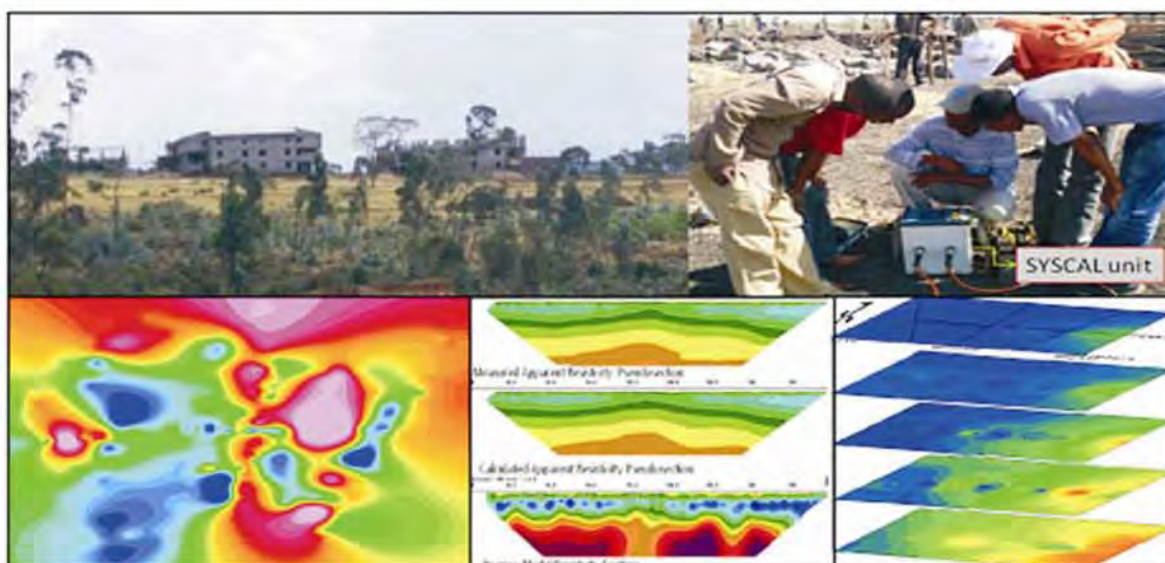




ADDIS ABABA UNIVERSITY
School of Earth and Planetary Sciences
College of Natural Sciences

**Integrated Geophysical and Geotechnical Investigations
for Building Site Characterization of Wachemo University,
North-east of Hosanna Town, Southern Ethiopia**



A Thesis
Submitted to

The School of Graduate Studies
of Addis Ababa University

*In Partial Fulfillment of the requirements for the Degree of
Masters in Geophysics*

Yonatan Garkebo
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By

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ABSTRACT

The present study was carried at Wachimo University which is located northeast of Hossana town in Southern Ethiopia, 230 km from Addis Ababa city. The main objective of the present study was to assess the suitability of the foundation condition for the new building site at Wachemo University campus. In order to achieve the proposed objective systematic methodology was followed. The methodology adopted for this purpose includes an integrated approach where geophysical and geotechnical investigation was carried out. For geophysical investigation Electrical Resistivity Tomography (ERT) and magnetic methods were employed. For geotechnical investigation the physical properties of the foundation soils were characterized and classified based on their visual interpretation and different laboratory tests.

The recently developed technique of Electrical Resistivity Tomography (ERT) gives 2-D electrical resistivity variation of the subsurface geological conditions. During the present study four profiles of ERT were conducted to know the different electrical properties of subsurface conditions at the proposed building site. The ERT results showed presence of thick top soil, weathered and fresh bedrocks, continuous moisture content and geological weak zone below the proposed building site. Further, the stacked apparent resistivity pseudo section map presented the depth-wise electrical variation at the proposed building site. The VES and well log results indicated that the site has deep groundwater table. Magnetic anomaly map prepared during the present study exhibits good anomaly contrast. From this it may be deduced that high magnetic anomaly responses are the results of fresh igneous rocks whereas, low magnetic anomaly responses are resulted due to weak zones and high degree of weathering in rocks. Analytical signal map clearly presents a contrast between lithological contacts and geologic structures. The correlation of the magnetic anomaly and the inverse model resistivity section has enabled identification of geological weak zones where specific design considerations are essential.

During the present study in total soil samples from 9 test pits were tested for specific gravity, natural moisture content, grain size distribution, Atterburg limits and swelling potential. All soil samples from the study area falls in low plasticity silts to intermediate clays, except for two soil samples which showed high plasticity silt soils. Low to intermediate plasticity soils of the study area shows good to fair engineering property but high plasticity silt show poor engineering property. In general, the soils of the study area may be classified as CI, ML and MH. In terms of suitability for building foundation 33.3% of the soils possess good to fair bearing capacity, 44.4% as fair and remaining 22.2% of soils possess poor bearing capacity.

Shallow foundation material in the study area is thick residual soils which possess moderate to good bearing capacity and may be suitable for low rise buildings. Further, the geophysical investigation has revealed potential hazardous sub-surface conditions which may have adverse effect on the proposed buildings therefore, it is strongly recommended that the building foundation sites should be selected away from these geologically active/weak zones. The study area is situated in seismically active zone therefore designers should consider the seismic code in addition to the building code before designing the multi-story buildings.

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Acronym

A: Activity

AASHTO: American Association of State Highway and Transportation Officials

AS: Australian Standards

BS: British Standards

CDSC: Construction Design Share Company

CH: High plasticity Clay

CI: Intermediate plasticity Clay

CL: Low plasticity Clay

ERT: Electrical Resistivity Tomography

LL: Liquid Limit

MH: High plasticity Silt

ML: Low plasticity Silt

NMC: Natural Moisture Content

PI: Plasticity Index

PL: Plasticity Limit

RMS: Root Mean Square

SL: Shrinkage Limit

TP: Test pit

USCS: Unified Soil Classification System

W: Water Content

1.1 Background

Since practically all civil engineering works are built on soils or from the soils, detailed understanding of the type, nature and characteristics of the soil is most valuable to civil engineers. Quite different types of soils exist, owing to varied climate, geomorphology and geology that form the building foundations. Buildings need to be safely designed and founded over more suitable Earth materials. Soils of various engineering property, electrical resistivity and magnetic susceptibility have different bearing capacity (Anderson, 2006).

Geotechnical investigations provide information on the physical properties of soils underlying a site to evaluate soil conditions that may affect the safety, cost effectiveness and design of a proposed structure. If the foundation studies are not conducted properly, it may affect the performance of the structures. Any irregularities of the subsurface revealed during excavation of building foundations might change the planning or the founding.

Geophysical prospecting has many advantages in geotechnical investigations. The effectiveness and importance of geophysical methods together with their nondestructive mode of implementation made them necessary and adequate. Geophysical methods are applicable to investigate, detect and determine soil properties, inhomogenities of the subsurface, cavities, ancient relics and generally any underlying structures or bodies that have different physical properties from their geological surroundings (Sirles, 2006).

The electrical resistivity method, which is one of the most widely used geophysical prospecting methods, has in the past usually been applied for groundwater and underground resource exploration; Today the electrical resistivity method is highly advanced and widely used for civil engineering and environmental application because of the new development of electrical resistivity tomography (Goes and Meekes, 2004). It gives the 2-D electrical resistivity variation of the subsurface geology of the site. Electrical resistivity tomography provides a relatively low cost, non-invasive and rapid means of generating spatial models of physical properties of the subsurface (Sirles, 2006).

The magnetic method measures variations in the Earth's magnetic field to determine the location of subsurface features. This nondestructive technique has numerous applications in

engineering and environmental studies, including the location of lithological contacts, near-surface faults, igneous dikes, and buried ferromagnetic objects (storage drums, pipes, etc.) based on the differences in their magnetic susceptibility relative to their surrounding Earth materials (Bell, 1980). The method is relatively easy to perform and inexpensive as it requires little data processing or manipulation. The technique has good depth of penetration compared to the DC-resistivity (Reynolds, 1998).

Wachemo (Hosanna) University, located northeast of Hosanna town in southern Ethiopia, is one of the new Universities being established in the country with the aim of strengthening and expanding the learned manpower. A new set of buildings are under construction at the sites selected for future University campus. The construction site locally is covered by thick soils that overlie extrusive igneous rocks. The weathered volcanic igneous rocks are exposed along river and road cut sections. Both geophysical and geotechnical investigations may give good quality information for engineering site characterization of the present study. Accordingly, the present research work is directed at determining the groundwater table (if it exists at shallow depth), identify geological features (such as weak zones, bedrock depth, fractures, geologic contacts and areas of igneous intrusion) and characterize the engineering property of the soil units over the proposed construction site.

1.2 Problem Statement

Civil engineering structures are constructed either on rocks or on soils. In reality, not all soils and rocks may be practical for civil engineering works. From geotechnical perspective, soils are classified based on their engineering properties to identify good bearing capacity of soil with the acceptable settlement potential. Wachemo University site is relatively new site and covered by thick residual soils that overlie younger igneous rocks and therefore the characterization of these soils is essential. Properly conducted surface geophysical surveys can provide information over relatively large areas on overburden depths, depth to the water table and critical geologic structures. Geophysical surveys can also provide continuous subsurface information to identify inhomogeneity and/or discontinuities that affect the building foundation of the proposed structures where geotechnical tests such as pit tests and boreholes would probably miss the information. Such surveys can as well reduce the number of borings and extrapolate the information between two boreholes.

Therefore, during the present study geophysical and geotechnical investigations have been conducted to provide actual foundation conditions so that the proposed buildings may be constructed safely.

1.3 Objective of the Study

1.3.1 General Objective

The aim of the proposed research work is to characterize the Wachemo University building site for engineering works based on the results from geotechnical and geophysical investigations.

1.3.2 Specific Objectives

- (i) To characterize the engineering property of soils;
- (ii) To map the subsurface resistivity stratification of the site from which the subsurface geology could be deduced;
- (iii) To map the magnetic susceptibility distribution of the construction site from which subsurface geological structures that affect the foundation could be revealed;
- (iv) To determine depth of shallow groundwater table (if it exists) as this would affect the engineering structures.

1.4 Description of the Study Area

1.4.1 Location, Physiography and Accessibility

The Wachemo University site is located at the western margin of the Main Ethiopian Rift valley that runs from northeast to southwest almost dissecting Ethiopia into two parts. Locally, the study area is located northeast of Hosanna town of Hadiya Zone in Southern Regional State along the main asphalt of Addis Ababa–Hosanna road, and is situated about 3km from Hosanna town and 230 km from Addis Ababa. The location map of the study area is shown in Fig. 1.1.

Nearly gentle slope characterize the study area. Topographical features that are found in the study area are a result of youngest volcanism and its weathered material. Thick residual deposit, ignimbrite, tuff and rhyolite unit covers the study area from very gentle slope to

nearly steep slope of river cut. The maximum elevation of the area is 2300 m above mean sea level.

The study area is accessible through main asphalt road from Addis Ababa to Hossana and later through new gravel road to University construction site. In general, the study area has good accessibility. The landscape of the study area is shown in Plate 1.1

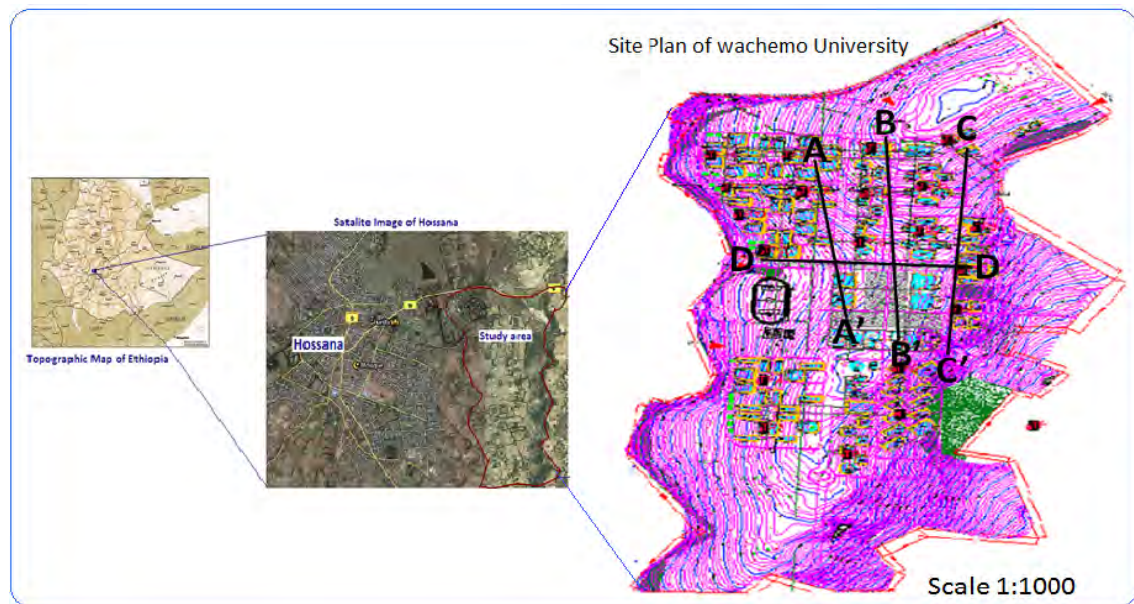


Fig. 1.1 Location Map of the study area



Plate 1.1 Landscape of the University site

1.4.2Climate

Annual rainfall in the area varies mainly from 900 mm–1400 mm. The mean annual rainfall analyzed from 26 years of rainfall data is 1028.67 mm. The rainfall in the study area is a bimodal type and the main rainy seasons are from March to April and June to September. Mean annual temperature varies from 15°C to 18°C. The lowest temperature occurs during the main rainy season (June, July and August). The maximum and minimum relative humidity of the area is estimated as 79.8 % during July and 57.5 % during February, respectively (Children's Home Society, 2009).

1.4.3Drainage Pattern

The study area is characterized by dendritic drainage pattern and high erosional effect along the river cuts. The drainage pattern of the area is highly controlled by the structures. The pattern shows that the streams in the area occupy weak zones mainly along the major faults. The main perennial drainage in the area is Batena River, which is adjacent to the campus site where as Ann-gita stream is intermittent.

1.4.4 Land Use/Land Cover

Topography and soil types govern land use activity of the study area. The central portion of the area forms a gentle slope and thick soil cover due to in-situ weathering. Almost all of the study area has been used for agricultural purposes and the main agricultural products are wheat, maize, teff, sorghum, bean, pea and enset.

1.4.5 Erosion and Weathering

Sheet erosion occurs on the gentle slope whereas gully erosion occurs along the river cut of the study area. The eastern and southern peripheries of the study area are characterized by gully erosion that is shown in Plate1.2. High degree weathering of ignimbrite unit was observed along river cut that is shown in the Plate1.3. The type and development of soils in the study area ins depending on topography, parental materials and degree of weathering. The degree and rate of weathering in humid regions depends primarily on the temperature and amount of moisture available.

The study area is characterized by intensive tropical rainfall due to that chemical weathering are generally much more significant than mechanical disintegration of the volcanic rocks. The area is characterized by in-situ weathering which forms thick residual soil. The fine-grained nature of the study area soil is the result of in-situ weathering of extrusive igneous rocks.

1.5 Outcome of the Study

The outcome of the present study will be useful to identify areas within the construction site of the Wachemo University which have good soil bearing capacity for preferential location of the buildings. The results have also located areas that require special design consideration due to the presence of subsurface weak zones, shallow groundwater table, lithological contact zones etc. that have effect on building foundations.

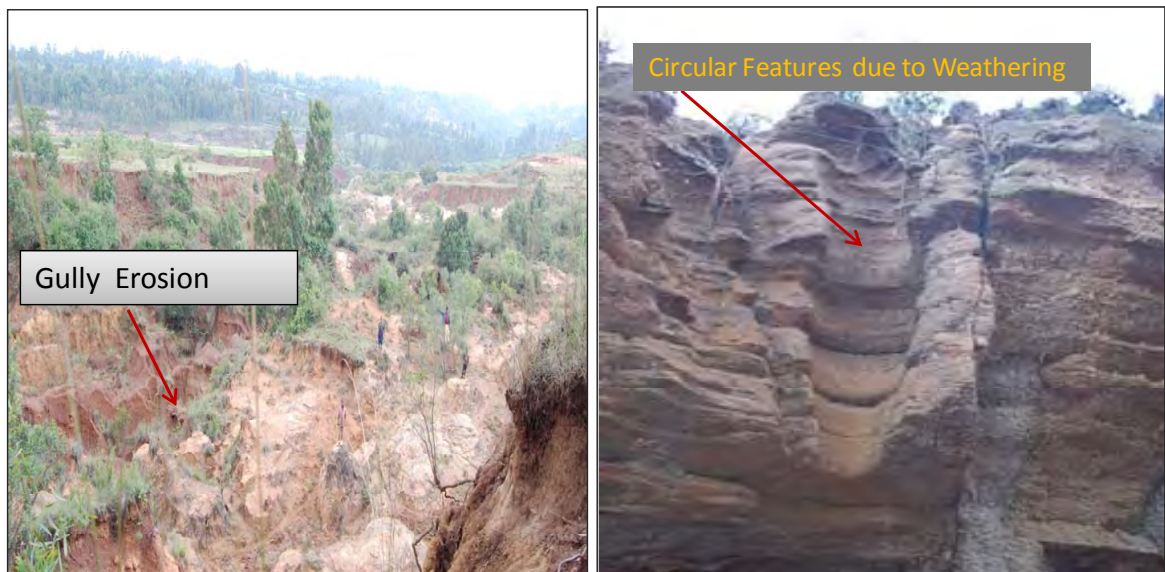


Plate 1.2 Deeply incised gully erosion Plate 1.3 Erosional effects on the ignimbrite units

1.6 Limitation of the Present Study

All efforts are being made to carry out the study in a systematic manner, well supported with actual field data and laboratory tests. However, these efforts were being made under the limitation of financial support.

1.7 Methodology

In order to achieve the objectives of the study, primary and secondary data collections and laboratory testing were employed. Literature on geophysical and geotechnical investigation techniques as applied to foundation studies were thoroughly reviewed. For this, different textbooks, journals, various official documents and reports on geophysical and geotechnical investigation for building site characterization were reviewed. Also, inter related secondary and primary data were collected. The basic sources of secondary and primary data for this study were from various organizations and physical field observations.

Geophysical and geotechnical methods of investigation were employed in which the electrical resistivity imaging, magnetic, and soils and rocks analysis techniques were respectively used. The 2D electrical resistivity and magnetic data were collected along the profiles. The spatial geophysical mapping and modeling has been assisted using software's such as GEOSOFT, RES2DINV, and PROSYS-II and Geosoft Oasis Montaji 6.4.2 software.

Disturbed soil samples have been collected from the desired depth while pit digging was in progress. The laboratory test of these soil samples were analyzed and processed by Construction Design Share Company. The soils of the study area were classified on the basis of their engineering geological properties according to Unified Soil Classification Systems (USCS) and classification proposed by International Association of Engineering Geologists (IAEG, 1981). Overall methodology followed during the present study is shown in the flowchart given in Fig. 1.4.

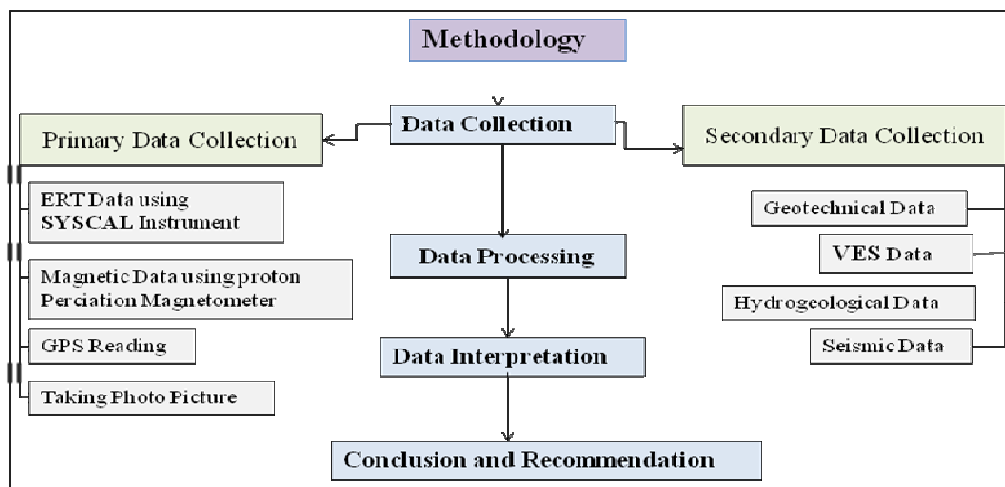


Fig. 1.4 Schematic Diagram of the methodology employed during the present research work

Chapter 2 GEOLOGICAL, HYDROGEOLOGICAL AND SESMIC SETTING

2.1 Geological Setting

2.1.1 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 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 (Mohr, 1967; Gidey Woldegebrielet *et al.*, 1990). The volcanic rocks are dominantly fissural basaltic lava flows, rhyolites and ignimbrites associated with volcanoclastic tuff and ash deposits (Tenalem Ayenew et al., 2008).

Older volcanic units (Pre-Pliocene) outcrop on the rift escarpment or margin and the recent volcanic 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.

2.1.2 Regional 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 NNE–SSW and N–S trending faults are the dominant faults.

2.1.3 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 general geological map of the study area and its surrounding is given in Fig. 2.1.

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 pyroclastic and water lain pyroclastic 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 extensively developed on the escarpments.

Nazereth Group (Upper Miocene – Pliocene Succession): the Nazereth Group of the study area comprises alkaline and peralkaline silicics like rhyolite domes and ignimbrite, and stratoid silicics 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 ignimbrite of the Nazereth Series is 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 of Wonji Group comprises rhyolitic and trachytic lava, ignimbrites and peralkaline silicics of 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 Sediment (Pleistocene Volcano-sediments):- they are essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during 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.

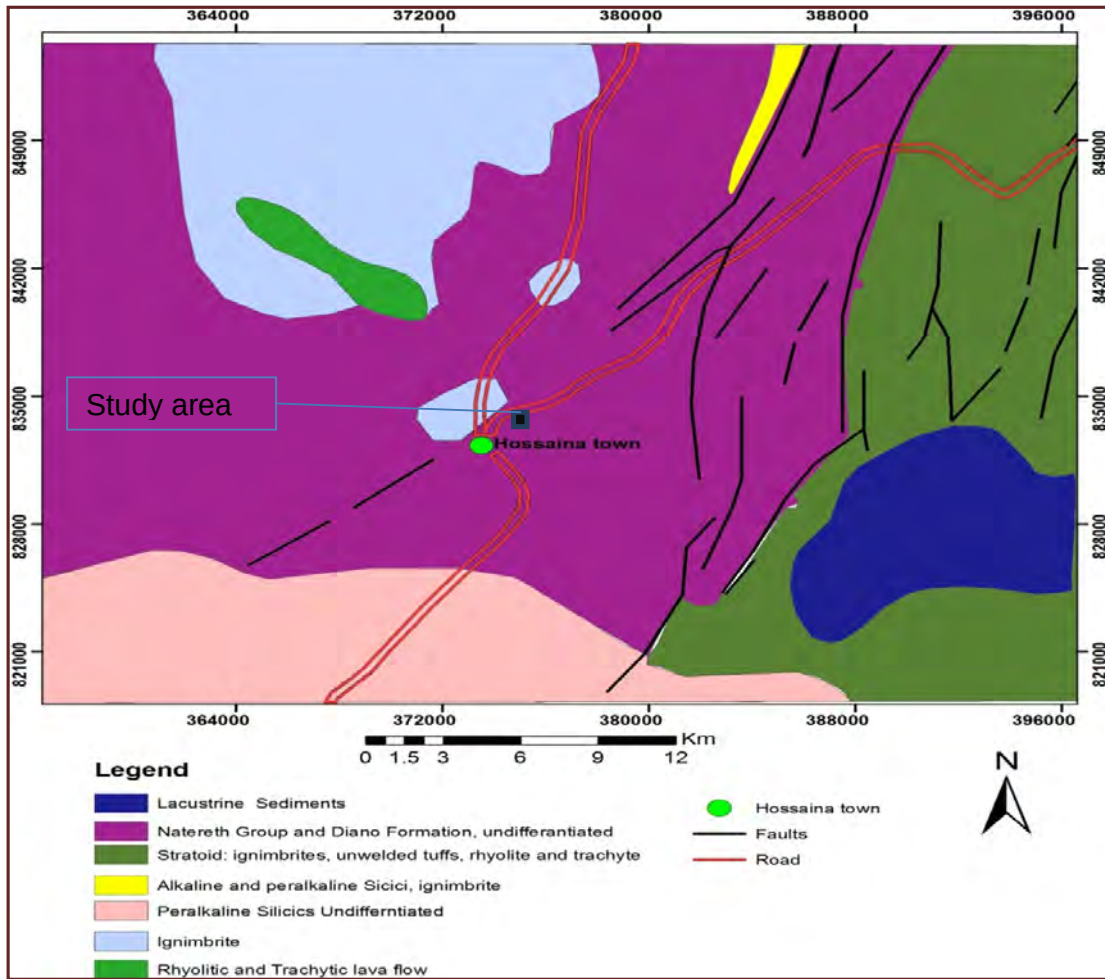


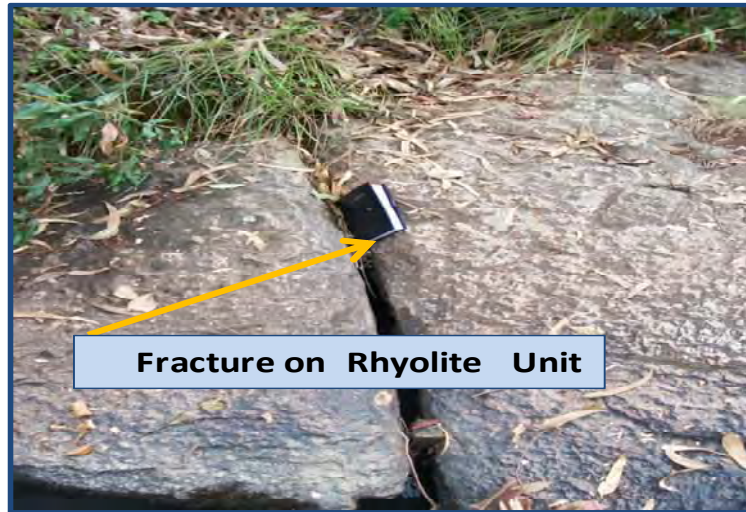
Fig. 2.1 Geology of the study area and its surroundings

2.2.4 Geology of the Project Site

The study area is covered by thick soils, except river cut, road section, and quarry sites are rock unit exposures. Cenozoic (young) volcanic rocks and thick residual deposits characterize the area.

Local geologic setup of the study area was described based on the observations of river cut, road section, quarry sites, bore holes, pitting and drainage network patterns. Lithological units of the study site are rhyolite, ignimbrite, tuff, volcanic ash and residual soils.

Rhyolite: this rock unit is exposed in the western side of the University site along river exposure. It is characterized by black weathered and light fresh color. It is a medium grained, strong and fractured rock unit.



Ignimbrite: it is welded tuff and a special group of pyroclastic rocks. It exposed along river cut in the eastern and western portion of the study area. Fresh ignimbrite deposits are characterized by poorly sorted aggregates of tuff and pumice. The ovoid to lenticular shapes of pumice fragments observed on fresh compacted ignimbrite in the western side of the study area that is shown in Plate 2.3 a.

The ignimbrite found in the eastern and southern portion of the study area is highly fractured and weathered that is shown in the Plate 2.3 b. The ignimbrite unit is characterized by gray color and fine-grained texture. It is intercalated with reddish clayey soil and tuff in many parts of river exposure. The intercalation shows depositional series of pyroclastic materials.

Tuff: this pyroclastic unit is exposed in the eastern, western and southern portion of the study area along river cut and road section. It is characterized by white color and fine-grained texture. The tuff unit of the study area is relatively soft and porous that is usually formed by the compaction and cementation of volcanic ash. The study area tuff is also highly eroded and weathered; the resulted block of tuff forms like butte and mesas along the river cut which is presented in Plate 2.4 a.

Weathering resistant scoraceous tuff is also observed along the river cuts in the eastern part of the construction site. In many places, it is intercalated with ignimbrite and reddish clay soil depending on the eruptional series. Close to the main gate of the University construction site, light gray pyroclastic tuff deposit is sandwiched with its weathering products of reddish silty clay soil along the Addis Ababa- Hosanna road cut that is shown in Plate 2.4 b.

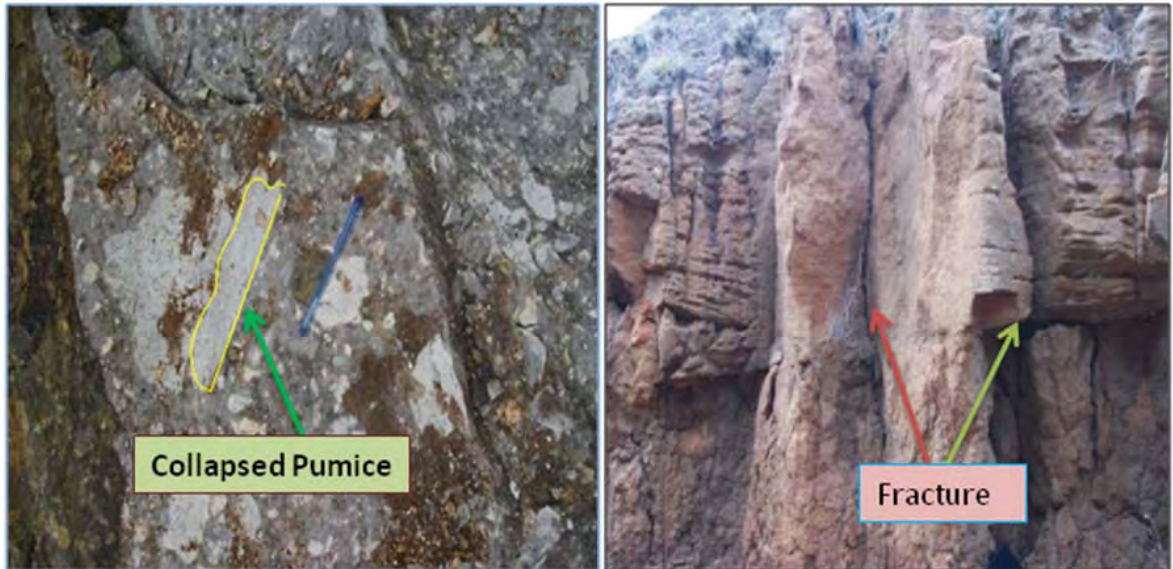


Plate 2.3 a) Welded ignimbrite with collapsed pumice Plate 2.3 b) Fractured and weathered ignimbrite

Fractured and Scorious Tuff unit

Plate 2.4 a) Butte and messes of tuff unit along road

Plate 2.4 b) Sandwiched tuff units section

Volcanic Ash: it is a pyroclastic material exposed in the western side of the construction sites. The volcanic ash consists of powder size to sand-size particles of igneous rock material that have been blown into the air by an erupting volcano and deposited on the ground as ash fall deposit. It is characterized by light-gray color and insoluble in water.

Residual Soil: this unit covers almost all of the study area except marginal portion. Residual soil is the soil that remains at the place of their formation. The upper portion of the deposit is

totally altered in to brown clayey silt soil. Thick soil deposit is observed at central portion of the study area.

2.2 Hydrogeological Setting

The groundwater potential of the study area depends on 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, the groundwater table of the study area and the surroundings is located at relatively greater depth. The Batena well of University site, 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. The Kalisha well located about 2 km from University site is nearly at the same topography as that of the Batena well. The main water strike 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 formations of the area is 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 Kalisha and Batena geological logs are shown at the Annex-A.

2.3 Seismic Setting

An earthquake is ground vibration due to seismic waves, which are the result of the release of stored energy when rocks deformed or forced to strain beyond their elastic limit. 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 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 strains build up is not enough to cause large earthquakes.

Earthquakes occur every day on Earth, but the majority of them is minor and causes no damage. Large earthquakes 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 kinds 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 (Tilahun Mammo, 2005). These are Afar Depression, Escarpment and Ethiopian Rift System seismic source zones which are very near to the study area. The epicenter map of the region in the Fig.2.5 shows that small and intermediate earthquakes are dominated. The location of the earthquake is not uniformly distributed throughout the region, but it is clustering along the Main Ethiopian Rift system.

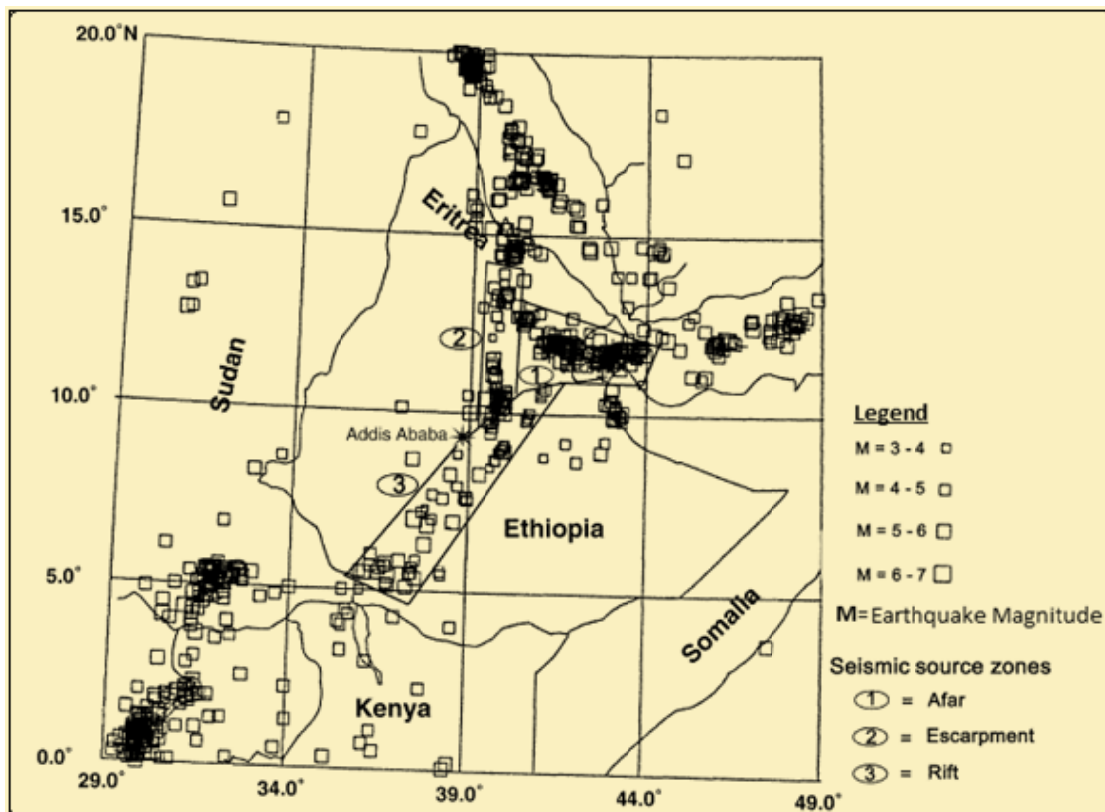


Fig. 2.1 Seismicity of the region with the seismic source zones (Tilahun Mammo, 2005)

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 (Robert, 2001).

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 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 Ethiopia 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 Fig.2.6. These zones are no damaging zone (0 zones), less damaging zones (zone 1 and 2) and zones of major damaging (zone 3 and 4).

2.3.1 Liquefaction

Soil liquefaction occurs when, due to shaking, water-saturated granular material (such as sand) temporarily loses its strength and transforms from a solid to a liquid state. The most common cause of a seismic bearing capacity failure is liquefaction of the underlying soil. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink into the liquefied deposits (Ishihara, 1993).

There are aspects that should be considered in a comprehensive evaluation of liquefaction hazards. These are susceptibility, initiation and effects of liquefaction. The geologic setting and geologic criteria provide very useful information for preliminary assessment of liquefaction susceptibility. Geologic processes that sort soils into uniform grain size

distributions and deposit them in loose states, produce soil deposits with high liquefaction susceptibility. Experiences indicate that liquefaction with engineering consequences largely happens in hydraulic fills and very recent alluvial and fluvial deposits. Initiation of liquefaction refers to the phenomena of seismic generation of large pore-water pressures and consequent softening of granular soil (Kramer, 1996).



Fig. 2.2 Seismic hazard map of Ethiopia (Ethiopian Building Code Standards, 1995)

Chapter 3

THEORETICAL BACKGROUND

METHODS OF INVESTIGATION

3.1 Preamble

The purpose of a construction site investigation is for the evaluation of foundation material 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).

A geophysical exploration is mainly included in a site investigation for an important engineering project in order to provide subsurface information over a large area at reasonable cost and within a short period of time. The information obtained may help to eliminate less favorable alternative sites, may aid the location of test holes in critical areas and may prevent unnecessary repetitive drilling in uniform ground. A geophysical survey helps to locate the position of boreholes and detects variations in subsurface conditions between boreholes. Boreholes provide the information about the strata where they are sunk but not tells about the underground in between the two boreholes. Therefore, an appropriate combination of direct and indirect methods can yield a high standard of results for engineering site selection (Bell, 1980).

3.2 The Electrical Resistivity Method

3.2.1 Preamble

The purpose of electrical resistivity survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. Any electrical resistivity survey is dependent on the resistivity value of Earth materials. Ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity, nature and degree of water saturation in the rocks, etc. Electrical resistivity surveys have been used for many decades in hydro-geological and mining exploration. More recently, it has been used for geotechnical and environmental investigations (Robert and William, 1981).

3.2.2 Principles of Resistivity Method

The well-known resistance R, in ohm, of a wire is directly proportional to its length L, and is inversely proportional to its cross-sectional area A. That is:

$$R = \rho \frac{L}{A} \quad \text{.....(3.1)}$$

where ρ , the constant of proportionality, is known as the electrical resistivity. It describes the characteristic of the materials, which is independent of its shape or size.

According to Ohm's law, the resistance is given by

$$R = \frac{\Delta V}{I} \quad \text{.....(3.2)}$$

where ΔV is the potential difference across the resistance and 'I' is the electric current through the resistance.

The resistivity ' ρ ' of homogeneous and isotropic materials in the form of regular geometric shapes, such as cylinder, cubes are determined from the following equation;

$$\rho = \frac{\Delta V}{I} \left(\frac{A}{L} \right) \quad \text{.....(3.3)}$$

In resistivity surveys, commutated direct current is introduced into the ground via two electrodes. The potential difference is then measured with another pair of electrodes. The current and potential measurements along with the parameters that determine the distribution of the electrodes over the ground are used to calculate resistivity.

The electric potential 'V' caused by a point electrode emitting an electric current 'I' into a homogeneous and isotropic medium of resistivity ' ρ ' is given by;

$$V = \frac{\rho I}{2\pi r} \left(\frac{1}{r} \right) \quad \text{.....(3.4)}$$

Where, $r^2 = x^2 + y^2 + z^2$ is the distance between the point of measurement and the current electrode.

For a semi-infinite medium, which is the simplest Earth model, and with both current and potential point electrodes placed at the Earth surface ($z = 0$), equation (3.4) reduces to;

$$V = \frac{\rho I}{2\pi} \left(\frac{1}{r} \right) = \frac{\rho I}{2\pi} \left(\frac{1}{AM} \right) \quad \text{.....(3.5)}$$

Where, AM is the distance on the Earth's surface between the positive current electrodes 'A' and the potential electrode 'M'. When two current electrodes, 'A' and 'B', are used and the potential difference, ∇V , is measured between two measuring electrodes, 'M' and 'N', we obtain;

$$V_{AM} = \frac{\rho I}{2\pi AM}, \text{ is potential at 'M' due to positive electrode 'A'}$$

$$V_{AN} = \frac{\rho I}{2\pi AN}, \text{ is potential at 'N' due to positive electrode 'A'}$$

$$V_{BM} = \frac{\rho I}{2\pi BM}, \text{ is potential at 'M' due to negative electrode 'B'}$$

$$V_{BN} = \frac{\rho I}{2\pi BN}, \text{ is potential at 'N' due to negative electrode 'B'}$$

The total net potential at 'M' is then,

$$V_M = \frac{I\rho}{2\pi} \left[\frac{1}{AM} - \frac{1}{BM} \right] \text{ and}$$

The total net potential at 'N' is then;

$$V_N = \frac{I\rho}{2\pi} \left[\frac{1}{AN} - \frac{1}{BN} \right]$$

Therefore, the net potential difference is;

$$\Delta V = \frac{I\rho}{2\pi} \left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN} \right] \quad \dots\dots\dots (3.6)$$

Rearranging equation (3.6), we can express the resistivity ρ by;

$$\rho = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \left(\frac{\Delta V}{I} \right) \quad \dots\dots\dots (3.7)$$

Equation (3.7) is a fundamental equation in direct current electric prospecting.

The factor $\frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$ is known as the geometric factor of the electrode arrangement and generally is denoted by 'K'.

Then, equation (3.7) can be rewritten as;

$$\rho = K \left(\frac{\Delta V}{I} \right) \quad \dots\dots\dots (3.8)$$

If the measurement of resistivity (ρ) is made over a semi-infinite space of homogeneous and isotropic material, then the value of resistivity computed from equation (3.8) will be the true

resistivity of that material. However, if the medium is heterogeneous and anisotropic then the resistivity computed from equation (3.8) is called an apparent resistivity (ρ_a).

The value of the apparent resistivity is a function of a number of parameters: the electrode spacing, geometry of the electrode array, and the true resistivity and other characteristics of the subsurface materials, such as layer thicknesses, angles of dip, and anisotropic properties. From these we can infer that the apparent resistivity, depending on the electrode configuration and on the geology, may be a resistivity (Zohdy, 1980).

3.2.3 Electrical Properties of Earth Materials

Enormous variation in electrical resistivity, found in different rocks and minerals, makes electrical resistivity techniques possible. Variations in the resistivity of Earth materials, either vertically or laterally, produce variation in the relations between the applied current and the potential distribution as measured on the surface, or provide the information about the composition, extent, and physical properties of the subsurface materials. Materials that differ geologically may also differ electrically and such differences are distinguished by an electrical resistivity survey. 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.

Sedimentary rocks, which are usually more porous and have higher water content, normally have lower resistivity values compared to igneous and metamorphic rocks. The resistivity values range from 10 to about 10000 Ω m. The resistivity values are largely dependent on the porosity of the rocks, and the salinity of the contained water. Unconsolidated sediments generally have even lower resistivity values than sedimentary rocks, with values ranging from about 10 to less than 1000 Ω m. The resistivity value is dependent on the porosity (assuming all the pores are saturated) as well as the clay content. Clayey soil normally has a lower resistivity value than sandy soil. Clays and a few other minerals, notably magnetite, hematite may be found in sufficient concentration to contribute measurably to the conductivity of the soil or rock. Soil conductivity is a function of grain size, with finer grains producing higher values and coarse grains resulting in lower values. Bodies of clay or shale generally have lower resistivity than soils or rocks composed of bulky mineral grains

Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is greatly dependent on the degree of fracturing, and the percentage of the fractures filled with groundwater. Thus, a given rock type can have a large range of resistivity, from about 1000 to 10 million Ω m, depending on whether it is wet or dry. This characteristic is useful in the detection of fracture zones and other weathering features, such as in engineering and groundwater surveys.

Water, in a pure state, is virtually non-conductive but forms a conductive electrolyte with the presence of chemical salts in solution, and the conductivity is proportional to the salinity. The resistivity of groundwater varies from 10 to 100 Ω m depending on the concentration of dissolved salts.

A typical resistivity survey has low resistivity for the soil layers, with underlying bedrock producing higher resistivity. Usually, this will be the case, but the particular conditions of a site may change the resistivity relationships (Bernard, 2003). The resistivity value of some common Earth materials is shown in Annex-B.

3.2.4 Types of Resistivity Surveys

Electrical resistivity techniques have been used in many geological formations for characterizing the subsurface. There are two basic types of resistivity investigations; profiling and depth sounding 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).

3.2.4.1 Electrical Resistivity Profiling

Profiling provides information about lateral variations, usually with some information about vertical variations. Wider electrode spacing results in deeper penetration. The profile is usually set at regular interval distances. The entire electrode is moved laterally along the profile, the procedure is called lateral inhomogeneity hunting, and it is shown in Fig. 3.1. The procedures are especially useful to locate and map vertical contacts like dykes, faults, fissures and segregated mineralization zones (Loke, 2001).

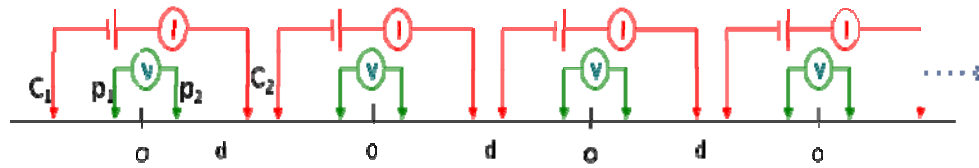


Fig. 3.1 Schematic Plan for Electrical resistivity profiling (After Loke, 2001).

3.2.4.2 Electrical Resistivity Sounding

The procedure involved in vertical electrical sounding is primarily based on the assumption that the subsurface has a horizontal stratigraphy. In other words, it consists of discrete, horizontal, homogeneous and isotropic layers. The measurements are taken with gradually increasing distances of the current electrodes (the potential electrodes remain constant at some station) and the procedure is called “electrical drilling” (Fig. 3.2). As the distance between current probes is increased, there is also an increased in the depth at which the current penetrates below the surface of the distribution below the center of the array is determined (Loke, 2001).

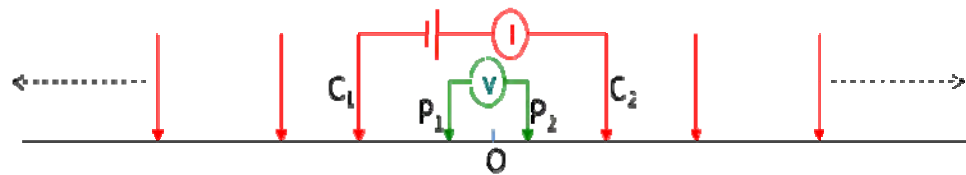


Fig.3.2 Schematic Plan for Electrical resistivity sounding (After Loke, 2001)

3.2.4.3 Electrical Resistivity Imaging/Tomography (ERT)

It is a recent development in resistivity survey procedures, which involves a combination of both traversing and sounding, to produce an image along a section through the subsurface. This array is a hybrid between Wenner-Schlumberger arrays arising out of a relatively recent work with electrical imaging surveys (Loke and Barker, 2001).

Electrical resistivity imaging is one of the new developments in recent years to map areas with moderately complex geology where conventional resistivity sounding or profiling surveys are inadequate (Griffiths and Barker, 1993). Such surveys are usually carried out using a large number of electrodes connected to a multi-core cable. It is more accurate and

very high-resolution model of the sub-surface where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line.

Two-dimensional prospecting is nowadays a routine as the fieldwork, the data analysis and the interpretation procedures have been developed to the extent that the whole process is almost as quick and effective as the one-dimensional sounding investigations (Loke and Barker, 1996).

A typical field layout for electrical imaging survey is as illustrated in Fig. 3.3.

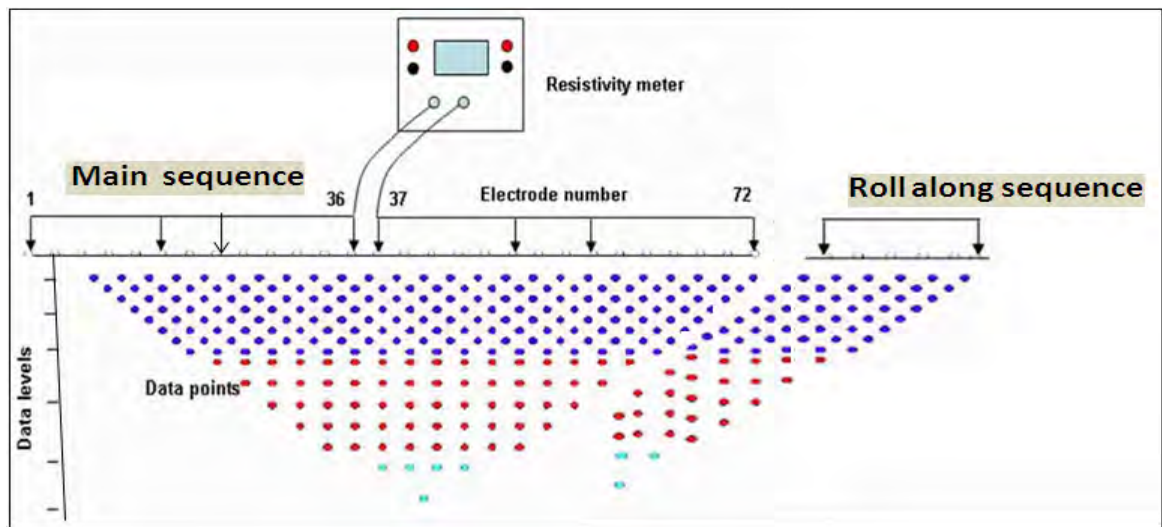


Fig. 3.3 Field layout of electrical resistivity tomography survey

The figure shows a possible sequence of measurements for the Wenner electrode array with a system, for example, of 72 electrodes. The spacing between adjacent electrodes is “a”. The first step is to make all possible measurements with the Wenner array with electrode spacing 1a. For the first measurement, electrodes number 1, 2, 3 and 4 are used. Notice that electrode 1 is used as the first current electrode C_1 , electrode 2 as the first potential electrode P_1 , electrode 3 as the second potential electrode P_2 and electrode 4 as the second current electrode C_2 . For the second measurement, electrodes number 2, 3, 4 and 5 are used for C_1 , P_1 , P_2 and C_2 respectively. This is repeated down the line of electrodes until electrodes 68, 69, 70 and 72 are used for the last measurement with 1a spacing. For a system with 72 electrodes, note that there are 69 (i.e. $72-3*1$) possible measurements with 1a spacing.

After completing the sequence of measurements with 1a spacing, the next sequence of measurements with 2a electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for

the first measurement. For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until the last electrodes. For a system with 72 electrodes, illustrated above, note that there are 66 (i.e. $72-2*3$) possible measurements with 2a spacing.

The same procedure is repeated for measurements with other spacing. To get the best results, all the measurements in the field survey should be carried out in a systematic manner. When the electrode spacing increases the number of measurement decreases while depth of investigation increases (Ewusi, 2006).

Two-Dimensional Resistivity Inversion

Two-dimensional electrical imaging surveys are now widely used to map areas of moderately complex geology where conventional 1D resistivity surveys are inadequate. 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. The smoothness constrained least squares method is based on the following equation.

$$(J^T J + \mu F)d = J^T g \quad \dots\dots(3.9)$$

Where, $F = f_x f_x^T + f_z f_z^T$; f_x = horizontal flatness filter, f_z = vertical flatness filter, J = matrix of partial derivatives, μ = damping factor, d = model perturbation vector and g = discrepancy vector.

One advantage of this method is that the damping factor and flatness filters can be adjusted to suit different types of data. The program supports a new implementation of the least-squares method based on a Quasi-Newton optimization technique. This technique is significantly faster than the conventional least squares method for large data sets. Numerical modeling techniques for surface electrode arrays have been extensively used on a trial-and-error basis to interpret resistivity data in terms of two-dimensional (2D) geologic structures. At the same time, forward modeling does not yield much information on resolution. Thus, there is a need to develop an inverse technique to interpret resistivity data in terms of 2D or 3D subsurface structures (Loke and Barker, 1996).

Depth of Investigation of ERT

As mentioned in the above sections, electrical resistivity imaging is a recent development that has been introduced to make possible the acquisition of many readings in a reduced amount of time for environmental and engineering applications for shallow investigation depth. It

uses multi-core cables that contain as many individual wires as number of electrodes, with one take-out every 5m. The total length of cable is the product of the electrode spacing by the number of electrodes. The maximum depth of investigation is the order of 0.2 times the total length of cables (Ewusi, 2006).

Advantages of ERT over Conventional Resistivity Surveys

Data gathering in electrical resistivity imaging is less laborious compared with the conventional type where equipment and electrodes are moved from one station to the next in a straight-line traverse with more than five personnel in a survey team. In imaging technique, all the units are arranged and a command given to take all the measurements in a traverse. Computer interpretations of raw (apparent resistivity) data enable inversion to true resistivity, which increases accuracy and quality of data in complex geology.

Data obtained are normally plotted either manually or by the use of Microsoft excel and interpretation of data takes time in the conventional electrical resistivity techniques. Convectional electrical resistivity survey relatively poor horizontal coverage as the electrode spacing is increased. This problem is normally observed in a system with relatively small number of electrodes.

The multi-electrode resistivity survey of electrical resistivity imaging overcomes this problem by obtaining information's of both horizontal and vertical directions (Loke, 2001).

3.2.5 Soil Corrosivity

Steel structures are affected by corrosivity of the soil type over which building foundations are erected. One of the best and most reliable parameters indicating soil corrosivity is the electrical resistivity of the soil at the relevant location and depth. High corrosivity would occur in area of lowest resistivity values where there is high moisture content (Table 3.1).

Table 3.1 British Standard Classification of soil corrosivity (BS, 1973)

Soil Resistivity (Ωm)	Corrosivity
Up to 10	Severely Corrosive
10–100	Moderately Corrosive
100 and above	Slightly Corrosive

3.2.6 Limitations of Electrical Resistivity Methods

Profiling methods measure the lateral variations of apparent resistivities but do not easily provides insight into true actual resistivity. 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 (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.

3.3 Magnetic Method

3.3.1 Preamble

Magnetic prospecting is the oldest method of exploration. However, at the beginning the method was used for iron-ore prospecting. Later on, the method was greatly employed, in prospecting for oil as the source of information from which one can determine the depth and morphology of the basement rocks, and locates and defines the extent of sedimentary basins. Nowadays, the method is used for engineering and environmental applications to locating contacts between rock units, near-surface faults, dikes, and buried ferromagnetic objects (storage drums, pipes, etc) based on the differences in magnetic susceptibility between these and the host rocks (Reynolds, 1998).

3.3.2 Basic Principles and definitions

To conceptualize the magnetic effects associated with Earth materials one requires knowledge of the principle of magnetism.

Magnetic Poles: are the points near the ends of a magnet from which lines of force orient themselves. They are called north and south poles or positive and negative poles, respectively.

Magnetic Force: if two poles of strength ' p_1 ' and ' p_2 ' are separated by a distance ' r ', the magnetic force between them will be;

$$\vec{F} = \frac{1}{\mu} \frac{\rho_1 \rho_2}{r^2} \hat{r} \quad \dots\dots(3.10)$$

Where; ' μ ' is constant and, it is known as the magnetic permeability, depends on the magnetic properties of the medium in which the poles are situated. If the poles are like type, the force is repulsive, if they are unlike it is attractive.

Magnetic Field Strength (H): this is a more practical quantity than the magnetic force. The magnetic field strength ' H ' at a point in space because of a pole of strength ' p ' located at a distance ' r ' from it is defined as the force per unit pole.

$$\vec{H} = \frac{\vec{F}}{\rho} \quad \dots\dots(3.11)$$

Magnetic Moment (M): true magnet has always two poles. Thus, they are called magnetic dipoles. A dipole consists of two poles of equal strength ' p ' and opposite sign separated by a short distance ' L '. The product ' pL ' is defined to be the magnetic moment of the dipole. It is a vector quantity with both magnitude and direction. The direction of the moment is along the line between the poles and by agreement is toward the North Pole.

Intensity of Magnetization: intensity of magnetization defined as the magnetic moment per unit volume.

$$I = \frac{M}{V} \quad \dots\dots(3.12)$$

Magnetic Susceptibility (K): the degree to which body gets magnetized when subjected to an external field. Susceptibility is the fundamental parameter in magnetic prospecting. Since the magnetic response of minerals and rocks to the geomagnetic field is determined by the amount of magnetic materials in them, measurements of variation in this property can be used as a geophysical tool.

In homogeneous external field ' H ' makes an angle ' θ ' with the normal to the surface of a material capable of being magnetized the induced pole strength per unit area is;

$$K = \frac{I}{H} \quad \dots\dots(3.13)$$

Then, $I = K H \cos\theta$

For a field normal to the surface (i.e $\theta = 0$)

$$I = k H$$

Where; 'k', the proportionality constant, is called the magnetic susceptibility. For a vacuum and for entirely nonmagnetic substances, $k = 0$. Magnetic materials having positive susceptibilities are known as paramagnetic. A paramagnetic material of high susceptibility may be referred to as ferromagnetic. A few substances with negative susceptibilities are referred as diamagnetic (Dobrin, 1976).

Magnetic Induction (B): a magnetic body placed in an external field 'H' has its internal poles (elementary magnets) more or less lined up by the field 'H' to produce a corresponding field 'H' of its own. This increases the total field within the magnetic body. The internally produced field 'H' is related to the intensity of magnetization 'I' and the external field 'H'.

The magnetic induction 'B' is defined as the total field in the body and is given by;

$$B = H + 4\pi I = H (1 + 4\pi K) \quad \text{.....(3.14)}$$

where; $I = KH$

By definition, the ratio of the magnetic induction 'B' to the magnetic field strength 'H' is the magnetic permeability ' μ '

$$\mu = \frac{B}{H} \quad \text{.....(3.15)}$$

So that from the above equation;

$$\mu = 1 + 4\pi K \quad (3.16)$$

This is the relation between the magnetic susceptibility 'K' and the permeability ' μ '.

3.3.3 Remanent Magnetization

If the magnetic material has relatively large susceptibilities, or if the inducing field is strong, the magnetic material will retain a portion of its induced magnetization even after the inducing field disappears and results a remanent magnetization. The magnetic rock shows a remanent magnetization that is not related to the Earth's present field but is governed instead by the field that existed when the rock was formed. If such rock is igneous, its direction of magnetization will be that of the Earth's field at the time it cooled from its initial molten state

to a temperature below Curie point. If the rock is sedimentary, any orientation of its magnetic grains during deposition, generally in quiet water, would have been in alignment with the field that existed when the deposition occurred.

The laboratory analysis for measuring the remanent magnetic component of a rock is time consuming and expensive. As a result, in exploration geophysics, typically assume there is no remanent magnetic component in the observed magnetic field though the assumption is wrong and could possibly bias the interpretations.

The existence of remanent magnetization in rock gives to Earth scientists a powerful tool for studying the history of the Earth's field and by inference the geologic history of the Earth itself. This type of study is referred as paleomagnetism. Many of our modern concepts in geology, such as crustal spreading and plate tectonics, were developed, at least in part, with the aid of paleomagnetic evidence (Dobrin, 1976).

3.3.4 The Earth's Magnetic Field

The observed magnetic field on the Earth's surface can be broken into three separate components (Reynolds, 1998).

Main Field: this magnetic field is the largest component and believed to be caused by electrical currents in the Earth's outer core. It acts as the inducing magnetic field for exploration purposes.

External Magnetic Field: it is a relatively small portion of the observed magnetic field that is generated from magnetic sources external to the Earth. This field is believed to be produced by interactions of the Earth's ionosphere with the solar wind. Hence, temporal variations associated with the external magnetic field are correlated to solar activity.

Crustal Field: this field is the portion of the magnetic field associated with the magnetism of crustal rocks. This portion of the field contains both magnetism caused by induction from the Earth's main magnetic field and remanent magnetization. The magnetizable materials within the Earth's crust create small amplitude magnetic fields that cause spatial variations of the Earth's main magnetic field. These materials are the targets of the magnetic method.

Total Field Measurements

Most exploration geophysical surveys employ proton precession magnetometer it measure only the magnitude of the total magnetic field as a function of position. Ignoring for the moment of the temporally varying contribution to the recorded magnetic field caused by the external magnetic field, the magnetic field recorded with proton precession magnetometer has two components (main magnetic field and anomalous magnetic field). The main magnetic field is a part of the Earth's magnetic field generated by deep (outer core) sources. The anomalous magnetic field that is a part of the Earth's magnetic field caused by magnetic induction of crustal rocks or remnant magnetization of crustal rocks. Typically, the main magnetic field is much larger than anomalous magnetic field, and then total field will point almost in the same direction of the main magnetic field (Burger, 1992).

3.3.6 Temporal Variations and Correction of the Earth's Magnetic Field

The observed magnetic readings obtained from a magnetic survey reflect the Earth's total magnetic field including the Earth's main field, temporal variations and crustal magnetization sources. When describing temporal variations of the magnetic field, it is useful to classify these variations into one of three types depending on their rate of occurrence and source (Telford, Geldart and Sheriff, 1990).

Secular Variations: these long-term variations in the main magnetic field are presumably caused by convection current motion in the Earth's outer core. These changes cause the magnitude, inclination and declination of magnetic field to change with time. These secular variations are used to understand the dynamics of the Earth's outer core.

Diurnal Variations: these variations in the magnetic field occur over the course of a day and are related to variations in the Earth's external magnetic field. These variations are believed to be caused by electric currents induced in the Earth from an external source in the upper atmosphere, or the ionosphere. These electric currents in the ionosphere are in turn driven by solar activity. This variation can be the order of 20 to 30 nT per day and should be accounted when conducting exploration of magnetic surveys.

Magnetic Storms: occasionally, magnetic activity in the ionosphere will abruptly increase. The occurrence of such storms correlates with enhanced solar flares sunspot activity. The magnetic field observed during such times is highly irregular and unpredictable, having

transient or large amplitudes (up to 1000 nT) variations in the field. The most intense storms can be observed globally and may last for several days. Exploration magnetic surveys should not be conducted during times of magnetic storms. Because large and rapid variation in the fields and difficult to correct in acquired data.

As compared to the gravity method there are few corrections applied to observed magnetic data. Correction of spatial variation like latitude corrections, elevation corrections, slab corrections, and topography corrections are not done in magnetic survey because the variation is generally considered small enough to ignore. Terrain effects are usually small and neglected unless the topography is caused by steep slopes consisting of a high magnetic susceptibility material. The problem is the large variation in susceptibilities associated with Earth materials even when those materials are of the same rock type (Sharma, 1997).

3.3.7 Magnetism Properties of Rocks

When the magnetic field is measured along the surface of the Earth, the operator would record magnetization due to both the main and induced fields. The induced field is the one of interest to geophysicists because it relates to the existence of rocks of high or low magnetic susceptibility near the instrument. Most engineering and environmental magnetic studies involve taking readings over soil, which in most situations has a low magnetic susceptibility, will not be concerned with anomalies caused by magnetic susceptibility variations within the soil. However, the magnetic susceptibilities of a soil reflect their source rocks, as soils derived from mafic igneous rocks tend to have high magnetite content (Sharma, 1997). The magnetic prospecting potentially locates subsurface rocks having high magnetic susceptibilities by mapping variations in the strength of the magnetic field at the Earth's surface.

Magnetic susceptibility is a significant variable in magnetic prospecting playing the same role as density in gravity prospecting. The susceptibility of a rock usually depends on its magnetite content. The volcanic rock shows higher susceptibility than common sedimentary rocks. Accordingly, sedimentary rock, acidic volcanic rock, intermediate one and basic one shows ascending magnetic susceptibility. Weathering generally reduces susceptibility because magnetite is oxidized to hematite, but some laterites are magnetic because of the presence of maghemite and remanently magnetized hematite (Telford, Geldart and Sheriff, 1990).

Magnetic susceptibility of various rocks and minerals is shown in Annex-C.

3.3.8 Magnetic Data Presentation and Interpretation

The aim of the magnetic method is to determine information about the Earth's subsurface. The techniques used to analyze and interpret magnetic data are basically the same as those used in the gravity method.

Magnetic data Presentation: magnetic data are collected either along a profile or in a grid. The most basic field data acquisition amenable to sound interpretation technique is to collect data along a profile and plot the profile. The most common technique in magnetic interpretation is visualizing a grid of magnetic data. There are a number of techniques to display gridded data including contour maps, wire meshes and color images.

Magnetic Anomaly Patterns: the magnetic field intensities of buried magnetized objects produce different anomaly patterns than gravity anomalies produced by similarly shaped objects. Because of the dipolar nature of magnetic fields, a single magnetized body will produce both a positive and negative anomaly and thus is more difficult to interpret than gravity anomalies.

The shape of the anomaly depends on the magnetic inclination (I) where the body is located. At the magnetic north pole ($I = 90^\circ$) the maximum peak is directly over the sphere whereas at the magnetic equator ($I = 0^\circ$) the minimum is centered over the sphere. Thus, the body is not always directly under the maximum or minimum anomaly. Individual east-west profiles will not show the positive and negative anomaly patterns and a misinterpretation on the location of the buried body is possible. If possible, north-south profiles should be collected.

Magnetic Data Enhancement: these enhancement techniques are used to increase the perceptibility of magnetic anomalies that are related to bodies of interest. This is not important in all types of shallow magnetic surveys as the anomalies due to iron and highly magnetic rocks that produce high magnetic anomalies. However, enhancement techniques highly used in detailed magnetic surveying for faults and geologic mapping where magnetic anomalies may have small amplitude and obscured by nearby anomalies.

Recently, the enhanced analytic signal technique has been shown to be a superior edge detection method than the traditional first and second derivative techniques (Sharma, 1997).

The enhanced analytic signal technique produces a result that is not dependent on magnetic inclination as the traditional methods.

3.4 Geotechnical Investigation

For the proposed engineering structure, geotechnical investigations are mandatory which provides a necessary means to know the physical properties of the rocks and the soils present in the foundation. Geotechnical investigations for building foundations are also conducted to know the behavioral characteristic of the foundation material and the possible interaction of the foundation material with the structure when subjected to impose static and dynamic loads of the structure (Arora, 1997).

A geotechnical investigation includes surface and subsurface exploration of a site. Design of foundations or solving geotechnical problems begins with the determination of the soil properties. The engineering property of soils are affected by four main factors; the predominant size of the mineral particles, the type of mineral particles, the grain size distribution, and the relative quantities of mineral, water and air present in the soil matrix.

3.4.1 Soil Descriptions

Soil, in engineering practices, is defined as an unconsolidated material composed of solid particle produced by disintegration of rocks. Soils are formed from weathering of rocks due to mechanical disintegration or chemical decomposition. The weathering agents responsible for the formation of soils are moisture content, temperature changes, frost action and plant roots. Soil deposits are affected by the mechanism of transport and deposition to their location (Mills and Cameron, 2002).

There are various types of soils the most important of which are described in the following paragraphs;

Residual Soils

These are formed in-situ by weathering of the original rock unit. Genetically, residual soils are formed from igneous, sedimentary and metamorphic rocks. The engineering properties of residual soils vary considerably from the top layer to the bottom layer. Residual soils have a gradual transition from relatively fine material near the surface to large fragments at greater depth (Mills and Cameron, 2002)

Transported Soils

These soils are formed from particles that have been removed from rocks, then transported and deposited away from the original source. They are transported by the action of water, air and glacier. The engineering properties of transported soils are entirely different from the properties of the rock at the place of deposition (Alam Singh, 1990).

Marine Soils

These soils are formed in the sea or at the estuaries of rivers. Marine clays have a structure reflecting the saline conditions during deposition.

3.4.2 Organic Matter Content

The organic matter of a soil has a significant influence on its behavior. Organic soils are highly compressible and should be avoided from foundation. Liquid limit and plasticity limit are directly proportional to the organic matter content while plasticity index relates inversely.

3.4.3 Index Property of Soils

Laboratory testing entails the establishment of index and engineering properties. The purpose of laboratory testing is to quantify the index properties of the soil and thereby allowing the soils to classify according to defined rules (Mills and Cameron, 2002).

3.4.4 Moisture Content

The moisture content of a soil is the weight ratio of water to dry solids in a soil mass. It can range from zero percent as in single grained soils to almost six hundred percent as in flocculent soils and peat (Karol, 1960). Moisture content can highly affect the engineering properties of the soils such as; shear strength and consolidation properties. It also affects the future swelling and shrinkage.

3.4.5 Specific Gravity

The specific gravity of any substance is the ratio of the weight of a given volume of that substance divided by the weight of an equal volume of water. It is required to compute void ratio, unit mass of soil and stock's law in hydrometer analysis. The specific gravity of

different soil minerals range from as low as 2.3 to as high as 5.2. However, most mass have specific gravity ranging from 2.4 to 3.0 (Karol, 1960).

3.4.6 Grain Size and Grain Size Distribution

Soils are usually comprised of more than one particle size. The principal particle sizes of soils are; gravel, sand, silt and clay. All soils are made up of one or all of these distinct components in combination. Each component has a definite grain size range characteristic reaction in the soil mass. The grain size distribution of a coarse-grained soil is generally determined through sieve analyses, where the soil sample is passed through a stack of sieves and the percentages passing different sizes of sieves are noted. Coarse-grained soils are readily sieved whereas fined-grained soils are impractical to sieve. The grain size distribution of the fines are determined through hydrometer analysis, where the fines are mixed with distilled water to make 1000 ml of suspension and a hydrometer is used to measure the density of the soil-water suspension at different times. Hydrometer analysis is effective for soil fractions down to about 0.5 μ m (Das 1994).

Table 3.2 Soil types and average grain sizes according to USCS

Soil type	Average grain size (mm)
Gravel	75-4.75
Sand	4.75-0.075
Silt	0.075-0.002
Clay	<0.002

Mostly soils contain both coarse and fine grains and it is necessary to do sieve and hydrometer analysis to obtain the complete grain size distributions data. The grain size data obtained from sieve and hydrometer analyses is generally presented graphically as shown in Fig.3.4. Logarithmic scale is used for the grain sizes since they vary in a wide range. The percentage passing is generally cumulative. The grain size distribution curve gives a complete and quantitative picture of the relative proportions of the different grain sizes within the soil mass (Das, 1994).

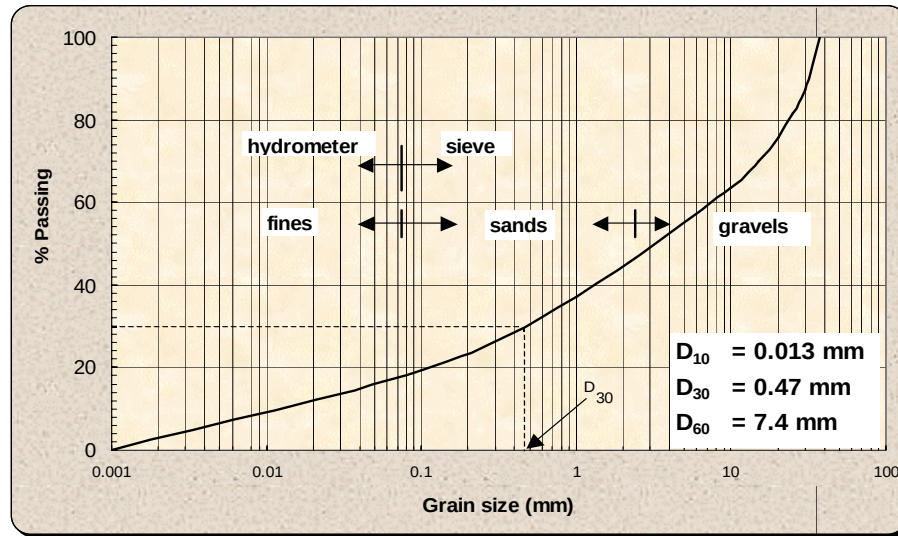


Fig. 3.4 Grain size distribution curve (Das, 1994).

3.4.7 Atterberg Limits

The consistency of a fine-grained soil is the physical state in which it exists; it relates largely to the water content. Consistency denotes the degree of firmness of the soil that is indicated by tests in the field as soft, firm, stiff or hard (Abramson et al., 1996). As the water content of a fine-grained soil is increased gradually from 0%, it goes through different consistencies, namely brittle solid, semi-solid, plastic and liquid states as shown in Fig. 3.5. Atterberg limits are the borderline water contents between two such states (Mills and Cameron, 2002).

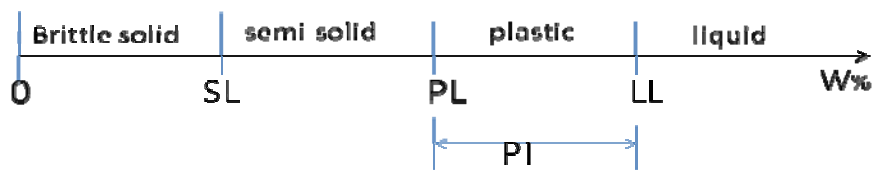


Fig. 3.5 Consistency limits

Shrinkage Limit (SL): shrinkage limits the water content below which a soil sample will not shrink when dried.

Plastic Limit (PL): plastic limit is the lowest water content at which the soil changes from a fluid to plastic state. According to description of plasticity of fine soils in terms of range of plasticity index given by IAEG (1983), the clay, sandy clay/silty and clayey/silty sand soils are moderately to extremely plastic and the silty soils are moderately to highly plastic type.

Liquid Limit (LL): liquid limit is the lowest water content at which the fine-grained soil behaves like a viscous mud and flowing under its own weight. It is the transition water content between plastic and liquid states. Generally, soils having high values of liquid and plastic limits are considered as poor foundation materials.

Plasticity Index (PI): plasticity Index is a measure of the range of water content over which soil is in a plastic state. Soils with high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 tend to have little or no silt or clays (Holtz, 1981).

$$PI = LL - PL \quad \text{.....(3.17)}$$

Plastic index is important in classifying the fine-grained soils. The more plastic a soil means the more compressible, higher shrinkage-swell potential and the lower is its permeability will be (Abramson et al., 1996).

The larger the plasticity index, the greater will be the engineering problems associated with using the soil as an engineering material, such as foundation support for residential building and road sub-grades (Bowles, 1992).

3.4.8 Activity of the Soils (A)

Activity of the soils is another measure of the plasticity of a soil. Fine-grained soils often contain clays and silts. Clays are plastic and silts are non-plastic. Therefore, the plasticity index of a fine-grained soil will depend on the relative proportion of the clays and silts within the soil.

$$A = \frac{PI}{\%clay} \quad \text{.....(3.18)}$$

Activity is a good indicator of the potential swell-shrink problems associated with specific clay. Higher the activity, higher is the swell-shrink potential. Clays with $A < 0.75$ are classified “inactive”; clays where $0.75 < A < 1.25$ are normal and clays where $A > 1.25$ are active (Skempton, 1953).

3.4.9 Soil Unit Classification

Approximate assessment of the engineering properties of soils can be obtained from the index properties after appropriate classification is made. From geotechnical or engineering geological point of view, the classification of soil may be done with the objective of finding

the suitability of the soil for construction of structures. Such a classification should provide some guide to the engineering performance of the soil type and should provide a means by which soils can be identified quickly (ISRM, 1981).

A soil classification system is a universal language, which all the geotechnical engineers understand, where soils of similar behavior are grouped together, and systematic and rational ways are proposed to classify and describe them. The use of such standard and precise terms eliminates any ambiguity in communicating the soil characteristics. Unified Soil Classification system is one of several types of soil classification systems for engineering purposes (Australian Standards 1726, 1993).

Unified Soil Classification System (USCS)

The USCS originally developed for use in airfield construction but later slightly modified to make it applicable in dams and other civil engineering works based on the Casagrande classification. Fine-grained soils are classified based on sieve analysis and Atterberg limits. However, coarse-grained soils are classified based on the particle size distribution and whether the soil is well graded or poorly graded. The soils are coarse-grained if more than 50% of the soil is retained on No. 200 (0.075mm) sieve and fine-grained, if more than 50 % passes No. 200 sieve (Casagrande, 1948)

Generally, sedimentation tests are not conducted to distinguish between clays and silts in a fine soil. Instead, the relationship between the plastic index and liquid limit of the soil provides empirical evidence as to whether it is silt or clay.

3.4.10 Free Swell

Free swell tests consists of placing a known volume of dry soil in water and noting the swelled volume after the material settles, without any surcharge, to the bottom of a graduated cylinder. The difference between the final and initial volume, expressed as a percentage of initial volume, is the free swell value (Chen, 1975).

Indirect methods of swell classification, which involves the use of soil properties and classification schemes to estimate swell potential, are based on the plasticity and liquid limit approach of Holtz and Gibbs (1956) that is presented in Table 3.3.

Table 3.3 Relationship of LL, PL and swelling limit values of the soil

Classification of Potential Swell	Liquid Limit (%)	Plasticity Limit (%)	Swelling Limit (%)
Low	20-35	<18	>15
Medium	35-59	15-28	10-15
High	50-70	25-41	7-12
Very high	>70	>35	<11

Soils having free swell value as high as 100% can cause considerable damage to lightly loaded structures, and soils having free swell value below 50% seldom exhibit appreciable volume change even under very light loadings (Holtz and Gibbs, 1956).

3.5 Suitability of Soil for Building Foundation

Suitability of soil for building foundations depend on the physical and engineering geological characteristics of soil. The performance of engineering works will depend on the correct assessment of engineering properties to determine suitability and to predict performance of soil for its intended use (Arora, 1997). From building foundation point of view safe performance of the foundation depends on bearing capacity of the foundation material and its settlement potential. Settlement of a foundation is vertical and downward movement due to a volume decrease of the soil on which it is built. Poor shear strength directly correlates to poor bearing capacity which ultimately reflects the unsafe building foundation (Annex-D).

Shear Strength

Shear strength is a term used to describe the maximum strength of soil at which point significant plastic deformation or yielding occurs due to an applied shear stress. Shear strength of soil is its maximum resistance to shear usually expressed by stress. To determine the shear strength properties of a soil samples, laboratory test should be conducted on undisturbed samples. The shear strength is measured in terms of two soil parameters, cohesion or inter-particle attraction, and angle of internal friction, Φ , the resistance to inter-particle slip. Shear strength is a basic geotechnical property of soils and helps to understand their importance and limitations in engineering practice. Shear strength parameters; cohesion and angle of shearing resistance are the key parameters used in the determination of bearing capacity of the foundation soils (Arora, 1997).

Compressibility

When a soil mass is subjected to a compressive force its volume decreases. The property of the soil due to which a decrease in volume occurs under compressive force is known as the compressibility of the soil. The compression of soils can occur due to one or more of the causes; (i) Compression of solid particles and water in the void, (ii) Compression and expulsion of air in the void or (iii) Expulsion of water in the void. A study of consolidation characteristic is extremely useful for forecasting the magnitude and time of the settlement of the foundation (Arora, 1997).

Suffusion and Collapsibility

Suffusion is the washing out of fine particles from unconsolidated materials in particular sands and gravels. Suffusion in large decrease in overall volume, which is called collapsibility, of loose cohesionless soils when they are saturated. Collapse of soils can cause excessive settlement in foundation when the clay binders or other cementing materials, which strengthen the soil fabric, are washed out by water action. Soils most susceptible to suffusion or collapse are:

- (i) Loose fills
- (ii) Altered windblown sands
- (iii) Hill wash of loose consistency
- (iv) Decomposed granite or other acidic volcanic rocks

Generally, for collapse and suffusion to occur a soil must have a partly unstable open fabric (large void ratio) with moisture content (Kapol, 1960).

3.6 Subsurface Water and Building Foundations

Subsurface water is often a critical factor in various engineering works. It may pose problems not only during the construction stage but it has a potential to affect the safe functioning of an engineering structure. Almost every engineering project like, buildings, highway pavements, airport runways, dams, underground structures, structures on rock and soil slopes may be affected in one way or other by the subsurface water, which may lead to failure of such structures, thus causing loss to life and property. When there is groundwater fluctuation inside the foundation of the building then it pose problem on the buildings. The capillary

fringes that increase upward pressure have also an effect on the structure. Capillary moisture can rise from water table through the minute pores inside the soil particles until it attained the equilibrium between force of gravity that pull down and surface tension that moves up. The height of the capillary fringe depends largely on the particle size distribution and density of the soil mass that influence pore size. The smaller the pore size, the greater is the height of the fringe. Capillary moisture can rise to great heights in clay soils but the movement is very slow. Where the water table is at shallow depth and the maximum capillary rise is large, moisture continually attracted from the water table, due to evaporation from the surface, so that the uppermost soil is near saturation (Bell, 2007).

Table 3.4 Capillary rises and pressures in soils.

Soil	Soil Capillary rise (mm)	Capillary pressure (kPa)
Fine gravel	Up to 100	Up to 1.0
Coarse sand	100–150	1.0–1.5
Medium sand	150–300	1.5–3.0
Fine sand	300–1000	3.0–10.0
Silt	1000–10,000	10.0–100.0
Clay	Over 10,000	Over 100.0

3.7 Role of Geophysical Investigations for Building Site Characterization

Geotechnical-geophysics is not a substitute for boring and direct physical testing. Rather it complements a well-planned, cost-effective drilling and testing program, and provides a volumetric image of the subsurface over large study areas rather than a point measurement. Geophysical methods are implemented in a wide range of applications ranging from building ground investigations to the inspection of dams aiming towards the exploration of geological structures and the determination of the physical parameters of the rock formations.

In engineering geophysics, the question of the quality of building foundations is frequently addressed in the very late stages, when earthquake damage is either observed or expected. In the case of building construction, geophysics can be applied for exploration purposes to provide useful information regarding the early detection of potentially dangerous subsurface conditions (Sharma, 1997).

The most important geophysical properties are electrical resistivity and seismic wave velocity that can be used directly in engineering studies. Geophysical investigation is commonly used

to determine the depth to bedrock and can also be used to locate potential hazards, such as fault zones and voids. Such information needs to be established for settlement analysis' and the assessment of subsidence risk, as well as for the calculation of bearing capacity. The application of geophysical methods is able to investigate, detect and determine soil properties, inhomogenities of the subsurface, cavities, ancient relics and generally any underlying structures or bodies that have different physical properties from their geological surroundings (Reynolds, 1998).

Many geophysical techniques have been applied to structural engineering problems and now form a significant component of non-destructive testing. Two-dimensional resistivity surveying can form a powerful geological mapping tool, for use in engineering and environmental applications, including hydrogeological mapping (Dahlin, 1996).

Magnetic method measures variations in the Earth's magnetic field to determine the location of subsurface features such as near-surface faults, lithological contacts and igneous dikes that pose a problem on building foundation (Sharma, 1997).

Chapter 4 DATA ACQUISITION, ROCESSING AND PRESENTAION

4.1 Introduction

For the present study reliable geophysical and geotechnical data were collected in the field and from different organizations to achieve the objectives of the research works. The data were acquired and 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 paragraphs.

4.2 Electrical Resistivity Tomography

The recently developed IRIS electrical imaging unit, used in the present study, deploys 72 electrodes in series and gathers high-resolution data with the help of SYSCAL R1 Plus Switch 72 resistivity meter. It uses Electre II software to generate and upload data acquisition sequences onto the instrument and the PROYS II software for downloading data from the instrument, initial filtering and exporting the data in “.dat” format and the RES2DINV software to processes and invert the input data.

4.2.1 Field Procedure and Data Acquisition of ERT

In order to investigate the ground structure and determine the individual formation resistivity, a series of measurements must be made with the deploying electrodes on the ground surfaces in different positions. The SYSCAL R1 Plus resistivity meter reads consecutively and takes the readings automatically, and the results are averaged continuously. Resistivity imaging use multi-conductor seismic type cable to layout all electrodes per profile and give about thousands of data points by manipulating one electrode with anther. Electrodes are set in main sequence and roll along sequences. Those electrodes are arranged in series and sets in constant distance. The distance between each electrode is 5m and the total distance of one profile is 360m (for 72-electrode type), and its maximum depth of investigation is about 72m.

Electrical resistivity tomography surveys were conducted on Wachemo University site to get inverse model resistivity section that exhibit continues subsurface geological formation for building site characterization. In this study 72 electrodes type of multi-core cable is used. These electrodes were set in one series and the SYSICAL unit obtains 648 data points from

the main sequences and 297 data points from roll along sequences. In the case of roll along sequences, the first 18 electrodes were rolled and connected at the end of the main sequence and additional data points were acquired (again for this particular generated sequence). In this study, four roll along sequences were done for every profiles of electrical resistivity imaging.

The electrodes are connected to deployed multi-core cable with connecting cables and the first 18 electrode segments are connected with the next 18 electrode segments by connecting boxes, and the SYSCAL instrument connected 1-36 electrodes and 37-72 electrodes. Connecting cables with electrodes, connecting box and SYSCAL unit are manually controlled and shown in Plate 4.1.



Plate 4.1 ERT data acquisition by SYSCAL unit

The survey has three parallel profile lines and one cross-sectional line that is perpendicular to them. For the shallow subsurface investigation of the present study building foundations, the electrode spacing is minimized to 3m and the depth of investigation accordingly decreases to about 40m, a depth more than adequate for shallow foundation studies. The orientation and extent of those lines are shown in the post map of Fig. 4.2.

Global Positioning System (GPS) was used to obtain the coordinates at every 18 electrode segments, i.e. the location of the connecting boxes.

4.2.2 Processing and Presentation of the ERT Data

During field survey, unwanted data (noise) were recorded due to improper manipulation and instrument setting (lack of ground contact of electrode, improper connection of connecting box and connecting cable, etc). The PROSYS II software was used to process (filter) and ignore the noise that can bias the interpretation of the results.

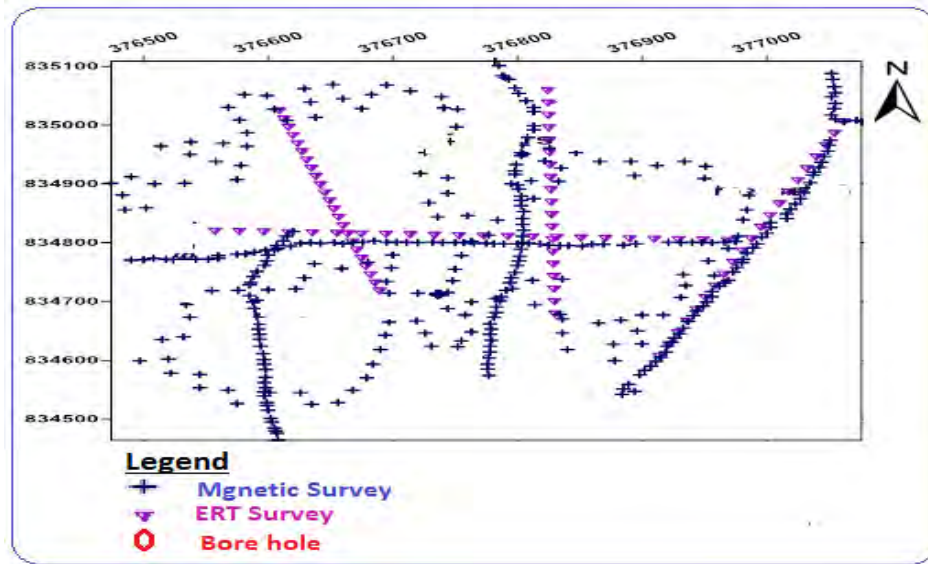


Fig. 4.2 Location and distribution map of the magnetic and ERT survey profiles and data points.

Main sequence and the entire roll along of every profile were merged in one line because they are successive segments of the same profile. The abscissa (X-value) of electrode spacing (5m) was modified to shorter electrode spacing (3m) by PROSYS II software and it interpolates the topography (Z-value) of the referenced locations.

The pseudosection forms the input for the inversion techniques, which produce a two-dimensional subsurface model (Loke and Barker, 1996).

The RES2DINV inverts the measured and calculated apparent resistivity pseudosection to give a geoelectric section that corresponds to true resistivity of the subsurface Earth materials. The inversion procedure divides the subsurface into a number of small rectangular prisms, and attempts to determine the resistivity values of the prisms to minimize the difference between the calculated and the observed apparent resistivity values. A typical output of the

RES2DINV software showing the three components of the interpreted sections for the profile AA' as shown in Fig. 4.2.

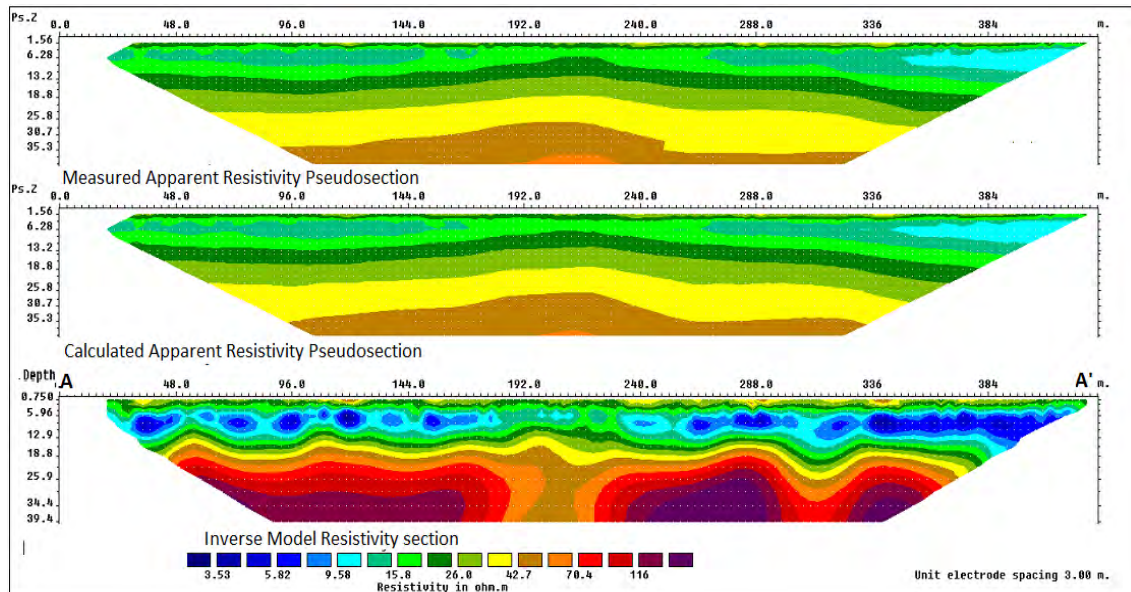


Fig. 4.2 Presentation of the RES2DINV data processing results, illustrating the results of the Profile AA'.

The difference between the measured and calculated apparent resistivity values is given by the RMS error. Normally RMS value of 2–5% should be used depending on the quality of the data. The RMS error of the present study ranges 2.8–4.8%. Number of iterations allows the user to set the maximum number of iterations for the inversion routine. By default, the maximum number of iterations is set to 5. For most data sets, this is probably sufficient. It is usually not necessary to use more than 10 iterations. The inversion process of this study used 5–6 iteration. Stacked apparent resistivity pseudosection was done by using apparent resistivity and true depth. Apparent resistivities at each depth were gridded and contoured using the Golden Software Surfer-9. Then, sliced apparent resistivity map was stacked in a single section.

4.3 Magnetic Method

Magnetic method is routinely employed for subsurface study to outline geological structures that affects the building foundation. To get good quality data and anomaly results, careful field data collection and data processing are essential and discussed separately.

4.3.1 Field Procedures and Data Acquisition of Magnetic Methods

The Scintrex made MP-2 Proton Precision Magnetometer, most widely used equipment for many years, and were used in order to measure magnetic readings. It can only give a series of discrete measurements because of the polarizing and relaxation time needed by the protons. The surveys were carried out along profiles to obtain a grid of data points.

During the midday hours, sunspot activities relatively increases and disturb the readings. Most of the investigation magnetic surveys were carried out at the morning to minimize the erroneous data that resulted from solar activity. In the present study magnetic data were collected in three parallel profiles (trending north south) and one perpendicular profiles, and to cover the survey area data were collected randomly as shown in Fig. 4.2. All magnetic surveys were conducted along the same profiles as those of the ERT survey, except profile AA'.

The magnetic reading, time and GPS coordinates of the measuring stations were recorded at every 10m station interval along the profile and at 30m station spacing randomly. The reoccupation time to base station was 30minute for the correction of diurnal variation due to the absence of continuously recording magnetometer that measures the variation of reading with time at the base station. During the measurement the magnetometer was mounted on a back harness and is oriented in such a way that the “equatorial region up” arrow imprinted on it points as required by the geographic location of the survey area and also measurements were made always facing to one direction, towards north, that is the direction of the ambient field.

4.3.2 Data Processing and Presentation of Magnetic Data

The magnetic field can vary quite erratically with time. The most common processing technique in magnetic survey is to remove the diurnal variations using the data collected at a base station. In acquiring magnetic readings, periodically reoccupying of base station of closed loop was done to correct temporal variation. The first reading at the base station is regarded as the base value. By recording the times at which each magnetic station readings are made and subtracting the magnetic field strength at the base station recorded at that same time, temporal variations in the magnetic field can be eliminated. The resulting field then represents relative values of the variation in total field strength with respect to the magnetic base station.

Other processing technique may be applied to remove the Earth's main magnetic field. This is usually performed on surveys covering many kilometers and is not performed for small-scale engineering and environmental surveys because the Earth's main magnetic field changes 0 to 2 gamma/km in east west and 2 to 5 gammas/km in north south directions.

The diurnal variations of the present studies were corrected with a simple program of Microsoft Excel spreadsheet. The maximum diurnal variation in the survey is about 34.3nT. The approximate main magnetic field at the survey area is obtained from International Geomagnetic Reference Field (IGRF) and this value is subtracted from the diurnal corrected total field to obtain the anomalies.

The linear interpolation technique is used to prepare the anomaly maps. Interpolation, in general, assigns value to points that have originally no measured data values, depending on the selected searching radius and grid cell. Interpolation is necessary, since it is not possible to take infinite measurements that represent infinite points on the Earth's surface. The linear interpolation, in this study, gives magnetic values for areas covered between different profiles.

The anomalous field values are gridded and contoured using the Geosoft Oasis Montaji 6.4.2 software. In addition to the magnetic anomaly map, data enhancement techniques were applied to produce the analytical signal maps, which help to recognize more shallow features. These are done by using the Geosoft Oasis Montaji software.

4.4 Geotechnical Investigations

Different methods were employed for the geotechnical investigation at the Wachemo University site. For foundation studies of the selected campus site, sufficient and reliable soil information was determined and identified. The laboratory test of building site soils were analyzed and processed by Construction Design Share Company.

Test pits were employed in order to collect soil sample randomly. Twenty test pits with a depth range of 2.5–4.0m were excavated by hand using pick axe and shovel. To check the lateral extension and thickness of the overburden material trial pits are the best tools and hence the pits were properly logged.

Disturbed soil samples have been collected from the desired depth while pit digging was in progress. The disturbed soil samples were collected from representative pits in plastic bags

and transported to the soil laboratory of Construction Design Share Company (CDSC) in order to perform the required tests.

5.1 Result and Interpretation of Electrical Resistivity Imaging Data**5.1.1 Introduction**

During the present study a combination of geophysical and geotechnical investigations have been carried out to characterize the construction site for its suitability for the proposed building foundation site. Whereas the geotechnical surveys give only discontinuous and localized information for the subsurface conditions and are limited in depth at randomly selected areas; in contrast, the electrical resistivity imaging work provides a 2-D subsurface image that delivered continuous information and greater depth of investigation of the building site.

Accordingly, in the present work electrical imaging surveys were carried out along four profiles three of which are oriented nearly north south and the fourth one is perpendicular to the others. Total length of each of these profiles were 432m (obtained by one main sequence and four roll along sequences at 3m electrode spacing with the 72-electrode set up) and depth of investigation acquired is 39.4m. All the profiles are plotted on site plan in location map of the study area shown in Fig. 1.1. The inverse model geoelectric sections for each profile were obtained from inversions of field data. This is acceptable as it showed good quality raw data. Three geoelectric sections are correlated with Batena well and discussed separately in the following paragraphs.

5.1.2 Profile AA'

The inversion shows good quality data with the RMS errors of 2.5% after 5 iterations. The obtained inverse model for this profile is shown in Fig. 5.1. The model actually describes the depth wise variation of low to high resistivity zones (3.53–116 Ωm). A topsoil of relatively low and varying resistivity is observed in the upper part of the profile. The variation in resistivity response could have resulted either from variation in moisture content of the top dry soil or from variations in lithology. The overall thickness of this top layer is the same over the entire profile (about 3m). The second layer is relatively low resistivity horizon extending along the entire profile and with nearly the same thickness, probably resulting from higher moisture content or water saturation, is mapped below this top soil layer. This layer thickness extends about 10 m.

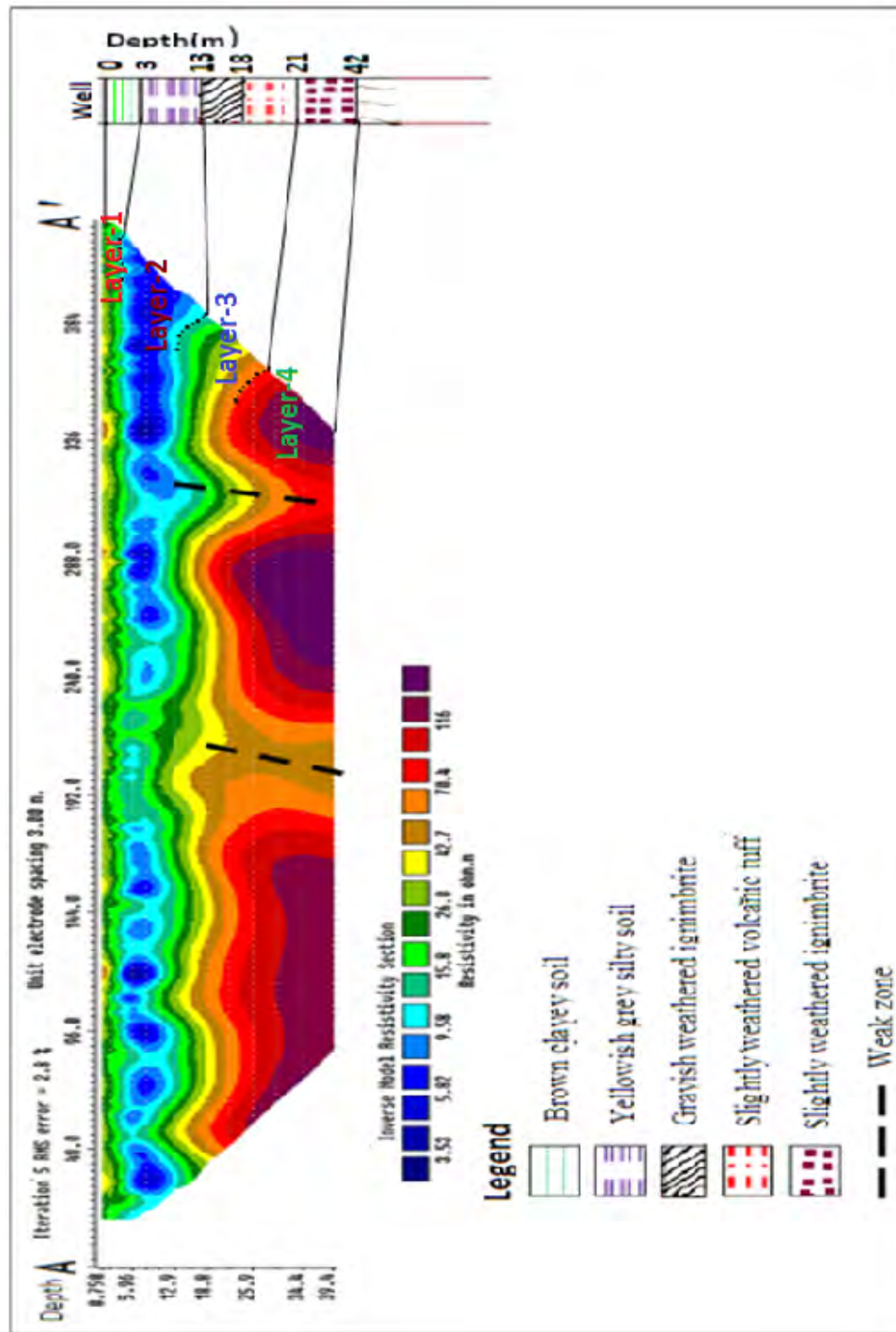


Fig. 5.1 Correlation of inverse model resistivity section along profile AA' and the Batena well.

The third zone is a transition zone showing variation in resistivity with depth and this represents the weathered and fractured bedrock horizons. This transition zone underlies relatively fresh bedrocks and its depth extends about 25m. The bottom stratum mapped with this survey is slightly weathered/relatively fresh bedrocks and extends for about 39.4m depth.

Two distinct areas of the low resistivity responses extending to depth are mapped on the profile. They are interpreted as weak zones within the ignimbrite unit that resulted in low resistivity responses due to high weathering activity. These are essential results from the point of view of the survey objectives.

Due to the absence of shallow and/or deep wells that are very important to verify geophysical investigations, lithologic log data from the only well in the area- the Batena well- has been used to correlate the electrical tomography results.

The correlation with geoelectric section of the profile AA' is shown on the right side of Fig. 5.1. The correlation depicts relatively low resistivity zone of topsoil matches with the brown clayey soil, the low resistivity zone of layer two correlate yellowish gray silty soil, and the transition zone of different weathering bedrocks correspond to grayish weathered ignimbrite and slightly weathered volcanic tuff, and the bottom stratum of slightly weathered/relatively fresh bedrocks corresponds to relatively fresh/slightly weathered ignimbrite to of the Batena well.

5.1.3 Profile BB'

Profile BB' runs parallel to the first Profile AA' and is about 150m from it. Its orientation is in the north-south direction and runs over a relatively flat ground, with construction being undertaken during the time of the survey. The resulting ERT section of this profile shown in the Fig.5.2 actually has the resistivity range of 2.74–106 Ωm and the inversion shows good quality data with the RMS error of 3.5% after 5 iterations. The profile describes the depth wise variation of low to high resistivity zones. Profile BB' is relatively similar to Profile AA', but in the Profile BB' different weathering zone of bedrock is shallower and more fractured than Profile AA'.

Thin topsoil is observed in the entire profile. The resistivity ranges 7.8 – 37 Ωm and this resistivity range is relatively greater than the underling layers due to the dry nature of the topsoil. Its thickness extends for about 4m in depth. The second zone or low resistivity layer is observed at the immediate depth below the dry topsoil. In this layer, continuous high moisture content was observed that probably will have slight effect on the building foundations i.e. the capillary pressure and capillary rise in fine-grained soil is greater and the soil moisture extends to the surface. The presence of moisture content decreases the resistivity of Earth materials and then the resistivity of this layer is about 2-10 Ωm .

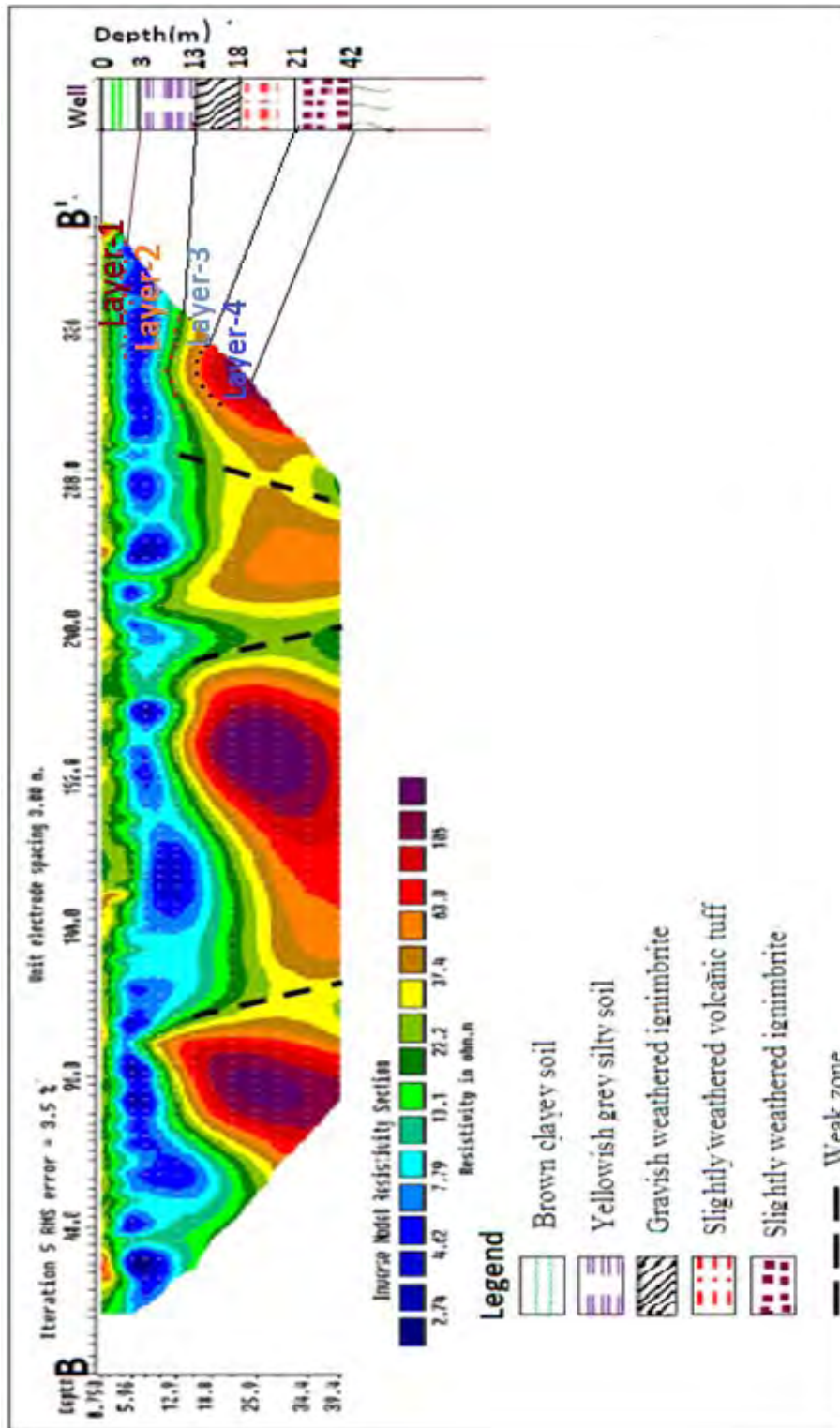


Fig. 5.2 Correlation of inverse model resistivity section of the profile BB' and the Batena well.

The third zone is alteration zones which characterizes variation in resistivity that corresponds to different weathering zones of bedrocks. These zones are highly affected by fractures along which high weathering activity was observed. The resistivity of these weathering zones ranges from 20 to 70Ωm and extends for about 15m in depth. The bottom geoelectric section

that overlies different weathering zones is relatively higher in resistivity and was interpreted as relatively fresh bedrocks. This relatively fresh bedrock extends to a depth of 39.4m and resistivity for this zone varies from 70 to 105 Ωm .

The resistivity contrast describes the areas of the low resistivity responses extending to the depth along the profile are mapped and interpreted as weak zones. The high weathering activity along the weak zones decreases the resistivity responses. These are very crucial areas for consideration of building design.

The geoelectric section of Profile BB' was also correlated with the Batena well and its correlation is shown in Fig. 5.2. The correlation shows relatively low resistivity zone of topsoil which matches with the brown clayey soil, the low resistivity zone of layer two correlates with yellowish gray silty soil, the transition zone of different weathering bedrocks (third layer) correspond to grayish weathered ignimbrite and a relatively fresh/slightly weathered volcanic tuff, and the bottom stratum of the geoelectric section corresponds to fresh/slightly weathered ignimbrite of the Batena well.

5.1.4 Profile CC'

This traverse is also oriented in nearly north south direction and runs almost parallel to the other two profiles. It is about 150m towards east from profile BB' and has again a total length of about 432m. The inversion results of Profile CC' are shown in Fig. 5.3 and overall resistivity ranges from 1.78 to 171 Ωm over the model section. The inversions of data give good result with RMS error of 4.3% after 6 iterations.

The profile has different resistivity stratification and is interpreted separately. The top thin resistivity sections are observed in both sides of geoelectric sections. At the central portion of the profile relatively lower resistive second layer is exposed on the surface. This dry nature of top soil extends to about 3m of depth and the resistivity value ranges from 24 to 50 Ωm . The second layer is low resistive thin zone of the profile. The low resistivity nature of this layer is due to the high moisture content that is present in the pore spaces of residual soils and it is observed at a very shallow depth. In the third resistivity variation zone, resistivity relatively increases (18-30 Ωm) and it has been interpreted as low permeable zone except for some portion of the layer where groundwater percolates along the fractures in to the fourth layer.

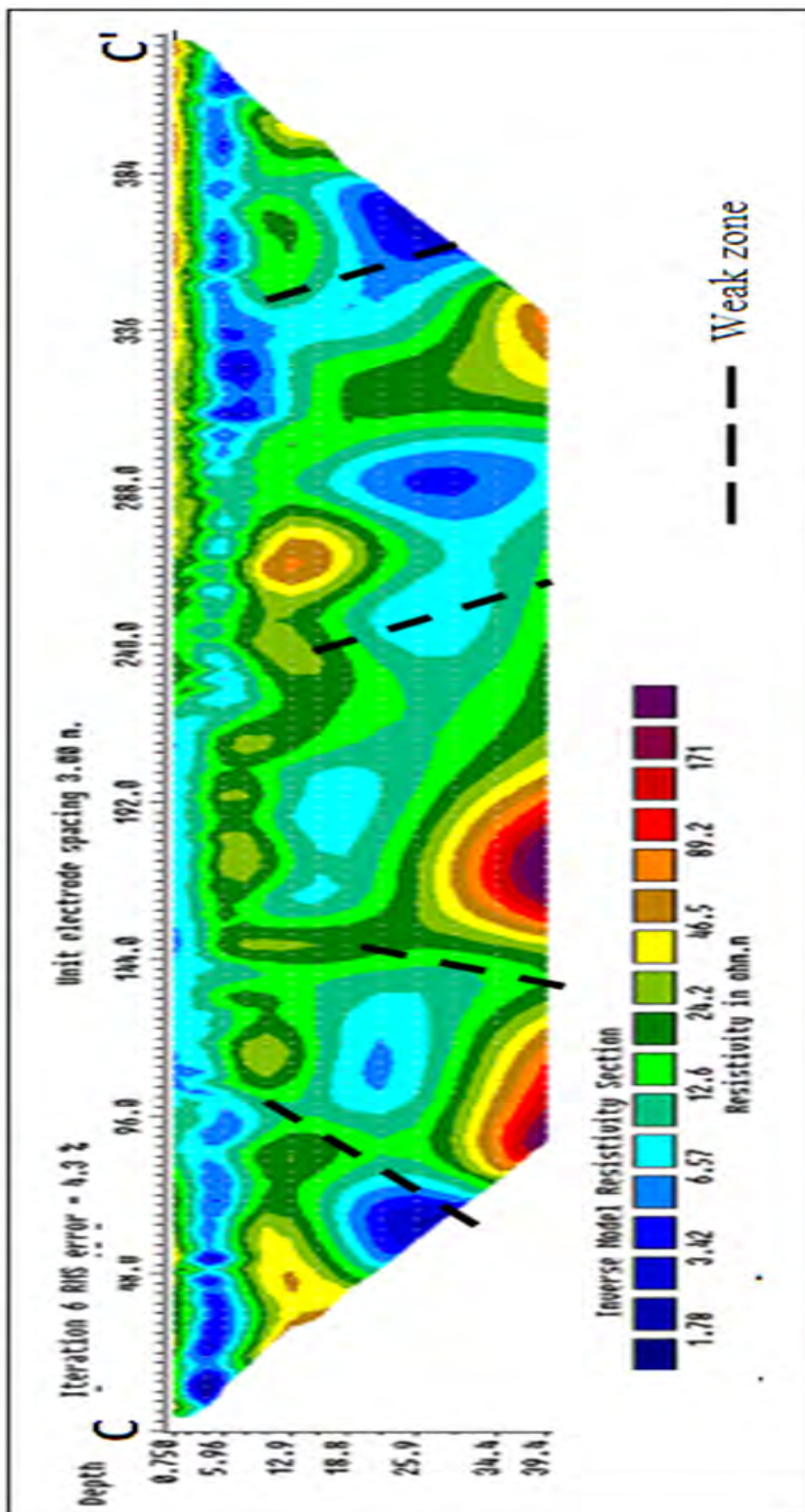


Fig. 5.3 Inverse model resistivity section of the profile CC'.

This layer extends for about 17m in depth. Three small blocks of relatively weathering resistant than the surrounding Earth materials are observed in the northern, central and southern part of the layer three of the profile CC'.

Also the low resistivity response of the fourth layer is due to the presence of local pockets of groundwater. This layer is highly saturated, especially along weak zones, than any other layers. Relative to the other layer it is very thick and extends for about 30m in depth. The alteration zone is observed at greater depth as compared to other profiles. The alteration layer of this profile mainly comprises of different resistivity stratification which corresponds to different weathering zones of bedrocks. This layer extends to about 34m in depth and the resistivity value varies from 20 to 100 Ωm . It is highly affected by weak zones along which the low resistive section goes to the depth. The bottom layer is relatively of higher resistivity which has been interpreted as slightly weathered to fresh bedrocks and extends to a depth of 39.4m. This layer is also affected by weak zone that increases weathering activity and extends the low resistive zone to the greater depth (39.4m). Relatively the fresh bedrock is observed in the profile however it is situated at the greater depth and to a limited extent.

Profile CC' has high electrical resistivity inhomogeneity in the subsurface feature that is difficult to be visualized from the geological point of view, as correlation with Baten well did not produced good results.

The low resistive zones (weak zones) are also identified and mapped in Fig. 5.3. In general, Profile CC is characterized by deep weak zones, limited extent of fresh to weathered bedrocks, thick residual soils and high moisture content. Due to these points, special consideration should be necessary during planning and designing of buildings along this profile.

5.1.5 Profile DD'

This is the fourth profile along which imaging data have been collected. This profile was chosen to run perpendicular to the other three profiles. The profile was intended to map the presence of structures oriented north-south or in a direction other than those mapped by the other three lines. This cross-profile was denoted as Profile DD' and its inverse model is shown in Fig.5.4. This profile runs from east to west and gives better perception of depth variation of low to high resistivity zones (1.43–7547 Ωm).

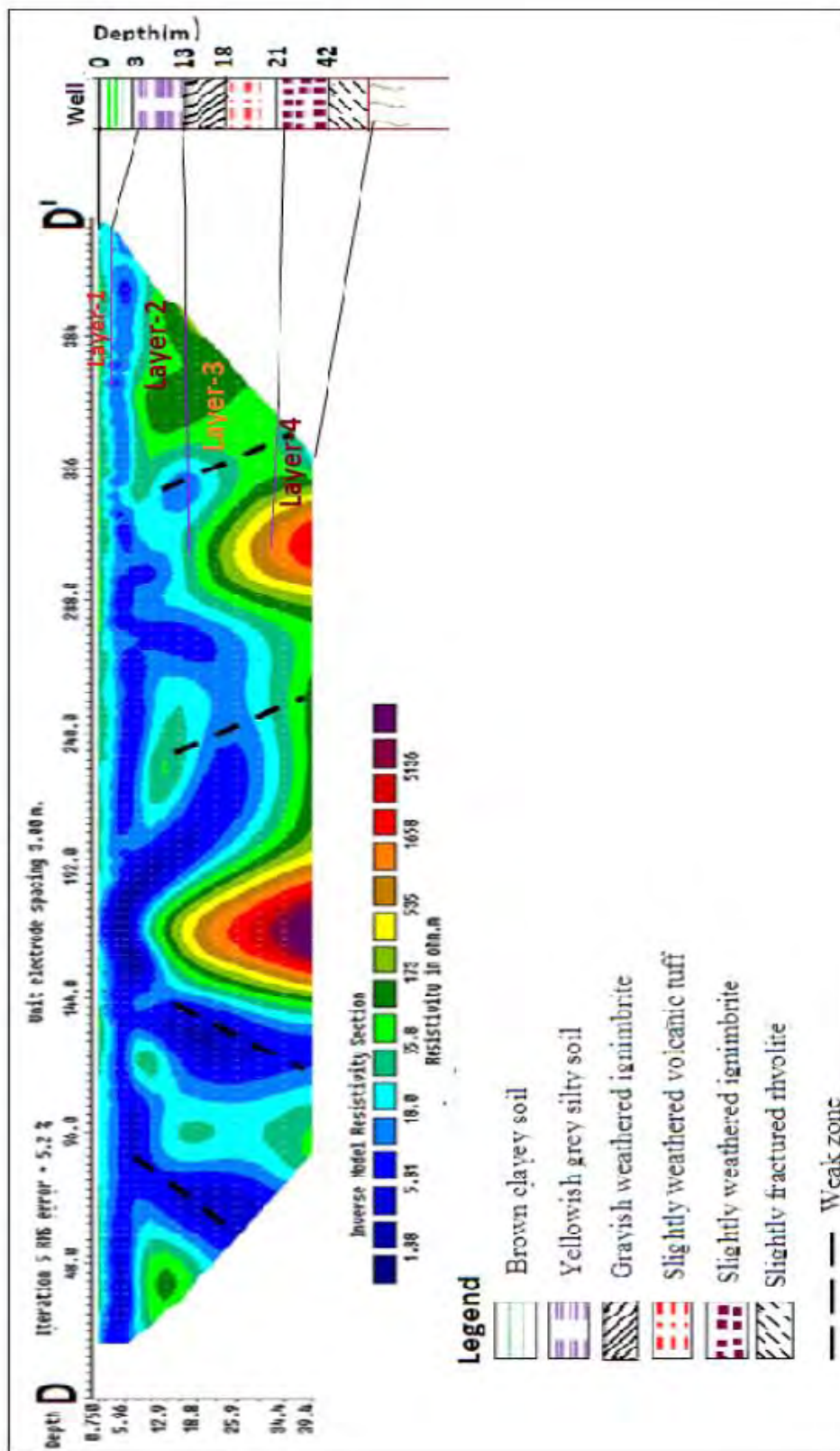


Fig. 5.4 Correlation of the inverse model resistivity section of the Profile DD' and the Batena well.

The greater resistivity variation has resulted due to anisotropy of Earth materials in different directions. The inversion of data gives good results with RMS error of 5.4% after 6 iterations showing again a good quality raw data. This inverse model resistivity section has four major resistivity layers that correspond to different geologic layers.

The thin top layer of resistivity range 18-55 Ωm is interpreted as dry soil. The overall thickness of this top layer is nearly the same over the entire profile (about 3m). The second layer of relatively very low resistivity zone is interpreted as saturated zone or zone with high moisture content. This zone is continuously observed in the profile and extends for about 11m in depth.

The alteration zone shows variation in resistivity with depth which represents different weathering bedrock horizons. Its depth extends for about 25m. The bottom geoelectric section is of very high resistivity variation and is interpreted as fresh bedrock that overlies different weathering horizons. The fresh bed rock of this profile extends for about 23m in depth.

Further, four distinct areas of the low resistivity responses extends to depth are mapped on the profile. They are interpreted as weak zones within the ignimbrite unit. This zone has resulted in to low resistivity responses due to high weathering activity which extending to a considerable depth. This identified weak zone may cause a measurable effect on building foundations.

Similar to Profile AA and Profile BB, correlation of geoelectric section with Batena well was done for Profile DD (Fig. 5.4). The correlation depicts low resistivity zone of topsoil which matches with the brown clayey soil, relatively very low resistivity zone of layer two correlate yellowish gray silty soil, and the alteration zone of bedrock corresponds to grayish weathered ignimbrite and slightly weathered volcanic tuff. The bottom stratum of high resistive fresh bedrock corresponds to relatively fresh/slightly weathered ignimbrite and slightly fractured rhyolite of the Batena well.

5.1.6 Stacked Apparent Resistivity Pseudosection

The stacked apparent resistivity pseudosection map (Fig. 5.5) shows the sub-surface resistivity section of the entire study area which was constructed by extracting apparent resistivity values of all profiles at the same depth of investigations. In order to obtain a more

reliable and realistic representation of the possible subsurface structures, five depth slices (3.9m, 8.6m, 18.8m, 33.3m and 39.4m) were selected from the electrical resistivity tomography data to characterizes the sub-surface. The four traverses over which the resistivity imaging surveys were conducted are shown on the top slice for references.

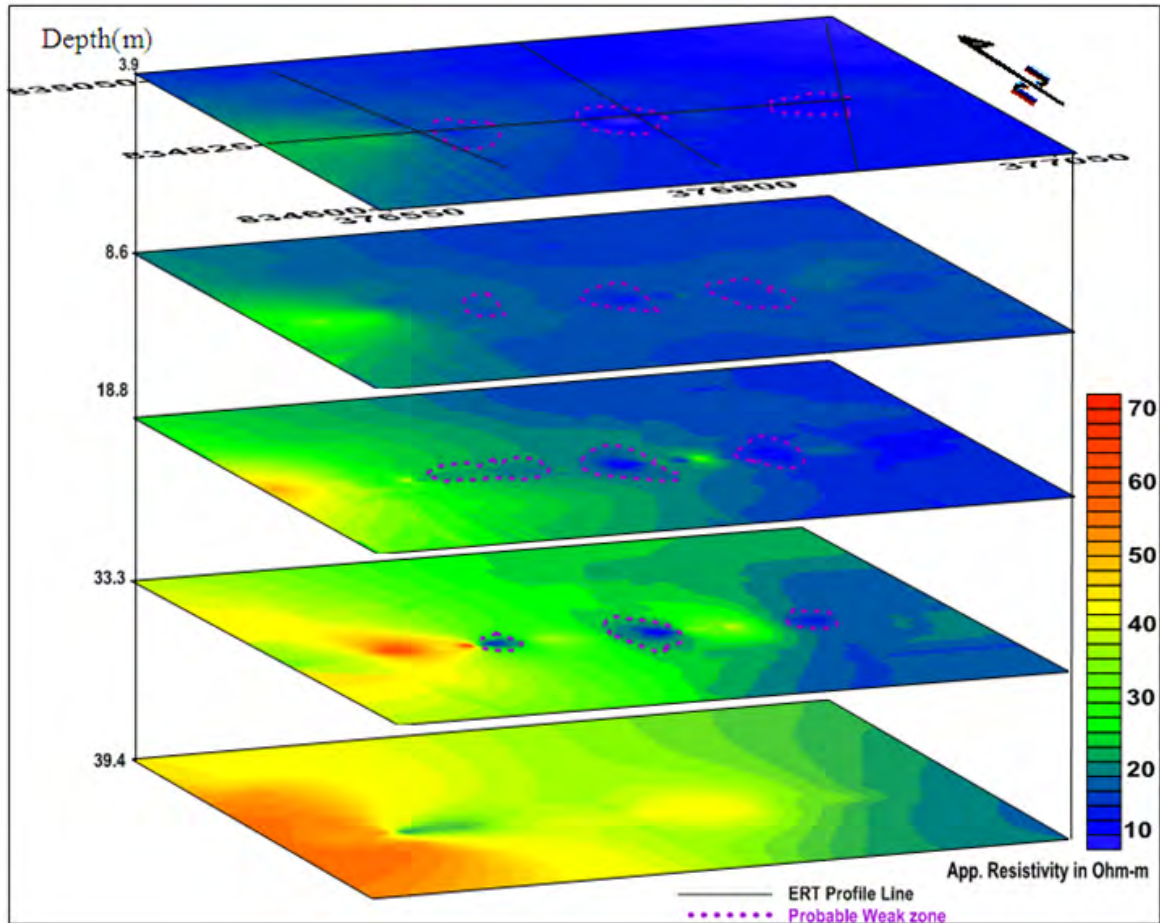


Fig. 5.5 Stacked apparent resistivity map of construction site

Depth-wise, the thick residual soil, the weathered and fresh bedrocks and localized weak zone areas are identified based on the apparent resistivity variations of the stacked map of the survey area. The first (3.9m depth) and second (8.6m depth) slice sections show extensive low resistivity regions over the area except small portions of relatively greater resistivity is observed in the western region.

The resistivities of the study area are gradationally decreases towards the eastern direction. Relatively higher resistivity of the weathered to fresh bedrocks is observed nearly shallow depths in the western side of the survey area which is situated at the downstream of the Batena River.

Three distinct low resistivity weak zones marked with dashed ellipses are observed from the surface to 33.3m depths are interpreted as fractured/weak zone that pose problem for building foundation and are regions where special design considerations are essential.

5.1.8 Soil Corrosivity of the study area

The present building site is situated in the tropical region where high temperature and rainfall varies. The area is characterized by thick residual soils that were probably originated from in-situ weathering of volcanic rocks. Moisture content of the present construction site partially fills the pore spaces of the topsoil and open spaces of weak zones that were clearly shown in the inverse model resistivity section. Moisture content decreases the resistivity of the soils. The resistivity of the soil of the study area ranges from 1.78 to 70 Ω m. This low resistivity values of soils may severely corrode the footing steel structures. Therefore, the civil engineer should consider the type of foundation material during the construction of proposed buildings.

5.2 Results and Interpretation of Magnetic Data

Magnetic survey were conducted on the study area along the traverses over which the electrical imaging survey were carried out and additionally on distributed points so as to get a good representation of the magnetic response of the area. The data from these readings were manually filtered and corrected for diurnal variations. The IGRF value of the base station obtained from internationally posted data were later used to obtain the magnetic anomalies. The application of magnetic survey for the identification of geologic structures and contact between different lithologic units was well established. Accordingly, the resulting magnetic anomaly map (Fig. 5.6) clearly shows good anomaly contrast where clear variation in magnetic susceptibility of sub-surface geology of the building site can be observed. This relatively high response of magnetic anomaly is probably due to the result of moderate to slightly magnetized volcanic rocks that could be found in the area while the low magnetic responses are the effect of geologically weak zone and weathering of bedrocks.

5.2.1 Magnetic Anomaly Map

The magnetic data points over which data have been collected (both nearly straight lines which denoted as Profile AA', BB', CC' and DD' and also over distributed points) and four regions of magnetic anomaly responses are shown in Fig. 5.6. Zone A of the magnetic anomaly map shows higher magnetic anomaly response and covers small portion of the

construction site. Zone B exhibit medium magnetic anomaly responses and cover relatively greater portion of the study area. Zone C depicts low magnetic anomaly responses which is relatively affected by geologic structures and covers relatively large area of the construction site. Zone D shows very low magnetic anomaly responses where weak zones or geologic structures have highly affect the rock units. Zone A and B are relatively of good bearing capacity zones from magnetic investigation point of view whereas region C and D are of low bearing capacity due to fracturing and weathering of rock unit. However, the observed bedrocks are not shallow enough for building foundations, especially for shallow foundations.

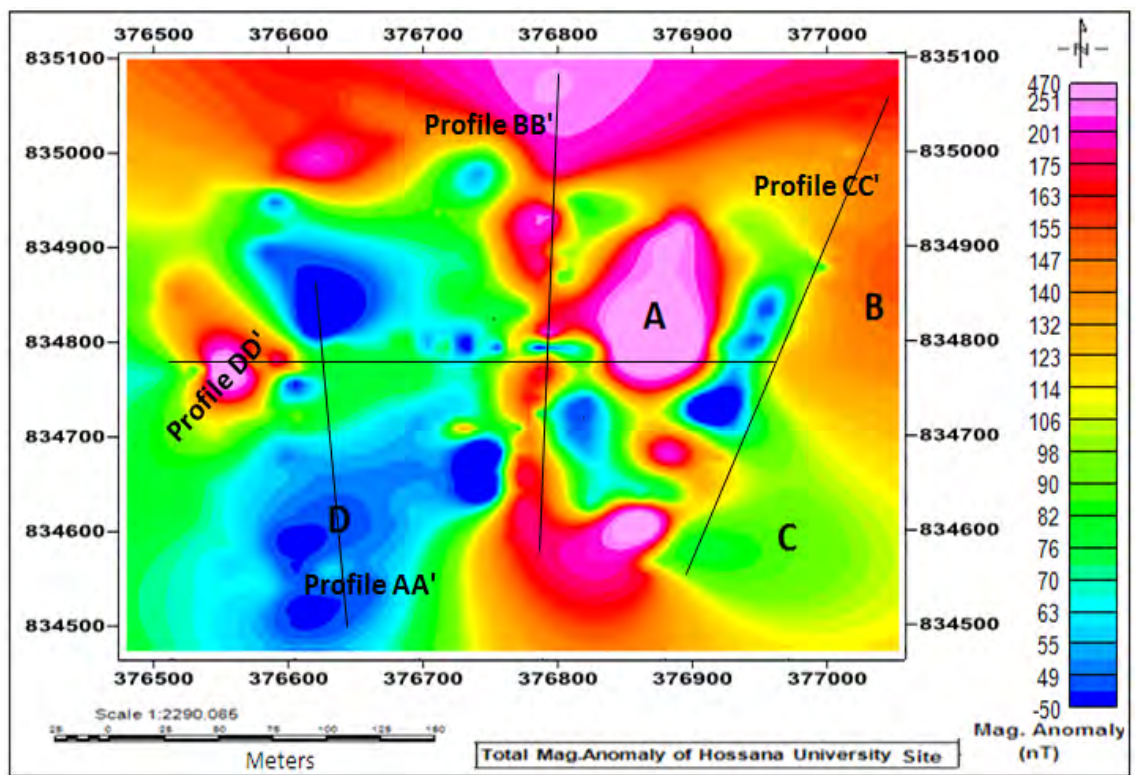


Fig. 5.6 Total magnetic anomaly map of the study area.

5.2.2 Analytical Signal Map

The analytical signal map enhances near surface anomalies at the expense of deeper anomalies and is good at locating the edges of shallow bodies. The analytical signal map depicts the removal of deeper sources of long wavelength and increasing of the clarity of shallow features that obscured by nearby anomalies. The amplitude of analytic signal of the total magnetic anomaly produces maxima over magnetic contacts. Different geological structures are clearly identified and mapped on analytical signal map of Fig. 5.7.

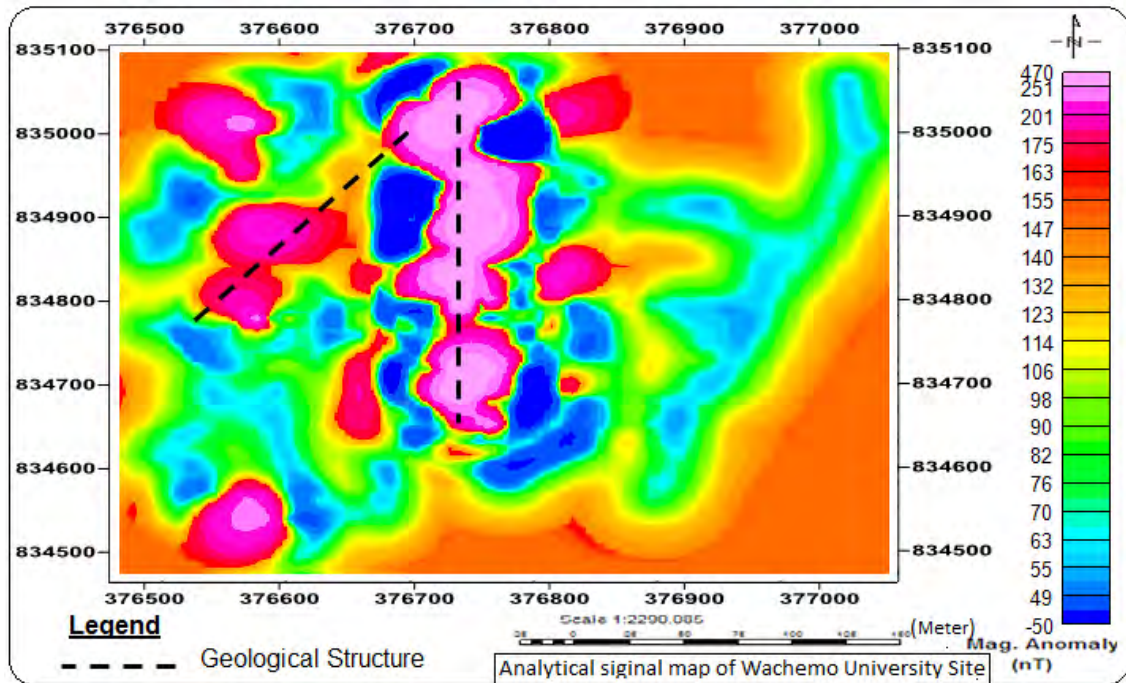


Fig. 5.7 Analytical anomaly map of the study area.

5.1.7 Combined Interpretation of Magnetic and Electrical Results for Identifications of Weak Zones

Weak zone can pose number of problems for building foundation both for low and high-rise buildings. To clearly identify and locate the weak zone/probable fault line, both magnetic and ERT survey were interpreted in combination and the results are discussed in the following paragraphs.

In magnetic survey plot, a weak zone of low magnetic anomaly was observed. This may be due to the alteration effects that were introduced by the effect of intensive weathering of bedrocks. This causes the high magnetic susceptibility of Earth materials into low magnetic susceptible materials. In general, good magnetic susceptibility contrast characterizes the building site, as the site is located in volcanic terrains. Further, within these areas low magnetic responses were clearly observed.

From the ERT survey, low resistivity weak zone were successfully identified based on the high resistivity contrast between the surrounding rocks. These low resistivity zones were observed along the fractured and weathered zone of sub-surface Earth materials. Moisture

content present within the open spaces of this faulted and jointed section further increases the weathering activity.

Based on the above basic principles, in the present study, correlation of the magnetic anomaly and inverse model resistivity section were carried out. This was mainly done to verify the presence and location of the weak zones. With regards to these weak zones special attention would be necessary during designing and construction of the foundation for the proposed buildings.

Since the magnetic survey of Profile AA was not done identical to lines of ERT survey of Profile AA therefore correlation of the magnetic anomaly and inverse model section has not been included for interpretation. However, in the other three traverses, four distinct weak zones were identified and are shown in Fig. 5.8, 5.9 and 5.10. The fracture and probable fault zones which are sub-vertical are difficult to be located by drilling. The integration of electrical resistivity tomography and magnetic method can overcome this problem. Thus, geophysical techniques may be very useful in supplementing information during building site characterizations.

5.3 Result and Interpretation of Geotechnical Data

The present study area of Wachemo University site was selected in an area of thick residual soils. Characterizing and classifying these soils are mandatory to know the physical property of the foundation soils. In the present study, different laboratory tests were performed to estimate/ determine the physical properties of the resident soils. These physical properties are called index properties and include soil moisture content, specific gravity, consistency limit, activity, free swell and grain size distribution. Other parameters such as soil descriptions, organic matter content, shear strength and compressibility, and suffusion and collapsibility are also important for characterizing the study soil and these are also included in the discussions. The results were obtained from the tests made by Construction Design Share Company (CDSC, 2010).

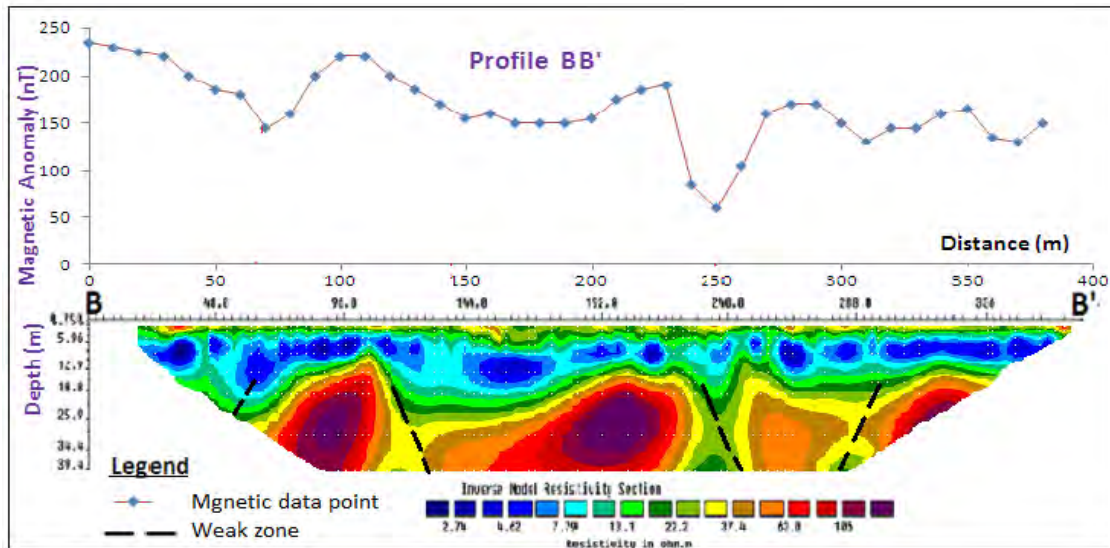


Fig. 5.8 Correlation of Magnetic anomaly with Geo-electric section of profile BB'.

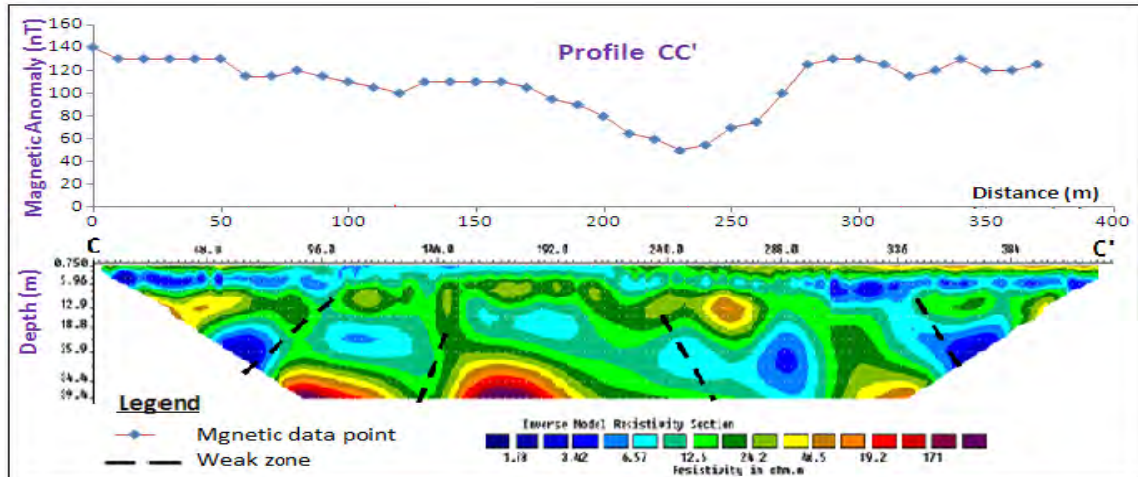


Fig. 5.9 Correlation of Magnetic anomaly with Geo-electric section of profile CC'.

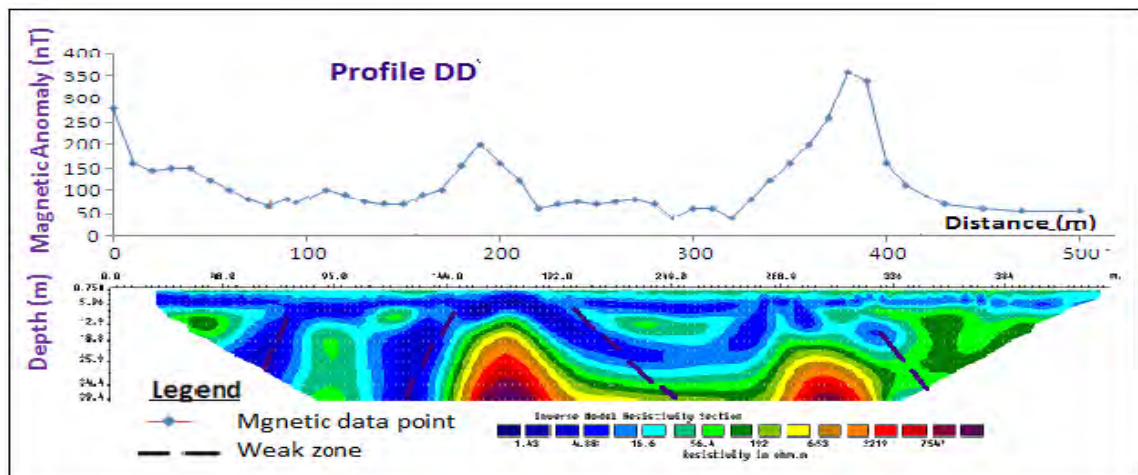


Fig. 5.10 Correlation of magnetic anomaly with the Geo-electric section of Profile DD'

5.3.1 Soil Description of the study area

The study area soils are residual in origin which was formed by in-situ weathering of volcanic rocks. The soil of the area comprises silty clay, clayey silt and sandy silt as shown in laboratory sheet log presented at Annex-E.

Silty Clay Soil: These soils constitute the upper most part of residual soils. The sieve analysis of these soil type shows: 46.0% clay, 42.3% silt and 16.6% sand fraction. These soils are grey in color and possess intermediate plasticity. In the field these soils are soft that can easily be molded with light finger pressure.

Clayey Silt Soil: These soils were observed below the clayey silt in hand-dug well (pit test). These soils are light brown to grey in color and medium dense to firm in strength. The grading characteristic of these soils from sieve analysis shows 23.3–36.6% clay, 40.7–65.7% silt and 4.7–10.8% of sand fraction.

Sandy Silt Soil: These soils were situated at the bottom of test pit 6. These soils are light brown to grey in color and medium dense in strength. The grading characteristic of these soils from sieve analysis shows 3.3–9.8–% clay, 65.8–78.1% silt and 10.1–12.1 % of sand fraction.

5.3.2 Index Properties

To characterize the engineering properties of the soils of the study area, laboratory index test were conducted for samples from nine representative test pits. The results and description of different index properties are presented in the following section.

5.3.2.1 Moisture Content

Moisture content affects the settlement condition; shear strength and suitability of soil for compaction. Moreover, the swelling-shrinkage condition of the soil is related to its moisture content and its change with time. During the present study, natural moisture content of soils was determined for the representative soil samples from the study area. The results thus obtained (Table 5.1) clearly indicates that the sandy silt soils have a moisture content of 6.46–10.91%, silty clay soils have 17.37% and clayey silt soils have 11.45–21.65%. Continuous moisture determinations are also shown in the inverse model resistivity sections.

Table 5.1 Natural moisture content, specific gravity, particle size analysis and resulted soil type of the study area soils

N ^o	TP N ^o	Depth (m)	NMC (%)	Specific Gravity	Particle Size Analysis			Soil Type
					%Sand	%Silt	%Clay	
1	1.00	3.50	10.91	2.56	12.14	78.08	9.85	Sandy silt
2	3.00	4.00	19.11	2.50	10.88	65.79	23.33	Clayey silt
3	5.00	3.00	21.65	2.50	8.46	64.87	26.67	Clayey silt
4	6.00	3.00	6.46	2.56	9.88	86.84	3.28	Sandy silt
5	7.00	2.50	17.37	2.55	16.62	42.32	46.06	Silty clay
6	11.00	2.50	19.85	2.55	4.96	58.50	36.19	Clayey silt
7	14.00	4.00	21.27	2.50	7.30	56.03	36.67	Clayey silt
8	18.00	3.00	13.39	2.55	4.72	62.38	32.90	Clayey silt
9	20.0	2.50	11.45	2.55	7.86	62.38	32.90	Clayey silt

5.3.2.2 Specific Gravity

The specific gravity for various soil samples from the study area is presented in Table 5.1. All the soil samples from the study area have nearly similar specific gravity which ranges from 2.50 to 2.56. Sandy silt soils possess relatively greater specific gravity (2.56%) as compared to other soil types.

5.3.2.3 Particle Size Analysis

Grain size analysis results for soil samples from the study area are presented in Table 5.1. The study area soil comprises 4.72–16.62% Sand and 40.76–78.08% Silt fraction. The dominant particle size in the soils from the study area is silt but considerable clay fraction (3.28–46.06%) is also present in the soils of the study area. In none of the soil samples Gravel fraction was observed.

A combined sieve and sedimentation procedure enable continuous particle size distribution curve for the given soil sample. Thus, during the present study combined sieve and sedimentation procedure enabled to prepare grain size distribution curve for the soil samples to indicate the proportion of clay, silt and sand fraction. The grain size distribution curve for soil samples from 9 test pits in the study area is presented at Annex-F.

5.3.2.4 Atterberg Limits

The engineering properties of fine-grained soils are generally related to these index properties. To characterize engineering properties of soils, Atterberg limit of selected soil

samples were determined in the laboratory (Table 5.2). From the results of plastic limit and liquid limit an important parameter, plasticity index was derived. The liquid limit is a good indicator for the compressibility of the soils. The liquid limit of the soils from the study area ranges from 38.59 to 54.59% whereas; plasticity limit ranges from 22.32 to 40.79%, respectively.

Table 5.2 Consistency limits for the soils from the study area

No	TP No	Depth (m)	NMC (%)	Atterberg Limit		
				LL (%)	PL (%)	PI (%)
1	1.00	3.50	10.91	48.08	39.07	9.01
2	3.00	4.00	19.11	51.37	31.02	20.35
3	5.00	3.00	21.65	44.54	26.60	17.94
4	6.00	3.00	6.46	43.25	34.15	9.10
5	7.00	2.50	17.37	54.59	40.79	13.80
6	11.00	2.50	19.85	38.59	22.60	15.99
7	14.00	4.00	21.27	39.89	22.32	17.57
8	18.00	3.00	13.39	45.23	28.01	17.22
9	20.00	2.50	11.45	41.73	30.19	11.54

The higher the plasticity index the greater the amount of fines and greater will be the engineering problems associated with such soil particularly if such soils forms the foundation for buildings. The plasticity index of the soils from the study area ranges from 9.01 to 20.35%.

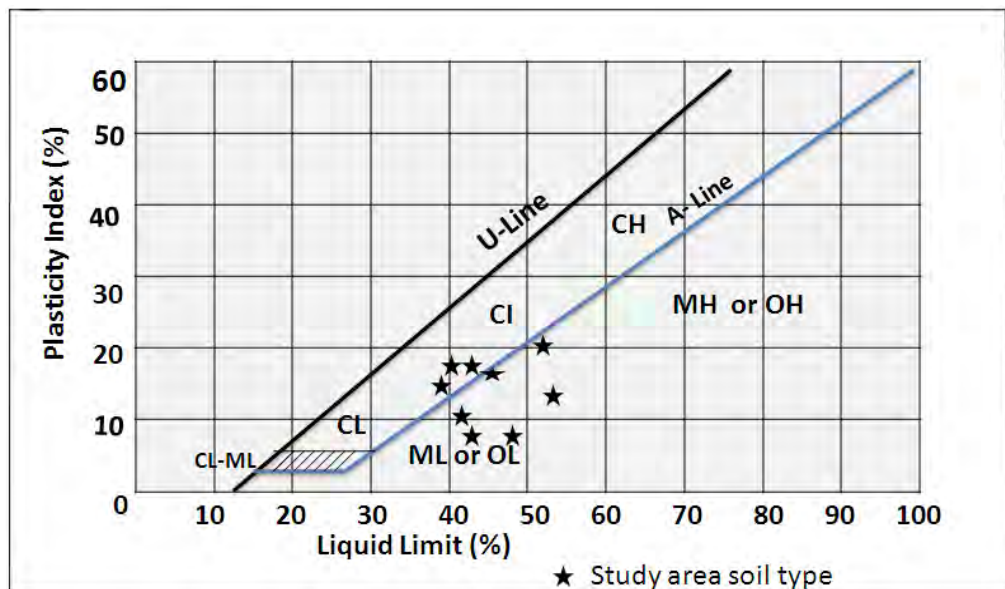


Fig. 5.11 Plasticity chart

About 33.3% of soils from the study area exhibit intermediate plasticity of clayey soils where as 66.7% shows low to high plasticity of silty soils (Fig. 5.11). All soil samples from the study area falls in low plasticity silts to intermediate plasticity clays, except for two soil samples which shows high plasticity silt soils. Low to intermediate plasticity soils of the study area shows good to fair engineering property but high plasticity silt show poor engineering property.

5.3.2.5 Activity of Clay Soil

The activity of clay soils of the study area ranges from 0.299 to 2.774 (Table 5.3). The results indicate that 66.7% of soils are inactive, 22.2% of soils are normal and 11.1% of soils are active. Only one sample exhibit active clay property thus indicates high volume change during swelling or shrinkage process. In general, the soils of the study area possess normal to inactive nature as far as activities are concerned. Therefore, with respect to activity potential of the soils of the study area is concerned the soils possess good engineering property for building foundation.

Table 5.3 Activity of clay and Expansion Potential

<i>N^o</i>	<i>TP N^o</i>	<i>Depth (m)</i>	<i>Clay (%)</i>	<i>PL (%)</i>	<i>Activity of clay</i>	<i>Potential of Expansion</i>
1	1.00	3.50	9.85	9.01	0.915	Normal
2	3.00	4.00	23.33	20.35	0.872	»
3	5.00	3.00	26.67	17.94	0.673	Inactive
4	6.00	3.00	3.28	9.10	2.774	Active
5	7.00	2.50	46.06	13.80	0.299	Inactive
6	11.00	2.50	36.19	15.99	0.442	»
7	14.00	4.00	36.67	17.57	0.479	»
8	18.00	3.00	32.90	17.22	0.523	»
9	20.00	2.50	32.90	11.54	0.351	»

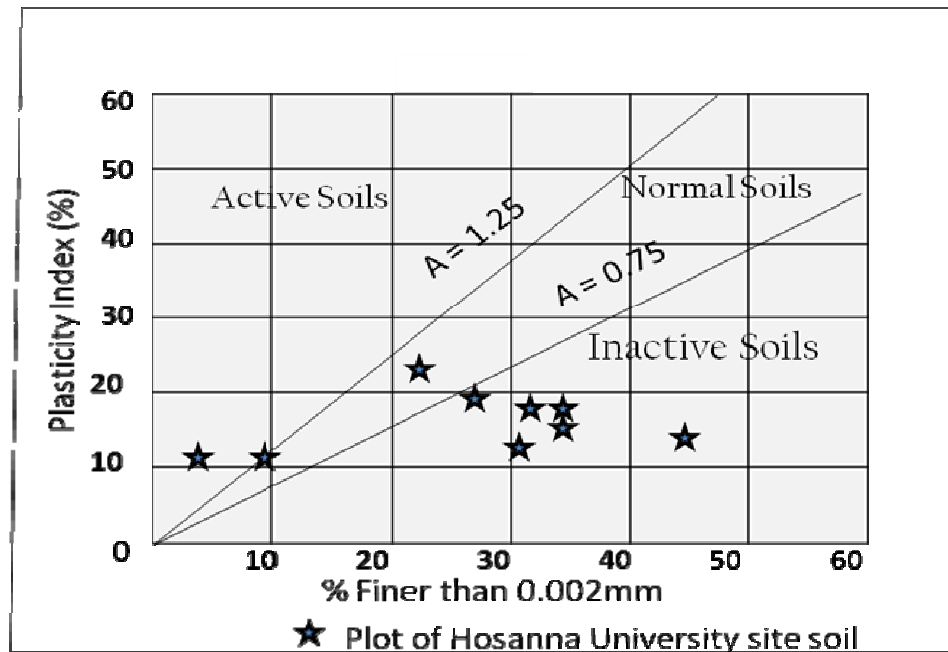


Fig. 5.12 Activity chart for soil samples from the study area

5.3.3 Soil Classification

The empirical boundary designed by A-line in the plasticity chart separates clays from silts (Reference). About 33.3% of the soils from the study area were plotted above A-line that exhibit intermediate plasticity of clayey (CI) soils where the liquid limit values are less than 50%. The remaining 66.7% of soil lies below A-line and fall in silty soil. About 67% of the silty soils of the study area is low plastic whereas, 33% of silts are highly plastic (Fig. 5.11).

5.3.4 Swelling Index

Many tests and methods have been developed for estimating the potential swell of soils. These methods include both indirect and direct measurements. In this study, indirect methods were used to evaluate the swelling nature of the soils from the study area. Indirect methods of swell classification, which involves the use of soil properties and classification schemes to estimate swell potential, are based on the plasticity and liquid limit approach of Holtz and Gibbs (1956). The change in moisture contents (Atterberg limit) of a soil sample can be used to indicate the degree for potential swell.

Table 5.4 Determination of Swelling Potential of soil using Liquid Limit and Plastic Limit

No	Test Pit No	Depth (m)	Moisture Content%	LL (%)	PL (%)	Swelling Potential
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1	1.00	3.50	10.91	48.08	39.07	Medium to High
2	3.00	4.00	19.11	51.37	31.02	Medium to High
3	5.00	3.00	21.65	44.54	26.60	Medium
4	6.00	3.00	6.46	43.25	34.15	Medium to High
5	7.00	2.50	17.37	54.59	40.79	Medium to High
6	11.00	2.50	19.85	38.59	22.60	Medium
7	14.00	4.00	21.27	39.89	22.32	Medium
8	18.00	3.00	13.39	45.23	28.00	Medium
9	20.00	2.50	11.45	41.73	30.19	Medium to High

Based on the above approach the soils of the study area indicate 44.4% of medium and 55.6% of medium to high swelling potential. The free swell test conducted on the collected samples shows that the soil has medium to high capacity for volume change due to the presence and absence of moisture condition in the area.

5.3.5 Shear Strength Test

The shear strength and stiffness of soil determines whether soil will be stable or not. Knowledge of soil strength is necessary to determine slope stability of building foundation. High shear strength soils possess better bearing capacity for building foundation. In the present study, systematic sampling was done to conduct test on soil samples to know its shear strength. Results of direct shear strength tests are presented in Table 5.5. The results clearly shows that under unconsolidated state the cohesion of the soil varies from 8 to 26 KN/M², whereas the angle of shearing resistance varies from 19° to 23°. Angle of shearing resistance and cohesion of the study area soil implies good to fair workability for engineering structures.

Table 5.5 Engineering properties of soils from the study area

No	TP No	Depth (m)	Bulk Density (g/cm ³)	Dry Density (g/cm ³)	Shear strength	
					C KN/m ²	Ø Degree
1	1.00	3.50	1.430	1.289	13	21
2	3.00	4.00	1.443	1.244	16	21
4	6.00	3.00	1.434	1.347	8	23
6	11.00	2.50	1.518	1.266	26	19
8	16.00	3.00	1.443	1.244	15	22

5.3.6 Bearing Capacity and Settlement Potential of the study area soil

In the present study, an attempt has been made to classify the study foundation soils based on visual interpretation and index properties. Grain size analysis of the soils from the study area indicates that silt and clay size particles are the dominant fraction and a reasonable proportion

of sand is also present. The liquid limit of samples indicate medium ranges (38.59 – 54.59%) and the plasticity (Fig. 5.11) exhibits 33.3% medium plasticity of clay, 44.4% low plasticity of silt and 22.2% high plasticity of silt.

According to general engineering suitability chart presented at Annex-D, the CI soil demonstrates impervious permeability, medium compressibility and fair shear strength. The ML soil demonstrates semi-pervious to impervious permeability, medium compressibility and fair shear strength. The MH soil exhibits semi-pervious to impervious permeability, high compressibility and fair to poor shear strength. Therefore, the study area soils exhibits 33.3% good to fair, 44.4% fair and 22.2% poor bearing capacity. The study area soils have cohesion in the range of 8 to 26 KN/M² and angle of shearing resistance in the range of 19° to 23. Fair shear strength indicates fair bearing capacity of the study soil. Generally, the construction site soils have fair bearing capacity from bearing capacity and settlement potential point of view.

5.4 Groundwater Condition

The study area is situated on the high-altitude plateau at the margin of Main Ethiopia Rift valley with pyroclastic rocks forming the dominant rock units. These rocks are highly weathered and fractured with high permeability at places. The water bearing formations for the study area and the surrounding areas are basaltic rocks that overlain pyroclastic rocks.

An international NGO, Children's Home Society, conducted VES in the northern margin of Hosanna University building site to study the groundwater potential of the area (Children's Home Society, 2009). From the results, the subsurface of the area is mapped to have different resistivity layers. The very low resistivity layer (3.5 ohm-m) with a thickness of 147.6m at the depth of 89.2-236.8m is interpreted as highly weathered and fractured water bearing ignimbrite which is similar to geological log of Batena well where the depth of static water level is 132.5m. 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 arrive 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 University 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 northern part of University Site is presented at Annex-G.

5.5 Recent Earthquakes in the Study area

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 causes the ground vibration in the study area rises from Shashogo worada, which is situated about 30km east (towards MER) of the construction site and Hossaina town.

Among the significant earthquakes which occurred in the study area are the 2010 and 2011 earthquakes of magnitudes 5.6 and 5.1, respectively. They are one of the major earthquakes recorded in Ethiopia. These greater earthquakes are happened to break the thicker lithosphere of rift margins that develops greater stress than thin lithosphere of the rift center. They causes a visible crack on the buildings, some window glasses and smaller furniture's were fall down and broken, and many people were injured simple to medium. During the earthquake taller buildings tend to shake for longer period than smaller buildings as a result of these more measurable cracks were occurred in multi-story buildings of the study area. From the seismic hazard map of Ethiopia, the project site falls almost at the boundary of zone three near to the zone four as shown in Fig. 2.4. Throughout the earthquake liquefactions were not observed due to the absence of significant amount of sand and shallow groundwater. The thick soil of the study area may amplify the seismic wave that arose during the earthquakes. Therefore, the civil engineers should consider the present construction site to be selected in thick residual soils and seismically active zone.

5.6 Overall Assessment of the Building Foundation Site

Combination of geophysical and geotechnical investigations gives respectable results for characterization of the proposed building foundation site. Profiles AA , BB and DD have nearly similar geoelectric sections. The upper two layers of these profiles are low resistive zones and correspond to clayey and silty soils of Batena well. This indicates that the shallow depth of construction site is covered by low resistivity clayey and silty soil. These

thick soils of the study area may amplify the seismic wave that arose during the earthquakes. Additionally the low resistivity values of soils may severely corrode the footing steel structures.

The high magnetic responses are observed in the study area where fresh to slightly weathered bedrocks are present at shallow depth. However, the observed bedrocks are not shallow enough for building foundations, especially for shallow foundations. Geoelectric section and analytical magnetic anomaly map clearly identify different geological structures. The present studied project site is highly affected by these geologic structures. Therefore, building foundation should be selected away from the geological structures.

All soil samples from the study area falls in low plasticity silts to intermediate clays, except for two soil samples which shows high plasticity silt soils. Low to intermediate plasticity soils of the study area shows good to fair engineering property but high plasticity silt show poor engineering property. The soils of the study area possess normal to inactive nature as far as activities are concerned. Therefore, with respect to activity potential of the soils of the study area is concerned the soils possess good engineering property for building foundation. The free swell test conducted on the collected samples shows that the soil has medium to high capacity for volume change. Angle of shearing resistance and cohesion of the study area soil implies good to fair workability for engineering structures. According to general engineering suitability chart presented at Annex-D, the study area soils exhibits 33.3% good to fair, 44.4% fair and 22.2% poor bearing capacity.

Generally, the geophysical investigation detected that the material at shallow depth of the project site is mainly clayey and silty soils. Thus, proper estimation of bearing capacity of these soils is relatively poor foundation material from geophysical investigation point of view but geotechnical investigation observed that the project site soils are fair bearing capacity of building foundation. Therefore, the study area soil is relatively poor to fair bearing capacity based on geophysical and geotechnical point of view. These soils may be suitable for adequately designed low-rise buildings.

6.1 Conclusion

Wachemo (Hosanna) University, located northeast of Hossana town in southern Ethiopia proposes to construct new buildings for future expansion of campus. In order to examine the suitability of the foundation condition for the new building site at Wachemo University campus a combination of geophysical and geotechnical investigation was carried out during the present study. Besides, through the present study an attempt is being made to utilize the geophysical techniques in building foundation studies and to assess its applicability in supplementing the geotechnical studies.

The geophysical techniques employed for the present study include high-resolution Electrical Resistivity Tomography (ERT) and total field magnetic surveys. The electrical surveys were carried out over the four profiles which were appropriately selected to cover the proposed building sites. Similarly magnetic survey were conducted along the profiles over which the electrical imaging survey were carried out except Profile AA'.

Three geoelectric sections were correlated with lithologic log data of the Batena well. This interpretation revealed good correlation between geo-electric sections and lithologic log data. The correlation of geo-electric sections of profile AA and BB with the Batena well lithologic log data represents almost similar features. Further, correlation of profile DD revealed that the bottom stratum of geo-electric section of high resistive fresh bedrock which corresponds to relatively fresh/slightly weathered ignimbrite and slightly fractured rhyolite of the Batena well. The layers with relatively higher resistivity values represent competent strata with good bearing capacity. Thus, the weathered bedrock which has shown relatively higher resistivity responses possess good bearing capacity in comparison to upper layers of clayey and silty soils which has exhibited lower resistivity responses. The layers with high resistivity response represent fresh bedrock with excellent bearing capacity but such layers were observed at a greater depth with limited extent.

Through the geophysical investigation it has been observed that the material at shallow depth is mainly clayey and silty soils. Thus, proper estimation of bearing capacity of this relatively poor foundation material is required so that adequate building foundation can be designed.

The stacked apparent resistivity section indicates that the western portions of the study area may provide better bearing capacity for building foundation than the eastern portion. Further, it is also anticipated that the strata with low resistivity may possess corrosive potential which may severely affect the steel structures in building foundation. Therefore, while designing the footing for proposed buildings proper care must be taken to protect it from the possible corrosive effect within strata of low resistivity.

Magnetic anomaly map prepared during the present study exhibits good anomaly contrast. From this it may be deduced that high magnetic anomaly responses are the results of fresh igneous rocks whereas, low magnetic anomaly responses are resulted due to weak zones and high degree of weathering in rocks. Analytic signal map clearly identified and mapped a contrast between lithological contacts and geologic structures. These geological structures may have possible adverse effect on the building foundation. The integration of electrical resistivity tomography and magnetic method identifies the exact location of hazardous/weak zones.

In order to know the physical properties of the foundation soils the soils of the study area were characterized and classified based on visual interpretation and different laboratory tests. In total soil samples from 9 test pits were tested for specific gravity, natural moisture content, grain size distribution, Atterburg limits and swelling potential.

The test results indicate that the specific gravity of the soils falls in the range of 2.5 to 2.56. Natural moisture content varies from 6.46 to 21.65%. Further, grain size analysis indicates that the dominant particle size in the soils from the study area is silt but considerable clay fraction (3.28–46.06%) is also present in the soils of the study area. In none of the soil samples gravel fraction was observed.

The liquid limit of the soils from the study area ranges from 38.59 to 54.59% whereas; plasticity limit ranges from 22.32 to 40.79%, respectively. The plasticity index of the soils from the study area ranges from 9.01 to 20.35%. All soil samples from the study area falls in low plasticity silts to intermediate clays, except for two soil samples which shows high plasticity silt soils. Low to intermediate plasticity soils of the study area shows good to fair engineering property but high plasticity silt show poor engineering property. The activity results indicate that 66.7% of soils are inactive, 22.2% of soils are normal and 11.1% of soils are active.

In general, the soils of the study area may be classified as 33.3% of CI, 44.4% of ML and 22.2% as MH. Therefore, in terms of suitability for building foundation 33.3% of the soils possess good to fair bearing capacity, 44.4% as fair and remaining 22.2% of soils possess poor bearing capacity. The soils of the study area have cohesion in the range of 8 to 26 KN/M² whereas, angle of shearing resistance ranges from 19° to 23°. Further, the soil of the study area shows that 44.4% of the soils possess medium swelling potential whereas, 55.6% of soils possess medium to high swelling potential. Commonly, the construction site soils have fair bearing capacity from bearing capacity and settlement potential point of view.

The water bearing formation as deduced from deep wells of the study area is pyroclastic rocks which are underlain by basalts. Water bearing formation and static groundwater level is situated at greater depth. The capillary rise from deep groundwater in the study area may not affect the building foundations. However, the in-situ moisture content that was continuously observed in the upper part of the geo-electric sections may have little effect on the building foundations. Further, the building designers must consider that the University site is located along the active zone of Main Ethiopian Rift margin and may be affected by minor to major earthquakes in future. Therefore, while designing the footing and superstructure for the proposed buildings they must consider the seismic hazard of the area.

Combination of geophysical and geotechnical investigations gives respectable results for characterization of the proposed building foundation site. Therefore, the study area soil is relatively poor to fair bearing capacity based on geophysical and geotechnical point of view. These soils may be suitable for adequately designed low-rise buildings.

6.2 Recommendations

Based on the present study the following recommendations are forwarded;

- The top soil strata which possess relatively low resistivity may show corrosive potential which may severely affect the steel structures in building foundation. Therefore, while designing the footing for proposed buildings proper care must be taken to protect it from the possible corrosive effect within strata of low resistivity.
- In general, soils of the study area have been classified as MH, ML and CI which demonstrate intermediate suitability for building foundation. Therefore, for design purpose these soils must be considered to possess medium compressibility and fair shear strength. Thus, the footing must be designed accordingly.
- Systematic in-situ test would be required to characterize in-situ engineering property and quantify the bearing capacity and settlement potential of the soil in the study area.
- The geophysical investigation has revealed potential hazardous sub-surface conditions which may have adverse effect on the proposed buildings therefore, it is strongly recommended that the building foundation sites should be selected away from these geologically active/weak zones.
- The study area is situated in seismically active zone therefore designers should consider the seismic code in addition to the building code before designing the multi-story buildings.

All efforts were made to conduct the present study in a systematic manner, well supported by actual test results and scientific observations made at the site; however; all these efforts were carried out under the constraint of resource, time and finance. Therefore, it is recommended to make further analysis using more number of samples and in-situ tests for a more dependable and practical result. The results and findings of the present research must be considered as indicative, more elaborate field and laboratory testing on representative samples would be mandatory before implementing results from the present study for actual design purpose.

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a) Geological 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	Scoraceous 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	Silty 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	Scoracious Basalt	
20	171-177	6	Sand with volcanic ash and transported materials	
21	177-200	3	Basalt	

b) Geological log of Kalisha well

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 colour)	
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

Resistivity values for some common Earth material (Bernard, 2003)

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

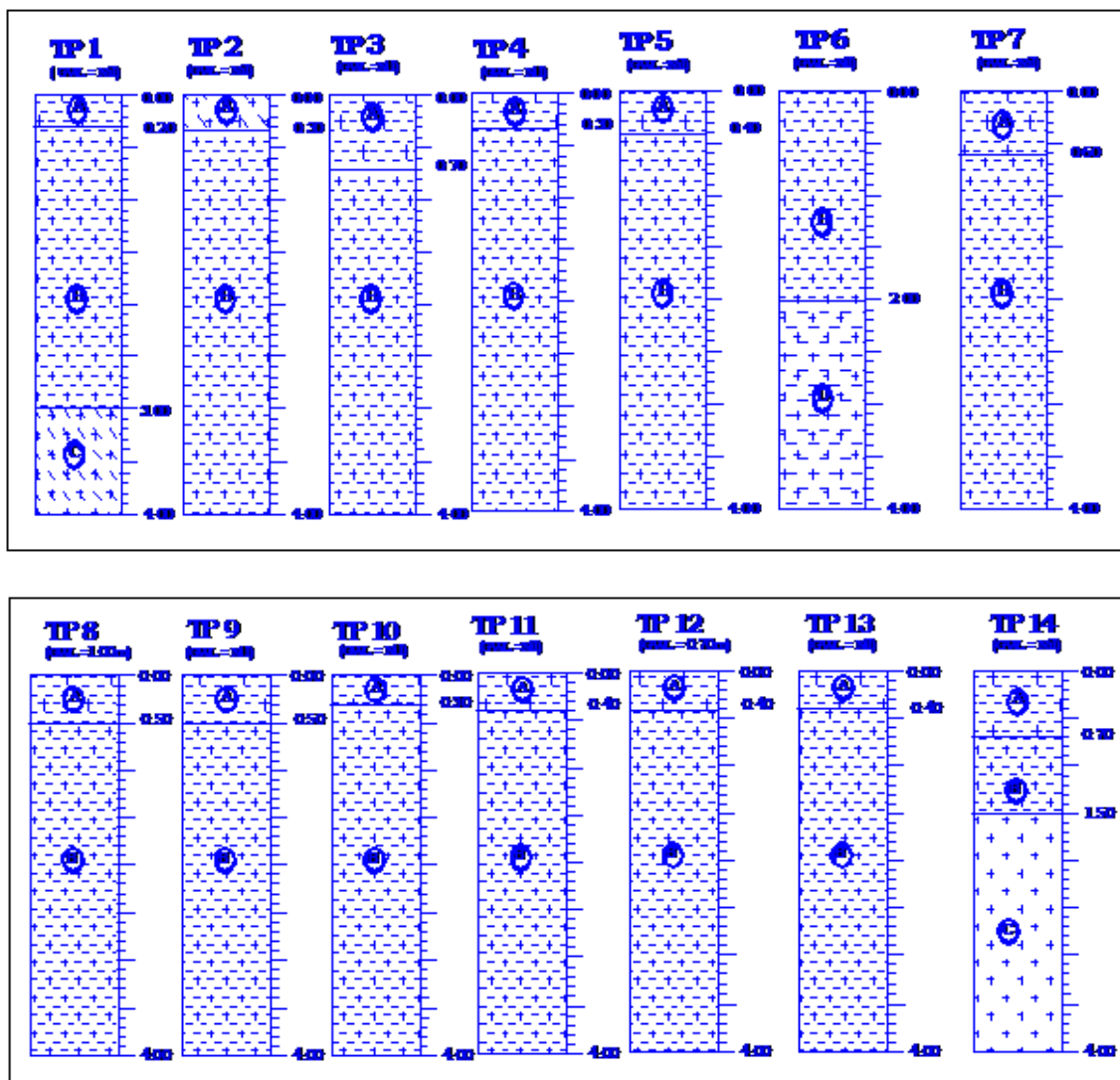
Magnetic susceptibility of various rocks and minerals

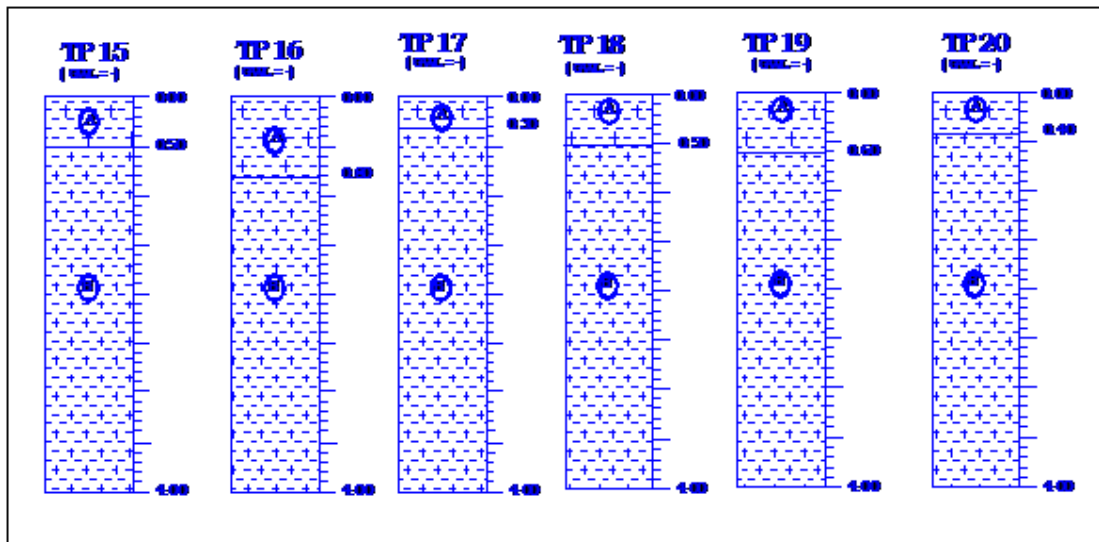
Rock and mineral type	Susceptibility (K) ($\times 10^6$ eu)	
	Range	Average
Sedimentary		
Dolomite	0 – 75	10
Limestone	2 – 280	25
Shale	0 – 1600	30
Sandstone	5 – 1480	50
Metamorphic		
Amphibolite	----	60
Schist	25 – 240	120
Phillite	----	130
Gneiss	10 – 2000	---
Quartzite	----	350
Slate	0 – 3000	500
Igneous		
Granite	0 – 4000	400
Dolerite	100 – 3000	1400
Olivine-Diabase	----	2000
Diabase	80 – 13,000	4500
Gabbro	80 – 7200	6000
Basalt	20 – 14,000	6000
Diorite	50 – 10,000	7000
Peridotite	7600 – 15,000	13,000
Andesite	----	13,500
Minerals		
Calcite	0.6--1	---
Coal	»	2
Clays	»	20
Chalcopyrite	»	32

General engineering suitability of the soils (Arora, K, R, 1997)

Soil Group	Permeability	Compressibility	Shear strength	Workability
<i>a) Gravels</i>				
GW	Pervious	Negligible	Excellent	Excellent
GP	Very pervious	Negligible	Good	Good
GM	Semi-Pervious to Impervious	Negligible	Good	Good
GC	Impervious	Very Low	Good to fair	Good
<i>b) Sands</i>				
SW	Pervious	Negligible	Excellent	Excellent
SP	Pervious	Very low	Good	Good
SM	Semi-Pervious to impervious	Low	Good	Good
SC	Pervious	Low	Good to fair	Good
<i>c) Low and medium plasticity silt and clays</i>				
ML,MI	Semi-Pervious to impervious	Medium	Fair	Fair
CL,CI	Impervious	Medium	Fair	Good to Fair
OL, OI	Semi-Pervious to Impervious	Medium	Fair	Fair
<i>d) High plasticity silts and clays</i>				
MH	Semi-Pervious to impervious	High	Fair to Poor	Poor
CH	Impervious	High	Poor	Poor
OH	Impervious	High	Poor	Poor

Test pit log Sheet



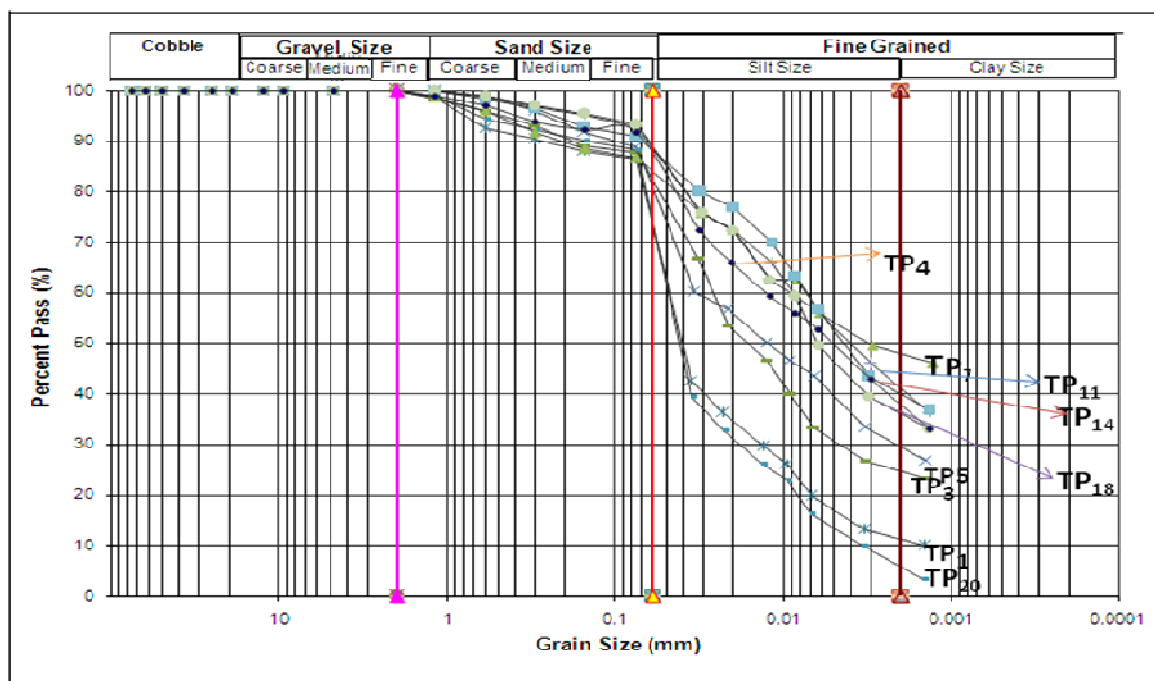


Total result for the above test pit log sheet

No	Soil type	Consistency	Remark
A	Gray silty Clay	Soft	-
B	Light brown to grey, wet, silty Clay/clayey silt with some sand	Firm	-
C	Yellowish gray silt	Medium dense	-
D	Light brown to grey sandy silt	Medium dense	-

\

Grain Size Distribution Curve for nine test pit (TP₁, TP₃, TP₄, TP₅, TP₇, TP₁₁, TP₁₄, TP₁₈ and TP₂₀)



**Vertical electrical sounding interpretation result at junction of Shilanisha and Batena
River in the northern part of University site**

No	Resistivity (Ω -m)	Thickness(m)	Depth (m)	Lithological description
1	14.7	0.9	0.9	Dry reddish brown soil
2	4.9	0.9	1.8	Wet reddish brown soil
3	3.6	4.7	6.5	Intregranular river deposit
4	5.3	13.21	19.7	Wet black cotton soil intercalated with silty clay and Intregranular river deposit
5	3.7	20.71	40.41	Intregranular river deposit with silty clay
6	26.35	48.73	89.2	Moderately weathered and un welded pyroclastic rock
7	3.5	147.6	236.8	Highly weathered and fractured water bearing ignimbrite
8	7.3	∞	Sub stratum	Highly to moderately weathered and fractured basalt