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ADDIS ABABA UNIVERSITY

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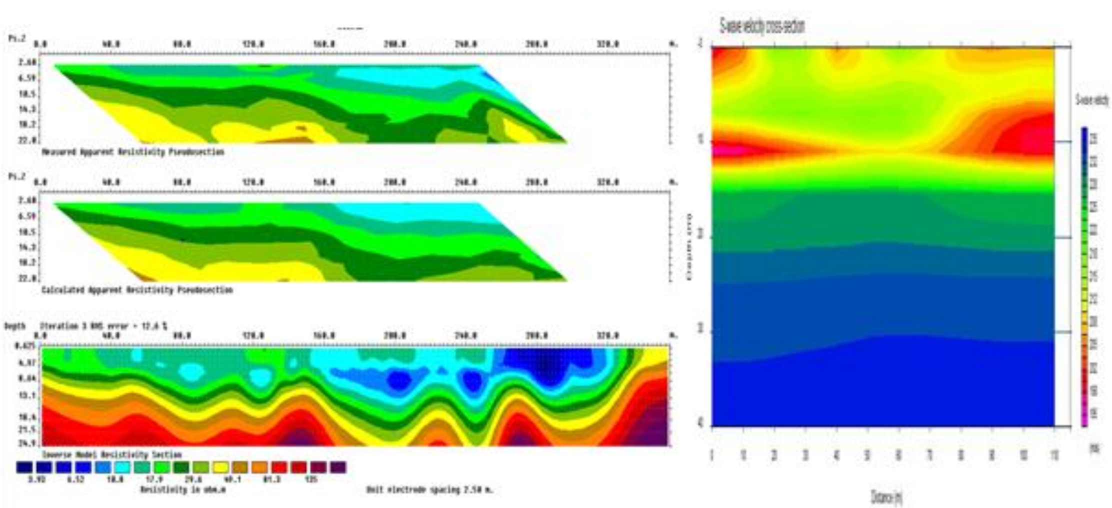
Application of Geophysical Methods for Engineering Site Characterization of Wachamo University Referral Hospital building foundation in Hossana Town, Southern Ethiopia.



By

Tamrat Eramo

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirements for the Degree of Master of Science in Exploration Geophysics

AUGUST /2020
Addis Ababa

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A Thesis

by

Tamrat Eramo

School of Earth science

Approved by Board of Examiners	Signature	Date
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ABSTRACT

Application of the electrical resistivity and multichannel analysis of surface wave geophysical methods provide information on engineering site characterization of Wachamo University referral hospital site, in Hossana, southern Ethiopia. Often, existing hospital buildings and other large civil engineering structures found in Hossana town were constructed with limited point observation data, without continuous assessment of the site for foundation work and without knowledge of the possible subsurface discontinuities and structures through and without considerable understanding of earthquake effects on such structures. Vertical Electrical Sounding (VES), Electrical Resistivity Imaging (ERI) and Multichannel Analysis of Surface Wave (MASW) survey methods were employed on the site to get a better understanding of the site condition in a continuous manner. The VES, electrical resistivity imaging and MASW were processed by using winRsist, Res2Dinv and Seisimager software's respectively to get the desired information.

The geo-electrical data haves shown that the depth of bedrock /competent rock is in range 5-13.1m beneath the subsurface having resistivity value roughly in between 39.5 and 75Ω-mfor shallow foundation of low rising buildings design while for deep foundation of high rising buildings design, the depth to the bedrock/competent rock is in the range of 13.1-21.5m beneath the subsurface having resistivity value roughly between 49.1-125Ω-m in the northern and central parts of the study area considering the presence of weak zone within the bedrock formation. In the case of southern part of the survey lines of the study area, the geo-electrical data has shown that the depth to the competent /bed rock is in range 5-13.1m and it is suitable for both shallow and deep foundation of the building design of the study area.

The average shear wave velocities of the upper 30m depth of the study area are 219.7 and 239.7m/s. According to the NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards the soil can be classified as D. Also based on the average shear wave velocity of up to 36.43 and 34.74m depth of the site are 216.84 and 240.91 m/s respectively and period (T_0) the site is classified as D1 and D2 according to new site-soil classification scheme. The Gmax of the study area in the two multichannel analysis of surface wave are 105.74 and 169 pa.

Therefore, both electrical resistivity and multichannel analysis of surface wave methods revealed that the material that lie between the third and the fourth layers over the site to be having with fair- good geotechnical properties.

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TABLE OF CONTENT

ABSTRACT .... **I**

ACKNOWLEDGMENT .... **II**

CHAPTER ONE BACKGROUND **0**

1.1 Introduction 0

1.2. Description of Study area 2

1.2.1 Location and Accessibility of Study Area 2

1.2.2 Derange pattern and physiography of the study area 3

1.3. Statement of the problem 4

1.4. Significance of the study 5

1.5. Research Questions 6

1.6. Objectives the study 6

1.6.1 General objectives 6

1.6.2 Specific Objective 6

1.7. Methodology 7

1.7.1. Methodologies and procedures 7

1.7.1.1 Vertical Electrical sounding (VES) 7

1.7.1.2 The Multichannel Analysis of Surface Waves (MASW) method 8

1.7.1.3 Electrical Resistivity Tomography (ERT or 2-D resistivity imaging) survey 8

1.8 Previous Works 10

CHAPTER TWO: GEOLOGICAL, SEISMICITY AND TECTONICS REVIEW **11**

2.1 Regional Geological Setting 11

2.2 Regional Geological Structures 11

2.3 Regional geology of the Study Area and its Surroundings 12

2.4 Local geology of the study area and its surroundings 13

2.5 Hydrogeological Setting 15

2.6 Hydrogeology of study area 17

2.7 Seismic Setting 18

2.8 Basis for Site Classification 21

2.9 New site soil classification scheme 21

CHAPTER THREE: THEORETICAL BACKGROUND OF METHODS OF INVESTIGATION 24

3.1 Introduction to Seismic methods 24
3.1.1 Body waves 24
3.1.2 Surface waves 25
3.1.2.1 Rayleigh waves 25
3.1.2.2 Love waves 25
3.1.2.3 Seismic wave velocity 26
3.2 Multichannel Analysis of Surface Waves 28
3.2.1 General procedure 29
3.2.2 Field measurements 29
3.2.3 Data processing 30
3.2.4 Inversion analysis 30
3.3 Electrical Resistivity 31
3.3.1 Preamble 31
3.3.2 Electrical Resistivity methods 32
3.3.3 Types of Resistivity Surveys 33
3.3.3.1 Vertical Electrical Sounding (VES) 34
3.3.3.2 Electrical Resistivity Imaging/Tomography 35
CHAPTER FOUR: DATA ACQUISITION, PROCESSING AND PRESENTAION 37
4.1 Introduction 37
4.2 Multichannel Analysis of Surface Waves 38
4.2.1 Data acquisition 38
4.2.2. Data Processing and interpretation 39
4.3 Vertical Electrical sounding 42
4.3.1 Data acquisition and instrumentation 42
4.3.2 VES data Processing and presentation 43
4.4 Electrical Resistivity Imaging 44
4.4.1 Data acquisition and instrumentation 44
4.4.2 ERI Data processing and presentation 45
CHAPTER FIVE: RESULT, DISCUSSION AND INTERPRETATION 47
5.1 Result, Discussion and Interpretation Electrical Resistivity imaging data 47
5.1.1 Introduction 47

5.1.2 Results from Electrical Resistivity Imaging (ERI) Parallel Lines 01, 02, 03,04 and 05 47
5.1.3 ERI section for the Perpendicular imaging survey Line 05 54
5.1.4 Apparent resistivity sliced-stacked depth map 56
5.2 Result, Discussion and Interpretation of Multichannel Analysis of Surface Wave (MASW) 57
5.2.1 Introduction. 57
5.2.2 Dispersion curve 57
5.2.3 1D layer model of the section (The dispersion characteristic of a layered earth model) 59
5.2.4. Site-Soil classification 61
5.2.5 New site-soil classification and site period 65
5.2.6 Seismic wave velocity and elastic moduli 66
5.2.7 Site-amplification 69
5.3 Vertical Electrical Sounding Surveys 71
CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS 74
6.1 CONCLUSION 75
6.2 RECOMMENDATION 77
7. REFERENCES 78

List of Figures

Figure 1. 1 location map of the study area. 2
Figure 1. 2: Physiographic map of the study area 4
Figure 1.7 1. Schematic flowchart diagram of the methodology employed during the study 9
Figure 2. 1 Exposures of the rocks in the study area 14
Figure 2. 2 Geological map of Hossana Area 15
Figure 2. 3 (a 1) A conceptual hydrogeological model of the eastern plateau, the rift escarpment and rift floor (Demis Alemirew (2009) and Halcrow (2008) 16
Figure 2. 4 (b 1) Conceptual hydrogeological model of the western plateau, escarpment and rift floor (Demis Alemirew (2009) and Halcrow (2008). 17
Figure 2. 57 1 Seismicity of the region with the seismic Zone (Tilahun Mammo, 2005). 19
Figure 2. 6 Seismic hazard map of Ethiopia (Ethiopian Building Code Standards, 1995) and location of Project area. 20
Figure 3. 1 Particle motion associated with compressional waves 24
Figure 3. 2 Particle motion associated with shear waves 24
Figure 3. 3 Particle motion associated with Rayleigh waves. 25
Figure 3. 4Particle motion associated with Love waves 26
Figure 3. 5 General measurement procedure in MASW survey. 30
Figure 3. 6An overview of the main steps of the MASW method 31
Figure 3. 7.The Schlumberger array. 34
Figure 3. 8The procedure for Vertical Electrical Sounding survey where the current electrode layouts are systematically expanded about the central point for deeper current penetration 34
Figure 4. 1 The Geophysical survey lines of all methods employed in the study area 37
Figure 4. 2Instrumentation and MASW data acquisition 39
Figure 4. 3Flowchart for the analysis of surface wave data 40
Figure 4. 4 General steps of the 2D Multichannel Analysis of Surface Waves (MASW) 40
Figure 4. 51Data acquisition by PASI-GL16 Earth resistivity Meter and P100-N_X Energizer units 44
Figure 4. 6Typical example of inverse model resistivity section for imaging Line 01 46
Figure 4. 7Typical example of inverse model resistivity section for imaging Line 02 46
Figure 5. 1Inversion model resistivity section for Line 01 and correlation of the different subsurface units with Batena borehole lithologic log. 48
Figure 5. 2 Inversion model resistivity section for Line 02 and correlation of the different subsurface units with Batena borehole lithologic log 50

Figure 5. 3 Inversion model resistivity section for Line 03 and correlation of the different subsurface units with Batena borehole lithologic log 52
Figure 5. 4 Inversion model resistivity section for Line 04 and correlation of the different subsurface units with Batena borehole lithologic log 53
Figure 5. 5 Inversion model resistivity section for Line 05 and correlation of the different subsurface units with Batena borehole lithologic log 55
Figure 5. 6 The apparent resistivity sliced-stacked depth map 56
Figure 5. 7 Dispersion curve of MASW profile 01 58
Figure 5. 8Dispersion curve of MASW profile 02 58
Figure 5. 9 1D layered model section of profile MASW 01 59
Figure 5. 10 1D layered model section of MASW 02 60
Figure 5. 112D shear wave velocity distributions section for MASW profile 01 62
Figure 5. 12 Vs30m plot of MASW profile 01 63
Figure 5. 132D shear wave velocity distributions section of MASW profile 02. 64
Figure 5. 14Vs30m plot of MASW profile 02 64
Figure 5. 15VES 01curve H type pattern. 72
Figure 5. 16VES 02 curve H type pattern 72
Figure 5. 17 VES 03 curve A type pattern 72
Figure 5. 18 pseudo section of VES 01, 02 and 03 74
Figure 5. 19 Geo-electric section of VES 01, VES 02 and VES 03 74

List of Tables

Table 1. 1According to climatically classification of Ethiopia Mapping agency based on altitude are mentioned 2
Table 1. 2 Acquisition Parameter 8
Table 2. 1The site classification, according to the NEHRP code 21
Table 2. 2Soil classification scheme by Pitilakis et al. (2013) 22
Table 3. 1Velocity of different earth materials 27
Table 3. 2 Resistivities of common geologic materials 33
Table 4. 2 physical properties of permeable and low permeable layers 42
Table 5. 1 average shear wave velocity, Vs30 and periods 66
Table 5. 2 shear modulus of MASW 01 Profile 68
Table 5. 3 shear modulus of MASW 02 Profile 68

Table 5. 4 Amplification of MASW 01 69
Table 5. 5Amplification of MASW 02 70

Lists of Appendices

a) 1Geological log of Batena well Anex-A..81
a) 2Geological Log of Kelisha Well Annex-B...82

CHAPTER ONE
1. BACKGROUND

1.1 Introduction

The population of Hosanna town has been rapidly increasing during the last few decades due to migration of people from rural to urban areas raising the need for expansion of facilities like house, roads, water, and electricity supply, health services, etc. When one considers the health facility needs of the town, the existing Wachamo University, Nigist Eleni Memorable Hospital is the only major health facility giving services to the existing and ever increasing population. This hospital itself was constructed without detailed subsurface engineering site characterization and proper design. Because of this, in 2010, the existing Hospital building wall cracked and failed especially at the time when the last earthquake hit the town as cited in (Yonatan Gerkabo, 2011). As consequence of this problem on the existing building and its failure to provide the required services adequately, and the increasing demand in the town, Wachamo University proposed to construct a safely founded and designed Referral Hospital building for the community of Hosanna town and to assist in medical teaching of the University.

It is well known that subsurface investigations involving the use of geophysical methods are important for assessing the suitability of an area for the construction of buildings, bridges and dams among others. Principal to the construction of any building and large infrastructure on any site is the suitability of the geology of the site to withstand and support the load on a permanent basis.

Most buildings are constructed on and or within the Earth surface that needs to be safely designed and founded over more suitable Earth materials to support the weight of the structure.

Site investigation is the process of determining the layer of natural soil deposits that will underlie a proposed structure and their physical properties and site characterization or investigation of subsurface engineering sites for building purposes are generally achieved through geotechnical investigations. In the general scheme of things, subsurface exploration and testing involved in site investigation respectively define the following for the soil and rock strata, where applicable. For the soil strata site investigation will seek to reveal its depth, thickness, and variability and relevant engineering properties such as shear strength, compressibility, stiffness, permeability, expansion etc. While for the rock strata, the investigation involves identifying the location of rock-head and its quality which is determined in terms of the presence of fractures, joints and similar partings (Das, 1994).

Geotechnical investigations provide information on the physical or mechanical properties of rocks and soils that are relevant to the design of foundation for proposed structures, assessing risks posed by site conditions, designing earthworks and structure foundation and monitoring site conditions as well as, earthwork and foundation construction. It is performed to evaluate geologic, seismologic and soil and rock conditions that may affect the safety, cost effectiveness and design of proposed engineering works.

Foundation investigation is an important program in building and engineering structures. Site detailed information derived from foundation site investigation which includes such properties as mentioned above could be obtained through geophysical survey. Integrated geophysical investigation is one of several methods used in probing the soil/subsoil and subsurface for any engineering construction activities. Several approaches have been used for the success of foundation investigations. Geophysical methods, particularly the electrical resistivity tomography, vertical electrical resistivity sounding (VES) and seismic method or MASW (Multi channel analysis of surface wave), are the most widely used geophysical prospecting methods, that have been extremely applied for wide variety of geotechnical subsurface engineering site characterization. The methods give the 2-D electrical resistivity (both lateral and vertical) variation of the subsurface geology of the site (Robert, and William, 1981). Integrating geophysical with geotechnical methods provide solutions that are preferred over discrete information that are usually got from conventional engineering soil characterization methods that lack competent imaging subsurface of subsurface and provide continuous data coverage, especially when the site is large. Geophysical data interpretation can image the subsurface to the depth of the competent layer and evaluate the real distribution of geological Earth material.

Application of geophysical investigation methods provides a relatively low cost, non-invasive and rapid means of generating models of physical properties of the subsurface (Bell, 1980).
The good agreement between geophysical and geotechnical investigation may give a good data profile and information for subsurface engineering site characterization of the proposed building site.

1.2. Description of Study area

1.2.1 Location and Accessibility of Study Area

Hossana town, which is the study area and, is the administrative center of Hadiya Zone, is located about 232km from the country's capital, Addis Ababa, in the Southern Nations Nationalities people's Regional State ((SNNPRS), southern Ethiopia. The proposed Wachamo University Referral Hospital site is located North West of Hosanna town. The area is accessible through an asphalted road that runs from Addis Ababa to Hossana. The location of the study area is shown in Figure 1.2

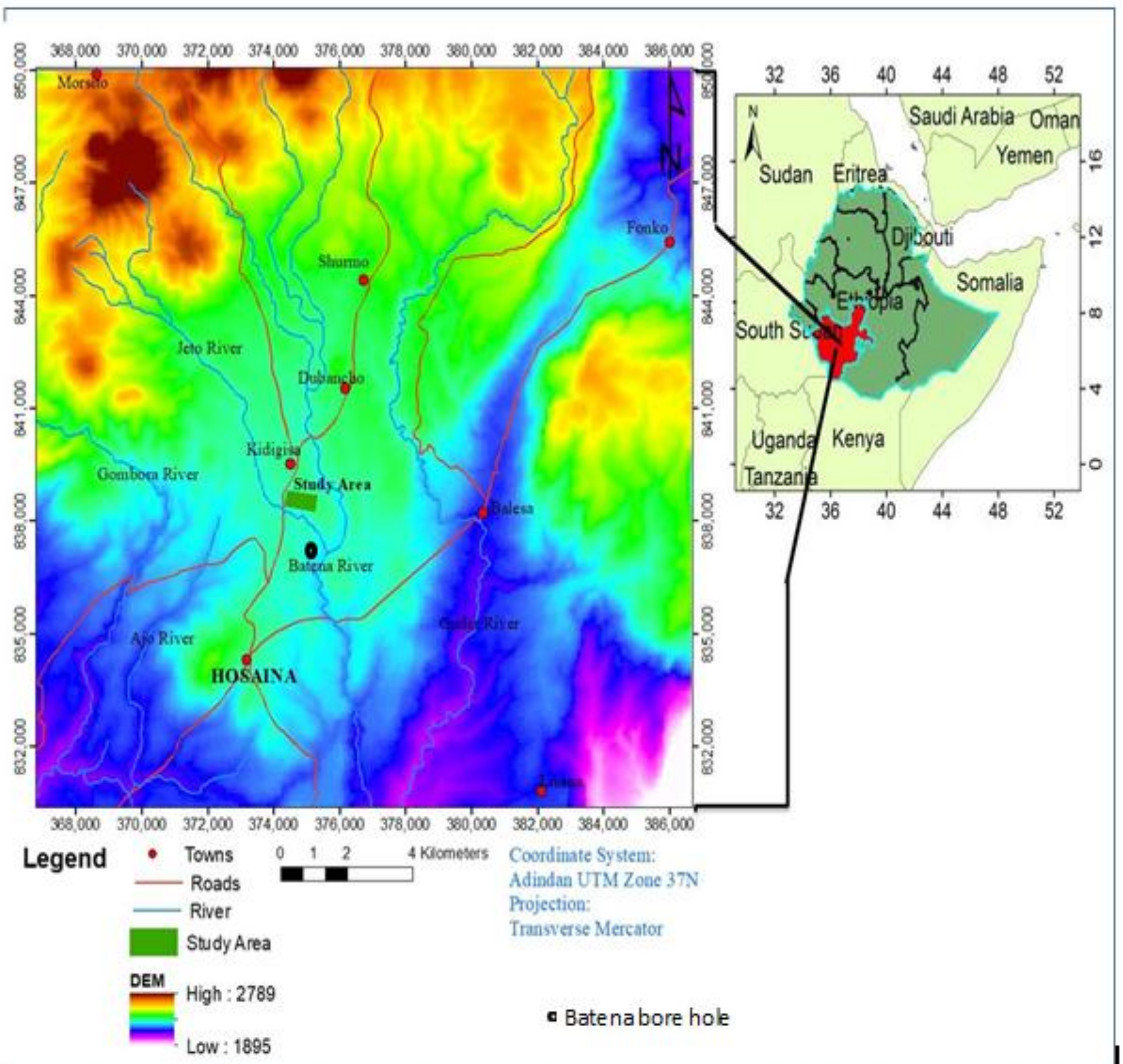


Figure 1. 1location map of the study area.

According to Children's Home Society (2009) as cited in Garkebo (2011) the altitude of the area is between 1500-2300m elevations and is climatologically, categorized under climatic zone Woina Dega (Table 1.1). The annual rainfall of the Hossana area varies mainly from 900mm-1400mm, with the mean annual precipitation, analyzed from 26 years of rainfall data is 1028.67mm. The rainfall in Hossana area is bimodal type and the main rainy seasons are from March to April and June to September. The mean annual temperature varies from 15℃ to 18℃. The lowest temperatures occurs these during the main rainy season (Table 1.1). The maximum relative humidity of the area is estimated as 79.8% while the minimum relative humidity of the area is 57.5%.

Table 1.1To climatically classification of Ethiopia based on altitude (Ethiopia Mapping agency

No	Altitude(m.a.s.l)	Temperature(^{o}c)	Description	Local name
1	3,300 and above	Less than 10	cool	Kur
2	2,300-3,300	10-15	Cool temperate	Dega
3	1,500-2,300	15-20	temperate	Weina dega
4	500-1,500	20-25	Warm temperate	Kola
5	Below 500	25 and above	Hot	Bereha

The vegetation cover of the area is highly dominated by eucalyptus trees and shrub vegetation covers. Other trees like Zigba, Weyra, Warka, etc. are observed in certain areas.

1.2.2 Derange pattern and physiography of the study area

The Hossana topographic map sheet is divided by the main surface water divide. These are the western and south eastern part. The western belongs to the Omo-Gibe basin and southeastern part belongs to the Gudar-Bilate basin. The drainage system of the study area is attributed to the existing topographic condition. About half of the study area is relatively of elevated topography while the remaining half portion is having a relatively low elevated topography. Hossana town has an overall tilt from the highest elevation on the western side and relatively flattened at eastern and southern side (Figure 1.2). Some streams and tributaries are controlled by this tilt. The whole pattern in the study area is characterized by dendritic drainage pattern and the erosional effects along the river cuts are very high. The drainage pattern of the area is highly controlled by geological structures. The pattern indicates that the streams in the area occupy weak zones. Batena River is the main perennial river at the northern and eastern side. The main perennial rivers at the western and southern side of the study area are small and these are Shilansha and Ajo rivers. The flow direction of the two main rivers in the study area is from northeast to southwest following weak zones and its direction is the same with the direction of major faults in the study area.

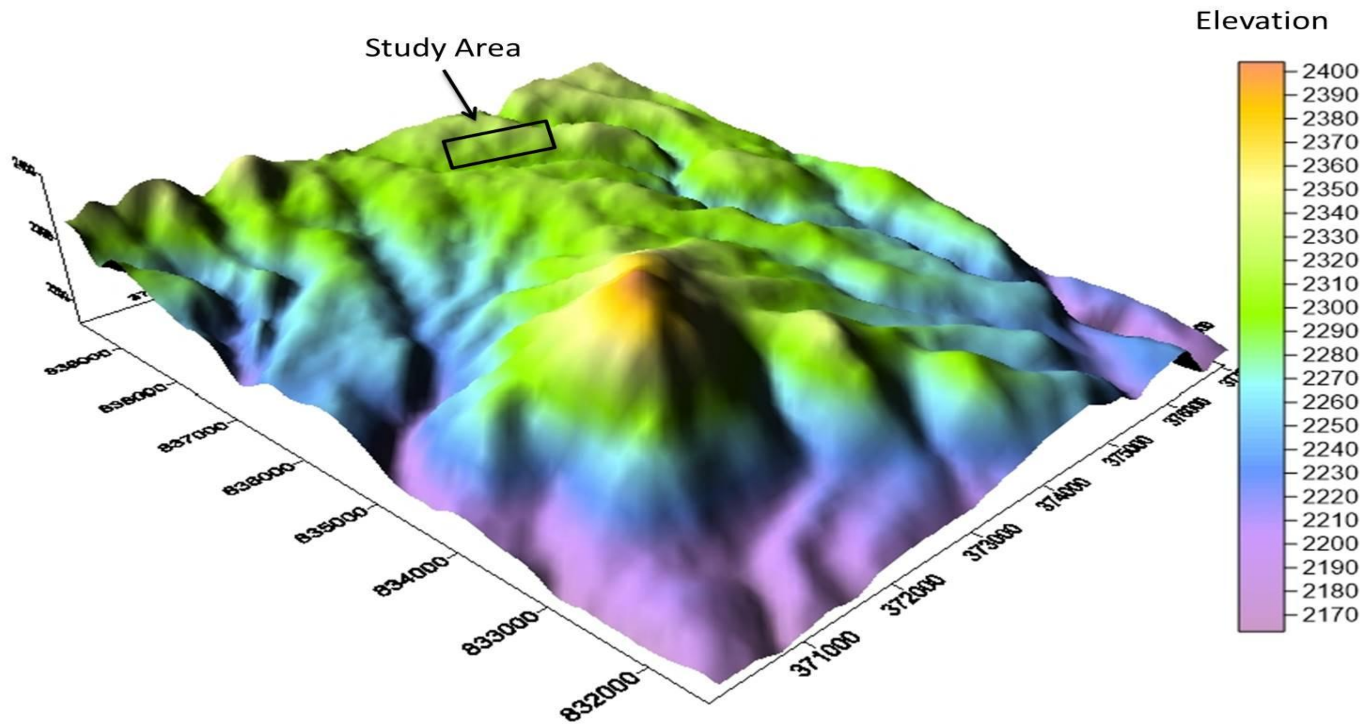


Figure 1. 2: Physiographic map of the study area

1.3. Statement of the problem

Any civil engineering structure is built either on rocks or soils. However, a substantial amount of these large infrastructure works lie or are found in the near vicinity of some of the most seismically active regions of the country such as the Afar, the Main Ethiopian Rift (MER) and the South Eastern Rift (SMR) where well-documented damage-causing earthquakes are common (Kassegne, 2011). From the most significant earthquakes of the 20th and 21st centuries over Ethiopia, the 2010 and 2011 Hosanna earthquakes were felt in some of the major cities in the country (Kassegne, 2011). In Hossana during the past 20 years, there has been dramatic increase in urbanization related with increasing population. These have resulted in quick growth for the number of high rise buildings, residential houses, schools, dams, bridge, water supply pipes and other infrastructure construction undertaken in the town and surroundings. The rapid growths in the number of existing constructions are expanding in size. As a result of this, uncontrolled lateral expanding, subsidence and cracking of building structures occurs in a town due to design deficiencies and poor quality construction conducting detailed geotechnical investigation to delineate and characterize subsurface soils and the application of geophysical methods for engineering site characterization to fill up data gaps and provide a continuous mapping of the construction sites will go a longway to alleviate these problem.

More specifically, most existing engineering works of Hosanna town were constructed with improper design, poor subsurface investigation and with the use of substandard construction materials. The proposed Referral Hospital site, which is the subject of this study, is a comparatively new site and is covered with very thick residual soil deposits. Therefore, correctly conducted application of geophysical methods for engineering site characterization integrated with geological, geophysical and geotechnical investigation of the soils and rocks can afford information used to overcome poor building construction and failure of engineering structures at the proposed referral hospital site.

1.4. Significance of the study

Properly performed subsurface engineering site characterization with application of geophysical methods have been conducted to provide cost effective, actual foundation condition of the future Wachamo University Referral Hospital site with hope to overcome any possible damage and failure that may arise both during and after construction period. Therefore, the research output of this work is hoped to act as input for future contractors and consultants that would be engaged in building this important infrastructure. The results of the work will also be useful to the scientific community in general and for geotechnical engineers, geophysicists and engineering geologists, civil engineering students as a resource material for problems related to site characterization in the specific area of rift margin geology.

1.5. Research Questions

The research tries to answer the following questions

- How shear wave velocities are measured on the surface can be used to understand subsurface rock units?
- The type soils covering the study area and their geophysical characteristics and their suitability for building foundation?
- How to determine the lateral and vertical subsurface stratification of the subsurface layers and their thickness?
- At what depth does the groundwater table is occur in the study site and, in the event that it is found at shallow depth, its possible effect on the infrastructure to be built ?

1.6. Objectives the study

1.6.1 General objectives

The aim of this research work is to map and characterize the subsurface condition (property of soils and rocks) for a detailed understanding of foundation condition of the proposed Wachamo University Referral Hospital site.

1.6.2 Specific Objective

a. Map the subsurface resistivity and shear wave velocity variation

b. Determine the depth and thickness of the sound geological formation/the bed rock over the area of study,

c. Determine the depth to the groundwater table if it exists over the area,

d. To classify the soils of the study area based on average shear wave velocity of the upper 30m depth and

e. To correlate the obtained geological results with findings from the geophysical survey and come up with a detailed description of the subsurface that could be used as inputs to the proposed Wachamo University Referral Hospital design and construction (Extract engineering parameters that could be used as inputs for the design of referral Hospital construction).

1.7. Methodology

To achieve the objectives of the project set out in the preceding section (section 16) the following methodology are used.

1.7.1. Methodologies and procedures

Primary data are collected using:-

a. Vertical Electrical Sounding (VES) : AB/2 =1.5-330m; PASI-16GL Earth Resistivity Meter, IPI2win and winResist
b. Electrical Resistivity Imaging (ERT) : were collected using the combination of Wenner-Schlumberger array where by sounding points at 20m stations spacing with 5m electrode spacing are used on each line ; PASI-16GL Earth Resistivity Meter excel sheet ,notepad and Res2DINV and
c. Multichannel Analysis of surface wave (MASW) survey methods: 24 channel Geode Seismograph with 24 receivers (vertical geophones were used) of low-frequency geophones (4.5 HZ capacity) are always recorded critical as in the reflection survey where any minor drop in sensitive may become critical and a 12kg sledge hammer source; geophone of 3m and 5m to observe the resolution and depth variation.

1.7.1.1 Vertical Electrical sounding (VES)

Vertical electrical sounding (VES) were carried out using the PASI-16GL Earth Resistivity Meter and Energizer P100-N_X to define the vertical (and to some extent the lateral) (https://pasirl.en.ecplaza.net) lithological stratification of the proposed site. The VES surveys were conducted using the Schlumberger electrode configuration at three (3) selected points that lie on a single profile. The four-electrode system required for such a survey were systematically expanded from a minimum current electrode spacing (AB/2) of 1.5 m to a maximum of 330m along with increased potential measuring electrode separation to obtain consequent depth information.

The VES data obtained were analyzed by plotting the apparent resistivity value against the half electrode spacing (AB/2) on a log- log graph sheet. The plots were then compared to two layer curve or standard multilayer Earth model curves to first qualitatively determine the possible number of layer, their relative thickness, and their relative resistivity value. Computer software IPI2win and winResist were then used for their interpretation of the VES curves into true depth and true resistivity values of the different layers of the subsurface. This method was used to obtain information on the electrical stratification of the subsurface in the area and their possible geological interpretation through the use of additional information like borehole log data or information on stratigraphic sequences of the area.

1.7.1.2 The Multichannel Analysis of Surface Waves (MASW) method

Multichannel analysis of surface wave (MASW) is a non-invasive, non-destructive, and continuous profiling seismic method to evaluate materials layer thickness, their shear wave velocity 1D (depth) or 2D (depth and surface location) of the layers of the subsurface over the area of study. This seismic method is generally utilized for geotechnical characterization of shallow subsurface formations (Park et al., 1999; Xia et al., 1999; Miller et al., 1999). The Multichannel analysis surface wave (MASW) was conducted using the 24 channel Geode seismograph with 24 receivers (geophones) of 4.5 HZ capacity and a 12kg sledge hammer source (Table 1.2). The geophones spacing of 3m and 5m were used for both survey. Data analysis and interpretation was done by use of updated software for data analysis Seisimager (Evrett, 2013) and basic knowledge for data interpretation.

Table 1. 1 Acquisition parameters for the MASW survey

Item/ parameter	**For MASW 01**	**For MASW 02**
Energy/ source	Sledge Hammer	Sledge Hammer
Stack	5	5
Geophone distance	5m	3m
Length of spread	115m	70m
Shot position	Every 5m interval (starting from -2.5m to 117.5m)	Every 3m interval (starting from -1.5m to 71.5m)
Recoding time	2000ms	2000ms
Sampling	0.125ms	0.125ms
Filter	Open	Open

1.7.1.3 Electrical Resistivity Tomography (ERT or 2-D resistivity imaging) survey

Before data acquisition, field orientation and survey lines selection was conducted using existing topographic map. The field orientation for planning to collect the data is essential prior to conducting the survey as this would enable one to properly choose the survey lines in relation to the local geology of the site. The elevation and position of every resistivity line from start to end was recorded using GPS.

In this field work, electrical resistivity data were taken with the PASI-16GL Earth Resistivity Meter and PASI energizer P100-Nx imaging device with four multi core cables which can be fully extended to cover the required recording distance. The survey technique used thirty (30) stainless steel electrodes with internal electrodes spaced at 5m and recording, station spacing of 20m and arranged in the Wenner-Schlumberger configuration. The measured potential, injected current and the geometric factor are used to compute the apparent resistivity of the subsurface for each reading. The geo-electrical data, thus collected have been processed by using a combination of software that included Microsoft excel, Microsoft note pad, Res2DINV and Surfer-9.These software allow the interpreter to do data rearrangement, data filtering and finally the generation of 2D inverse model resistivity cross-section and stack section will the Res2DINV and surfer software respectively. The 2D inverse model resistivity section will give the lateral and vertical stratification of the subsurface with high resolution as well be required by engineering site characterization surveys. In general, the methodology followed during the present study is shown in the flowchart given Figure 1.7.1

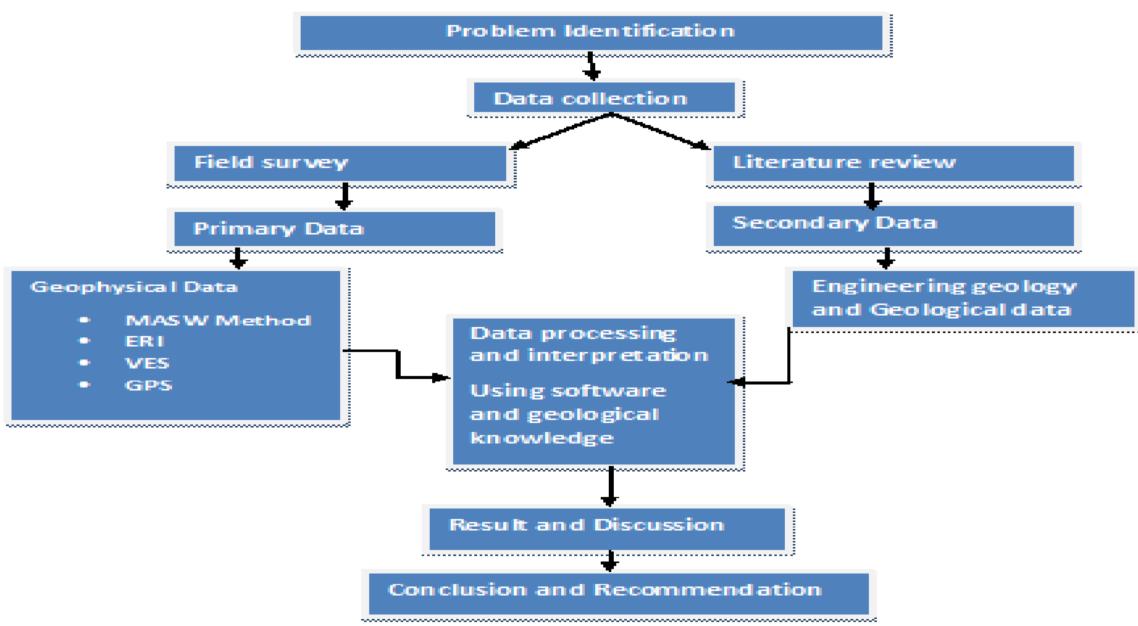


Figure 1.7 1. Schematic flowchart diagram of the methodology employed during the study

1.8 Previous Works

In the past many geological, geophysical, Hydrogeological, geo-hazard and other related works have been performed for different purposes in the study area and its surroundings. A number of works have been done by different scholars some of the relevant works are:

- Yonatan Garkebo, (2011).Integrated Geophysical and Geotechnical investigation for Building site characterization of Wachamo University, North east of Hossana town, southern, Ethiopia, unpublished MSc thesis.
- Alemayehu Paulos. (2019).Engineering geological characterization of soils in Hosanna town, southern Ethiopia, unpublished MSc thesis.
- Debebe and Yekoye Bizuye (2014). Geological Hazard and Engineering Geology maps explanatory notes.

CHAPTER TWO
2. GEOLOGICAL, SEISMICITY AND TECTONICS REVIEW

2.1 Regional Geological Setting

According to Kazmin (1980), the orogenic belt of the Arabian Nubian Shield and the Mozambique Belt are believed to be more prominent as outcrop in Ethiopia than in other countries of Africa. However, Tefera (1996) has pointed out that the rocks belonging to the orogenic belts are only exposed in few areas, which have not been affected by Cenozoic volcanism and rifting.

The Cenozoic rocks of Ethiopia are divided into Trap and Aden series (Mohr, 1967). The name Trap Series is used to represent the Tertiary flood basalt sequences while the Aden series represent post rift (Middle Miocene-Quaternary) volcanic rocks of the Main Ethiopian Rift depression (Tefera et al., 1996). The rift is covered with Cenozoic volcanics and, Tertiary and quaternary sediments except patchy Precambrian rocks in some areas (Mohr, 1967; Gidey Woldegebriel et al., 1990). The volcanic rocks are dominantly fissural basaltic lava flows, rhyolites and ignimbrites associated with volcano clastic tuff and ash deposits (Tenalem Ayenew et al., 2008).

Older volcanic units (Pre-Pliocene) outcrop on the rift escarpment or margin and the recent volcanics cover the entire rift (Kazmin et al., 1981). The Main Ethiopian Rift (MER) contains abundant acidic lavas and ignimbrites and they are associated with central volcanoes containing wide calderas. Quaternary central volcanic products cover the axial rift. On the MER, per-alkaline silicic ignimbrites, unwelded pyroclastics and minor lavas related to fissural eruptions of regional extent are the most abundant volcanic rocks.

2.2 Regional Geological Structures

The rift floor and its escarpments are highly faulted. The faults in the MER are parallel and sub-parallel to the NE–SW trending rift axis (Gidey Woldegebrielet et al., 1990). The Rift floor is affected by several faults that form smaller horst and graben structures. The NNESSW band N-S trending faults are the dominant faults.

2.3 Regional geology of the Study Area and its Surroundings

The general geologic setup of the study area and its surroundings are discussed in the following paragraphs. The following are some important rock units of the area of study and its surroundings:

Nazereth Group and Dino Formation (Upper Miocene): the Bofa Basalt and Nazereth Series are in most places overlain by green and gray ignimbrites with well-developed fiamme and associated unwelded pyroclastics and water lain pyroclastic materials with occasional intercalated lacustrine beds and aphnytic basalts. The pyroclastics of the Dino Formation may have sources from axial felsic volcanic eruptions complexes (Kazmin et al., 1981). The felsic lava of the Dino formation are peralkaline in composition and the ignimbrite members are not confined only to the rift floor but are extensively developed on the escarpments.

Nazereth Group (Upper Miocene – Pliocene Succession): the Nazereth Group of the study area comprises of alkaline and peralkaline silicic like rhyolite domes and ignimbrite, and stratoid silicices such as ignimbrite, unwelded tuff, ash flows, rhyolites and trachyte which occur in the MER, rift margins and adjacent plateaus. This formation includes basalts and ignimbrites of the plateau Trap Series. The Nazereth Group volcanic products are exposed over the surrounding areas along the rift margins and escarpments. The ignimbrites of the Nazereth Series are considered to be products of eruptions mainly from marginal centers in the rift. An age range of 9 – 3 Ma has been given to the Nazereth Series (Tefera et al., 1996).

Wonji Group (Pleistocene – Holocene): this group built up mainly from extensive basaltic flows. The study area Wonji Group rocks comprise of rhyolitic and trachytic lava, ignimbrites and peralkaline silcics volcanic rocks. They are central volcanic complexes of the Main Ethiopia Rift Valley. The volcanic products of this group are observed to be associated to NNE-SSE running faults. The Wonji volcanism spanned from Pleistocene up to recent (Kazmin et al., 1981).

Lacustrine Sediments (Pleistocene Volcano-sediments):- they are essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during the Pleistocene time (Mohr, 1967). They are generally yellowish grey colored, horizontally bedded and poorly sorted with fragments of rhyolites, obsidian and basalt in a matrix of ash and silty clay.

2.4 Local geology of the study area and its surroundings

The general geological setup of the study area and its surroundings are briefly presented as follows.

Bedrock Geology

Bedrock is a general term that includes any of the generally crystalline materials that make up the Earth's crust. Individual stratigraphic units or units significant to engineering geology within bedrock may include poorly or non-crystalline materials such as beds, lenses, or intercalations. The bedrocks of the study area are underlain by igneous rocks of various types. There is no sedimentary or metamorphic bedrock known to be encountered in the study area. From field observations at river cuts, road sections, quarry sites, bore holes, pitting and drainage network patterns and previous local geological setup of the study (Kazmin et al., 1981) the bedrock geology of the study area comprises mainly of three types of rocks including rhyolite, ignimbrite and volcanic tuff. The largest part of the study area is covered by residual soil.

Rhyolite

Rhyolite is an igneous, volcanic rock which is exposed along river sides of the proposed project site. It is characterized by black weathered and light gray color when it is fresh. It is a medium grained, silica rich composition, hard and fractured rock unit. Rhyolite is good quality, columnar jointed rock, which is easily workable and can be used for the production of masonry for the construction of building and other engineering structures.

Ignimbrite

Ignimbrite is characterized by closely spaced discontinuities, and as a consequence, it is affected by weathering, which forms the lateritic cover. This unit comprises of pyroclastic rocks and welded tuff. It is well exposed along Batena River in the southeastern side, along Ajo River in the southwestern side, within quarry sites in the eastern portion of the study area (Figure 2.1). In this area, the rock unit is characterized by its dark grey color and poorly sorted aggregates of tuff and pumice. The ignimbrites exposed along small and big Ajo River in southwestern part of the study area are comparatively well welded. In the study area and around, river Shilansha the ignimbrite rock is intercalated with tuff in many parts of the river exposure. This intercalation indicates depositional series of pyroclastic materials. In the study area ignimbrite rocks are extensively used for road construction. Cobble size ignimbrite rocks are shaped into different patterns to make secondary road which branch out from main roads.

Tuff

In the study area, this pyroclastic rock unit is exposed in northeastern portion of the area along road section and river cut. It is characterized by white color and fine grained texture. This rock unit is soft that is resulting from the poor compaction and cementation of volcanic ash. The tuff unit in the study area is intercalated with ignimbrite. As shown in Figure (2.1) the tuff also sandwiched with other pyroclastic rocks and its weathering product of reddish clayey silt and silty clay soil around Hossana Soro Bar and along Addis Ababa to Hossana road cut respectively

Figure 2. 1Exposures of the rocks in the study area

Residual Soils

Residual soil is the soil that remains at the place of their formation. Residual soil develops over ignimbrite, rhyolite and unconsolidated sediments. It is characterized by variable thickness, silt-clay in composition and is reddish in color and texture. The texture of the sediments ranges from clay to sand and gravel, ash, tuff and diatomaceous materials. The dominant materials are silts inter-bedded with tuffs. As presented in geological map of the study area Figure (2.2), the largest portion of the study area is covered by this unit. During field work, the thick soil deposit is observed at the northwestern, northeastern and central parts of portion of the study area.

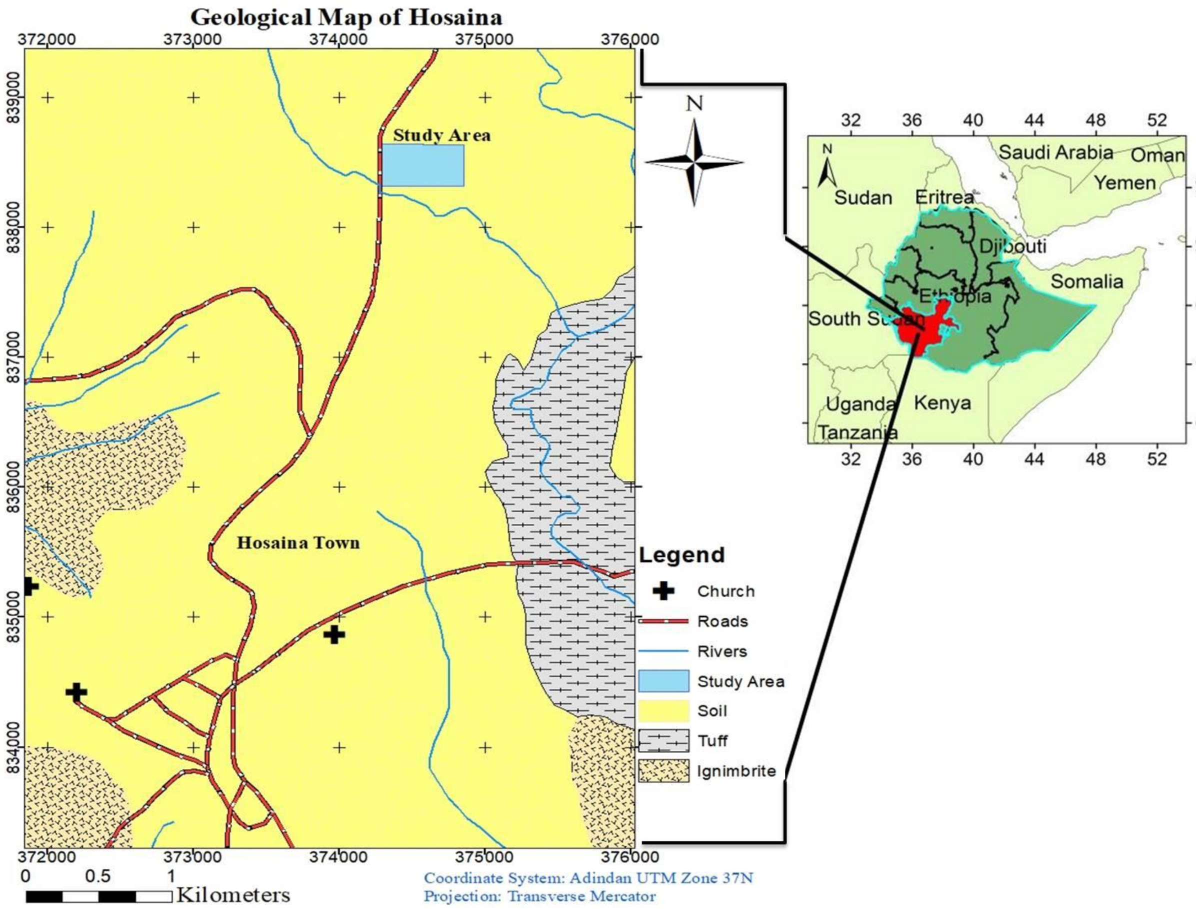


Figure 2. 2 Geological map of Hossana Area

2.5 Hydrogeological Setting

The general concept of infiltration and groundwater circulation on the Hossana map sheet is divided into western and eastern parts of the map consisting of the relevant parts of the highlands, escarpments and the rift floor.

Eastern Plateau, Escarpment and Rift Floor

According to Debebe (Nida and Yakoye Bizuye, 2014) the eastern plateau area is covered by various volcanic rocks forming a gently undulating plain that receives adequate rainfall and has moderate runoff resulting in good infiltration and formation of extensive and moderately productive or locally developed and highly productive fissured and mixed aquifers. Infiltration is particularly good in areas where the plateau is covered by thick alluvial sediments. Aquifers outcropping in the plateau area also feed deeper fissured aquifers that developed in the underlying volcanic and sedimentary rocks. The escarpment area is relatively steep for infiltration; however, in some parts, e.g. Katar basin there are local grabens (Keyensho) providing a good opportunity for water to percolate underground and feed the aquifers Debebe (Nida and Yakoye Bizuye, 2014) .

The groundwater Flow system and direction in the escarpment area (see Figure.2.3 (a)) were described by Demis Alemirew (2009) and Halcrow (2008) as flow which is mainly controlled by faults within the rift, but there is cross fault flow through the fault rays. He also found some faults which seem to act as barriers to flow. The Cl map generated from the present water analysis map and flow map generated from the existing water point data in the area show relatively good correlation and indicate a major flow from SE to NW. However, there seems to be some flow of water from Katar towards Langano Lake. The Cl distribution indicates fresh water flow zones in the rift.

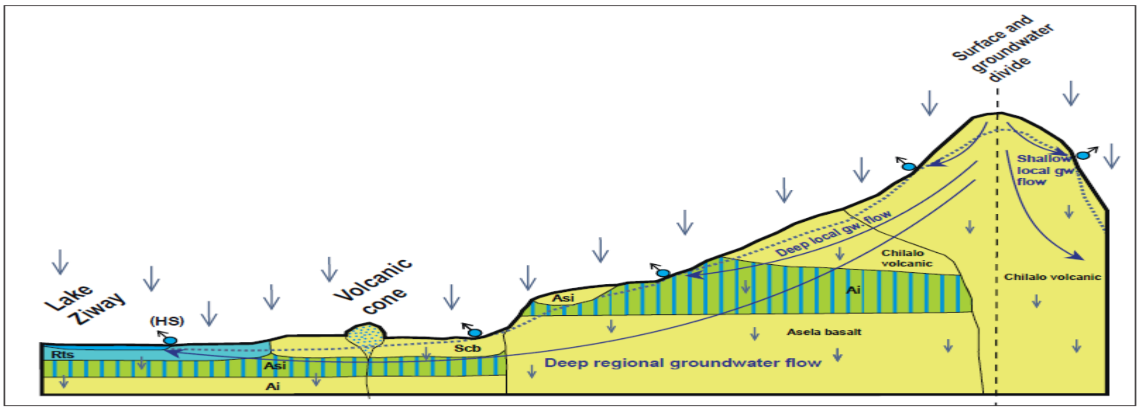


Figure 2. 3 (a 1) A conceptual hydrogeological model of the eastern plateau, the rift escarpment and rift floor (Demis Alemirew (2009) and Halcrow (2008)

Western Plateau, Escarpment and Rift Floor

The western plateau is built by faulted basalts and ignimbrites intercalated with volcano clastic and sedimentary rocks. Groundwater percolates into the rock and infiltration is particularly good in areas where the plateau is covered by thick alluvial sediments (Demis Alemirew (2009) and Halcrow (2008). Aquifers outcropping in the plateau area also feed deeper fissured aquifers developed in underlying volcanic rocks. Springs are relatively small in mountain areas and represent shallow local groundwater flow. Springs at the foot of the escarpments are large representing deep local groundwater flow. The existence of deep regional groundwater flow is expected; however, direct evidence in the form of hot springs is missing. The occurrence of hot springs is mainly in the eastern part of the rift. Groundwater from the escarpment area recharges the volcanic and sedimentary aquifers of the rift floor. A conceptual hydrogeological model of the western plateau, escarpment and rift floor is shown in Figure 2.4b (Demis Alemirew (2009) and Halcrow (2008).

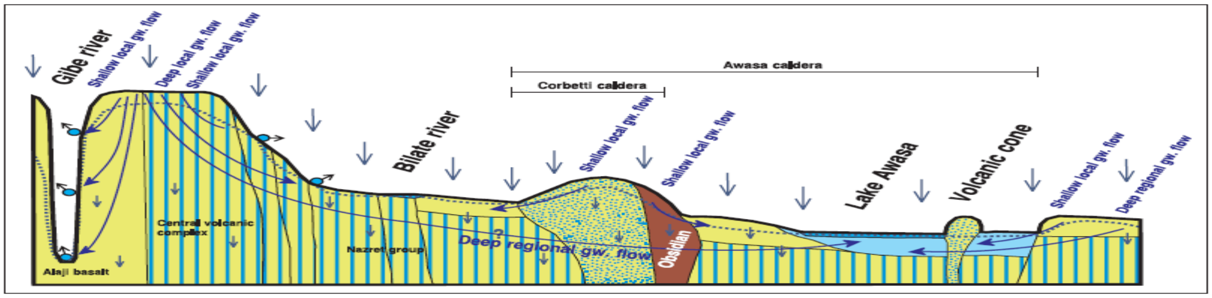


Figure 2. 4 (b 1) Conceptual hydrogeological model of the western plateau, escarpment and rift floor Demis Alemirew (2009) and Halcrow (2008).

The principles of the general conceptual model of the Hossana sheet are based on main mechanisms of recharge as well as discharge and these are stated as follows:

• Direct recharge to outcropping aquifers,

• Vertical recharge from overlying aquifers into underlying aquifers,

• Horizontal recharge from neighboring aquifers and lakes,

• Direct discharge by springs from outcropping aquifers (cold and hot springs at the foot of the escarpment and rift floor),

• Direct discharge to rivers and lakes, and

• Indirect discharge from one aquifer to another (vertical as well as horizontal)

2.6 Hydrogeology of study area

According to Children’s Home Society (2009) as cited in (Yontan Gerkebo, 2011) the groundwater potential of the study area depends on a number of factors. These factors include climate, geology, vegetation, topography, etc. Among these, physiography and climate play greater role (Children’s Home Society, 2009). The central portion of the study area serves to recharge the groundwater whereas the marginal portion is discharging. Various types of springs were observed in the eastern, western and southern portion of the study area. As described by the Water Bureau of Hadiya Zone 2011, the groundwater table of the study area and the surroundings is located at relatively greater depth. The Batena well, for example, has a total depth of 200 m and the static water level of 132.5 m. The first water strike is at 78 m depth and the yield increases gradually as multiple aquifers were penetrated. The main water bearing formations are the fractured rock especially ignimbrite unit (Yontan Gerkebo, 2011). The Batena and Kalisha wells located about 600 m and 2.5 km respectively from the current study site is nearly at the same topography as that of the Batena well. The main waters trike depth of this well was observed at a depth of 90 m and the yield of the well increases gradually to the final depth (189m) through different aquifer penetration. The principal water bearing formation of the area is the highly weathered and fractured basalt, coarse-grained sand and gravel, pumice, agglomerate and medium grained sands. Gombora well and other wells around Hossana town are also characterized by deep groundwater table. The Batena and kalisha geological logs are shown in the Annex-A and Annex-B. Batena geological logs are shown at the Annex-A and Annex-B (Hydiya Zone Water, Mines and Energy Department).

2.7 Seismic Setting

Extensional tectonics is predominant activity for earthquake occurrence in Ethiopia and the surrounding region according to (Tilahun Mammo, 2005).as cited in Yontan Gerkebo (2011). This condition is most often found at the boundaries of the tectonic plates into which the Earth's lithosphere can be divided. Diverging boundaries occur along spreading centers where plates are moving apart. Divergent boundaries in continental regions are known as rift zones. The earthquakes that occur at shallow depth (2-8 km) are mostly small and occurrence of earthquake with magnitude greater than six is rare. This is because the lithosphere is very thin and weak at divergence boundaries, so the strain, build up is not enough to cause large earthquakes according to (Tilahun Mammo, 2005).as cited in Yontan Gerkebo (2011).

Earthquakes occur every day on Earth, but the majority of them is minor and causes no damage. Large earthquake can cause serious destruction and massive loss of life through a variety of agents of damage , including fault rupture, vibratory ground motion (i.e.,, shaking), inundation (tsunami ,dam failure) , various kind of permanent ground failure (e.g. liquefaction ,landslide) , and fire or a release of hazardous materials. In a particular earthquake, any of these agents of damage can dominate, and historically each has caused major damage and great loss of life, but for most of the earthquakes, shaking is the dominant and most widespread cause of damage.

The study area is located in the western margin of Main Ethiopia Rift which is tectonically active. Based on the seismicity and the knowledge of the geology and tectonics, the region can be broadly divided into three seismic source zones according to (Tilahun Mammo , 2005) as cited in Yontan Gerkebo (2011).These are the Afar Depression , Escarpments and the Ethiopian

Rift system seismic source zones which are very near to the study area. The epicenteral map of the region gicen in Figure 2.5.7.1 shows that small and intermediate magnitude earthquakes are dominant. The location of the earthquakes is not uniformly distributed throughout the region, but is clustered along the Main Ethiopian Rift System.

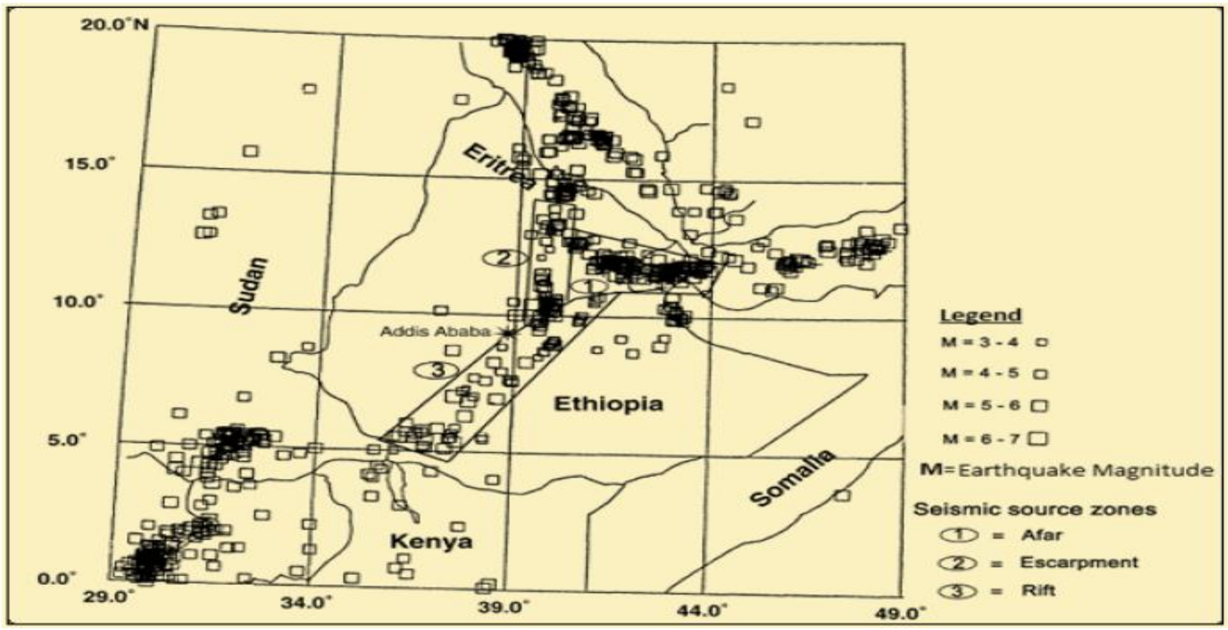


Figure 2. 5.7 1 Seismicity of the region with the seismic Zone (Tilahun Mammo, 2005).

From the point of view of the work in this thesis, seismic activity may affect the stability of engineering structures in many ways. The bearing capacity failures during earthquakes could be thought as being influenced by three main factors according to (Robert, 2001) as cited in Yontan Gerkebo (2011).The most important geophysical properties, in this respect, are electrical resistivity and seismic wave velocity, as they can be used directly in engineering studies (Veness, K.J, 1996).

Source Effect: it determines how the size and nature of the earthquake source controls the generation of earthquake waves. The amplitudes are largest close to large earthquakes and the duration generally increases with the size of the earthquake (larger quakes shake longer because they rupture larger areas).

Travel Path Effect: describes the effect of the Earth on the earthquake waves as they travel from the source to a particular location. The longer the travel path of the earthquake waves the smaller will be the damage of the structures.

Local Site Condition: describes the effects of the uppermost several hundred meters of rock, soil and surface topography of the particular location. Regional geology can affect the level and duration of shaking but more important are local site conditions. Generally, shaking in soft sediments is larger and longer than when compared with the shaking experienced at a hard rock site. The amplitude of shaking in soil can be more than 10 times stronger than the surrounding rocks. According to the Ethiopian Building Code Standard (1995), the country is divided into five zones approximately equal seismic risks depending on the known distribution of earthquakes as shown in Figure.2.6. These zones are no damaging zone (0 zones), less damaging zones (zones1 and 2) and zones of major damage (zones 3 and 4).

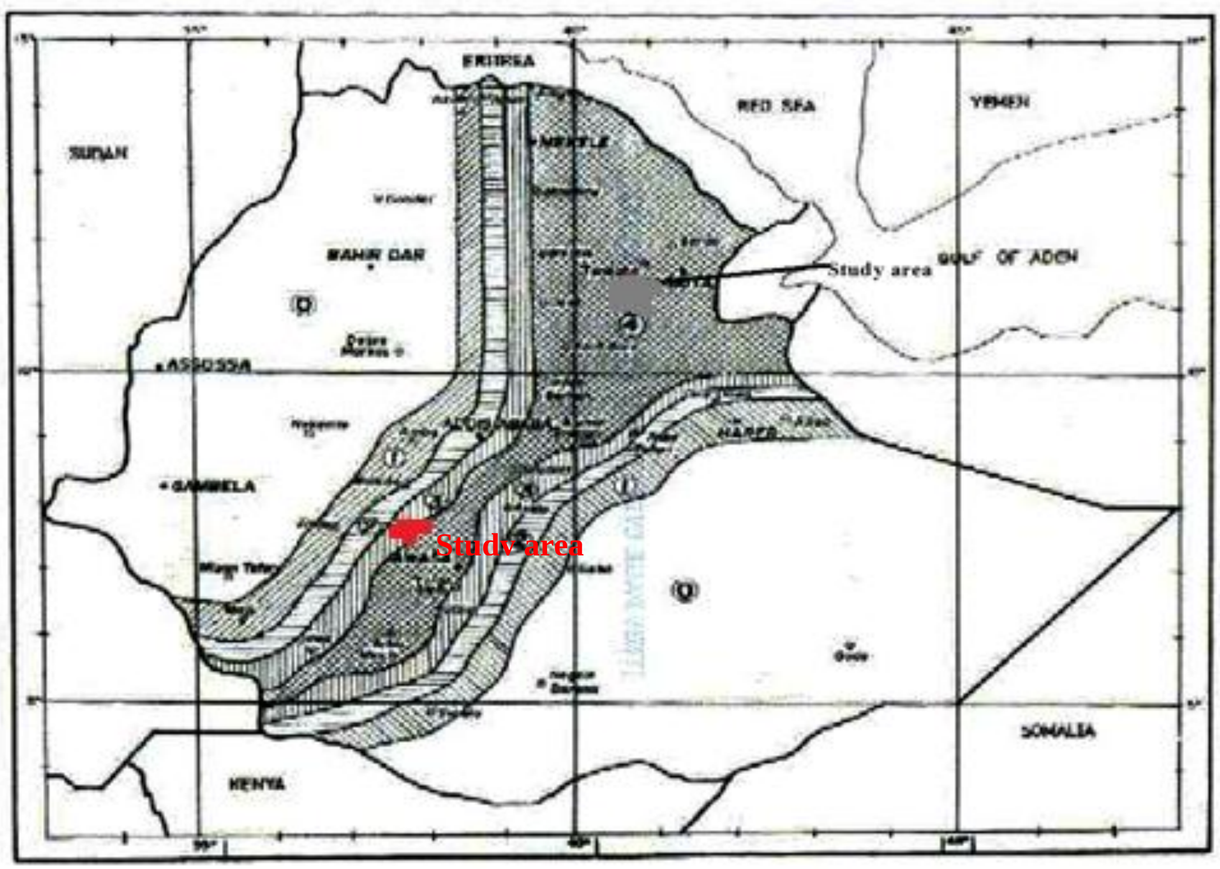


Figure 2. 6 Seismic hazard map of Ethiopia (Ethiopian Building Code Standards, 1995) and location of Project area.

2.8 Basis for Site Classification

Soils contain the products of physical and chemical weathering of the rocks of the Earth's crust. Soil layers are in interaction with constructions and earthquakes. For example, the earthquake wave affects the soil strength characteristics, while soil strength character frequency, duration and amplitude properties of earthquake waves. Shear wave velocity of soil layers is a useful property for evaluating site amplification. Soil amplification was evaluated by empirical approaches based on shear wave velocity according to (Ferhat and Tazegul, 2011) as cited in **F**reweyni Mekonen (2016).

According to Kelly (2006), the source document for the site classifications defined in the IBC (International Building Code) is NEHRP (National Earthquake Hazard Reduction Program) which recommended provisions for seismic regulations for new buildings and other structures. The amount of ground motion amplification depends on wave propagation characteristics of the soil, which can be anticipated from the measurements of shear wave velocity. Soft soils have slower shear wave velocity and generally produce greater amplification than stiff soils with faster shear wave velocity. The site classes of the IBC are defined in terms of shear wave velocity. Table 2.1shows the site classification based on Vs30.

Table 2. 1The site classification, according to the NEHRP code

Site class	Average shear wave velocity Vs30 (m/s)	Remarks
A	Vs30>1500	Hard rock
B	760≤Vs30≥1500	Rock
C	360≤Vs30760	Very dense soil and soft soil
D	180<Vs30≥360	Stiff soil
E	180≤Vs30	Soft clay soil
F		Soil required site response analysis

2.9 New site soil classification scheme

According to Pitilakis et al. (2013) the main parameters new site classification are Fundamental period of the soil deposit T0, Average shear wave velocity of the entire soil deposit Vs,av ,Thickness of the soil deposit H to the "seismic" bedrock and N-SPT, PI, Su show in detail in table (2.2)

Table 2. 2 Soil classification scheme by Pitilakis et al., (2013)

	Description	T0	Remark
A	Rock formations		Vs ≥ 1500 m/s
A2	Slightly weathered / segmented rock formations (thickness of weathered layer <5.0m)	≤ 0.2s	Surface weathered layer: Vs,av ≥ 200 m/s Rock Formations: Vs ≥ 800 m/s
	Geologic formations resembling rock formations in their mechanical properties and their composition (e.g. conglomerates)		Vs ≥ 800 m/s
B1	Highly weathered rock formations whose weathered layer has a considerable thickness (> 5.0m - 30.0m)	≤ 0.5s	Weathered layer, Vs,av ≥ 300 m/s
	Soft rock formations of great thickness or formations which resemble these in their mechanical properties (e.g. stiff marls)		Vs,av: 400-800 m/s N-SPT > 50 Su> 200 KPa
	Soil formations of very dense sand – sand gravel and/or very stiff/ to hard clay, of homogenous nature and small thickness (up to 30.0m)		Vs,av: 400-800 m/s N-SPT > 50 Su > 200 KPa
B2	Soil formations of very dense sand – sand gravel and/or very stiff/ to hard clay, of homogenous nature and medium thickness (30.0 - 60.0m), whose mechanical properties increase with depth	≤ 0.8s	Vs,av: 400-800 m/s N-SPT > 50 Su > 200 KPa
C1	Soil formations of dense to very dense sand – sand gravel and/or stiff to very stiff clay, of great thickness (> 60.0m), whose mechanical properties and strength are constant and/or increase with depth	≤ 1.5s	Vs,av: 400-800 m/s N -SPT> 50 Su > 200 KPa
C2	Soil formations of medium dense sand – sand gravel and/or medium stiffness clay (PI > 15, fines percentage > 30%) of medium thickness (20.0 – 60.0m)	≤ 1.5s	Vs,av: 200-450 m/s N -SPT> 20 Su > 70 KPa
C3	Category C2 soil formations of great thickness (>60.0 m), homogenous or stratified that are not interrupted by any other soil formation with a thickness of more than 5.0m and of lower strength and Vs velocity	≤ 1.8s	Vs,av:200-450 m/s N-SPT > 20 Su > 70 Kpa
D1	Recent soil deposits of substantial thickness (up to 60m), with the prevailing formations being soft clays of high plasticity index (PI>40), high water content and low values of strength parameters	≤ 2.0s	Vs,av ≤ 300 m/s N-SPT < 25 Su < 70KPa
D2	Recent soil deposits of substantial thickness (up to 60m), with prevailing fairly loose sandy to sandy-silty formations with a substantial fines percentage (not to be considered susceptible to liquefaction)	≤ 2.0s	Vs,av ≤ 300 m/s N-SPT < 25

D3	Soil formations of great overall thickness (> 60.0m), interrupted by layers of category D1 or D2 soils of a small thickness (5 – 15m), up to the depth of ~40m, within soils (sandy and/or clayey, category C) of evidently greater strength, with Vs≥ 300 m/sec	≤ 3.0s	Vs,av : 150-600 m/s
E1	Surface soil formations of small thickness (5 - 20m), small strength and stiffness, likely to be classified as category C and D according to its geotechnical properties, which overlie category A formations (Vs ≥ 800 m/sec)	≤ 0.7s	Surface soil layers, Vs,av ≤ 400 m/s
X	Loose fine sandy-silty soils beneath the water table, susceptible to liquefaction (unless a special study proves no such danger, or if the soil's mechanical properties are improved) Soils near obvious tectonic faults Steep slopes covered with loose lateral deposits Loose granular or soft silty-clayey soils, provided they have been proven to be hazardous in terms of dynamic compaction or loss of strength. Recent loose landfills Soils with a very high percentage in organic material Soils requiring site-specific evaluations		

Table 2.3 Summarized comparison of past Ethiopian codes with proposed code modifications (kindey et al; 2011)..

Criteria	EBCS8-1995	Model/International Codes	Proposed Review for Ethiopia
Seismic Zoning and PGA			
1. Seismic Zoning	4 zones	UBC 1997 - 5 in the US (1, 2A, 2B, 3, 4). But generally 4.	Keep 4 zones for buildings
2. Soil Type	Limited to 3: A, B and C.	UBC-1997 has 6 soil type, i.e., S_A-S_F	Consider more to account for variation in different parts of the country
3. Return Period	100 years	475 years in most codes and countries.	475 years for buildings as well as large infrastructures like bridges, dams, power plants. Also makes it consistent with the region.
4. Seismic ground motion used	Allows user defined typical ground motion records	Same	Consider shallow ground motions for time history analysis, recent earthquakes tend to be that type.
5. Topographic/Site amplification effects	Does not consider site effects	Eurocode (2004) considers when $\gamma > 1$.	Need to consider
Design			
1. Model Code used	Predominantly Eurocode	For IBC, ASCE 7-10 is used as the model code	Use ASCE 7-10 as engineering curricula in Ethiopia is based on ASCE predominantly.
2. Design Philosophy Basis	Elastic response	Performance-based	Move towards Performance-based
3. [illegible]	[illegible]	[illegible]	[illegible]

CHAPTER THREE

3. THEORETICAL BACKGROUND OF METHODS OF INVESTIGATION

3. Introduction to Seismic methods

3.1 Seismic waves

Seismic waves are propagating vibrations that carry energy from the source of shaking out ward in all directions. Seismic waves are elastic waves that propagate through the medium without causing permanent deformation at any point in the medium. The waves generated can be divided into two main categories: - body waves and surface waves (Evrett, 2013).

3.1.2 Body waves

Body waves are transmitted through the interior of the Earth, the medium of the wave, and consist of compressional waves (P-waves/primary waves) and shear waves (S-waves/secondary waves). The particle motion associated with compressional waves is parallel to the motion of the wave itself, causing stretching and compressing of elementary volume particles (Figure 3.1).

The particle motion of shear waves is perpendicular to the direction of wave propagation and has therefore both a vertical and a horizontal component. The transverse particle motion causes shear deformation of volume elements within the medium, i.e. change in shape, as shown in Figures 3.2 (Reynolds, 1997).

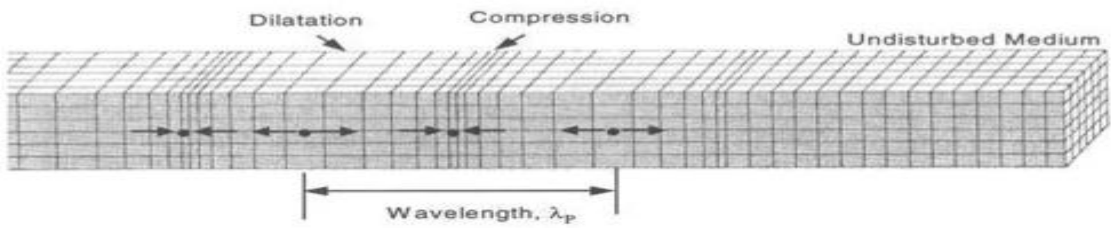


Figure 3. 1 Particle motion associated with compressional waves

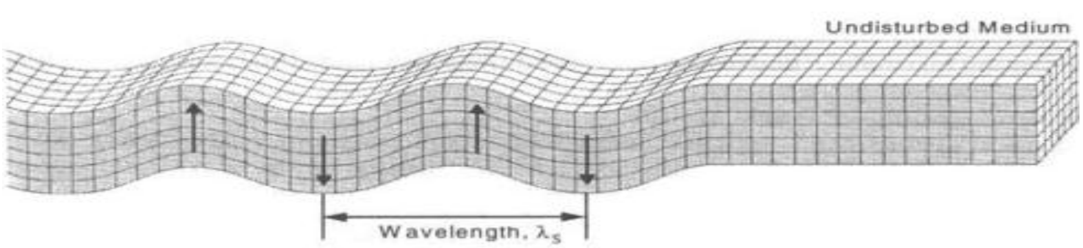


Figure 3. 2 Particle motion associated with shear waves

3.1.2 Surface waves

Surface wave are waves that propagate along the Earth's surface .Their amplitude at the surface of the Earth can be very large, but this amplitude decays exponentially with depth. These are waves that do not penetrate deeply into subsurface media. Surface waves propagate at speeds that are slower than' S' waves and have amplitudes that decay with distance from the source more slowly than body waves. Though they arrive after body waves, it is surface waves that are almost entirely responsible for the damage and destruction of engineering structures. This damage and the strength of the surface waves are reduced in deeper earthquakes because of the amplitude of the wave decay with depth (Reynolds, 1997). Surface waves travel along the interface between two different media, i.e. near the surface of the Earth, and are the results of interfering P-waves and/or S-waves. There are two main types of surface waves:- Rayleigh waves and Love waves (Evrett, 2013).

3.1.2.1 Rayleigh waves

Rayleigh waves are waves that travel along the surface of the Earth with their amplitude decreasing exponentially with depth. Rayleigh waves are the slowest of all the seismic wave types and in some ways the most complicated. Particle motion consists of elliptical in vertical plane and parallel to the direction of propagation. Rayleigh wave can travel only through a solid medium. The material returns to its original shape after the wave passes (Figure 3.3).

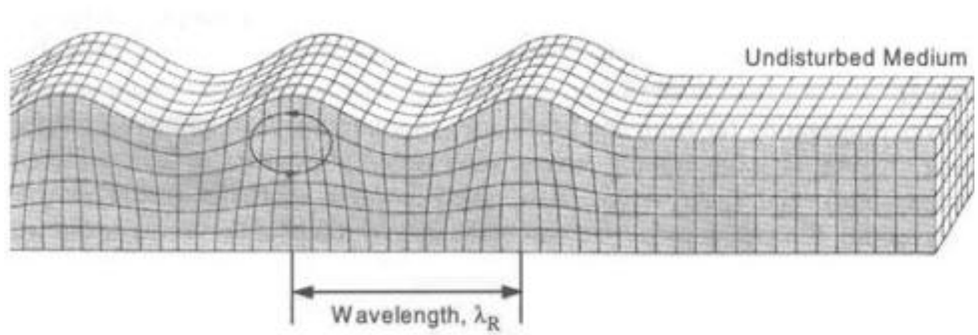


Figure 3. 3 Particle motion associated with Rayleigh waves.

3.1.2.2 Love waves

They are formed by the interaction of S -waves with Earth's surface and shallow structure. These waves occur only where a medium with a low velocity overlies a layer with a higher S-waves velocity. Particle motion is at right angle to the direction of wave propagation but parallel to the surface. The material involved in the wave motion returns to its shape after the wave passes (Figure 3.4).

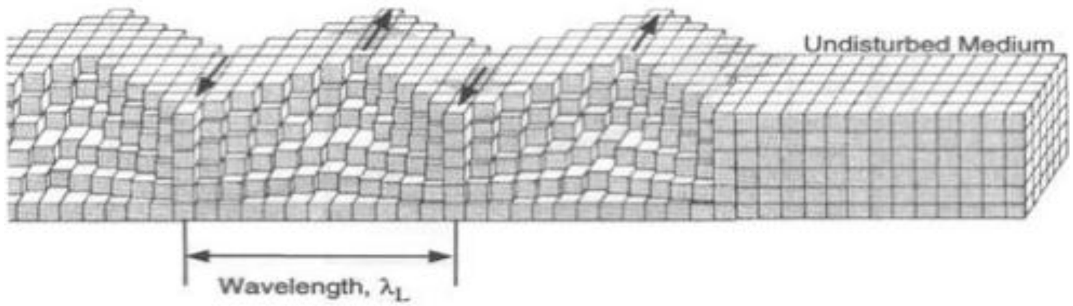


Figure 3. 4Particle motion associated with Love waves

3.1.2.3 Seismic wave velocity

The velocity of seismic wave propagate through elastic media are dictated by the elastic moduli (bulk modulus (k)) and shear modulus (μ) and density of the rock through which they pass. As a broad generalization, velocity increase with increasing density. The velocity of seismic waves is increase with depth in the earth. As we go to depth the shear modulus, bulk modulus, and density of the materials are increase. Due to this the seismic wave velocity increase with depth .However, the increase in the velocity of seismic is a result of the shear and bulk modulus of the materials increase with depth faster than density. See the equation in the Box3.1 (Reynolds, 1997).

3.1 Box Seismic wave equations (Reynolds, 1997).

Velocity of propagation V through an elastic material is:

V= (Appropriate elastic modulus /density ρ) ½

Velocity of p-wave is:

$$Vp = \left(\frac{k+4\mu/3}{\rho}\right)^{½}$$

Velocity of S-waves:

$$Vs = \left(\frac{\mu}{\rho}\right)^{1/2}$$

The ratio Vp/Vs is defined in terms of Poisson's ratio (σ) and given by:

$$\frac{Vp}{Vs} = \left(\frac{1-\sigma}{\frac{1}{2}-\sigma}\right)^{½} \qquad (*)$$

Note that μ = 0 for a fluid, as fluids cannot support shear, and the maximum value of Poisson's ratio is 0.5; σ ~ 0.05 for very hard rocks, ~0.45 for loose, unconsolidated sediments, average ~ 0.25.

From the last equation (asterisked) in the box, it is clear that Poisson's ratio has maximum value of 0.5 (at value the denominator become zero). When Poisson's ratio equal 0.33 s-wave velocity are a half p-wave velocity of surface waves , love waves , as they polarized s-wave, but Rayleigh wave travel slightly slower at about 0.92Vs (Poisson's ratio =0.25) (Reynolds, 1997).Seismic wave velocities of rocks: By virtue of their various compositions, textures (e.g. grain shape and degree of sorting), porosities and contained pore fluids, rocks differ in their elastic moduli and densities and, hence, in their seismic velocities. Information on the compressional and shear wave velocities, Vp and Vs of rock layers encountered by seismic surveys is important for two main reasons: first, it is necessary for the conversion of seismic wave travel times into depths, second it provides an indication of the lithology of a rock or, in some cases, the nature of the pore fluids contained within it. Velocity of seismic waves of different earth materials are shown in the table below.

3.2 Multichannel Analysis of Surface Waves

Knowledge of the geotechnical properties of subsoil sites, such as the stiffness of the top most soil layers, is essential in various civil and earthquake engineering projects. Several different methods can be applied to estimate the stiffness of soils. Among those are drilling methods such as down-hole and cross-hole seismic surveys, methods where the resistance of soil to penetration is measured like the standard penetration test (SPT) and the cone penetration test (CPT) and surface wave analysis methods. In surface wave methods, Rayleigh-type surface waves are generated and used to infer the shear wave velocity profile of the test site as a function of depth. The shear wave velocity of individual soil layers is directly proportional to their shear modulus, which is their stiffness. Compared to other available methods, surface wave methods are low-cost, as well as being non-invasive .Moreover, surface wave methods have been shown to provide consistently reliable results (Park, Miller and Xia, 1997; Xia et al., 2002). Surface wave analysis methods for estimating shear wave velocity/stiffness of subsoil sites are therefore of great interest. The dispersive nature of Rayleigh-type surface waves in layered medium provides key information regarding the properties of near-surface materials.

Table 3. 1Velocity of different earth materials

Material	P wave velocity(m/s)	S wave velocity(m/s)
Air	332	-
water	1400-1500	-
petroleum	1300-1400	-
Steel	6100	3500
concrete	3600	2000
granite	5500-5900	2800-3000
basalt	6400	3200
sandstone	1400-4300	700-2000
limestone	5900-6100	2800-3000
Sand (unsaturated)	200-1000	80-400
Sand (saturated)	800-2200	320-880
Clay	1000-2500	400-1000
Glacial tilt(saturated)	1500-2500	600-1000

The Multichannel Analysis of Surface Waves (MASW) method was introduced by Park et al. (1999). In general, MASW surveys can be divided into active and passive surveys based on how the surface waves required for analysis are acquired. In the active MASW method, surface waves are generated actively by impulsive or vibrating seismic sources whereas the passive MASW method utilizes surface waves generated by natural sources or cultural activities.

Principal advantages of the MASW method are the following:

- Data acquisition in the field is much less time-consuming method. The MASW method requires only a single shot gather for one source receiver configuration. (Park et al., 1999; Xia et al., 2002).
- The dispersion analysis involved in MASW is faster and easier to automate. Data from all receivers is processed at once.
- The MASW technique can provide more investigation depth given the same impact load. The maximum depth of investigation that can be achieved by using the (active) MASW method is generally around 30 m, assuming that surface waves are generated by a reasonably heavy seismic source, e.g. a sledgehammer.
- The MASW method makes it cost- and time-effective to evaluate shear wave velocity in two/three dimensions.

3.2.1 General procedure

MASW surveys can be broken down into three steps: - field measurements, data processing and inversion analysis (Park et al., 1999).

3.2.2 Field measurements

For data acquisition, geophones are lined up in a straight line on the surface of the test site. As the geophones only record vertical motion, it is important that they are placed vertically on the ground. The geophones are connected to a data acquisition card and a computer equipped with the necessary software. Low-frequency geophones (e.g. 4.5 Hz) are recommended (MASW).

The number of geophones used is usually twelve or more, each connected to a separate recording channel (Park et al., 1997). In reported surveys, a common number of geophones used is either 24 and 48.A general measurement profile for an active MASW survey with 24 geophones is shown in Figure (3.5).

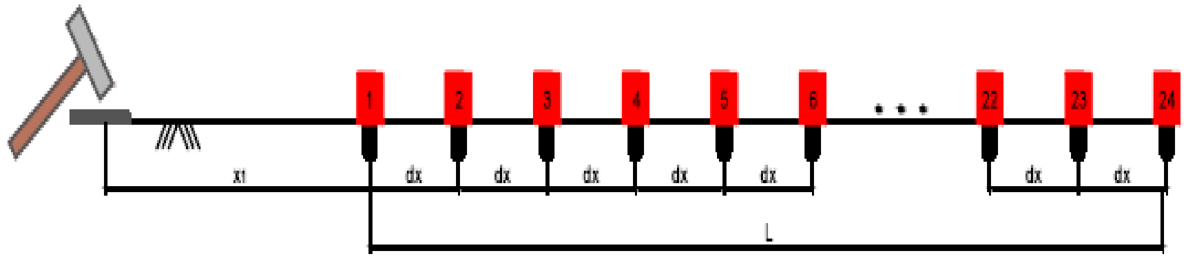


Figure 3. 5 General measurement procedure in MASW survey.

In general, a heavier seismic source will result in increased investigation depth. A common choice is a reasonably heavy sledgehammer (e.g.10 kg) that can result in an investigation depth of 10-30 m. A source that is capable of delivering more impact power into the ground, such as a crane and a heavy falling load, has potential to create surface waves of lower frequencies (longer wavelengths), therefore increasing the investigation depth below 30 m. The use of an impact plate (base plate), either metallic or non-metallic, and can in addition help in generating lower frequency surface waves. A metallic plate is a more conventional choice. However, it has been reported that it is possible to generate surface waves containing noticeable lower frequencies by using a firm rubber plate.

3.2.3 Data processing

A dispersion curve is extracted from the measured surface wave data. Two different analysis methods are described: swept-frequency approach and the phase shift method.

3.2.4 Inversion analysis

A theoretical dispersion curve for the test site is obtained, with iteration, based on an assumed number and thickness of soil layers and assumed material properties, such as shear wave velocity, for each layer. The experimental dispersion curve is used as a reference (Park et al., 1999). The shear wave velocity profile and the layer structure that result in a theoretical dispersion curve that fits the experimental one are taken as the result of the survey (Figure 3.6).

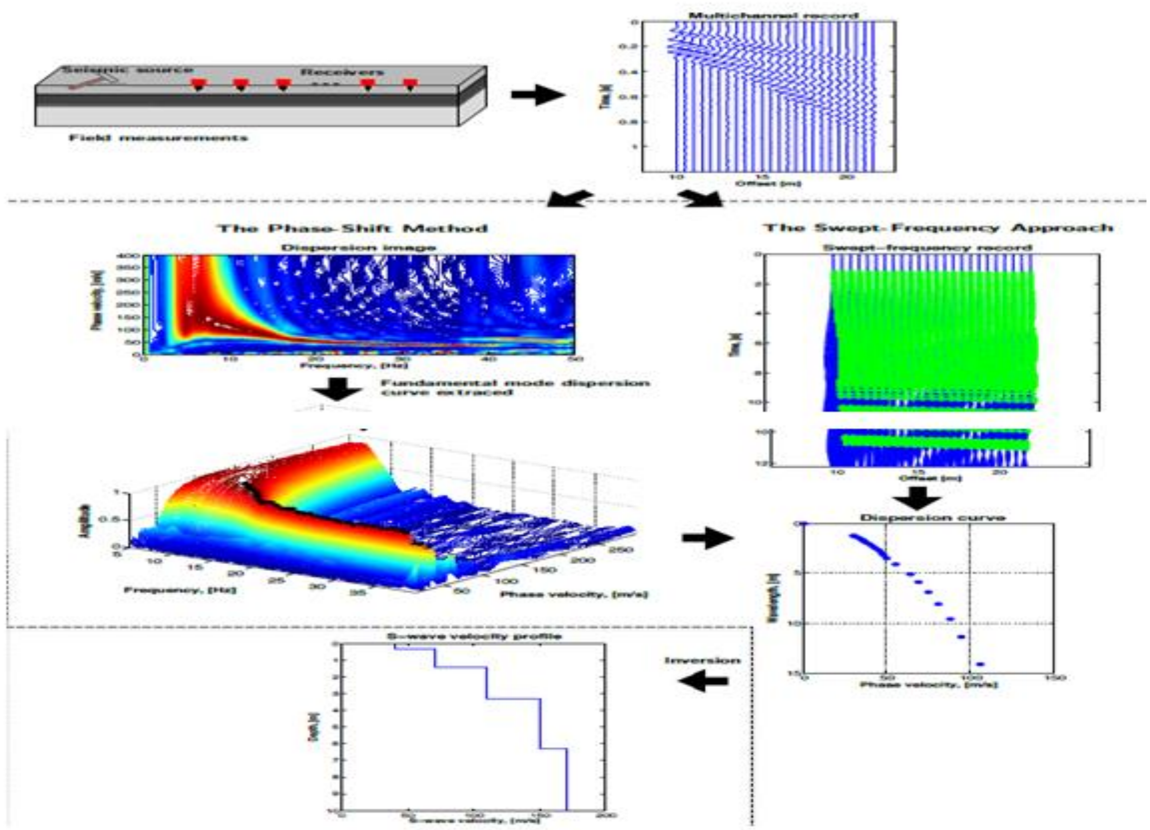


Figure 3. 6An overview of the main steps of the MASW method

3.3 Electrical Resistivity

3.3.1 Preamble

Geo-electrical methods are applied to map the resistivity structure of the underground. Rock /soil resistivity is of special interest for engineering site characterization purposes. The measurements have been used to an increasing extent in engineering site characterization where resistivity measurements are used in foundation studies to determine the presence of subsurface layers that can be considered as competent/bed rock the depth to the basement/bed rock and the presence of weak zones within the bed rock. The aim of a building construction site investigation is for the evaluation of foundation materials for the proposed structure. Ground investigation is usually required to determine the variation in thickness and nature of the rocks and engineering soils within the zone of influence of the proposed structure (Das, 1994).

3.3.2 Electrical Resistivity methods

Electrical resistivity is a fundamental and diagnostic physical property that can be determined by a wide variety of techniques. Resistivity of the ground is measured by injected currents and the measurement of resulting potential differences at the surface. Furthermore, the approaches used to determine electrical resistivity may be quite distinct; for example, ground contact methods compared with airborne induction techniques. Mutually consistent but independent interpretations give the interpreter greater confidence that the derived model is a good approximation of the sub-surface (Reynolds, 1997).The true resistivity of the subsurface formation can then be estimated from the measured apparent resistivity. The estimated ground resistivity valve corresponds to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. This surveying technique has been utilized for hydro-geological, mining, environmental and geotechnical investigations (Loke, 2001).

To relate the resistivity valve into geological information, prior knowledge of typical resistivity values for different types of subsurface materials and the geology of the site is important. The resistivity of geological materials exhibits one of the largest ranges of all physical properties, from 1.6 x 10-^{8} Ohm-m for native silver to 10^{16} Ohm-m for pure sulphur. Igneous rocks tend to have the highest resistivities; sedimentary rocks tend to be most conductive, largely due to their high pore fluid content; and metamorphic rocks have intermediate but overlapping resistivity. The age of a rock also is an important consideration: a Quaternary volcanic rock may have a resistivity in the range 10-200 Ohm-m while that of an equivalent rock Precambrian in age may be an order of magnitude greater resistivity. This is a consequence of the older rock having been far longer to be exposed to secondary infilling of its interstices by mineralization, compaction decreasing the porosity and permeability, etc. Different class of rocks and soils of the resistivity values are similar (Table 3.2). Properties that affect the resistivity of a soil or rock include porosity, permeability, water content, composition (clay mineral and metal content), salinity of the pore water, and grain size distribution. Resistivity values show larger significant range compared to other physical quantities mapped by other geophysical methods. The resistivity valve of rocks and soils for a specific site can vary by several ranges of magnitude (Loke, 2001).

Table 3. 2 Resistivities of common geologic materials (Reynolds, 1997).

Geological materials	Resistivity in Ohm-m
Slate	6×102-4×107
Marble	102-2.5×108
Quartzite	102-2×108
Granite	5×103-106
Basalt	103-106
Sandstone	8-4×103
Shale	20-2×103
Limestone	50-4×102
Clay	1-100
Alluvium	10-800
Groundwater (fresh)	10-100
Sea water	0.2
Ash	4
Colliery spoil	10-20
Dry sandy soil	80-1050

In this study, Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) methods are used to investigate the engineering site characterization of the proposed Wachamo University Referral Hospital site near Hossana town. Both methods can provide extensive spatial data about the subsurface.

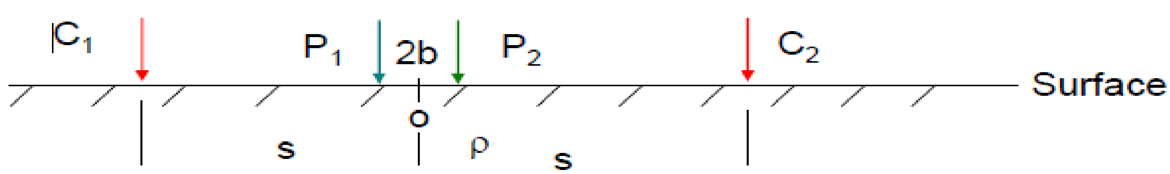
3.3.3 Types of Resistivity Surveys

There are two basic types of resistivity investigations: - profiling and depth sound investigations. A combination of both has also been possible through the development in electronic switching that has resulted in improved data acquisition and interpretation. Moreover, the earlier techniques, although still widely used were considered very labor intensive and the development of the multi-electrode surveys has been able to reduce this aspect of the survey (Heather et al., 1999). There are a number of electrode arrangements (or arrays) used in electrical measurement as convention whereby, the two current and potential electrodes are by C_1, C_2, and P_1, P_2

respectively are disposed of over the ground surface. The most commonly used ones are Schlumberger, the Wenner and Dipole-Dipole array although quite a number of other arrays are also getting acceptance.

3.3.3.1 Vertical Electrical Sounding (VES)

Vertical (1D) electrical soundings are applied to a horizontally or approximately horizontally layered earth. It uses a fixed center the sounding point with an increasing spreads symmetrically. The procedure is especially utilized to study the vertical resistivity variations. In the most favorable case, the number of layers, their thicknesses and resistivities are the outcome of a VES survey. The Schlumberger array, the most commonly employed array type in sounding surveys, is a symmetrical arrangement in which the point C_1, P_1, P_2 and C_2 are taken on a straight line such that the points are symmetrically placed about the center of the spread ‘0’ (Figure 3.7). As the distance between the current electrode is increased (Figure 3.8), there is also an increased in depth at which the current penetrates the subsurface and the resistivity distribution below the center of the array is determined. When the distance between the potential electrodes is’b’and‘**s’**is half distance of the current electrode, the apparent resistivity is given by:



Here r1= s - b; r2 = s + b; r3 = s + b, and r4 =s – b

Figure 3. 7.The Schlumberger array.

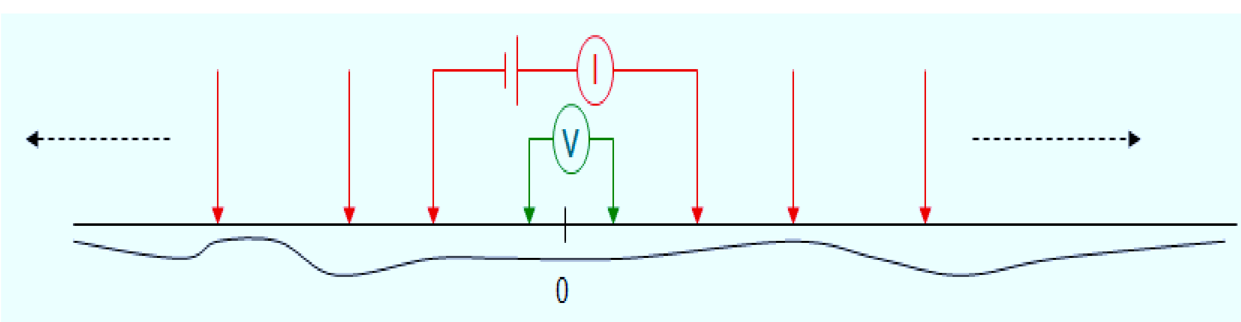


Figure 3. 8The procedure for Vertical Electrical Sounding survey where the current electrode layouts are systematically expanded about the central point for deeper current penetration

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{s-b} - \frac{1}{s+b}\right) - \left(\frac{1}{s+b} - \frac{1}{s-b}\right)\right]$$

$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{2b}{(s^2 - b^2)}\right)$$

$$\rho_{as} = \pi\left(\frac{s^2 - b^2}{2b}\right)\left(\frac{\Delta V}{I}\right)$$

Where the geometrical factor in this case is:

$$\pi\,(s^2 - b^2)/2b$$

The ratio $\Delta V/2b$ is the potential gradient or the intensity of electric field.

3.3.3.2 Electrical Resistivity Imaging/Tomography

Electrical resistivity imaging is an advanced geophysical method used to determine the subsurface resistivity distribution with high resolution by making measurement on the ground surface survey; procedure, which involves a combination of both resistivity profiling and sounding techniques to produce an image along a section through the subsurface. The measurement protocol used for the data acquisition is a combination of Wenner-Schlumberger configuration ensuring both vertical and horizontal precision (Loke and Barker, 2001).

Electrical resistivity imaging technique is one the most commonly new developmental techniques in recent years used to map areas with moderately complex geology where conventional resistivity sounding or profiling survey are inadequate, such surveys are usually carried out using a large number of electrodes connected through multi-core cables.

It produces a more accurate and very high resolution model of the subsurface where the resistivity varies in both the horizontal and vertical directions along the survey line. In many geological conditions, the use of 2-D electrical imaging surveys can provide useful results that are complementary to the information obtained by other geophysical surveys (Loke, 1999).

According to Robert and William, (1981); and Bell, (1983) as cited Tigistu Haile and Alemayehu Ayele (2014), the technique has an added attraction of providing a relatively low cost, non-invasive and rapid means of generating 2D models of the geo-electrical properties of the subsurface.

Data Acquisition

The multi–electrode PASI Earth Resistivity Meter system aided with the P100-3Energizer and associated accessories like large number of electrodes and connecting cables, was used for the resistivity measurement. A total 30 electrodes were used, employing the Wenner-Schlumberger array. The resistivity measurement station spacing is 20m and the electrodes were arranged along a line with 5mspacing between adjacent electrodes. Electrode C_1 and C_2 at a constant spacing (7.5m) from the central '0' resistivity measurement point and also P_1 and p_2 at 2.5m spacing from resistivity measurement point. The electrodes were connected to the multi-core cable which was alternatively connected to the PASI unit as it has no automatic switching technology. After each measurement, the progressive current injection electrodes are connected and new measurements taken for successive deeper penetration. After adequate data are acquired, the whole array is advanced (by 20m) to the next sounding point.

Two-Dimensional Resistivity Inversion

Electrical Resistivity Tomography (ERT) is being widely in resistivity instrumentation and data acquisition to map areas with moderately complex geology where conventional sounding or profiling surveys are inadequate (Loke, 1999). The RES2DINV program uses the smoothness constrained least squares method of inversion techniques to produce a 2D model of the subsurface from the apparent resistivity data.

Limitations of the Electrical Resistivity Methods

Profiling methods measure the lateral variations of apparent resistivity but do not easily provide insight into true actual resistivity of the subsurface materials. Identified electric boundaries separating layers of different resistivity may or may not perfectly coincide with boundaries separating layers of different lithologic composition. This may result in the electrical stratigraphy varying from the gross-geologic stratigraphy. According to Hoover et al., (1999), Earth resistivity measurements have been made using an array of grounded electrodes (Wenner, Schlumberger, etc.) with which to inject current into the ground and to measure the potential difference. The use of grounded electrodes can sometimes give problems in areas of high surface resistivity because in such situation obtaining useful levels of current flow in the ground could be difficult (problem of poor galvanic contact**.**

4. DATA ACQUISITION, PROCESSING AND PRESENTAION

4.1 Introduction

To successfully carry out the primary data collection program using the different stipulated method, i.e. the Electrical Resistivity Imaging (ERT), Vertical Electrical Sounding (VES) and Multichannel Analysis of Surface Wave (MASW), systematic survey lines selection exercise was conducted to cover as much coverage as possible and to have data well distributed the study area. Survey lay out**:** four (4) NW-SE and one (1) perpendicular (NE-SW) trending profile were laid for Electrical imaging and two NW-SE profiles for seismic survey. Three VES point were occupied, basically at the SE portion of survey area. Besides, two (2) seismic profiles were run. The survey line is governed by natural condition (at the surface that may impact a survey like dense vegetation), man-made fence and getting long line distribution to cover the area. The resulting data collection survey lines and points are illustrated in figure (4.1).

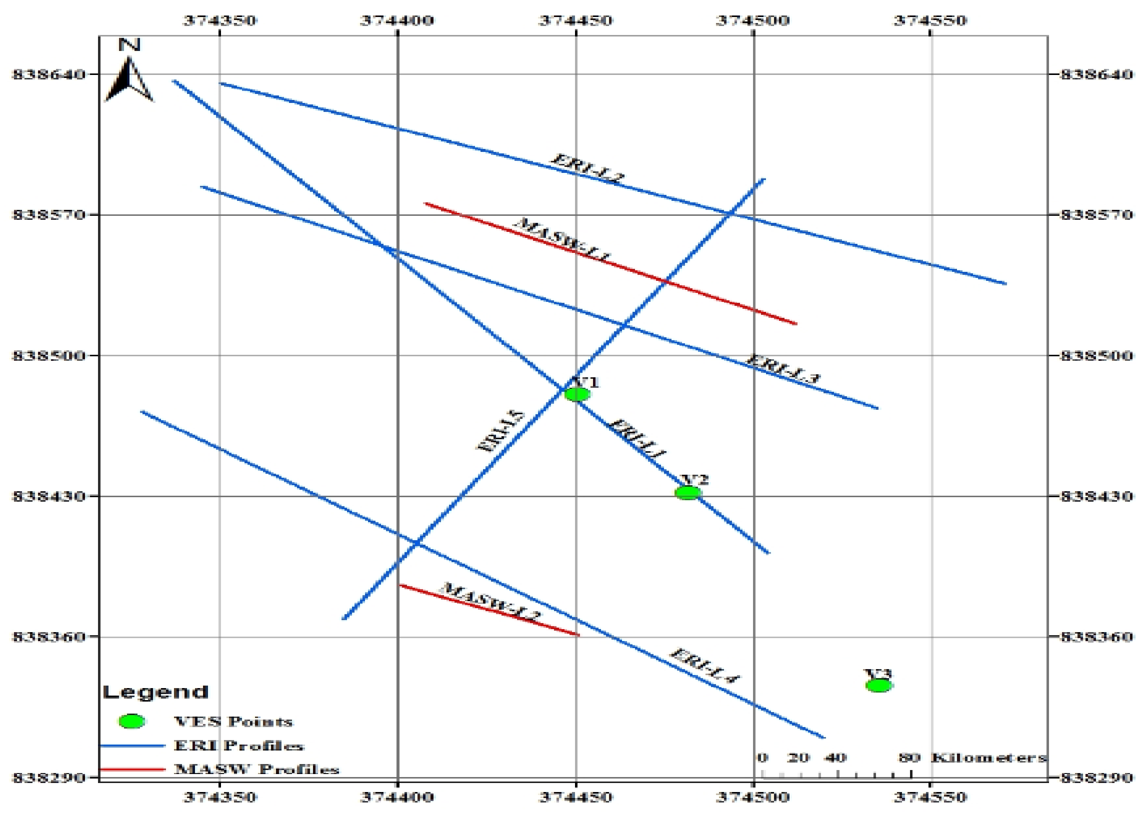


Figure 4. 1 The Geophysical survey lines of all methods employed in the study area

The acquired data were acquired then analyzed to get the relevant information for the subsurface foundation condition for the proposed building site. Data collection, processing and interpretation during the present study are discussed in detail in the following section.

4.2 Multichannel Analysis of Surface Waves

To achieve the objectives of the thesis and to determine the influence of the local geologic and soil conditions, the seismic surface wave dispersion analysis methods were employed as one of the geophysical methods planned to be deployed on the proposed building site. This method is well established in providing map of the subsurface soil layers, shear wave velocity of the different horizons and the depth to the bedrock.

The basic idea behind this technique, as discussed in detail in the preceding sections is based on the fact that surface waves travel at velocities that are controlled by their wavelengths. Longer wavelength, and hence lower frequency, waves penetrate deeper than shorter wavelength, higher frequency waves. In areas of varying velocity with depth, the relationship of frequency versus velocity for a surface wave train is called a dispersion curve. Several inversion methods to extract dispersion curves from recorded multichannel analysis of surface wave data. For our case the phase-shift method (also known as the wave field transformation method (park et al., 1998).

4.2.1 Data acquisition

Data acquisition for surface wave analysis is achieved through the use of recently developed Geode Seismograph with 24 receivers (geophone) of 4.5 Hz frequency, seismic source of 12kg sledge hammer and geophone spacing of 5m for MASW 01 and 3m for MASW 02 were used to collect data over the proposed building site. Each channel is dedicated to recording vibration from one receiver. One multiple-channel record (commonly called a shot gather) consists of a multiple number of time series from all receivers in an ordered manner. Impulsive source (a sledgehammer) is used to generate surface wave.

The acquisitions parameters are were given Table 1.2 (chapter 1). The field procedure employed was in-line spread in which the source and the geophones were placed in a straight line (Figure 4.2). Data analysis and interpretation was done by using of updated software for data analysis Seisimager and basic knowledge for data interpretation.

Figure 4. 2Instrumentation and MASW data acquisition

4.2.2. Data Processing and interpretation

Data analysis and processing was done by using SeisImager /SW software (Park et al., 1998) the detailed steps involved in the analysis of surface wave data to obtain a two dimensional shear wave velocity models are shown in the flow chart Figure 4.3. The two main objectives of data processing are to obtain the dispersion curves of Rayleigh wave phase velocity from the records and determining the various layers and their shear wave velocities. A dispersion curve is extracted from the measured surface wave data or from recorded data by phase-shift method or wave field transformation method. Dispersion curve is obtained for each recorded, e.g. by using the data processing procedures and subsequently inverted to a one dimensional shear wave velocity profile. Each profile is assumed to be representative of the soil deposits directly below the centered of the receiver array at the time of the corresponding measured. From the one dimensional shear wave velocity the (Vs) 30 values are calculated. A two-dimensional shear wave velocity model is then obtained by interpolation between the various one-dimensional profiles (Park et al., 1998). Finally Data analysis and interpretation was done by using of updated software for data analysis Seisimager and basic knowledge for data interpretation.

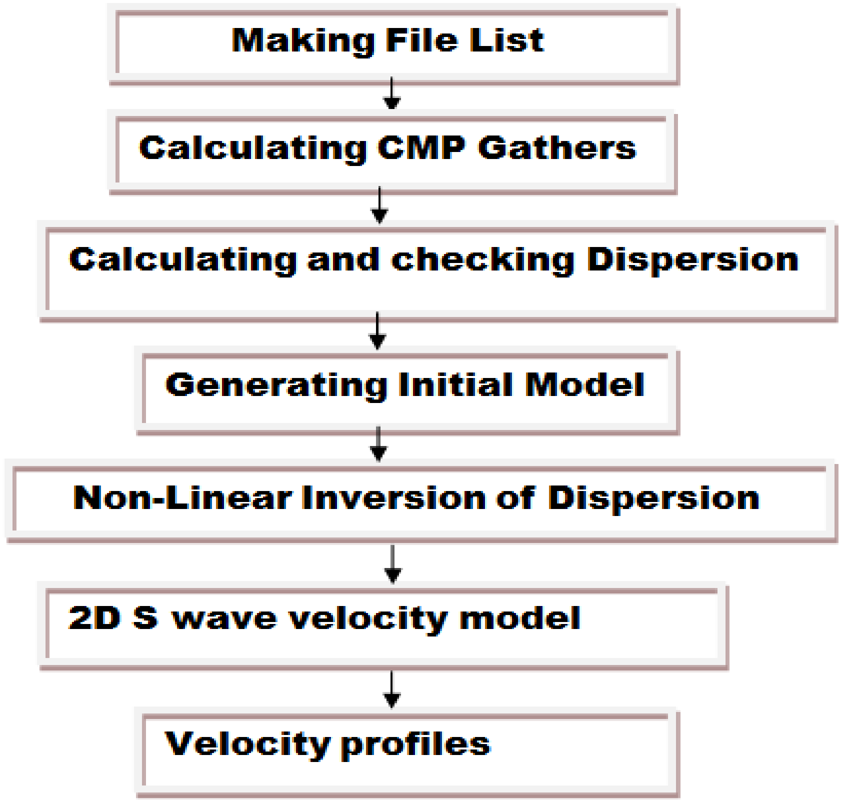


Figure 4. 3Flowchart for the analysis of surface wave data

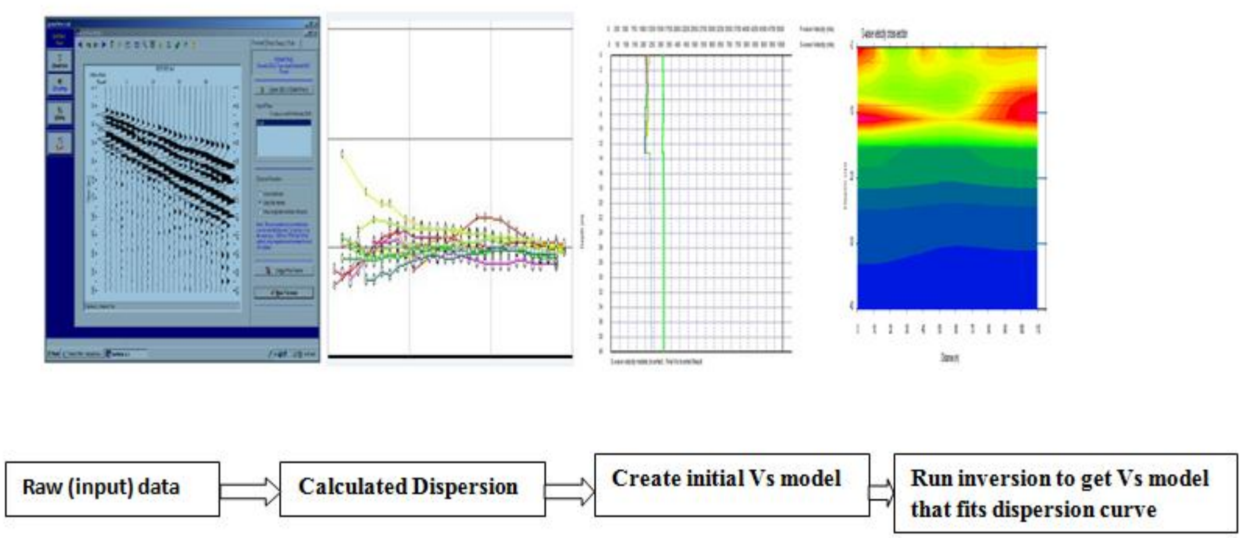


Figure 4. 4 General steps of the 2D Multichannel Analysis of Surface Waves (MASW)

Processing flow Chart

- Reading waveform data files (Acquired survey data)
  a. Setup survey geometry and display setting
- Editing raw data
  a. High cut, low cut filters
  b. Delete noisy trace
- Calculating cross-correlation CMP gathers
  a. Extract all pairs that have common mid-point from all traces and calculate its cross-correlation for making cross-correlation CMP gathers.
- Calculating dispersion curves
  a. Calculate phase-velocity image in frequency domain for each cross-correlation CMP gathers and pick dispersion curves.
  b. Set up the frequency and phase-velocity range to be calculated.
     i. 4-20hz frequency range
     ii. 0-800m/s phase velocity range are used for this research
  c. Pick the phase velocity
- Dispersion curve view
- Checking dispersion curves
- Initial velocity model
  a. 15 layers and 30m depth are used for initial modeling
- Non-linear inversion for dispersion curves
  a. Iterate 10 times
- 2D S-wave velocity model
  a. Final Inverted result

For the purpose of correlation with the electrical resistivity imaging data and interpretation of geological formation some of data are picked with the apriori information given in table (4.2)

Table 4. 1 physical properties of permeable and low permeable layers (Reinhard, 2009)

Description	**Seismic**	**Geo-electrical**	
	Vp (m/s)	**Resistivity(Ωm)**	**Conductivity (ms/m)**
Gravel, sand (dry)	300-800	500-2000	0.5-2
Gravel, Sand (saturated)	1500-2000	40-200	20-30
Fractured rock	1500-3000	60-2000	0.5-17
Solid rock/fresh rock	>3000	>2000	<0.5
till	1500-2200	20-60	17-34
clay	1500-2500	1-100	34-100

4.3 Vertical Electrical sounding

4.3.1 Data acquisition and instrumentation

In the resistivity survey technique employed in this work, the Vertical Electrical Sounding (VES) survey was conducted using the Schlumberger electrode configuration. The data were acquired to get the relevant geological information for the subsurface foundation condition for the proposed building site. Before starting the geophysical investigation, the first step was identifying the traverses appropriate to the survey the sounding points were selected to be in line and a maximum possible half-current electrode spacing as possible was to be used. To get this linear spacing, the areas clear of buildings and fences that would allow maximum current chosen.

In Vertical Electrical Sounding (VES) survey, an electrical current is injected into the ground through steel electrodes in an attempt to measure the electrical properties of the subsurface. A total of three Schlumberger vertical electrical sounding surveys were carried out over one profile line in an area with array spread for maximum half current electrodes spacing (AB/2) max of 330m. The distance between the successive sounding stations vary from 55 to 110m. In the VES method of survey current is injected into the ground using the current electrodes C_1 and C_2 and the resulting potential is measured using two potential electrodes P_1 and P_2 (Figure 3.7). The potential electrode remain fixed at point while the current electrodes are expanded symmetrically about the center of spread (Figure 3.8): the potential electrodes was also increased at a large value of the current electrode spread to ensure that the distance between C_1 and C_2 never exceeds AB/2 and AB being the distance between current electrodes. A Schlumberger configuration with a maximum half current electrode spacing of 330m (AB/2=330m) was utilized to investigate the ground in depth this depth is believed to be adequate and even exceed to study the possibility of groundwater presence in the subsurface affecting the foundation work and subsequent infrastructure. The value of the resistance was measured by using the instrument Earth Resistivity Meter unit (PASI; GL-16) and Energizer PASI P100-N_X (Figure 4.2). Handheld (GARMIN 64) GPS was used to record the VES point locations. The sounding profile was made with the consideration of the 2D imaging and Multichannel analysis of surface wave (MASW) survey profiles.

4.3.2 VES data Processing and presentation

Each acquired VES data from three stations were processed by IPI2winWinsoftware then WinResist software to obtain the primary layer model parameters (thickness and true resistivity). By using AutoCAD software the geo-electric section the subsurface layer parameters obtained. The resulted VES data were plotted as sounding curve and interpreted qualitatively and quantitatively. The qualitative interpretation was carried out by using visual inspection to characterize the curve. The quantitative interpretation was result through partial curve matching by computer software iteration.

Figure 4. 51Data acquisition by PASI-GL16 Earth resistivity Meter and P100-N_X Energizer units

4.4 Electrical Resistivity Imaging

4.4.1 Data acquisition and instrumentation

In order to obtain investigate the information about the subsurface layer resistivity of the area with a greater resolution, 2D electrical resistivity data were acquired along a number of appropriately selected traverse lines that are well distributed and cover the area of study. A total of five profile lines were selected for survey; four profile lines that are parallel to each other and one line perpendicular to them and design to examine the subsurface characteristics in the direction different from the rest. The instrument that was employed to collect the data is the PASI 16-GL Earth Resistivity Meter unit with PASI P100-Nx Energizer, and the GPS data were recorded at every data measuring points using a handheld GPS. The electrical imaging data were collected using the combination of Wenner-Schlumberger array where by sounding points at 20m stations spacing with 5m electrode spacing are used on each line.

4.4.2 ERI Data processing and presentation

The acquired electrical resistivity data was processed using the Res2DINV software. The data were arranged and corrected by using the Microsoft excels spreadsheet. The elevation data was not included in the plotting because the survey area is comparatively flat. To remove bad data, the data was first filtered by the usingRes2DINV software "Automatic Filtering" option and moreover through visual inspection of the data to remove the data whose resistivity value was obviously an outlier compared to the neighboring data points. Least square inversion was then carried out on the data using theRes2DINV software to obtain the 2D inverse resistivity models. In order to generate the stacked apparent resistivity pseudo-section, on the other hand, apparent resistivity and true depth was used. Apparent resistivities at each depth were contoured and gridded using the Golden Software Surfer-10 software. After these operations, sliced apparent resistivity maps were stacked in a single section and presented as inverse resistivity models. Figures 4.6 and 4.7 give typical examples of a 2D inversion process output where the raw apparent resistivity data recoded from the field, the computer generated initial model data and the inverse model resistivity sections are presented side by side.

The inverse model resistivity section plot, which is the result of a fitting process between the observed field data and the calculated data values through the least square iteration process, is the final output of the imaging exercise that is subjected to interpretation. Due to the large number of data points involved in the inversion process, the model section is a highly resolved representation of the subsurface from which both lateral and vertical discontinuities in the subsurface along the surveyed profile are clearly visible and interpretable. The depth and morphology of the competent bed rock (if it exists) as well as the presence of weak zones and vertical and near vertical structures in the subsurface could readily be extracted from the last plot.

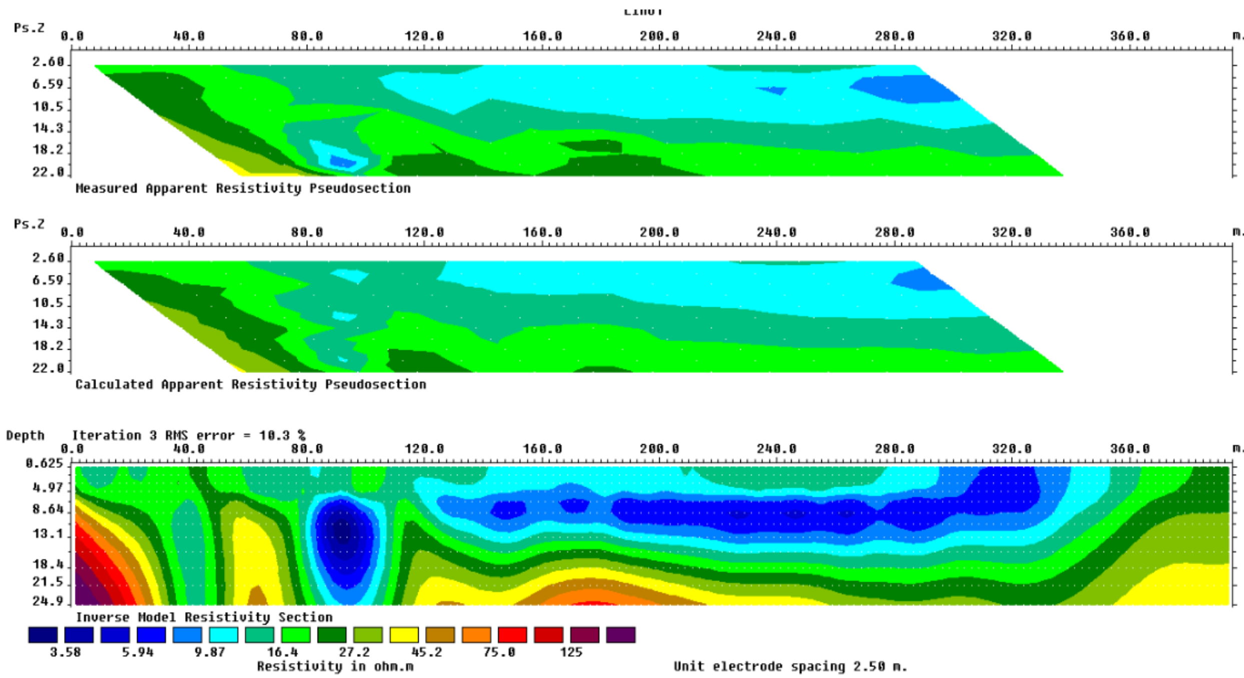


Figure 4. 6Typical example of inverse model resistivity section for imaging Line 01

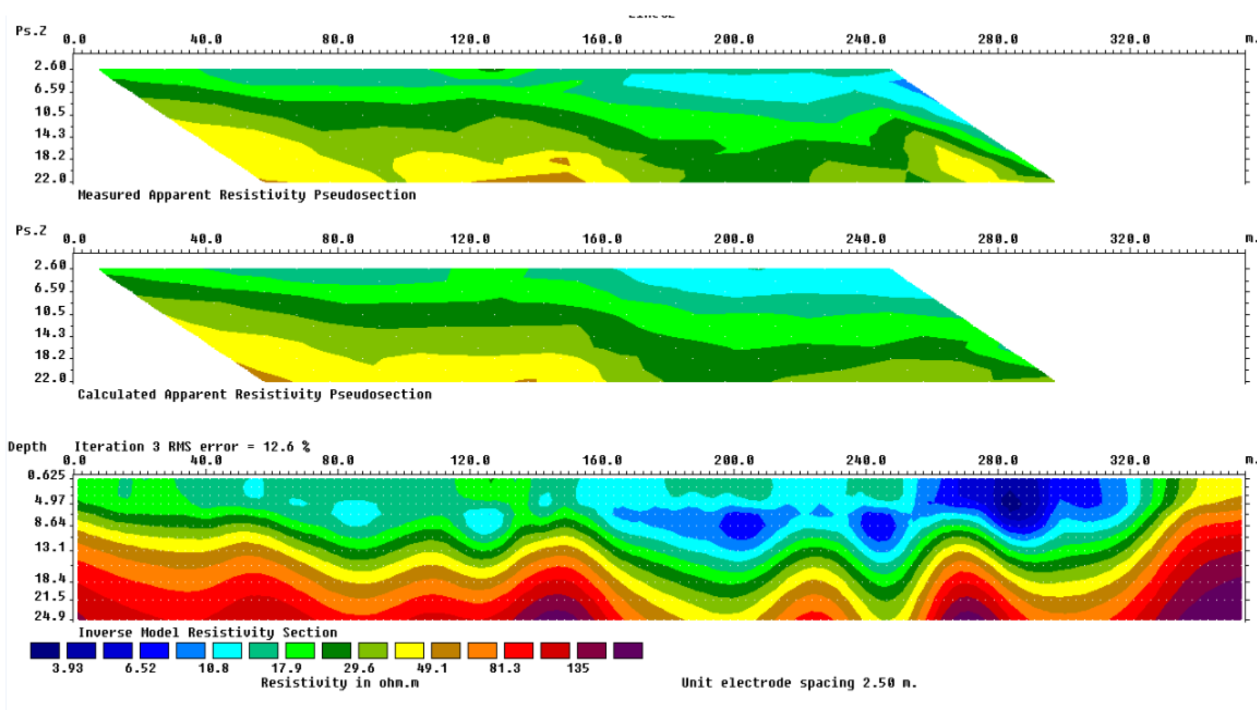


Figure 4. 7Typical example of inverse model resistivity section for imaging Line 02

CHAPTER FIVE

5. RESULT, DISCUSSION AND INTERPRETATION

5.1 Result, Discussion and Interpretation Electrical Resistivity imaging data

5.1.1 Introduction

Electrical resistivity imaging affords a successful 2D subsurface imaging that has greater depth and provides continuous data to characterize a building site. The ultimate result of the imaging exercise if that it gives a better resolved 2D plot for Referral Hospital site which is presented as inverse model resistivity section along the many survey profiles. Totally five profile lines were selected for the proposed survey site, four of which are parallel to each other and are oriented nearly east -west while the fifth one is perpendicular to others. The data is collected using the Wenner-Schlumberger arrangement with inter electrode spacing of 5m. The imaging works carried out on profile lines 01, 02, 03, and 04 cover horizontal distances of 400m, 360m, 360m and 360m respectively. The perpendicular line 05 has a horizontal distance covering 400m. It is clear from the line lengths; therefore, that good data coverage of the building site has been achieved. The average depths of investigation for all the profiles were 26.42m, adequate to image the subsurface to foundation depths required for most large buildings. The Elevation data were not included (the impact of the topography is insignificant) because the topography of the area is quite flat. The 2D resistivity inversion layered models were correlated with Batena borehole. Batena borehole have five geological layers up to 42m; layer one (top soil), layer two (yellowish gray silty soil or saturated clay, layer three (grayish weathered ignimbrite), layer four (slightly weathered volcanic tuff) and layer five slightly weathered ignimbrite. The correlations were sometimes combines layer four and five. The weak zone and basement structure were traced based reflected by low resistivity values. The results of all the profiles are discussed separately and in detail in the following sections.

5.1.2 Results from Electrical Resistivity Imaging (ERI) Parallel Lines 01, 02, 03,04 and 05

Imaging Line 01

As discussed in the preceding sections in much detail, the acquired 2-D resistivity data employed by Wenner-Schlumberger array configuration with inter-electrodes spacing of 5m and sounding station spacing of 20m. The inverse resistivity model sections was obtained by processing the filtered the data with the Res2DINV software. The resulting inverse resistivity model has good quality data with RMS error of 10.3% after 3 iterations and the section is shown in Figure (5.1) has the resistivity range of 3.58-125Ω-m. The total length of horizontal extent covering at survey, the number of data points used to correct the inverse model resistivity section after initial filtering the noise data and maximum depth of investigation of this profile are 400m, 165 and 24.9m respectively. The model in this profile line showed that gradual increase in resistivity with depth from surface. From the inverse model resistivity section the subsurface can be divided into four distinct layers.

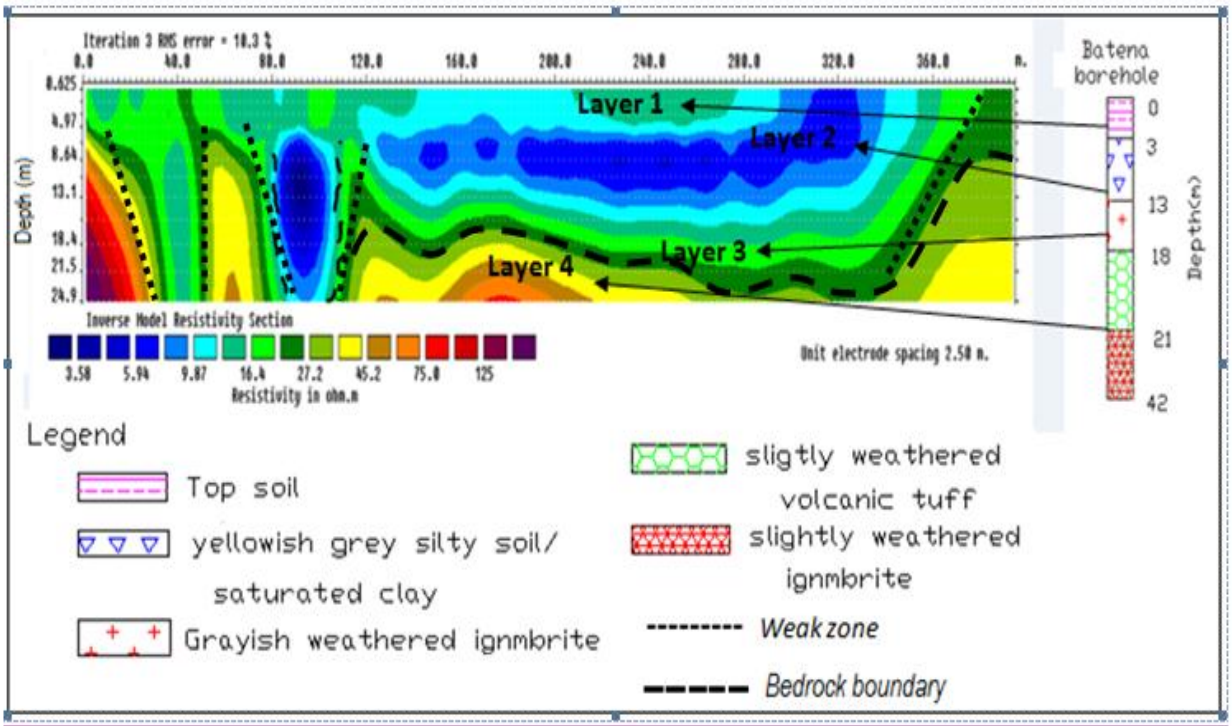


Figure 5. 1Inversion model resistivity section for Line 01 and correlation of the different subsurface units with Batena borehole lithologic log.

A top layer of resistivity variation (3.58 to 14.5Ω-m) corresponding to brown clay soil and sandy silt with average thickness of about 3 to 4m is mapped. The difference in resistivity response of this layer could have resulted either from variation in moisture content of the top dry soil or from variations in lithological composition.

The seconded layer resistivity is relatively low resistivity and varies between 4.8 to 10.4Ω-m probably corresponding to clay soil with containing water and slightly silty sand with average thickness 5m.

The third (intermediate) layer resistivity considered as a transition zone showing intermediate to high variation in resistivity (5.8 to 75Ω-m) with depth and probably this zone represents the highly weathered and fractured volcanic tuff or weathered and fractured ignimbrite. The thickness of this layer is about 12m.

The resistivity contrast describes low resistivity variation at the eastern part of the profile in the region of a near vertical discontinuities attributed to the presence of a weak zone of a fractured zone. Due to this weak zone weathering and infilling with material of the top regions accounts for the decrease the resistivity responses along the weak zone. Therefore these geological structures or weak zone should be given critical consideration during the proposed building structural design.

The bottom or fourth stratum/layer mapped shows high resistivity variation (16.4 to 125 Ω-m) as compared to the above layers, and corresponds to the response of the slightly weathered ignimbrites and extends to about 24.9m depth. The top two layers are thicker and are with low resistivity response at the western side of the study area. Those first two layers have relatively low resistivity responses near surface. Therefore, the result of the 2D imaging section low resistivity (exposed the soft to firm geological materials with this profile) is not extensive enough to support heavy load or the structural load of either high or low rising buildings. The two basal subsoil stratums/ layers have intermediate to high resistivity layer. These two layers can be characterized as competent/bedrock, they are taken as required results from the point of view of the survey objectives. The boundary to this horizon is indicated on the figure (Figure 5.1) and its boundary is clearly seen to undulate over the length of the survey line going deeper on the eastern side. A number of near vertical discontinuities are also worth considering during the foundation design and locating the physical buildings. In general, the basal substratum have adequate enough to support the structural load or heavy load either high rising or low rising building foundation. Hence, the foundation should be placed directly on the bottom layer. Therefore, a deeper type foundation on the basal geo-electric section/layer is recommended.

Imaging Line 02

The electrical resistivity imaging data for Line 02 were collected by using the Wenner-Schlumberger array with inter- electrode spacing at 5m and sounding station spacing of 20m. The inversion scheme was processed by Res2DINV software to obtain an image of the true resistivity distribution as function of the depth for the surveyed line. The inverse resistivity model sections produced has a good quality data as shown with RMS error of 12.6% after 3 iterations and the resulting section is shown in Figure (5.2), with actually resistivity range of 3.93 -135Ωm. The profile has:- covered a horizontal survey length of 360m and the number of data points and maximum depth of investigation after filtering the noisy data through automatic filtering and visual /manual inspection are 143 and 24.9m respectively. Close examination of the inverse model resistivity section of this profile shows that the subsurface can be divided into four distinct layers.

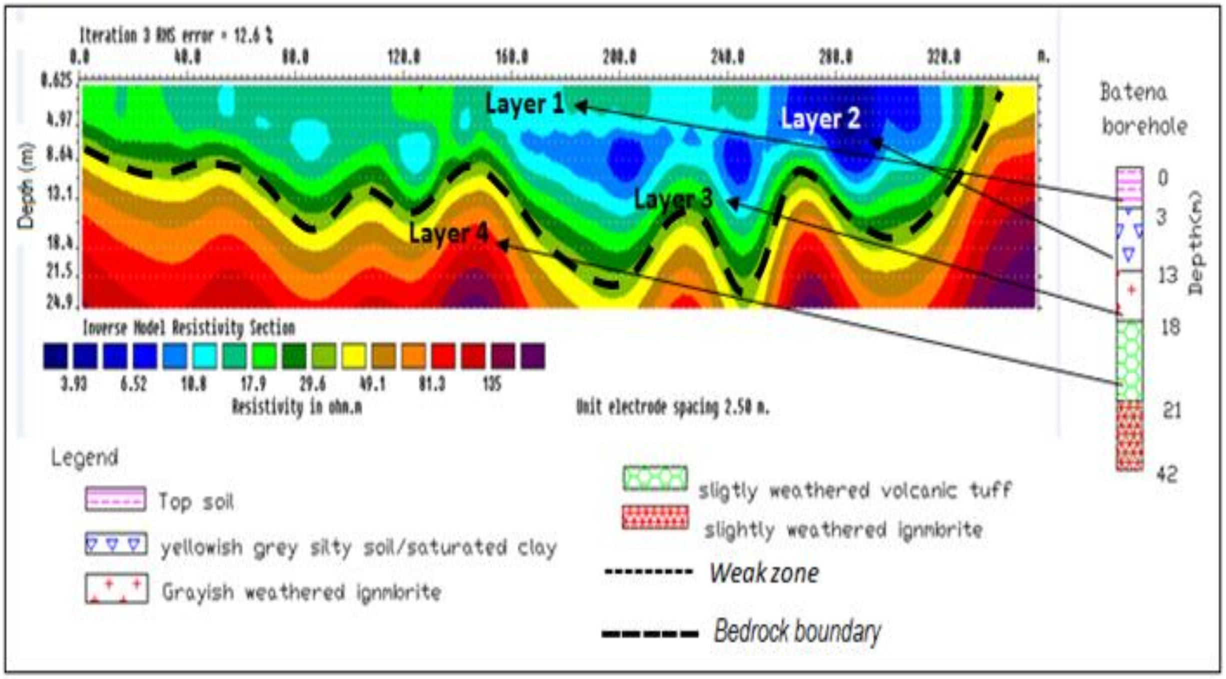


Figure 5. 2 Inversion model resistivity section for Line 02 and correlation of the different subsurface units with Batena borehole lithologic log

The first layer /top overburden layer is occupied by Earth materials interpreted as dominantly dry clay soil or top soil with the resistivity values ranging from 3.93-17.9Ω-m and average thickness 3m.

The second layer mapped with the survey shows resistivity variation 6.93- 22.5 Ω-m and average thickness of 2m and this could be the saturated clay soil.

The third layer or intermediate resistivity layer has variation in an apparent resistivity value ranging from 17.9-49.1Ω-m that corresponds to the sandy clay and silt layer. The average thickness of this layer is 4m.

The bottom high resistivity layer shows range of resistivity value from 49.1-125Ω-m. Its lithology probably considered as a weathered ignimbrite or weathered tuff with average thickness of 15m.The top two layers have relatively low resistivity value at western part of the profile with average thickness of 4.7m with horizontal extent that increases while relatively intermediate to high resistivity responses are recorded at eastern portion of the profile with significant thickness and smaller lateral or horizontal extent. The depth of the competent rock unit that could act as good foundation material and its variation in depth across the profile is indicated (Figure 5.2 dashed line).

Therefore, based on the 2D imaging section of this profile (Figure 5.2) the two upper layers in the western portion cannot support heavy load or are not of adequate enough compactness to support the structural load of high rise or even low rise building foundation whereas the eastern portion of this profile has adequate strength to support heavy load or are composed of materials adequate enough to support the structural load of low rise and high rise building foundation. But, the two basal sub-stratums or the bottom two layers are adequate enough to support either high or low rising structural load of building foundation.

Imaging Line 03

The electrical resistivity imaging data were again collected by using the Wenner-Schlumberger array with inter- electrode spacing of 5m and sounding point station spacing of 20m.The inverse resistivity model section for this line is given in Figure (5.3) showing good data quality with the RMS errors of 7.1% after only 3 iterations as obtained by the optimization skill of the Res2DINV software by minimizing the variation between the calculated and measured pseudo-sections of the apparent resistivity data sets. The total length of the traverse, the number of data points used for the inversion and the depth of investigation for this profile respectively are 360m, 132 data points and 24.9m.

A top layer observed is a thin layer with range of resistivity variation between 8.92- 15.2Ω-m. This layer shows low resistivity response due to the nature of dry soil with water content. Its thickness extends for about 3m.

The second layer shows that very low resistivity response with the ranges of (6.15-12.9Ω-m).

This layer contain high amount of moisture content or saturated silty clay soil or clay zone. Thickness of this layer is11.5m.Over all finding of this layer is show that maybe will have consequence on building foundations.

Third layer or alteration zones which characterize the result in resistivity that probably corresponds slightly weathered and fractured ignimbrite or slightly weathered volcanic tuff . The resistivity of these layer ranges from 18.8 to 39.5 Ω-m with thickness of 5m.

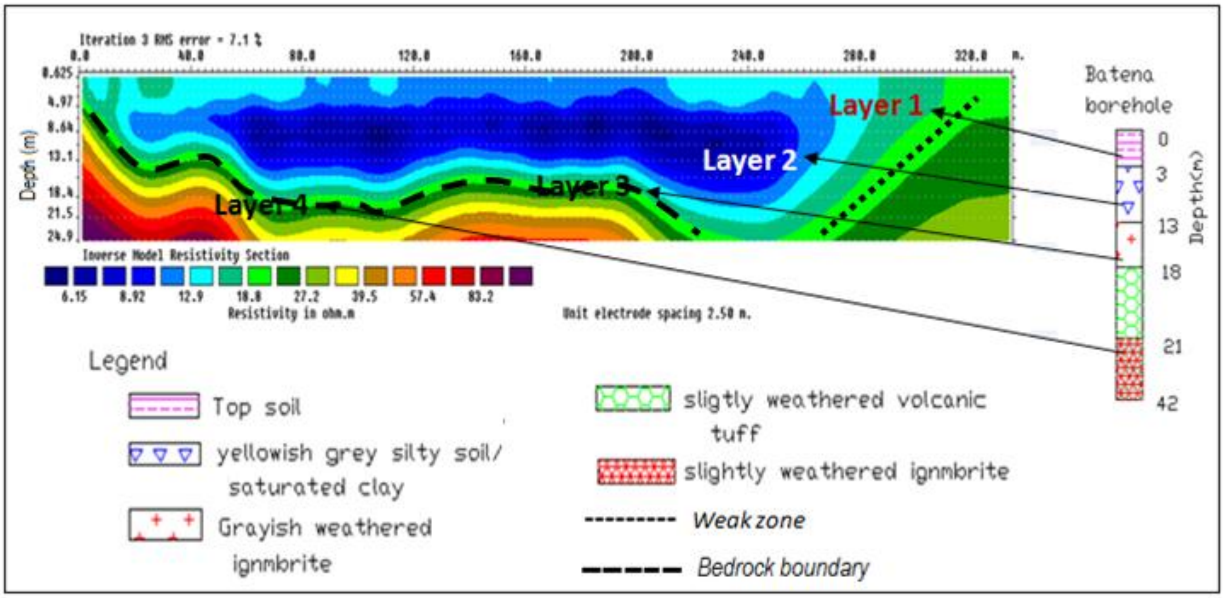


Figure 5. 3 Inversion model resistivity section for Line 03 and correlation of the different subsurface units with Batena borehole lithologic log

The bottom layer /fourth layer geo-electric section that relatively higher in resistivity and were interpreted as relatively fresh bedrock or volcanic bedrocks. The substratum thickness of this layer is up to 24.9m depths and resistivity for this layer varies from 57.4 to 83.2 Ωm. From the observed resistivity contrast of the upper two layers that describes the low resistivity responses zone along this profile are describe as discontinuity or weak zone(saturated).

The bottom resistivity of the two layers is considered as relatively competent volcanic bedrock. In general, the top two layers are not adequate enough to support the structural building load of high rise or low rise building foundations. This implies that the geological materials in the top two layers cannot support heavy load as this could lead to possible failure foundation failure. Therefore this profile needs special consideration building design and a deep type foundation.

Imaging Line 04

The Electrical resistivity imaging data, for this profile with similar array type and electrode spacing as well as sounding point spacing similar to the others.

The inverse model resistivity section shown in Figure (5.4) shows relatively poor data quality with RMS 34.6% after 3 iterations. Total horizontal distance/ length of surveyed line, the number of data points and the depth of investigation of this profile are 360m, 156 number data points and 28.7m respectively. The imaging resistivity section obtained as result of measurement carried out on this profile section proved that four layer resistivity.

The first layer has different resistivity stratification and is interpreted separately. The top thin resistivity sections are observed in both end of geo-electric sections sides (eastern and western part) are medium resistivity with resistivity range (15.6-72.7Ω-m) this corresponds welded tuff ,dry clay and sandy silt whereas the central part of the top layer is low resistivity zone with resistivity range of (3.35-15.6 Ω-m) this corresponds wet clay. Medium to high resistivity of this layer is due to dry nature of top soil while low resistivity nature of this thick layer is due to the moisture content within the presence of the pore spaces of residual soils. Average thickness extent of top layer is 3 to 4 m.

Quite a good number of vertical and near vertical discontinuities in the bedrock are mapped at various places along the profile that need special consideration during the building design. The bedrock which shows an undulating nature and appears at about an average depth of 10 m with breakup at various locations as indicated by the dotted

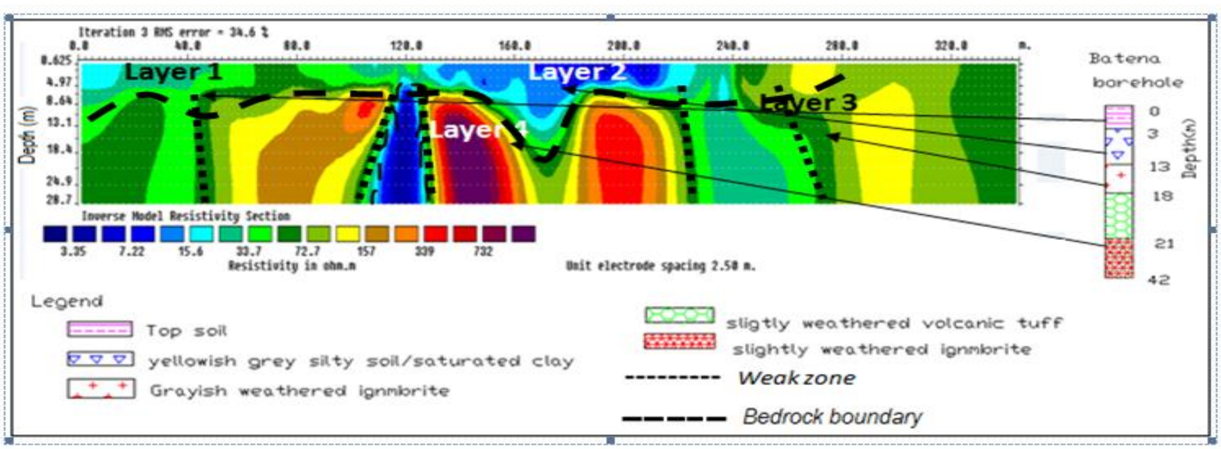


Figure 5. 4 Inversion model resistivity section for Line 04 and correlation of the different subsurface units with Batena borehole lithologic log

The second layer indicates medium resistivity with range of (33.7-72.7 Ω-m). Average thickness of 3m and probably corresponds fractured ignimbrite and slightly weathered ignimbrite.

The third layer shows that relatively high resistivity zone with resistivity range of (72.7-157 Ω-m) which indicates fresh ignimbrite and welded tuff. This layer is affected by weak zones along which the low resistive section goes to the depth.

The bottom layer shows high resistivity zone that is interpreted as massive ignimbrite or fresh ignimbrite with resistivity variation ranges (157-732Ω-m).This layer also is affected by weak zones along which the low resistive section and extensive from third layer goes to the depth.

Therefore this profile is in general characterized by wet clay (saturated clay), residual soils, and fresh and weathered and slightly fractured bedrock. The bottom two layers were characterized by deep geological features or discontinuity. Discontinuity is limited extent of fresh to weathered bedrock, top two layers. Due to these points, special consideration should be necessary during designing of buildings along this profile. Except this problem, the resistivities from second layer to bottom layer are adequate enough to support the structural load of proposed building foundation. The foundation can be either shallow or deep for this profile.

5.1.3 ERI section for the Perpendicular imaging survey Line 05

Imaging Line 05

This profile is also surveyed by using Wenner-Schlumberger array and with similar survey specification as the others except that its orientation approximately north to south and nearly perpendicular to survey traverses (01, 02, 03 and 04). This profile has a length of 400m, corresponding data volume of 168 data points or points (after filtering and removing noise) and the expected depth of investigation is about 28.7m. The inversion processing has yielded the 2D model resistivity section shown in figure 5.5. A least square inversion of the acquired raw data has RMS error 25.4% after 3 iterations. This profile is basically in-tended to map the presence (if any) of geological features oriented parallel to four profiles which would be otherwise missed by the four parallel profiles.

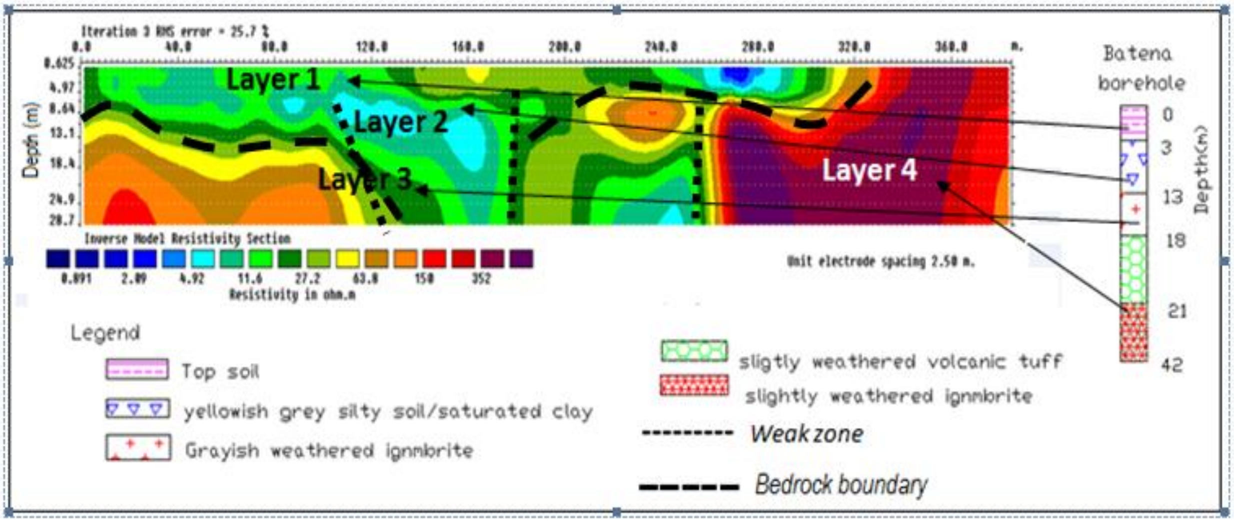


Figure 5. 5 Inversion model resistivity section for Line 05 and correlation of the different subsurface units with Batena borehole lithologic log

The first top layer shows resistivity range of 2.09 -11.6Ω-m which is interpreted as a dry soil. The overall thickness of this top layer is nearly the same over the entire profile (about 2m). The second layer of relatively very low resistivity zone is interpreted as unsaturated zone or zone with sandy clay. This zone is continuously observed in the profile and extends for about 4.7m in depth.

The third layer shows variation in resistivity with depth which represents different weathering bedrock horizons. Its depth extends for about 13.5m. The bottom geo-electric section is of very high resistivity variation and is interpreted slightly weathered bedrock that overlies different weathering horizons. The slightly weathered bed rock of this profile extends for about 28.7m in depth.

This zone has resulted in to almost high resistivity responses due to low weathering activity which extending to entire depth of the surveyed line. This identified as good building foundation zone or competent rock layers.

Therefore , based on the result apparent resistivity section this profile , depth to bedrock is relatively shallow at the southwestern, western, and southern part of the study are, as a result, those parts of the study area are better for building foundations.

5.1.4 Apparent resistivity sliced-stacked depth map

The result of the apparent resistivity of sliced-stacked depth map (Figure 5.6) was prepared at selected depth (3m, 5m, 9m and 21m) from the 2Delectrical imaging data. This plot is essential to understand and visualize the apparent resistivity distribution over the survey area vertically as well as laterally and to correlate this variation with subsurface geological variation.

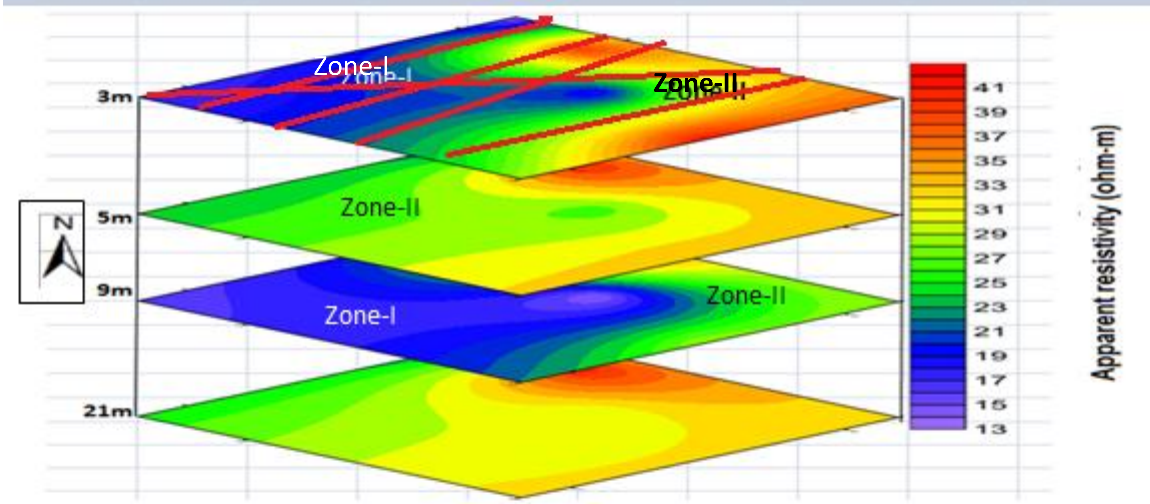


Figure 5. 6The apparent resistivity sliced-stacked depth map

When the sliced depth sections are arranged in stacked plot form, they provide a simple image that depicts the whole picture of the subsurface of the surveyed area.

From the apparent resistivity values, the sliced-stacked map could be discussed as follows.

Zone-I is characterized by relatively low resistivity with resistivity result variation ranges from 15.89 to 21.5 Ohm-m. This low resistivity is probably considered the response of saturated clay deposits or silty sand. The resistivities of the study area are gradationally decreases towards the western direction.

Zone-II is distinguished by relatively intermediate resistivity values ranging from 13.64 to 42 Ohm-m. Slightly Contradictory to zone-I, the surface area coverage of this zone is increasing with depth. Results obtained from the 2D electrical resistivity imaging profiles and borehole data the intermediate resistivity value could be the response of weathered to slightly weathered and fractured ignimbrite or volcanic tuff.

Therefore, relatively higher resistivity of the weathered to slightly bedrocks is observed nearly shallow depths in the western and southern side of the survey area which is situated at the downstream of the shilansha River. Based on stacked resistivity pseudo-section map, depth to bedrock is relatively shallow at the southwestern, western, and southern part of the study are, as a result, those parts of the study area are better for building foundations.

5.2 Result, Discussion and Interpretation of Multichannel Analysis of Surface Wave (MASW)

5.2.1 Introduction.

Multichannel Analysis of Surface Wave (MASW) is a seismic method that can be used for geotechnical characterization of near surface materials and applied in geotechnical engineering for the measurements of dynamic properties of subsurface materials at a site. The aim of this method is mainly to correlate the subsurface velocity distribution with 2D electrical resistivity inversion result within depth investigation to give a meaningful geological interpretation and observe the suitability of the construction site for the building foundation.

Particularly, the MASW method is widely used in geotechnical engineering for measurement of shear wave velocity, identification of the subsurface material properties and special variation of ground characteristics. The multichannel analysis of surface wave generates dispersion curves, 2-D shear wave velocity section and Vs and Vp plots through using Seisimger software.

Two MASW survey profiles have been carried out to measure the dynamic properties of the proposed building site. The shear wave velocity down to 30 m depth, which is obtained from the MASW technique, plays a critical role in evaluating the site response of the upper 30 m depth.

Very important dynamic properties (Vs, Vs30 and Gmax) of the geotechnical materials have been evaluated using this method. The description of each layer has been obtained based on shear wave velocity for each layer as per NEHRP classification of site categories (Martin, 1994) and IBC code site classification. The surveyed MASW results are discussed in the following sections

5.2.2 Dispersion curve

The dispersion curve is the recorded data (raw data) needed to be formatted and then dispersion curve has been prepared from these data. The dispersion curve (DC) is the type of phase velocity Vs frequency of the materials. Generation of a dispersion curve is one of the most critical steps for eventually generating an accurate shear-wave velocity profile. A dispersion curve is extracted from the measured surface wave data or from recorded data by phase-shift method or wave field transformation method to determine the subsurface dynamic parameters: the Poisson’s ratio, 2D shear wave velocity models; Vs30, shear modulus, and site amplification. Dispersion curve

(Figure 5.7 and Figure 5.8 are typical example) is obtained for each recorded, e.g. by using the data processing procedures and subsequently inverted to a one dimensional shear wave velocity profile. Each profile is assumed to be representative of the soil deposits directly below the centered of the receiver array at the time of the corresponding measured

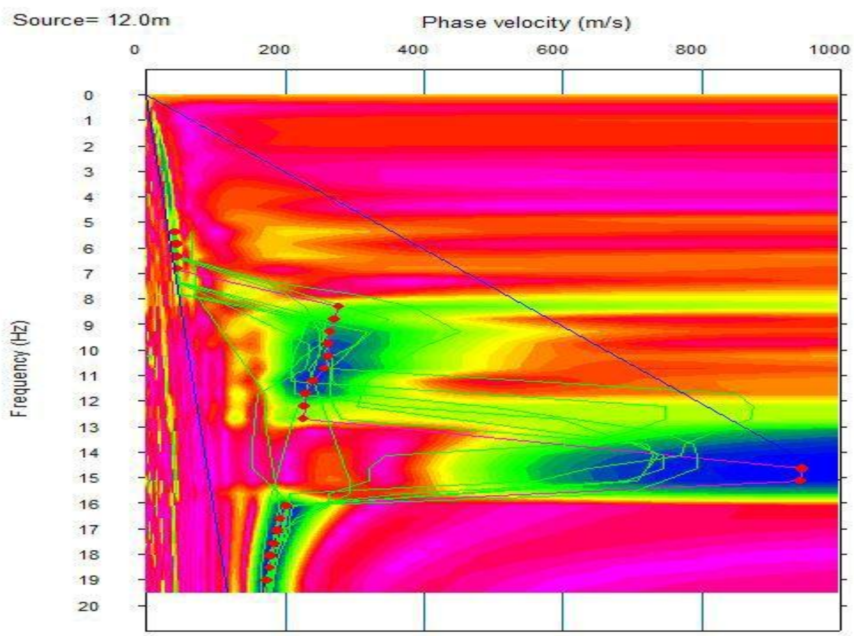


Figure 5. 7Dispersion curve of MASW profile 01

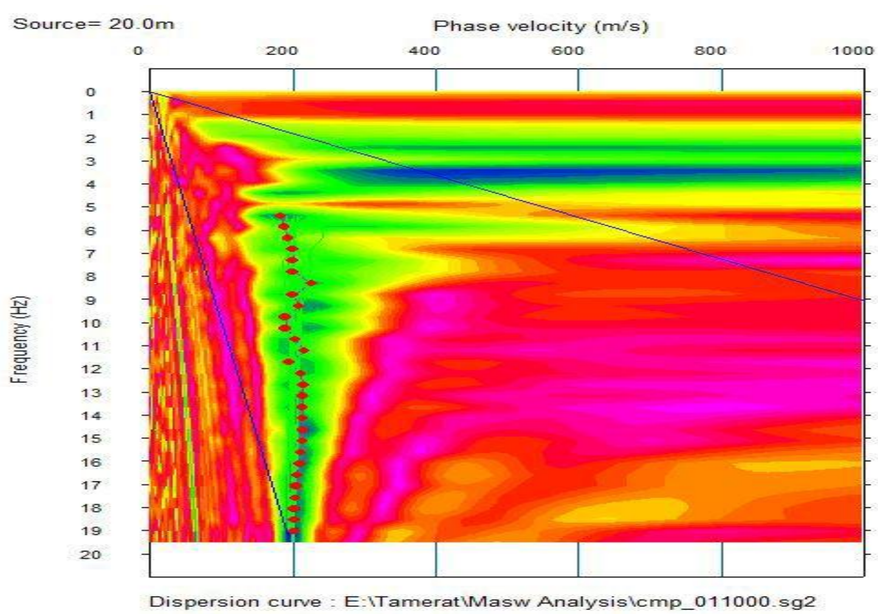


Figure 5. 8Dispersion curve of MASW profile 02

5.2.3 1D layer model of the section (The dispersion characteristic of a layered earth model)

The 1-D inversion gives the shear wave velocity structure that is the most representative of the subsurface materials below the receiver spread, approximating them as a layered Earth even though lateral variation does not exist. The 1D inversion consists of velocity (P-wave and S-wave), thickness or depth and shear wave velocity is updated after each iteration. Among all these parameters, Vs has the most significant effect on the convergence of the algorithm. Typical 1D inversion processes (Vp and Vs plots) in Seisimager for the proposed site is shown in Figures (5.9) and (5.10).

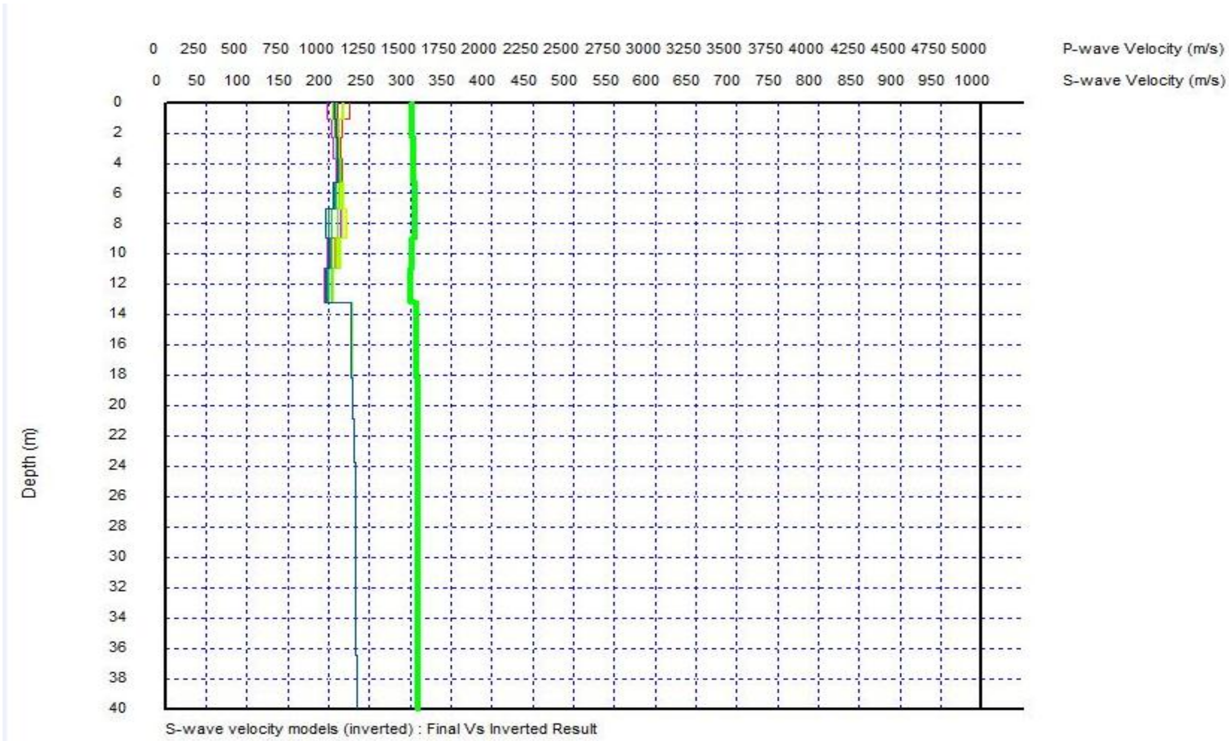


Figure 5. 9 1D layered model section of profile MASW 01

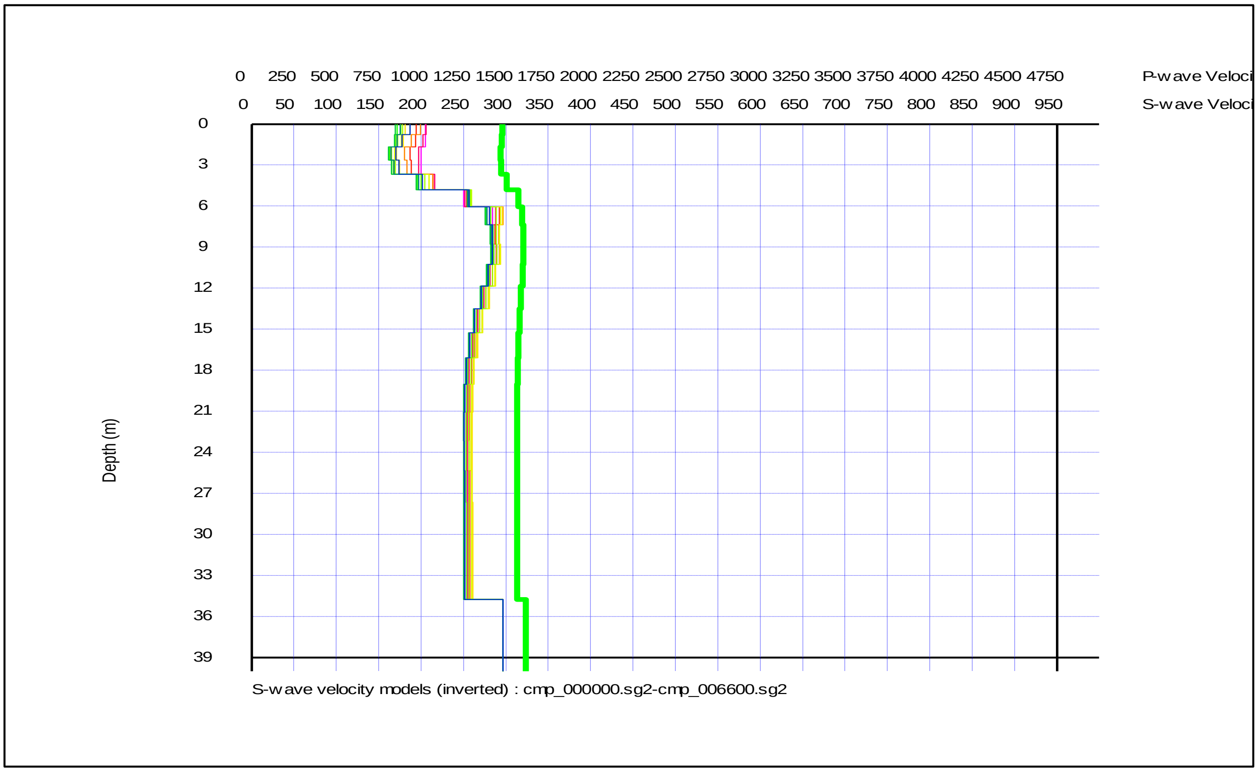


Figure 5. 10 1D layered model section of MASW 02

Poisson's Ratio and Vp

From the above 1D layered model plot one can determine the thickness of the layer, Poisson's ratio and characterize the sub surface condition with P-wave velocity.

The ratio Vp/Vs is defined in terms of Poisson's ratio (σ) and is given as (Reynolds, 1997)

$$\frac{\mathbf{Vp}}{\mathbf{Vs}} = \left(\frac{1-\sigma}{\frac{1}{2}-\sigma}\right)^{1/2}$$

where Vp is the p-wave velocity, Vs the S-wave velocity and $'\sigma'$ is the Poisson's ratio Vp = 2Vs according to Figure (5.9 and 5.10) as the observed value of the p-wave velocity and S-wave velocity from the 1-D layer model Poisson's ratio or Vp/Vs one can characterize the formation of the subsurface layers. The Poisson's ratio for unconsolidated or sand and gravelly sites typically has the value of $\sigma \approx 0.45$. In1D layer model or Vp and Vs plot, the S-wave velocity increase with the depth indicates that different layers have been included within the depth range. Therefore, P-waves show that the site has saturated nature of the subsurface materials thought the depth within these profiles. That means, in seismic method the p-wave velocity range in the layer formation that lies within 1500-2000 m/s range indicates the layer is probably saturated sand and gravel (Hardin and Drnevich, 1972).

5.2.4. Site-Soil classification

2-DVs section or 2-D shear wave velocity distributions

Important dynamic subsurface properties (Vs, Vs30 and G_{max}) of geotechnical material have been determined using MASW. 2-D velocity profiles were used to evaluate layer thickness, number of layers and layering information (soft or hard). Generally as depth increases, the shear wave velocity is also founded to increase. The Vs30 or average shear wave velocity analysis within depth which is obtained from the MASW method, plays a serious role in evaluating the site response of the upper 30 m depth to know the site classification according to the NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards.

The shear wave velocity distribution within depth range shown in Figures (5.11) and (5.13) and this 2D shear wave distribution consist of four different layer zones. The description of each layer has been obtained based on shear wave velocity for each layer as per NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards. In the following sections, the results of the individual profile lines and their interpretations are presented.

MASW 01 profile 2D Section and Vs30m

The survey line MASW 01 was oriented in east to west direction. Figures (5.11) and (5.12) respectively show the 2-D section and Vs30m plots below the obtained value after final inversion, the shear wave velocity varies from 195m/s to 235m/s and compressional velocity varies from 1450m/s to 1500m/s up to depth of 40m.

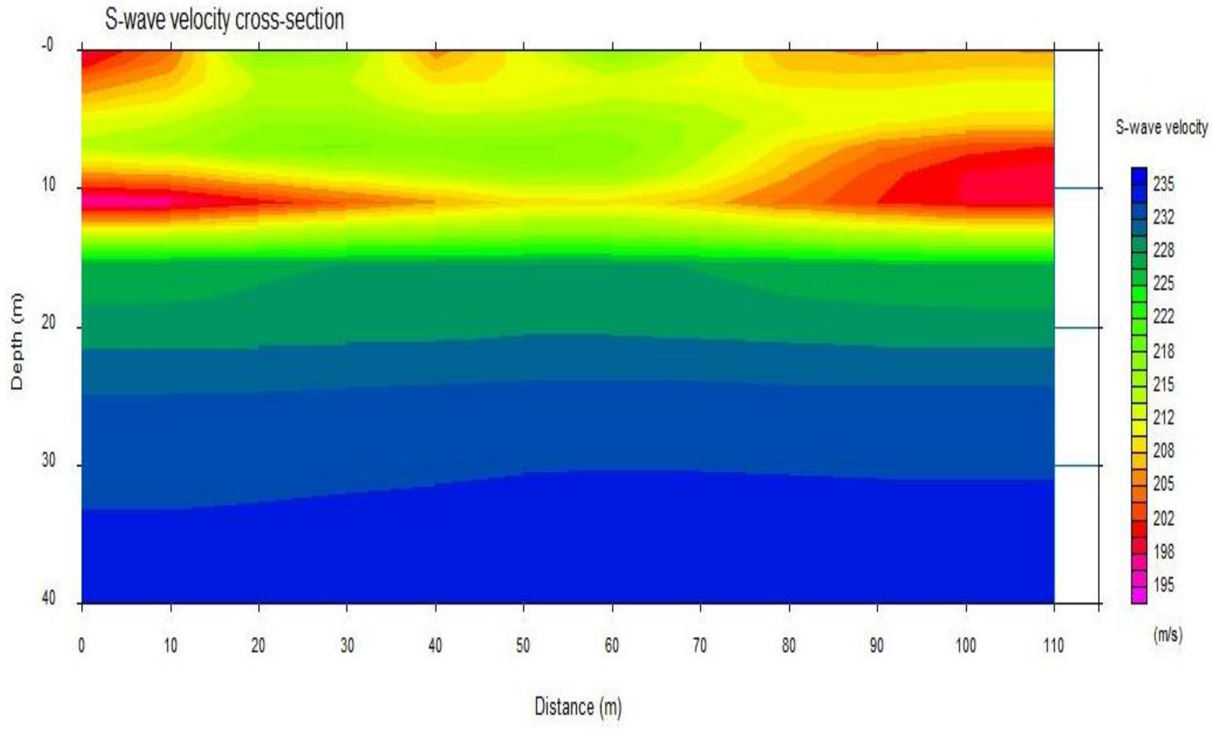


Figure 5. 112D shear wave velocity distributions section for MASW profile 01

Elastic properties of near-surface materials and their effects on seismic wave propagation are very important in earthquake, civil engineering and earth science studies.

The Vs30 plot shown in Figure (5.12) the average shear wave velocity of the upper 30 m (Vs30) should be computed in accordance with the following expression (Hardin and Drnevich, 1972).

$$\mathbf{Vs30} = \frac{\mathbf{30}}{\sum_{i=1}^{N}\left(\frac{hi}{vi}\right)}$$

where hi and vi denote the thickness (in meters) and shear-wave velocity of the i^{th} formation or layer, in a total of N, existing in the top 30 m.

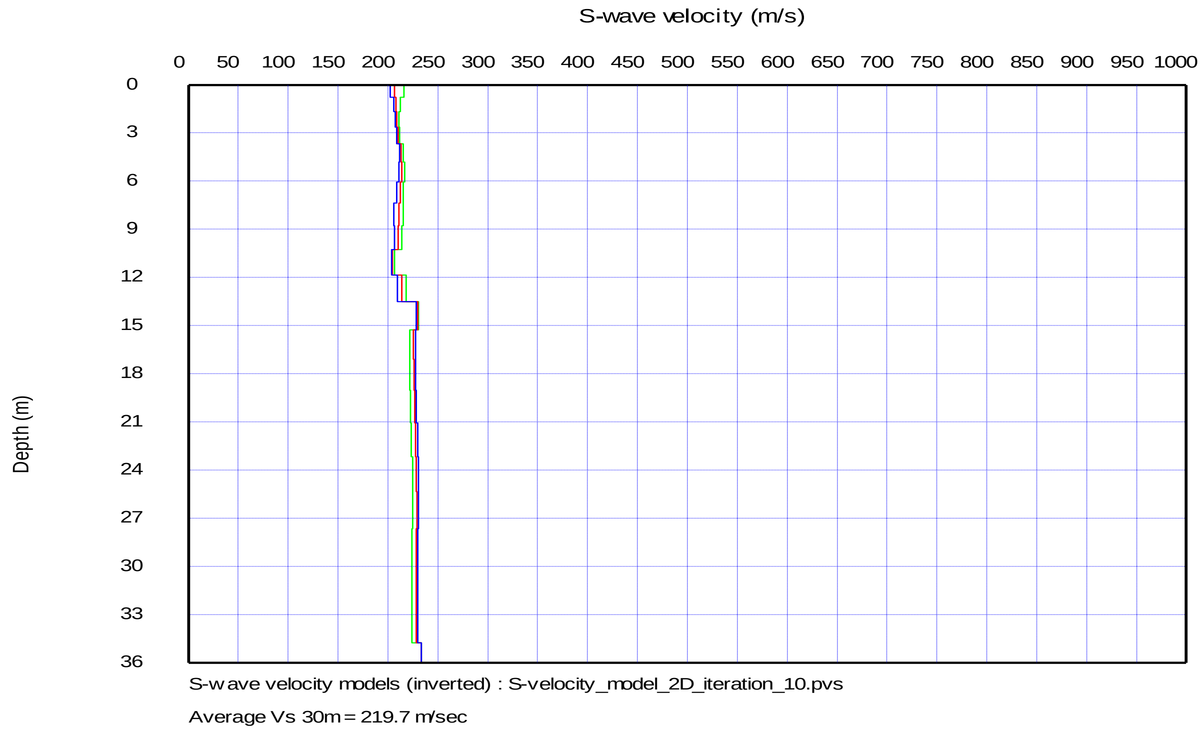


Figure 5. 12 Vs30m plot of MASW profile 01

Vs30 was accepted for site classification in the NEHRP and UBC (Uniform Building Code) in 1997 (Dobryet al. 2000).The average shear wave velocity of the upper 30m depth of the site is 219.7m/s. The average shear wave velocity down to 30 m depth, which is obtained from the MASW technique, plays a critical role in determining the site response of the upper 30 m depth. According to the NEHRP and IBC standards the Vs30 value of this site is classified as D class. In this corresponding survey line of the site the hard rock is not found up to depth of 40m. As observed from the 2D section, the shear wave velocity increases central part of the survey up to depth 12m. After depth 12m blow the velocity of the area became higher in the eastern part of the survey line. A 2D section result consist four different layer velocity zones

2D Section and Vs30m for MASW profile 02

The survey line MASW 02 parallel to the MASW 01 and was oriented in east to west direction of survey area. The elastic properties of the near-surface materials and their effects on the seismic wave propagation are very important in earthquake geotechnical engineering, civil engineering and environmental earth science studies. The seismic site characterization for calculating the Vs30m and site classification are usually carried out based on the near-surface shear wave velocity values up to depth 30m. In the figure (5.13) is shown that the obtained shear wave velocity in this 2D section varies 162m/s to 297m/s and calculated average shear wave velocity of the this profile is 239.7m/s. Based on these obtained value of Vs30 (Figure 5.14) of this profile the site classification is classified as D class according to the NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards. This corresponds the geological formation of the area are stiff soil or hard soil.

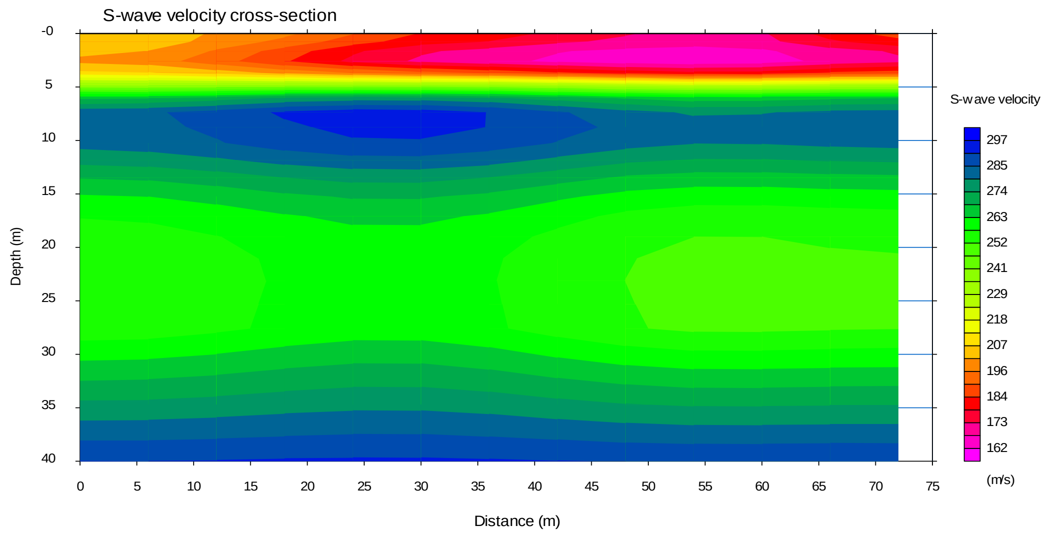


Figure 5. 132D shear wave velocity distributions section of MASW profile 02.

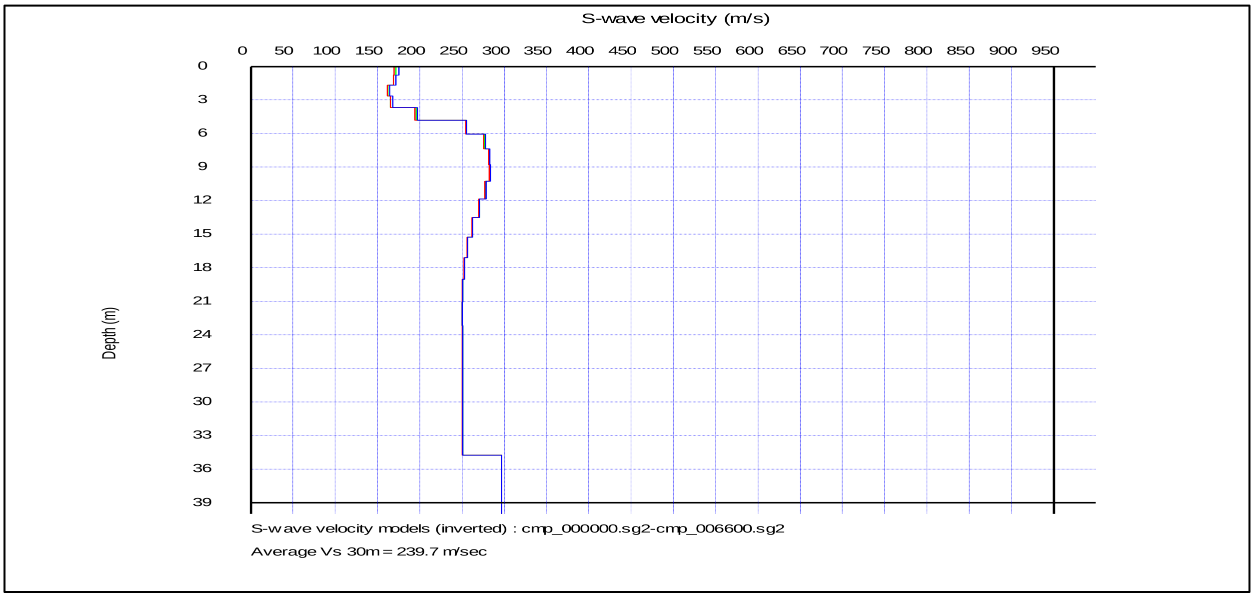


Figure 5. 14Vs30m plot of MASW profile 02

Therefore, Based on calculated average shear wave velocities of the two profiles shown in the above figures, the study area is considered or classified as D classes')according to the NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards for local seismic site effect.

5.2.5 New site-soil classification and site period

Is Vs30 appropriate for site classification?

The answer is yes but only under certain conditions. For example very shallow and very deep, rather soft soil profiles should be excluded of the use of Vs30

Advantages of Vs30:

- Simple and effective in practice and requires few data: a simple N-SPT of 30m long or less is maybe enough!

Disadvantages of Vs30:

- It is not a fundamental (neither a geotechnical) parameter and Could mislead grossly in different cases like: deep low stiffness deposits lying on much harder rock; sites with a shallow velocity inversion; sites with velocity profiles which are not monotonically increasing with depth etc.

The characteristic of site period, T0, is essential parameter to estimate the impact of local site effect on ground motion and it is useful for determine the site-soil classification.

The characteristic site period (or site dominant frequency fs) which depends on the thickness (H)and average shear wave velocity (Vs30) of the soil provides a very useful indication of the period of vibration at which the most significant amplification can be expected according to Dabbeek, (2011)

$$\mathbf{T_0} = \frac{\mathbf{4.(H)}}{\mathbf{Vs}}$$

where H is the soil thickness, T0 is period, and Vs is the average shear wave velocity of the soil

$$\mathbf{T_{30}} = \frac{\mathbf{4.(H)}}{\mathbf{Vs30}}$$

where H is the soil thickness,T_{30} is period and Vs30 is the average shear wave velocity of the soil.

Table 5. 1 average shear wave velocity, Vs30 and periods

Survey line	Vs,av	Vs30	Period (T0)	Period (T_{30})
MASW 01	216.84	219.7	0.58	0.500
MASW 02	240.91	239.7	0.67	0.546

Therefore, based on calculated site period, thickness of the soil and average shear wave velocity the present study area is considered as D1(Recent soil deposits of substantial thickness (up to 60m), with the prevailing formations being soft clays of high plasticity index (PI>40), high water content and low values of strength parameters, period ≤ 2.0s and Vs,av ≤ 300 m/s) and D2 (Recent soil deposits of substantial thickness (up to 60m), with prevailing fairly loose sandy to sandy-silty formations with a substantial fines percentage (not to be considered susceptible to liquefaction, period ≤ 2.0s and Vs,av ≤ 300 m/s) according to new Soil classification scheme by Pitilakis et al., (2013).

5.2.6 Seismic wave velocity and elastic moduli

Multichannel analysis of surface waves (MASW) is a non-invasive technique which allows estimation of seismic shear wave velocity (Vs). This is a key parameter for the evaluation of the small strain shear modulus (Gmax) of a soil, which is used for a range of geotechnical design applications. The body wave velocities of geological materials; shear wave velocity (Vs) and compressional wave velocity (VP), can be directly related to the elastic moduli of the medium which the waves propagate through. The relationships between the elastic moduli and the body wave velocities are widely utilized in geophysical surveys in order to gain information about the spatially distributed mechanical properties of subsoil sites (Evrett, 2013).

The shear wave velocity (Vs) is especially a valuable indicator of the stress-strain behavior of soil due to its relations to the small-strain shear modulus (Gmax) (Wair, DeJong & Shantz, 2012).For small shear deformations the behavior of soil is very close to being elastic, i.e. the shear modulus for small strains can be assumed to be constant at its maximum value, Gmax.

Gmax is calculated using the density (ρ) and Vs with the formula

$$Gmax = \rho.Vs^2$$

where Gmax is the shear modulus (in Pa), Vs is the shear wave velocity (in m/s), and ρ is the density (in kg/m3).

Gmax and Vs are primarily functions of soil density, void ratio, and effective stress, with secondary influences including soil type, age, depositional environment, cementation and stress history Hardin and Drnevich (1972).A constant mass density of 1.92 g/cc for each profile was assumed. This is reasonable because the effect of changes in mass density on phase velocity within the normal density range encountered in geotechnical engineering is small (1-2%) and density data were not available.

The shear strains induced by geophysical seismic method of MASW surveys are small and well within the range where the behaviors of soil can be assumed elastic. The calculated shear wave velocity can therefore be used to conclude the stiffness of the material through which the waves propagate i.e.

$$Gmax = \rho . Vs^2$$

From calculated value the in the tables, the study area have the Gmax of the MASW 01 and MASW 02 profiles are 105.74 and 169 pa respectively. The result of Gmax indicates shear modulus at small strain.

Therefore, generally the Gmax values of the study area indicate the geological materials relatively good for bearing capacity of building foundation.

Table 5. 2 Shear modulus of MASW Profile 01

Depth (m)	shear wave velocity in m/s (Vs)	Vs^2(in m^2/s^2)	mass density (in kg/m3)	shear modulus (G)
0	198.536485	39416.73588	0.00192	75.68013288
1.071429	203.518763	41419.88689	0.00192	79.52618283
2.307692	205.912158	42399.81681	0.00192	81.40764828
3.708791	209.829018	44028.21679	0.00192	84.53417625
5.274725	213.677794	45658.19965	0.00192	87.66374333
7.005495	214.866564	46167.64033	0.00192	88.64186942
8.901099	197.659403	39069.23959	0.00192	75.01294002
10.961538	195.058599	38047.85704	0.00192	73.05188552
13.186812	227.868736	51924.16085	0.00192	99.69438882
15.576922	227.666408	51831.99333	0.00192	99.5174272
18.131867	228.576466	52247.20081	0.00192	100.3146256
20.851647	230.211452	52997.31263	0.00192	101.7548403
23.736263	231.862098	53760.03249	0.00192	103.2192624
26.785713	232.676595	54138.39786	0.00192	103.9457239
36.428571	234.676018	55072.83342	0.00192	105.7398402

Table 5. 3 Shear modulus of MASW Profile 02

Depth(m)	S-wave velocity(m/s)	V^2(in m^2/s^2)	mass density (in kg/m3)	shear modulus (G)
0	169.445768	28711.86829	0.00192	55.12678712
0.789474	168.693557	28457.51617	0.00192	54.63843105
1.666667	161.868066	26201.27079	0.00192	50.30643992
2.631579	165.01458	27229.81161	0.00192	52.2812383
3.684211	194.201708	37714.30339	0.00192	72.41146251
4.824562	254.334122	64685.84561	0.00192	124.1968236
6.052632	275.727719	76025.77502	0.00192	145.969488
7.368421	281.305641	79132.86366	0.00192	151.9350982
8.77193	282.29326	79689.48464	0.00192	153.0038105
10.263158	277.270406	76878.87804	0.00192	147.6074458
11.842106	269.631207	72700.98779	0.00192	139.5858966
13.508772	262.117147	68705.39875	0.00192	131.9143656
15.263159	256.231815	65654.74302	0.00192	126.0571066
17.105265	252.431393	63721.60817	0.00192	122.3454877
19.03509	250.47639	62738.42195	0.00192	120.4577701
21.052634	249.832466	62416.26107	0.00192	119.8392212
23.157898	249.948055	62474.0302	0.00192	119.950138
25.350882	250.31957	62659.88712	0.00192	120.3069833
27.631583	250.529259	62764.90962	0.00192	120.5086265
34.736846	296.670854	88013.59561	0.00192	168.9861036

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5.2.7 Site-amplification

The increase of amplitudes in soft sediments is one of the most important factors responsible for the amplification of earthquake motions.

Amplification is proportional to

$$\frac{1}{\sqrt{\mathrm{Vs}.\rho}}$$

Where V s is the shear wave velocity and ρ is the density of the investigated soil. Since density is relatively constant with depth, the V s value can be used to represent site conditions

As observed in the tables below there is an inversely proportionality relation between amplification and shear wave velocity values. That means as the shear wave velocity increases the value of amplification also decreases and vice versa. In this site the lower amplification indicates pose problem for building foundation and are regions where special design considerations are essential. Such assessment of shallow shear wave velocity is crucial for foundation design and earthquake hazard assessment studies.

Table 5. 4 Amplification of MASW Profile 01

Depth (m)	Vs (shear wave velocity in m/s)	Density of the materials in kg/m3	Amplifications
0	198.536485	0.00192	1.619695
1.07	203.518763	0.00192	1.599744
2.30	205.912158	0.00192	1.590584
3.71	209.829018	0.00192	1.575548
5.27	213.677794	0.00192	1.56128
7.00	214.866564	0.00192	1.557147
8.90	197.659403	0.00192	1.623377
10.96	195.058599	0.00192	1.634254
13.19	227.868736	0.00192	1.511944
15.58	227.666408	0.00192	1.51263
18.13	228.576466	0.00192	1.509662
20.85	230.211452	0.00192	1.504212
23.74	231.862098	0.00192	1.498801
26.43	232.676595	0.00192	1.496334
36.43	234.676018	0.00192	1.489869

Table 5. 5 Amplification of MASW profile 02

Depth(m)	Vs (shear wave velocity in m/s)	Density of the materials in kg/m3	Amplifications
0	169.445768	0.00192	1.75346309
0.789474	168.693557	0.00192	1.757160429
1.666667	161.868066	0.00192	1.794043775
2.631579	165.01458	0.00192	1.776830135
3.684211	194.201708	0.00192	1.637733377
4.824562	254.334122	0.00192	1.431024614
6.052632	275.727719	0.00192	1.374570447
7.368421	281.305641	0.00192	1.360729351
8.77193	282.29326	0.00192	1.358326542
10.263158	277.270406	0.00192	1.375705049
11.842106	269.631207	0.00192	1.389854065
13.508772	262.117147	0.00192	1.409641951
15.263159	256.231815	0.00192	1.425719989
17.105265	252.431393	0.00192	1.436575205
19.03509	250.47639	0.00192	1.442169022
21.052634	249.832466	0.00192	1.444043321
23.157898	249.948055	0.00192	1.443626389
25.350882	250.31957	0.00192	1.442585113
27.631583	250.529259	0.00192	1.441961067
34.736846	296.670854	0.00192	1.325029813

5.3 Vertical Electrical Sounding Surveys

Vertical electrical sounding surveys have also been carried out with the Schlumberger array spreading on a profile to examine the deeper electrical stratification of the geological subsurface condition over the entire proposed construction site. The vertical electrical survey results of the study area are presented in both qualitative and quantitative interpretations. In the quantitative interpretation the shape or the pattern of the field curve is observed to obtain an idea qualitatively about the number of the layer s. the result of this method involved the geo-electrical resistivity section and pseudo-section. In the quantitative method the true resistivity and layer thickness are obtained. It is hoped that the result of this study could be used to determine the competent bedrock and ground water table of the study area. Three of the vertical electrical soundings were carried at AB distance of 660m for each. This reflects lateral variations of the electrical resistivity at depth 165m.

The result of geophysical survey is presented in sounding curves, geo-electrical and pseudo sections. The layer model curves, geo-electrical and pseudo section interpretations of all VES points are shown in figure below. The result of the interpretation shows a system four geo-electric section layers for all VES 01, VES 02 and VES 03. Two curves or VES 01 and VES 02 are show an Hk type curve pattern (V1> V2<V3) and VES 03 curve show Ak type curve pattern (V1<V2 >V3).

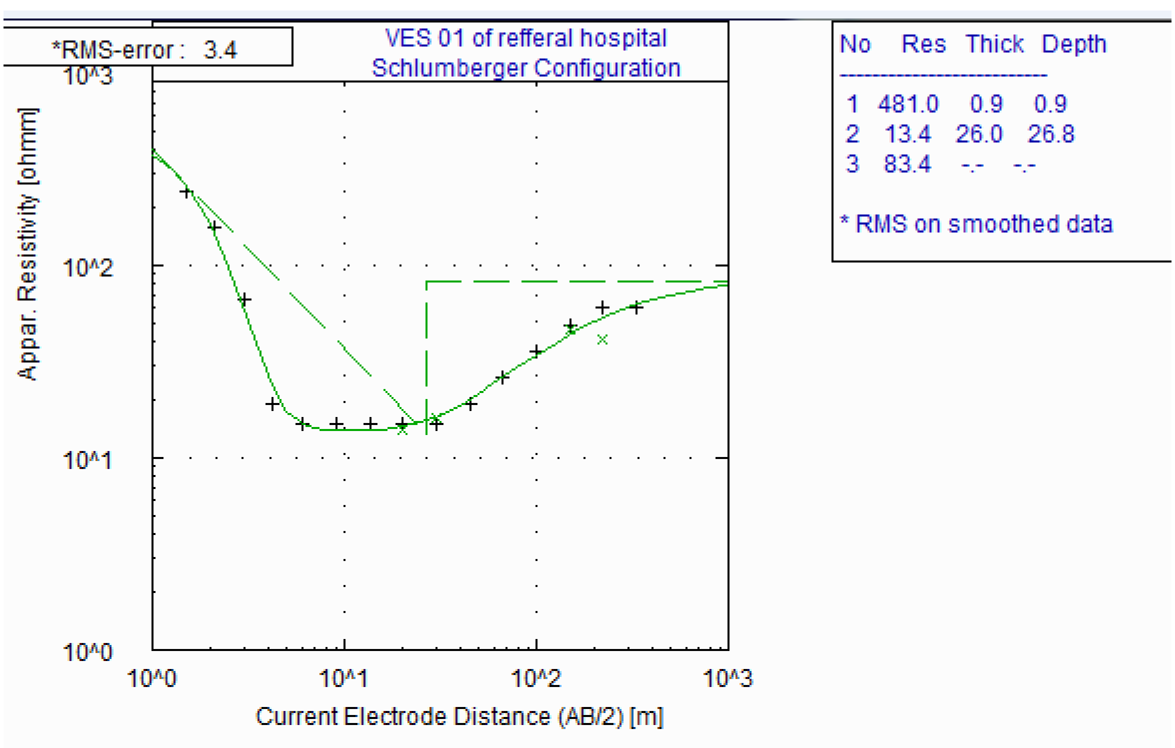

Figure 5. 15VES 01curve Hk type pattern.

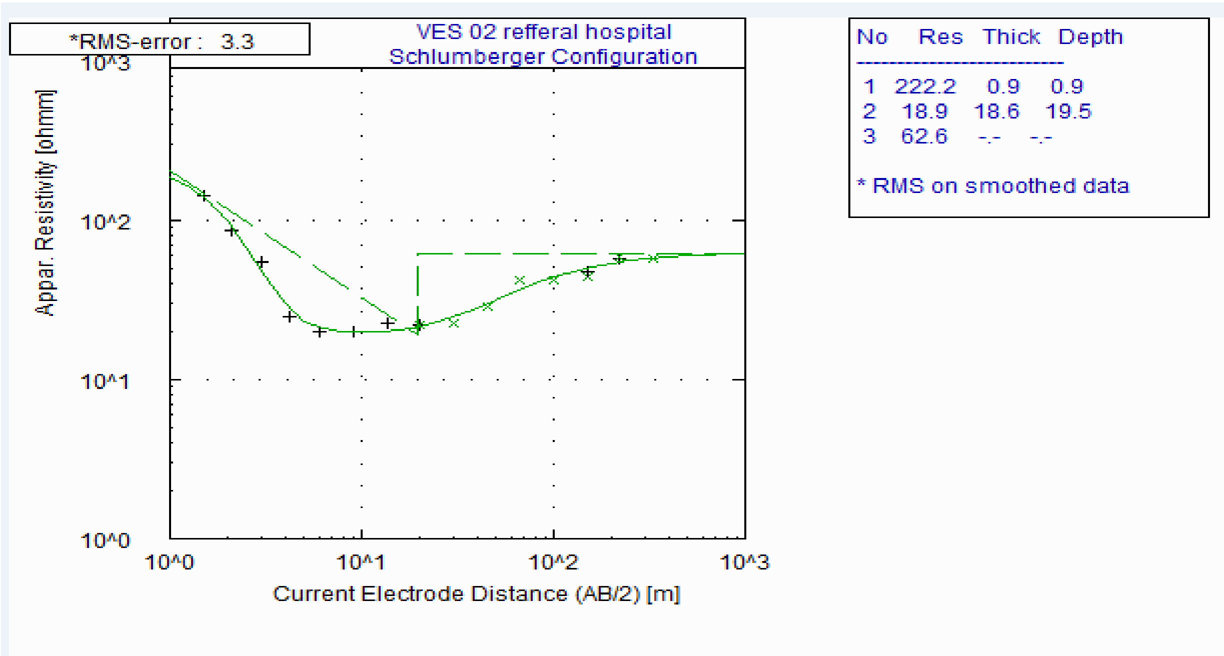

Figure 5. 16VES 02 curve Hk type pattern

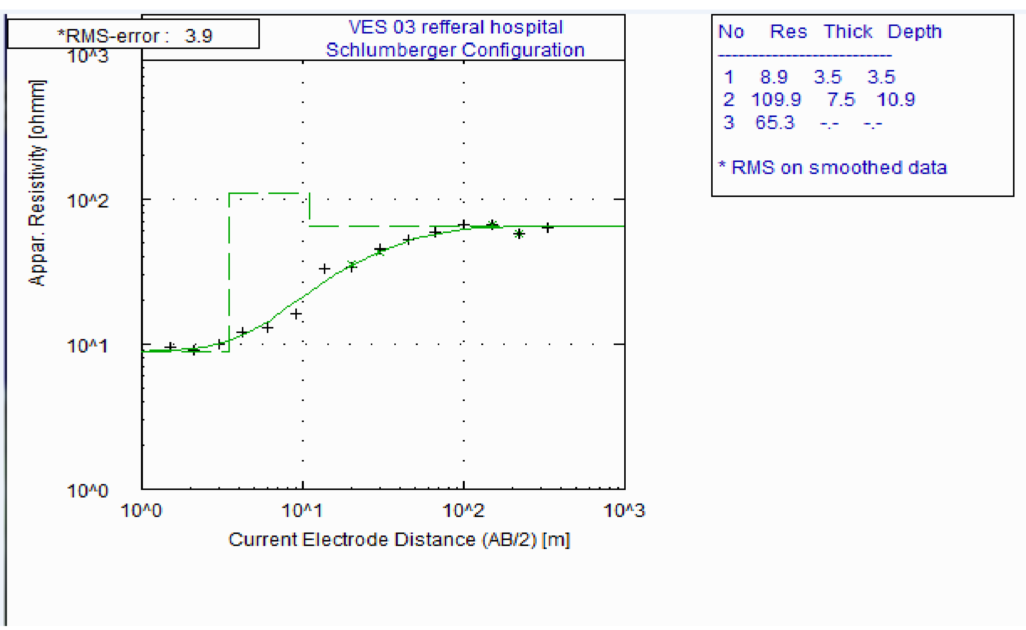

Figure 5. 17 VES 03 curve Ak type pattern

Geo-electric section and lithological characteristic

Based on the obtained geo-electrical section the lithologies of the area are characterized as follows. The first top layer of the two profiles (VES 01 and VES 02) very thin and high resistive with resistivity range s 222- 4816Ω-m due to dry nature of the soil.

The second lay have the resistivity value ranges 8.9-18.6 Ω-m for the three profiles but it is very thin for VES 03 profile and probably considered as saturated sandy clay or silty clay /weathered ignimbrite

Third layer result have shown that high resistivity variations with resistivity range 62.5- 110 Ω-m the lithology of this layer may be slightly weathered ignimbrite/volcanic tuff

Therefore, the resistivity values of the layer were identified to towards the southeastern part of the study area. Often the resistive or competent geologic materials such as slightly saturated silty sand, slightly weathered ignimbrite/slightly weathered tuff and weathered basalt /weathered and fractured basalt are high capacity to support the stability of heavy engineering structures whereas the low resistive geological materials such as saturated clayey or water materials, often less competent to support the stability of heavy engineering structures.

Geo-electrical and pseudo depth sections

This reflects the apparent resistivity distribution versus electrode value (AB/2) and it correlated with above geo-electric section the study area in (figure 5.18 and 5.19)

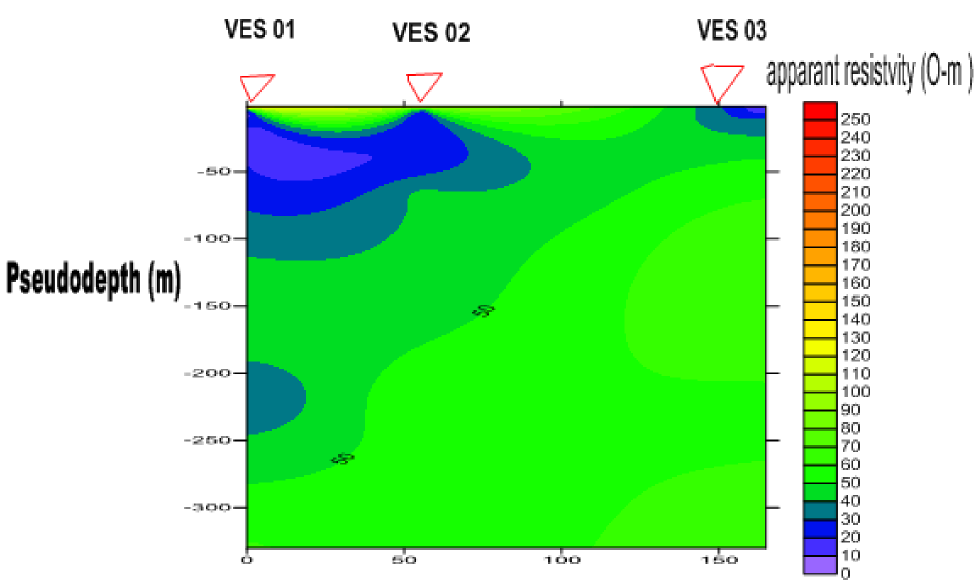

Figure 5. 18 pseudo depth section of VES 01, 02 and 03

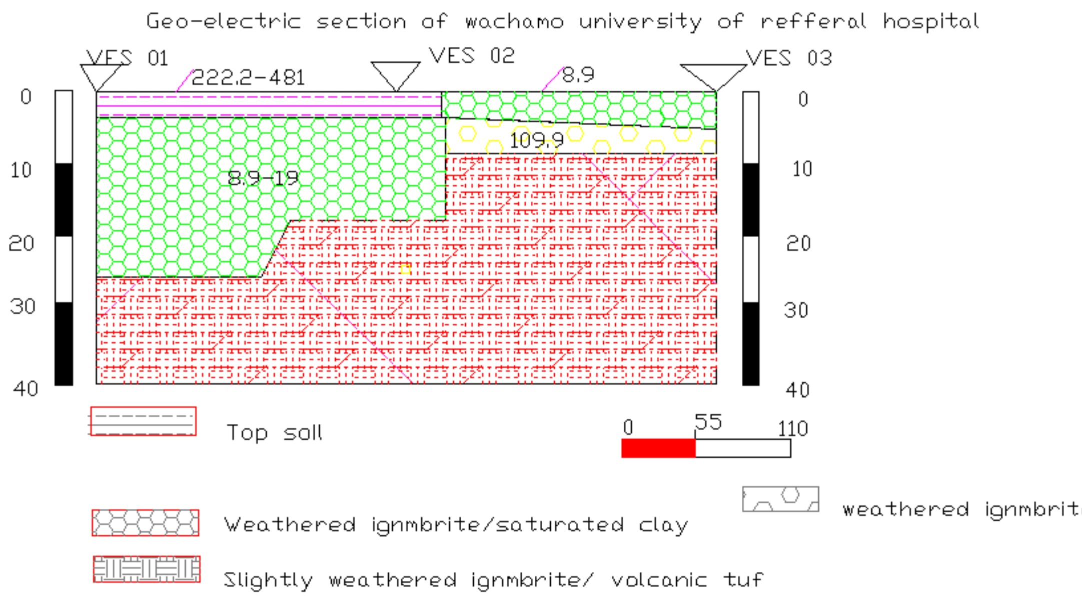

Figure 5. 19 Geo-electric section of VES 01, VES 02 and VES 03

Groundwater Condition

Electrical resistivity tomography also conducted to clearly identify areas of shallow groundwater or saturation zone in the building foundations of the study area. In the central portion of the study area perched groundwater has been observed at shallow depth inside the exploratory two test pits that matches low resistivity value or high moisture content of geoelectric sections of electrical resistivity tomography.

The capillary rise in silt and clay may arrives about 1000-10,000mm, but the study area water table is at greater depth except the in-situ high moisture content that was continuously observed in the upper part of geoelectric section has little effect on the building foundations.

The present study Referral Hospital building site has deep water table. Therefore, there will not be any measurable groundwater effect on the building foundation. VES result at the junction of Shilansha and Batena River in the eastern part of referral hospital Site is presented at Annex.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The electrical resistivity and multichannel analysis of surface wave techniques have been carried out in wachamo university referral hospital, northwest of Hossana, southern Ethiopia for building foundation engineering site characterization. Hosanna town and Wachemo University are located at the margin of Main Ethiopia Rift (MER) and are affected by the tectonic activity. Most minor to major earthquakes that cause the ground vibration in the study area rises from MER (Ataly Ayele, 2016; 2017). Among the significant earthquakes which occurred in the study area are the 2010 and 2011earthquakes of magnitudes 5.6 and 5.1, respectively (kindey et al; 2011). So, the study area existing buildings were damaged during the ground shaking such as houses wall, some window glasses and road structure cracking. Moreover, existing buildings and other civil engineering structures may not have been built properly and considerable the causes of this earthquake.

This study has pointed out the application of VES, MASW and ERI which increase the extent site characterization to determine; (i) The presence of subsurface layers that can be considered as competent/bed rock (ii) The depth to the basement/bed rock (iii) The presence of weak zones within the bed rock (iv) Very important dynamic property of geological materials for foundation (Vs, Vs30 and G_{max}) and (v) seismic site- soil classification.

Based on the geological information from the Batena borehole and profiles of the 2D electrical resistivity imaging, vertical geo-electric section value for all of the lines revealed that the subsurface layers of covering the research area generally have four different layers. These layers are classified based on apparent resistivity value.

The geo-electrical data has shown that the depth of bedrock or competent rock is in range 5-13.1m beneath subsurface having resistivity value roughly in between 39.5 and 75Ω-m for shallow foundation of low rising buildings design while for deep foundation of high rising buildings design, the depth of bedrock or competent rock is in range 13.1-21.5m beneath subsurface having resistivity value roughly in between 49.1-125Ω-m in the northern and central survey lines of the study area with considering the presence of weak zone within bedrock formation. In the case of southern part of the survey line of the study area, the geo-electrical data has shown that the depth of competent or bed rock is in range 5-13.1m. As result of this, it suitable for both shallow and deep foundation of the building design of the study area. Through the observed apparent resistivity value of the all profiles, the depth to the bed rock is relatively shallow on profile 04.

The stacked apparent resistivity section indicates that the eastern and southern portions of the study area may provide better result of bearing capacity for building foundation than the eastern and northern portion.

Multichannel Analysis of Surface Waves (MASW) is a seismic exploration method to estimate the shear wave velocity profile of near-surface materials of the present study area. Elastic properties of near-surface materials and their effects on seismic wave propagation are significant in building foundation engineering structures. Shear-wave velocity is an important parameter for evaluating the dynamic behavior of soil in the shallow subsurface. The average shear-wave velocity for the top of 30 m of soil is referred as VS30 and was accepted by the NEHRP (National Earthquake Hazard Reduction Program), IBC (International Building Code) standards and new site-Soil classification scheme by Pitilakis et al. (2013) to classify sites according to the type of soil.

The average shear wave velocities of the upper 30m depth of the study area are 219.7 and 239.7m/s. According to the NEHRP (National Earthquake Hazard Reduction Program) and IBC (International Building Code) standards the soil can be classified as D. Also based on the average shear wave velocity of up to 36.43 and 34.74m depth of the site are 216.84 and 240.91 m/s respectively and period (T0) the site is classified as D1 and D2 according to new site-soil classification scheme by Pitilakis et al. (2013).

The Gmax of the study area in the two multichannel analysis of surface wave are 105.74 and 169 pa.

The study shows that the site classification and new site classification tends to underestimate the current design building practice code of Ethiopia (site classification A, B and C –EBCS8-1995).

Finally, this study pointed out the founding or results that results; resistivity variations of the layers in 2D, geo-electric section and pseudo-section of VES points, shear wave velocity of the layers, shear modulus, site amplification of the site, Gmax, Vs30 and Site classification (D,D1 and D2).

Therefore, applications of geophysical methods give results for characterization of the proposed building foundation site. Based on both electrical resistivity and multichannel analysis of surface wave methods revealed that the material with fair- good geotechnical properties lies between the third and the fourth layers.

6.2 RECOMMENDATION

Based on the outcomes of this study, the following recommendations are forwarded.

- The study area situated in active seismic zone and the site soil overlaying the bedrock is stiff and relatively thick. This shows that the nature of the site characterization of the area will amplify and aggravate the earthquake effect. Therefore, designers should consider the seismic code as well as building code before designing the multi-story buildings foundation.
- Before building construction, the top soil must be removed or excavated to 2m depth at which weak zone area and selected material (borrow material) should be added up to the soil become adequately competent or should use pile foundation.
- Proper consideration in identified geological structures /weak zone of the study area is important at a time of building foundation design (structures confirmed by other techniques).
- The geotechnical investigation (SPT and Atterberg Limits or Liquid Limit and Plastic limit) should be added in order to understand the detailed surface and subsurface engineering properties of the soil.
- Furthermore, it is proposed that site amplification factor study should be conducted based on this research.

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ANNEX (Hadiya zone Water, Mines and Energy Department)

a) 1Geological log of Batena well

No	Depth in (m)	Thickness in (m)	Description	Remark
1	0-3	3	Brown clayey soil	Slightly weathered
	3-13	10	Yellowish grey silty soil	
2	13-18	5	Grayish weathered ignimbrite	Weathered
3	18-21	3	Slightly weathered volcanic tuff	
4	21-42	21	Slightly weathered ignimbrite	Slightly weathered
5	42-60	18	Slightly fractured basalt	
6	60-78	18	Slightly fractured rhyolite	
7	78-87	9	Scorceous basalt	First aquifer strike
8	87-90	3	Medium grained sand	
9	90-99	9	Clay soil (red in colour)	
10	99-102	3	Very fine grained sand	
11	102-111	9	Clay sand	
12	111-120	9	Sility clay	
13	120-126	6	Gravel	
14	126-129	3	Fractured basalt with boulders	
15	129-132	3	Tuff	
16	132-135	3	Very fine grained sand	
17	135-144	9	Tuff intercalated with clay	
18	144-150	6	Highly fractured and slightly weathered ignimbrite	
19	150-171	21	Scorious Basalt	
20	171-177	6	Sand with volcanic ash and transported materials	
21	177-200	3	Basalt	

a) 2Geological Log of Kelisha

No	Depth in (m)	Thickness in (m)	Description	Remark
1	0-3	3	Slightly weathered ignimbrite	Slightly weathered
2	3-12	9	Slightly weathered volcanic tuff	Weathered
3	12-27	15	Rhyholite (white in colour)	white in colour
4	27-54	27	Slightly weathered ingrimbrite	Slightly weathered
5	54-66	12	Alluvial deposited intercalated with volcanic ash	
6	66-70	4	Clay soil (red in colour)	
7	70-82	12	Trachyte (brownish in colur)	
8	82-88	6	Volcanic ash	
9	88-90	2	Clay soil (red in colour)	
10	90-102	12	Highly weathered and fractured basalt	First aquifer strike
11	102-132	30	Weathered reworked fragmented materials	
12	132-156	24	Course grained sand and gravel	Main aquifers
13	156-180	24	Pumice	Main aquifers
14	180-186	6	Agglomerate	Main aquifers
15	186-189	3	Medium grained sand	Main aquifers