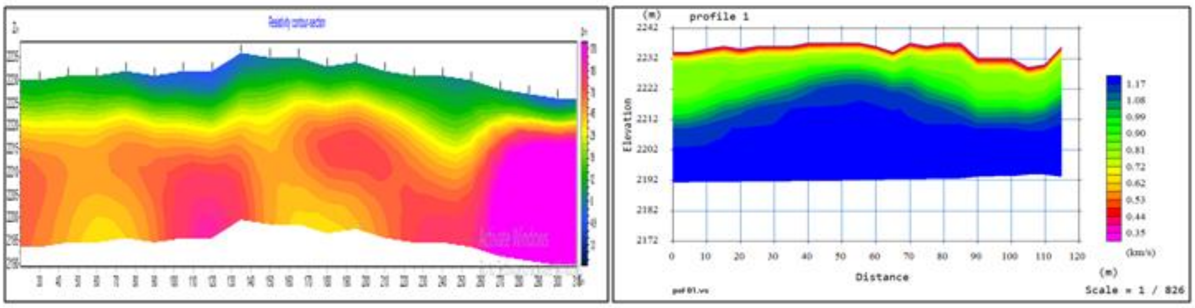
ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF GRADUATE STUDIES

ELECTRICAL RESISTIVITY IMAGING AND SEISMIC REFRACTION: APPLICATION FOR RESIDENTIAL BUILDING FOUNDATION AT SOUTH EAST OF ADDIS ABABA, LEBU AREA, ETHIOPIA



A Thesis Submitted to School of Graduate Studies of Addis Ababa University

In partial fulfillment of the requirements for the Degree of Masters of Sciences

(Applied Geophysics)

By
Genet Assefa
Advisor: Getnet Mewa (Dr)

May 2019
Addis Ababa

ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

SCHOOL OF GRADUATE STUDIES

ELECTRICAL RESISTIVITY IMAGING AND SEISMIC REFRACTION: APPLICATION FOR RESIDENTIAL BUILDING FOUNDATION AT SOUTH EAST OF ADDIS ABABA, LEBU AREA, ETHIOPIA

By

Genet Assefa

Faculty of Science

School of Earth Sciences

Approved by board of examiners:-

1. Dr. Balemwal Atnafu **Signature_______________** **Date_______________**

(Head, School of Earth Sciences)

2. Dr. Getnet Mewa **Signature______________** **Date______________**

(Advisor)

3.________________________ **Signature_____________** **Date ____________**

(Examiner)

4.________________________ **Signature_____________** **Date ____________**

(Examiner)

Declaration

This is to certify that the thesis prepared by Genet Assefa entitled: "***Electrical Resistivity Imaging and Seismic Refraction: Application for Residential Building Foundation at South East of Addis Ababa, Lebu Area, Ethiopia***" is my original work conducted under the supervision of Dr. Getnet Mewa and has not presented to any university or institution for the award of any degree or diploma program and all sources of materials used for the thesis are properly acknowledged.

Name of the candidate	Signature	Date
Genet Assefa	________	_______

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and it has been submitted for examination with my approval as university advisor.

Dr. Getnet Mewa	Signature	Date
(Advisor)	_________	________

Abstract

In this study, geophysical method of seismic refraction and electrical resistivity measurements using electrical resistivity tomography and vertical electrical sounding (VES) technique was utilized for the acquisition of geotechnical information of the subsurface at a proposed site. The site is located in south East of Addis Ababa at a place locally called Lebu Mebrat Haile.

The study is aimed to image the subsurface geology and understand the soils and rocks characteristics in terms of site's suitability for civil engineering applications. Three lines of seismic refraction data, two lines of electrical resistivity tomography data and six vertical electrical sounding stations with AB/2 ranging from 150m-220m were conducted.

The geophysical results discovered that the study area can be characterized as five geologic layers. Layer filled by loose sand and gravel, layer filled by silt clay with some sand, layer filled by silt clay with some sand with less moisture content, layer filled by clay with considerable fluid content and highly weathered and fractured basalt. The study also characterizes the presence of weak zones in the subsurface. This geophysical data's were linked to the borehole log result near the study area and the outputs correlate each other.

Generally the result of the study shows that the area is filled by loose sediments and clay with variable degree of moisture content and mineralogical composition. Since the study area is found in a place susceptible to low and medium earthquakes, such formation can amplify even small amount of earthquakes and cause any damage in the buildings. Up to survey depth which is 40m the researcher not found bedrock and ground water in the study area. Therefore, great caution should be taken by the engineer when designing foundation for the residential buildings found in the study area.

ACKNOWLEDGMENT

First of all I would like to thank my advisor Dr. Getnet Mewa for his positive energy to support me in all aspects of the research work. Without his scientific advices, fruitful comments and inspirational consultations this research work would not been successful as it is now.

Secondly, I would like to thank Geological Survey of Ethiopia (GSE) for its full sponsorship and its financial and logistic supplements during the field work.

I am also tank full to DMC construction for giving me the Borehole log results.

I would like to thank the MSc. candidates of the geophysics stream at the School of Earth Sciences of Addis Ababa University.

Finally, my sincere thanks go to my parents who helped me a lot in finalizing this thesis work within the limited time frame.

Table of Contents

Abstract ……………………………………………………………………………….………-i-

Acknowledgement ………………………………………………………………………....-ii-

List of Figures………………………………………………………..…………………-v-

List of Tables ………………………………………………….……………………-vi-

List of Appendices……………………………………………………………………...-vi-

Acronym ………………………………………………………………………..-vii-

CHAPTER I .... - 1 -

INTRODUCTION .... - 1 -

1.1 Background .... - 1 -

1.2 Location and site description of the study area .... - 3 -

1.2.1 Location of the study area .... - 3 -

1.2.2 Site Description of the study area .... - 4 -

1.3 Previous works .... - 4 -

1.4 Statement of the problem .... - 6 -

1.5 Objectives .... - 7 -

1.6 Significance of the Study .... - 7 -

1.7 Limitation of the Study Area .... - 7 -

1.8 Methodologies .... - 8 -

1.8.1 Pre-field work .... - 9 -

1.8.2 Field work .... - 9 -

1.8.3Post-field work .... - 9 -

CHAPTER II .... - 10 -

GEOLOGY AND HYDROGEOLOGY .... - 10 -

2.1Regional Geology .... - 10 -

2.2Local Geology 14

2.3Hydrogeology of the study area 15

2.4.Seismicity .... - 16 -

CHAPTERIII ....- 18 -
THEORETICAL BACKGROUND OF GEOPHYSICAL METHODS..................................- 18 -
3.1 Electrical Resistivity Method..- 18 -
3.1.1 Electrode Configurations..- 21 -
3.1.2 Electrical Properties of Earth Materials ....- 23 -
3.1.3 Techniques in Electrical Resistivity Surveys ....- 24 -
3.2 Seismic Refraction Survey...- 26 -
CHAPTER IV ....- 30 -
GEOPHYSICAL INVSTIGATIONS ....- 30 -
4.1 Geophysical Data Acquisition and Processing ....- 30 -
4.1.1 Seismic refraction..33
4.1.2 Electrical Resistivity Tomography..- 36 -
4.1.3 Vertical Electrical Resistivity Sounding ....- 37 -
CHAPTER V ....- 39 -
RESULT, DISCUSSION AND INTERPRETATION ....- 39 -
General ……...- 39 -
5.1 Seismic refraction data..33
5.2 Vertical Electrical Sounding Data ....- 45 -
5.3 Electrical Resistivity Tomography Data ....- 50 -
CHAPTER VI ....- 56 -
CONCLUSION AND RECOMMENDATION..- 56 -
6.1Conclusions..- 56 -
6.2Recommendations..- 59 -
Reference ....- 60 -
Appendices..- 62 -

List of Figures

Figure 1.1 Location map of the study area……………………………………………………..-3-
Figure 1.2 Partial view of the study area………………………………………………………-4-
Figure 2.1 engineering geological map of the study area……………………………………..-12-
Figure 2.2 clay soil distributed in the study area……………………………………………...-13-
Figure 2.3 Location map of the study area……………………………………………………-14-
Figure 2.4 Hydro geological map of the study area…………………………………………..-15-
Figure 2.5 Seismic hazard map of the study area……………………………………………-16-
Figure 2.6 Epicenter map of the study area with seismic source zones………………………-17-
Figure 3.1 electric field lines and equi-potential surfaces around a single electrode …..……-19-
at the surface of a uniform half-space hemispherical equi-potential surface
Figure 3.2 configurations for resistivity measurement using a pair of ………………………-20-
current and potential electrodes
Figure 3.3 wenner electrode configuration…………………………………….…………-21-
Figure 3.4 Schlumberger electrode configuration……………………………………………-22-
Figure 3.5 Dipole-Dipole configuration…………………………………………………...…-22-
Figure 3.6 electrode arrangements in electrical resistivity profiling ………………………...-24-
Figure 3.8 electrode setup used in ERT………………………………………………………-26-
Figure 3.9 the path of seismic wave's propagating from a source to the surface…………….-27-
Figure 3.10 Flow chart of Seismic refraction method ……………………………….…-28-
Figure 4.1 Location map of seismic refraction and ERT profiles, ……………………….... -31-
VES and BH- log points of the study area
Figure 4.2 Instruments used for collecting seismic refraction data…………………………..-32-
Figure 4.3 Sample of a seismogram representing the mid-shoot position (52.5m)…………-33-
Figure 4.4 Seismogram for the central shot with picked first arrivals ……………………..….. -34-
Figure 4.5 Flow chart of data acquisition and analysis for surface-wave method……….…..-35-
Figure 4.6 field data acquisition of ERT and VES……………………………………….…..-38-
Figure 5.1 p-wave velocity model of profile-1 ………………………………………….….... -41-
Figure 5.2 p-wave velocity model of profile-2 …………………………………...……. -43-
Figure 5.3 p-wave velocity model of profile-3…………………………………………….….-44-
Figure 5.4 Sample of H and HK-type sounding curves obtained from VES 4 and VES 5…...-45-

Figure 5.5 apparent resistivity pseudo depth section map of Profile -1…………………….…...-46-
Figure 5.6 Geo-Electric section of Profile - 1………………………………………………...-47-
Figure 5.7 apparent resistivity pseudo depth section map of Profile –2……………….……..-48-
Figure 5.8 Geo-Electric section of Profile - 2……………………………………………...…-49-
Figure 5.9 Electrical resistivity tomography section of profile 1…………………………….-50-
Figure 5.10 Electrical resistivity tomography section of profile2…………………………….-51-
Figure 5.11 integrated geophysical and borehole log results of profile-1……………………-53-
Figure 5.12 integrated geophysical and borehole log results of profile-2……………………-55-

List of Tables

Table 2.1 bed rock acceleration ratio ………………………………………………………...-17-
Table 3.1 resistivity values of some common earth materials ……………………………….-24-
Table 3.2 P and S-wave velocities of some rocks and other materials ……………………….-29-
Table 5.1 elastic parameters of various soils…………………………………………………-42-
Table 5.2 shear wave velocity range for profile-1……………………………………………-42-
Table 5.3 shear wave velocity range for profile -2……………………………………………-43-
Table 5.4 shear wave velocity range for profile -3……………………………………………-45-

List of Appendices

Appendix-1 travel time distance curves.. - 62 -
Appendix-2 VES points .... - 63 -
Appendix-3 resistivity of common rock .... - 66 -
Appendix-4 p- wave velocities of diffrenent materials.. - 67 -
Appendix -5 BH log results …...………………….…………………………………………-67-

Acronym

m	meter
m/s	meter per second
Km	Kilometer
Ω-m	ohm-meter
Hz	Hertz
GPS	Global Positioning System
NE	Northeast
NW	Northwest
RMS	Root Mean Square Error
SE	Southeast
SW	Southwest
UTM	Universal Transversal Mercator
VES	Vertical Electrical Sounding
2D	Two Dimensional
ERT	Electrical resistivity tomography
V_p	Primary wave velocity
V_S	Secondary wave Velocity

CHAPTER I
INTRODUCTION

1.1 Background

Buildings can be built to have different designs that make them attractive for many uses such as, residential, educational, commercial or industrial and meet the needs of people. However, if they are built without adequate consideration of the subsurface characteristics, they may be easily exposed to hazards. Before constructing any type of building an engineer should have a good understanding about the subsurface behavior of the site such as if the site encounter complex subsurface condition like, whether there are active fault in the area/region , weak surfaces, underground cavities, lateral transition of geological formations and ancient remains or in general inhomogeneity's of the underlying earth materials. (Hailemariam Siyum., 2011).

Geophysical methods are non-invasive approach for solving varieties of geotechnical, geological, hydrological and environmental problems .In recent years, there has been an increased awareness that subsurface characterization using standard drilling methods which offers a point measurement does not provide the information to accurately evaluate the true distribution of geologic parameters beneath ground surface at many sites (Holt et al., 1998). Hence, as complement to drill hole, geophysical technique can provide broad composite images of the subsurface over large areas at relatively lower cost and higher speed (Amigun et al., 2012).

A number of geophysical methods can be used for foundation investigation, such as seismic refraction, magnetics, electrical resistivity, ground penetrating radar and some others. In this research based on site conditions electrical resistivity (multi-level profiling and sounding) and seismic refraction methods are implemented

Electrical resistivity imaging was used to investigate the subsurface geological structures which include the possible presence of faults, fractures, and voids, determine depth to bedrock. Meanwhile, the seismic refraction method was used to map bedrock topography, obtain information about elastic properties of the subsurface that are essential for engineering design, for calculating the subsurface velocity profile, to determine the depth of gravel, sand or clay deposits and to determine the depth of the water table. The vertical electrical sounding can also be used to detect the depth of ground water and identify the nature of the subsurface geology. Thus, these three methods integrate together to characterize the sub surface layers, thickness of the overburden materials, depth to the groundwater table, extents of probable aquifer beds and nature of the bedrock.

The purpose of this research is to use the electrical imaging, seismic refraction and vertical electrical sounding method to get full information about the nature of the subsurface within study area and to provide inputs to civil engineers. Since the survey site is found within an area where massive residential buildings are expected, these outputs of this study may provide additional insight about the foundation conditions and develop appropriate mitigation measures to be implemented during the design and construction periods.

1.2 Location and site description of the study area

1.2.1 Location of the study area

The project area is located at the SE of Addis Ababa and geographically bounded by 0988814N/0470741E and 0989046N/0470713E at a place locally known as Lebu Mebrat Haile, Nifas Silk Lafto sub-city (Figure 1).

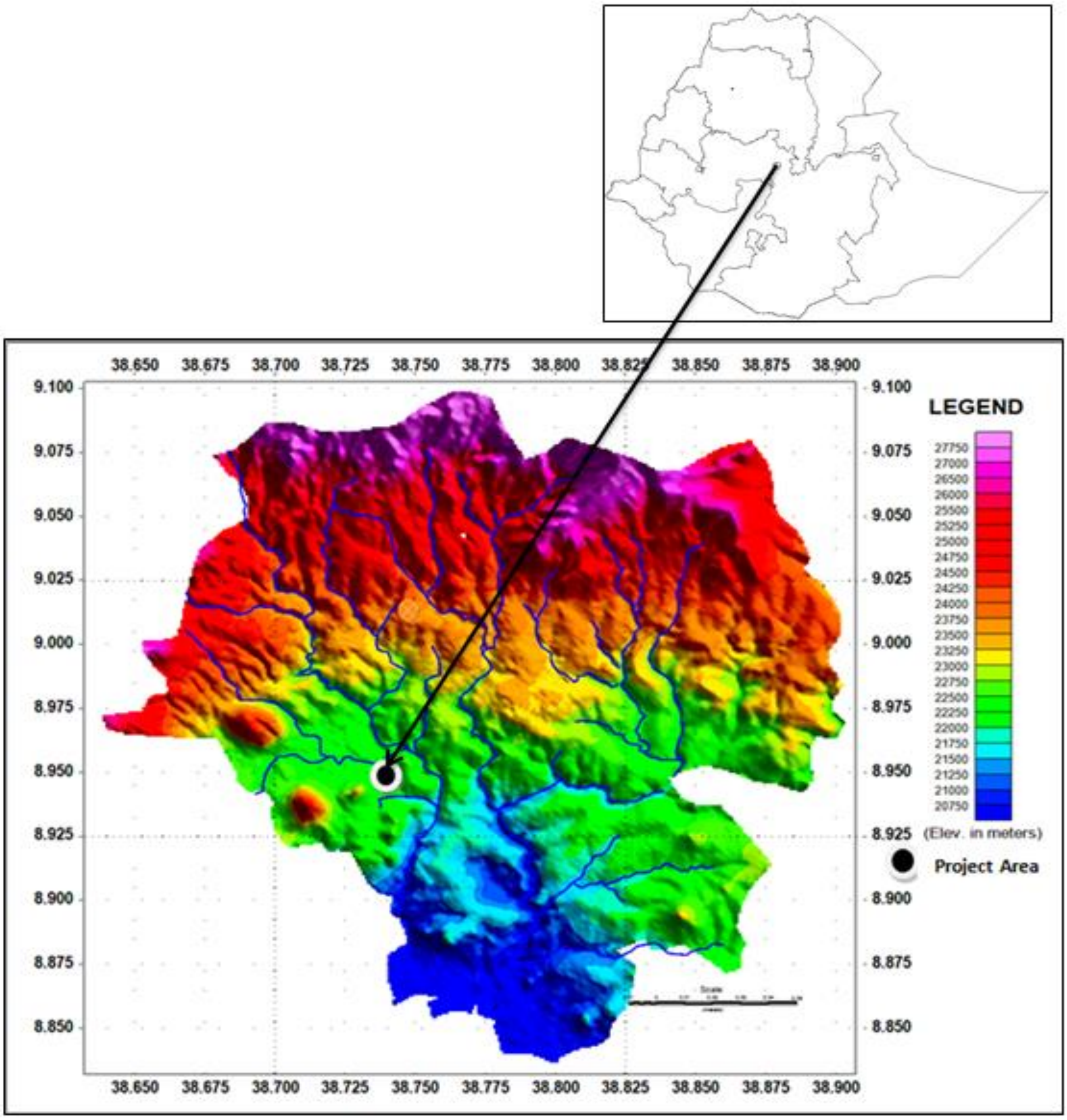


Figure 1.1. Location map of the study area

1.2.2 Site Description of the study area

The project area is characterized by a flat topography with no visible surface undulations, including features such as gullies and river cuts.

Figure 1. 2 Partial view of the study area

1.3 Previous works

Around the study area a number of geological, hydro-geological, engineering geological and geotechnical studies have been conducted for different purposes. Some of the relevant works are summarized below.

DMC construction PLC has performed a geotechnical investigation in close proximity to the study site. For the purpose of investigation six boreholes with maximum depth of 10m were drilled and the geological log revealed a simple geological setup. Accordingly, three layers are delineated and characterized. These are: the upper most layer, with a thickness of 2.5m, is represented by backfill materials; the second layer is intercepted by all boreholes is distributed in depth range of 1.6-2.5 to 3.5-4m. Geologically, it is described as firm, dark grey, clay (black cotton soil) which has average bulk unit weight of 18KN/m^3, average free swell 150% and average PI of 41%. And the third layer which is encountered in all borehole starts at the depth of 4.00m in BH-1, BH-3 and BH-5, 3.00m in BH-2 and 3.50 in BH-4 and BH-6 it extends to a maximum drilling depth of 10.00m and it is characterized as Stiff to very stiff, light gray, silty clay soil which has an average bulk unit weight of 18KN/m^3, average cohesion of 38KN/m^3 and average initial friction angle of 19^0.

The Geological survey of Ethiopia has conducted Engineering Geological Mapping & Geo-hazard Assessment of Akaki Map Sheet (NC37-14) by. According to the study five engineering geological rock units and one soil unit are identified based on their mass strength. These are rock with very high, high, medium and low rock mass strengths as well as alluvial and residual soil. The main geological hazards that affect the project area are tension cracks, volcanic hazards, landslides, rock falls and soil erosion.

Merga Negasa. (2014) has conducted geotechnical characterization and foundation analysis for selected sites of Addis Ababa Housing Projects. One of his project areas is located in Jemo condominium site which is found near to the study area of this research. In his study it is seen that there is foundation problems in the area.

1.4 Statement of the problem

Before the construction of any civil engineering structures it is essential to obtain, at least basic information about the geological, engineering geological and hydro-geological characteristics of the site selected for construction. However, in this country this standard procedure is not satisfactorily implemented (exercised). Rather, most medium and small construction companies conduct some soil tests, not to assess the foundation conditions, but to show for supervising agencies.

Since the earth is not homogeneous, simple tests on soils from pits and very rarely from single boreholes don't give enough information about the characteristics of the subsurface geology. At this particular site the maximum borehole depth is 10m, which doesn't seem to be adequate to understand the subsurface conditions and develop designs, particularly for heavy engineering structures. The borehole results show that to 10m depth the area is underlain by clay soil with different degree of compaction, which requires a great caution when the foundation is built. Unfortunately, the boreholes have neither intercept any water bearing horizon nor reached to the bedrock.

It is obvious that integration of geophysical survey results with geotechnical investigation data provides solid information to civil engineers to develop sustainable engineering designs and implement them in effective manner. Thus, the purpose of this research is to understand the subsurface engineering characteristics through application of integrated geophysical techniques, particularly Vertical Electrical Sounding and Imaging as well as seismic refraction. In doing so, attempt is made to fill information gaps and complement drilling data which provide discrete information about the underlying features. Research question

To deal with the above problems in this study the research questions are framed as follows:

a) What is the depth of the bedrock, and what are its likely characteristics from the engineering perspective?
b) Is there any tectonic feature (lithological contacts, fault, and fracture) within the study area, which may have influence on the engineering structures to be erected?
c) What are the physical characteristics of the soils within the site in terms of their engineering properties?
d) Is there any shallow groundwater? If yes, at what depth? And what possible impact it will have on the stability of engineering foundation?

1.5 Objectives

The principal objective of this research is to conduct detail geophysical investigations at Lebu site to image the subsurface geology and understand the soils and rocks characteristics in terms of site's suitability for civil engineering applications.

Specific objectives:

a. Map the different lithology underlying the survey site;
b. Estimate depth and competent bedrock which often serve as solid foundation for heavy engineering structures;
c. Delineate structural discontinuities (lithological contacts, faults, fractures) that are considered as critical spots during geo-hazard events;
d. Classify the soils and rocks of the site in terms of their engineering geological parameters and their influence on the building foundation.
e. Determine groundwater table and its distribution (if any).

1.6 Significance of the Study

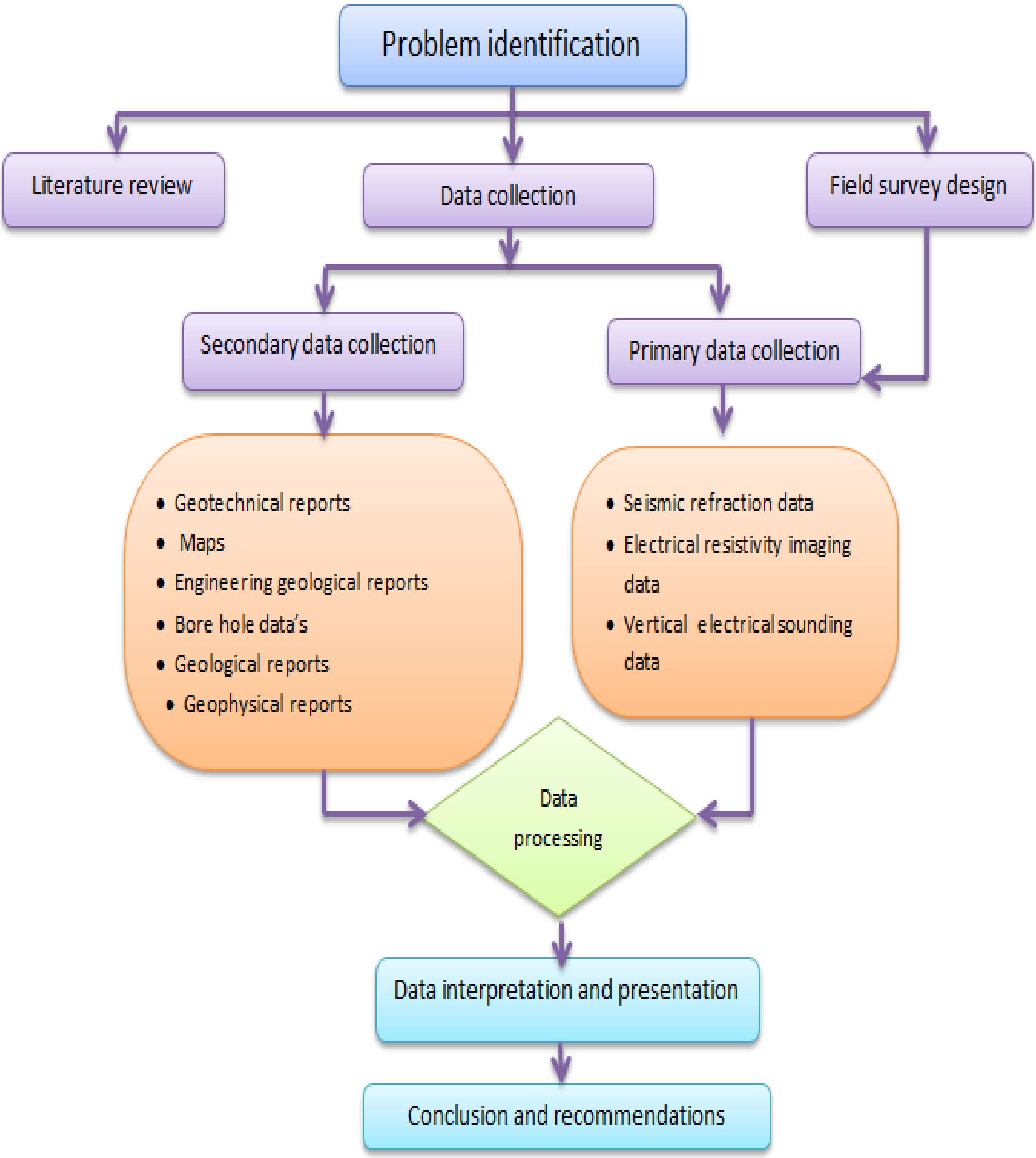
The project area is found in a region where many new private and governmental constructions are constructed. Before designing and constructing any building the engineer should have enough information about the subsurface nature of the site. Since the study area is found in Akaki map sheet which is mainly affected by tension cracks, volcanic hazards, landslides, rock falls and soil erosion. It is susceptible to such kind of hazards. Due to this the geotechnical study alone will not give enough information about the subsurface behavior of the site. So the significance of the study is to give detail information about the study area and give the engineer additional information about the subsurface behavior of the site.

1.7 Limitation of the Study Area

This research had limitations related to the small space located at densely populated part of the city and it cause presence of cultural noises, like high tension cables as well as high traffic flow. This space limitation restricts the length of the survey line which limits the depth of investigation required.

1.8 Methodologies

In order to achieve the objective of this research the studies have been carried out in three stages, namely pre-field, field and post- field works. The overall approach of the survey methodology is displayed in the chart below.



1.8.1 Pre-field work

At this stage collection and review of secondary data from different sources (textbooks, journals, various official documents and technical reports by government and private companies) is mad Therefore, geological, engineering geological and geotechnical, including borehole, data were gathered and carefully analyzed to get better understanding about the research area.

1.8.2 Field work

At this stage primary data is collected applying appropriate geophysical methods to investigate the subsurface. In this research, three methods namely seismic refraction, electrical resistivity imaging and vertical electrical sounding methods, are applied. The dipole-dipole configeration was used for electrical resistivity imaging and on the same profile seismic refraction data was collected using a 24-channel sesmograph. Moreover, Vertical Electrical Sounding is conducted with maximum of AB/2 equals 220m.

1.8.3 Post-field work

The major activities to be performed at this stage are geophysical data processing, interpretation, analyses and result compilation using different software packages (Ipi2win, Res2Dinv, Seis-Imager, ArcGIS, MapInfo).

CHAPTER II
GEOLOGY AND HYDROGEOLOGY

2.1 Regional Geology

The study area is found at the SE part of Addis Ababa Map sheet, where the geology consists of Tertiary volcanic, such as basalts rhyolites, ignimbrites, trachyte and trachy basalts (GSE, 2012)

Aiba -Alaj basalts: This basalt is found in small areas of central, southern and northeastern part of Akaki map sheet. These units are fine to medium grained, dark gray in color and have very high rock mass strength. Microscopically, it is composed of plagioclase, pyroxene and opaque minerals

Addis Ababa basalts: The Addis Ababa basalt is found at the NE part of Akaki map sheet and it has fine grained texture, dark gray in color and very high rock mass strength. Microscopically, it is composed of plagioclase, pyroxene opaque and olivine with inter-granular texture, where pore spaces are filled with secondary minerals.

Tertiary-Quaternary products of Nazret pyroclastic rocks: It is distributed in southern, central and NE parts of Akaki Map sheet. It comprises two rock units, welded to partially welded pyroclastic flows and rhyolitic and trachytic lava flows. The welded pyroclastic flows are found in the NE part of Aakaki map sheet and are characterized by high rock mass strength, light to dark in color and fine to medium grained. It is fine grained when it is highly welded deposit containing flanine and lithic fragments with associated rhyolitic lava flows inter-layed with ash and tuffs. Microscopically, it is composed of K-feldspar, quartz and plagioclase.

Wechacha trachytes

This unit is found in the northern and NE parts of Aakaki map sheet and consists of western rift shoulder central silicic volcanoes such as Wechacha, Furi and Yerer. These central volcanoes preferentially aligned in the E-W direction. It has medium to coarse-grained, light gray to dark-grey and very high strength. Microscopically it is composed of K-feldspar, plagioclase, quartz and hornblende showing trachytic texture.

Quaternary alluvium

It covers the central, northern, northeastern and northwestern parts of Akaki map sheet. This unit commonly inhabits depressions such as calderas, grabens, crater floors, bases of escarpments and wide flat basins. Compositionally, it consists of reworked materials of volcanic origin sand, silt and clay-sized particles which are the result of transportation and deposition of weathered material by running water.

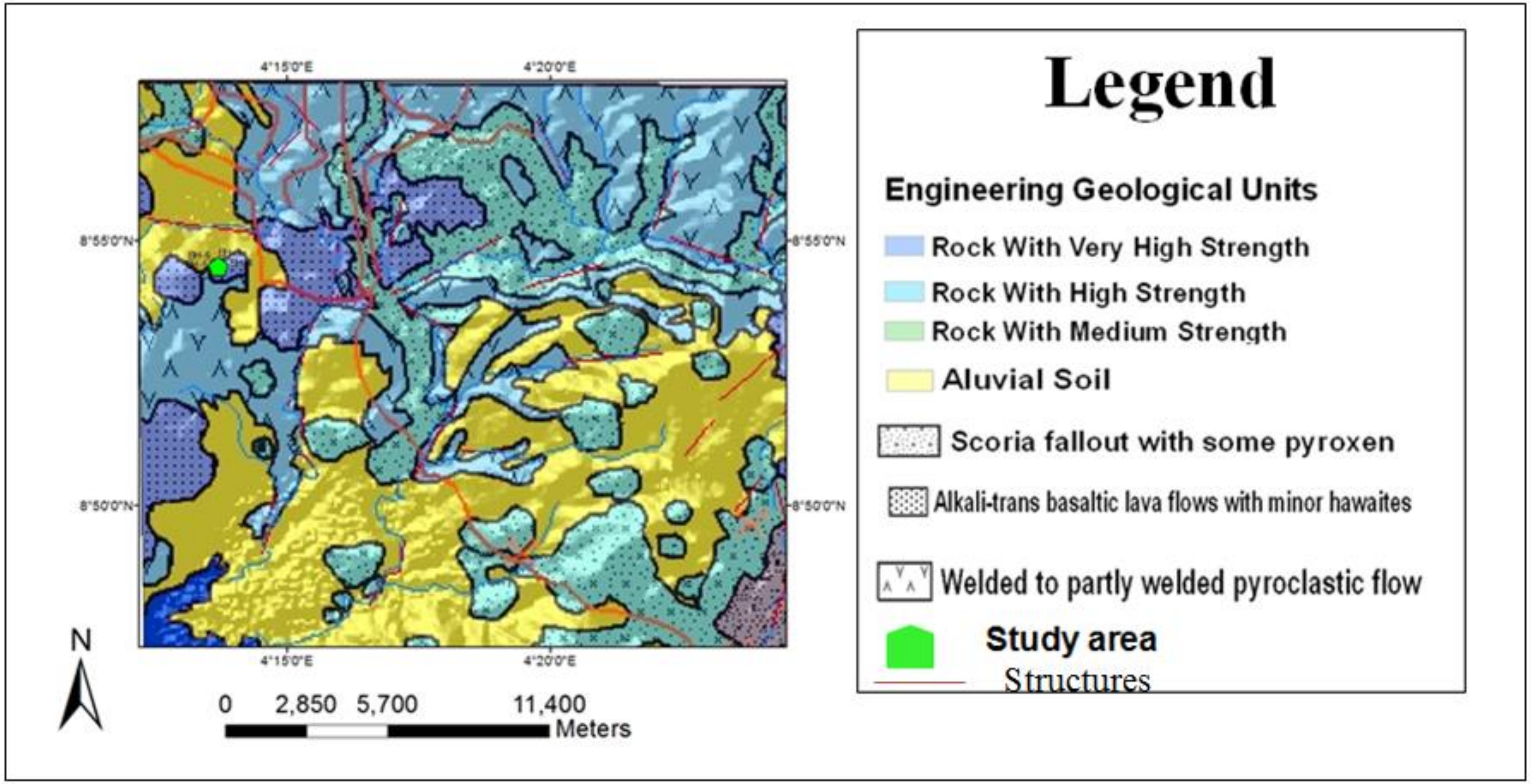


Figure 2.1. Engineering geological map of the study area (Engineering geological map of Akaki map sheet, GSE unpublished technical report, 2012).

2.2 Local Geology

Field observations revealed that the proposed site and its surroundings are covered by black cotton soil (clay, silty clay soils and at places backfill materials. Boreholes drilled in the vicinity of research site revealed the following units:

Backfill materials

a) Layer-1: The uppermost layer is represented by loose, light gray to brow color and sandy silty gravel, which has nearly 2.5m thickness. ,.
b) Layer 2: Firm, dark gray, clay (black cotton soil); This layer is detected in the depth range of 1.6-4m, SPT test results revealed N value that vary from 8 to 13 blows suggesting the layer to have weak physical strength.
c) Layer: 3 Stiff to very stiff, light grey, silty clay with some sand

This layer is seen in all boreholes. It starts at the depth of 4.00m in BH-1, BH-3, BH-5, 3.00m in BH-2 and 3.50 in BH-4 and BH-6 and extends to a maximum drilling depth of 10.00m where drilling was terminated. SPT-N value of this layer ranges from 13 to 28 blows for the 30cm depth of penetration indicating the layer to have stiff to very stiff consistency.

Figure 2.2 Clay soil distributed in the study area

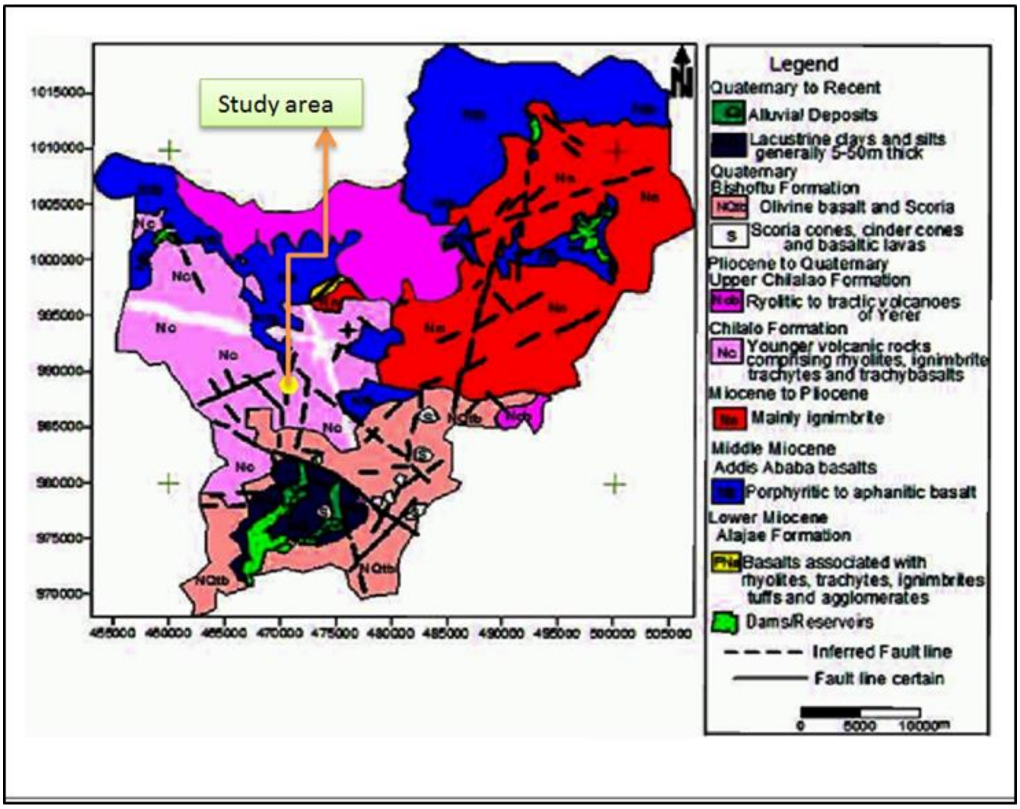


Figure2.3. Location map of the study area

2.3 Hydrogeology of the study area

According to the study performed by Geological survey of Ethiopia, hydrogeological element of the study area is characterized by Extensive (larger than 100 sq.km) and high productive fissured aquifers (T= 100-500 sq.km/d) with spring and well discharges of 5-25 l/s which is shown by green color in the map below. The study performed by DMC construction shows that there is no ground water record with in the six boreholes which are 10m deep.

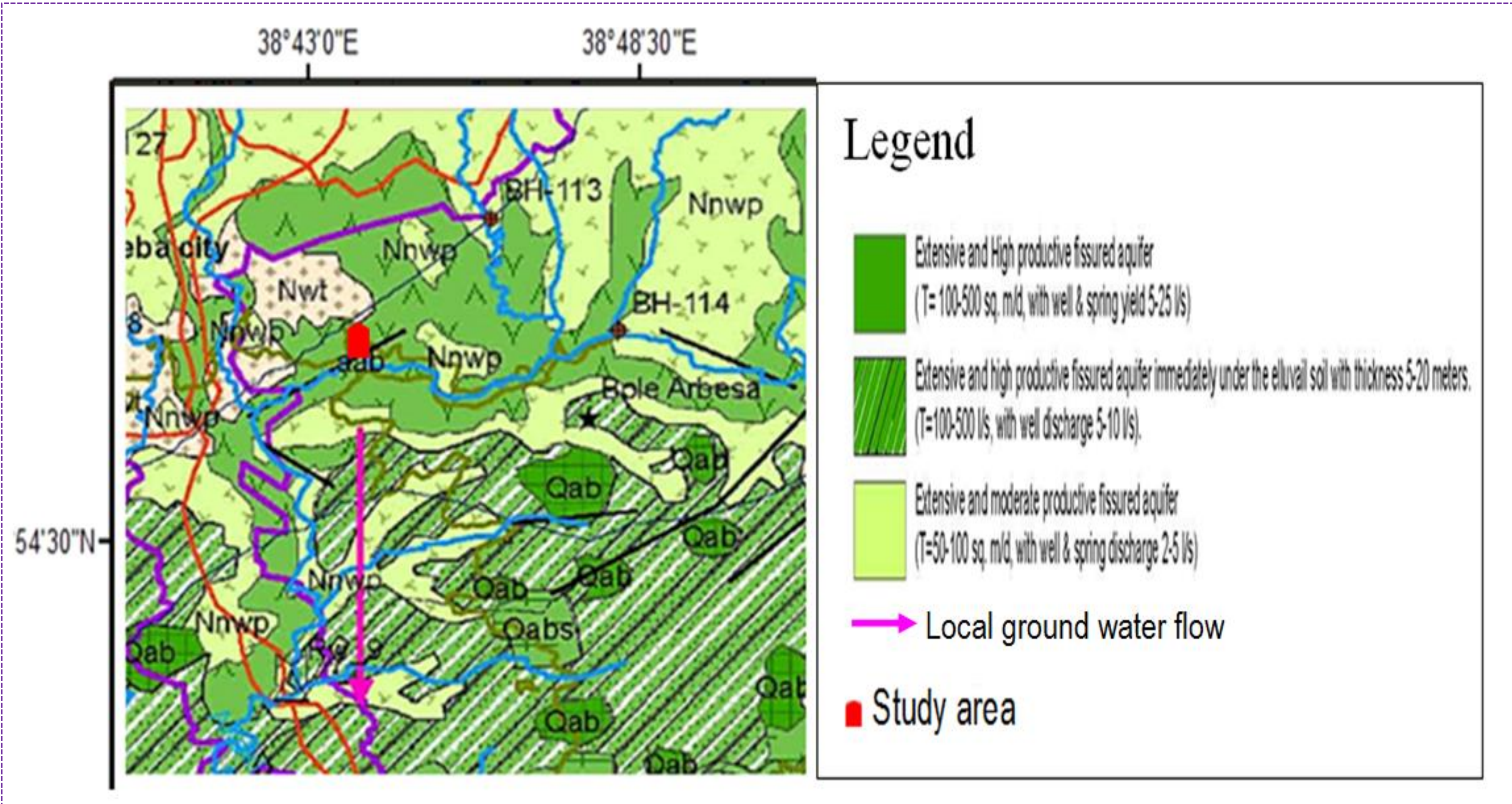


Figure 2.4 hydro-geological map of the study area

2.4. Seismicity

The seismicity of an area can be considered based on the seismic source zones of the site and its geology. Seismic zone map can be prepared based on the frequency and intensity of expected earthquakes in the study areas. According to Ethiopian building code standard (1995), the Ethiopian territory is classified into five seismic zones, from zone 0 to zone 4 with seismically passive zone, to the one which is highly susceptible to seismic hazard. Accordingly, the study area is situated at the intersection of two zones, Zone 2 and zone 3 (Figure 2.3).

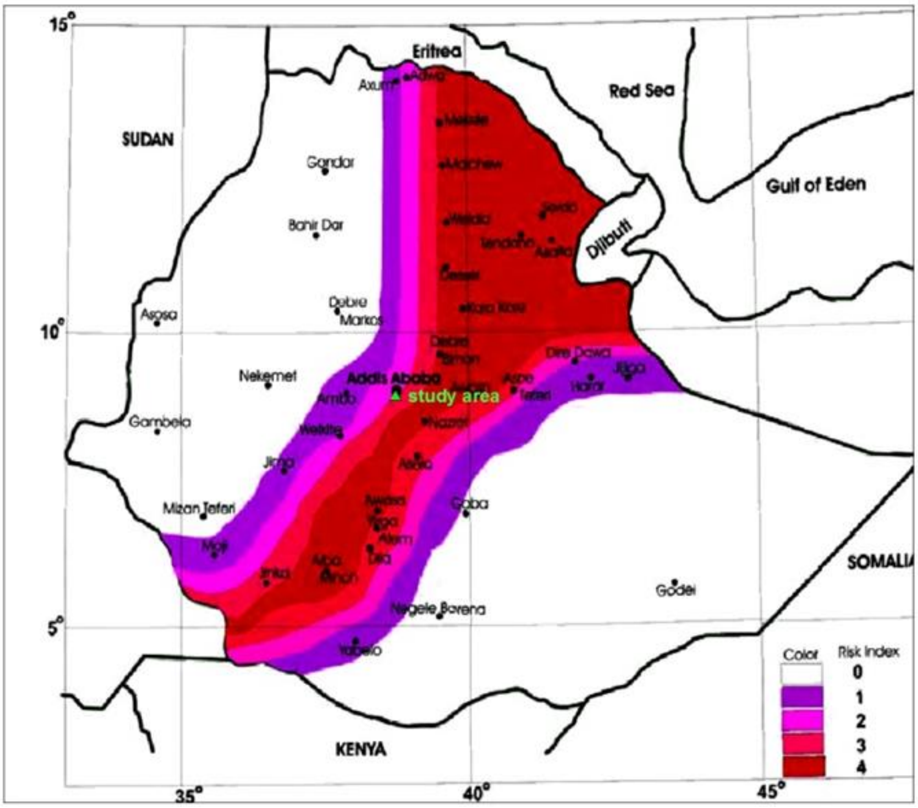


Figure 2.5 Seismic hazard map of the study area (Ethiopian Building Code Standards, 1995 as sited in Hailemariam , 2011)

The study area can be divided into three seismic source zones (TilahunMamo, 2005 as sited in Hailemariam, 2011). According to the study the seismic sources are; Afar Depression, Escarpment and Ethiopian Rift Systems. The study area is mainly affected by small and intermediate earthquakes as shown in Figure 2.5.

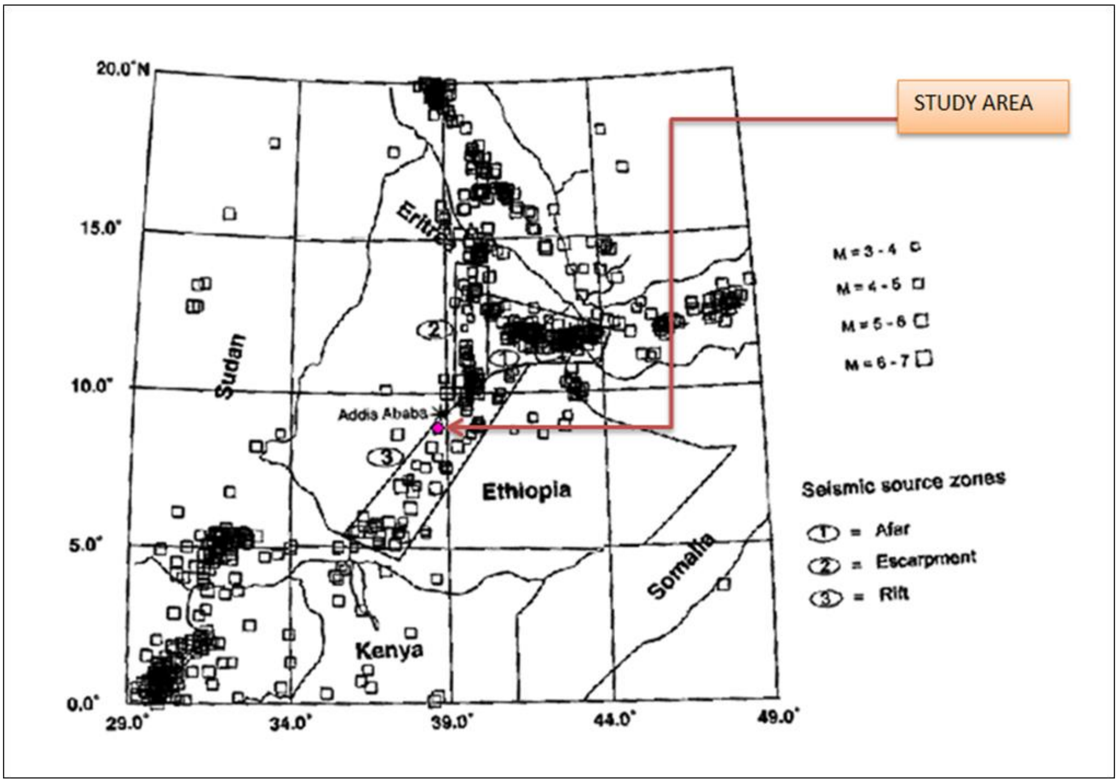


Figure 2.6 Epicenter map of the study area with seismic source zones (Tilahun Mamo, 2005 as sited in Hailemariam, 2011)

The geological setup of the study area is dominated by expansive clay (black cotton soil) and silty clay soil. Due to this the buildings found in the study area and its surrounding may be affected by earthquakes which have small magnitude. According to the Ethiopian Building code standard the ground acceleration of the study area for 100 years return ranges from 0.05g to 0.07g since the area is found in between zone 2 and zone 3 as shown in table 2.1 below.

Table 2.1 bed rock acceleration ratio (Ethiopian Building Code Standards, 1995 as sited in Hailemariam, 2011)

Zone	4	3	2	1
α^{o}	0.10	0.07	0.05	0.03

CHAPTERIII

THEORETICAL BACKGROUND OF GEOPHYSICAL METHODS

The application of geophysics in civil and environmental engineering has become a common practice in the last decades (Soupios et al., 2007). In this regard, the geophysical methods are used for the investigation of subsurface conditions, including investigation of building foundations, ground water distribution , determination of depth to hard rock (bedrock) and outlining geological structures (contacts, faults, fractures).

Even though there are a number of geophysical methods that can be used for geotechnical investigations, in this paper the fundamentals of those methods that are implemented in the project area are briefly discussed.

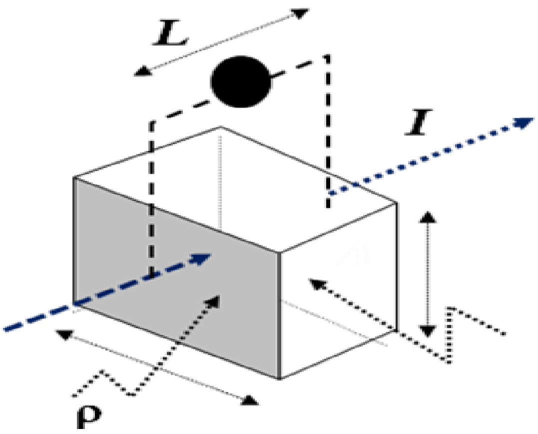
3.1 Electrical Resistivity Method

Electrical resistivity method is a technique that can be used in two ways (sounding and profiling) and earth materials are studied from the perspectives whether they are active or passive conductors of electricity or not. It is one of the widely used and effective methods applied in geotechnical investigations. It is used for to the determination of depths to the bedrock and detecting the presence of structural features in the bedrock or potentially dangerous subsurface conditions before the erection of any engineering structure (Soupiosetetal., 2007).

The important physical parameter of rocks to be determined is resistivity (or its inverse conductivity. Metallic ores are mostly characterized by very low values, but igneous rocks that contain no moisture / fluid can have very high resistivity. In principle, the resistivity of rocks is strongly influenced by the presence of water/fluid, which acts as an electrolyte. This is especially important in porous sediments / sedimentary rocks. The minerals that form the matrix of rocks are generally highly resistive than groundwater, so the conductivity of sediment increases with the amount of fluid it contains.

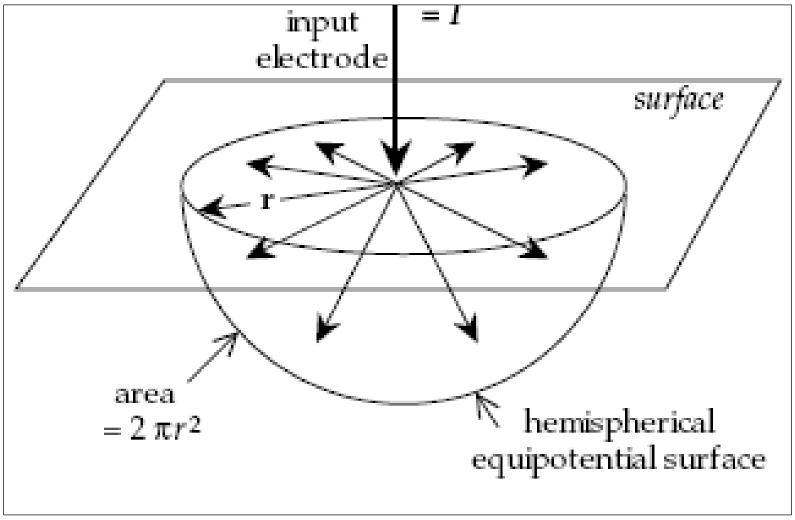
The conductivity of the rock is proportional to the conductivity of the groundwater, which is quite variable because it depends on the concentration and type of dissolved minerals and salts it contains (Lowrie, 2007).

This method is based on the resistivity (or its inverse, conductivity) contrasts of subsurface materials. The electrical resistance (R) of a material is related to its physical dimension, i.e., cross-sectional area (A) and length (L), of the material through which the current flows (eq.1).



$$R = \frac{1}{\sigma} = \frac{\rho L}{A} \qquad (1)$$

When current is induced into the earth by using pair of current electrode it follows a hemispherical path (Figure 3.1).



Figur 3.1 Electric field lines and equi-potential surfaces around a single electrode at the surface of a uniform half-space hemispherical equi-potential surface (Lawrie, 2007)

The current density and the electric field intensity can be related by Ohm's law (eq.2):

$$E = \rho J = \rho \frac{I}{2\pi r^2} \qquad \text{(eq.2)}$$

But

$$dU=-Edr \qquad \text{(eq.3)}$$

Putting eq.2 into eq.3 and integrating both sides we can get the expression for the electric potential at a distance *r* from a source to be:

$$U = \rho \frac{I}{2\pi r} \qquad \text{(eq. 4)}$$

Consider an arrangement consisting of a pair of current electrodes and a pair of potential electrodes as shown in the figure below.

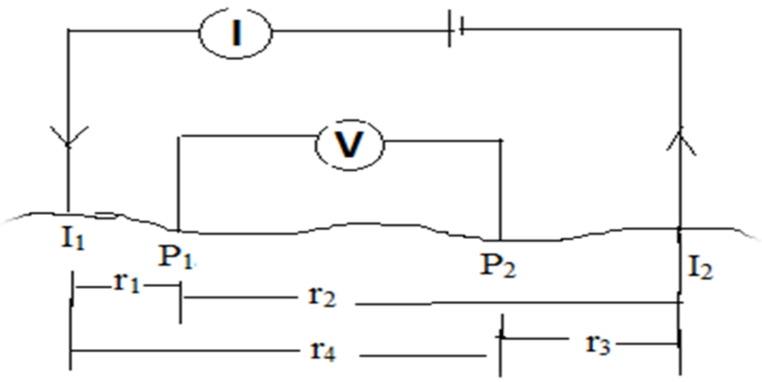


Figure 3.2. Configuration for resistivity measurement using a pair of current and potential electrodes

The potential difference between P_1 and P_2 is given by

$$\Delta V = V_{P1} - V_{P2} = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_4} + \frac{1}{r_3}\right]$$

where

$$\rho = \frac{2\pi V}{I}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_4} + \frac{1}{r_3}\right]^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq\,(5)$$

3.1.1 Electrode Configurations

Depending of the arrangement of the potential and current electrodes there can be different electrode arrays or configurations and the most commons are Wenner, Schlumbereger and Dipole-Dipole.

a) Wenner Array

In this configuration all the four electrodes are equally spaced and the current and potential electrodes have common mid-point, which means,r_1= a; r_2 = 2a; r_3 = a, and r_4 = 2a. This array uses four electrodes that advance along the survey line by maintaining constant the distances between successive current and potential electrodes. The separation of the current electrodes is set based on the need / expectation of maximum depth of investigation.

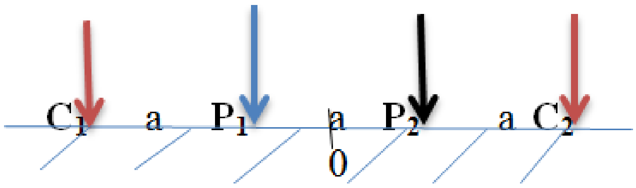


Figure 3.3.Wenner electrode configuration

Substituting the electrode separation in eq (5) the resistivity for such configuration becomes:

$$\rho_a = 2\pi a \frac{V}{I} \qquad \text{(eq. 6)}$$

b) Schlumberger Array

In this configuration the current and potential electrodes have common point but the separation distance between adjacent electrodes is different. Let the separation between the current electrodes be L and that of the potential electrode be a then r_1= r_3 = (L-a)/2 and r_2 =r_4= (L+a)/2. This configuration is most commonly used for VES investigations. The mid-point of the array is kept fixed while the distance between the current electrodes is progressively increased. This causes the current lines to penetrate to ever greater depths, depending on the vertical distribution of conductivity (Lowrie, 2007).

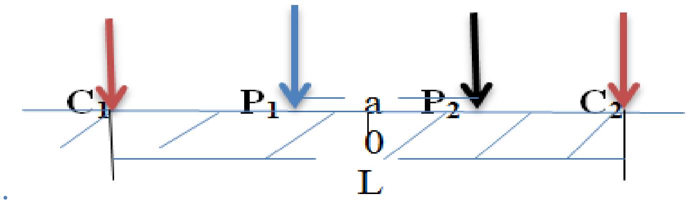


Figure 3.4. Schlumberger electrode configuration

Substituting the electrode separation in eq (5) the resistivity for such configuration becomes:

$$\rho = \frac{\pi V}{4I}\left[\frac{L^2 - a^2}{a}\right] \qquad \text{(eq. 7)}$$

For such kind of configuration the separation distance of the current electrode kept much higher than that of the potential electrodes. So the resistivity value will be:

$$\rho = \frac{\pi V}{4I}\left[\frac{L^2}{a}\right] \qquad \text{(eq. 8)}$$

c) Dipole-Dipole Array

In this kind of configuration the separation distance between the current and potential electrode pairs is kept constant (a) but the distance between their mid-points is much larger than that of the separation between adjacent electrodes (L).

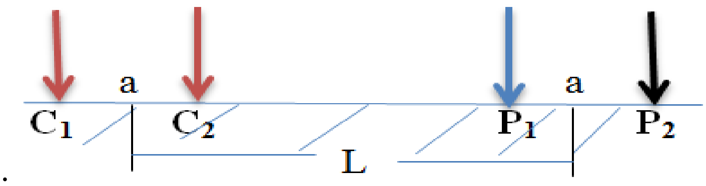


Figure 3.5. Dipole-Dipole electrode configuration

$$\rho = \frac{\pi V}{I}\left[\frac{L(L^2 - a^2)}{a^2}\right] \qquad \text{(eq. 9)}$$

The double dipole array can be used in two modes of investigation. The first one is the Wenner configuration, which is used to map the lateral variations of resistivity of units distributed within a specific depth level. It is best suited to locating steeply dipping contacts between rocks with a strong resistivity contrast and good conductors such as mineralized dikes, which may be potential ore bodies.

The second one is the vertical electrical sounding (VES) the purpose is to observe the variation of resistivity with depth. The technique is best adapted to determining depth and resistivity for flat-lying layered rock structures, such as sedimentary beds, or the depth to the water table.

3.1.2 Electrical Properties of Earth Materials

The electrical resistivity of most rocks and minerals vary depending on composition of mineral grains/rock skeleton, moisture/fluid content, degree of salinity, volume of pores and property of materials that fill pore spaces, permeability, temperature, pressure in the subsurface, structures and textures, degree of compaction, degree of fracturing, degree of physical and chemical weathering and depth of continuation, types and degrees of metamorphism.

Generally, depending on the types of rocks and their age clear variations in resistivity values are observed. Igneous rocks have high resistivity and due to high fluid content sedimentary rocks are relatively conductive than metamorphic rocks, which are characterized by intermediate resistivity responses The resistivity values of some common earth materials are listed in the Table 3.1.

Table 3.1 resistivity values of some common earth materials (Bernard, 2003 as sited in Yonatan, 2011)

Resistivity values for some common geological formation	Resistivity (Ω-m)
Quartz	$3 \times 10^2 - 10^6$
Granite	$3 \times 10^2 - 10^6$
Granite (weathered)	30 – 500
Consolidated shale	$20 - 2 \times 10^3$
Sandstones	200 – 5000
Sandstone(weathered)	50-200
Clays	$1 - 10^2$
Boulder clay	15 – 35
Clay (very dry)	50 – 150
Gravel (dry)	1400
Gravel (saturated)	100
Lateritic soil	120 – 750
Dry sandy soil	80 – 1050
Sand clay/clayed sand	30 – 215
Sand and gravel(saturated)	30 – 225
Mudstone	20-120
Siltstone	20-150

3.1.3 Techniques in Electrical Resistivity Surveys

3.1.3.1 Vertical Electrical Sounding (VES)

Vertical Electrical Sounding (VES), which is also called as Vertical Electrical drilling, is a process by which depth investigations are made through successive resistivity measurements done with regularly increasing electrode separations, while the center of the configuration and its orientation remain fixed. It is used to characterize the boundaries between horizontally/sub-horizontally layered (stratified) media. Large electrode spacing enables to have greater depth of investigation. The limitation of this technique is that it is not applicable to map lateral resistivity variations

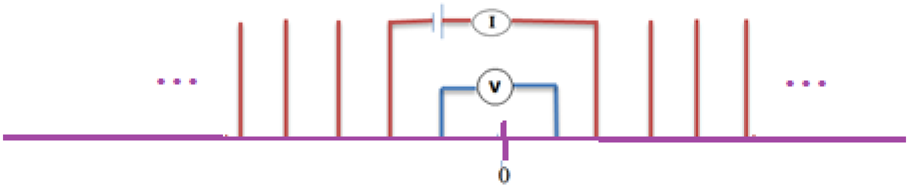


Figure 3.6 Electrode arrangements of VES configeration

3.1.3.2 Electrical Resistivity Profiling

Electrical resistivity Profiling (EP), also called as horizontal profiling, is used to map horizontal variations in resistivity characteristics**.** This variation is useful to map anomalously conducting and non-conducting vertical contacts, like dykes, fissures and faults. In this case fixed electrode spacing is chosen and the whole electrode array is moved along the survey profile as shown in the figure below**.**

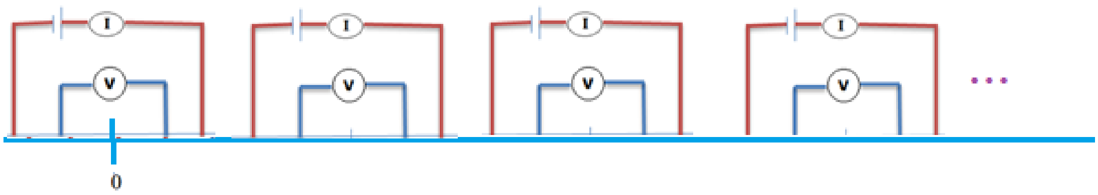


Figure 3.7 Electrode arrangements in electrical resistivity profiling

3.1.2.3 Electrical resistivity tomography (ERT)

Since electrical resistivity varies both vertically and horizontally, neither electrical profiling nor electrical sounding methods alone give full information about the subsurface nature of the earth. To map lateral and vertical variations in resistivity, electrical resistivity tomography is used. It is more accurate and very high-resolution model of the sub-surface where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. The 2D electrical survey can be used in combination with seismic and ground penetrating radar methods to provide complementary information about the subsurface (Loke., 2001).

The method requires data to be recorded with many different electrode separations along a profile. It is important to have a dense enough data cover laterally and in terms of electrode separations to recover complex structures in the ground (Griffiths and Barker, 1993; Dahlin and Loke, 1998 as sited in Torleif , 2000), which demands the use of automated multi-electrode data acquisition systems to be practical.

In electrical resistivity tomographic analysis the methods of direct-current resistivity and induced polarizations are readily adapted. Instead of arranging a single pair of current-electrodes and a single pair of potential-electrodes, an array of regularly spaced electrodes is deployed. For two-dimensional surveys a linear arrangement of electrodes is used. Various combinations of pairs of current and potential-electrode are analyzed. The resolution and depth of investigation depend on the separation and geometry of electrodes (Lowrie, 2007).

Field survey setup for electrical resistivity tomography using Dipole-Dipole array is shown in Figure . The procedure requires two current electrodes and a number of potential electrodes depending on the survey area and topography. The depth of investigation can be increased by increasing the separation between the current and potential dipoles.

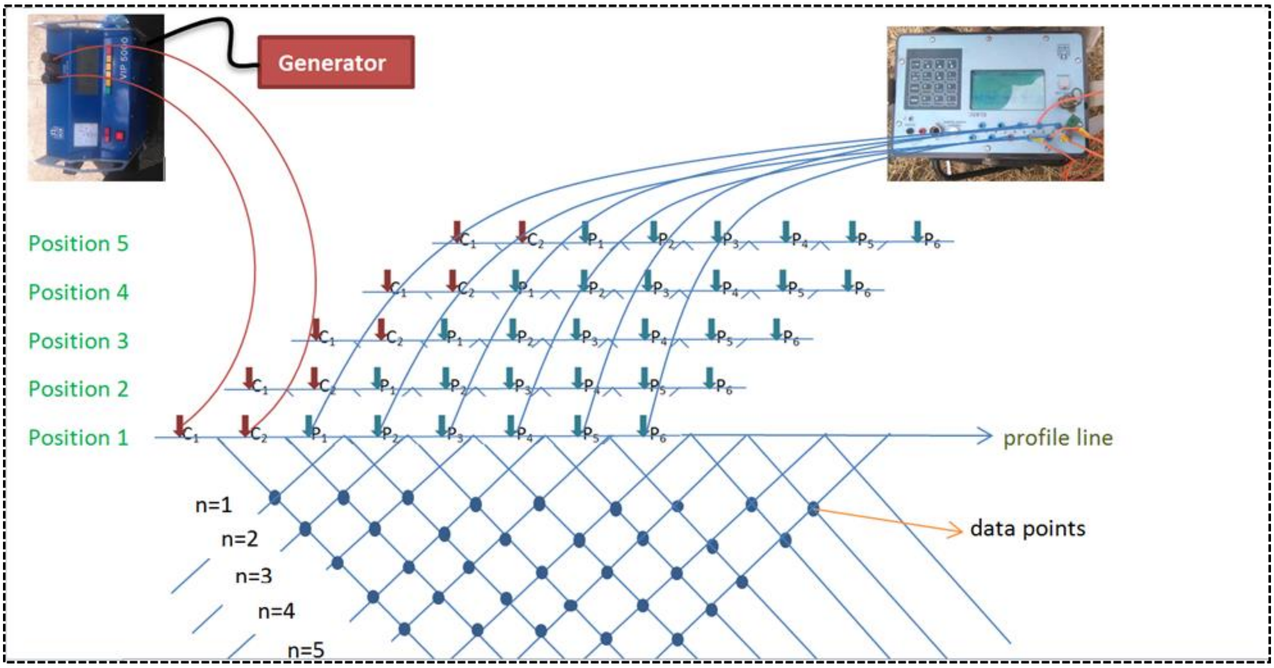


Figure 3.8 Electrode setup used in ERT (Naveen et al., 2005)

3.2 Seismic Refraction Survey

The principle of this technique is based on the refraction of seismic energy at the boundary between subsurface features with different velocities caused by density variations. Seismic waves arriving at positions along the survey line are recorded by geophones that are connected to a seismometer by seismic cable and record the arrival times. Seismic energy is generated by kicking a plate placed on the ground or using dynamite or vibrator. In this research a sledge hammer and a plate are used for the shallow seismic refraction survey. The greater the energy of the seismic source, the deeper penetration of the signal and the better image of the subsurface. (http://www.environmental-geophysics.co.uk/brousher/p RSK Geophysics.pdf)

Some of the seismic energy travels along the surface in the form of a direct wave. However, when a seismic wave encounters an interface between two different units with contrasting velocities a portion of the energy is reflected and the rest will propagate through the layer boundary at a refracted angle. Analysis of seismic refraction data is primarily based on interpretation of critical refraction travel times. Usually P-wave refraction data is analyzed, but S-wave data occasionally recorded (KSU, 2012-2013).

Layers velocity and thickness can be related in terms of time required by the seismic wave to travel between the seismic sources and receiver. According to Fermat's principle, seismic wave chooses the least path. As the geophone distance increases the critical refracted wave reaches first. To increase the depth of investigation it is necessary to increase the distance between the receiver and the source. Due to the need of large distance for great enhanced depth of investigation, the frequency of interest to refraction seismic is less than in seismic reflection (KSU, 2012-2013)

At a critical angle of incidence the wave is critically refracted and will travel parallel to the interface at the speed of the underlying layer. Energy from this critically refracted wave returns to the surface in the form of a head wave, which may arrive at the more distant geophones before the direct wave. By picking the time of the first arrival of seismic energy at each geophone, a plot of travel-time against distance along the survey line can be generated. As shown in Figure 3.8 the gradients of the lines in this type of plot are related to the seismic velocity of the subsurface layers.

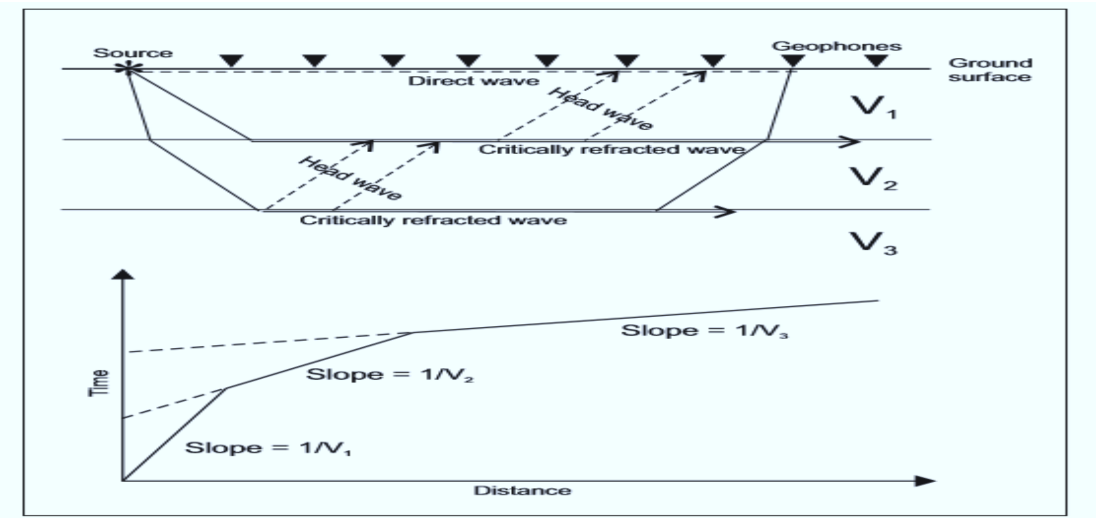


Figure 3.9The path of seismic waves propagating from a source to the surface (http://www.environmental-geophysics.co.uk/brousher/p RSK Geophysics.pdf).

The principle of seismic refraction survey can be summarized by the flow chart shown Figure below. . To investigate the subsurface using this method the first thing needed is a seismic source. The energy sent using seismic sources is detected by a geophone, a device that uses the principle of electrical induction to convert mechanical energy generated by seismic sources to electrical energy. Inside the geophone there is a spring mounted around a magnet. When sound energy is sent towards the earth it can cause the spring inside the geophone to vibrate.

The vibration induces an electric current in the spring and this electric current is converted into electrical waves and displayed on the seismograph. The wave forms detected by the seismograph are processed using software package and then interpreted in terms of the survey objectives.

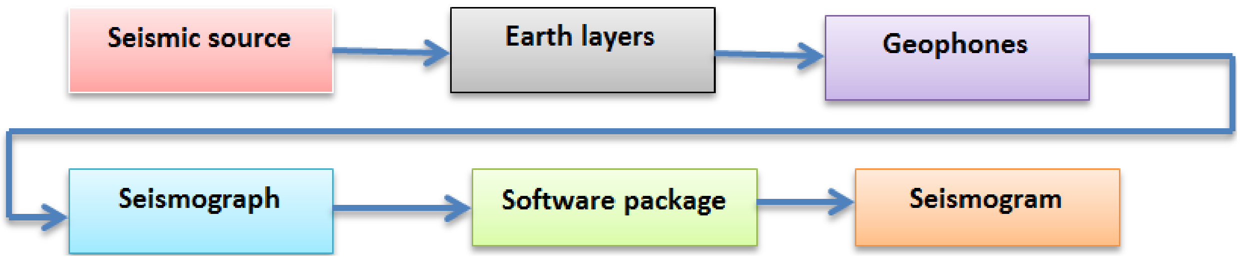


Figure 3.10 Flow chart of Seismic refraction method as modified from (Fkirin et al., 2016)

The seismic wave velocity varies from layer to layer depending on the density and elasticity of the subsurface material. The velocities of the seismic wave (V_p and V_s) in a homogeneous isotropic medium are given by:

$$V_P = \sqrt{\frac{k + \frac{3}{4}m}{\sigma}} \quad V_p = \sqrt{\frac{k + \frac{3}{4}\mu}{\sigma}} = \sqrt{\frac{\lambda + 2\mu}{\sigma}} \qquad \text{(eq. 10)}$$

$$V_S = \sqrt{\frac{\mu}{\sigma}} \qquad \text{(eq. 11)}$$

Where *K* is the bulk modulus (the modulus of incompressibility), μ is the shear modulus (modulus of rigidity, sometimes denoted as G and also called the second Lamé parameter), σ is the density of the material through which the wave propagates, and λ is the first Lamé parameter.

Table 3.2 P and S-wave velocities of some rocks and other materials (Geological Society of London, 2002)

Material	Compressional velocity (m/s)	Shear velocity (m/s)
Air	330	
Water	1450	
Sands and clays	300–1900	100–500
Glacial till	1500–2700	600–1300
Gravels	1000–2000	
Chalk	1700–3000	600–1500
Strong limestones	3000–6500	1500–3500
Weathered granite	100–3000	500–1500
Fresh granite	3000–6000	1500–3000
Slate	5000–7000	2500–3800
Weak sandstones	1000	

CHAPTER IV

GEOPHYSICAL INVSTIGATIONS

4.1 Geophysical Data Acquisition and Processing

To achieve the objectives of this research relevant geophysical data, i.e., seismic refraction, electrical resistivity imaging and VES datas are collected. At first seismic refraction and resistivity imaging data were collected and based on rough assessment resistivity sounding data are gathered from selected locations. The data acquisition, processing and interpretation applied during the present study are discussed in detail in the following sections.

Figure 4.1 Location map of Seismic refraction and ERT profiles, VES and BH- log points of the study area

4.1.1 Seismic refraction

The instruments used for collecting the seismic refraction data are DOLANG seismograph, Laptop computer to display the wave form, geophones to convert mechanical energy to electrical wave form, triggering cable and a 10Kg sledge hammer and a metal plate as an input source. In this research one 12 and two 24 channel seismic surveys were carried out with a geophone spacing of 5m. . These geophones are connected to the Dolang system unit that is controlled by a laptop computer. Moreover, a 10kg sledge hammer and plate are connected to the trigger point, whose end goes to the seismograph. When taking measurements at one shot point is done the same process continues at the next trigger position.

Figure 4.2 Instruments used for collecting seismic refraction data

The field setup to collect the seismic refraction data was the one which is called an in-line spread in which the source and the geophones are placed in a straight line. The 24 geophones are laid on the ground at a regular interval of 5m spacing. These geophone spacing was chosen due to the accessibility of the study area and the purpose of the research work. The geophones were connected to the seismograph using seismic cables. For this arrangement six shoot points are set, i.e., 2.5, 27.5,52.5,62.5,87.5 and 112m that correspond to the mid-points of geophones 1-2, 6-7, 11-12, 13-14, 18-19 and 23-24 respectively. The positions of each geophone and shot points are determined using Garmin 62map GPS.

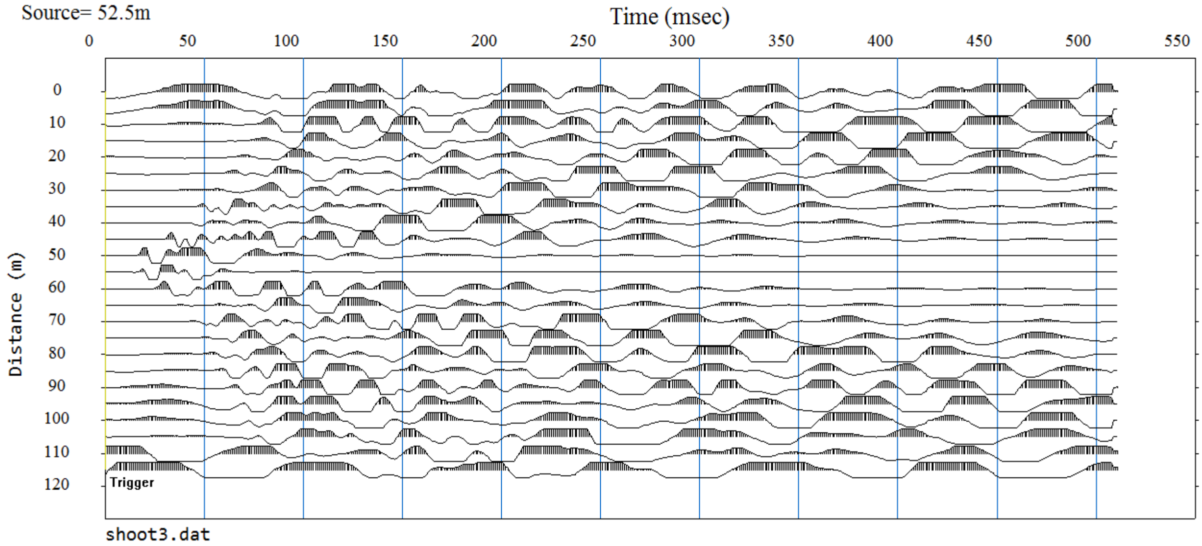


Figure 4.3 Sample of a seismogram representing the mid-shoot position (52.5m)

The seismic refraction data were processed by using 2D seismic refraction analysis software called SeisImager. The software consists of two-software packages, named "PickWin95"and "PlotRefa". "PickWin95" is software for picking first arrival and that of "Plotrefa" is software for seismic refraction analysis.

The field data, which are in '*seg2*' and *txt* formats were imported and the first arrival of the p-waves were picked using the *pickwin 95* package. After picking the first arrival data are imported in to the *plotrefa* package and a plot of *time* versus *distance* graph are generated. The plotrefa checks the parallelism of the travel time curves and reciprocal times for multiple shot locations. From travel time curve by identifying crossover points, the refracted arrivals from 2nd and 3rd layers are considered and layers are assigned for each travel time curve. After the layer assignment, a time-term inversion was done by importing an elevation data and then a velocity model is generated. By doing ray tracing, the RMS error is checked. The separation between the theoretical and calculated values of the travel time curve is called Root Mean Square error (RMS). For best result the RMS error should be less than 5%. Most of the data have an RMS error of less than 5% but there are some data's with higher values. Since the survey site is found in an area where there is high traffic flow, the error level is considerable due to movement of people and trucks.

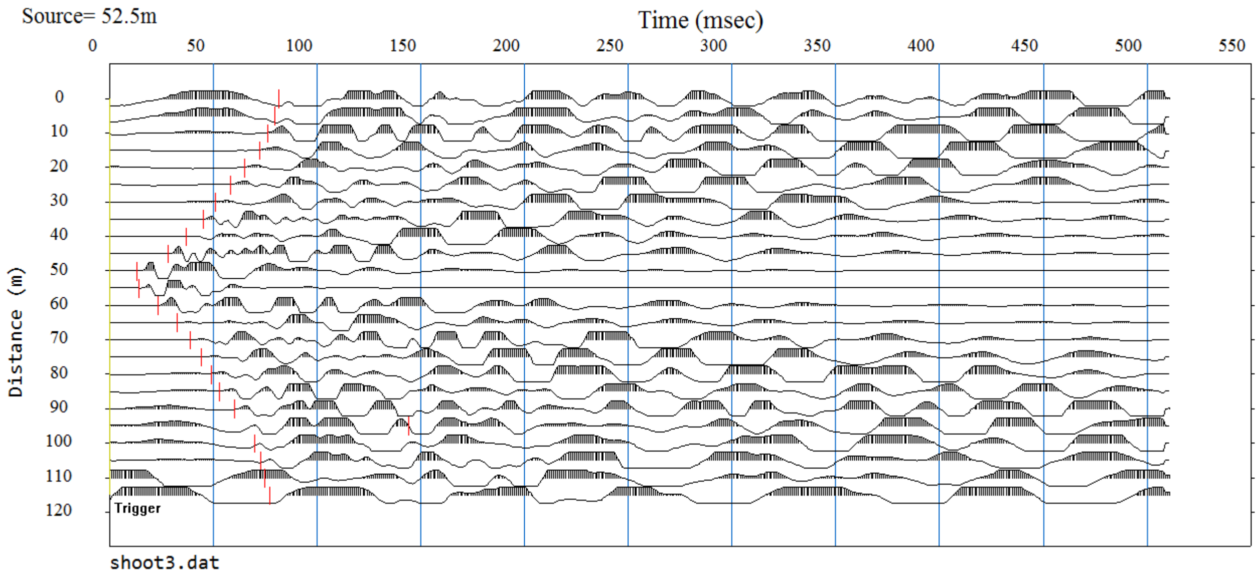


Figure 4.4. Seismogram for the central shot with picked first arrivals

For surface wave analysis the packages used are Pickwin95 for reading the data and Wave processing, *Plotrefa* for analyzing seismic refraction data, *WaveEq.exe* for analyzing surface-wave data and *GeoPlot.exe* for Plotting, editing and interpretation of 2D velocity model. The analysis for surface wave is started by using *pickwin 95* to make a "file list" where all waveform files and source-receiver configuration are mentioned. Then source receiver geometry is set so that all waveforms are loaded onto computer memory according to the geometry. The cross-correlation was calculated for all pairs that have common mid-point (CMP) from all traces. For each cross correlation CMP gather phase velocity image in frequency domain was calculated and dispersion curve was picked. Most of the cases automatically picked dispersion curve includes unnecessary data points such as noises. Such data can decrease the accuracy of the analysis result. To overcome this data must be removed before analysis by using the nature of a theoretical dispersion curve. A theoretical dispersion curve must be smoothed or straight line and starts at the upper left and ends at the lower right since velocity increasing with depth. To calculate the 2D shear wave (S-wave) velocity model using the dispersion curve which is obtained from the waveform data by non-linear least square method and correct the dispersion curve, waveEq.exe program package was used. To remove unnecessary data from the dispersion curve a minimum and maximum frequency is set in between 8Hz to 45Hz. This frequency range is chosen by considering the behavior of the waveform data. After correcting the dispersion curve an initial velocity model is generated for non-linear least square method. From the non-linear least square method s velocity model is obtained. For generating the two-dimensional S wave velocity model we use another software package called Geoplot.exe by using this software the S wave velocity is converted to N-values and a 2D N-model is generated. The following flow chart summarizes the data acquisition and analysis for 2D S wave survey.

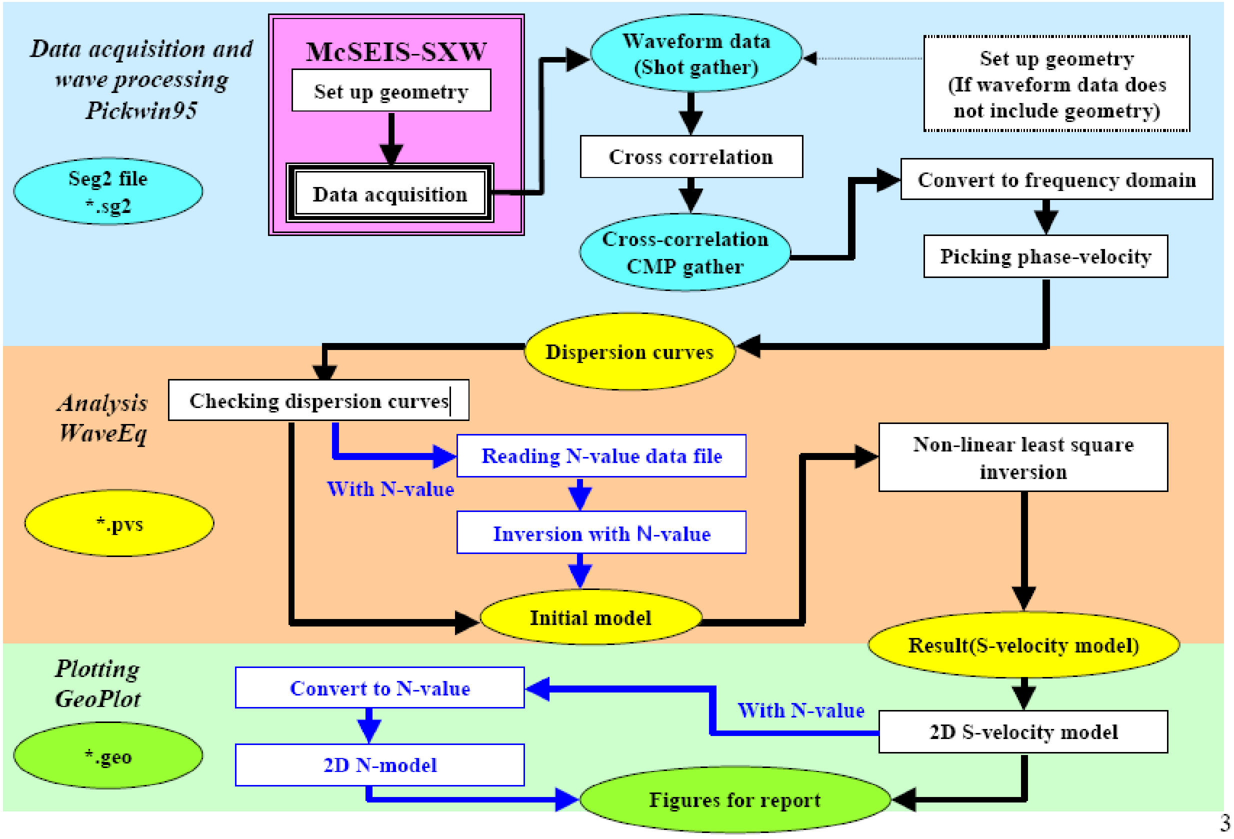


Figure 4.5. Flow chart of data acquisition and analysis for surface-wave method

4.1.2 Electrical Resistivity Tomography

The electrical resistivity tomography method is chosen so that it is an effective method for the investigation of geological formations and for delineation of lateral resistivity variations.
The instruments used for collecting the electrical resistivity imaging data are The Elrec Pro switch, VIP series of high power transmitter, electrodes, current and voltage cables and generator. The *Elrec Pro* switch is a 10-channel Induced Polarization (IP) and Resistivity receiver designed to improve productivity when recording deep profiles and soundings.

The Elrec Pro is designed for use with the VIP series of high power transmitters. It automatically synchronizes with the transmitting signal; through the wave recognition process ensures high measurement repeatability. For large 2D and 3D surveys, the Elrec Pro switches the ten channels of the receiver among 48, 72, 96, 120, electrodes. In practice, this allows to read very large combinations of electrode without connect/disconnect several times wires and electrodes. Acquisition time can be strongly reduced compared to receiver's featuring a high number of channels but no automatic switching capability. When operating the system in this manner complex measurement sequences can be designed and uploaded to the system via electre II or Electre pro software.(http://geomatrix.co.Uk/and-products/electrical-resistivity/elrec-pro/)

The electrical resistivity tomography data was collected by using a dipole-dipole configuration. For this configuration the current and potential electrodes are aligned in a straight line where the spacing between each current and potential electrodes to be 15m. As shown in the figure 3.8, at position 1 the VIP high power transmitter injects a regulated current into the ground by using the current electrodes C1 and C2. This current is feed in to the Elrec Pro switch manually and it automatically reads the resistivity of each dipole points in this case from potential electrode P1 to P6. Before moving to the second position all the current and potential electrodes shift together to 15m from previous point. This procedure is continues until the end of the profile line.

For this study a total of two profiles were selected depending on the objective of the study and the cross-sectional area of the site. The two profile lines are oriented in N-S direction and they were parallel to each other. The first profile has a length of 255m and that of the second profile 330m. The coordinates of each electrode position was recorded using Garmin GPS.

The field data which were collected using the above procedure was analyzed using Prosys II software which is designed by IRIS instrument for managing Syscal and Elrec type units. After analyzing the data it is processed using Zond RES2D and RES2DINV software.RES2DINV is a computer program that will automatically determine 2-D resistivity model for the subsurface for the data obtained from electrical imaging surveys (Griffiths and Barker 1993). Finally the two profiles were processed and inverted by least square inversion with 3 iteration process independently to a representative earth model for the purpose of analysis.

4.1.3 Vertical Electrical Resistivity Sounding

The vertical electrical resistivity data was collected with Schlumberger array along profile lines 1 and 2 to have additional information about the subsurface. A total of six VES with maximum 220 m current electrodes separation have been conducted using Sintrex-Made SARIS (Sintrex Automatic Resistivity Imaging System) instruments used for the survey which has a maximum power of 100W.This instrument automatically displays ρ_a values along with Standard Deviation (SD), Current (I) and Primary Voltage (V_p) on its digital screen.

The VES data was processed by IPI2WIN software and layer parameters, i.e., thickness (depth) and resistivity of layers were determined. The maximum RMS error found in this study is less than 3%. And the pseudo section was generated for three parallel VES points for each profile. The data also introduced in surfer software to draw a pseudo section. Surfer is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid.

The pseudo depth does not reflect the actual depth of investigation but they are a basic guide for drawing the geo-electric section. For plotting geo-electric section based on the result from pseudo section the researcher uses Mapinfo software.

Figure 4.6 field data acquisition of ERT and VES

CHAPTER V

RESULT, DISCUSSION AND INTERPRETATION

General

To characterize the subsurface behavior of the site, an integrated geophysical method has been used together with the borehole log data. These boreholes are dig to 10m depth and they provide limited and localized information. Whereas; the integrated geophysical methods: seismic refraction, electrical resistivity tomography and vertical electrical sounding data's give continuous information with much better depth.

The seismic refraction data was collected within three profile lines where two of them are oriented in North South directions and parallel to each other. The third profile is chosen to be almost perpendicular to the first two profiles as shown in figure 4; the maximum depth of investigation for this method is to be around 27m.

The electrical resistivity tomography data was collected within two profiles which are parallel to each other and oriented in North south direction as shown in figure 4. The first profile has a length of 240m with depth of investigation around 45m.The second profile has a length of 315m and depth of investigation the same as that of profile one.

The vertical electrical sounding is performed along the electrical resistivity profiles. The first three VES points with 50 meter spacing are chosen to lie in the first profile line of ERT and that of the remaining three VES points to be in line to the second profile of ERT as shown in figure 4. The pseudo section for each three VES points is generated using Ipi2win and surfer software's. The geo-electric section is drawn using MapInfo software.
The result of this research work will be presented in the next sections based on borehole logs, geo-electric sections, pseudo sections and 2-D inversion model outputs.

5.1 Seismic refraction data

The 2D seismic tomography velocity model was generated for p wave and for each profile. The S wave velocity is estimated from the p-wave model by using seis-imager software and by using elasticity theory. The first and the second profile have a spread distance of 115m and that of the third one which is almost perpendicular to the first have 60m. In the p wave velocity model the depth of investigation of each profile ranges from 7m to 27m depending on the spread length. The 2D seismic tomography p wave velocity model result of each profile shows that the study area has p wave velocity ranges from 190m/s to 1170m/s. This velocity range shows that the subsurface is filled by sands and clays. This result is correlated with the BH log results and they have the same interpretation. The velocity model of all profiles shows the presence of three layer earth. The first layer is characterized by loose sand and gravel, the second as layer filled silt clay with some sand and the third layer as silt clay with sand with less moisture content. The interpretation result of each velocity model will be presented in the following sections for each profile.

Profile1

P-wave velocity model

The velocity model of this profile has a maximum depth of investigation around 27m at the beginning of the survey line and minimum depth of 20m at the middle portion of the survey line as shown in figure 5.1.The model presents p wave velocities between 350m/s to 1,170 m/s can be characterized by three layers. The first layer which is characterized as loose sand and gravel has a thickness of around 2.5m throughout the survey line and p-wave velocity ranges from 350m/s-720m/s. The second layer which is characterized as silt clay with some sand has a maximum thickness of 20m at the beginning of the survey line and minimum thickness of 6m around the midpoint of the survey line. The p-wave velocity for this layer ranges from 810m/s-990m/s. The third layer which is characterized as silt clay with sand with less moisture content has a maximum thickness of 11m up to 90m distance and the thickness reduces to 5m to the end of the survey line. This layer has p-wave velocity ranges from 1,080m/s-1,170m/s.

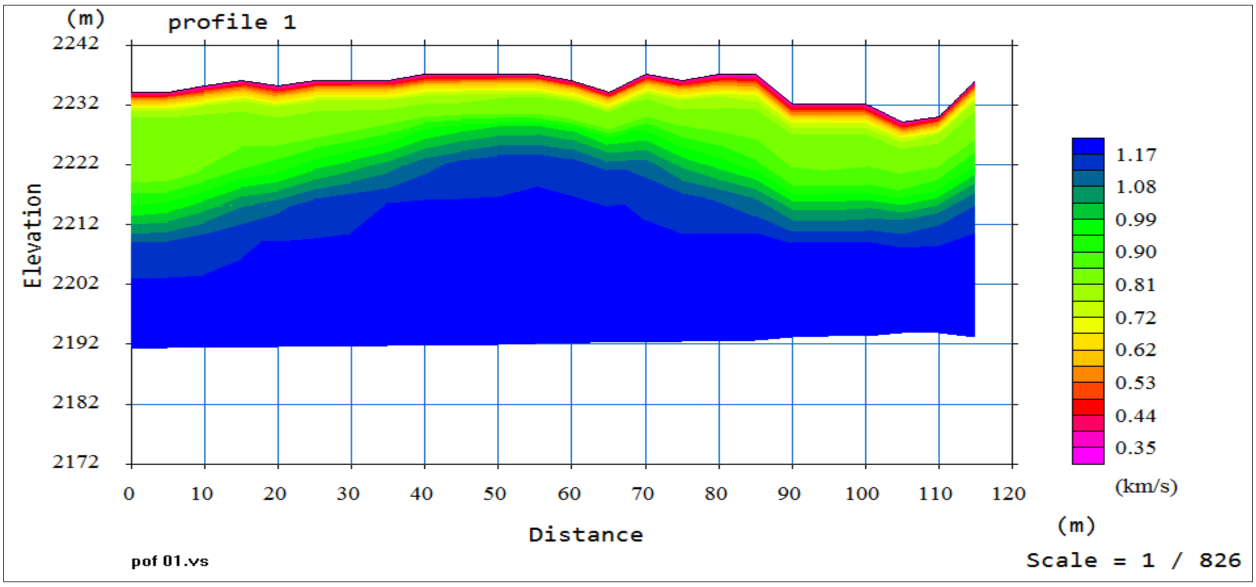


Figure 5.1 p-wave velocity model of profile 1

S-wave velocity

The shear wave velocity for this study has been determined in two ways: First by using the Seis imager software as discussed in section 4.1.and second by using standard elasticity theory formulated by:-

$$\frac{V_P}{V_S} = \sqrt{\frac{2(1-\upsilon)}{1-2\upsilon}}$$

Where, υ is the material's Poisson's ratio.

As it is seen from the p-wave velocity model and that of the borehole log data, the profile is characterized by silt clay with some sand, loose sand and clay formation. Depending on this result systematically the poison ratio is chosen by using table 5.1 which gives the approximate range of the elastic parameters for various soils. For this study the poison ratio is chosen to be 0.35 which is an average value for all stated soil types.

Table 5.1 elastic parameters of various soils(Braja M. Das, 2005)

Type of soil	Modulus of elasticity, E_s (MN/m^2)	Poisson's ratio, μ_s
Loose sand	10–25	0.20–0.40
Medium dense sand	15–30	0.25–0.40
Dense sand	35–55	0.30–0.45
Silty sand	10–20	0.20–0.40
Sand and gravel	70–170	0.15–0.35
Soft clay	4–20	
Medium clay	20–40	0.20–0.50
Stiff clay	40–100	

The result obtained by using the seis-imager software gives the overall velocity range of the profile so it will be used us a reference about the shear wave velocity range of the study area. The shear wave velocity value of the profile is summarized in the following table.

Table 5.2 shear wave velocity range for profile 1

Layers	V_p range(m/s)	V_s range(m/s)	
		Using elasticity formula	Using Seis Imager
1st	350-720	169-348	40-500
2nd	810-990	391-478	
3rd	1,080-1,170	522-565	

The shear wave velocity obtained by seis –imager software has been converted to N- values using the Seis- imager software. The result generally shows that the N value for this profile ranges from 1-13. Which is a result of loose surface thus, great caution has to be taken when designing the building foundation.

Profile 2

P- Wave velocity model

The p wave velocity model of this profile shows almost the same depth of investigation throughout the survey line which is 10m as shown in figure 5.2. This model also characterized by three layers. The first layer which is loose sand and gravel has a minimum thickness of 2m around spread distance of 30 and a maximum thickness of 5m around spread distance of 6m. The layer has p wave velocity ranges from 370m/s-460m/s. The second layer which is filled by silt clay with some sand has a thickness of 2.5m throughout the survey line has p-wave velocity ranges from 540m/s-710m/s. The third layer which is represented by silt clay with sand with less moisture content has a maximum thickness of 5.5m around spread distance of 20m and minimum thickness of 1m around spread distance of 56m. This layer has p-wave velocity ranges from 790m/s -1,120m/s.

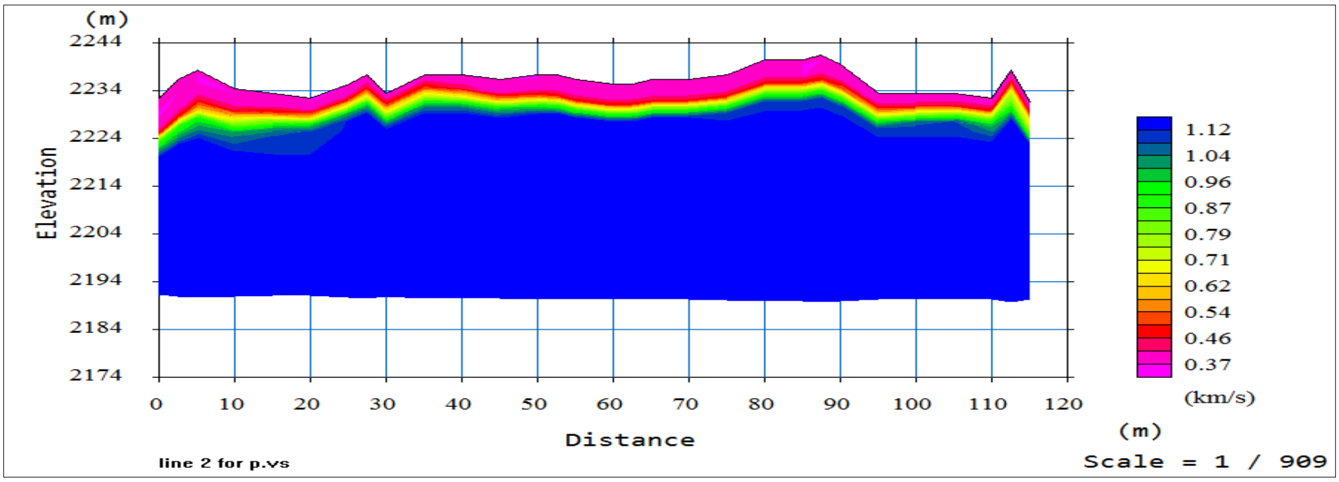


Figure 5.2 p-wave velocity model of profile 2

S-wave velocity

The shear wave velocity of profile two also calculated by using the procedure used in profile one. The value obtained by using the two approaches is summarized in the table below.

Table 5.3 shear wave velocity range for profile 2

Layers	V_p range(m/s)	V_s range(m/s)	
		Using elasticity formula	Using Seis Imager
1st	370-460	179-222	40-500
2nd	540-710	261-343	
3rd	790-1,120	382-541	

The shear wave velocity obtained by Seis–imager software has been converted to N- values using the Seis- imager software as discussed above. The result generally shows that the N value for this profile ranges from 2-44. The maximum value shows the presence of dense surface and that of the minimum values show the presence of very loose materials. Since the subsurface is a loose surface this result also shows that a great caution has to be taken when designing the building foundation.

Profile 3

p- Wave velocity model

The p wave velocity model of this profile shows minimum depth of 1m at the beginning of the survey line and maximum depth of 6m at a spread distance of 15m.The p wave velocity for this model ranges from 190m/s-980m/s as shown in figure 5.3.Like the above two models this model also characterized by three layers. The first layer which is soil, loose sand and gravel has a minimum thickness of 0.5m at the beginning and end point of the survey line and maximum thickness of 1.5 around spread distance of 35m. The layer has p wave velocity of 190m/s-360m/s. The second layer which is represented by silt clay with some sand has a thickness of 1m throughout the survey line has p-wave velocity ranges from 450m/s-540m/s. The third layer which is represented by silt clay with sand with less moisture content has a minimum thickness of 0.5 m at the beginning of the survey line and the thickness increases up to 5m to the end of the survey line. This layer has p-wave velocity ranges from 630m/s -980m/s.

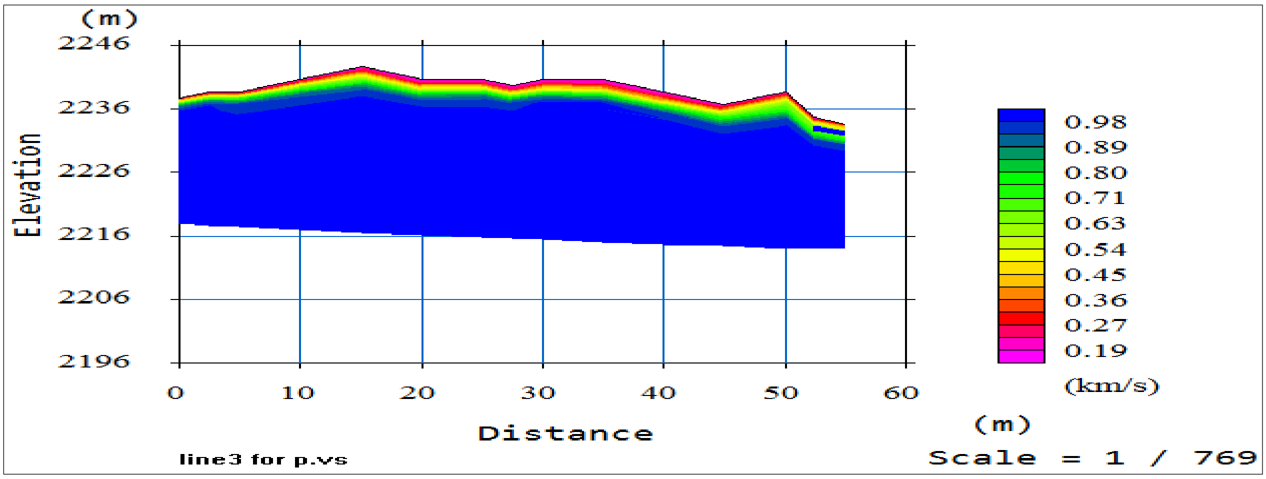


Figure 5.3 p-wave velocity model of profile 3

S-wave velocity

The shear wave velocity of this profile also calculated as the procedure used above. table 5.4 summarizes the velocity range obtained.

Table 5.4 shear wave velocity range for profile 3

Layers	V_p range(m/s)	V_s range(m/s)	
		Using elasticity formula	Using Seis Imager
1^{st}	190-360	92-174	40-500
2^{nd}	450-540	217-261	
3^{rd}	630-980	304-473	

The converted N values of profile three from shear wave velocity using seis-imager software ranges from 2-44. The maximum value shows the presence of dense surface and that of the minimum values show the presence of very loose materials. These loose materials almost cover all portion of the model. Since the subsurface is a dominated by minimum and intermediate N values a great caution has to be taken when designing the building foundation.

5.2 Vertical Electrical Sounding Data

The VES data's are presented in the form of Pseudo section and Geo-electric section. The pseudo section result shows an H-type and HK- type curves. The H-type is seen in VES points 2, 3 and 5 were as the HK- type in VES points 1, 4 and 6. Figure 5.4 shows sample VES curves the remaining curves are presented in Appendix 2.

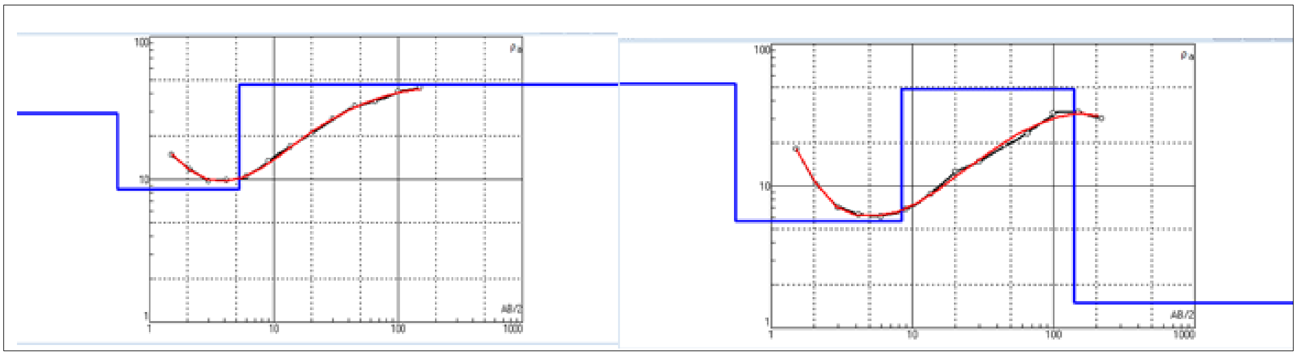


Figure 5.4 Sample of H and HK-type sounding curves obtained from VES 4 and VES 5

Profile 1

Pseudo depth section Map

The pseudo depth section map for profile-1 is made by using the first three sounding points as shown in figure 5.5. From the pseudo section it is clearly seen that the top most part the section has minimum resistivity value ranges from 6Ω-m-18Ω-m. This may be due to loose sand and gravel. The maximum resistivity value which ranges from 32Ω-m-44Ω-m is seen along VES 2 at a pseudo depth of 40m and along VES 3 at pseudo depth of 120m. This indicates the presence of silt clay with sand which has low moisture content. The intermediate resistivity values are seen in the remaining portion of the section results from silt clay with some sand.

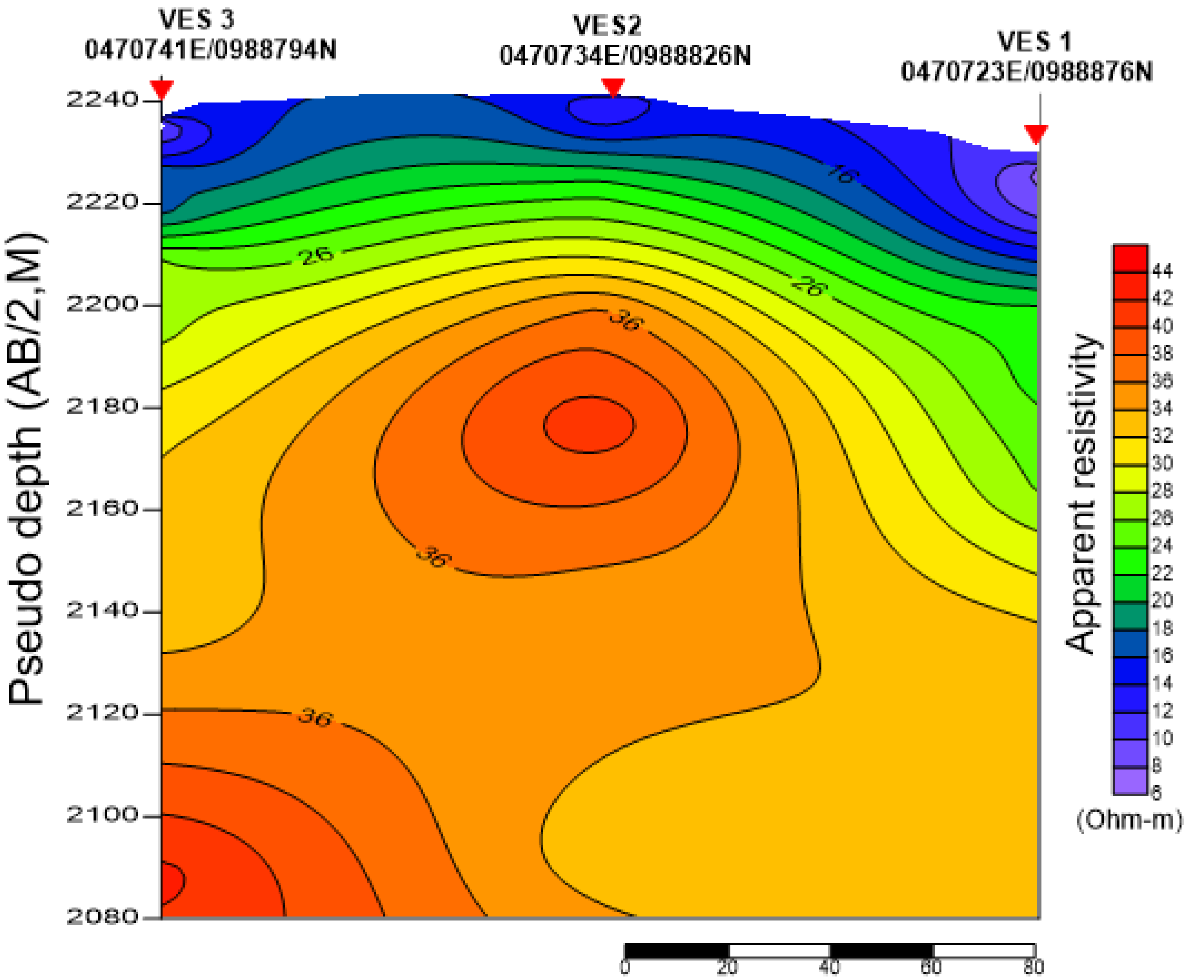


Figure 5.5 apparent resistivity pseudo depth section map of Profile -1

Geo-electric section map

The Geo-Electric section of profile-1 identifies four geologic subsurface layers as shown in figure 5.6. The first layer which is loose sand and gravel has resistivity values range from 22Ω-m -29Ω-m and thickness of around 1m throughout the survey line. The second layer characterized by Silt clay with some sand has resistivity varies from 6Ω-m-10Ω-mat a depth of around 6m. The third layer with resistivity value ranges from 48Ω-m-68Ω-m has a thickness of 30m between VES 3 and VES 2 and 12m between VES 2 and VES. This layer is characterizes as a layer filled by silt clay with sand which has les moisture content. The forth layer is seen between VES 2 and VES 1 at a depth of 20m has 27Ω-m resistivity value.This is a result of clay with high or considerable fluid content.

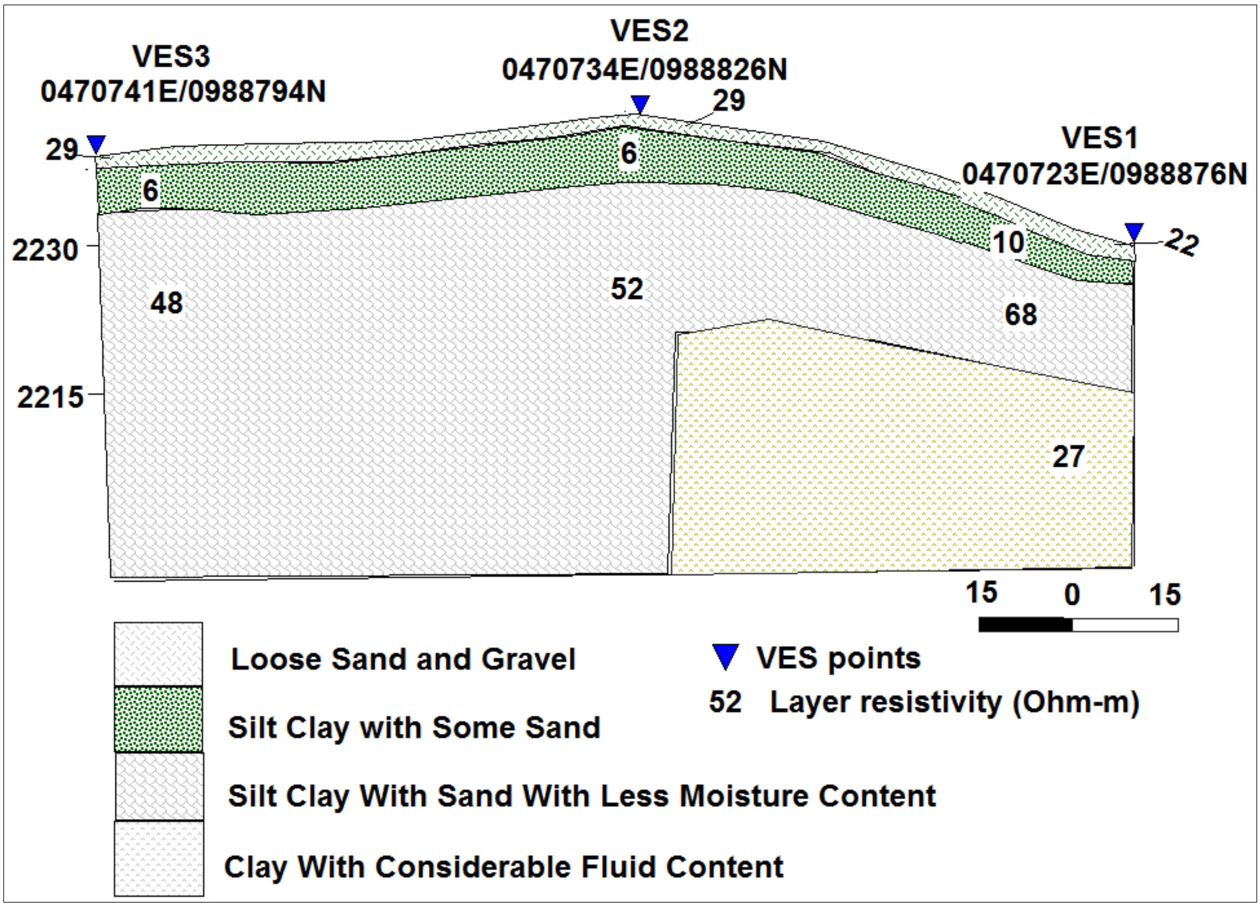


Figure 5.6Geo-Electric section of Profile - 1

Profile 2

Pseudo depth section Map

The pseudo depth section map for profile two is made by using the second three sounding points V4, V5 and V6 as shown in figure 5.7.Theupper layer has a minimum resistivity value ranges from 6Ω-m-18Ω-m. This may be due to loose sand and gravel. The intermediate resistive values are seen in the middle portion of the section results from silt clay with some sand formations. The maximum resistivity value which ranges from 32Ω-m-40Ω-m is seen at the end portion of the section. These values Indicates that the presence of silt clay with sand which has low moisture content.

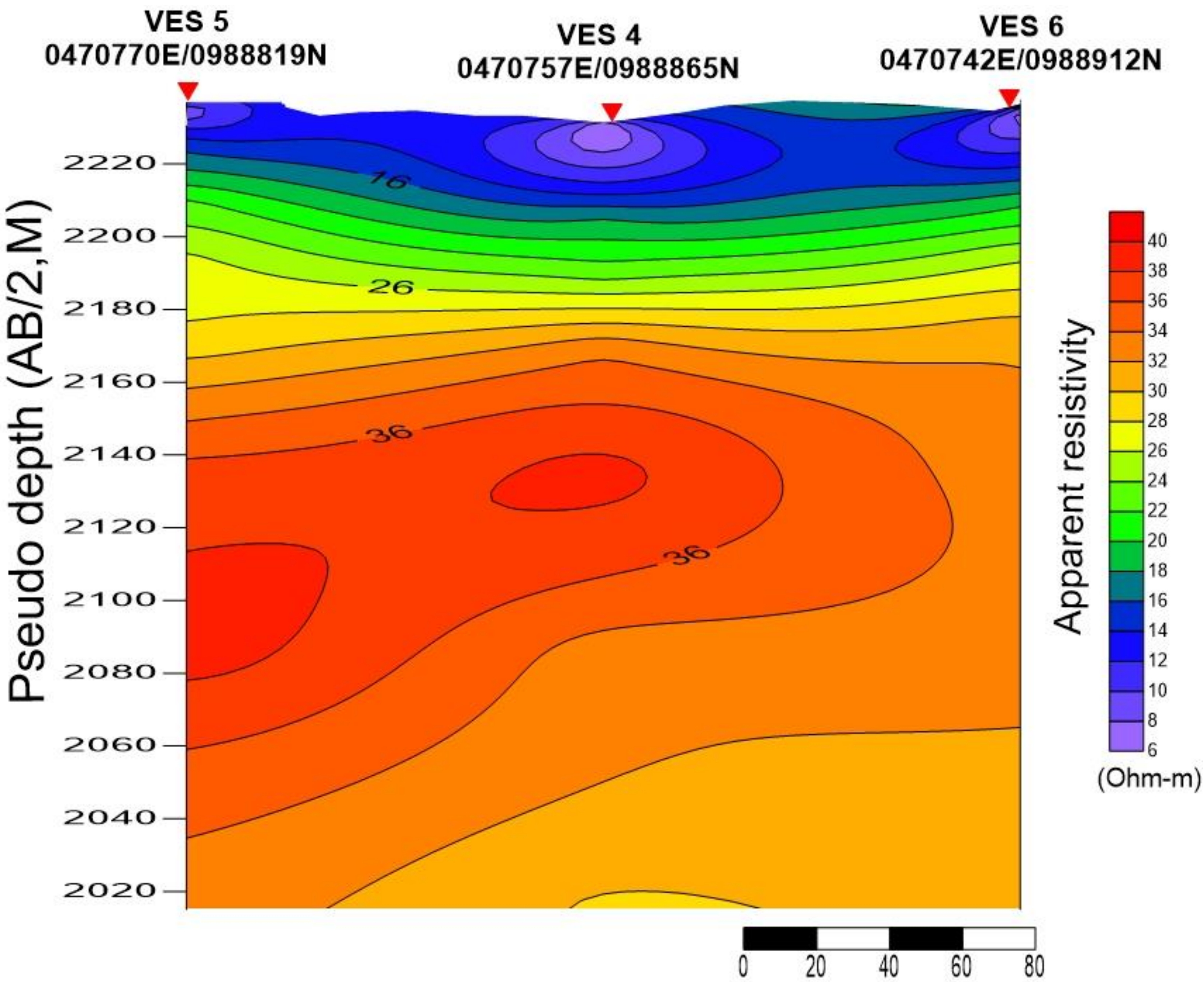


Figure 5.7 apparent resistivity pseudo depth section map of Profile – 2

Geo-electric section map

The geo electric section of profile 2 identifies four geologic subsurface layers as shown in figure 5.8. The first layer which is loose sand and gravel has resistivity values range from 29Ωm-52Ω-m and thickness of around 1m. The second layer characterized by Silt clay with some sand has resistivity value from 5Ω-m-8Ω-m and thickness of around 7m. The third layer with resistivity value range from 46Ω-m-59Ω-m is characterized as silt clay with sand which has less moisture content. This layer has a thickness of 16m between VES5 and VES 4 and around 10m between VES 4and VES 6. The forth layer which is found at a depth of 17m in between VES 4 and VES 6has a resistivity of 16Ω-m. This decrease in resistivity value is observed since the subsurface is filled by clay with considerable fluid content.

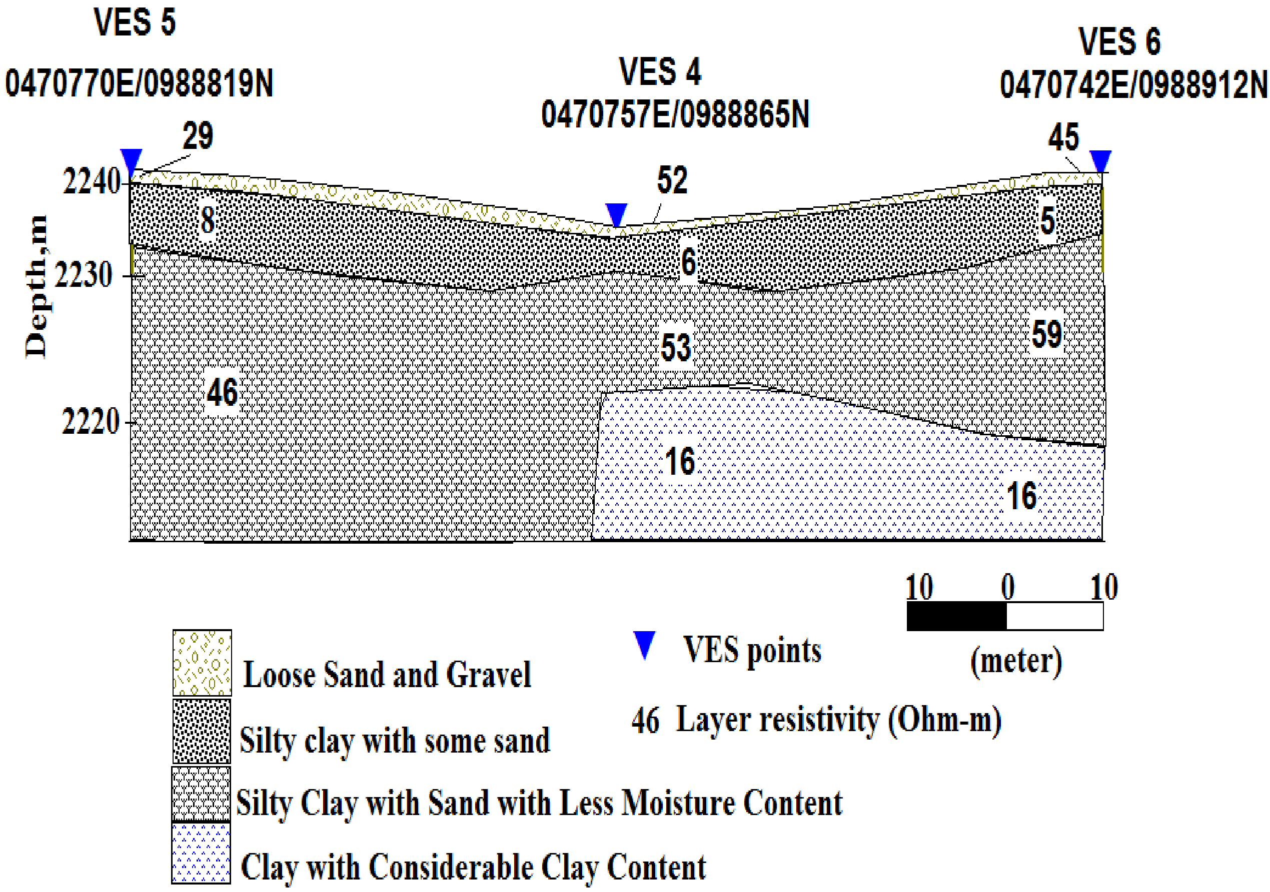


Figure 5.8Geo-Electric section of Profile - 2

5.3 Electrical Resistivity Tomography Data

In the present study electrical tomography survey has been carried out along two profiles which are parallel to each other and oriented in NS direction and have a profile length of 230m and 330m respectively. The electrode spacing for each survey line was 15m and the depth of investigation found is around 40m.The resistivity values obtained from this survey ranges from 3.1Ω-m to 260Ω-m. This range implies that the subsurface is filled by sands, clays and weathered basalt. which is also shown in the BH log result. Depending of their resistivity value the subsurface is characterized by four layers. The interpretation result of each profile will be discussed in the following section accordingly.

Profile 1

The resistivity value of Profile-1 ranges from 4.7Ω-m to 260Ω-m with depth of investigation around 45m; as shown in figure 5.9. The low resistivity value is seen at a depth of 15m at a distance of 25m-60m. This implies the presence of clay with high moisture content. The high resistivity value at profile distance of 60m-170m and 175m-230m is observed due to the presence of weathered and highly fractured basalt. Between these high resistive regions there is a weak zone with intermediate resistivity value filled by silt clay with some sand with less moisture content.

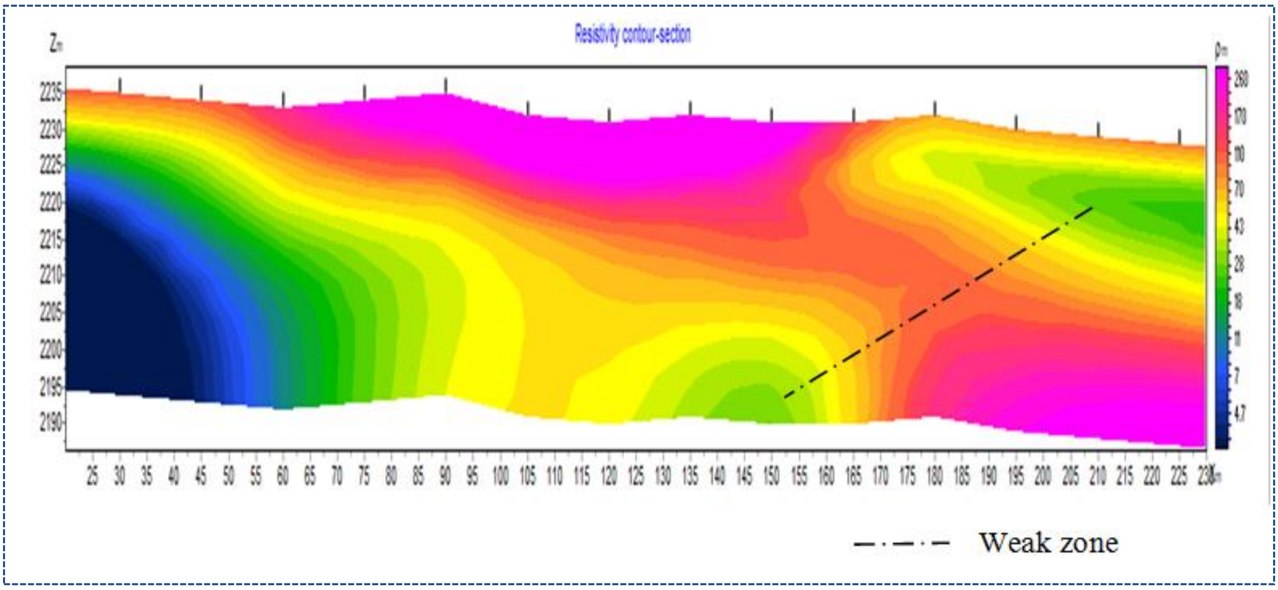


Figure 5.9 Electrical resistivity tomography section of profile 1

Profile 2

The second profile line has a resistivity value from 3.1Ω-m to 170Ω-m with depth of investigation 45m as shown in figure 5.10. The resistivity section shows that up to 10m depth the subsurface has resistivity value ranges from 3.1Ω-m to 29Ω-m as a result of silt clay with some sand formation. The maximum resistivity value which ranges from 70Ω-m to 170Ω-m is seen in the lower portion from 100m-140m and from 220m to the end of the profile line. This range of resistivity value is seen due to the presence of highly fractured and weathered basalt. The intermediate resistivity value from 45Ω-m to 70Ω-m is characterized as weak zone which is filled by silt clay with some sand which has less moisture content.

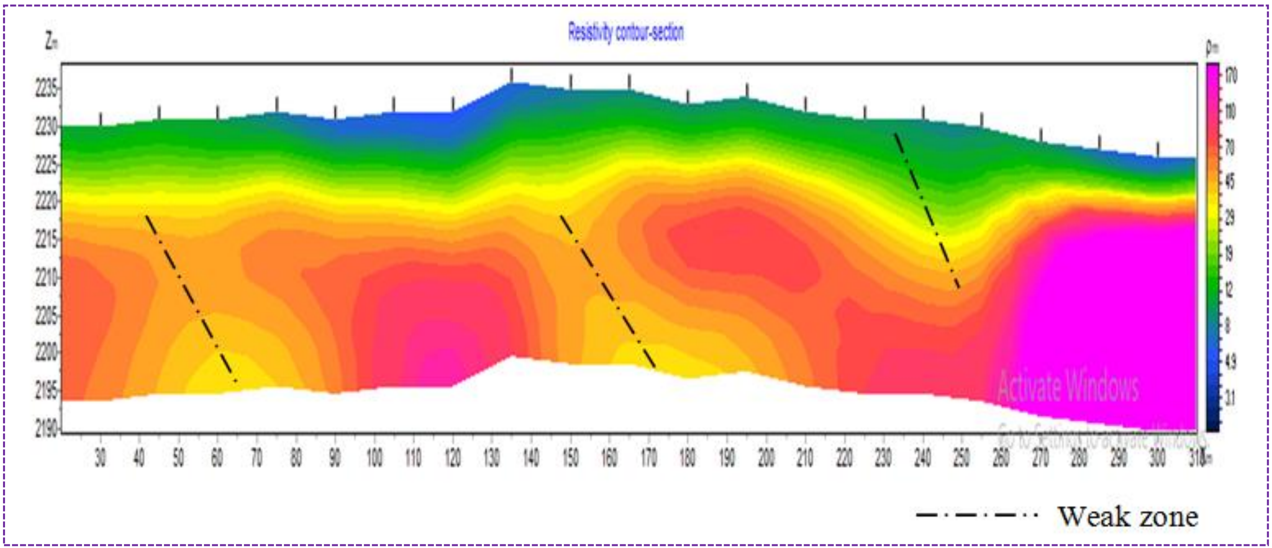


Figure 5.10 Electrical resistivity tomography section of profile2

Integrated result of seismic refraction, VES and ERT outputs

Profile -1

The integrated result of all the geophysical methods applied for profile-1is summarized in figure 5.11 according to the alignment shown in figure 4.1. The overall result shows the presence of weak zones and four geological layers. These layers can have different resistivity as well as velocity values depending on the moisture content and mineralogical composition.

The electrical resistivity tomography result and geo-electric section shows that at a depth of 15m and above between VES 2 and VES 1 there is a low resistive region. This is as a result of clay soil which has high moisture content.

The p wave velocity model shows as we go deeper there is an increment in velocity. This is as a result of the top layer is filled by loose sand and gravel as well as silt clay with sand formation which cause the p wave velocity to decrease. But when we go deeper there is highly weathered basalt in the subsurface which increase the seismic velocity. The ERT output also shows the same result. But there is considerable difference between these two methods since there is resolution difference in vertical depth. The ERT result clearly shows the presence of weak zones between high resistive regions but the seismic refraction has limitation of hidden layers.

The p wave velocity model also relates with the borehole data up to 10m depth. To a depth of 1.3m both outputs show the presence of loose sand and gravel, at a depth of 1.3m - 3m the subsurface is filled by silt clay with some sand formation. From 3m and above the p wave velocity increases since the moisture content of the silt clay decreases. The ERT result also shows below 20m depth at a distance of 170m and above there is an increase in resistivity value this indicates the decrease in moisture content of silt clay. As we go deeper this increment in resistivity continues since there is weathered basalt in the subsurface.

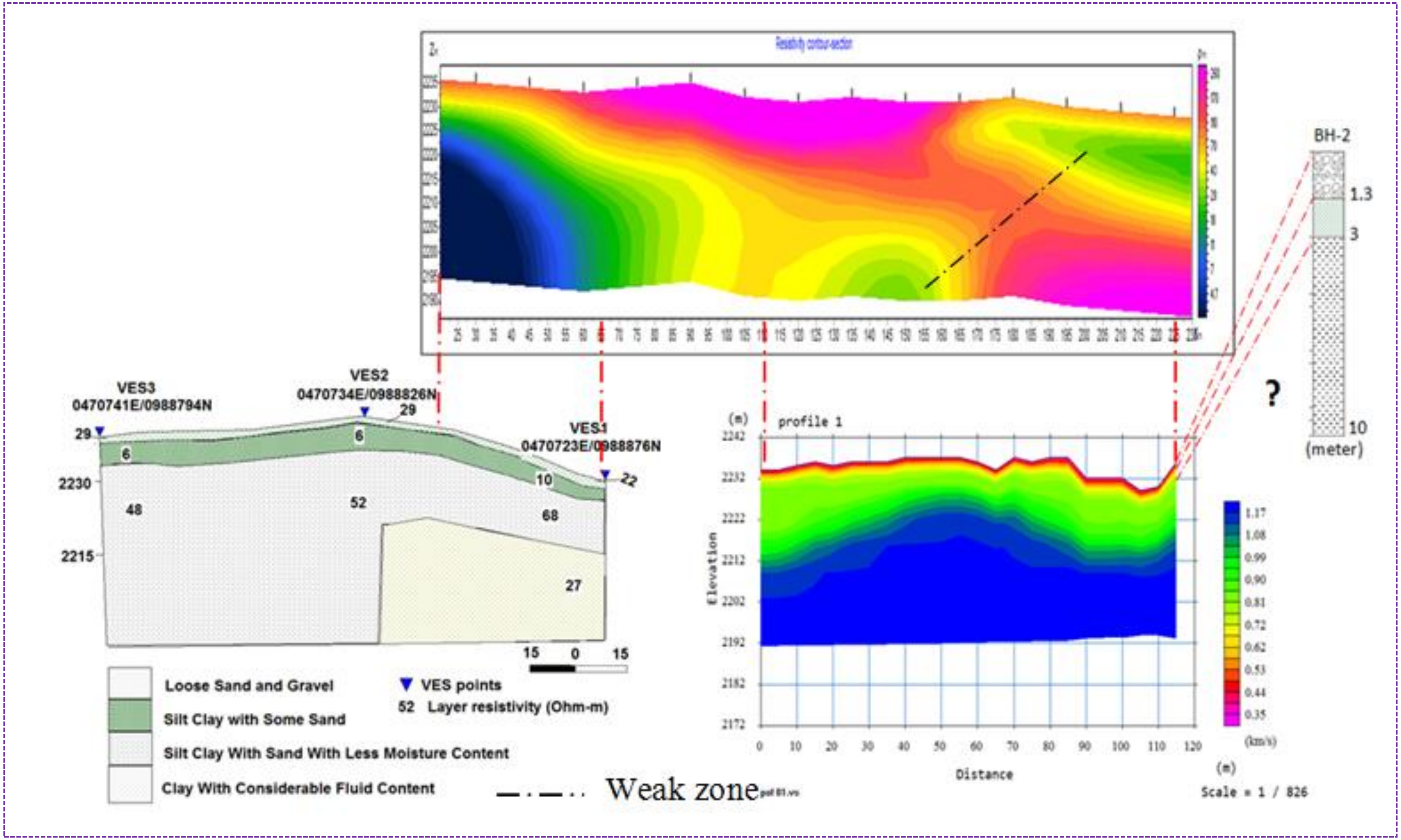


Figure 5.11 integrated geophysical and borehole log results of profile-1

Profile -2

The integrated result of all the geophysical methods applied for profile-2 is summarized in figure 5.13 according to the alignment shown in figure 4.1. The overall result shows the presence of four geological layers. These layers can have different resistivity as well as velocity values depending on the moisture content and mineralogical composition.

The result found from electrical resistivity tomography and geo-electric section shows; up to 20m depth there is a resistivity variation 3.1Ω-m - 59Ω-m. implies the moisture content of silt clay with sand formation decreases as we go deeper. From a depth of 20m and above within the ERT profile line at a distance from 95 to150m there is a high resistive region which may be due to highly weathered basalt. This formation also extends from 170m to the end of profile line. It is clearly seen that between this regions there is a weak zone filled by silt clay with some sand formation.

The p wave velocity model of this profile also shows there is an increment in velocity up to the survey depth which is around 12m. Within this depth the ERT result also shows there is an increment in resistivity values.

The geo-electric section of profile-2 is correlated with the BH log data up to 10m depth. The result shows that up to 2m the subsurface is filled by loose sand and gravel, from 2m-3.2m the subsurface is filled by silt clay with some sand formation. From 3.2m-10m the resistivity value increases since the moisture content of the silt clay with sand formation decreases.

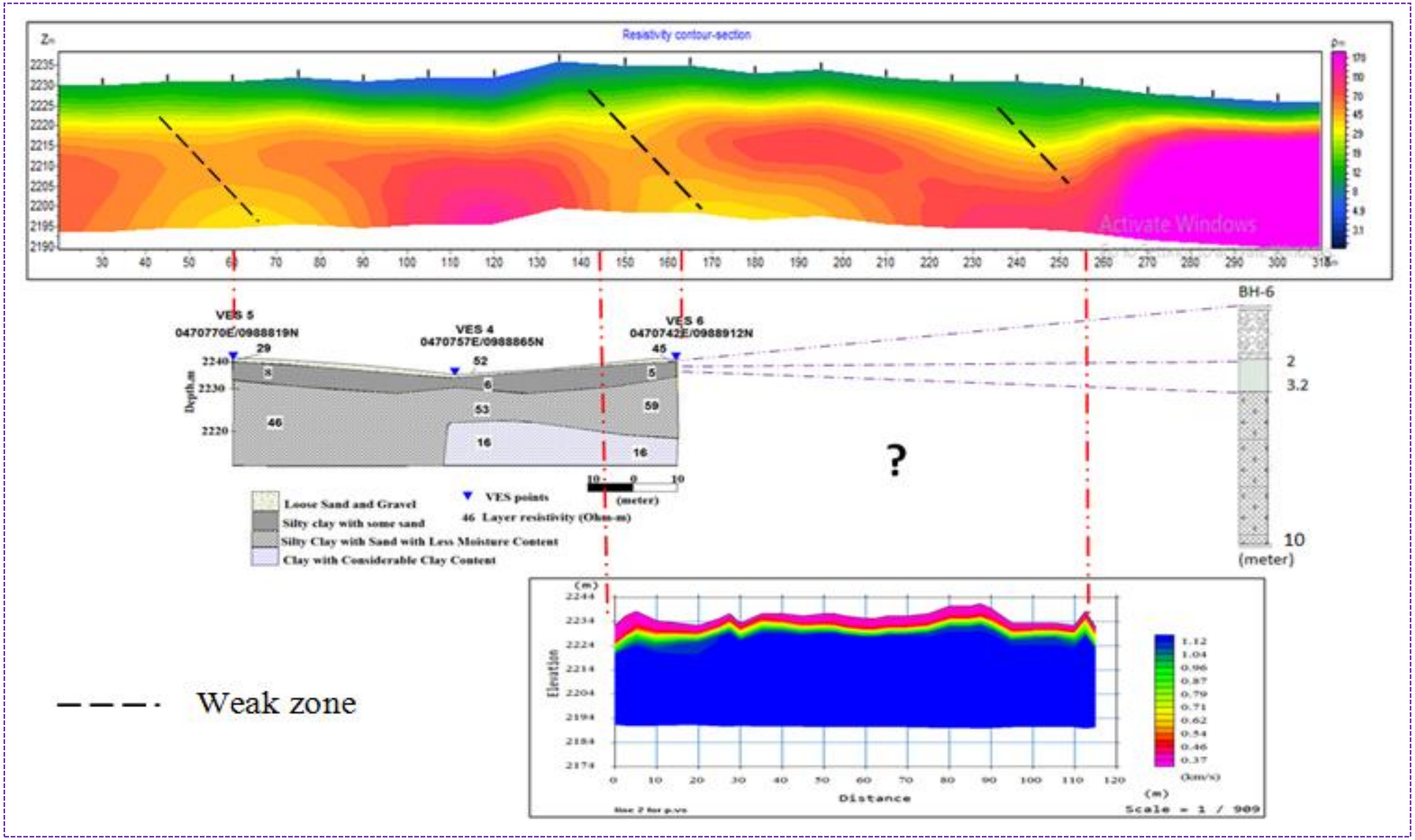


Figure 5.12 integrated geophysical and borehole log results of profile-2

CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusions

A geophysical investigation involving seismic refraction, electrical resistivity and sounding methods was conducted for this study at a place found in Lebu Mebrat Haile which is found in south East of Addis Ababa. The geophysical outputs are correlated with the borehole log data. Based on the results found from the geophysical and borehole data, the researcher concludes the following.

1. From the seismic refraction p-wave velocity models and calculated S-wave velocity values, three layers are identified. The p-wave velocities of these layers vary from190m/s to 1,170m/s. The result obtained from p-wave velocity model of all of the three profiles shows that: the top soil has p-wave velocity ranges from 190m/s-720 m/s which is a result of the upper layer filled with loose sands and gravels. The second layer has a p wave velocity ranges from 450m/s- 990m/s this layer is characterized as a layer filled by silt clay with some sand formations. The third layer with p-wave velocity ranges from 630m/s-1,170m/s has relatively high velocity range this increment in velocity is seen due to the presence of clay in the subsurface.

2. The calculated S wave velocity result shows that the shear wave velocity for all three profiles ranges from 92m/s-565m/s. The minimum velocity which is 92m/s is observed in the third profile of layer three and the maximum value is seen in the third layer of Profile -1. This range of shear wave velocity implies the study area is dominated by clay soil.
3. The geo-electric section of the two profiles shows a resistivity value ranges from 6Ω-m-68 Ω-m. The minimum resistivity value is observed in the second layer of each section since the subsurface is filled by silt clay with some sand formation. This layer is found at a depth of around 1m and it has an average thickness of 6m. The maximum resistivity is found in the third layer of each profile since the moisture content of the silt clay with some sand formation decreases. Both of the geo-electric sections shows the presence of

low resistive region under the third layer with resistivity value ranges from 16Ωm-27Ωm. this may be due to an increase in the moisture content of the clay soil.

4. The ERT result shows a better depth of investigation as compared to the above two methods which is around 45m. The resistivity values from this survey ranges from 3.1Ω-m - 260Ω-m. This variation in resistivity is observed due to the moisture content and mineralogical composition of the clay soil (content of clay soil) as well as the presence of highly weathered and fractured basalt in the subsurface. The low resistivity value is seen in profile-1 with a depth of 15m at a distance of 25m-60m. Implies the presence of clay with high moisture content. The maximum values observed in both profiles shows that the presence of highly weathered and fractured basalt in the subsurface. Both profiles show the presence of weak zones in the subsurface. In profile-1 the weak zone is oriented in S-E direction starting from a distance of 115m up to the end of survey line. Profile -2 shows the presence of three weak zones which are fund at a depth of 20 meter in between profile distance of 30m-100m, 140m-220m and 230m-280m.
5. The sear wave velocity range found from this study is considered as low shear wave velocity values which may be due to the presence of clay soil in the subsurface. Such kind of formation can amplify the magnitude of small earthquakes

From the overall results of the geophysical survey and the borehole logs, five main geologic layers and weak zones were delineated with in the study area. These are a layer filled loose sand and gravel formation, a layer filled by silt clay with some sand, a layer filled by silt clay with sand with less moisture content, a layer filled by clay with considerable fluid content and that of highly weathered and fractured basalt.

Generally the study area is characterized us an area filled by loose materials, weak zones and weathered basalt. Thus it is not possible to find competent basement or bedrock suitable for building foundation. As a result when designing foundation for buildings the civil engineer should take into account the behavior of the subsurface and choose a competent foundation type.

Since the study area is found in a place were low and medium earthquakes can occur, the presence of loose sands, and clay formation found in the subsurface can amplify the seismic activities and the amplification can cause any damage to the buildings. So when designing building foundation the engineer has taken in to account such considerations.

From all of the findings it is noticed that up to survey depth of 45m; there is no bedrock or ground water table seen.

6.2 Recommendations

From the result obtained from seismic velocity models and resistivity sections the researcher recommends the following points.

1. The study area is found in a place filled by loose sands, clay, weak zones and highly weathered and fractured basalt. Thus proper foundation design has to be prepared by the civil engineer.
2. Since the area is mapped as a place susceptible to small and medium earthquake activities the subsurface nature of the study area can amplify such small and medium amplitude earthquakes. Thus the engineer should take in to account such activities when designing the foundation for the building.
3. The current study covered only small part. So, additional investigation will be required for the future expansion of buildings.

Reference

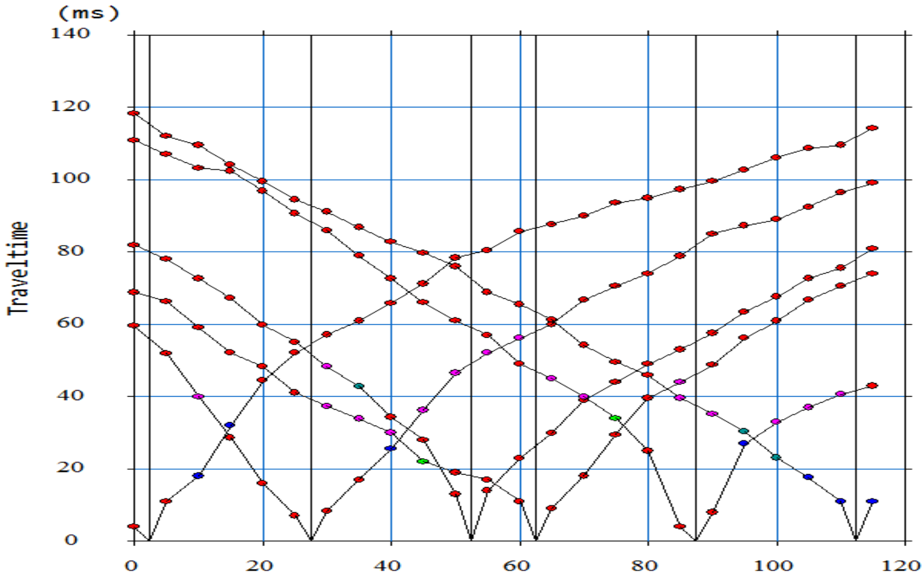
1. Abraham Mulualem. (2017). Integrated geophysical characterization of Injibara university campus building site, Injibara, Amhara, north western Ethiopia. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 111pp.
2. Addisu Haile. (2014). Integrated Geophysical investigations for mapping possible inflow of water from Merti-Fentale irrigation canal into Lakebeseka, Metaharaarea, Eastern Ethiopia. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 88pp.
3. Aderoju A. Ademola, and Adebayo, O.O.(2015). Geophysical Investigation for Foundation Studies at Ogudu River Valley Estate, Lagos, Southwestern, Nigeria. *Geos*. **4**: 295-302.
4. Ahzegbobor, P.A. (2010). 2D and 3D geoelectrical resistivity imaging. *Phy*. **5(23),** 3592-3605.
5. Andy A. Bery and Rosli,S. (2013). Seismic Refraction Velocities and Engineering Parameters Analysis for Environmental Study. *Geop.***18**:3720-3729.
6. Ayolabi, E.A., Folorunso, A.F. and Jegede, OE. (2012). An application of 2D electrical resistivity tomography in geotechnical investigations of foundation defects, *Geol and Mining Research* **3(12)** : 142-151
7. Cedric.S.(2007). Seismic-Reflection and Seismic-Refraction Imaging of the South Portuguese Zone Fold-and-Thrust Belt. Unpublished PHD dissertation, Uppsala University, Uppsala, Sweden, 41-47.
8. DMC Construction (2015). A report on Geotechnical Investigation and Foundation Recommendation for Industrial Building. Unpublished Report, Addis Ababa,Ethiopia.
9. Ethiopian Building Code Standard (1995). Code of Standards for Seismic Loads. Ministry of Work and Urban Development, Addis Ababa, Ethiopia.
10. Fkirin, MA.,Badawy, S. and El deery, MF. (2016). Seismic Refraction Method to Study Subsoil Structure, *Geol and Geop*. **5**: 259.
11. GSE (Geological survey of Ethiopia) (2012). A report on Engineering Geological Mapping &Geohazard Assessment of Akaki Map Sheet (NC37-14). Unpublished Report, Addis Ababa,Ethiopia.

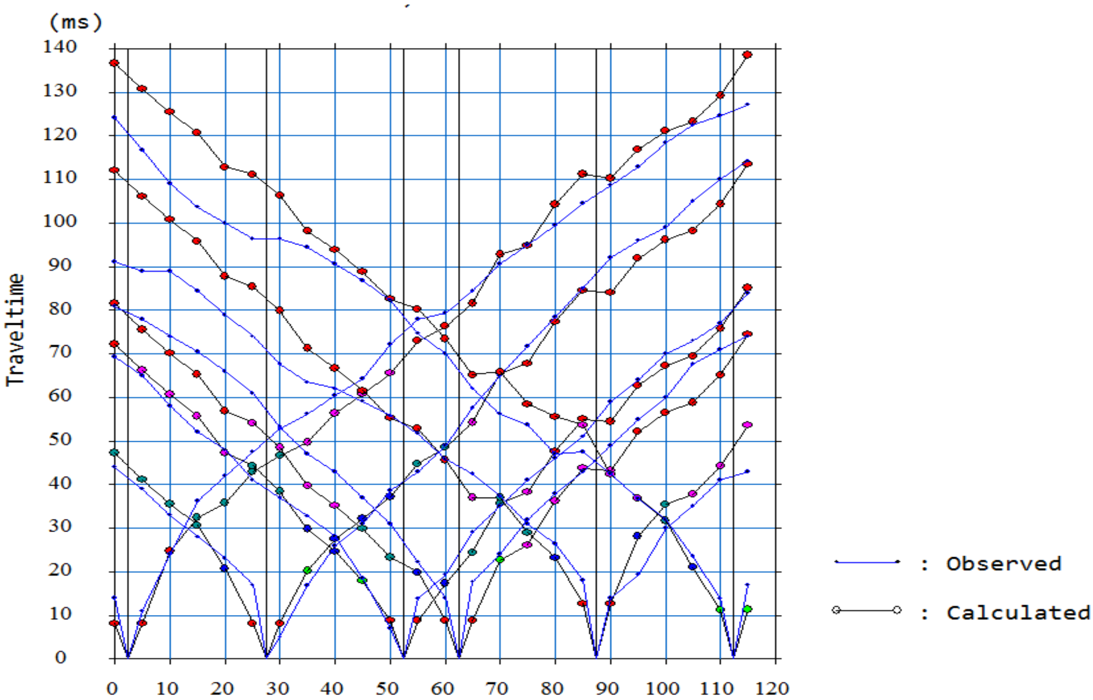
12. GSE (Geological survey of Ethiopia) (2011). A report on Hydrogeology and hydrochemistry of the Akaki-Beseka Sheet (NC 37-14). Unpublished Report, Addis Ababa,Ethiopia.
13. HailemariamSiyum. (2011).Integreated Geophysical and Direct Geothechnical Investigation for Building Foundation at Addis Ababa Science and Technology University. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 100 pp.
14. Naveen Kumar T., Rama Rao P. and Naganjaneyulu K.(2015).Electrical resistivity imaging (ERI) using multi electrodes for studying subsurface formations in Cauvery plains. *Adv. Appl. Sci. Res*. **6(5)**:47-53
15. Oyedele, K. F., Oladele, S. and Okoh, C. (2015). Assessment of Subsurface Conditions in a Coastal Area of Lagos using Geophysical Methods, *Geos*, **12**:36-40.
16. U.S. Department of Energy Office of Environmental Management Office of Science and Technology (2000). A summary report on Electrical Resistance Tomography for Subsurface Imaging. Livermore, California.
17. Yonatan Garkebo. (2011). Integrated Geophysical and Geotechnical Investigations for Building Site Characterization of Wachamo University, North-east of Hosanna Town, Southern Ethiopia. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 102pp.
18. Youd, T.L., Idriss, I.M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Finn, W.D.L., Harder, L.F., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S.S.C., Marcuson, W.F., Martin, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S., Robertson, P.K., Seed, R.B. and Stokoe K.H. (2001). "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaciton Resistance of Soils." Journal of Geotechnical and Geoenvironmental Engineering. 817833.
19. http://www.enviromental-geophysics.co.uk.pdf accessed on 13.01.2019.
20. http://www.HGI-Geotechnical-Brochure.pdf accessed on 10.11.2018
21. http://www.geomatrix.co.Uk/and-products/electrical-resistivity/elrec-pro. Pdfaccessed on 4.16.2019

Appendices

Appendix-1

Travel time distance curves

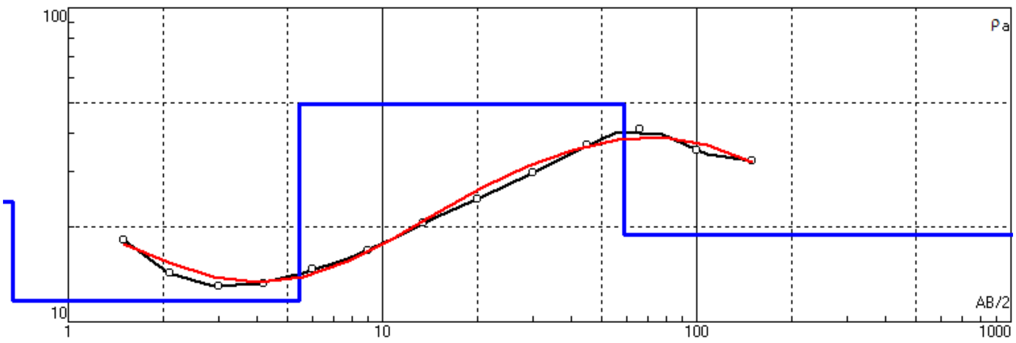




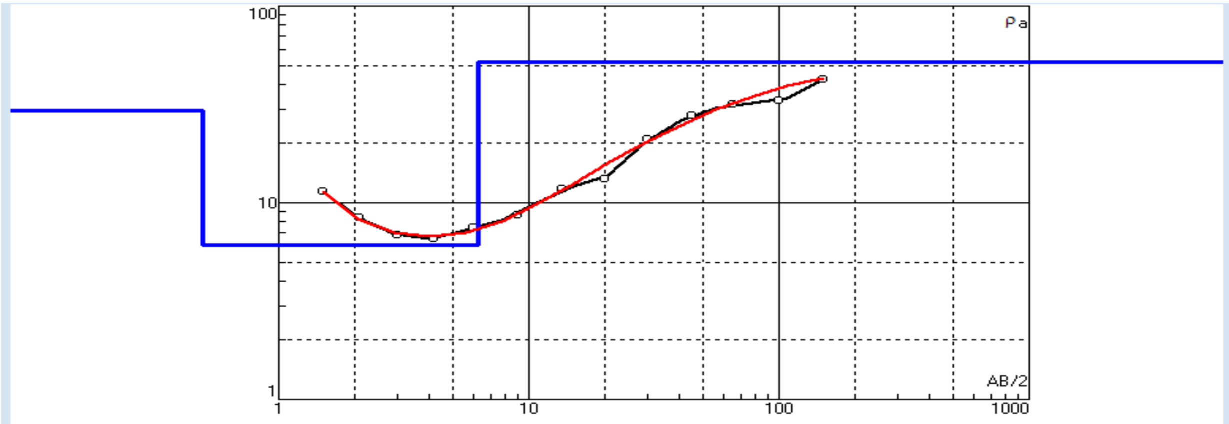
Appendix-2

VES outputs

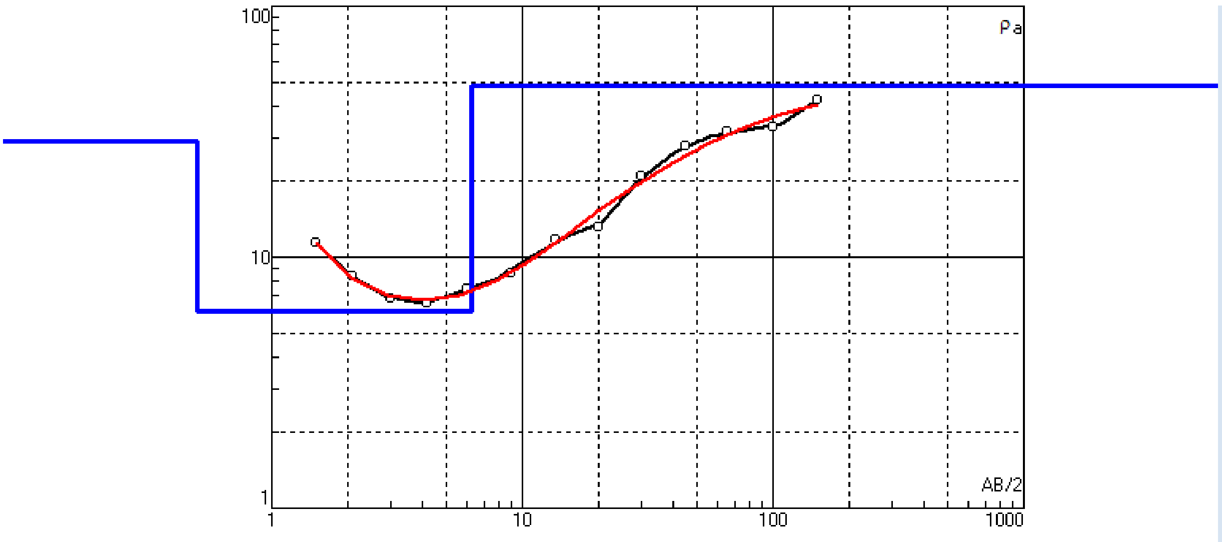
VES 1



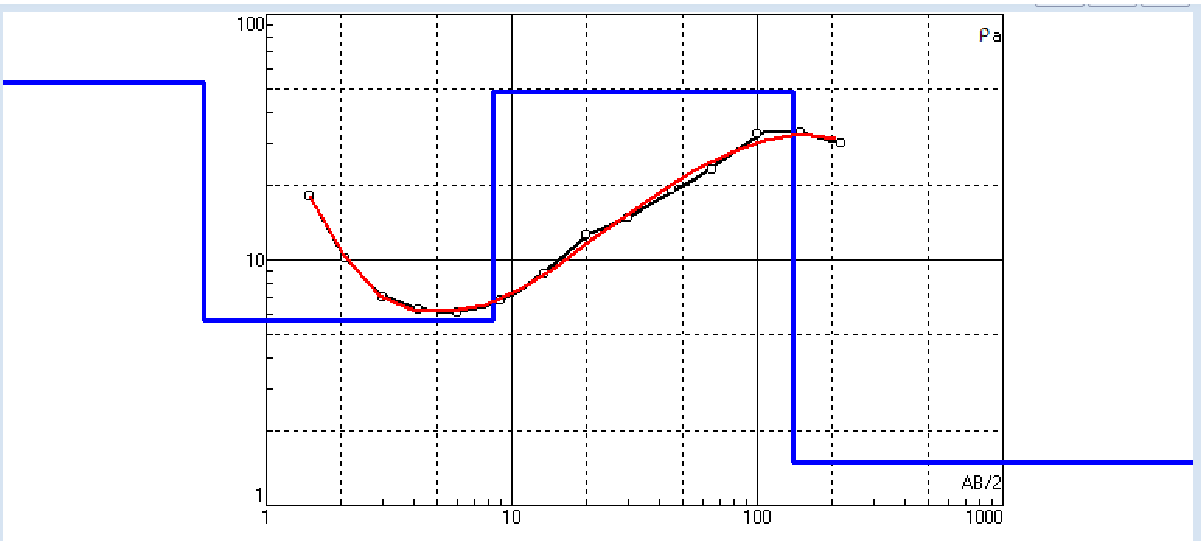
VES 2



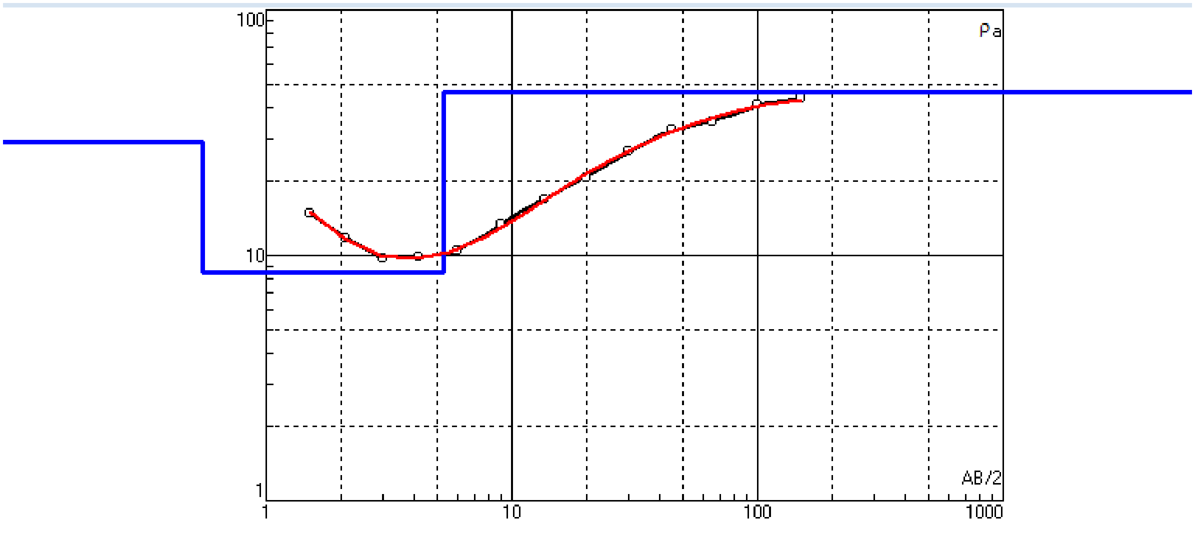
VES 3



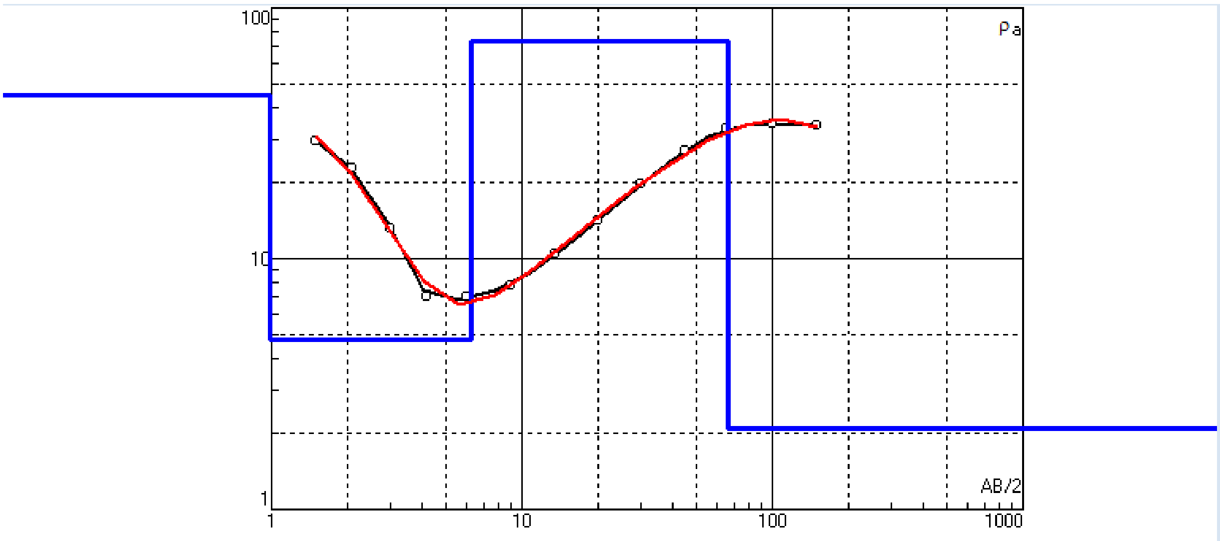
VES 4



VES 5



VESS 6



Appendix-3

Resistivity of common rocks

Common rocks	Resistivity(Ω-m)
Topsoil	50–100
Loose sand	500–5000
Gravel	100–600
Clay	1–100
Weathered bedrock	100–1000
Sandstone	200–8000
Limestone	500–10 000
Greenstone	500–200 000
Gabbro	100–500 000
Granite	200–100 000
Basalt	200–100 000
Graphitic schist	10–500
Slates	500–500 000
Quartzite	500–800 000

Appendix-4

P-wave velocities of different materials (Gerhard, 2005)

Earth materials	V_{p}(m/s)
water	1450-1530
Petroleum	1300-1400
loess	300-600
Soil	100-500
Snow	350-3000
Solid glacier ice	3000-4000
Sand loose	200-2000
Sand (dry, loose)	200-1000
Sand (water saturated loose)	1500-2000
Glacial moraine	1500-2700
Sand and gravel (near surface)	400-2300
Sand and gravel at 2km depth	3000-3500
Clay	1000-2500
Estuarine mud's/clay	300-1800
Flood plain alluvium	1800-2200
Permafrost quaternary sediments	1500-4900
Limestone (soft)	1400-4500
Limestone (hard)	2800-7000
Dolomites	2500-6500
Anhydrite	3500-5500
Rock salt	4000-5500
Gypsum	2000-3500

Appendix-5

BH log results (DMC construction, 2015)

ADDIS GEOSYSTEMS PLC	Page 1 of 1
Tittle: BOREHOLE LOG SHEET	BH-1

PROJECT: Industrial Bulding
LOCATION : Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC.
DATE STARTED: 13/11/2015
DATE COMPLETED :14/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989074, E-0470675
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (m)	Hole Diameter (mm)	Sample Record	SPT/DPT N_value	Legend	Strata Description	Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0					Back Fill Material	0.35	100		
						0.6	100		
						0.85	100		
1						1.25	100		
						1.85	100		
2			9		Soft, dark grey, CLAY (Black Cotton Soil).	2	100		
						3.15	100		
3		UD				4	100		
4			14		Stiff to very stiff, light grey, silty CLAY with some sand.				
5	89					6	100		
6			21			7	100		
7		UD				8	100		
8			28			9	100		
9		UD				10	100		
10									

BH BOREHOLE
(Nc) CONE PENETRATION TEST
SPT STANDARD PENETRATION TEST
N BLOWS/30cm
W WATER SAMPLE
NGL NATURAL GROUND LEVEL
RQD ROCK QUALITY DESIGNATION
TCR TOTAL CORE RECOVERY
▼ STATIC GROUND WATER LEVEL

DS DISTURBED SOIL SAMPLE
UD UNDISTURBED SOIL SAMPLE
RK ROCK SAMPLE
R REFUSAL

LOGGED BY : Eyerusalem Abdulkedir	Date:27/11/2015
DRAWN BY: Ehete Gashaw	Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke	Date:27/11/2015

ADDIS GEOSYSTEMS PLC	Page 1 of 1
Tittle: BOREHOLE LOG SHEET	BH-2

PROJECT: Industrial Bulding
LOCATION :Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC
DATE STARTED: 14/11/2015
DATE COMPLETED :16/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989094, E-0470686
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (m)	Hole Diameter (mm)	Strata Description
0 – 1.65	89	Back Fill Material
1.65 – 3	89	Soft, dark grey, CLAY (Black Cotton Soil).
3 – 10	89	Soft to very stiff, light grey, silty CLAY with some sand.

Depth (m)	Sample Record	SPT/DPT N_value
2	UD	
3		14
4	UD	
5		14
6	UD	
7		15
8	UD	
9		18

Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0.35	100		
0.85	100		
1.15	100		
1.65	100		
2	100		
3	100		
4	100		
5	100		
6	100		
7	100		
8	100		
8.65	100		
9	100		
10	100		

BH BOREHOLE
(Nc) CONE PENETRATION TEST
SPT STANDARD PENETRATION TEST
N BLOWS/30cm
W WATER SAMPLE
NGL NATURAL GROUND LEVEL
RQD ROCK QUALITY DESIGNATION
TCR TOTAL CORE RECOVERY
▼ STATIC GROUND WATER LEVEL

DS DISTURBED SOIL SAMPLE
UD UNDISTURBED SOIL SAMPLE
RK ROCK SAMPLE
R REFUSAL

LOGGED BY : Eyerusalem Abdulkedir Date:27/11/2015
DRAWN BY: Ehete Gashaw Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke Date:27/11/2015

ADDIS GEOSYSTEMS PLC	Page 1 of 1
Tittle: BOREHOLE LOG SHEET	BH-3

PROJECT: Industrial Bulding
LOCATION : Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC
DATE STARTED: 16/11/2015
DATE COMPLETED :17/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989090, E-0470680
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (m)	Hole Diameter (mm)	Sample Record	SPT/DPT N_value	Legend	Strata Description	Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0–2	89				Back Fill Material	0.4	100		
						1	100		
						1.25	100		
						1.65	100		
						2	100		
2–4		UD (3.0)	8 (2.0)		Soft, dark grey, CLAY (Black Cotton Soil).	3	100		
						4	100		
4–10		UD (5.0)	15 (4.0)		Stiff to very stiff, light grey, silty CLAY with some sand.	5	100		
						6	100		
		UD (7.0)	18 (6.0)			7	100		
						8	100		
		UD (9.0)	15 (8.0)			9	100		
						10	100		

BH	BOREHOLE
(Nc)	CONE PENETRATION TEST
SPT	STANDARD PENETRATION TEST
N	BLOWS/30cm
W	WATER SAMPLE
NGL	NATURAL GROUND LEVEL
RQD	ROCK QUALITY DESIGNATION
TCR	TOTAL CORE RECOVERY
▼	STATIC GROUND WATER LEVEL
DS	DISTURBED SOIL SAMPLE
UD	UNDISTURBED SOIL SAMPLE
RK	ROCK SAMPLE
R	REFUSAL

LOGGED BY : Eyerusalem Abdulkedir Date:27/11/2015
DRAWN BY: Ehete Gashaw Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke Date:27/11/2015

AGS ADDIS GEO SYSTEMS	ADDIS GEOSYSTEMS PLC	Page 1 of 1
	Tittle: BOREHOLE LOG SHEET	BH-4

PROJECT: Industrial Bulding
LOCATION : Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC
DATE STARTED: 17/11/2015
DATE COMPLETED :18/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989099, E-0470704
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (cm)	Hole Diameter (mm)	Sample Record	SPT/DPT N_value	Legend	Strata Description	Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0					Back Fill Material	0.35	100		
						0.75	100		
1						0.95	100		
						1.15	100		
						1.65	100		
2						3	100		
3			9		Soft, dark grey, CLAY (Black Cotton Soil).	3.5	100		
4		UD			Soft to very stiff, light grey, silty CLAY with some sand.	4	100		
						4.6	100		
5	89		14			5	100		
6		UD				6	100		
7			13			7	100		
8						8	100		
9			20			9	100		
10						10	100		

BH	BOREHOLE	DS	DISTURBED SOIL SAMPLE
(Nc)	CONE PENETRATION TEST	UD	UNDISTURBED SOIL SAMPLE
SPT	STANDARD PENETRATION TEST	RK	ROCK SAMPLE
N	BLOWS/30cm	R	REFUSAL
W	WATER SAMPLE		
NGL	NATURAL GROUND LEVEL		
RQD	ROCK QUALITY DESIGNATION		
TCR	TOTAL CORE RECOVERY		
▼	STATIC GROUND WATER LEVEL		

LOGGED BY : Eyerusalem Abdulkedir Date:27/11/2015
DRAWN BY: Ehete Gashaw Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke Date:27/11/2015

ADDIS GEOSYSTEMS PLC	Page 1 of 1
Tittle: BOREHOLE LOG SHEET	BH-5

PROJECT: Industrial Bulding
LOCATION :Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC
DATE STARTED: 18/11/2015
DATE COMPLETED :19/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989077, E-0470701
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (cm)	Hole Diameter (mm)	Sample Record	SPT/DPT N_value	Legend	Strata Description	Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0					Back Fill Material	0.4	100		
						0.85	100		
1						1.5	100		
						2	100		
2			12		Soft, dark grey, CLAY (Black Cotton Soil).	3.2	100		
3		UD				4	100		
4			13		Stiff to very stiff, light grey, silty CLAY with some sand.	5	100		
5	89	UD				6	100		
6			19			7	100		
7		UD				8	100		
8			16			9	100		
9		UD				10	100		
10									

BH	BOREHOLE
(Nc)	CONE PENETRATION TEST
SPT	STANDARD PENETRATION TEST
N	BLOWS/30cm
W	WATER SAMPLE
NGL	NATURAL GROUND LEVEL
RQD	ROCK QUALITY DESIGNATION
TCR	TOTAL CORE RECOVERY
▼	STATIC GROUND WATER LEVEL
DS	DISTURBED SOIL SAMPLE
UD	UNDISTURBED SOIL SAMPLE
RK	ROCK SAMPLE
R	REFUSAL

LOGGED BY : Eyerusalem Abdulkedir Date:27/11/2015
DRAWN BY: Ehete Gashaw Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke Date:27/11/2015

ADDIS GEOSYSTEMS PLC	Page 1 of 1
Tittle: BOREHOLE LOG SHEET	BH-6

PROJECT: Industrial Bulding
LOCATION : Addis Ababa, Lebu Area
CLIENT : DMC CONSTRUCTION PLC
DATE STARTED: 19/11/2015
DATE COMPLETED :20/11/2015

BORING TYPE : Rotary coring
GROUND WATER LEVEL : Nil
BH COORDINATES : N-0989094, E-0470678
BH ELEVATION : 2223m
INCLINATION : Vertical. TOTAL BH DEPTH 10m

Depth (cm)	Hole Diameter (mm)	Sample Record	SPT/DPT N_value	Legend	Strata Description	Run Length Depth (m)	TCR (%)	RQD (%)	Remark
0–2.1	89				Back Fill Material	0.4	100		
						0.8	100		
						1.5	100		
						2	100		
2.1–3.5					Soft, dark grey, CLAY (Black Cotton Soil).	2.1 / 2.5	100		
						3	100		
			13						
3.5–10					Stiff to very stiff, light grey, silty CLAY with some sand.	4	100		
		UD				5	100		
			20						
						7	100		
			13						
						8.3	100		
		UD				9	100		
			15			10	100		

BH	BOREHOLE	DS	DISTURBED SOIL SAMPLE
(Nc)	CONE PENETRATION TEST	UD	UNDISTURBED SOIL SAMPLE
SPT	STANDARD PENETRATION TEST	RK	ROCK SAMPLE
N	BLOWS/30cm	R	REFUSAL
W	WATER SAMPLE		
NGL	NATURAL GROUND LEVEL		
RQD	ROCK QUALITY DESIGNATION		
TCR	TOTAL CORE RECOVERY		
▼	STATIC GROUND WATER LEVEL		

LOGGED BY : Eyerusalem Abdulkedir Date:27/11/2015
DRAWN BY: Ehete Gashaw Date:27/11/2015
APPROVED BY : Dr.Addis A. Zeleke Date:27/11/2015