GEOPHYSICAL PARAMETERS DETERMINATION USING 2-D RESISTIVITY IMAGING AND GROUND PENETRATING RADAR FOR SUBSURFACE STRUCTURES

MUHAMAD AFIQ BIN SAHARUDIN

UNIVERSITI SAINS MALAYSIA

2017

GEOPHYSICAL PARAMETERS DETERMINATION USING 2-D RESISTIVITY IMAGING AND GROUND PENETRATING RADAR FOR SUBSURFACE STRUCTURES

by

MUHAMAD AFIQ BIN SAHARUDIN

Thesis submitted in fulfillment of the requirements for the degree of Master of Science

August 2017

ACKNOWLEDGEMENT

In The name of Allah S.W.T, the Most Beneficent and Merciful. Praise to Allah.

First of all, I would like to express my sincere gratitude to my main supervisor, Dr. Nordiana Mohd Muztaza who always keeps on assisting me and guiding me towards the end. Her enthusiastic encouragement and constructive criticism really help me to develop to become a better person. Not to forget, my co-supervisors Dr. Nur Azwin Ismail and Prof. Dr. Mohd. Nawawi Mohd Nordin for being supportive all the time and continue to guide me during my research program. I would also like to thanks Assoc. Prof. Dr. Rosli Saad and Dr. Andy Anderson Bery for sharing most of their valuable knowledge and experiences. Million thanks go to all Geophysics lab staffs starting with Mr. Yaakub Othman, Mr. Azmi Abdullah and Mr. Abdul Jamil Yusof for their time and effort in assisting me in the research period.

Special thanks to all my fellow friends which are very helpful towards me by assisting me and share the knowledge that they had with me; Mr. Hazrul Hisham bin Badrul Hisham, Mr. Taqiuddin bin Zakaria, Mr. Tarmizi, Mr. Fauzi Andika, Mr. Kiu Yap Chong, Mr. Mark bin Jinmin, Mr. Muhammad Iqbal Mubarak bin Faharul Azman, Mr. Azim Hilmy bin Mohd Yusof, Mr. Muhamad Hafizuddin bin Mohd Mansor, Mr. Amsir, Mr. Sabirin Trianda, Mr. Rais bin Yusoh, Mr. Yakubu Mingyi Samuel, Mr. Muhammad Sabiu Bala, Ms. Rose Nadia binti Abu Samah, Ms. Umi Maslinda binti Anuar, Ms. Nordiana binti Ahmad Nawawi, Ms. Nabila binti Sulaiman, and Ms. Nur Amalina binti Khoirul Anuar.

I would like to express my sincere appreciation towards my beloved parents Saharudin bin Mohd Sahari and Norhaiza binti Abas, my brother Muhamad Fahmi bin Saharudin, and two of my younger sisters Anis Suraya binti Saharudin and Anis Sofea binti Saharudin who always been there for me and trusted me to finish my master research program with flying colors.

I want to thank Kementerian Pengajian Tinggi (KPT) for providing the schorlarship scheme known as MyMaster programme. I also want to thank Dr. Nordiana Mohd Muztaza for providing the Research University Grant (RUI) with the title "Geophysical Application and Approaches in Engineering and Environmental Problems" (1001/PFIZIK/811323). Lastly, I want to thank all that not mention here such as the Geophysics undergraduate students for keep on give me strength to complete this master program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Cross-sectional area
a	Electrode spacing
d	Depth
dB	Decibel
g	Gram
I	Current
k	Geometric factor
km	Kilometer
kg	Kilogram
L	Length
m	Meter
mS	Millisiemens
n	Nano
R	Resistance
s	Second
t	Time travel
V	Velocity
ω	Angular frequency
α	Attenuation
σ	Conductivity
ε_r	Dielectric permittivity
µ	Magnetic permeability constant
Ω	Ohm

%	Percentage
ρ	Resistivity
<	Less than
>	More than

LIST OF ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
E	Easting
EM	Electromagnetic
EMR	Electromagnetic radiation
GPR	Ground Penetrating Radar
MAPE	Mean Absolute Percentage Error
N	Northing
N-S	North South
RES2DINV	Resistivity 2-D Inversion software
RES2DMOD	Resistivity 2-D Modeling software
RQD	Rock Quality Design
SAS	Signal Averaging System
SMART	Stormwater Management and Road Tunnel
SoLLAT	School of Languages, Literacies, and Translation
S-N	South North
TBM	Tunnel Boring Machine
USM	Universiti Sains Malaysia
VES	Vertical Electrical Sounding
W-E	West East
2-D	Two-Dimensional
3-D	Three-Dimensional

PENENTUAN PARAMETER GEOFIZIK MENGGUNAKAN PENGIMEJAN KEBERINTANGAN 2-D DAN RADAR TUSUKAN BUMI UNTUK STRUKTUR SUBPERMUKAAN

ABSTRAK

Kaedah pengimejan keberintangan 2-D dan radar tusukan bumi adalah kaedah geofizik yang boleh digunakan untuk mengkaji subpermukaan. Kawasan kajian terletak di Pulau Pinang, Perlis, Kedah dan Kelantan. Kajian ini menggunakan susun atur Pole-Dipole dan Wenner Schlumberger bagi kaedah pengimejan keberintangan 2-D dan antenna 250 MHz bagi kaedah radar tusukan bumi bagi kesemua kawasan kajian. Objektif kajian ini adalah untuk mengesan dan mengenal pasti kemungkinan tanda kenal yang mewakili rongga–rongga dengan menggunakan kaedah pengimejan keberintangan 2-D dan radar tusukan bumi, untuk menghubung kaitkan parameter geofizikal seperti nilai konduktiviti daripada kaedah pengimejan keberingtangan 2-D dan radar tusukan bumi, perambatan halaju gelombang elektromagnetik (EM), ketelusan dielektrik, nilai pengurangan gelombang EM dan Ralat Peratusan Purata Mutlak yang diperolehi dari kaedah pengimejan keberintangan 2-D dan radar tusukan bumi dan akhir sekali, untuk membezakan parameter geofizikal antara rongga berisi udara, struktur konkrit dan rongga yang berisi sedimen. Nilai keberintangan yang lebih tinggi bermula dari 500-800 Ωm mewakili rongga berisi udara manakala nilai keberintangan bermula dari 5-250 Ωm menunjukkan rongga yang berisi yang berkait dengan struktur konkrit dan nilai keberintangan bermula dari 5-60 Ωm mewakili rongga berisi sedimen. Nilai konduktiviti terhitung bermula dengan rongga yang berisi udara ialah 0.0016 S/m dan bagi rongga yang berisi yang berkait dengan struktur konkrit pula ialah 0.0926

S/m dan 0.0772 S/m. Nilai konduktiviti terhitung bagi semua kawasan kes kajian bermula dengan nilai tertinggi 0.0148 S/m dan nilai yang terendah ialah 0.0053 S/m. Nilai pengurangan gelombang EM bagi rongga yang berisi yang berkait dengan struktur konkrit adalah lebih tinggi dengan nilai 57.0448 dB/m dan 41.5438 dB/m berbanding dengan 0.9672 dB/m bagi rongga berisi udara. Nilai pengurangan gelombang EM bagi rongga berisi sedimen bermula dgn nilai pengurangan tertinggi adalah 8.9725 dB/m dan yang terendah adalah 2.9447 dB/m. Kesimpulannya, kesemua objektif dalam kajian ini berjaya dicapai dan kaedah pengimejan keberintangan 2-D dan radar tusukan bumi berjaya membezakan antara parameter geofizikal bagi rongga berisi udara, struktur konkrit dan rongga berisi sedimen.

GEOPHYSICAL PARAMETERS DETERMINATION USING 2-D RESISTIVITY IMAGING AND GROUND PENETRATING RADAR FOR SUBSURFACE STRUCTURES

ABSTRACT

2-D Resistivity Imaging and Ground Penetrating Radar (GPR) methods are geophysical methods that can be used to study the subsurface. The study areas are located at Pulau Pinang, Perlis, Kedah and Kelantan. This research using the Pole-Dipole and Wenner Schlumberger arrays as for the 2-D Resistivity Imaging method and 250 MHz antenna as for the Ground Penetrating Radar (GPR) method at all the study locations. The objectives of this research are to detect and identify the possible signatures that signifies the cavities by using 2-D Resistivity Imaging and GPR methods, to correlate the geophysical parameters such as conductivity values from 2-D Resistivity and GPR, velocities of the EM wave propagation, dielectric permittivity, attenuation values of EM wave and Mean Absolute Percentage Error (MAPE) values that can be obtain from 2-D Resistivity Imaging and GPR methods and lastly, to distinguish the geophysical parameters between air filled cavity, concrete structures and sediments filled cavity. A higher resistivity value starting from 500-800 Ωm indicates the air-filled cavity while resistivity value starting from 5-250 Ωm indicates the in-filled cavity associated with concrete structures and resistivity value starting from 5-60 Ωm represents the sediment filled cavity. The calculated conductivity values for the field models starting with the air filled cavity is 0.0016 S/m and for in-filled cavities associated with concrete structure are 0.0926 S/m and 0.0772 S/m. The calculated conductivity values for all case studies starting with the highest value 0.0148 S/m and the lowest value is 0.0053 S/m. The

attenuation value of EM wave for the in-filled cavity associated with concrete structure is much higher with 57.0448 dB/m and 41.5438 dB/m compared with 0.9672 dB/m for the air-filled cavity. The attenuation value of EM wave of sediments filled cavities starting with the highest attenuation value is 8.9725 dB/m and the lowest is 2.9447 dB/m. In conclusion, the objectives in this research were successfully achieved and 2-D Resistivity Imaging and GPR methods were able to differentiate between the geophysical parameters for air-filled cavity, concrete structure and sediments filled cavity.

CHAPTER 1

INTRODUCTION

1.0 Background

There are many differences related to geophysical studies and geotechnical studies. Basically, both of them have one objective, to represent an accurate data about the subsurface but in different kind of field. Geotechnical studies are usually used by the engineers to map ground subsurface and environmental works. Geophysical studies provide additional data for engineers to improve the work and it is cost effective. Geophysical studies can be used to determine the subsurface structures such as depth of bedrock, nature of overburden materials and near surface structures such as sinkholes, cavities, voids, faults and boulders. Appropriate geophysical method has to be based on objectives and site conditions to produce a good result and has the ability to produce an accurate data for future use.

Basically, geophysical methods consist of some regular methods such as microgravity, seismic, magnetic, Ground Penetrating Radar (GPR) and 2-D Resistivity Imaging. Each of geophysical methods has their own limitation. Regarding some of the limitation of each method, it is crucial to not only depend on one method in order to achieve a good and accurate result. It is also depends on the financial provided, the survey area and the most important thing is the objective of the survey.

There are several approaches are available to gather information about ground subsurface. The best solution is direct observation of the sediments and rocks but of course this is rarely possible in terms of financially and work rates. Commonly, when subsurface information is necessary, it acquired the physical measurements to be applied to the ground subsurface in order to deduce the subsurface over substantial are in a reasonable time-frame and in a cost-effective manner (Burger et al., 2006).

Cavity or void is an empty space inside a solid body or object. The detection of cavities and tunnels at study area using geophysical methods has gained wide interest in the past few decades. The discovery of cavities is important since the presence of natural voids or cavities at the subsurface particularly at limestone area which may causes some severe problems that can be related with engineering management (Sum et al., 1996). A variety of geophysical methods can be used to study about the presence of caves and voids at all types of subsurface materials. Physical contrast between a cave and the surrounding rocks can be detected using the geophysical methods. For example, the resistivity value that indicates the void is higher than the surrounding materials, hence 2-D Resistivity Imaging is used successfully (Noel and Xu, 1992; Manzanilla et al., 1994). The geophysical methods such as 2-D Resistivity Imaging method are most likely to be successful if it is used in conjunction with other methods since the limestone will also have high resistivity value. (El-Qady et al., 2006). Cavities in the limestone area are considered one of the major concerns to engineers with many catastrophic events occurring associated with the cavities in the limestone bedrock. The cavities have various sizes and thicknesses and occur at various depths. A survey was conducted to investigate the size of cavity based on borehole data in Ipoh area showed that they are mostly <3 m in thickness (Tan, 1988). According to Ting, (1985) and Ting et al., (1993), the most common cavity size is <1 m. In any case, occasional large cavities >3 m can still be encountered at a particular site. Therefore, the detection and identification of the detailed configuration of the cavity system at a particular construction site can be considered as major efforts for site investigation. The detection and identification of cavities can be considered as a major effort is because it can help the people to understand more about the subsurface area.

Based on the 2-D Resistivity Imaging results, it shows that the difference in resistivity value between an air-filled cavity and the surrounding limestone may be the most outstanding physical feature of a cave, hence this is the main reason for the 2-D Resistivity Imaging method has been the most widely method used for cave detection (Elawadi et al., 2001; Ushijima et al., 1989; Smith, 1986). Based on geological engineering and environmental management prospect, Ground Penetrating Radar (GPR) has been a very useful method for mapping shallow targets (Fisher et al., 1992). GPR method is based on the detection of electromagnetic (EM) wave reflections from short bursts of EM wave emitted by a portable radar transmitter (Conyers and Goodman, 1997). The subsurface imaging by GPR will give the best resolution for the GPR results if the subsurface area is made up of dry fine grained materials because of low conductivity value that allows the EM wave to propagate properly (Reynolds, 1997).

1.1 Problem statements

Most known caves that have visible entrances are because of natural erosion causing the roof to collapse hence exposing the cave. Detection undiscovered caves that related with karst topographic area is important in the evaluation in terms of the environmental problems such as land subsidence and development of sinkholes.

Naturally formed enormous void in karst topography may lead to sudden and catastrophic events, while as for the fine particles that slowly migrate at the subsurface area may cause gradational ground subsidence. Any engineering and environmental problems related with karst topography such as land subsidence and development of large sinkholes may lead to much costly expenditure for building any structures on top of karst environment if the engineers unable to encounter those problems.

Various geophysical methods can be used for detecting karst voids in subsurface. All of the geophysical methods measured physical contrast of the voids and the surrounding materials. The incompetent to differentiate the geophysical parameters between air filled cavity, concrete structures and in-filled cavity has lead to this research to be conducted. Geophysical methods allow large areas to be covered in a short period of time and represent an efficient and cost effective way in detecting subsurface heterogeneities at the karst environment, including voids, subsidence, and sinkholes. All such methods have shown great potential for accurately mapping subsurface under certain conditions, but 2-D Resistivity Imaging method is considered as one of the most promising methods for karst voids (Roth and Nyquist, 2003). Ground Penetrating Radar (GPR) also can be considered as one of the geophysical method that is useful to detect the cavities or voids with diameters less than 10 m in subsurface (Collins et al., 1994; Benito et al., 1995; Harris et al., 1995). Geophysical or geotechnical methods unable to stand alone and this may lead to data misinterpretation.

1.2 Research objectives

The objectives of this research are;

i. To detect and identify the possible signatures that signifies the cavities by using 2-D Resistivity Imaging and GPR methods.

ii. To correlate the velocity of EM wave, dielectric permittivity, EM attenuation value, conductivity value from 2-D Resistivity Imaging and GPR, and Mean Absolute Percentage Error (MAPE) value obtained from both geophysical methods.

iii. To distinguish the geophysical parameters between air-filled cavity, concrete structures and sediments filled cavity.

1.3 Scope of study

Two geophysical methods which are 2-D Resistivity Imaging and GPR were applied at various locations throughout Malaysia for the cavity detection and identification. The methods were used with the main purpose of to integrate both geophysical methods and obtaining the geophysical parameters. There are two main field models in this research. The field models can be divided into two major groups which are air-filled cavity and in-filled cavity. The geophysical parameters obtained by integrating 2-D Resistivity Imaging and GPR are, velocity of the EM wave, dielectric permittivity, attenuation of the EM wave, conductivity value of the ground subsurface, and Mean Absolute Percentage Error (MAPE) value. The study was conducted at Pulau Pinang as for air filled and in-filled cavity field models while at Perlis, Kedah and Kelantan as for case studies related to those types of cavities.

1.4 Motivation and research novelty

Based on previous studies, the cavities can be classified into two major types air-filled and in-filled cavity as referred to 2-D Resistivity Imaging results. The GPR results only provide hyperbolic curves from radargram that indicate the cavities either air-filled or in-filled cavity. This research was conducted in order to scrutinize the difference between geophysical parameters of the air-filled and in-filled cavity which represent by the conductivity value from 2-D Resistivity Imaging and GPR methods. The difference between the in-filled cavity and concrete structures also can be distinguished precisely after obtaining the geophysical parameter which is the attenuation value of EM wave related with all the characterization regarding types of cavities.

1.5 Layout of thesis

The contents of this dissertation are structured as follows;

Chapter 1, the background of this research is introduced. Problem statements and research objectives to be achieved related with this research are highlighted. Furthermore, the scope of study, motivation and research novelty as well as the layout of thesis are presented in this chapter.

Chapter 2 includes fundamental theory about the 2-D Resistivity Imaging and GPR methods. The previous studies using the 2-D Resistivity Imaging and GPR methods applied in the engineering proposes and problems related in detecting karst features such as sinkholes, pinnacles and cavities in limestone formation are also being discussed in this chapter. The research gaps for this research as compared with other previous studies also being discussed in this chapter.

Chapter 3 includes about the research flowchart. This research applied 2-D Resistivity Imaging and GPR methods at various study areas located throughout Malaysia such as Pulau Pinang, Perlis, Kedah and Kelantan were described. The geological maps for each study area also being explained in this chapter. This chapter also discussed about the research involves the calculation of geophysical parameters indicating the air-filled or in-filled cavity such as EM wave velocity, dielectric permittivity, attenuation value of EM wave, conductivity value from 2-D Resistivity and GPR, and Mean Absolute Percentage Error (MAPE) value.

In Chapter 4, the final data is being shown. The detail information or data involving the signatures of the cavities from 2-D Resistivity Imaging and GPR methods, the geophysical parameters that distinguished between air-filled cavity, concrete structures and sediment filled cavity being discussed and the possible depth of the cavities at study area well explained.

Finally, Chapter 5 concluded that the 2-D Resistivity Imaging and GPR study in detecting cavities and geophysical parameters associated with air-filled cavity, concrete structures and sediments filled cavity were highlighted. Finally, the recommendations for future research involving 2-D Resistivity Imaging and GPR methods or using other methods are proposed.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Karst topography basically is an area that is majorly made up of limestone and other carbonate rocks such as dolomite, gypsum and marble. Karst topography or features such as pinnacles, cavities, and underground tunnels presents some of the most challenging conditions for designing or constructing new structures or rebuilds old buildings on top of the karst areas. This is because of highly variable conditions that often related to karst areas, which may increases in site development costs that can occur both during and after construction without proper understanding of the subsurface condition that is largely covered by karst. With proper selected and applied geophysical method, it significantly provide better prediction of development costs and better selection of appropriate foundations in the planning stage rather than during and after construction processes.

Recently, cavities detection using geophysical surveys has become common in field of exploration geophysics. Geophysical methods such as the 2-D Resistivity Imaging, seismic reflection, Ground Penetrating Radar (GPR), gravity, or magnetic have their own purposes that is different from other methods in terms of their parameters of the subsurface phenomena. Some of the methods have been used for shallow subsurface investigation in bedrock mapping, detecting abandoned coal mine, determining the bedrock or faults and detection of karst topography such as sinkholes, cavities, and pinnacles. All the methods depend on presence of contrast in the subsurface and also the environment factor such as for magnetic survey that may encounter some difficulties when there is metal object nearby (Pullan and Hunter, 1990).

2-D Resistivity Imaging method is based on injecting electrical current into the subsurface using electrodes, known as current electrodes (C_1 and $C_{2)}$ and then measuring potential between electrodes known as potential electrodes (P_1 and $P_{2)}$. The measured potential allows for the determination of the resistivity values in which the value of apparent resistivity can be calculated by multiplying the resistance by an appropriate geometric factor. The geometric factor depends on the type of acquisition array used during the survey conducted (Sheriff, 1999). The apparent resistivity is then being inverted to obtain true subsurface resistivity and provide information about thickness and depth of individual resistivity layers within the subsurface area. The step to produce inversion model of the 2-D Resistivity Imaging results is consider as an essential step in all modern 2-D Resistivity Imaging surveys for the subsurface analysis. Fundamentally, a mathematical procedure was used to calculate apparent resistivity value of the subsurface by which physical parameter distribution is estimated based on field measurements (Telford et al., 1990; Reynolds, 2000; Loke and Barker, 1995).

The GPR data can be obtained by distributing EM waves from transmitting antenna into the subsurface and later on being reflected diffracted by features coincide to the changes in the electrical properties of the earth materials. EM waves that were reflected and diffracted toward the surface receive by a receiving antenna. The time travel of the EM waves are measured and converted into depth penetration profile between the targets and the antenna. By analyzing some of characteristic properties of the returned EM waves, all the details such as dimensions of the target at the subsurface and possible depth about the target can be obtained (Daniels et al., 1988; Davis and Annan, 1989).

2.1 2-D Resistivity Imaging theory

Given these measurement it is possible to solve numerically for a resistivity distribution that results in a set of calculated resistivity measurements that best fits with the measured response (El-Qady et al., 2006). The survey data is processed to produce the inversion model sections of thickness and individual resistivity values of each layer of the subsurface. The common electrode arrays that being used in resistivity survey are Pole-Pole, Pole-Dipole, Wenner, Wenner-Schlumberger and Schlumberger array. The major variation of 2-D Resistivity Imaging results depends on an array used during the survey, the electrode spacing and the condition of the survey area whether the ground area is wet or dry.

The method consists of placing electrodes along the 2-D Resistivity Imaging survey line using certain electrode spacing that depends on the purposes of the study as this will affect depth and resolution of the data required. A higher resolution is obtained if the electrodes are placed closer, while for widely spaced electrodes, a greater depth can be obtained or investigated with lower resolution (Sasaki, 1992). The electrode arrangement was connected to a measuring device with specific control system was used to select the group of electrodes that should function simultaneously in any particular electronic arrangement. For each arrangement, the resistivity value of the subsurface are measured and attributed to a specific geometric point of the subsurface.

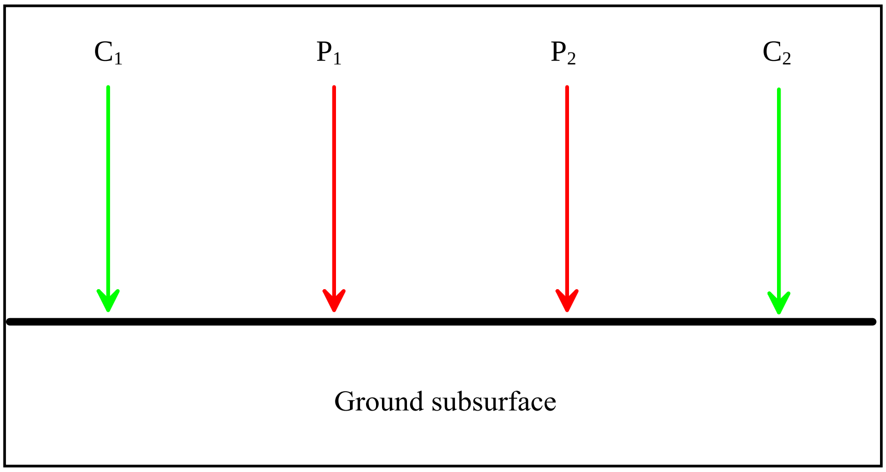

Figure 2.1: Four electrodes array for the basic 2-D Resistivity Imaging measurement.

2-D Resistivity Imaging surveys have been used for many decades in geotechnical investigations. Figure 2.2 shows the arrangement of 2-D Resistivity Imaging survey in order to produce resistivity inversion model. More recently, it been used for environmental surveys in detecting karstic features such as pinnacles, sinkholes and cavities. The purpose of 2-D Resistivity Imaging surveys are to determine the subsurface resistivity distribution by making measurements on the ground surface. The measurements estimate true resistivity of subsurface can be estimated. The ground resistivity value is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation (Loke, 1999).

The resistivity measurements shown in Figure 2.1 are normally made by injecting current (I) into the ground and the value of potential difference (V) is calculated (Loke, 1999) and electrical resistance is measured according to Ohm's law (Equation 2.1):

$$R = \frac{V}{I} \tag{2.1}$$

Where;

R : Resistance of the conductor.

The SI unit for resistance is volts per ampere or Ohm (Ω). The resistivity can be calculated by using Equation 2.2;

$$R = \rho \frac{L}{A} \tag{2.2}$$

Where;

ρ : Resistivity of the conductor material (Ωm),
L : Length of the conductor (m)
A : Cross-sectional area (m^2)

The calculated resistivity value is not a true resistivity of the subsurface, but an apparent value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between apparent and true resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out (Loke, 1999; 2004).

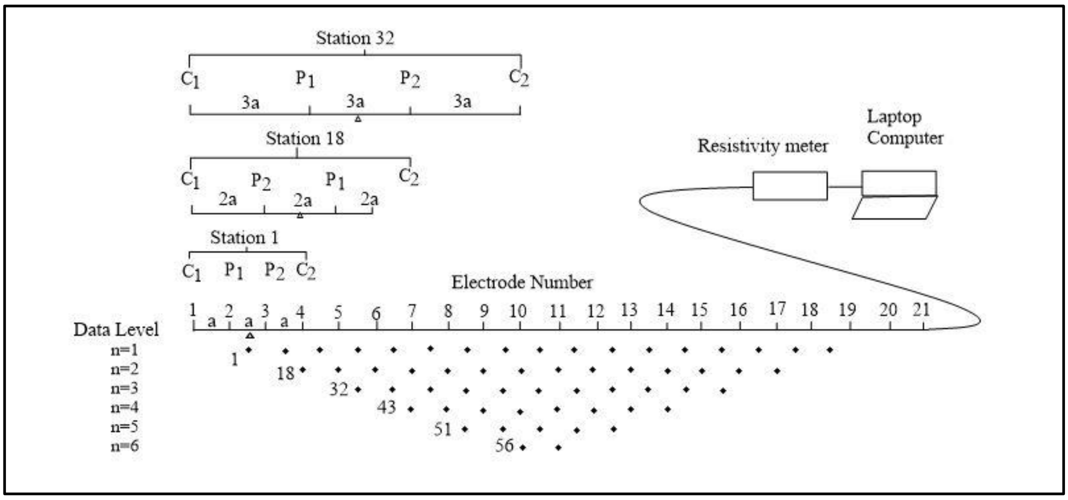

Figure 2.2: The arrangement for 2-D Resistivity Imaging survey and the sequence of measurements used to build up the resistivity section (modified from Loke, 1999).

The choice of the best array in a field survey depends on type of structure to be mapped, sensitivity of the resistivity meter and background noise level. In practice, the arrays that are most commonly used for 2-D imaging surveys are Pole-Dipole, Dipole-Dipole, Wenner-Schlumberger, Wenner Alpha, and Pole-Pole. Among the characteristics of an array that should be considered are the sensitivity of the array to vertical and horizontal changes in the subsurface resistivity, depth of investigation, horizontal data coverage and signal strength (ABEM, 2006). Based on this research in identifying and detecting karst features, most of the study areas used Pole-Dipole array in order to get deeper depth of penetration. The other study areas such as at Perlis, Kedah, and Kelantan, the arrays used were Pole-Dipole and Wenner-Schlumberger. Figure 2.3 shows the common array used in 2-D Resistivity Imaging survey with their geometric factor “k”.

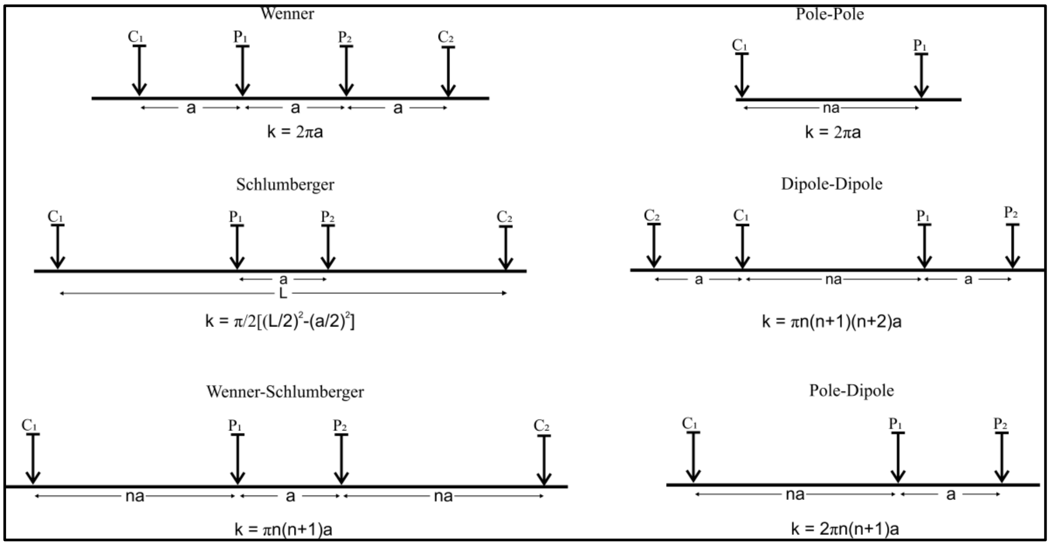

Figure 2.3: Resistivity common array and their geometric factors (modified from Loke and Barker, 1996).

2.2 Ground Penetrating Radar (GPR) theory

GPR is a geophysical method used to investigate ground subsurface with high resolution imaging. The depth range of GPR is limited by the electrical conductivity of the ground and frequency of the antenna used. The Ground Penetrating Radar (GPR) use the reflections of short bursts of electromagnetic energy with a range of frequencies being transmitted into the ground and register the reflected pulses as functions of time and position of the antenna pair along a survey line (Figure 2.4).

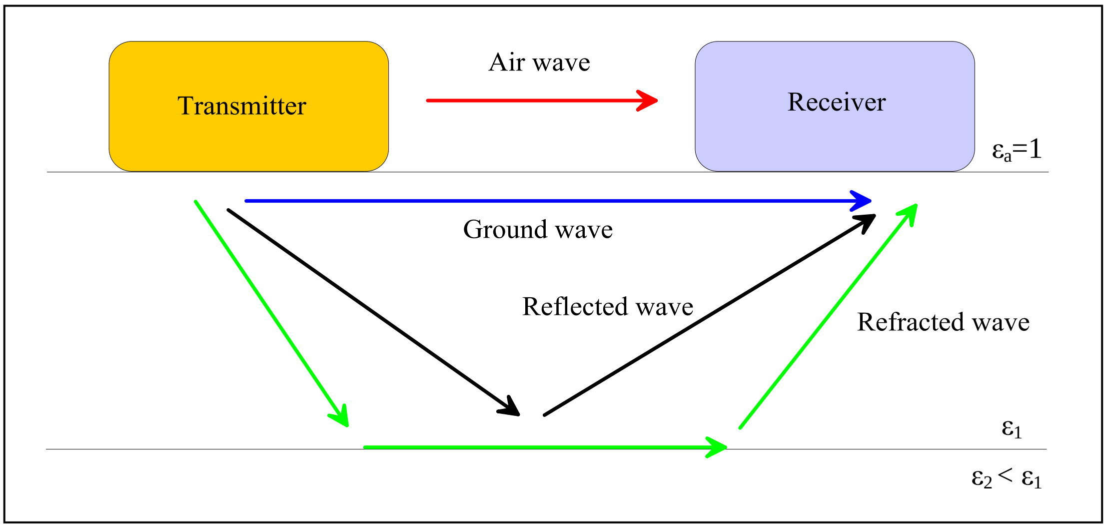

Figure 2.4: Basic principle of the GPR (modified from Jol, 2009).

Historically, the development of GPR derives from the use of radio echo sounding to determine any certain targets at subsurface (Milsom, 2003). Dry soils can be consider as a good medium for the GPR application, since higher radio-frequencies can be used for a given depth of investigation, which implies a better resolution of the buried structures (María et al., 2011). It was soon realized that some penetration was being achieved into the deeper depth of investigation, although unlikely to ever amount to more than a few tens of meters, could be increased by processing techniques virtually identical to those applied to seismic reflection data. GPR is now widely used to study about the shallow subsurface at landfill, construction, archaeological sites and many other survey sites.

GPR signals are recorded by transmitting and receiving the EM waves which propagates at the subsurface area, with high frequency, typically between 10 and 1000 MHz, as a periodic disturbance. EM waves have both electric and magnetic characteristics, which are perpendicular to each other. GPR can map the variations of the electrical and magnetic characteristics of the subsurface geological materials since all those materials have significant differences for the electrical and magnetic value. The depth penetration and resolution of the results obtained really depend on the electromagnetic properties of the geological materials located in the subsurface area and through which the EM waves propagate and based on the type of antenna that is used for the survey purposes. Therefore, EM wave propagation decreases as the conductivity of the subsurface area or the frequency of the emitted signal increases. For a single GPR survey profile, higher frequency antennas will produce higher resolution with shallower depth of penetration and vice versa if the lower frequency being applied (Davis and Annan, 1989).

Table 2.1 shows the resistivity values, dielectric values and velocity of material through different medium. The given velocity values were used to calculate the depth of the target.

Table 2.1: The resistivity values, dielectric and velocity of material through different medium (Davis and Annan, 1989; Reynolds, 1997).

Material	**Resistivity values (Ωm)**	**Dielectric permittivity, (ε_r)**	**Velocity (mm/ns)**
Limestone	$50 - 10^3$	7 - 9	100 - 113
Sand (dry)	30 - 225	3 - 6	120 - 170
Clay soil	1×10^2	3	173
Clay (wet)	30 - 100	8 - 15	86 - 110
Granite	$3 \times 10^2 - 10^6$	5 - 8	106 - 120
Concrete	80 - 500	6 - 8	55 - 112

2.3 Previous study

Previously many researchers have conducted various researches about the karst features such as cavities, pinnacles, and sinkholes at subsurface area. In karst topography, detection of cavities is considered as top priority. Al-Zoubi et al. (2012) stated that the identification of cavities, fractures and collapse zones can be considered as one of the most difficult subsurface investigations. The Dead Sea sinkholes at surface are caused by development of dissolution cavities forming in salt layers located at a depth of 40-50 m from the top surface. Development of karstic cavities causes the variations in properties and structure of both salt and its overlain sediments; density, porosity, electrical conductivity, seismic velocity and many more. The geophysical method used for sinkholes assessment and identification is seismic refraction method which used for mapping of salt layer, 2-D Resistivity Imaging was used in order to facilitate detection of high resistivity zones associated with air-filled cavities and decompaction of the subsurface. Ground penetrating radar (GPR) is used to allow detection of subsurface faults, buried voids and sinkholes. Electromagnetic radiation (EMR) was used to measures the electromagnetic radiation (EMR) emitted from cracks which dimensions in micro-scales that located within the rocks and estimates the active faults and cracks along the surveyed profiles.

Microgravity and Magnitometry methods are used for search of zones with the mass deficit and zones of magnetic anomalies as those zones are considered as zones of karst. Nano-Seismic was developed to detect and identify the extremely low-energy signals generated by soil falling into cavities.

The other research conducted by Kwon et al. (2000) stated that there are several geophysical methods were applied over the Manjang cave area in Cheju Island to compare the effectiveness of each method for exploration of underground cavities. The geophysical methods used are gravity, magnetic, 2-D Resistivity Imaging and Ground Penetrating Radar (GPR) survey, of which instruments are portable and operations are relatively economical and there are seven survey lines in total. In the case of magnetic method, two-dimensional grid-type surveys were carried out to cover the survey area. The geophysical survey results reveal the characteristic responses of each method relatively well. Among the applied methods, the electric resistivity methods appeared to be one of the most effective method in detecting the Manjang Cave and surrounding miscellaneous cavities. The gravity and magnetic data are contaminated easily by various noises and do not show the definitive responses enough to locate and delineate the Manjang cave. But those two geophysical methods provide useful information in verifying with the Dipole-Dipole 2-D Resistivity Imaging survey results. The grid-type 2-D magnetic survey data show the trend of cave development well, and it may be used as a reconnaissance regional survey for determining survey lines for further detailed explorations. The GPR data show very sensitive response to the various shallow volcanic structures such as thin spaces between lava flows and small cavities, but unable to identify the response of the main cave. Although each geophysical method provides its own useful information, the integrated interpretation of multiple survey data is most effective for investigation of the underground caves.

Choi et al. (2013) discussed about detection of cavities using 2-D Resistivity Imaging and optical borehole imaging methods to identify underground cavities and determine ground subsidence rate at the study area affected by land subsidence due to abandoned underground mines. At the first study area, the anomalous zones of low resistivity ranging from 100-150 Ωm were observed and confirmed as an abandoned underground mine by subsequent borehole drilling and optical borehole imaging. Although the 2-D Resistivity Imaging survey was unavailable due to the paved surface of the second study area, the method able to locate another abandoned underground mine with the collapsed mine shaft based on the distribution of the ore veins and later on being confirmed by borehole drilling method. In addition, the measured vertical displacements of underground features indicating underground subsidence by conducting optical borehole imaging 6 times over a period of 43 days at the second study area. The displacement magnitude at the deep segment caused by subsidence appeared to be 3 times larger than those at the shallow segment. Similarly, the displacement duration at the deep segment was 4 times longer than those at the shallow segment. Therefore, the combination of 2-D Resistivity Imaging and optical borehole imaging methods can be effectively applicable to detect and monitor ground subsidence caused by underground cavities.

Farooq et al. (2012) discussed about determining the extent of the karst voids using 2-D Resistivity Imaging technique to investigate the subsurface geology beneath the proposed road network construction. This investigation was aimed at imaging karstic voids and detecting the prone areas that could be affected by ground subsidence through the collapse of cavities beneath a road segment overlying such features. The survey data set consisted of eleven 2-D Resistivity Imaging profiles acquired using Dipole-Dipole array with the 2-D Resistivity Imaging profiles (100 m and 300 m length) with the electrode spacing of 5 m. The inverted 2-D Resistivity Imaging profiles provide a clear view of weathered soils, the distribution of weak areas or karst voids and bedrock. Several low resistivity areas were identified and later on subsequent drilling of such anomalous areas led to the discovery of several weak zones or clay-filled underground cavities beneath the road network construction area. This proves that the drilling results had excellent correlation with the inverted 2-D Resistivity Imaging profiles thus the 2-D Resistivity Imaging is an excellent technique in delineating the karstic voids even on a complex geological structures. An action plan regarding the discovery of the weak zones will involved the consolidation grouting work has been suggested prior to road construction.

Carrière et al. (2013) highlighted the efficiency of geophysical techniques used to study about the structure of karst in which can be classified as unsaturated zone where soil cover is thin or absent in typical Mediterranean environment. The geophysical technique applied to the research area is Ground Penetrating Radar (GPR) and 2-D Resistivity Imaging. The GPR results will provide a near surface high resolution imaging and thus the relevant geological information such as stratifications and fractures can be obtained from the results. The 2-D Resistivity Imaging inversion profiles will show strong lateral and vertical variations for the subsurface area. These variations can explain about the general geological structuring and feature orientation below the surface. 2-D Resistivity Imaging profiles are able to displays up to 40 m below the surface but it will have a low resolution integrative technique. Basically, limestone study area will have about more than 2000 Ωm of resistivity value. However, the 2-D Resistivity Imaging profiles reveal some several zones of moderate resistivity value around 900 Ωm at depth more than 5-7 m. In these zones a stratification change corresponding to slanted bedding it can be clearly identified by GPR results as both of those two methods being correlated. The combination of both GPR and 2-D Resistivity Imaging data can allow a well-established geological interpretation to be made. The presence of perennial water flow point at 35 m below the surface can be explained by these moderate resistivity zones with slanted beddings.

Kang and Hsu (2013) explained about the study to detect and locate the cavities in a coastal dyke using the Ground Penetrating Radar method (GPR). The hidden cavities in a coastal dyke are the key indications of possible soil subsidence of the subsurface area or seepage piping within the soil of the dyke. A series of numerical simulations and field tests were conducted at the research area. The results show that the size of cavities influenced by the average area difference curve that can be obtained from GPR signals. By using the average area difference curve obtained, shallow cavities in a coastal dyke can be identified effectively.

Roth et al. (2002) discussed about the geotechnical investigations in northeastern Pennsylvania that have various structural failures regarding sinkholes The geotechnical technique used is primarily relied upon intrusive probe tests, either through borings or air-track drillings. The used of non-intrusive Ground Penetrating Radar (GPR) and electromagnetic methods are limited due to silty clay soils overlying the carbonate bedrock. However, multi 2-D Resistivity Imaging testing can be considered as suitable method for locating subsurface features associated with sinkhole formation in these areas. The bedrock at the site is located between 1 m and approximately 10 m below the surface in which the subsurface area primarily dominated by silty clay after 70 resistivity survey lines were conducted at the site.