Minden study area

3.2.3 Balik Pulau

Located at the west of Penang Island with the coordinates of 5° 22' 19.43" N, 100° 14' 26.34" E, the study area is within the oil palm plantation. Even though it is located at west of Penang Island, it is still in South Pinang pluton. Balik Pulau is dominated by unconsolidated marine clay, sand and gravel deposits. Moreover, the area is plain with elevation less than 30 m and about 690 m to the sea (Figure 3.5).

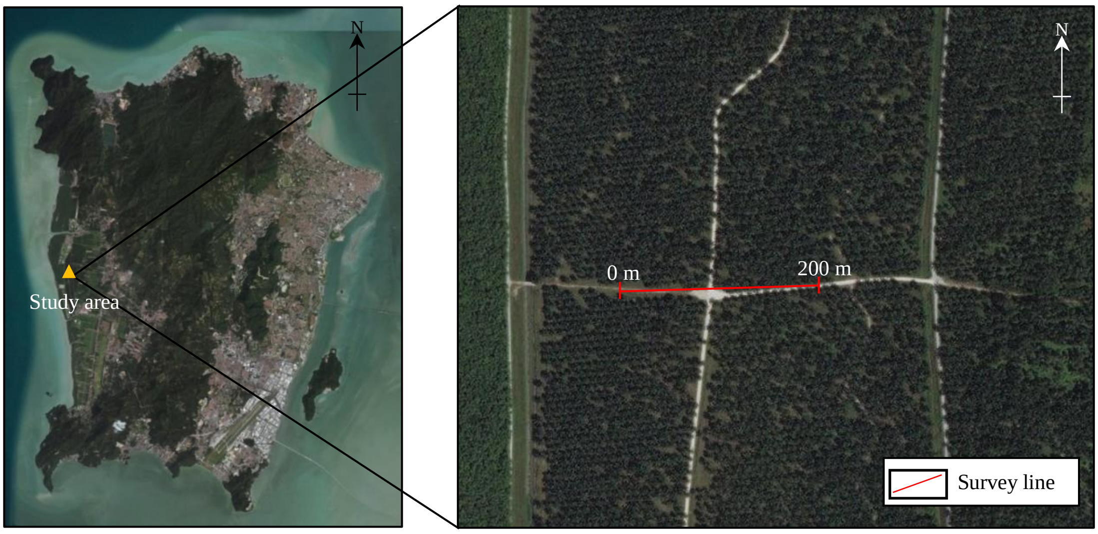

Figure 3.5: Aerial view of Balik Pulau study area

3.3 2-D resistivity imaging

Terrameter SAS4000 system measures voltage responses created by the transmitter current while rejecting uncorrelated voltage and noise. The ratio V/I is automatically calculated and display digitally in kiloohms (kΩ), ohms (Ω) or milliohms (mΩ). The relevant receiver resistance range will be automatically selected (ABEM, 2010).

Terrameter SAS4000 is powered by 12 V external battery and selector, ES 10-64 interconnected by the connecting cable. Two Lund cables, 42 jumpers and 41 electrodes were used along with Terrameter SAS4000 to conduct a survey. The

Terrameter SAS4000 and selector, ES 10-64 were place at the centre which connected the two Lund cables. Figure 3.6 shows the geometry illustration of 2-D resistivity imaging data acquisition setup.

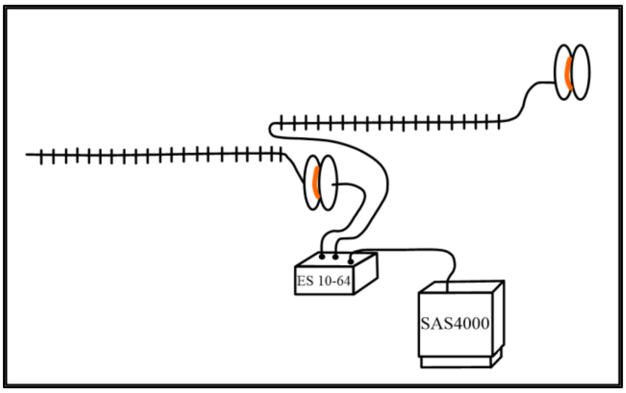

Figure 3.6: Geometry illustration of 2-D resistivity imaging data acquisition setup (Dahlin, 1996)

The array used in this research is Wenner – Schlumberger array. It has been chosen because the array has great horizontal and vertical resolution as well as good signal strength and depth of penetration. The data were processed by using RES2DINV software and Surfer was also been used to enhance the precision of interpretation of data.

3.4 Ground penetrating radar (GPR)

GPR uses electromagnetic waves radiated from the transmitter that pulses a signal into the ground. Then, the waves will be diffracted, refracted and reflected. The reflected signals are sent back to the surface which will be measured by the receiver unit, amplified and digitized by the computer unit used to record the measurements (Meyers et al., 1996). Figure 3.7 shows the illustration of GPR data acquisition setup.

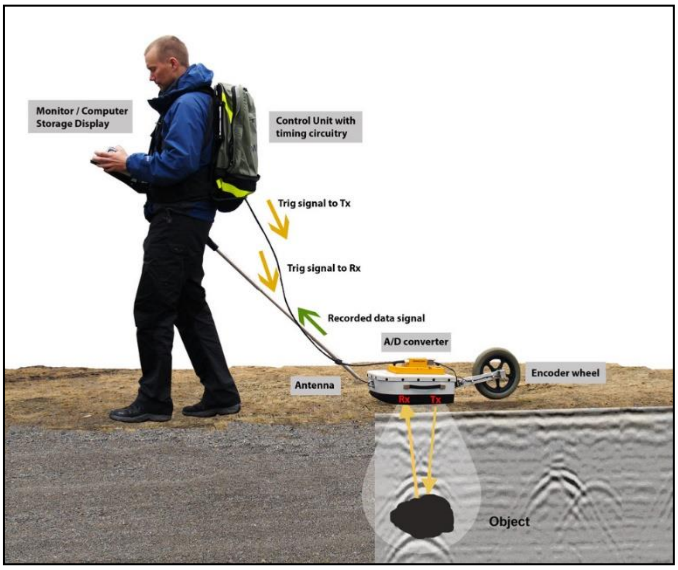

Figure 3.7: Illustration of GPR data acquisition setup (GeoScan Subsurface Surveys, 2010)

For this research, 250 MHz antenna was used to conduct the survey. This is because 250 MHz antenna can give good resolution along with great depth of penetration. After the acquisition of data, the data then will be processed using software called RAMAC GroundVision. The result will be showed up as a radargram (Figure 3.8) and the interpretation of data can be made.

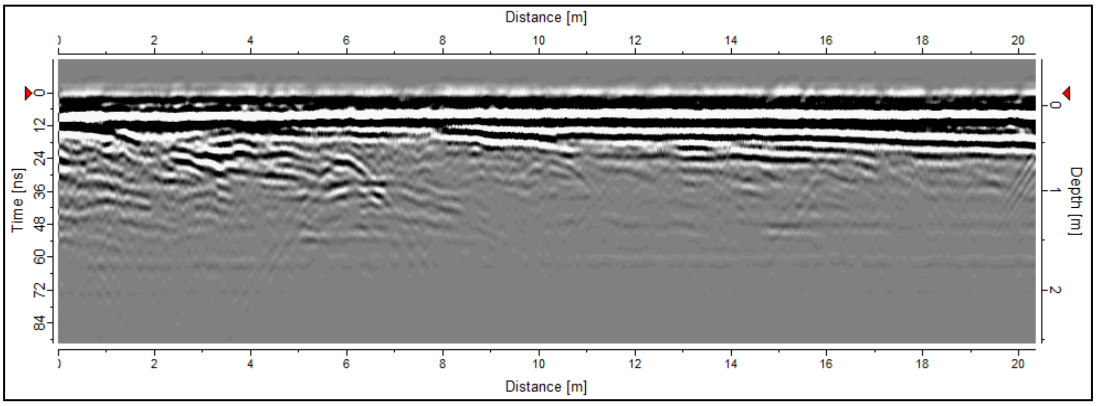

Figure 3.8: Example of radargram in RAMAC GroundVision software

Filters are also used to enhance the view of radargram. This is because noise and signal loss might occur when the data acquisition is processed. The filters can be combined to improve the quality of the radargram, hence the data is easier to interpret.

For this research, three filters have been chosen to be applied in the radargram which is DC removal, Band Pass and Time Varying Gain (Figure 3.9).

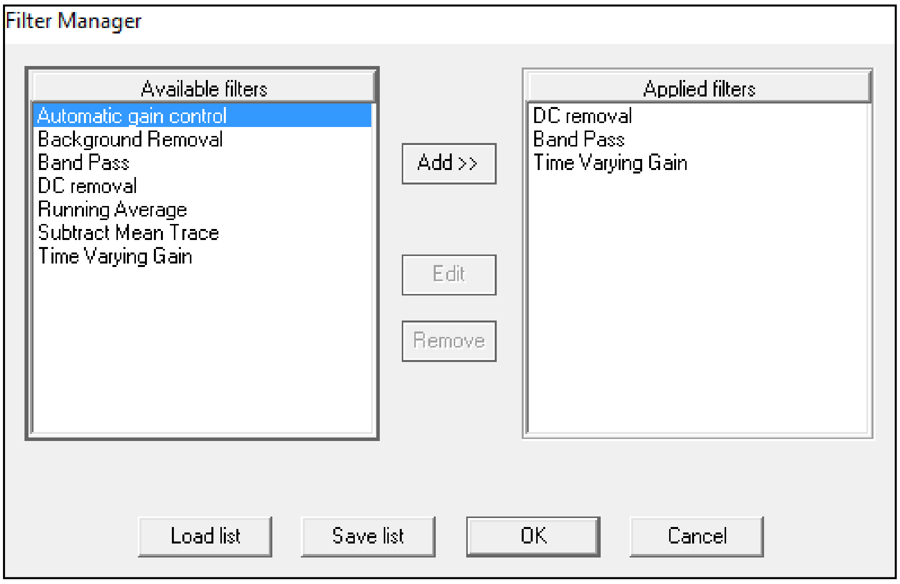

Figure 3.9: Filters used in the RAMAC GroundVision

EM waves velocity can be determined from the radargram by measuring its depth and the two-way time travel of its propagation. The formula is expressed in Equation 3.1:

$$v = \frac{2 \times d}{t} \tag{3.1}$$

Where,

v : velocity of the EM wave
d : depth
t : two-way time travel

The velocity obtained from Equation 3.1 can be used to obtain dielectric permittivity, ε_r with speed of light in vacuum, c and Equation 3.2 is expressed below:

$$\varepsilon_r = \left(\frac{c}{v}\right)^2 \tag{3.2}$$

3.5 Soil test

There are three soil samples taken along the survey line at each of the study area. The samples then undergo laboratory test to extract the parameters needed and to determine the soil characteristic at the study areas. All the procedure stated is based on BS 1377 (2007) unless stated otherwise.

3.5.1 Soil parameter

The objective of the moisture content analysis is to determine the amount of water present in a soil expressed as a percentage of the mass of dry soil. Equation 3.3 was used to obtain moisture contain of the soil.

$$W = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) \times 100 \qquad (3.3)$$

Where,

W : moisture content
m_1 : mass of the container
m_2 : mass of the container and wet soil
m_3 : mass of the container and dry soil

According to Nimmo (2004), porosity is the fraction of the total soil volume that is taken up by the pore space. Equation 3.4 – 3.6 are used to find bulk density, void ratio and porosity.

$$\rho_{bulk} = \frac{m_2 - m_1}{V} \qquad (3.4)$$

Where,

m_1 : mass of the container
m_2 : mass of the container and wet soil
V : volume of the soil sample
ρ_{bulk} : bulk density

$$e = \frac{V_{void}}{V_{dry}} \quad (3.5)$$

Where,

e	: void ratio
V_{void}	: volume of void in the sample
V_{dry}	: volume of the dry soil sample

$$\eta = \frac{e}{1 + e} \quad (3.6)$$

Where,

η	: porosity

Table 3.1 shows the relationship of soil bulk density for root growth and Table 3.2 shows the representative porosity values for various unconsolidated sedimentary material.

Table 3.1: Relationship of soil bulk density for root growth based on soil texture (Arshad et al., 1996)

Soil texture	**Ideal bulk densities for plant growth (g/mL)**	**Bulk densities restricted root growth (g/mL)**
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clay	< 1.10	> 1.47

Table 3.2: Porosity of unconsolidated material (Morris and Johnson, 1967)

Material	**Porosity (%)**
Gravel, coarse	24 – 37
Gravel, medium	24 – 44
Gravel, fine	25 – 39
Sand, coarse	31 – 46
Sand medium	29 – 49
Sand, fine	26 – 53
Silt	34 – 61
Clay	34 – 57

3.5.2 Particle size distribution (Dry sieving)

The purpose of this test is to determine the percentage of different grain sizes contained within a soil. Moreover, this test procedure is based on ASTM D422 (2007). By performing this test, the distribution of different grain sizes can be known and classification of the soil can be determined.

To conduct sieve analysis, the soil sample must be oven-dry and then the lumps are break into smaller size. The soil sample is then shaken through a stack of sieves with opening of decreasing size from top to bottom and at the bottom part is pan which retained soil sample particles that is smaller than 0.075 mm. After the soil sample is shaken, the mass of soil retained on each sieve can be determined.

Particle size distribution (PSD) curve shows type of distribution of various size particle and PSD curve can be used to determine C_c and C_u. C_c is the coefficient of curvature while C_u is the coefficient of uniformity. The equations are shown in Equation 3.7 and Equation 3.8:

$$C_c = \frac{(D30)^2}{D60 \times D10} \tag{3.7}$$

$$C_u = \frac{D60}{D10} \tag{3.8}$$

Where,

D10 : diameter corresponding to 10% finer
D30 : diameter corresponding to 30% finer
D60 : diameter corresponding to 60% finer