Engineering Geological Investigation of Jimma Town:-Implication to Engineering Practice

Mekdes Habtamu Tadele

A Thesis Submitted to the Department of Applied Geology

School of Applied Natural Science

Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Applied Geology

Office of Graduate Studies

Adama Science and Technology University

August, 2021

Adama, Ethiopia

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Approval Sheet

We, the advisors of the thesis entitled "Engineering Geological Investigation of Jimma Town:-Implication to Engineering Practice" and developed by Mekdes Habtamu, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Mekdes Habtamu have read and evaluated the thesis entitled "Engineering Geological Investigation of Jimma Town:-Implication to Engineering Practice" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied geology.

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Declaration

I hereby declare that this MSc thesis entitled “Engineering Geological Investigation of Jimma Town:-Implication to Engineering Practice**”** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of material that are used for this thesis have been duly acknowledged through citation.

Name of student	Signature	Date

Recommendation

we, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Engineering Geological Investigation of Jimma Town:-Implication to Engineering Practice'' prepared under our guidance by Mekdes Habtamu submitted in partial fulfillment of the requirements for the degree of Masters of Science in Applied geology. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Major Advisor	Signature	Date
Co-Advisor	Signature	Date

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LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials standard
CH	Inorganic clay of high plastic
GI	Group Index
Gs	Specific Gravity
GPS	Global positioning system
GW	Ground water
LI	Liquidity Index
LL	Liquid limit
MH	High plastic silt
MPa	Mega Pascal
NMC	Natural moisture content
PI	Plastic Index
PL	Plastic limit
RQD	Rock Quality Designation
RMR	Rock Mass Rating
S	Shear strength
USCS	Unified Soil Classification System
UCS	Uniaxial Compressive Strength
W	Weight

ABSTRACT

Jimma is one of the major and densely populated town in Ethiopia. It is located 356 Km southwest of Addis Ababa and, covers an area of 50.52 square Km. The topography is predominantly flat and rolling terrain. As in many towns of Ethiopia, very little is known about the soil and rock engineering properties and sub surface conditions of the town. The present research work is, therefore, aimed at assessing and evaluating the geological and engineering geological condition of the town. Detailed field survey, in-situ strength test sampling, geological mapping and laboratory testing of samples were conducted in order to achieve these objectives. A total of 12 disturbed soil samples were collected from 12 test pits, which were dug manually up to a depth of 3m. Depending on field observation, in-situ rock strength and laboratory analysis, the engineering geological properties of rocks and soils were determined. To give a picture of the location and extent of coverage of the different geological materials and their engineering properties, geological and engineering geological maps were prepared at a scale of 1:25,000. From the laboratory test results, the natural moisture content, liquid limit, plastic limit, plasticity index, specific gravity and free swell ranges from 42.18 - 62.45%, 66-101%, 31-53%, 19-53%, 2.36-2.75, and 33-130% respectively. The undrained shear strength of the studied soils ranges from 24.57 KPa to 173.66 KPa. According to the Unified Soil Classification System, the soils are classified as medium to high plastic silt and clay soils. As per AASHTO classification system, the soils are classified as clayey soils (A-7-6) which is unfavorable for subgrade material. The rocks of the study area were classified into very high strength, high strength and low (soft) strength rock units based on the strength (Unconfined Compressive Strength) of intact rock. The ignimbrite unit shows variable strength from very high rock strength (169.82MPa) to high rock strength (50.118MPa). Basalt unit revealed extremely high rock strength ranging from 89.12MPa to 194.98MPa. Tuff unit revealed extremely low rock strength (<1MPa). The soils of the area exhibits high swelling-shrinkage behavior that can cause problems on engineering structures. Hence, proper counter measures need to be considered during the design and construction of engineering structures in these areas.

Key words: *Jimma, Engineering geological investigation, engineering practice*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Site investigation is essential for the successful and economic design of engineering structures and earthworks (Bell, 2007). It is also necessary to obtain sufficient information for feasibility and economic studies for a proposed project. If the foundation studies are not conducted properly, it may affect the performance of the structures. Therefore, for many construction works at present and near future, engineering geological investigation is very important (Sushma, 2009). Because, the data obtained from engineering geological investigation is used to provide basic information for the current and future planning of land-use and for the planning, design, construction and maintenance of civil engineering works in the country (UNESCO, 1976). Of any civil engineering structures in big town, engineering geological investigation is very important before the construction. Because, engineering geological investigations are useful to estimate the project cost and safety of civil engineering structures proposed to construct in the town. It also helps to select technically feasible and appropriate methods of construction to ensure the life span of given engineering structures proposed to construct in the town (Bell, 1987).

All engineering structures such as multistory buildings, bridges, dams, tunnels, etc., are built on, in, or with soil or rock. The physical and mechanical properties of these materials have major influences on the success, economy, and safety of the work (Roy, 2017). Detail knowledge of the behavior of earth materials via engineering geological site investigation is, therefore, an essential requirement to the design and construction of civil engineering projects (Kelly, 2016). According to Sushma (2009), insufficient ground exploration may lead to inappropriate design and failure of the structure. Improper design of foundation over earth materials may affect the performance of structure. The suitability of the foundation depends on the stability of supporting earth materials Therefore, to obtain information on the type, characteristics and distribution of rock and soils and geodynamic conditions, engineering and geotechnical investigation should be done/on the rocks and soil underlying any construction sites (Sushma, 2009).

Soil swelling problems mostly occur in ordinary and lightweight structures such as buildings, roads, retaining walls and canal and landfill liners. Ethiopia is one of known country with wide coverage of expansive soil (Mohr, 1963). Properties of the expansive soils vary from place to place due to topography, climate and geological history. Similarly geological hazards such as volcanic eruptions, earthquakes, landslides, floods, etc. that can pose serious constrains on development are also vary from place to place. Therefore, it is important to make localized study for the different regions (Lucian, 2008).

Engineering geological investigation is very important for big towns similar to engineering structure. In other words, deep knowledge of the geomorphological, geological and geotechnical condition of urban areas is necessary to provide basic information on the ground condition to local authorities, engineers and contractors (Bowles 1996). Also, it is used in the prediction, prevention or mitigation of damages caused by natural hazards such as avalanches, mud flows, landslides, rockslides, sinkholes, and volcanic eruptions. This research was therefore, aimed at assessing and evaluating the engineering geological and geotechnical conditions of Jimma town and to provide important engineering geological data that may help to plan, design and maintain civil engineering works. The characteristics of soil and rocks which underlie the town were investigated by interpreting secondary data, collecting primary data during field work and conducting different tests in the laboratory.

1.2 Statement of the problem

Jimma is one of the largest and densely populated towns in Southwestern Ethiopia, Oromiya National Regional State (Figure 1). It is one of the fastest growing town in the country. The construction of civil engineering structures is developing fast like other main town of Ethiopia. Currently different project like, Industry Park, roads and other engineering structures are under construction. It is also a major contributor of Ethiopia's main exports. Therefore, the need for investigation of engineering geological conditions has paramount importance for safe and economical design and construction.

Since Jimma is found in tropical region, residual tropical soils are abundantly found in the area. Some residual soils are used as construction materials such as road sub-grade and selected backfill for dams, building foundations and road constructions (Jemal, 2012). The topography of the town is predominantly flat with poor drainage condition and the area is mainly covered with black clay soils and has surface and subsurface water which mostly encloses the flat area. For this reason, constructions could be sensitive for structural failure as a result of excessive consolidation settlement and swelling shrinkage of soil. This could affect the stability of lightweight structures as a result of a cyclic swell-shrink process. So to assess the engineering behaviors of these soils, conducting basic engineering investigations is vital.

Despite the rapid urbanization and construction in Jimma town, no work was done in the engineering geology aspect and the engineering geological map of the town, which provides basic information for the future land use planning in the town, has not been produced as well. The research work was therefore intended to fill this gap.

1.3 Significance of the study

Unplanned expansion of towns can expose people and economic assets to the risk of natural disasters. This study significantly contributes to the understanding of the engineering behavior of soils and rocks and geodynamic conditions in the town. Therefore, the data, particularly the engineering geological map of the town, would guide the urban/ town planners and designers for proper land use planning of the town. Engineering characterization of soils and rocks in the study area also provides information on the engineering properties of soils and rock mass. This helps to minimize the cost of investigation if any company or researcher is interested to undertake further study. Having a good understanding or information on the engineering or geotechnical properties of rocks and soils will also help to mitigate and minimize any adverse effects as a result of any probable damage in the future to the buildings and road construction in this area.

This study can be conspicuous as one of the resources on the engineering geological characterization of rocks and soils in Jimma town. Therefore, this research acts as background knowledge for future engineering studies in the area. The result of the present study will also be used as an input in the design and construction phases of any building and infrastructure. It also plays a significant role in selecting a safe foundation that can support any anticipated load of the structure.

1.4 Objectives of the study

1.4.1 General objective

The general objective of this research work is to undertake an engineering geological investigation of Jimma town and provide important engineering geological data that may help land use planning of the town.

1.4.2 Specific objectives

- To asses and analyze important engineering geological and geotechnical properties of the soils and rocks of the town.
- To conduct engineering geological classification of rock and soil according to the standard engineering classification systems.
- To map the lithological and geological structure of the study area.
- To produce medium-scale multipurpose engineering geological maps of the town.

1.5 Description of the Study Area

1.5.1 Location of Study Area

Jimma town is located in the south western part of Oromia National Regional State. It is geographically located between 846007 to 855007m N latitude and 258036 to 267036m E longitude. Elevation within the town boundary ranges from the lowest 1720 m.a.s.l. of the airfield (Kitto) to the highest 2010 m.a.s.l. of Jiren. It is 356 Kms from the capital city of the country. It is bordered by Kersa Woreda in the east, Manna Woreda in the north, Manna & Seka Chekorsa in the west, and Dedo in the south direction. Jimma town lies in a wet land Ecosystem. It is bounded by a wet evergreen mountain forest land ecosystem. Because of the climatic stability, the green coverage of the city is very significant and estimated to be about 35% including farmlands & vacant places (UIIDP, 2013).

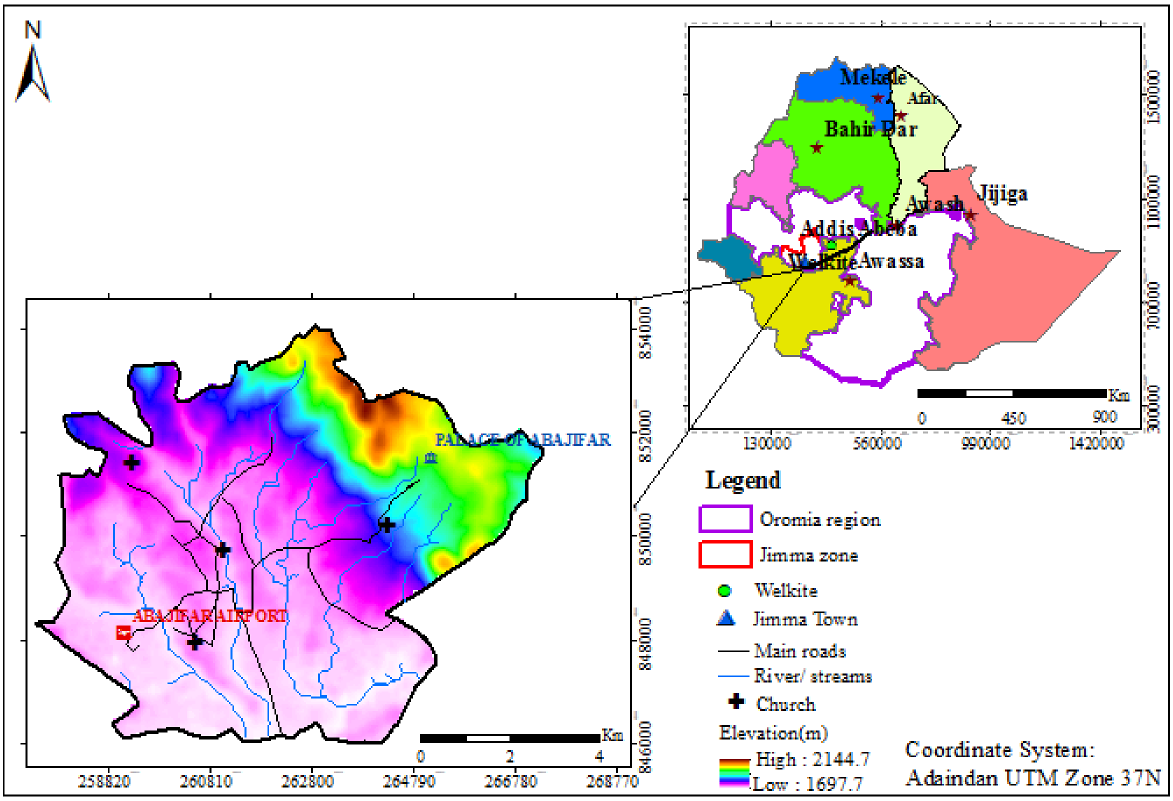


Figure 1: Location map of the study area

According to the current used master plan, Jimma town has a total area of 50.52Km^2. About 37.97% of the total area of the town is covered by residential buildings, 9.36% by social & public services, 11.85% covered by forest and 3.65% used for urban agriculture. Currently, the town is divided into 13 urban kebeles and 4 rural kebeles (UIIDP, 2013).

1.5.2 Physiography of the study area

The major part of Jimma town, including the central, southern and western parts, is characterized by flat to gently sloping/undulating topography, while the northern and eastern parts of the town and its peripheries are characterized by hilly/ sloping landscape. Elevation within the town boundary ranges from the lowest 1700 m.a.s.l. of the airfield (Kitto) to the highest 2200 m.a.s.l. of Jiren (Figure 2).

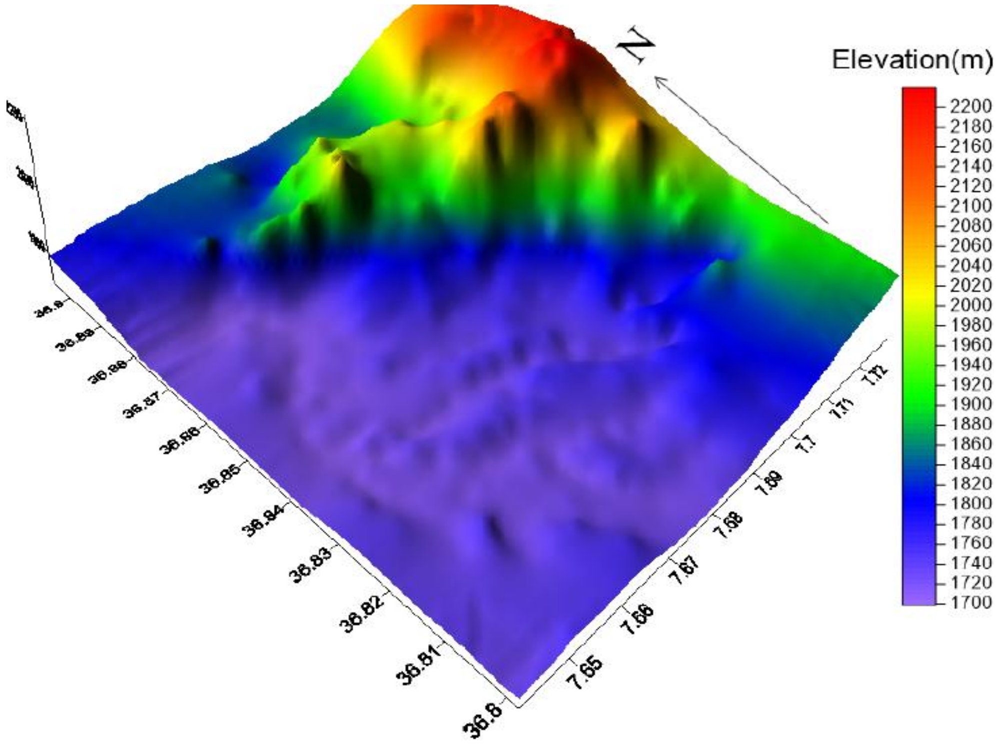


Figure 2: Physiographic map of Jimma Town

1.5.3 Climate

The temperature in the town is relatively low in the early morning and during the night, but high around noon. Temperature variation is observed among seasons. The lowest temperatures were observed during December -January period. According to the data optioned from Jimma metrology branch, (2006) the hottest months are February, March, and April. & the coldest months are July, August, September and October. But, December, January & February are the coldest months during morning time it is in the range of 6.2 C^o to 30.3C^o with the mean daily temperature of 19.8C^o (UIIDP, 2013).

Average humidity was 81.17 and the highest average humidity was observed during the main rainy season. According to the data presented in Ethiopian Metrological Agency (Jimma branch), the city receives a total of 1442.9 mm of rain fall in 2004. The rainfall, however, shows seasonal variation with monthly rainfall ranging between 1.8 mm in February and 335 mm in June. The town is located in “Weina Dega” which is to say it is found in Ethiopia, which enjoys moderately heavy rainfall throughout the year, with yearly rainfall was 1442.9 mm (UIIDP, 2013).

1.5.4 Vegetation

The natural vegetation is highly distributed through human intervention for urbanization. About 5% of the total area of Jimma is covered by vegetation (farm and agriculture). It is one of the most forested cities in Ethiopia, both exotic & indigenous trees Species are found in and around the town. The exotic tree species include perennial fruits and eucalyptus trees.

The indigenous once include coffee bushes and shades trees such as Oak, Acacias, Wedessa, birbirrisa, Makanisa, etc. The town and its surroundings well-protected of flush flood erosion and sedimentation except for the farm lands and agricultural plot (UIIDP, 2013).

1.5.5 Drainage

Jimma is found within the Gilgel Gibe basin, which is tributary of the Gibe River which in turn drains to Lake Turkana Gilgel Gibe, which is found at about 1.5km from the existing boundary of Jimma, originates from the highlands north and west of Jimma and drains an area of about 4750 square km. Its head stream tributaries mainly start from highland found north, North West and north east of the town. The local drainage of the town is basically from the north and northeast and drains to the south through the two most important perennial rivers Awetu and Kitto that form Boye. Boye is a very large swampy area of artificial water body bounding town.

The drainage in the upper parts of the town has many branches of water ways forming a tree branch structure following the following topography of the area (Figure 3). There are a number of streams that cross the town in the north-south direction within the built-up and expansion areas including; Furdisa, Abey, Faki, Mole and denge dawi.

All these streams have very small discharge and also shallow depths and some of them will not have water during dry season. Kitto & Aweytu Rivers constitute the major natural drainage system of the town. Awetu River, particularly, bisects the built-up parts of the town along the north-south direction (UIIDP, 2013).

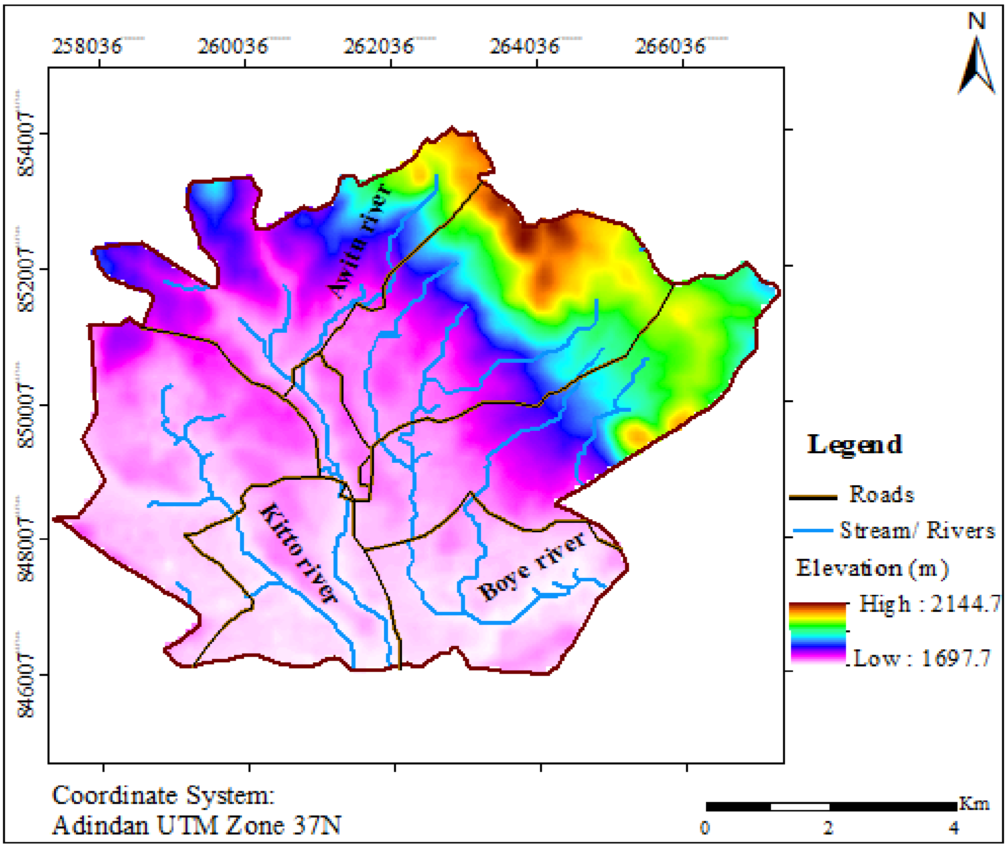


Figure 3: Drainage map of the study area

1.5.6 Land Use and Land Cover

Out of current Jimma city area, 84.65% is used for urban development and the remaining 15.35 % is for forest and agriculture and also partly vacant (UIIDP, 2013). The city exhibits intensive mixed-used development at the core while intermediate and periphery areas are dominated by residential land and forest. Among the farming activities being undertaken in the town, coffee dominate followed by vegetables, fruits &crops. Large parts of the town which used to be the swampy areas in Becho Bore Kebele and the others have now developed into a consolidated settlement with residences, offices and commercial activities.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Soil is a natural aggregate of mineral grains with or without organic constituents. Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. The composition of these soils depends on the environment under which they were transported and is often different from the parent rock. The profile of alluvial soils usually consists of layers of different soils. Much of our construction activity has been and is occurring in and on alluvial soils (Budhu, 2010) as cited in Almayehu (2019).

According to Budhu (2000), soils are formed from the physical and chemical weathering of rocks. Mechanical weathering of rocks to smaller particles is due to exfoliation, erosion, freezing and thawing processes. Temperature changes bring changes in the volume of the rocks in the superficial layers in terms of expansion and contraction. Chemical weathering formed due to chemical decomposition processes. In this disintegration process the rock minerals are transformed into new minerals by chemical reaction. After weathering takes place, the soil transported by water, wind, glacier and gravity (Murthy, 1994). For engineering purposes, Soil is used as a construction material in various civil engineering projects, and it supports structural foundations (Das, 2010).

2.2 Engineering Geological and Geotechnical Investigations

Engineering geologists and Geotechnical engineers perform geotechnical investigations to obtain information on the physical properties of soil and rock underlying (and sometimes adjacent to) a site to design earthworks and foundations for proposed structures, and for the repair of distress to earthworks and structures caused by subsurface conditions. A geotechnical investigation will include surface exploration and subsurface exploration of a site. Site investigation will often include subsurface sampling and laboratory testing of the soil samples retrieved. The digging of test pits and trenching may also be used to learn about soil conditions at depth. Surface exploration can include geologic mapping, geophysical methods or it can be as simple as an engineer walking around to observe the physical conditions at the site (Parker, 1996).

2.3 Engineering geological/Geotechnical Characterization of Soil

Soils are characterized by their index and engineering (design) properties (Arora 2003). The soil of the study area was characterized by the following index and engineering property.

2.3.1 Index Properties

The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties. Index properties can be determined by simple laboratory tests. These tests are natural moisture content, Grain size analysis, Atterberg limits, and free swell and specific gravity test (Arora, 2003).

2.3.1.1 Natural Moisture Content

The water content test is performed to determine the water (moisture) content of soils. It is the ratio, expressed as a percentage of the mass of “pore” or “free” water in a given mass of soil to the mass of dry soil solids. For most soils, the water content may be an important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. It is also used in expressing the phase relationships of air, water and solids in a given volume of soil (Krishna, 2002).

2.3.1.2 Grain Size Distribution/Particle size analysis

Particle size analysis is a method of separation of soils into different fractions based on particle size (Arora, 2003). Two methods generally are used to find the particle-size distribution of soil. Sieve analysis for particle sizes larger than 0.075mm in diameter (coarse-grained soils), and hydrometer analysis for particle sizes smaller than 0.075 mm in diameter (fine-grained soils). The grain size result obtained from sieve and hydrometer analyses is generally presented graphically on the grain size distribution curve.

2.3.1.3 Atterberg Limits

The Atterberg limit test is performed to determine the plastic and liquid limits of a fine-grained soil. The result of this test can be used to predict other engineering properties. A wide variety of soil engineering properties have been correlated to the liquid limit and plastic limits and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification System or AASHTO System (Krishna, 2002). Water content greatly affects the engineering behavior of fine-grained soils. The water content at the boundary of this state is known as Atterberg limits. Between the solid and semi-solid states is the shrinkage limit, between semi-solid and plastic states is plastic limit and between plastic and liquid states are liquid limit.

2.3.1.4 Liquid Limit (LL)

The liquid limit is arbitrary defined as the water content in percent at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13mm (1/2 in) (Arora, 2003).

2.3.1.5 Plastic Limit (PL)

It is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8in) diameter threads without crumbling. Soil can no longer behave as plastic; any change in shape will cause the soil to show visible cracks (Arora, 2003).

2.3.1.6 Plasticity index (PI)

Is the difference between the liquid limit and plastic limit and represents the range of moisture within which the soil is plastic. Plasticity index is an important in classifying the fine-grained soils. Silts have no or little plasticity indices while clays have higher plasticity indices (Arora, 2003).

2.3.1.7 Specific Gravity

Specific Gravity (Gs) of soil actually refers to the specific gravity of the solid matter of the soil. The specific gravity of solids is normally only applied to that fraction of a soil that passes the N0. 4 sieve. The specific gravity of the solid substance of most inorganic soils varies between 2.6 and 2.9, Sand particle composes of quartz have a specific gravity ranging from 2.64 to 2.66. Inorganic clay generally ranges from 2.7 to 2.9. Soils with large amount of organic matter or porous particle (such as diatomaceous earth) have specific gravity below 2.6 (Das, 2012).

2.3.1.8 Free swell

Free swell used to estimate soil swelling potential and to identify whether it is expansive or not. The amount of swelling known to be dependent on the clay minerals, the soil mineralogy and structure, texture and several physical and chemical aspect of the soil. Among clay minerals, montmorillonite influences the magnitude of swelling and activity of soils maximally as compared to Illites and kaolinites (Holtz and Kovacs, 1981).

2.3.2 Engineering property of soil

The main engineering properties of soils are permeability, compressibility and shear strength. In this research the soil of the study area was characterized by shear strength.

2.3.2.1 Shear Strength

Shear strength of soil is its ability to resist sliding along internal surfaces within a mass (Murthy, 1990). The stability of a cut, the slope of an earth dam, the foundations of structures, the natural slopes of hillsides and other structures built on soil depend upon the shearing resistance offered by the soil along the probable surfaces of slippage.

2.4 Classification of soils

There are different soil classification systems. In this research two elaborate classification systems were used. They are the: American Association of State Highway and Transportation Officials (AASHTO) classification system and Unified Soil Classification system (USCS). Both systems take into consideration the particle size distribution and Atterberg limits (Figure 1). In this research hydrometer test was conducted to distinguish fine-grained soils (silt and clay). Instead the liquid limit and plasticity index of the soil was used to distinguish whether the fine fraction is silt or clay (Arora, 2004).

Table 1: Grain Size Range (mm) according to USCS and AASHTO

Soil type	Grain Size Range (mm)	
	USCS	AASHTO
Gravel	76.2 to 4.75	76.2 to 2
Sand	4.75 to 0.075	2 to 0.075
Silt	Fines < 0.075	0.075 to 0.002
Clay		< 0.002

2.5 Engineering Characterization and Classification of Rocks

Rock is a natural aggregate of minerals that cannot be readily broken by hand and will no disintegrate on its first drying and wetting cycle. There are geological factors influence the rock mass in relation to engineering activities including rock type (intact rock), rock structures (discontinuities), any alteration to the rock, in situ stress state, hydro geological regime (water flow).

Based on mode of origin rocks are classified into three major groups: a) Igneous rock, b) Sedimentary rock and c) metamorphic rock. From these rock types the study area is characterized by various volcanic types of igneous rocks. Rock is involved in many civil engineering projects. Engineering uses of the rock require a more generic subdividing of rocks in to two groups. These are; (a) Intact rock (rock material) and (b) Rock mass (Bell, 2007).

2.5.1 Intact rocks (Rock material)

Are block of rock that do not contain mechanical discontinuities and do have tensile strength. It is described by color; grain size, compressive strength and rock type (Bell, 2007).

2.5.2 Rock mass

Rock mass is a mass of rock interrupted by discontinuity, with each constituent discrete block having intact rock properties. The evaluation of the engineering properties of a rock mass includes; a) the intact rock properties, b) the occurrence and nature of discontinuities and c) the degree and extent of chemical weathering.

Various rock mass classification methods are commonly adopted. The commonly adopted methods are:-Terzaghi (1946), Deere (1964), Bieniawski (1973), Barton et al (1974) and ISRM (1981). From these methods the present research is based on the classification system proposed by International Society for Rock Mechanics (ISRM, 1981) (Figure 2). This classification system is based on the following parameters Rock generic name and Discontinuity spacing.

Table 2: Classification Based on Discontinuity Spacing

Intervals (cm)	**Terms**
>200	Very wide
60-200	Wide
20-60	Moderate
6-20	Close
<6	Very close

In the absence of drill core data, rock quality designation was determined based on joint volumetric count method. In the case of the study area there is no drill core data but discontinuity traces are visible in surface exposures. There are different methods to classify the quality of rocks (RQD) that are used such as volumetric count method, weathering condition and condition of discontinuities from visual observations and calculated according to Bieniawski (1989).

RQD= 110-2.5Jv (Palmstrom, 1982)……………………………………...Eq. 2.1

Where: **Jv**= volumetric count

RQD= Rock Quality Designation

To determine the strength of the rock Schmidt hammer rebound value was recorded. From the R-value, UCS will determine using the dry density (γ) of the rock by bouncy technique.

Log 10 UCS= 0.00088γR + 1.01 (Barton and choubey, 1977)…………...…Eq. 2.2

Where**: γ=** Dry density of rock

R= Rebound value

Table 3: Classification Based on Uniaxial Compressive Strength of Rock Material

UCS(Mpa)	Description
>200	Very high
60-200	High
20-60	Moderate
6-20	Low
<6	Very low

RMR can be determined using different parameter such as uniaxial compressive strength of rock material, Rock quality designation (RQD), Spacing of discontinuities, Condition of discontinuities, Groundwater conditions, Orientation of discontinuities. Each of the six parameters is assigned a value corresponding to the characteristics of the rock. These values are derived from field surveys and laboratory tests. The sum of the six parameters is the RMR value (Bieniawski 1973).

2.6 Engineering Geological Mapping

Engineering geological maps consist of basic geological maps which show some engineering geological data. Particularly for the design, construction and performance of engineering structures interacting with the ground in, such as foundations, cuttings and other surface excavations (Dearman 2013). Simpson (1938) reviewed the information of maps contain geological features of rocks and soils which are closely related to physical properties, such as strength, deformability, durability and permeability, which are important in engineering geology. These properties are Determine from in situ and laboratory geotechnical testing of soils and rocks were carried out from boreholes and test pits. Then Arc GIS software is used to digitalize different zonation and engineering geological map. According to Unesco Press (1976) an area is mapped as a soil unit if the soil thickness exceeds 1 m. But, if the soil thickness is less than 1 m, the area is mapped as the underlying bedrock.

CHAPTER THREE

3. METHODOLOGY AND MATERIALS

3.1 Methodology

In order to achieve the objectives of the research work successfully, the following approaches have been followed by applying different systematic procedures and materials. The general procedure and methodology followed during desk study, detailed field survey, laboratory test, data processing and analyses are described in this chapter. The step followed to perform each of the activities was broadly described as follows.

3.1.1 Pre Field Work

Pre-field is a fundamental step before the field survey. The works that were carried out in this stage includes:

- Preliminary office compilation of previous information concerning the climatic, geomorphologic, hydrologic, structural and geological and soil characteristics of the study area. Ground water information (depth and static water level) were also collected. These data were collected from an existing geological map, topographic map, etc.
- Review of similar studies and cases in different parts of the world. Emphases were given to previous works done in Ethiopia.
- Preparation of base map of required scale that were used for field data collection and mapping.
- Later conceptual framework and general methodology was developed from the knowledge acquired through literature review.

3.1.2 Field Work

In order to acquire the general conditions of the study area such as topography, soil distribution, etc., information was gathered and a field reconnaissance survey was undertaken. During this field survey, some preliminary geological mapping and soil distribution identification were done. The reconnaissance surveys were then followed by detailed field survey which involves detailed field descriptions of rock and soils, in-situ strength tests and soil sampling.

Different traverses were made along with rock and soil exposures in different parts of the study area for the identification and mapping of lithological units. Surface mapping of geological structures was undertaken by measuring orientations (dip and dip directions) of discontinuities using the Brunton compass. Similarly, conditions of discontinuity such as joint roughness, aperture, infill and weathering conditions were visually estimated on the field (ISRM, 1978).

In selected rock outcrops, the unconfined compressive rock strength (UCS) was estimated by using N-type of Schmidt hammer on the smooth and uniform rock surface. The tests were conducted using the standard ASTM C805 (2018). After positioning the test hammer perpendicular to the surface, gradually pushed until the hammer impacts the test surface. The corresponding rebound value was then, recorded. Ten readings were taken at each test section with no two impacts tests closer together than 25mm and then, repeated at other locations. a representative rebound value was obtained by discarding the rebound values that differ from the average of 10 readings by more than 7 units and then by determining the average of values of the remaining readings. Finally, the representative rebound values were converted into UCS of rocks using empirical equation that was suggested by Barton and Choubey (1977).

For collection of soil samples, 12 test pits were excavated up to 3m depth in different parts of the town (Figure 4). Visual description and soil sampling were carried out at 3m depth to avoid redundancy in sampling. Only disturbed soil samples were taken for laboratory tests. The soil samples were kept in plastic bag immediately after sampling to keep their natural moisture content and then brought to the laboratory (Table 4).

Table 4: Sample location, depth and origin of the soil samples in the study area

No	Code	Location	Easting	Northing	Elevation	Depth
1	TP-1	Becho-bore	0263035	0848012	1751	3m
2	TP-2	Bosa-addis	0259234	0850489	1738	3m
3	TP-3	Legehar(merkato)	0261980	0850685	1705	3m
4	TP-4	Mendera	0259945	0846712	1773	3m
5	TP-5	Kochi	0263329	0852009	1743	3m
6	TP-6	Mentina	0260681	0852083	1746	3m
7	TP-7	Jiren	0265610	0850489	1968	3m
8	TP-8	Abajifar airport	0258768	0848919	1751	3m
9	TP-9	Awitu	0265610	0850489	1738	3m
10	TP-10	Jimma University	0264090	0850170	1757	3m
11	TP-11	Hermata	0259368	0847643	1725	3m
12	TP-12	Fernje arada	0261690	0847592	1753	3m

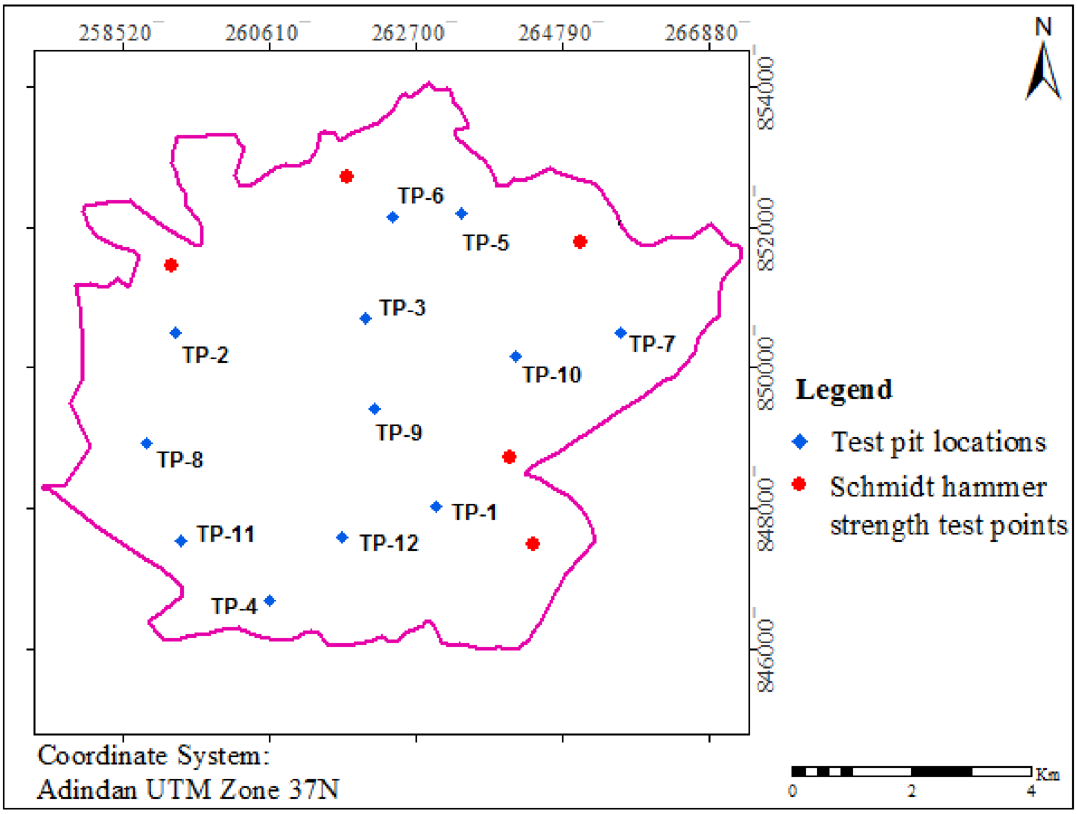


Figure 4: Map that shows test pit location and Schmidt hammer strength test points

3.1.3 Post Field Work (Lab test and data analysis)

A laboratory test was conducted to determine index properties of soil such as Atterberg limit (liquid limit, plastic limit and plasticity index), soil gradation and other parameters of soils (moisture content, specific gravity, free swell and shear strength). The tests were conducted on disturbed soil samples. Laboratory tests were done according to ASTM standards as discussed below:

3.1.3.1 Natural Moisture Content (NMC)

Natural moisture test was done according to the ASTM D 2216 (1998) standard using the oven drying technique. The test was done by using apparatus like digital balance, moisture can, gloves, spatula and drying oven.

This test was conducted by the following test procedure. First, the moisture can and lid numbers were recorded and the mass of an empty, clean and dry moisture can with its lid (Mc) was determined and recorded. Then the moist soil was placed in the moisture can and secured lid. The mass of moisture can with moist soil and lid (McMs) was determined and recorded. The lid was removed and the moisture can that contain the moist soil was placed in the drying oven that was set at 105 ^{o}C and it was left in the oven overnight. The moisture can was removed carefully, the lid replaced on the moisture can using gloves and it was cooled at room temperature to determine and record the mass of the moisture can that containing the dry soil (Mcds). Finally, clean the moisture can and lid to conduct the next test.

After conducting the test according to the above procedure, the analysis was done by using the following formulas.

$$\boldsymbol{W}(\%) = \frac{\boldsymbol{McMs-Mc}}{\boldsymbol{Ms}} 100\% \text{..Eq. 3.1}$$

Where: Mc= mass of can

Ms= mass of soil

W= moisture content

3.1.3.2 Specific Gravity

This test was done according to ASTM D 854 (1998) standard for each sample for which moisture content was determined. Two test methods: the oven-dry and moist specimen techniques were forwarded by (ASTM D 854, 1998) and this study utilized the former. Accordingly, the oven-dried and weighed (Md) part of soil specimen that passed 4.75mm sieve size were placed in a clean and dry pycnometer of mass (Mp). The pycnometer was then filled with distilled water to the level slightly above the soil and slowly soaked and the entrapped air was removed by boiling technique. Then, the distilled water was slowly 41 added to the level of calibration mark of the pycnometer and the corresponding mass of pycnometer filled with soil and water was measured (Mc).

Finally, the pycnometer was emptied and cleaned after which it was filled with distilled water to the level of calibration mark to obtain a mass of pycnometer filled with water (Ma). The specific gravity (Gs) at the testing pressure was then determined using the following equation:

$$\mathbf{Gs} = \frac{\boldsymbol{Md}}{\boldsymbol{Md}+(\boldsymbol{Ma-Mc})} \text{...Eq. 3.2}$$

Where: Gs = specific gravity

Wd = weight of sample of oven-dry soil

Wa = weight of pycnometer filled with distilled water and soil

Wc = weight of pycnometer filled with distilled water

3.1.3.3 Particle Size Analysis

The test contains two analyses mechanical and hydrometer analysis. The mechanical analysis was used for particle size larger than 0.075mm diameter (No. 200 Sieve) while hydrometer analysis was used for particle size smaller than 0.075mm diameter (No. 200 Sieve). Before performing the test the soils were subjected to oven-dry. To perform hydrometer analysis sodium hexametaphosphate was used as a dispersing agent. All analysis was determined based on ASTM D-421(1998) procedure.

The sieve analysis test was conducted by following the procedure defined below. At the begging, the weight of each sieve and the bottom pan that have been used in the analysis was written and the weight of soil sample was recorded. The sample was sieved through the sieve net of size 4.75mm. The mass retained on each sieve was recorded. The proportion of soils passing 4.75mm sieve have been dried in oven at 105 ^{o}C. The dried sample spread out in the large tray and it was soaked with water.

The soaked soil specimen was washed on a 75-micron sieve until the water passing was substantially clean. The fraction retained on the sieve was tipped in a try, dried in the oven and sieved through the sieve net of size 2mm up to 75-micron sieves and the fraction retained on each sieve was weighted separately and the masses were recorded. The percentage of soil retained on each sieve was calculated on the basis of the total weight of the sample taken. Then, cumulative percentage of soil retained (which will give % finer when deducted from 100) on the sieve was found. Finally, the graph was plotted on a log scale with “particle size (Diameter)” on the x-axis and “percent finer” on the y-axis and particle sizes were obtained from the graphs.

3.1.3.4 Atterberg Limits

The Atterberg limit test was conducted according to ASTM D 4318 (1998) standard test method for liquid limit, plastic limit and plasticity index of soils. equipment’s like liquid limit device, Porcelain (evaporating) dish, grooving tool with gage, moisture cans, Balance, Glass plate, Spatula, Wash bottle filled with distilled water and Drying oven set at 105 ^{o}C was used.

3.1.3.5 Liquid Limit Test

Liquid limit test conducted using Casagrande technique according to procedures provided by ASTM D 4318 (1998). Parts of soil samples that passed 0.425mm sieve size were taken for the test and the water content required to close a grooved soil samples by distance of 13mm at 25 number of blows applied at a rate of 2 revolutions per second.

Then the sample was taken from the edge to edge of the soil pat, using the spatula and it was placed in the moisture can and immediately the weight of moisture can containing the soil was recorded and placed in the oven for 18 hours. Then the entire soil specimen in the porcelain dish was remixed and a small amount of distilled water was added to increase the water content so that the number of drops required to close the groove decrease. Finally, the above step was repeated for two additional trials producing successively lower numbers of drops to close the groove. By computing average water content, the liquid limit was determined.

3.1.3.6 Plastic Limit Test

To conduct this test, first the weight of empty moisture cans with their lids and number of cans was recorded on the data sheet. Then the ¼ of the original soil sample was taken and the distilled water was added until the soil was at a consistency where it can be rolled without sticking to the hands. The mass was rolled between the palm or the fingers and the glass plate by using sufficient pressure. The thread was broken into several pieces when the diameter of the tread reaches the correct diameter. The thread was deformed when its diameter reaches 3.2 mm. the rolling was continued until the thread crumbles. The portions of the crumbled threads was gathered together, placed in the moisture can and the weight of the moisture can with containing the soil was recorded and leaved in the oven for 18 hours. The above step was repeated two times and the water content was determined from each trial by using the same method in the same laboratory. By computing average water content, the plastic limit was determined. After conducting liquid limit and plastic limit tests plasticity index was determined from the result of consistency limits. It was calculated by using the following formula.

$$\mathbf{PI = LL - PL} \quad \text{..} \text{Eq. 3.3}$$

Where: PI = Plasticity Index

LL = Liquid Limit

PL = Plastic Limits

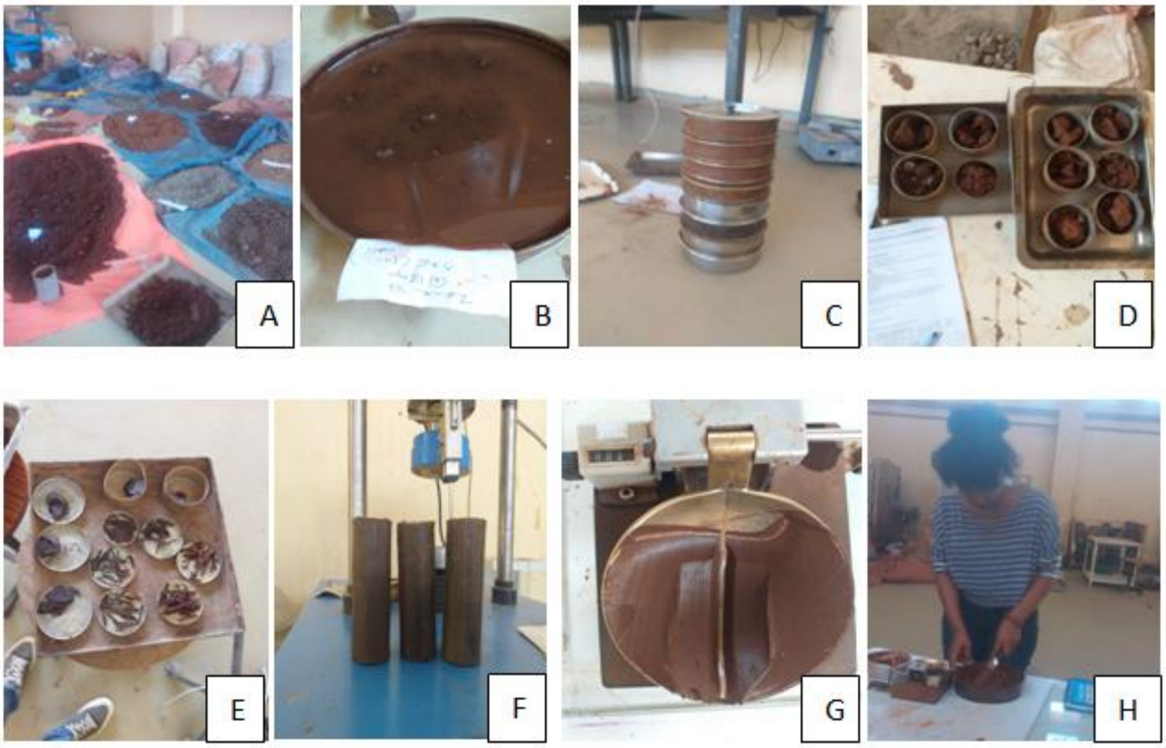


Figure 5: Liquid limit test and laboratory tests for soils

3.1.3.7 Shear strength for selected samples

Due to the high amount of clayey soil, the Unconfined Compression Test was conducted using ASTM D 2166 (1998) standard test method. The test was performed on cylindrical, moist clay specimens sampled from test pits. After extruding the soil sample from the tube sampler, the specimen diameter and length were measured. The weight of the sample was recorded and the deformation (original specimen length) was calculated from strain. After placing the specimen in the compression device, the device was adjusted to set the load and the load was applied at a rate of 0.5% to 2% per minute. The load was applied until the load dial decrease on the specimen.

The deformation was recorded and the stress-strain curve was sketched. Finally, the sample was removed from the compression device; cross-section area was computing also moisture content was obtained.

3.1.3.8 Free Swell Test

The free swell test was done according to the IS: 2720 (1977) standard test method. The test conducted by placing 10gm of dry soil passing the No 40 sieve into a graduated cylinder one filled with water and another with kerosene to 100 ml. Swelled volume of the soil in water is measured after 24 hours and the volume of soil in kerosene gives initial volume of the samples. Kerosene being non polar liquid it does not cause swelling of the soil.

The free swell (FS) is computed as:

$$FS = \frac{Vf - Vo}{Vo} \times 100\ \% \qquad \text{Eq. 3.4}$$

Where:

FS = free swell in%

Vf = final volume of the soil in water

Vo= volume of soil in kerosene

3.1.4 Data analysis and Interpretation

Laboratory test results and other field works were interpreted and analyzed by using different computer software’s. Some of these software’s are Surfer10, Arc GIS10, Dip 6.00, Microsoft Word 2010 and Microsoft Excel 2010.

3.2 Materials

- Global Positioning System (GPS), geological hammer, sample bag, Brunton compass and tape meter were used for geological mapping and discontinuity surveying.
- N-type of Schmidt hammer in the field was used for determination of Uniaxial Compressive Strength (UCS) of intact rocks.
- Grain size, Atterberg limit, direct shear strength and etc. were used for soil testing in the laboratory.
- Arc GIS, Sulfur 10, dips 6.00 and etc. were used for map preparation and data analysis.

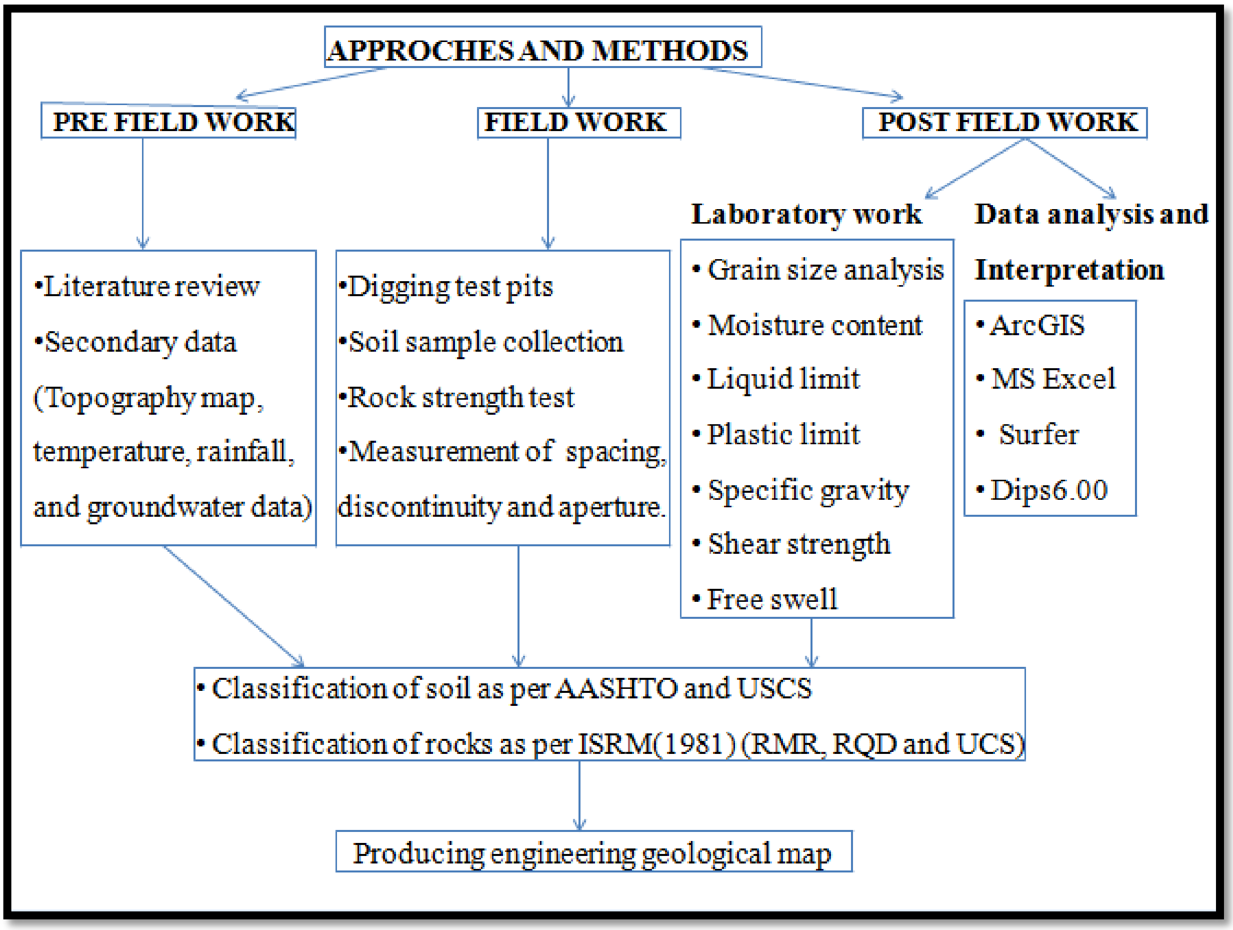


Figure 6: Methodology used in the research

CHAPTER FOUR

4. GEOLOGICAL SETTING

4.1 Regional Geology

Mohr (1963) divided the Cenozoic volcanic rocks of Ethiopia into the Trap series and Aden series. The term trap series refer to the whole pile of the Tertiary flood basalt sequence with intercalation of felsic lava and pyroclastic rock (commonly on the upper part). Aden series is confined to mafic lava flows within the younger Afar depression. At places, the thick volcanic pile of the plateaux attains a thickness of up to 3 km. These names are modified into groups and formations during the later compilation (Mengesha et al. 1996). As the term series implies, it is the time taken to deposit a rock unit.

The name Jimma volcanic was given by Merla et al. (1979) to trachybasalt and rhyolites which cover most part of the southwestern Ethiopia. The Jimma volcanics are considered analogues with the main sequence of Davidson (1983) and form a thick succession of basalt and felsic rocks with basalt dominating the lower part of most section. Davidson (1983) has reported K/Are age of 42.7 to 30.5 m.y. for the Jimma volcanics. Two units (the lower Jimma volcanic, are mainly basalts and the upper Jimma volcanics, are mainly, trachytes, rhyolites, ignimbrites and rare tuffs are known which shows a conformable relationship. The later ones are equivalent to the Magdela Group of Kazmin (1972. The Jima volcanics almost always rest on the Precambrian basement. Unconformity is being marked by basal residual sandstone. The basal flows form an unbroken succession several hundred meters thick in some places. In some areas silicic rocks are intercalated with basalt flows close to the base or form a thick succession just above the basal basalt (Haro, W. 2012).

Nazret Series rocks are younger post-rift rocks. The Nazret series in the area form rift shoulder deposits. The Nazret series is a name given for the thick succession of welded ignimbrite, minor basalt and rhyolite flows. The isolated peaks of basalt according to the works of Mengesha et al. 1996) are central basaltic flows. The Termaber basalts rocks are exposed in Jimma map sheet (Figure 7).

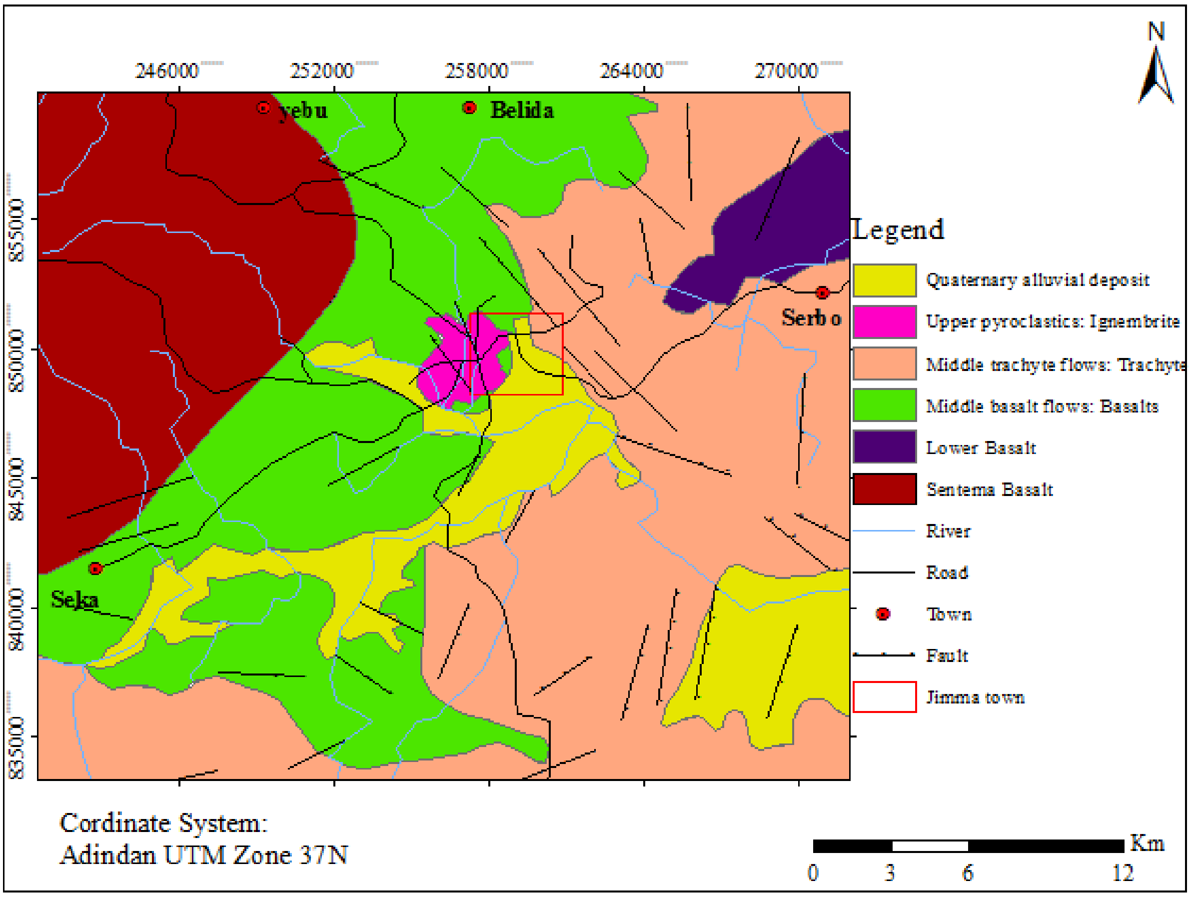


Figure 7: Geological map of Jimma area adopted from Mengesha et al. (1996)

4.1.1 Middle trachyte flows

The middle trachyte covers many areas of the map sheet. It is exposed west of Agaro northeast of Jima, southeast of Jima, in most areas of Gera and Belete Chaka, south of Bonga & Delbi Moye to Debo areas. It also forms the highlands of Waka and Wolde Hane and to the extreme northeastern part, east of Deneba and north of Gilgel Gibe dam site. In most of its exposure is light grey, fine to medium-grained trachyte. It often contains clear sanding and at places, soda pyroxene occurs. The rock is often massive, but at places show fractures. The trachyte is at placer porphyritic with sanidine phenocrysts. The middle trachyte covers a wide area of about 5750 sq. km (Mengesha et al. 1996).

4.1.2 Quaternary stratified tuffs

A type area of its exposure is Goro Mountain, east of Asendabo and around eastern part of Jimma different horizontally layered tuffs with 10 to 15 meters thick make a total of 50-meter thickness. The color of the tuff is grey to light grey and is loose or very slightly compacted at places. Different tuff beds are separated by paleosoil.

An alluvial channel deposit containing sand of about 30 cm thick was also observed between the tuff layers. Very loose, grey lithic tuff exposed at Bisho Genbo, east of Nada is also grouped under quaternary tuff. The rock fragments are pumice and tuff. It is massive and seems to be a subaerial deposit often filling the down-faulted area of Asendabo Graben. The fragments range from sand, gravel, breccias and cobble and with minor boulders (Mengesha et al. 1996).

4.1.3 Quaternary alluvial deposits

This unit is exposed along major rivers, Asendabo Graben, near Jima town, Kishe Graben, Konda low lands, Kemise lowlands. The minor unmappable Quaternary deposit also occurs on low flat highlands. The deposit is often bogy with soft clayey soil. At places, they form loose thick soil of clayey-silty material that is not consolidated. The color is mostly light grey covered with grass or low vegetation such as reeds and bogs. Most of the Quaternary exposure is swampy and occurs in meandering wide flat valleys (Mengesha et al. 1996).

4.2 Regional structures

The rifts (graben) in the Jimma map zone have a similar origin to the MER, even though pyroclasts formed are lesser in volume in Jimma rift graben. The major structures in the Jimma map zone show the ENE-WSW trend. This structure controls the location of local graben in the area. The graben is formed by normal faults which are asymmetrical. The eastern limit of the Asendabo Graben is east of Nada. Around the current study area, normal faults and lineaments are oriented NE-SW and N-S oriented faults are observed (Haro, W. 2012).

4.3 Local geology

The study area is covered by quaternary deposits and different types of volcanic rocks which include Basalt, Ignimbrite and tuff. They are described as follows from young to old.

4.3.1 Quaternary deposit

The recent sediments in the study area consist of alluvial and residual soils. The alluvial deposit is widespread and mainly exposed in the central, northern and southern parts of the town. It occupies a flat and low laying area. It is fine-grained, grey and red in color. These residual soils cover a large part of the study area (Figure 8). It is derived from the in-situ weathering of volcanic rocks such as ignimbrite and basalt.

Figure 8: Exposure of alluvial soil (left) and residual soil (right)

4.3.2 Basalt

Basalt is an extrusive volcanic rock and texturally fine-grained and vesicular. The vesicular basalt was exposed at the northern and north-eastern parts of the study area (Figure 9). It is mafic in composition and light gray in color. It is highly weathered and fractured, also the joints are horizontal and vertical that are exposed as a steep cliff. Some of the vesicles of vesicular basalt are filled by secondary materials (quartz/silica).

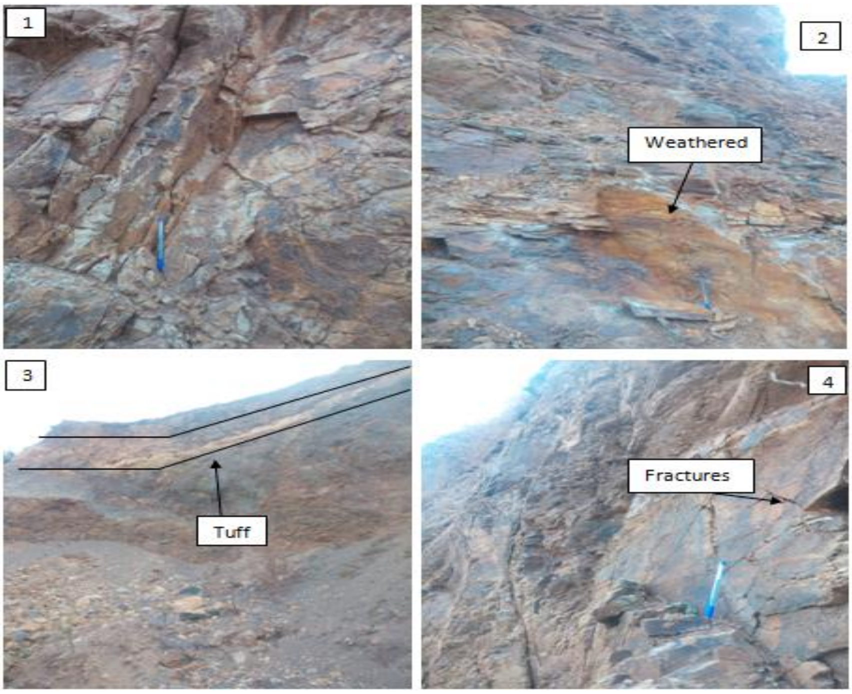


Figure 9: Exposure of basalt unit in the study area (1), weathered basalt (2), intercalation of tuff and basalt (3), fractured rock unit in the study area (4).

4.3.3 Ignimbrite

It is an igneous rock unit which is well exposed on the small quarry sites of the eastern, south-eastern and north-western part of the study area (Figure 10). In this area, the rock unit is characterized by its dark grey color and the rock units are highly weathered and fractured. Due to its workability, it is used as a masonry stone for building purposes.

Figure 10: Fresh and weathered Ignimbrite Exposure in the quarry sites

4.3.4 Tuff rock units

Tuff rocks units are exposed in the eastern part of the study area. It has white color and a fine-grained texture. This rock unit is soft that is resulting from the poor compaction and cementation of volcanic ash. The tuff unit in the northeastern part of study area is intercalated with basalt (Figure 11).

Figure 11: Weathered tuff units and intercalated tuff with basalt

4.3.5 Geological structure

Geological structures affect the stability of civil engineering structures constructed on discontinuous rock masses. Geological structures make the rocks weaker and permeable. If rock masses fractured it would be a conduit for groundwater to flow in it. The dominant geological structures found in the study area are joints. A fault was observed only in the NE part of the study area.

Fault: Fault is observed In the Northern part of Jimma around Jiren. It is identified in the field from physiographic features such as a sharp cliff which faces towards the west. This fault in striking in the NW-SE direction and it is nearly vertical.

Joint: The joints are the second common geological structures observed on basalt rocks found in the study. Figure 12 shows a rose diagram of joints measured in the study area. The observed major joint sets are striking in the direction of NE and NW, and a minor set with N-S strike.

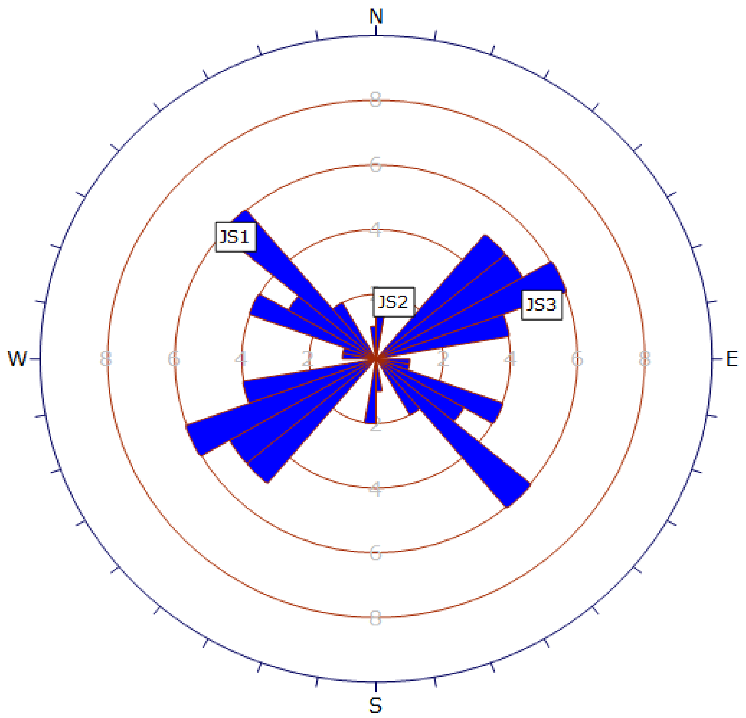


Figure 12: Rose Diagram of joints of the study area plotted using dips6.00 software.

Finally, a geological map of the study area was produced at a scale of 1: 25,000. The geological cross-section was also produced from the geological map of the study area (Figure 13).

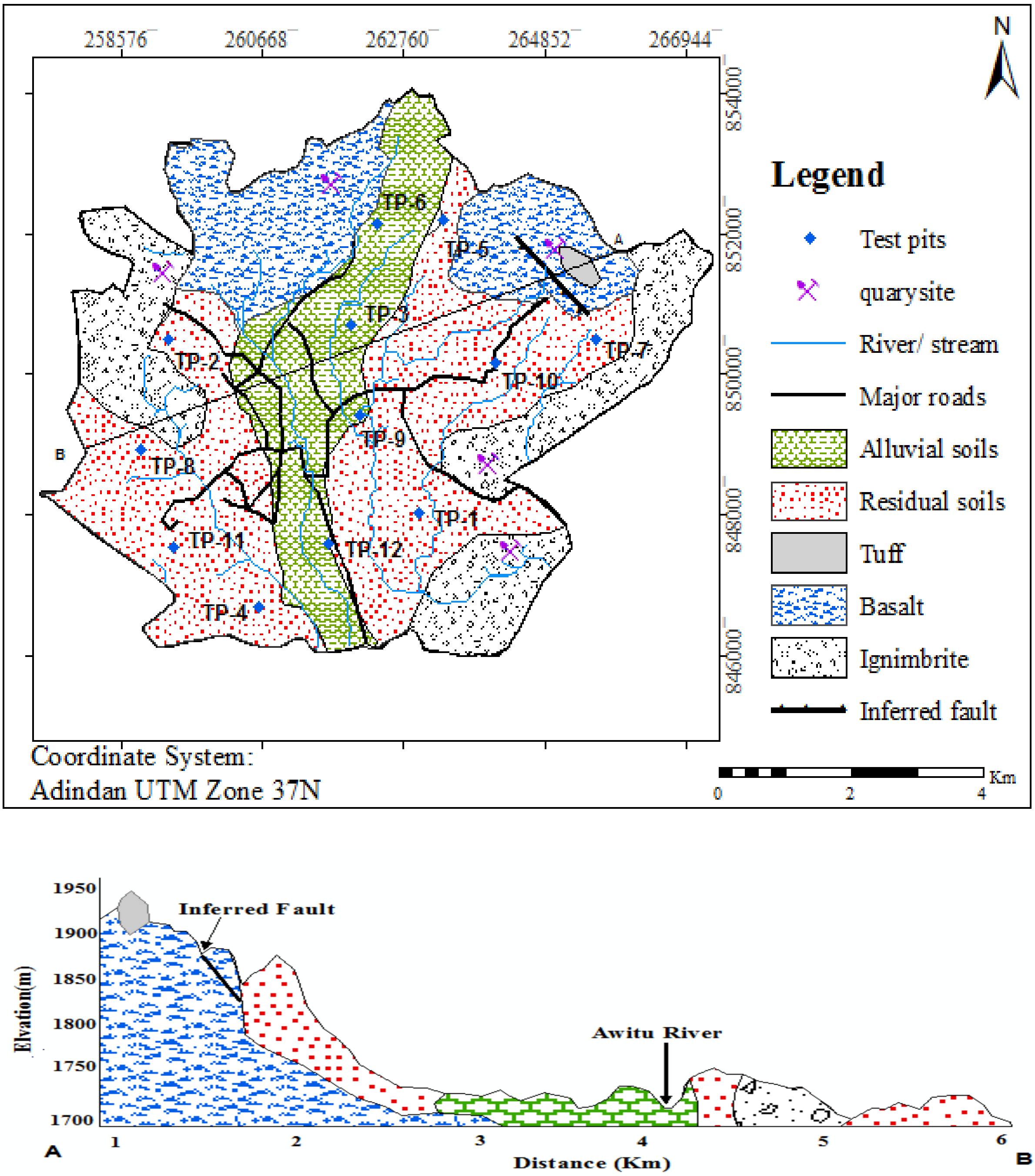


Figure 13: Geological Map and Geological Cross Section of the study area

4.4 land form and Geohazard of the study area

4.4.1 Land form and relief

The study area is characterized by different types of landforms, such as flat land in central and southern parts, while the northern and eastern parts of the town and its peripheries are characterized by hilly/ ridge landscape. The relief of the study area is 500m, i.e. the difference between high elevation (2200m) and low elevation (1700m) The low laying area is mainly plain and filled by thick overburden (alluvial and residual soil). Based on the range of slope, the study area is characterized by steep to gently slope which ranges from 0 % to 89 % (Figure 14).

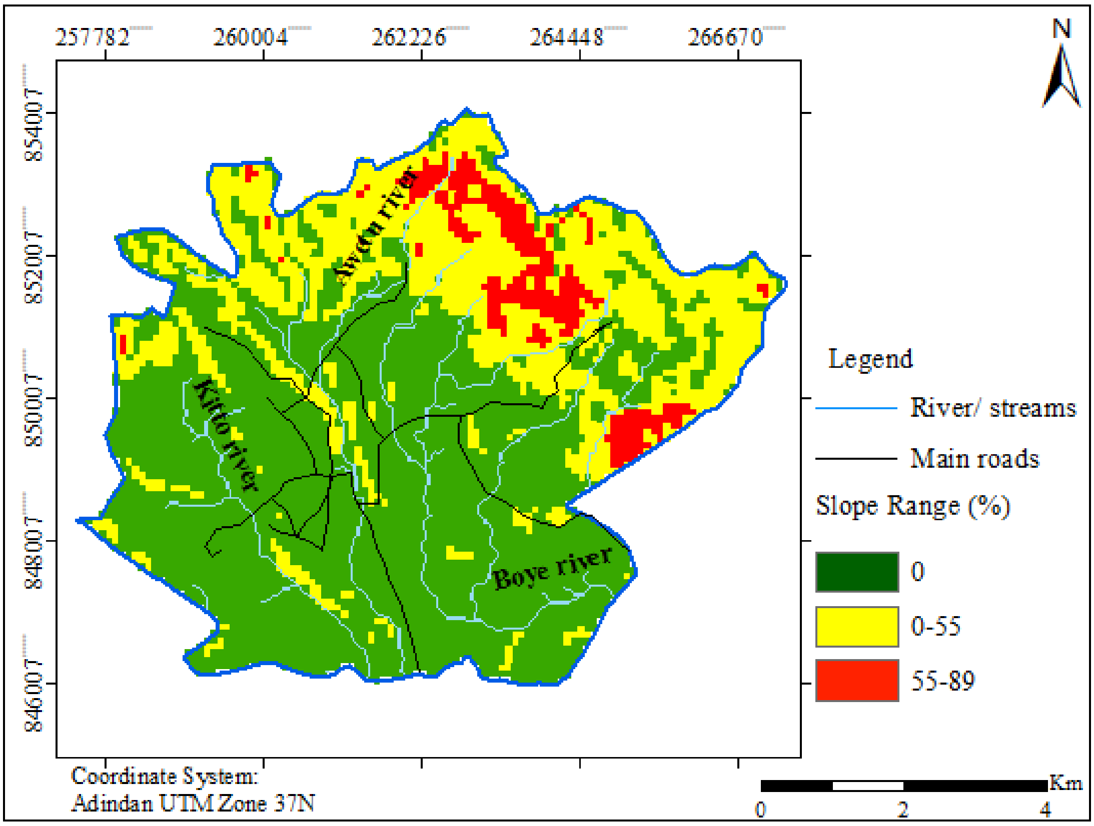


Figure 14: Slope map of the study area

4.4.2 Geohazard

Geological hazards can pose serious constraints on development. However, if the area prone to hazards is identified in advance, it will be very easy for the local government units to establish control or mitigating measures to lessen the effect of such hazards. Therefore, the establishment of land use zoning considering geo-hazards is very important to protect people and their properties.

4.4.3 Flooding

Jimma town is surrounded by steeply or hilly topography which makes the town vulnerable to flooding hazard in the rainy season. The flooding in the town is mainly an after effect of high precipitation (which is common during summer) and poor drainage system. Some of the flooding that occurred in the town caused serious damage on property and humans life. For instance, the flooding that occurred on October 7, 2013 forced vehicles to stop for some hours to give usual service. The over flooding on the road by storm water resulting in the accumulation of silt lead to overturning of cars. The storm water runoff is mainly originated from the very steep mountain surrounding the town (Feyissaa, 2019).

Figure 15: Flash flood of Awetu River in Jimma Town (Feyissaa, 2019)

Ginjo Guduru is one of the 13 kebeles of Jimma town located at a lower elevation which is directly affected by surface runoff water originated from Jiren Mountain. This flooded prone area is located at the downstream reach of the Guduru sub-catchment along the streams. Two small bridges over flooded with runoff water in July 2013 due to blockage by debris and the flooding extended to the surrounding residential buildings causing damages or loss to their property. In the 2014 rainy season, over flooding of runoff water also occurred to the bridge three times in a season (Getachew, 2015).

4.4.4 Earthquake

An earthquake is the vibration of Earth produced by the rapid release of energy and it is the most devastating earth process. The southwestern part of the Ethiopian rift is one of the most seismically and volcanically active tectonic units in East Africa. Notable seismic events have occurred in 2010 and 2011 in Hosanna and Yirgalem, respectively. The main shock of the Hosanna event occurred on December 19, 2010 with a magnitude of 5.2 mb and was located 15-20 km northwest of the town. It was also strongly felt in Jimma town and students from Jimma University accommodated at higher floors of the residence buildings were terrified and rushing down where it caused injuries of over 26 students during that event. The seismic activity continued for over a year.

Ethiopian building code standard (EBCS, 1995) is a seismic hazard map produced by the state building codes standard which recommends the engineering precaution to be taken in each rank of hazard in the maps. According to the map (Figure 16), the country is divided into zones of approximately equal seismic risks depending on the known distribution of the past damaging earthquake ranging from less damaging zones (zone 1 and 2) to zones of major damage (zone 4). Jimma is located in zone 1 of the seismic hazard map (Figure 16). The design ground acceleration value for the study area (zone 1) is 0.03g for 100 year return period.

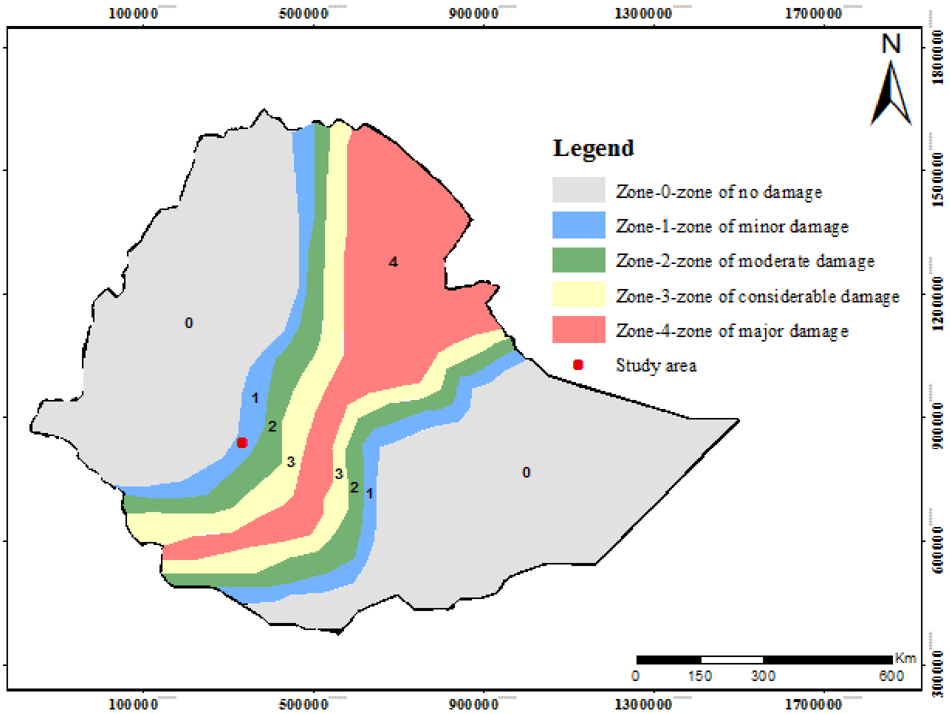


Figure 16: Map that shows study area on seismic hazard zone map of Ethiopia (Source: Ethiopian Building Code Standard (1995))

4.4.5 Shrinking and swelling soils

Shrink–swell, or expansive, soils are one of the most costly and globally widespread geological hazards that present significant geotechnical and structural challenges to lightweight structures. Shrink–swell is the volume change that occurs as a result of changes in the moisture content of clay-rich soils. This is a common problem in Jimma town that pose threat to the stability of light weighted structures such as residential building and pavement. The town is a typical example for pavement deterioration in Ethiopia.

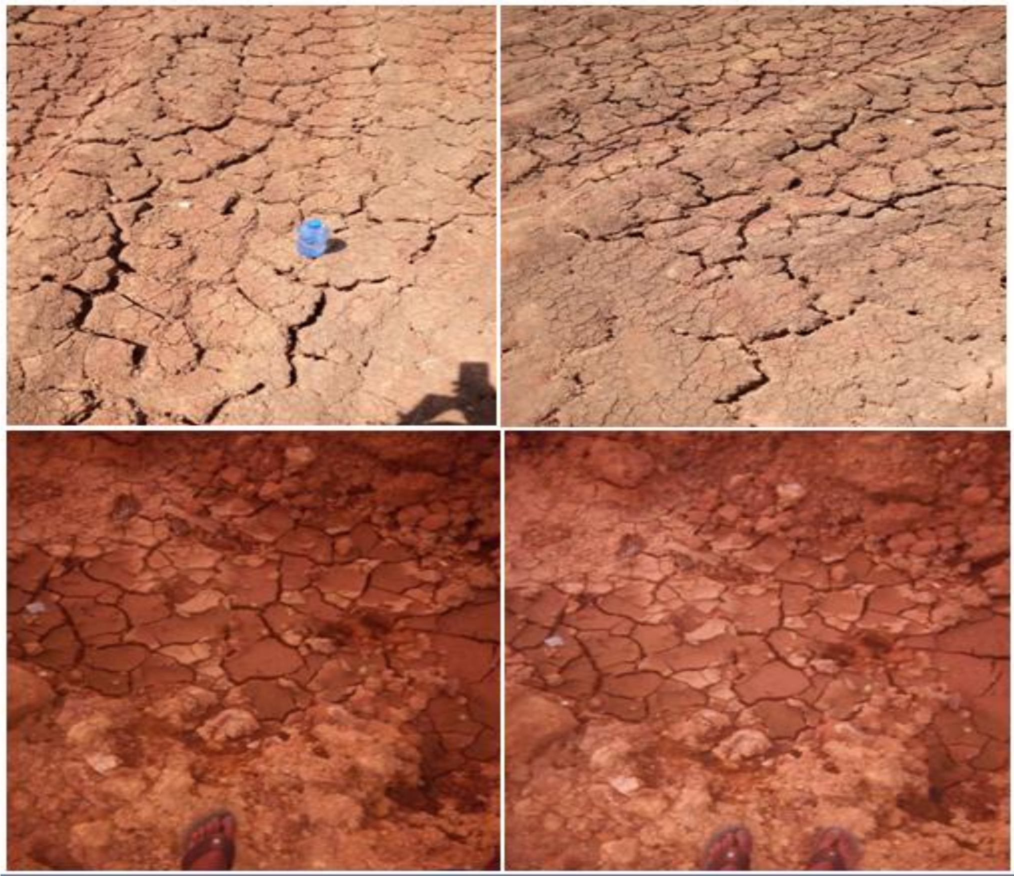


Figure 17: Shrinking and swelling soils in the study area

CHAPTER FIVE

5. RESULTS AND DISCUSSION

5.1 Engineering geological characterization of soil

The soils of the study area are broadly categorized into residual and alluvial soils hence, sample collection; characterization and engineering descriptions have been conducted on both soils. Based on the objective of this research, the field description and laboratory soil tests were conducted which greatly help in identifying and classifying the soils. The engineering geological characterization and geotechnical properties of soils were determined using different laboratory tests such as mechanical and hydrometer analysis, Atterberg limits, specific gravity and Undrained Shear Strength tests.

5.1.1 Index properties

For engineering geological characterization of soils of the study area, a laboratory index test was conducted on twelve representative soil collected from test pits. The results and interpretation of tests on index properties of the soils are presented below.

5.1.2 Natural moisture content

The physical properties of most fines grained and particularly clayey soils are greatly affected by the water content. The natural moisture content of the soil taken is presented in table 5. According to the test results, the natural moisture content of soils of the study area ranges from 41.97 to 62.45%. The results imply, the soil of the study area dominantly has relatively high water holding capacity as the fine fraction is the dominant grain size. Such soils are expected to exhibit relatively higher volume change (swelling and shrinkage) in association with moisture content variation (Table 5).

Table 5: Natural moisture content

Sample Designation	Depth(m)	NMC (%)
TP-1	3	44.79
TP-2	3	50.52
TP-3	3	62.45
TP-4	3	52.39
TP-5	3	52.08
TP-6	3	42.18
TP-7	3	48.61
TP-8	3	51.07
TP-9	3	44.69
TP-10	3	44.82
TP-11	3	44.25
TP-12	3	41.97

5.1.3 Specific gravity

Specific gravity test results for different soil samples in the study area are presented in the following Table 6. The result demonstrates the specific gravity of the soils in the study area varies from 2.36 to 2.75. The lower value for some soils, such as TP-3 could be due to the presence of organic matter (Table 6).

Table 6: specific gravity result

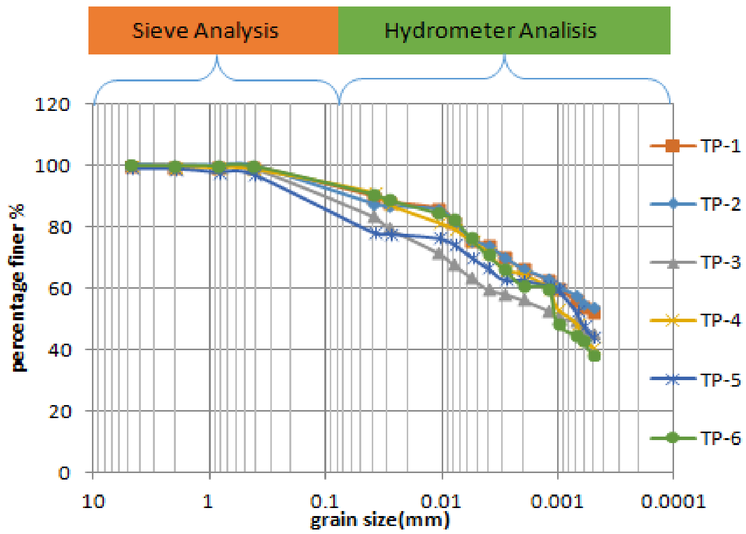
Sample Designation	Depth (m)	Gs
TP-1	3	2.63
TP-2	3	2.55
TP-3	3	2.36
TP-4	3	2.65
TP-5	3	2.61
TP-6	3	2.59
TP-7	3	2.62
TP-8	3	2.53
TP-9	3	2.74
TP-10	3	2.75

5.1.4 Grain size analysis

Grain size analysis was used to determine the textural classification of soils. It is used to determine the particle size distribution of the soils. The analyses results are presented in Table 7. The result shows that the predominant size of soil particles in the research area is fine-grained soils, which have gravel content ranging from 0-0.9%, sand fraction 0.35-4.95%, silt fraction 30-55.9% and clay 42-71% (Table 7).

Table 7: Grain size analyses of soil in the study area

No	Location	Sample Designation	Depth (m)	Percent amount of Particle size (%)			
				% Gravel	% Sand	% of fine soil	
						Silt	Clay
1	Bocho-bore	TP-1	3	0.13	1.20	38.03	60.51
2	Bosa-adiss	TP-2	3	0.03	0.62	48.08	50.95
3	Legehar	TP-3	3	0.00	3.16	40.15	56.69
4	Mendera	TP-4	3	0.12	2.18	35.15	62.42
5	Kochi	TP-5	3	0.98	0.35	37.34	57.20
6	Mentina	TP-6	3	0.00	1.21	41.59	57.20
7	Jiren	TP-7	3	0.12	1.64	50.69	47.55
8	Abajifar airport	TP-8	3	0.26	2.99	52.36	44.13
9	Awitu	TP-9	3	0.00	1.93	55.91	42.16
10	Jimma University	TP-10	3	0.00	4.59	24.05	71.36
11	Hermata	TP-11	3	0	2.32	30	67.6
12	Fernje arada	TP-12	3	0.02	3.38	41.6	54.98



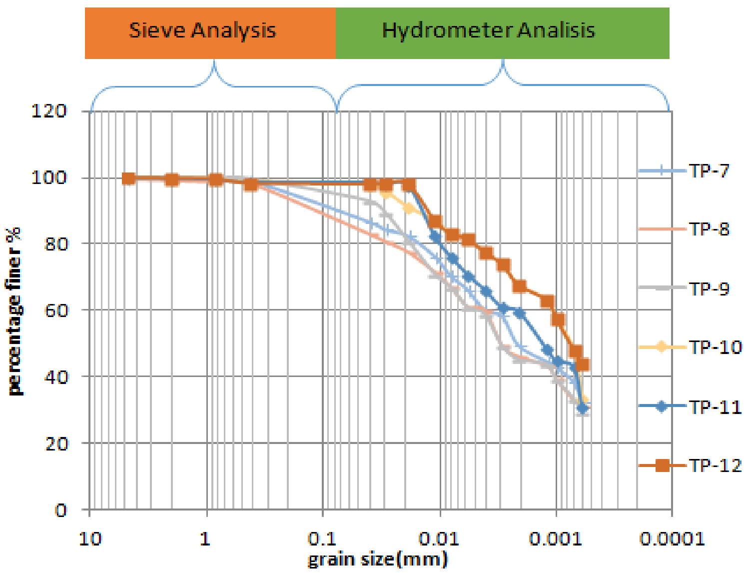


Figure 18: Grain size distribution curves of soil samples

5.1.5 Atterberg (consistency) limits

Atterberg limits were determined in the laboratory using Cassagrande's method. The analysis contains liquid limit and plastic limit tests. From the results of liquid limit (LL) and plastic limit (PL), the plasticity index (PI) of the soils of the study area was calculated. The test results are summarized in Table 8. The test result shows that LL and PL of the study area range from 87%-97% and 34%-43%, respectively. The plasticity index ranges from 49%-53% and 19%-48%. The soils of the study area fall medium to high plasticity. Generally, the larger the plasticity index, the greater will be the engineering problems associated with using the soil as an engineering material.

5.1.6 Activity of Soils

Activity is the function of the plasticity index and the number of clay particles finer than 2µm present in soil (Skempton, 1953). It indicates the potential swell and shrinkage (volume change) of soil. Generally, soils with activity less than 0.75 are low, 0.75-1.25 medium and those with greater than 1.25 are highly expansive. The soils of the study area fall in low and medium expansive soil and exhibit the property of normal and inactive soil types (Table 8).

$$\mathbf{A} = \frac{\mathbf{PI}}{\mathbf{\%\ of\ clay\ fraction}}$$ (Skempton, 1953...…..………………………….Eq. 5.1

Table 8: Atterberg Limits results of soils of the study area

No	Location	Sample Designation	Depth (m)	LL (%)	PL (%)	PI (%)	Activity & Clay Minerals	Potential of expansion
1	Bocho-bore	TP-1	3	66	31	35	0.57 (Kaolinite)	Inactive
2	Bosa adiss	TP-2	3	70	49	21	0.412 (Kaolinite)	Inactive
3	Legehar	TP-3	3	92	43	49	0.86 (Illite)	Normal
4	Mendera	TP-4	3	97	38	59	0.94 (Illite)	Normal
5	Kochi	TP-5	3	101	53	48	0.83 (Illite)	Normal
6	Mentina	TP-6	3	87	34	53	0.92 (Illite)	Normal
7	Jiren	TP-7	3	82	54	28	0.58 (Kaolinite)	Inactive
8	Abajifar airport	TP-8	3	72	53	19	0.43 (Kaolinite)	Inactive

9	Awitu	TP-9	3	74	42	43	0.75 (Illite)	Normal
10	Jimma University	TP-10	3	75	45	30	0.42 (Kaolinite)	Inactive
11	Hermata	TP-11	3	81	62	19	0.23 (Kaolinite)	Inactive
12	Fernje arada	TP-12	3	91	37	54	0.6 (Kaolinite)	Inactive

5.1.7 Shear strength

The shear strength of soil is one of the most important aspects of geotechnical engineering. The Bearing capacity of shallow and deep foundations, slope stability, retaining wall design and pavement design are all influenced by the shear strength of the soil. Structures and slopes must be stable and secure against total collapse when subjected to maximum anticipated applied loads.

The undrained shear strength of the soils determined on remolded soil at natural moisture content is summarized in Table 9. The undrained cohesion of the soils ranges from 27 to 173 kPa.

Table 9: Result of shear strength of soil

Sample Designation	Depth (m)	NMC (%)	cu (kPa)
TP-1	3	44.97	41.51
TP-2	3	50.53	164
TP-3	3	62.45	24.57
TP-4	3	54.10	66
TP-5	3	48.61	27
TP-6	3	42.93	47.47
TP-7	3	48.61	57.97
TP-8	3	47.50	118.65
TP-9	3	44.23	170.72
TP-10	3	44.82	173.66

5.1.8 Free swell

Free swell test is used to indicate the presence of swelling clay in soil. Also, the potential expansiveness of soil samples can be determined by using the result of free swell. In this study, free swell tests were conducted in some of the soil samples. The free swell tests of the soils are found to be in the range of 100 to 130% for clay soils and 33 to 63% for silt soils (Table 10). All of the soil type except test pit TP3 and TP7 have free swell greater than 50%. Therefore, considerable attention should be given for these types of soils.

Table 10: Free swell test results of Jimma soils

Depth (m)	Sample Designation	Free swell index (%)	Average (%)
3	TP-1-1	122.12	130
	TP-1-2	137	
3	TP-2-1	65	58
	TP-2-2	50	
3	TP-3-1	63.6	43
	TP-3-2	21.42	
3	TP-4-1	100	100
	TP-4-2	100	
3	TP-5-1	90	63
	TP-5-2	35.7	
3	TP-6-1	150	125
	TP-6-2	100	
3	TP-7-1	25	33
	TP-7-2	40	

5.2 Classification of the soil of the study area

5.2.1 Classification of soils of the study area based on AASHTO Classification System

The AASHTO system uses both grain-size distribution and Atterberg limits data to assign a group classification and a group index to the soil. AASTO classification system classifies soils into seven groups, A-1 through A-7-6. According to this classification system soils of which more than 35% pass through the No. 200 sieves are classified under groups A-4, A-5, A-6 and A-7. The soils in these groups are mostly silt and clay-type materials.

According to the AASHTO classification system, the soils in Jimma town fall under A-7-6 as presented in table 11. This indicates the soils in the study area are unfavorable for sub-grade materials.

Table 11: Classifications of Soils of the study area based on AASHTO classification system

Sample Design-ation	Percent of particle size				LL (%)	PI (%)	AASHTO system	Remark	Rating
	Gravel	Sand	Silt	Clay					
TP-1	0.13	1.33	38.03	60.51	66	35	A-7-6(42)	Clayey soils	Poor
TP-2	0.33	0.64	48.08	50.95	70	21	A-7-6(32)	Clayey soils	Poor
TP-3	0	3.16	40.15	56.69	92	49	A-7-6(60)	Clayey soils	Poor
TP-4	0.12	2.31	35.15	62.42	97	59	A-7-6(70)	Clayey soils	Poor
TP-5	0.98	4.48	37.34	57.20	101	48	A-7-6(61)	Clayey soils	Poor
TP-6	0	1.21	41.59	57.20	87	53	A-7-6(63)	Clayey soils	Poor
TP-7	0.12	1.64	50.69	47.55	82	28	A-7-6(41)	Clayey soils	Poor
TP-8	0.26	3.25	52.36	44.13	72	19	A-7-6(30)	Clayey soils	Poor
TP-9	0	1.92	55.91	42.16	74	32	A-7-6(42)	Clayey soils	Poor
TP-10	0	4.59	24.05	71.36	75	30	A-7-6(39)	Clayey soils	Poor
TP-11	0	2.32	30	67.6	81	19	A-7-6(33)	Clayey soils	Poor
TP-12	0.02	3.38	41.6	54.98	91	54	A-7-6(65)	Clayey soils	Poor

5.2.2 Classification of soils of the study area based on USCS

As per this classification system, the soils of the study area are fine-grained soils with a percentage finer than 75 µm is greater than 50%. Based on the plasticity index and liquid limit (plasticity chart), the soils were further classified into different groups (classes). Accordingly, the soils of the study area were classified as high plastic clay (CH) and high plastic silt (MH) According to general engineering suitability of the soils (Arora; 2003), the soils of the study area characterized by high compressibility, fair to poor shear strength and poor in engineering workability. The results indicate that they are problematic soils for engineering application with higher swelling-shrinkage potential.

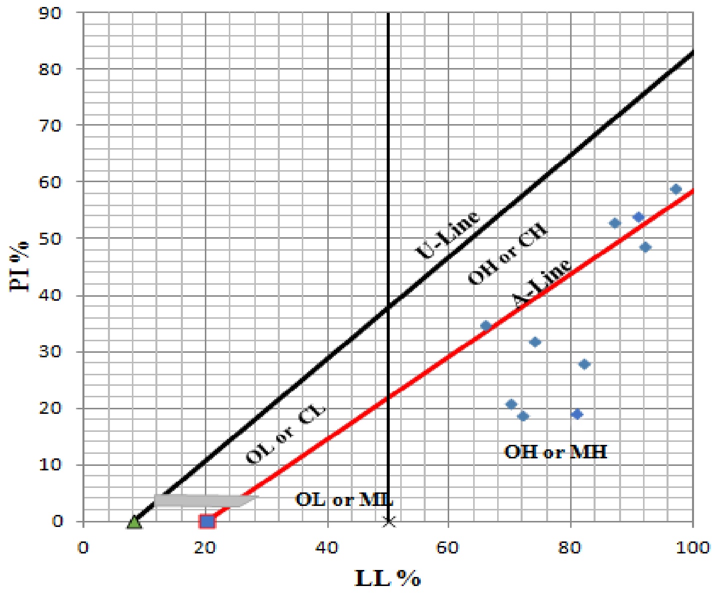


Figure 19: Classifications of Soils of the study area based on USCS

Table 12: Classifications of Soils of the study area based on unified soil classifications

Sample Design-ation	Percent of particle size				LL (%)	PI (%)	Group Symbol	Soil name
	Gravel	Sand	Silt	Clay				
TP-1	0.13	1.33	38.03	60.51	66	35	CH	Inorganic clay of high plasticity
TP-2	0.33	0.64	48.08	50.95	70	21	MH	Inorganic silt of high plasticity
TP-3	0	3.16	40.15	56.69	92	49	MH	Inorganic silt of high plasticity
TP-4	0.12	2.31	35.15	62.42	97	59	CH	Inorganic clay of high plasticity
TP-5	0.98	4.48	37.34	57.20	101	48	MH	Inorganic silt of high plasticity
TP-6	0	1.21	41.59	57.20	87	53	CH	Inorganic clay of high plasticity
TP-7	0.12	1.64	50.69	47.55	82	28	MH	Inorganic silt of high plasticity
TP-8	0.26	3.25	52.36	44.13	72	19	MH	Inorganic silt of high plasticity
TP-9	0	1.92	55.91	42.16	74	32	MH	Inorganic silt of high plasticity
TP-10	0	4.59	24.05	71.36	75	30	MH	Inorganic silt of high plasticity
TP-11	0	2.32	30	67.6	81	19	MH	Inorganic silt of high plasticity
TP-12	0.02	3.38	41.6	54.98	91	54	CH	Inorganic clay of high plasticity

5.3 Engineering geological characterization of rock

To classify the quality of rocks, different measurements were taken on the field to determine the compressive strength of the rock using Schmidt hammer, rock quality designation using volumetric count method, weathering condition and condition of discontinuities from visual observations. The quality of the rocks in the study area was calculated by adding the five basic parameter rating values according to Bieniawski (1989). Having this in context, in-situ Schmidt hammer testing was carried out to attain the intact rock strength of the rocks. Accordingly, rock exposures were identified around quarry sites. Discontinuity surveys and the associated acquisition of data for RQD determination were then carried out at each quarry site location.

5.3.1 Discontinuity data

Discontinuity survey has been carried to acquire data on parameters of discontinuities such as spacing, orientation and conditions such as persistence, aperture, roughness, wall weathering and type of infill materials. Table 13 presents a summary of some representative discontinuity measurements.

Table 13: Summary of representative discontinuity measurements of some rocks

Type of joint	Strike(°)	Dip(°)	Spacing (m)	Aperture (mm)	Infill material	Wall weathering
JS-1	326	84	0.07	0.25-0.5	None	Highly weathered
JS-1	320	84	0.15	0.25-0.5	None	Slightly weathered
JS-1	310	85	0.25	0.1-0.25	None	Highly weathered
JS-1	315	85	0.4	0.1-0.25	None	Highly weathered
JS-2	348	Vertical	0.05	0.25-0.5	None	Slightly weathered
JS-2	346	vertical	0.05	0.1-0.25	None	Slightly weathered
JS-2	40	Vertical	0.7	0.1-0.25	None	Slightly weathered
JS-2	84	Vertical	0.15	0.1-0.25	None	Highly weathered
JS-3	228	84	0.15	0.25-0.5	None	Highly weathered
JS-3	158	72	0.25	0.25-0.5	None	Highly weathered
JS-3	156	83	0.005	0.25-0.5	None	Slightly weathered
JS-3	155	72	0.25	0.1-0.25	None	Highly weathered

5.3.2 Intact rock strength

Strength is the property of rock to resist scratching. To make fairly accurate estimates on rock material strength, it is important to know the ability to resist scratching of rock. This can be readily calculated by uniaxial compressive strength or point load tests. In this study, a simple estimate was made from the field test (Schmidt hammer rebound test).

This method provides a rapid classification of the strength of the rock during site characterization for engineering design and construction purposes and the method is limited use on very soft rock (unconfined compressive strength less than approximately 1MPa) and very hard rock (unconfined compressive strength greater than approximately 100MPa). In this study, the Schmidt hammer, is used to determine the compressive strength of the rock in the study area. Table (14) below presents rebound value obtained from this test.

Afterwards, the rebound value (i.e. R-value) obtained from this test was converted into Uniaxial Compressive Strength (UCS) of rocks by using the dry density (ɣ) of the rock obtained using bouncy technique (Barton and choubey, 1977).

$$\mathbf{Log\ 10\ UCS = 0.00088\gamma R + 1.01} \qquad \text{Eq. 5.2}$$

Where: **UCS =** unconfined compressive strength

ɣ = Dry density

R =Rebound value

The unconfined compressive strength (UCS) of the rock of the study area is in the range between 50.118 and 194.98 MPa (Table 14). The rocks fall in the high strength class, Except for the ignimbrite of some areas and one basalt outcrop.

Table 14: Uniaxial Compressive Strength of rocks of the study area

No	Easting	Northing	Elevation	Rock type	Dry density (KN/m3)	Average SHV	Average UCS (MPa)	Description (ISRM,1978)
1	264605	852009	1968	Basalt	24.9	58.5	194.98	Very high strength rock
2	264679	853547	1970	Basalt	24.8	57.7	181.97	Very high strength rock
3	263745	853968	1974	Basalt	21.8	49.5	131.82	Very high strength rock
4	261564	852819	1978	Basalt	24.5	51.8	165.95	Very high strength rock
5	261697	852978	1982	Basalt	25	56.7	89.12	High Strength rock
6	263967	848723	1836	Basalt	21.1	55.1	107.15	Very high strength rock
7	262701	849489	1826	Ignimbrite	26.1	52.5	162.18	Very high strength rock
8	262690	851395	1818	Ignimbrite	24.7	53.3	144.54	Very high strength rock
9	262670	847250	1750	Ignimbrite	25	52.6	50.118	High strength rock
10	264605	847988	1745	Ignimbrite	22.5	53.4	169.82	Very high strength rock

11	267860	849233	1740	Ignimbrite	22.9	48.2	95.49	High strength rock
12	268863	859235	1741	Ignimbrite	22.3	48.1	89.25	High strength rock
13	259185	851519	1739	Ignimbrite	20	55.9	97.72	High strength rock
14	257876	849238	1738	Ignimbrite	23	55.1	131.87	Very High strength rock
15	257879	849269	1737	Ignimbrite	22.2	56.0	165.95	Very High strength rock

5.3.3 Rock Mass Rating (RMR) System

To determine the quality of rock mass for surface exposures and estimate their engineering properties, Bieniawski's (1989) basic rock mass rating system was applied. As for input parameters, intact rock strength (UCS) was determined through the Schmidt hammer test. Similarly, the RQD which was determined through the Volumetric Joint Count Method was used for the classification. Other input parameters such as spacing and conditions of discontinuities were obtained through the joint survey and parts of the data were shown in Table 15.

Later, the rating was assigned to each of these five parameters according to Bieniawski's (1989) and were added together to attain basic RMR. Accordingly, the basalt unit was classified as good with a corresponding rating value of 61 to 72.

Table 15: Rock mass classification based on RMR system for study area

Parameter	**Basalt**											
Description	Value	R	Value	R	Value	R	Value	R	Value	R	Value	R
UCS(MPa)	194.98	12	181.97	12	131.82	12	165.95	12	89.12	7	107.15	12
RQD (%)	76	17	67	13	87	17	93	20	89	17	66	13
Joint condition	P(<1m) 0.1 - 1mm open, SR, Infilling (none), HW	20	P(<1m) 1mm open, SR Infilling (none), SW	25	P(2m) 0.1- 1mm Open, SR, Soil fill, HW	18	P(<1m) 0.1- 1mm open,SR ,infillin g(none), HW	20	P(1m) 0.1- 1mm Open SR,so il fill, SW	25	P(<1) 1mm Open, SR,infi lling (none), SW	16
Spacing (m)	0.07	8	0.15	8	0.25	10	0.4	10	0.05	5	0.35	10
Water condition	Damp	10	Damp	10	Damp	10	Damp	10	Damp	10	Damp	10
RMR	67		68		67		72		64		61	
RMR class	Good Rock		Good Rock		Good Rock		Good Rock		Good Rock		Good Rock	
P= Persistence, SR= slightly rough , SW= slightly weathered , HW= highly weathered, RMR= rock mass rating, RQD= Rock Quality Designation, UCS= uniaxial compressive strength, R= rating												

5.4 Engineering Geological Characterization and Classification of Rocks of the study area

The engineering geological characterization and geotechnical properties of rock were determined using Schmidt hammer rebound test to estimate the unconfined compressive strength of intact rock in addition to describing the rocks of the study area by in-situ visual description. The description of rock involves a determination of the rock names, i.e., the lithological rock name, description of the properties of the rock material (texture, color, strength and state of weathering). Description of additional properties is necessary to describe the features of the rock mass (discontinuities, structure). The rocks of the study area were classified according to the international society of rock mechanics (ISRM, 1981) Based on their strength (unconfined compressive strength), a rock of the study area are classified into three major engineering geological subunits: Medium Strength rock units, High Strength rock units and very low (soft) rock units. The engineering geological map of the town is produced by the description and classification of both soil and rock and the delineation of engineering geological units.

5.4.1 High Strength Rock unit

These engineering geological subunits include slight weathered ignimbrite and basalt.

5.4.2 Slightly weathered very high strength Ignimbrite

High strength ignimbrite rock unit is found in the western, eastern and southeastern parts of the study area forming cliffs. It is gray in color. Texturally it is porphyritic in texture (i.e. clasts and groundmass) and slightly weathered. The strength varies from 131.87 to 169.82 MPa.

5.4.3 Slightly weathered very high strength basalt

The high-strength basalt is mostly found at the N and NE part of the study area. It is fine-grained and moderately to highly weathered. The strength of the rock material varies between 107.15 to 194.98MPa. Three sets (NW, SE and NS) joints are dominant. The joints are moderately spaced (250mm to 300mm). The joint surface is both smooth and rough. The aperture varies from tight to partly open (0.25mm to 1mm).

5.4.4 High strength Ignimbrite

The medium strength ignimbrite rock units were found in the northwestern part of the study area. It is light gray in color and highly weathered. The strength of the rock material ranges from 50.118 to 97.72 MPa.

5.4.5 Low strength (Soft) rock units

It is tuff rock unit. The strength of this unit is very low to measure using the Schmidt hammer. It is exposed in northeastern portion of the study area and, is highly weathered. The rock in the area can be peeled with a knife, hence the compressive strength of this rock is considered to be <1Mpa and very soft rock. It is characterized by white color and fine-grained texture.

5.5 Groundwater (GW)

Groundwater may influence excavation and construction methods by flowing into excavations, by producing seepage forces and uplift pressures and by its corrosive action (UNESCO, 1976). Hence, groundwater level and quality information are necessary for construction activities. For this work, the GW data are collected from previous research works as shown below (Table 16).

Based on topography, variation in hydraulic properties of the volcanic rocks and alluvial sediment, and their location the main hydrological basin of the Jimma area is classified into three sub-basins as the Kochi, Awetu and Kitto sub-basins. The Kochi sub-basin is drained by the Kochi stream which joins the Awetu stream at Boye. On the other hand, the Kitto sub-basin drains by the Kitto stream finally joins the Awetu stream at Dedo Bridge. Awetu stream, a perennial stream, originates from the north of the town and flows along the middle of the valley in the south direction.

As observed from the groundwater wells data from different parts of the town (Table 16), the depth of static water level was found at a shallower depth. Therefore, the influence of groundwater on the foundations could be critical in the town. From the values of GW level contours, the general direction of GW flow was determined and the map is produced at a scale of 1:50,000. The flow is towards the southwestern direction as shown in figure 20.

Table 16: Measurement values of water level elevations of the wells (Solomon, 2011)

Well	Longitude (m)	Latitude (m)	Altitude (m)	Depth to GW (m)	GW level (elevation)(m)
Ginjo School	264841	852239	1767.97	3.8	1764.17
Kito-furdisa	263366	851619	1756.98	3	1753.98
JU sport field	260398	852256	1744.85	2.2	1742.65
Main campus 1	262846	849088	1737.2	1.2	1736.00
Main campus 2	263265	848836	1736.24	0.8	1735.44
Airport	259040	849892	1725.48	0.91	1724.57
Boche-bore	263734	847830	1722.47	0.31	1722.16

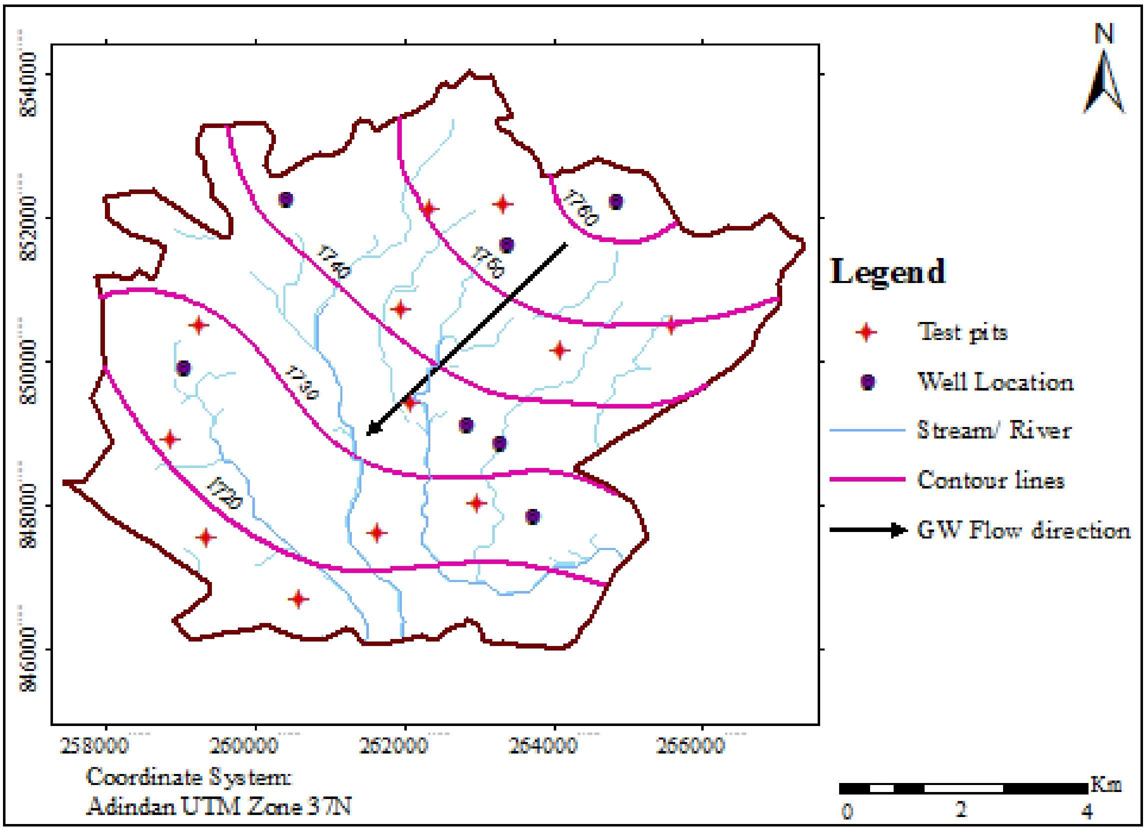


Figure 20: Groundwater level contours and GW flow direction of the study area

Based on the description of the soils and rocks from field and laboratory data, delineation of engineering geological units was made. In addition, information about groundwater conditions and potential geo-hazards in the area were assessed. Finally, all the necessary information is compiled on the same map to produce a multipurpose medium-scale engineering geological map for the town (Figure 21).

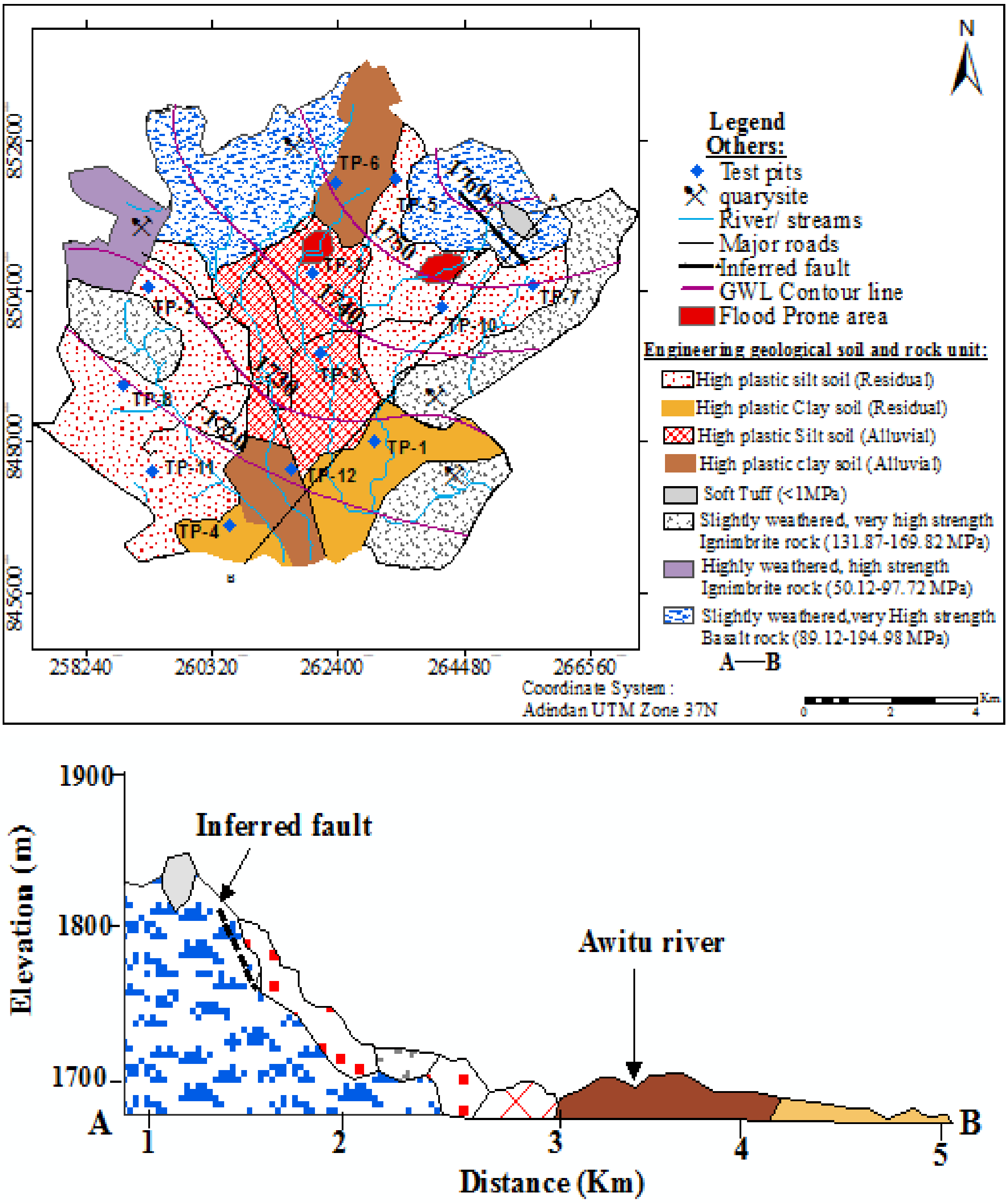


Figure 21: Engineering geological map and cross-section of the study area

6. CONCLUSIONS AND RECCOMONDATION

6.1 Conclusions

The main mapable soil units in the study area are alluvial and residual soils. From grain size analysis, the soils are dominantly fine grain with the content of gravel range from 0% to 0.98%, sand 0.6% to 4.6%, silt 24% to 55.9% and clay 42% to 71.4%. The natural moisture content varies from 42.2% to 62.5 and 44.7% to 52.1% for clay and silt soil respectively, indicating the water holding capacity of the soils is relatively very high. The liquid limits in a percentage range from 87 – 97 for clay soils and 66 -101 for silt soil. The plasticity index of the soils also varies from 49% to 53% for clay soils and 19% to 48% for silt soils indicating soil of the study areas has very high plastic. The degree of expansiveness varies from medium to very high. Their percentage of free swell extends from 33% to 130% which would have an adverse effect on light weight ordinary structures. According to the Unified Soil Classification System (USCS), the soils are classified as high plastic clay (CH) and high plastic silt (MH) and characterized by high compressibility, fair to poor shear strength and poor in engineering workability. Similarly, as per the AASHTO classification system, the soils are classified as clayey soils (A-7-6) which is unfavorable for subgrade material.

The main lithological rock units exposed in the study area are ignimbrite, basalt and tuff. The ignimbrite unit shows variable strength ranging from 50.118MPa to 169.82MPa, basalt from 89.12MPa to 194.98MPa and tuff <1MPa. These lithological rock units are classified into three major engineering geological subunits based on unconfined compressive strength: very high strength rock unit which includes slightly weathered basalt and ignimbrite, high strength rock unit (highly weathered ignimbrite) and low strength rock unit (soft tuff).

Flooding is the main geo-hazard that needs attention in the study area. Similarly, the soil underlying the study area is characterized by higher swelling-shrinkage potential. Such properties can pose damage to lightweight structures, like pavement, residential houses, etc. as these structures can’t counteract the pressure exerted by swelling clayey soils.

6.2 Recommendation

Based on the findings of the current work, the following recommendations are forwarded:

- ✓ Flooding is one of the threatening natural hazards in the northern and central parts of the town and is caused by seasonal heavy rainfall. Food control remedial measures, such as constructing drainage networks and diversion canals, proper waste management and increasing the size of canals, shall be carried out to minimize the risk.
- ✓ Areas dominated by soils with swelling and shrinking behaviors require careful consideration during the design and construction of engineering structures in these areas. It is recommended to use ground improvement methods like: removing the soil and replace with other materials, deep foundation, horizontal or vertical drainage system and Soil Stabilization by Admixtures.
- ✓ In the free swell test the result show high potential of soil to swell which might need further detailed investigation regarding swelling and swelling pressures under different field conditions.
- ✓ The groundwater is very shallow in the study area. The potential chemical attack on concrete foundations due to groundwater chemistry should be for safe and economic design of the foundation of the structures. Therefore, proper soil chemical tests and hydrochemical analysis of groundwater, such as pH, salinity, sulphate, chloride, etc. should be done for further understanding of their effects on the foundation.
- ✓ Fault zones and the sense of movement were not studied in detail with respect to nature and extent due to resource limitation. Further study might need to be investigate for their influence on the overall stability of the area.

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APPENDIX-A

Grain Size Distribution and Hydrometer Analysis

Test pit designation: TP-1 Weight of oven Dry soil (g): 500g

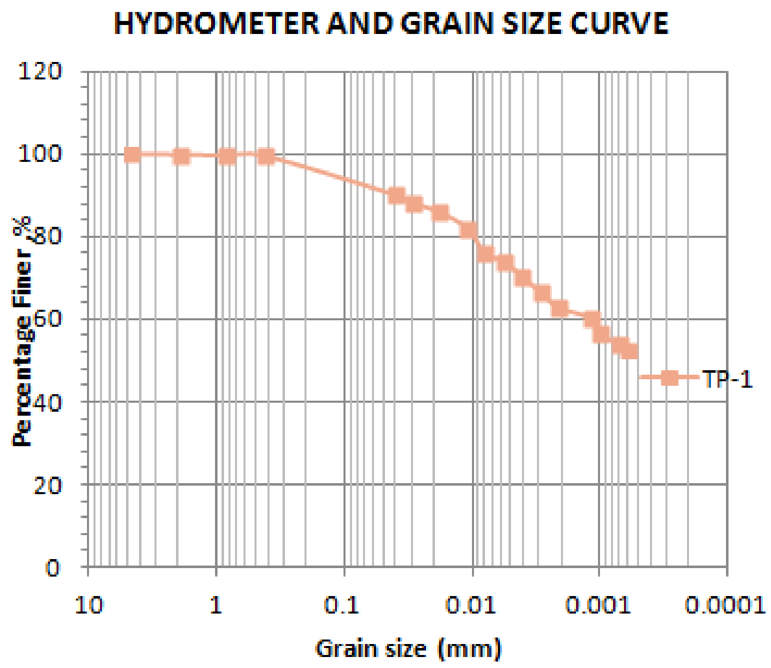
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0.65	0.13	0.13	99.87
No.10	2.0	0.85	0.17	0.30	99.70
No.20	0.85	0.81	0.16	0.47	99.53
No.40	0.425	0.36	0.07	0.54	99.46
No.50	0.3	0.31	0.06	0.60	99.40
No.100	0.15	1.07	0.22	0.82	99.18
No.200	0.075	2.52	0.51	1.33	98.67
Pan		493.437	100	101.33	-1.33
Sum = 500g					

TP.1										
Elapsed time (min)	tempratur e	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentag e of finer %	corrected (Pa)
1	20	49	8.3	0.01365	0.0393	0	1.00000	45	90.00	86.81
2	20	48	8.4	0.01365	0.0280	0	1.00000	44	88.00	84.88
5	20	47	8.6	0.01365	0.0179	0	1.00000	43	86.00	82.96
15	20	45	8.9	0.01365	0.0105	0	1.00000	41	82.00	79.10
30	20	42	9.4	0.01365	0.0076	0	1.00000	38	76.00	73.31
60	20	41	9.6	0.01365	0.0055	0	1.00000	37	74.00	71.38
120	21	39	9.9	0.01348	0.0039	0.2	1.00000	35.2	70.40	67.91
240	21	37	10.2	0.01348	0.0028	0.2	1.00000	33.2	66.40	64.05
480	22	35	10.6	0.01332	0.0020	0.4	1.00000	31.4	62.80	60.58
1440	21	34	10.7	0.01348	0.0012	0.2	1.00000	30.2	60.40	58.26
2160	21	32	11.1	0.01348	0.0010	0.2	1.00000	28.2	56.40	54.40
4320	20	31	11.2	0.01365	0.0007	0	1.00000	27	54.00	52.09
5760	21	30	11.4	0.01348	0.0006	0.2	1.00000	26.2	52.40	50.55

Hydrometric Analysis Data TP 1



Test pit designation: TP-2 Weight of oven Dry soil (g): 1000g

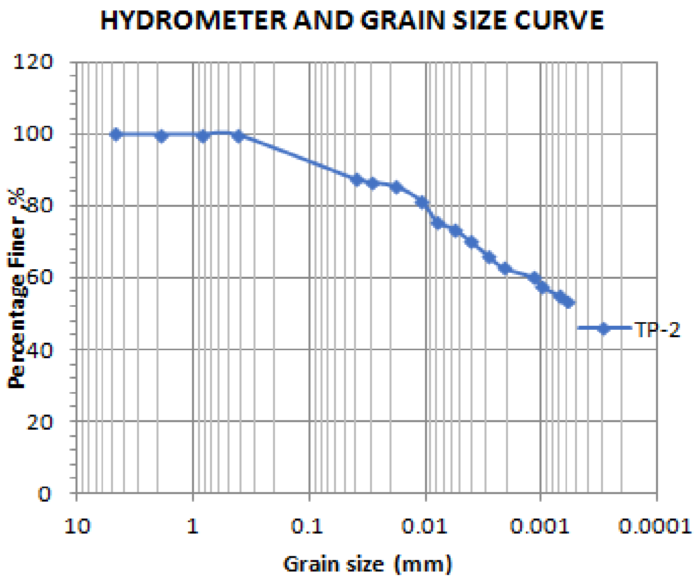
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0.27	0.03	0.03	99.97
No.10	2.0	0.66	0.07	0.09	99.91
No.20	0.85	0.42	0.04	0.14	99.87
No.40	0.425	0.61	0.06	0.20	99.80
No.50	0.3	1.10	0.11	0.31	99.69
No.100	0.15	1.63	0.16	0.47	99.53
No.200	0.075	1.75	0.18	0.64	99.36
Pan		993.56	99.36	100.0	0.00
Sum=1000g					

Elapsed time (min)	tempratur e	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentag e of finer %	corrected (Pa)
1	20	49	8.3	0.013482	0.0388	0.15	0.99100	44.15	87.51	84.41
2	20	48	8.4	0.013482	0.0276	0.15	0.99100	44.15	87.51	84.41
5	20	47	8.6	0.013482	0.0177	0.15	0.99100	43.15	85.52	82.50
15	20	45	8.9	0.013482	0.0104	0.15	0.99100	41.15	81.56	78.67
30	20	42	9.4	0.013482	0.0075	0.15	0.99100	38.15	75.61	72.94
60	20	41	9.6	0.013482	0.0054	0.15	0.99100	37.15	73.63	71.02
120	21	39	9.9	0.01332	0.0038	0.4	0.99100	35.4	70.16	67.68
240	21	37	10.2	0.01332	0.0027	0.4	0.99100	33.4	66.20	63.86
480	22	35	10.6	0.01316	0.0020	0.65	0.99100	31.65	62.73	60.51
1440	21	34	10.7	0.01332	0.0011	0.4	0.99100	30.4	60.25	58.12
2160	21	32	11.1	0.01332	0.0010	0.4	1.01417	28.4	57.60	55.57
4320	20	31	11.2	0.013482	0.0007	0.15	1.01417	27.15	55.07	53.12
5760	21	30	11.4	0.01332	0.0006	0.4	1.01417	26.4	53.55	51.65

Hydrometric Analysis Data TP2



Test pit designation: TP-3 Weight of oven Dry soil (g): 1000g

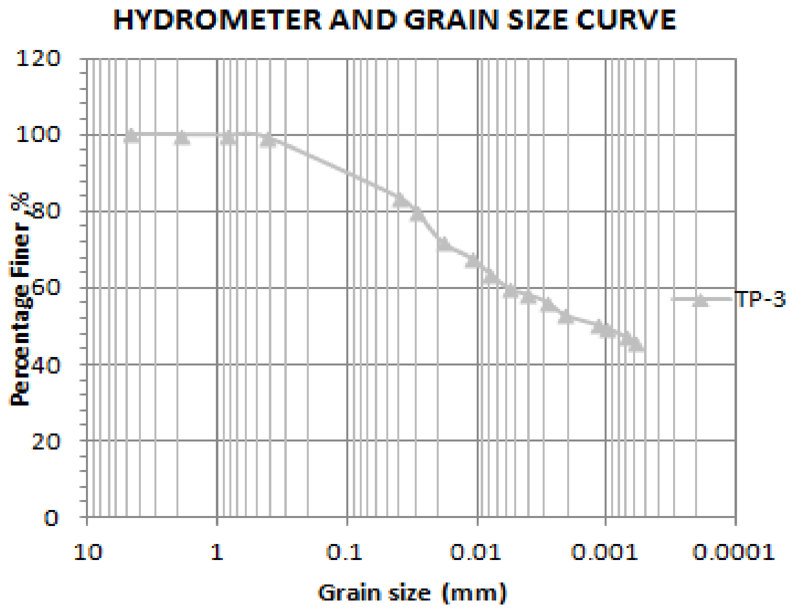
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0	0	0	100
No.10	2.0	0.80	0.80	0.80	99.92
No.20	0.85	1.88	0.19	0.28	99.72
No.40	0.425	4.80	0.50	0.77	99.23
No.50	0.3	5.96	0.62	1.39	98.61
No.100	0.15	10.01	1.04	2.43	97.57
No.200	0.075	7.05	0.73	3.16	96.84
Pan		965.495	100	103.16	-3.16
Sum= 1000g					

Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	47	8.6	0.01408	0.0413	0.15	0.99100	42.15	83.54	80.58
2	20	44	9.1	0.01408	0.0300	0.15	0.99100	40.15	79.58	76.76
5	20	40	9.7	0.01408	0.0196	0.15	0.99100	36.15	71.65	69.11
15	20	38	10.1	0.01408	0.0116	0.15	0.99100	34.15	67.69	65.29
30	20	36	10.4	0.01408	0.0083	0.15	0.99100	32.15	63.72	61.47
60	20	34	10.7	0.01408	0.0059	0.15	0.99100	30.15	59.76	57.64
120	21	33	10.9	0.01391	0.0042	0.4	0.99100	29.4	58.27	56.21
240	21	32	11.1	0.01391	0.0030	0.4	0.99100	28.4	56.29	54.30
480	22	30	11.4	0.01374	0.0021	0.65	0.99100	26.65	52.82	50.95
1440	21	29	11.5	0.01391	0.0012	0.4	0.99100	25.4	50.34	48.56
2160	21	28	11.5	0.01391	0.0010	0.4	1.01417	24.4	49.49	47.74
4320	20	27	11.9	0.01408	0.0007	0.15	1.01417	23.15	46.96	45.29
5760	21	26	12	0.01391	0.0006	0.4	1.01417	22.4	45.43	43.83

Hydrometric Analysis Data TP3



Test pit designation: TP-4 Weight of oven Dry soil (g): 1000g

Depth (m): 3m

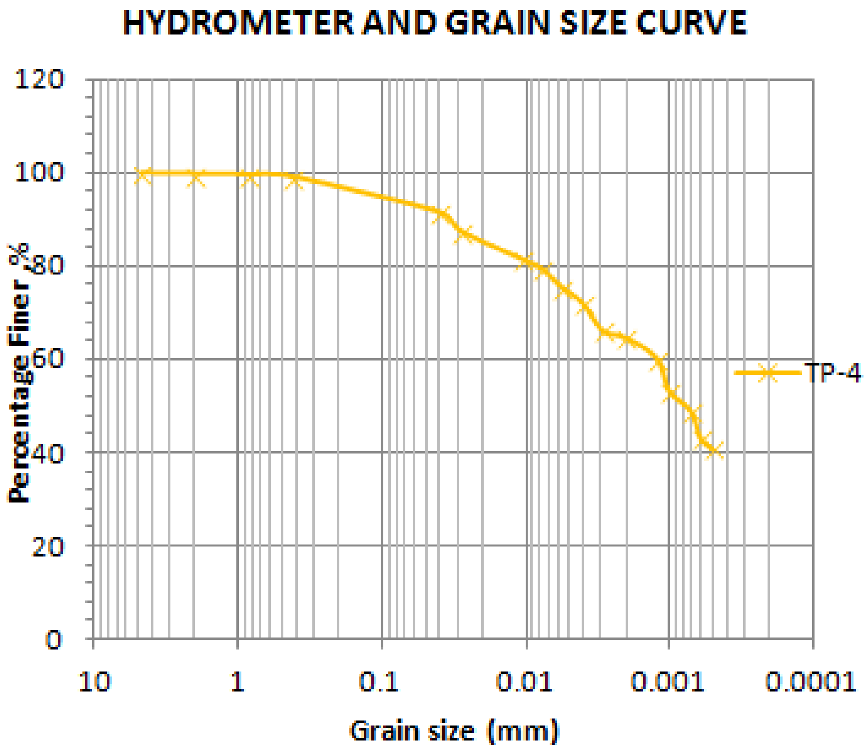
Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	1.23	0.12	0.12	99.88
No.10	2.0	1.58	0.16	0.28	99.72
No.20	0.85	2.02	0.20	0.48	99.52
No.40	0.425	4.52	0.45	0.94	99.07
No.50	0.3	4.00	0.40	1.34	98.67
No.100	0.15	3.20	0.32	1.66	98.35
No.200	0.075	6.50	0.65	2.31	97.70
Pan		976.95	97.70	100	0.00
Sum=1000g					

TP 4

Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	53	8.6	0.01365	0.0400	0.15	0.99100	48.15	95.43	92.06
2	20	50	9.1	0.01365	0.0291	0.15	0.99100	46.15	91.47	88.23
5	20	48	9.7	0.01365	0.0190	0.15	0.99100	44.15	87.51	84.41
15	20	45	10.1	0.01365	0.0112	0.15	0.99100	41.15	81.56	78.67
30	20	44	10.4	0.01365	0.0080	0.15	0.99100	40.15	79.58	76.76
60	20	42	10.7	0.01365	0.0058	0.15	0.99100	38.15	75.61	72.94
120	21	40	10.9	0	0.0000	0.4	0.99100	36.4	72.14	69.59
240	21	37	11.1	0	0.0000	0.4	0.99100	33.4	66.20	63.86
480	22	36	11.4	0.01332	0.0021	0.65	0.99100	32.65	64.71	62.42
1440	21	34	11.5	0	0.0000	0.4	0.99100	30.4	60.25	58.12
2160	21	30	11.5	0	0.0000	0.4	1.01417	26.4	53.55	51.65
4320	20	28	11.9	0.01365	0.0007	0.15	1.01417	24.15	48.98	47.25
5760	21	25	12	0	0.0000	0.4	1.01417	21.4	43.41	41.87

Hydrometric Analysis Data TP 4



Test pit designation: TP-5 Weight of oven Dry soil (g): 595g

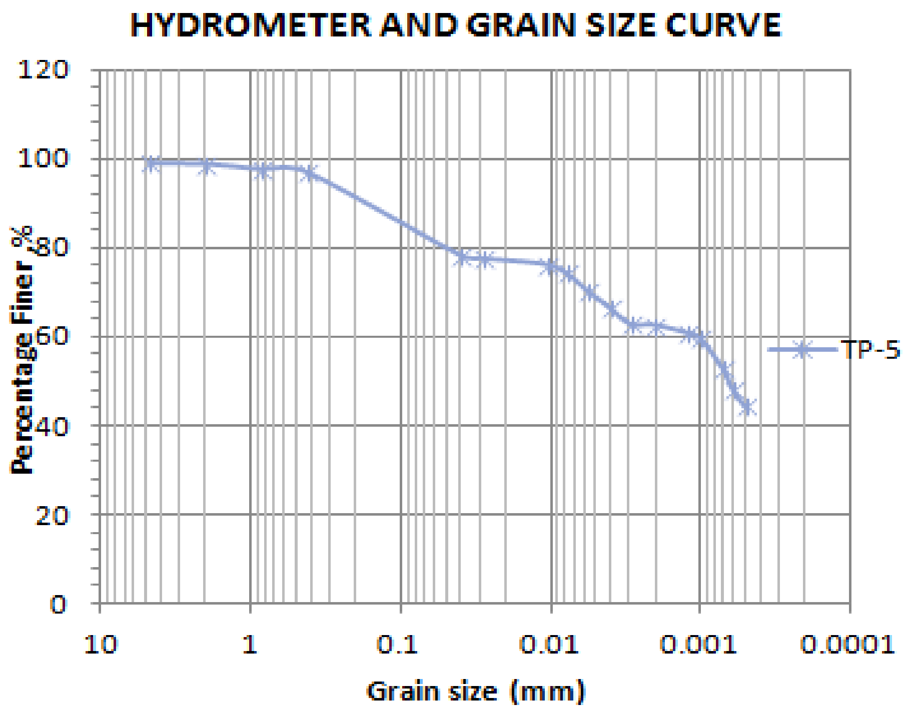
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	2.90	0.58	0.98	99.02
No.10	2.0	0.60	0.12	1.10	98.90
No.20	0.85	5.80	1.16	2.26	97.74
No.40	0.425	3.10	0.62	2.88	97.12
No.100	0.15	6.50	1.30	4.18	95.82
No.200	0.075	1.50	0.30	4.48	95.52
Pan		477.60	95.52	100.0	0.00
Sum=595g					

TP 5										
Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	44	9.1	0.01386	0.0418	0.15	1.00000	39.15	78.30	75.53
2	20	43	9.2	0.01386	0.0297	0.15	1.00000	39.15	78.30	75.53
5	20	42	9.4	0.01386	0.0190	0.15	1.00000	38.15	76.30	73.60
15	20	41	9.6	0.01386	0.0111	0.15	1.00000	37.15	74.30	71.67
30	20	39	9.9	0.01386	0.0080	0.15	1.00000	35.15	70.30	67.81
60	20	37	10.2	0.01386	0.0057	0.15	1.00000	33.15	66.30	63.95
120	21	35	10.6	0.01369	0.0041	0.4	1.00000	31.4	62.80	60.58
240	21	34	10.7	0.01369	0.0029	0.4	1.00000	30.4	60.80	58.65
480	22	33	10.9	0.01353	0.0020	0.65	1.00000	29.65	59.30	57.20
1440	21	30	11.4	0.01369	0.0012	0.4	1.00000	26.4	52.80	50.93
2160	21	28	11.7	0.01369	0.0010	0.4	1.00000	24.4	48.80	47.07
4320	20	27	11.9	0.01386	0.0007	0.15	1.00000	23.15	46.30	44.66
5760	21	26	12	0.01369	0.0006	0.4	1.00000	22.4	44.80	43.21

Hydrometric Analysis Data TP5



Test pit designation: TP-6 Weight of oven Dry soil (g): 500g

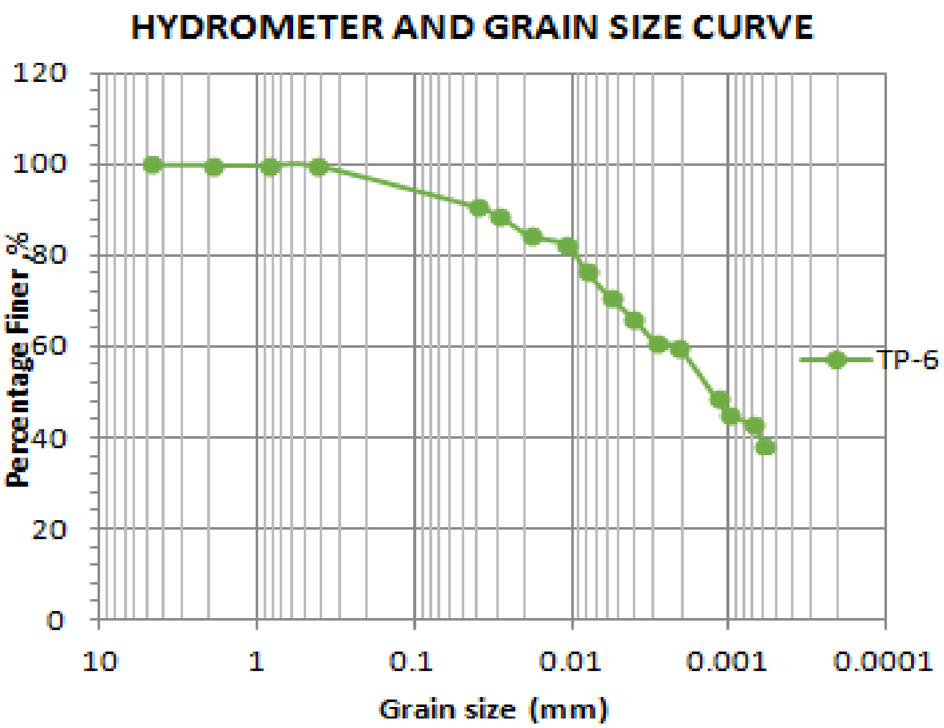
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0	0	0	100
No.10	2.0	0.03	0.03	0.03	99.97
No.20	0.85	0.26	0.05	0.08	99.92
No.40	0.425	0.32	0.06	0.14	99.86
No.50	0.3	0.70	0.14	0.28	99.72
No.100	0.15	1.84	0.37	0.65	99.35
No.200	0.075	2.73	0.55	1.21	98.79
Pan		494.037	100	101.21	-1.21

TP 6										
Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	50	8.1	0.01386	0.0394	0.15	1.00000	45.15	90.30	87.10
2	20	48	8.4	0.01386	0.0284	0.15	1.00000	44.15	88.30	85.17
5	20	46	8.8	0.01386	0.0184	0.15	1.00000	42.15	84.30	81.32
15	20	45	8.9	0.01386	0.0107	0.15	1.00000	41.15	82.30	79.39
30	20	42	9.4	0.01386	0.0078	0.15	1.00000	38.15	76.30	73.60
60	20	39	9.9	0.01386	0.0056	0.15	1.00000	35.15	70.30	67.81
120	21	37	10.2	0.01369	0.0040	0.4	1.00000	33.4	66.80	64.44
240	21	34	10.7	0.01369	0.0029	0.4	1.00000	30.4	60.80	58.65
480	22	33	10.9	0.01353	0.0020	0.65	1.00000	29.65	59.30	57.20
1440	21	28	11.7	0.01369	0.0012	0.4	1.00000	24.4	48.80	47.07
2160	21	26	12	0.01369	0.0010	0.4	1.00000	22.4	44.80	43.21
4320	20	25	12.2	0.01386	0.0007	0.15	1.00000	21.15	42.30	40.80
5760	21	23	12.5	0.01369	0.0006	0.4	1.00000	19.4	38.80	37.43

Hydrometric Analysis Data TP6



Test pit designation: TP-7 Weight of oven Dry soil (g): 500g

Depth (m): 3m

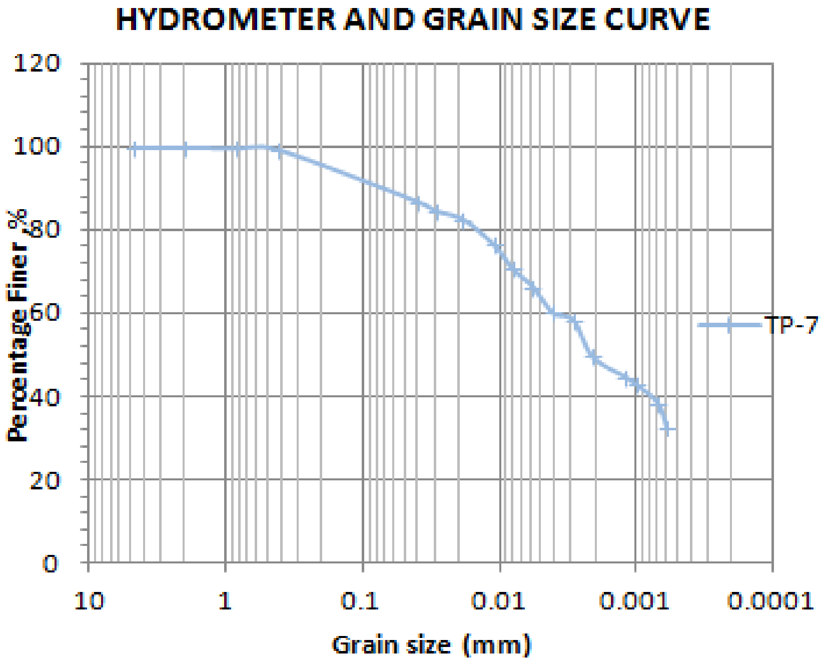
Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0.6	0.12	0.12	99.88
No.10	2.0	0.7	0.13	0.25	99.75
No.20	0.85	0.9	0.18	0.43	99.57
No.40	0.425	1.2	0.23	0.66	99.34
No.50	0.3	1.0	0.21	0.87	99.13
No.100	0.15	1.5	0.11	0.98	99.02
No.200	0.075	1.8	0.36	1.64	98.36
Pan		491.8	98.36	100.0	0.00
Sum= 500g					

TP 7

Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	48	8.4	0.01386	0.0402	0.15	1.00000	43.15	86.30	83.24
2	20	46	8.8	0.01386	0.0291	0.15	1.00000	42.15	84.30	81.32
5	20	45	8.9	0.01386	0.0185	0.15	1.00000	41.15	82.30	79.39
15	20	42	9.4	0.01386	0.0110	0.15	1.00000	38.15	76.30	73.60
30	20	39	9.9	0.01386	0.0080	0.15	1.00000	35.15	70.30	67.81
60	20	37	10.2	0.01386	0.0057	0.15	1.00000	33.15	66.30	63.95
120	21	34	10.7	0.01369	0.0041	0.4	1.00000	30.4	60.80	58.65
240	21	33	10.9	0.01369	0.0029	0.4	1.00000	29.4	58.80	56.72
480	22	28	11.7	0.01353	0.0021	0.65	1.00000	24.65	49.30	47.55
1440	21	26	12	0.01369	0.0012	0.4	1.00000	22.4	44.80	43.21
2160	21	25	12.2	0.01369	0.0010	0.4	1.00000	21.4	42.80	41.28
4320	20	23	12.5	0.01386	0.0007	0.15	1.00000	19.15	38.30	36.94
5760	21	20	13	0.01369	0.0007	0.4	1.00000	16.4	32.80	31.64

Hydrometric Analysis Data TP7



Test pit designation: TP-8 Weight of oven Dry soil (g): 1000g

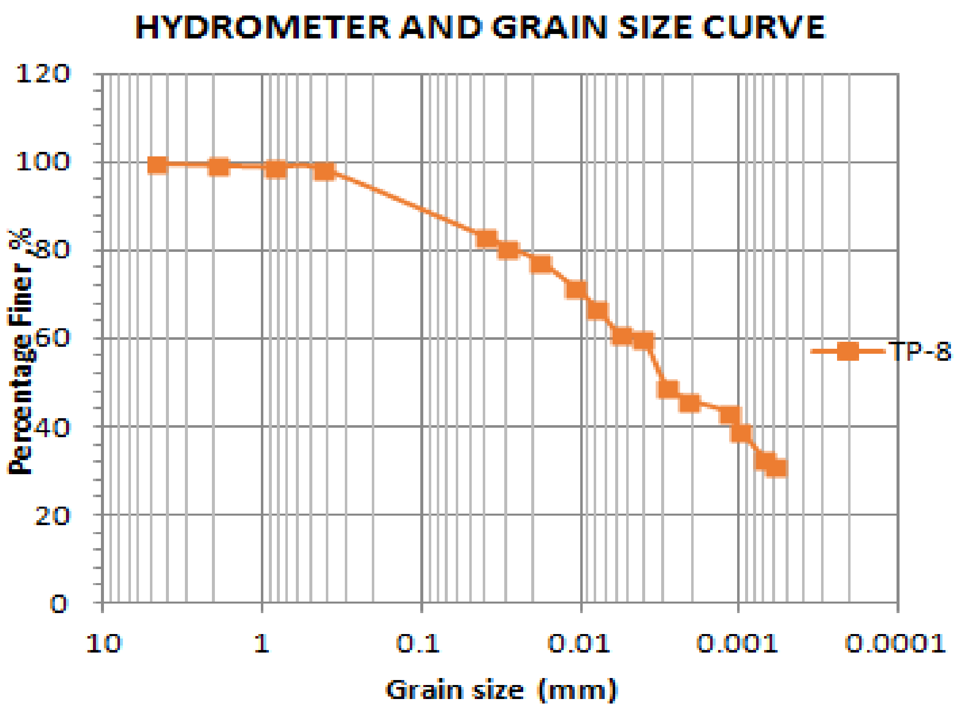
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	2.6	0.26	0.26	99.74
No.10	2.0	4.31	0.43	0.69	99.31
No.20	0.85	4.59	0.46	1.15	98.85
No.40	0.425	3.83	0.38	1.53	98.47
No.50	0.3	5.28	0.53	2.06	97.94
No.200	0.075	11.59	1.19	3.25	96.75
Pan		967.50	96.75	100.0	0.00

TP 8										
Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	46	8.8	0.01386	0.0411	0.15	1.01000	41.15	83.12	80.18
2	20	45	8.9	0.01386	0.0292	0.15	1.01000	41.15	83.12	80.18
5	20	42	9.4	0.01386	0.0190	0.15	1.01000	38.15	77.06	74.33
15	20	39	9.9	0.01386	0.0113	0.15	1.01000	35.15	71.00	68.49
30	20	37	10.2	0.01386	0.0081	0.15	1.01000	33.15	66.96	64.59
60	20	34	10.7	0.01386	0.0059	0.15	1.01000	30.15	60.90	58.75
120	21	33	10.9	0.01369	0.0041	0.4	1.01000	29.4	59.39	57.29
240	21	28	11.7	0.01369	0.0030	0.4	1.01000	24.4	49.29	47.54
480	22	26	12	0.01353	0.0021	0.65	1.01000	22.65	45.75	44.13
1440	21	25	12.2	0.01369	0.0013	0.4	1.01000	21.4	43.23	41.70
2160	21	23	12.5	0.01369	0.0010	0.4	1.01000	19.4	39.19	37.80
4320	20	20	13	0.01386	0.0008	0.15	1.01000	16.15	32.62	31.47
5760	21	19	13.2	0.01369	0.0007	0.4	1.01000	15.4	31.11	30.01

Hydrometric Analysis Data TP8



Test pit designation: TP-9 Weight of oven Dry soil (g): 500g

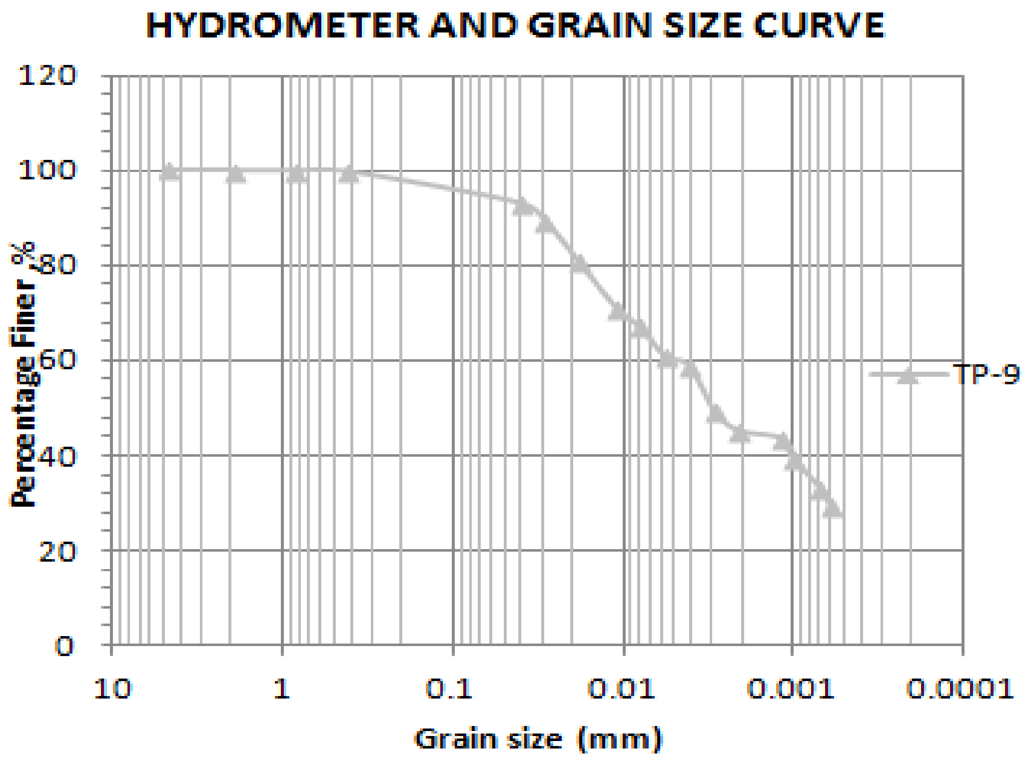
Depth (m):3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0	0	0	100
No.10	2.0	0.48	0.10	0.10	99.90
No.20	0.85	0.62	0.13	0.22	99.78
No.40	0.425	0.64	0.13	0.35	99.65
No.50	0.3	1.18	0.24	0.59	99.41
No.100	0.15	3.48	0.71	1.30	98.70
No.200	0.075	3.10	0.63	1.93	98.07
Pan		490.521	100	101.93	-1.93

TP 9										
Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	45	8.9	0.01325	0.0395	0.15	1.00931	40.15	81.05	78.18
2	20	42	9.4	0.01325	0.0287	0.15	1.00931	38.15	77.01	74.28
5	20	39	9.9	0.01325	0.0186	0.15	1.00931	35.15	70.95	68.44
15	20	37	10.2	0.01325	0.0109	0.15	1.00931	33.15	66.92	64.55
30	20	34	10.7	0.01325	0.0079	0.15	1.00931	30.15	60.86	58.71
60	20	33	10.9	0.01325	0.0056	0.15	1.00931	29.15	58.84	56.76
120	21	28	11.7	0.01309	0.0041	0.4	1.00931	24.4	49.25	47.51
240	21	26	12	0.01309	0.0029	0.4	1.00931	22.4	45.22	43.62
480	22	25	12.2	0.01294	0.0021	0.65	1.00931	21.65	43.70	42.16
1440	21	23	12.5	0.01309	0.0012	0.4	1.00931	19.4	39.16	37.77
2160	21	20	13	0.01309	0.0010	0.4	1.01417	16.4	33.26	32.09
4320	20	19	13.2	0.01325	0.0007	0.15	1.01417	15.15	30.73	29.64
5760	21	18	13.3	0.01309	0.0006	0.4	1.01417	14.4	29.21	28.17

Hydrometric Analysis Data TP9



Test pit designation: TP-10 Weight of oven Dry soil (g): 500g

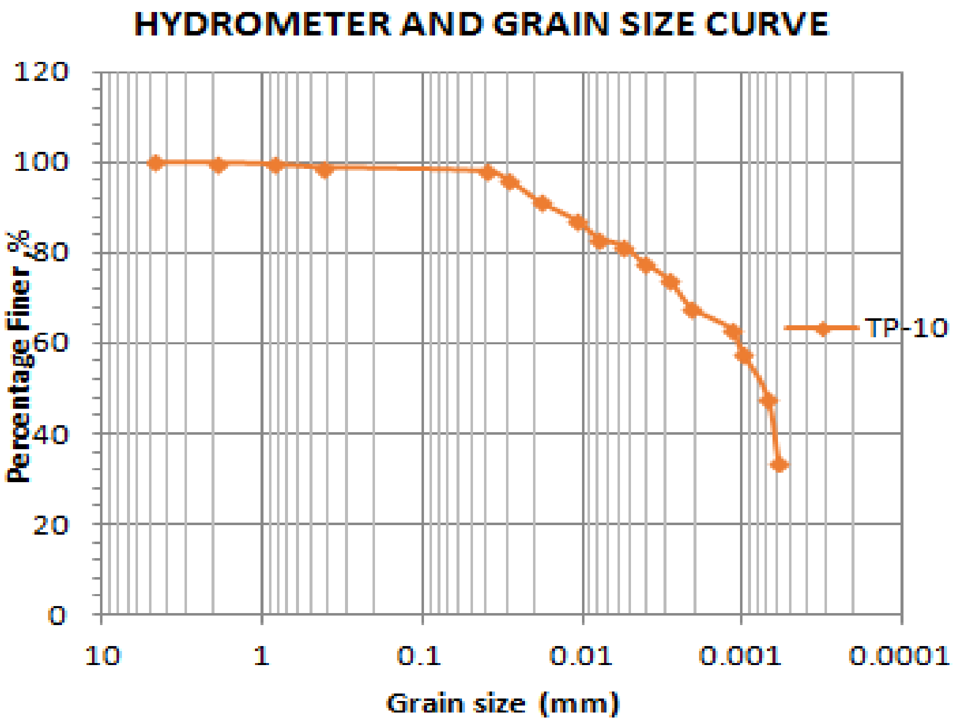
Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0	0	0	100
No.10	2.0	0.51	0.11	0.11	99.89
No.20	0.85	1.72	0.36	0.47	99.53
No.40	0.425	2.99	0.63	1.09	98.91
No.50	0.3	4.37	0.91	2.01	97.99
No.100	0.15	9.63	2.01	4.02	95.98
No.200	0.075	2.73	0.57	4.59	95.41
Pan		478.039	100	104.59	-4.59

TP 10										
Elapsed time (min)	temprature	actual hyd. Reading	L	K	D	Ct	a	Corrected hyd. Reading (Rc)	persentage of finer %	corrected (Pa)
1	20	54	7.4	0.01325	0.0360	0.15	1.00931	49.15	99.21	95.70
2	20	53	7.6	0.01325	0.0258	0.15	1.00931	49.15	99.21	95.70
5	20	50	8.1	0.01325	0.0169	0.15	1.00931	46.15	93.16	89.86
15	20	49	8.3	0.01325	0.0099	0.15	1.00931	45.15	91.14	87.91
30	20	47	8.6	0.01325	0.0071	0.15	1.00931	43.15	87.10	84.02
60	20	45	8.9	0.01325	0.0051	0.15	1.00931	41.15	83.07	80.13
120	21	44	9.1	0.01309	0.0036	0.4	1.00931	40.4	81.55	78.67
240	21	42	9.4	0.01309	0.0026	0.4	1.00931	38.4	77.51	74.77
480	22	40	9.7	0.01294	0.0018	0.65	1.00931	36.65	73.98	71.36
1440	21	39	9.9	0.01309	0.0011	0.4	1.00931	35.4	71.46	68.93
2160	21	37	10.2	0.01309	0.0009	0.4	1.01417	33.4	67.75	65.35
4320	20	35	10.6	0.01325	0.0007	0.15	1.01417	31.15	63.18	60.95
5760	21	32	11.1	0.01309	0.0006	0.4	1.01417	28.4	57.60	55.57

Hydrometric Analysis Data TP10



Test pit designation: TP-11 Weight of oven-dry soil (g): 500g

Depth (m): 3m

Test type: Grain size analysis (dry method)

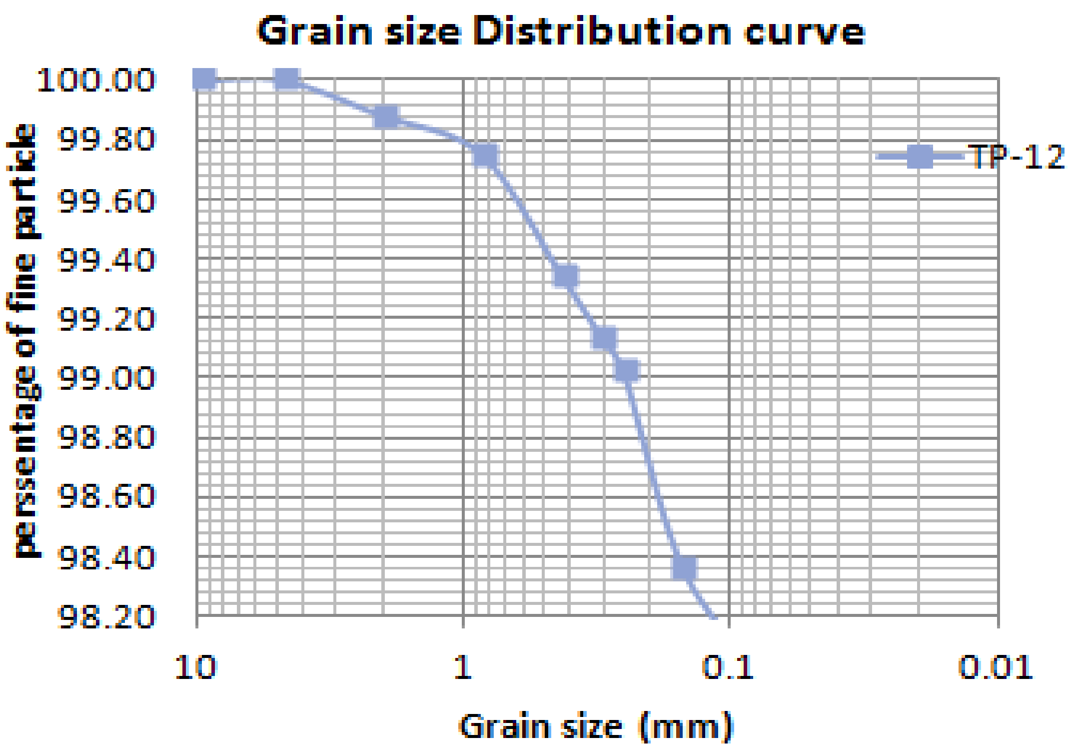
Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	0	0	0	100
No.10	2.0	0.7	0.15	0.15	99.89
No.20	0.85	1.7	0.33	0.48	99.53
No.40	0.425	1.3	0.25	0.73	98.76
No.50	0.3	1.4	0.28	1.01	98.62
No.100	0.15	2.5	0.50	1.88	98.12
No.200	0.075	2.2	0.43	2.32	97.68
Pan		488.4	97.68	100	0

Test pit designation: TP-12 Weight of oven-dry soil (g): 500g

Depth (m): 3m

Test type: Grain size analysis (dry method)

Sieve No.	Sieve size(mm)	Mass of retain	% of retain	Cumulative % retain	% passing
No.4	4.75	1.4	0.28	0.028	100
No.10	2.0	2.2	0.44	0.72	99.88
No.20	0.85	2.9	0.58	1.30	99.75
No.40	0.425	4.1	0.40	2.12	98.34
No.50	0.3	0.8	0.16	2.51	98.13
No.100	0.15	1.9	0.38	3.06	98.36
No.200	0.075	1.6	0.32	3.38	98.00
Pan		483.1	96.62	100	0

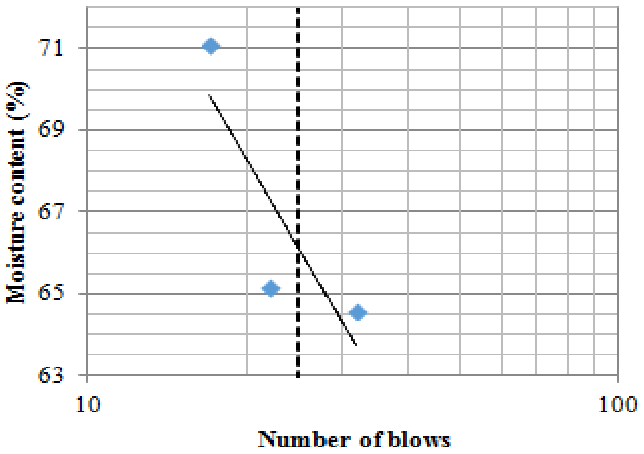


APPENDIX B

Atterberg Limits

Liquid Limit Plastic Limit

Test pit designation	**TP-1**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	32	22	17
Weight of container(Wo)	36.6	49.50	32.70
Weight of container + wet soil(W1)	59.30	69.50	53.10
Weight of container + dry soil(W2)	50.39	61.79	44.62
Weight of water(W1-W2)	8.91	8.01	8.48
Weight of dry soil(W2-Wo)	13.79	12.29	11.92
Moisture content (%)	64.61%	65.17%	71.14%

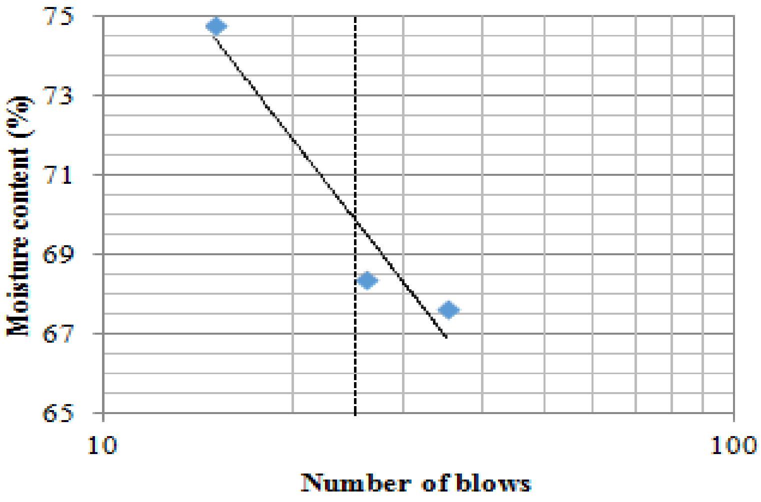


Plastic Limit

Weight of container(Wo)	25.20	36.80
Weight of container+ wet soil(W1)	34.60	45.60
Weight of container+ dry soil(W2)	32.40	43.50
Weight of water (W1-W2)	2.20	2.10
Weight of soil (W2-Wo)	7.20	6.70
Moisture content (%)	30.56%	31.34%
Average	30.95%	

Liquid Limit

Test pit designation	**TP- 2**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	35	26	15
Weight of container(Wo)	17.62	17.83	17.30
Weight of container + wet soil(W1)	35.78	35.06	34.82
Weight of container + dry soil(W2)	28.45	28.06	27.32
Weight of water(W1-W2)	7.33	7.00	7.50
Weight of dry soil(W2-Wo)	10.83	10.23	10.02
Moisture content (%)	67.68%	68.43%	74.85%

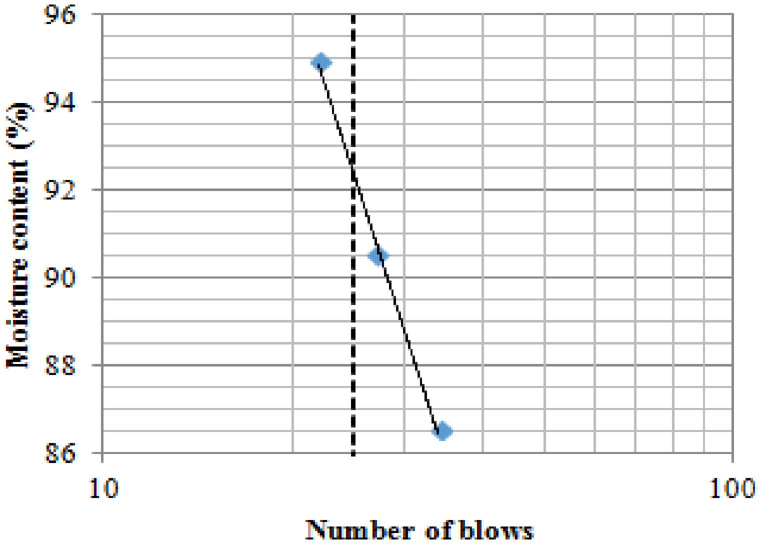


Plastic Limit

Weight of container(Wo)	5.92	6.67
Weight of container+ wet soil(W1)	11.63	12.15
Weight of container+ dry soil(W2)	9.78	10.33
Weight of water (W1-W2)	1.85	1.82
Weight of soil (W2-Wo)	3.86	3.66
Moisture content (%)	47.93%	49.73%
Average	48.83%	

Liquid Limit

Test pit designation	TP- 3		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	34	27	22
Weight of container(Wo)	17	17.70	17.60
Weight of container + wet soil(W1)	35.10	33.90	33.20
Weight of container + dry soil(W2)	26.70	26.20	25.60
Weight of water(W1-W2)	8.40	7.70	7.60
Weight of dry soil(W2-Wo)	9.70	8.50	8.00
Moisture content (%)	86.60%	90.59%	95.00%

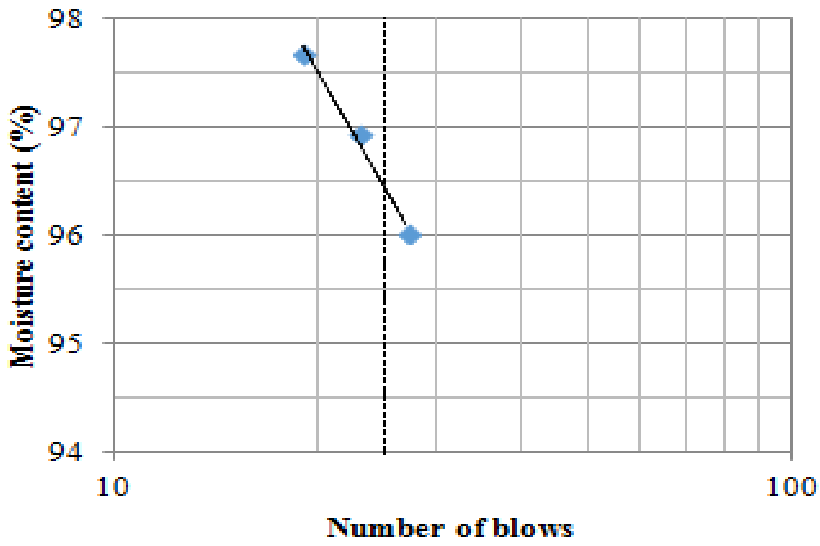


Plastic Limit

Weight of container(Wo)	17.55	17.65
Weight of container+ wet soil(W1)	30.36	29.05
Weight of container+ dry soil(W2)	27.40	24.96
Weight of water (W1-W2)	2.95	4.09
Weight of soil (W2-Wo)	9.85	7.31
Moisture content (%)	29.95	56.01
Average	42.98	

Liquid Limit

Test pit designation	TP- 4		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	27	23	19
Weight of container(Wo)	17.44	17.91	17.68
Weight of container + wet soil(W1)	27.85	30.87	30.59
Weight of container + dry soil(W2)	22.75	24.49	24.21
Weight of water(W1-W2)	5.10	6.38	6.38
Weight of dry soil(W2-Wo)	5.31	6.58	6.53
Moisture content (%)	96.05%	96.96%	97.70%

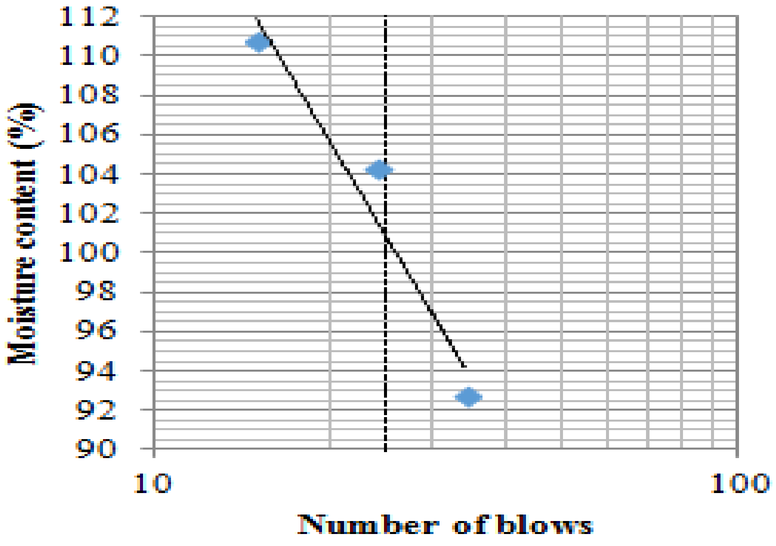


Plastic Limit

Weight of container (Wo)	5.60	6.56
Weight of container+ wet soil(W1)	12.10	13.62
Weight of container+ dry soil(W2)	10.32	11.68
Weight of water (W1-W2)	1.78	1.94
Weight of soil (W2-Wo)	4.72	5.12
Moisture content (%)	37.71%	37.89
Average	37.80%	

Liquid Limit

Test pit designation	**TP- 5**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	34	24	15
Weight of container(Wo)	18.60	17.40	17.50
Weight of container + wet soil(W1)	37.10	31.70	33.10
Weight of container + dry soil(W2)	28.20	24.40	24.90
Weight of water(W1-W2)	8.90	7.30	8.20
Weight of dry soil(W2-Wo)	9.60	7.00	7.40
Moisture content (%)	92.71%	104.29%	110.81%

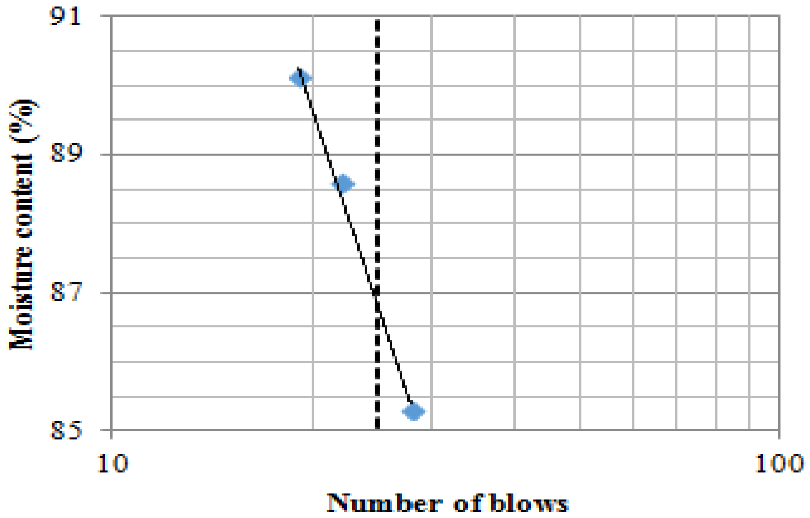


Plastic Limit

Weight of container(Wo)	17.90	17.20
Weight of container+ wet soil(W1)	25.00	23.40
Weight of container+ dry soil(W2)	22.60	21.20
Weight of water (W1-W2)	2.40	2.20
Weight of soil (W2-Wo)	4.70	4.00
Moisture content (%)	51.06%	55.00%
Average	53.03%	

Liquid Limit

Test pit designation	**TP-6**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	28	22	19
Weight of container(Wo)	35.51	35.54	18.37
Weight of container + wet soil(W1)	55.35	51.46	33.80
Weight of container + dry soil(W2)	46.21	43.98	26.48
Weight of water(W1-W2)	9.14	7.48	7.32
Weight of dry soil(W2-Wo)	10.71	8.44	8.12
Moisture content (%)	85.32%	88.60%	90.14%

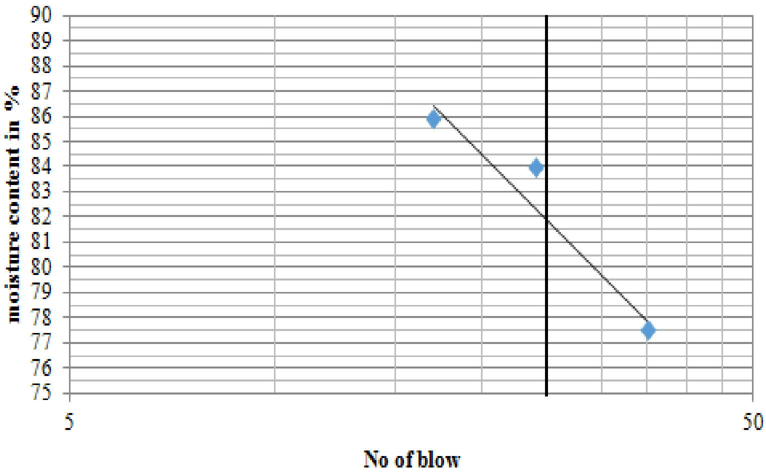


Plastic Limit

Weight of container(Wo)	6.06	6.67
Weight of container+ wet soil(W1)	14.51	16.84
Weight of container+ dry soil(W2)	12.35	14.24
Weight of water (W1-W2)	2.16	2.61
Weight of soil (W2-Wo)	6.28	7.56
Moisture content (%)	34.44%	34.49%
Average	34.47%	

Liquid Limit

Test pit designation	**TP-7**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	35	24	17
Weight of container(Wo)	17.68	17.57	18.16
Weight of container + wet soil(W1)	40.72	39.02	40.60
Weight of container + dry soil(W2)	30.66	29.23	30.23
Weight of water(W1-W2)	10.06	9.79	10.37
Weight of dry soil(W2-Wo)	12.98	11.66	12.07
Moisture content (%)	77.5%	84.0%	85.9%

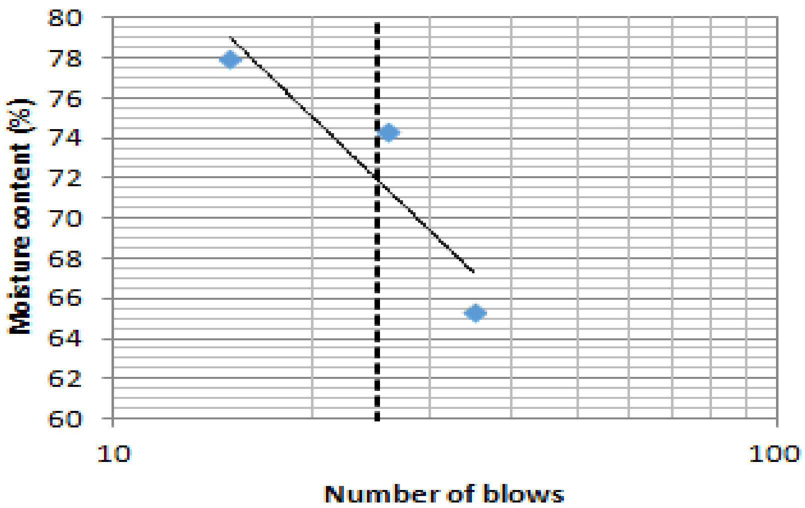


Plastic Limit

Weight of container(Wo)	6.4	6.28
Weight of container+ wet soil(W1)	14.6	15.87
Weight of container+ dry soil(W2)	11.66	12.61
Weight of water (W1-W2)	2.94	3.26
Weight of soil (W2-Wo)	5.26	6.33
Moisture content (%)	55.89%	51.50%
Average	53.70%	

Liquid Limit

Test pit designation	TP-8		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	35	26	15
Weight of container(Wo)	36.81	41.22	34.62
Weight of container + wet soil(W1)	71.61	68.98	60.03
Weight of container + dry soil(W2)	57.86	57.14	48.9
Weight of water(W1-W2)	13.75	11.84	11.13
Weight of dry soil(W2-Wo)	21.05	15.92	14.28
Moisture content (%)	65.35%	74.37%	77.94%

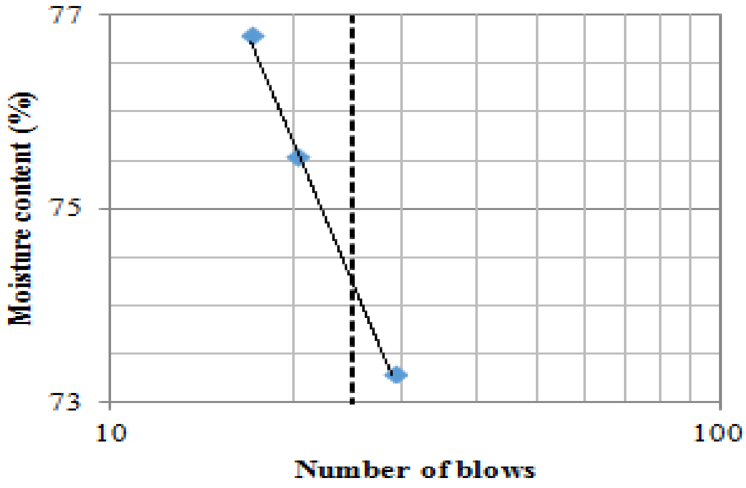


Plastic Limit

Weight of container(Wo)	28.32	37.08
Weight of container+ wet soil(W1)	34.93	43.36
Weight of container+ dry soil(W2)	32.66	41.19
Weight of water (W1-W2)	2.27	2.17
Weight of soil (W2-Wo)	4.34	4.11
Moisture content (%)	52.30%	52.80%
Average	52.55%	

Liquid Limit

Test pit designation	**TP-9**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	29	20	17
Weight of container(Wo)	5.54	6.75	5.85
Weight of container + wet soil(W1)	23.48	25.82	23.82
Weight of container + dry soil(W2)	15.89	17.61	16.01
Weight of water(W1-W2)	7.59	8.21	7.81
Weight of dry soil(W2-Wo)	10.35	10.86	10.16
Moisture content (%)	73.33%	75.55%	76.82%

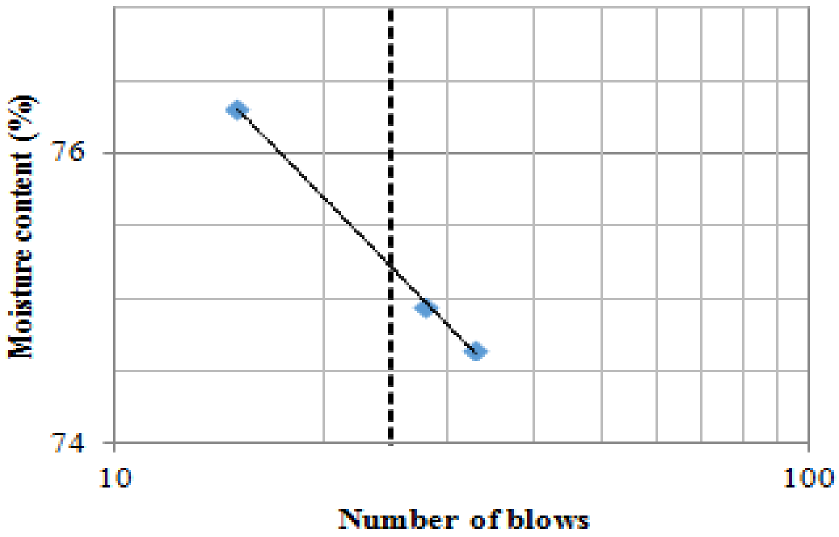


Plastic Limit

Weight of container(Wo)	17.11	18.37
Weight of container+ wet soil(W1)	25.85	32.26
Weight of container+ dry soil(W2)	23.33	28.03
Weight of water (W1-W2)	2.52	4.23
Weight of soil (W2-Wo)	6.22	9.66
Moisture content (%)	40.56	43.83
Average	42.20	

Liquid Limit

Test pit designation	TP- 10		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	33	28	15
Weight of container(Wo)	20.10	6.00	15.20
Weight of container + wet soil(W1)	37.50	22.80	31.80
Weight of container + dry soil(W2)	30.06	15.60	24.62
Weight of water(W1-W2)	7.44	7.20	7.19
Weight of dry soil(W2-Wo)	9.96	9.60	9.42
Moisture content (%)	74.65%	74.95%	76.31%

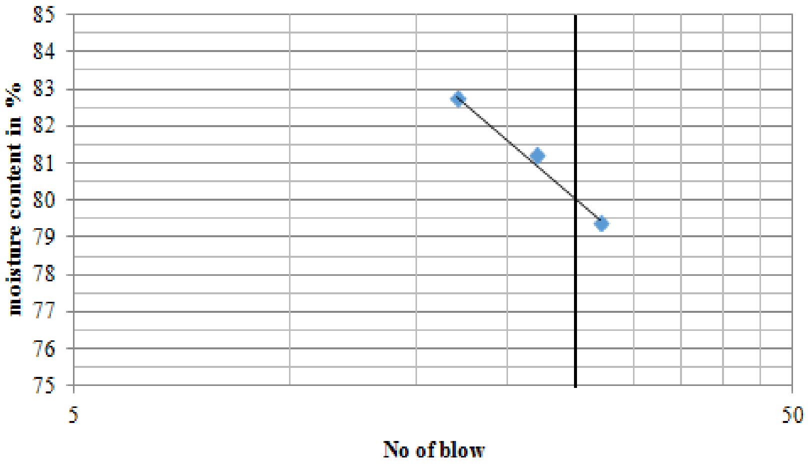


Plastic Limit

Weight of container(Wo)	16.38	19.94
Weight of container+ wet soil(W1)	25.18	28.78
Weight of container+ dry soil(W2)	22.47	26.05
Weight of water (W1-W2)	2.71	2.73
Weight of soil (W2-Wo)	6.09	6.11
Moisture content (%)	44.46%	44.64%
Average	44.55%	

Liquid Limit

Test pit designation	**TP- 11**		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	27	22	17
Weight of container(Wo)	16	17.64	17.31
Weight of container + wet soil(W1)	34.48	37.16	36.48
Weight of container + dry soil(W2)	26.72	28.41	27.80
Weight of water(W1-W2)	7.76	8.75	8.68
Weight of dry soil(W2-Wo)	9.77	10.77	10.49
Moisture content (%)	79.4%	81.2%	82.70%

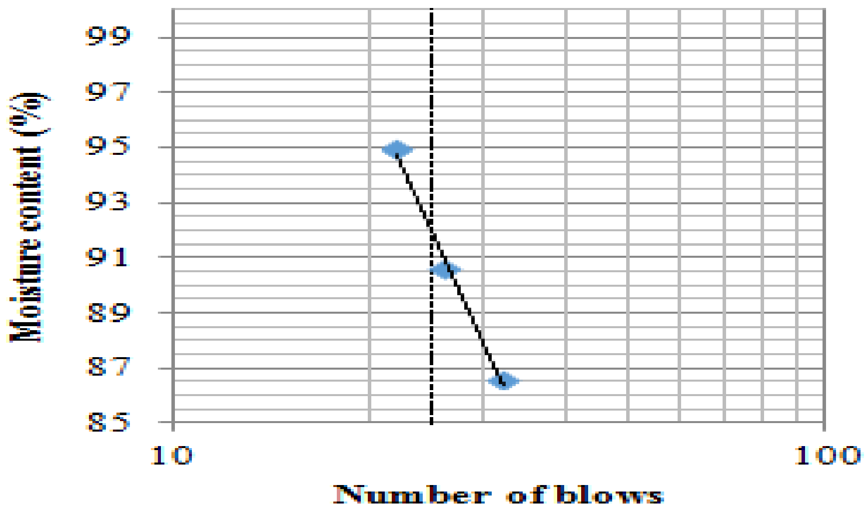


Plastic Limit

Weight of container(Wo)	6.05	6.58
Weight of container+ wet soil(W1)	13.51	14.06
Weight of container+ dry soil(W2)	10.64	11.19
Weight of water (W1-W2)	2.87	2.87
Weight of soil (W2-Wo)	4.59	4.61
Moisture content (%)	62.53%	62.26%
Average	62.39%	

Liquid Limit

Test pit designation	TP- 12		
Test type	liquid limit test		
Depth (m)	3	3	3
No of blow	27	22	17
Weight of container(Wo)	17	17.70	17.60
Weight of container + wet soil(W1)	35.10	33.90	33.20
Weight of container + dry soil(W2)	26.70	26.20	25.60
Weight of water(W1-W2)	8.40	7.70	7.60
Weight of dry soil(W2-Wo)	9.70	8.50	8
Moisture content (%)	87%	91%	96%



Plastic Limit

Weight of container(Wo)	25.9
Weight of container+ wet soil(W1)	34.70
Weight of container+ dry soil(W2)	32.25
Weight of water (W1-W2)	2.45
Weight of soil (W2-Wo)	6.35
Moisture content (%)	37

APPENDIX-C

Moisture Content Test Result

Test pit designation	**TP-1**		
Natural water content	44.79%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	32.77	31.39	32.76
Weight of container +wet soil (w1)g	184.76	131.39	147.76
Weight of container +oven-dry (W2)g	137.19	101.12	111.792
wet soil (WS)	47.57	30.57	35.54
Water content W%= WW/WS.100%	45.56%	43.84%	44.97%

Test pit designation	**TP-2**	
Natural water content	50.52%	
Depth (m)	3	3
Determination number	1	2
Container number	C1	C2
Weight of container (W0g)	18.62	17.42
Weight of container +wet soil (w1)g	97.83	90.58
Weight of container +oven-dry (W2)g	59.28	66.03
wet soil (WS)	40.66	48.61
Water content W%= WW/WS	50.54%	50.50%

Test pit designation	**TP-3**		
Natural water content	62.45%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	28.71	35.52	17.66
Weight of container +wet soil (w1)g	132.64	183.64	125.107
Weight of container +oven-dry (W2)g	91.82	128.70	83.297
wet soil (WS)	40.82	54.94	41.81
Mass of pore water(WW)	63.10	93.18	65.64
Water content W%= WW/WS	64.69%	58.96%	63.70%

Test pit designation	**TP-4**		
Natural water content	52.39%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	29.5	30.4	17.11
Weight of container +wet soil (w1)g	160	153.4	73.82
Weight of container +oven-dry (W2)g	115.7	111.34	53.91
wet soil (WS)	44.3	42.06	36.80
Water content W%= WW/WS	51.39%	51.96%	54.10%

Test pit designation	**TP-5**		
Natural water content	52.08%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	33.04	36.38	17.96
Weight of container +wet soil (w1)g	148.80	166.04	130.18
Weight of container +oven-dry (W2)g	105.02	122.90	95.05
wet soil (WS)	71.98	86.52	77.09
Water content W%= WW/WS	60.82%	49.86%	45.57%

Test pit designation	**TP-6**		
Natural water content	42.18%		
Depth (m)			
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	17.04	37.71	20.5
Weight of container +wet soil (w1)g	123.84	166.59	131.1
Weight of container +oven-dry (W2)g	93.67	125.69	100.3
wet soil (WS)	30.17	40.90	30.8
Mass of pore water(WW)	76.63	87.98	75.5
Water content W%= WW/WS	39.37%	46.48%	40.7%

Test pit designation	**TP-7**	
Natural water content	48.61%	
Depth (m)	3	3
Determination number	1	2
Container number	C1	C2
Weight of container (W0g)	17.86	17.88
Weight of container +wet soil (w1)g	83.09	88.03
Weight of container +oven-dry (W2)g	61.82	65.01
wet soil (WS)	43.96	47.13
Water content W%= WW/WS	48.38%	48.84%

Test pit designation	**TP-8**		
Natural water content	51.07%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	35.7	17.3	18.9
Weight of container +wet soil (w1)g	168.7	140.7	114.1
Weight of container +oven-dry (W2)g	127.1	100.9	78.3
wet soil (WS)	41.6	39.8	35.8
Water content W%= WW/WS	45.36%	47.60%	60.26%

Test pit designation	**TP-9**		
Natural water content	44.69%		
Depth (m)	3	3	3
Determination number	1	2	3
Container number	C1	C2	C3
Weight of container (W0g)	41.33	36.57	17.54
Weight of container +wet soil (w1)g	166.91	161.14	114.70
Weight of container +oven-dry (W2)g	127.96	123.39	84.26
wet soil (WS)	38.95	37.75	30.45
Water content W%= WW/WS	44.96%	43.49%	45.64%

Test pit designation	TP-10	
Natural water content	44.82%	
Depth (m)	3	3
Determination number	1	2
Container number	C1	C2
Weight of container (W0g)	35.56	18.18
Weight of container +wet soil (w1)g	169.20	117.64
Weight of container +oven-dry (W2)g	127.14	87.39
wet soil (WS)	42.06	30.25
Water content W%= WW/WS	45.93%	43.71%

Test pit designation	TP-11	
Natural water content	44.25%	
Depth (m)	3	3
Determination number	1	2
Container number	C1	C2
Weight of container (W0g)	5.89	6.27
Weight of container +wet soil (w1)g	16.19	14.43
Weight of container +oven-dry (W2)g	13.13	11.58
wet soil (WS)	7.24	5.58
Water content W%= WW/WS	42.27%	46.24%

Test pit designation	TP-12	
Natural water content	41.97%	
Depth (m)	3	3
Determination number	1	2
Container number	C1	C2
Weight of container (W0g)	5.78	6.27
Weight of container +wet soil (w1)g	14.84	14.43
Weight of container +oven-dry (W2)g	12.17	13.58
wet soil (WS)	6.39	7.58
Water content W%= WW/WS	41.70%	42.24%

APPENDIX-D

Specific Gravity Test Result

Test pit designation	TP-1
Depth (m)	3
Weight of empty pycnometer (Wo)	28.06g
Weight of pyc + dry soil (W1)	38.06g
W. Pyc+dry soil + water (W2)	143.8
Weight of pyc + water (W3)	137.6
Specific gravity (Gs)	2.63

Test pit designation	TP-2
Depth (m)	3
Weight of empty pycnometer (Wo)	29.30g
Weight of pyc + dry soil (W1)	39.30g
W. Pyc+dry soil + water (W2)	85.79
Weight of pyc + water (W3)	79.71
Specific gravity (Gs)	2.55

Test pit designation	TP-3
Depth (m)	3
Weight of empty pycnometer (Wo)	15.32g
Weight of pyc+dry soil (W1)	25.32g
W. Pyc+dry soil+water (W2)	84.17
Weight of pyc+ water (W3)	78.40
Specific gravity (Gs)	2.36

Test pit designation	TP-4
Depth (m)	3
Weight of empty pycnometer (Wo)	20.32g
Weight of pyc+dry soil (W1)	30.32g
W. Pyc+dry soil+water (W2)	85.95
Weight of pyc+ water (W3)	79.71
Specific gravity (Gs)	2.65

Test pit designation	TP-5
Depth (m)	3
Weight of empty pycnometer (Wo)	18.9g
Weight of pyc+dry soil (W1)	28.9g
W. Pyc+dry soil+water (W2)	84.55
Weight of pyc+ water (W3)	78.38
Specific gravity (Gs)	2.61

Test pit designation	TP-6
Depth (m)	3
Weight of empty pycnometer (Wo)	18.77g
Weight of pyc+dry soil (W1)	28.77g
W. Pyc+dry soil+water (W2)	85.81
Weight of pyc+ water (W3)	79.67
Specific gravity (Gs)	2.59

Test pit designation	TP-7
Depth (m)	3
Weight of empty pycnometer (Wo)	12.78g
Weight of pyc+dry soil (W1)	22.78g
W. Pyc+dry soil+water (W2)	85.74
Weight of pyc+ water (W3)	79.55
Specific gravity (Gs)	2.62

Test pit designation	TP-8
Depth (m)	3
Weight of empty pycnometer (Wo)	12.78g
Weight of pyc+dry soil (W1)	22.78g
W. Pyc+dry soil+water (W2)	84.36
Weight of pyc+ water (W3)	78.3
Specific gravity (Gs)	2.53

Test pit designation	TP-9
Depth (m)	3
Weight of empty pycnometer (Wo)	12.78g
Weight of pyc+dry soil (W1)	22.78g
W. Pyc+dry soil+water (W2)	84.66
Weight of pyc+ water (W3)	78.3
Specific gravity (Gs)	2.74

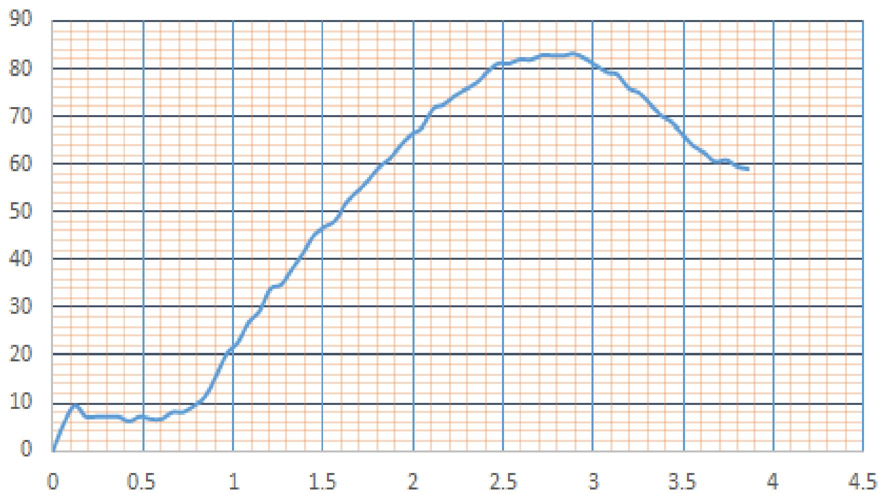
Test pit designation	TP-10
Depth (m)	3
Weight of empty pycnometer (Wo)	17.78g
Weight of pyc+dry soil (W1)	27.78g
W. Pyc+dry soil+water (W2)	84.75
Weight of pyc+ water (W3)	78.38
Specific gravity (Gs)	2.75

APPENDIX-E

Shear Strength Test Result

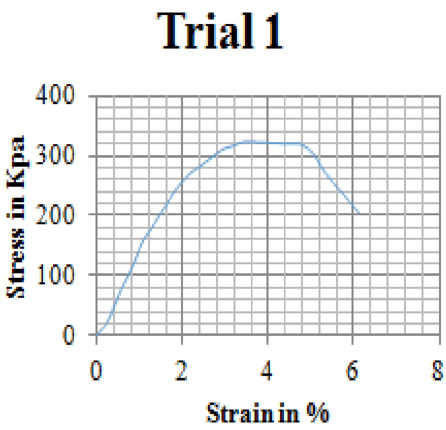
Test pit designation	TP-1
Depth(m)	3
Height of sample(mm)	83
Diameter of sample(mm)	38
Mass of specimen (gm)	161.785
Unit weight(KN/m^3)	16.87
Moisture content (%)	44.97
Dry unit weight(KN/m^3)	11.64
Unconfined compressive strength(qu (kPa)	83.02
Shear strength cu = qu /2 (kPa)	41.51

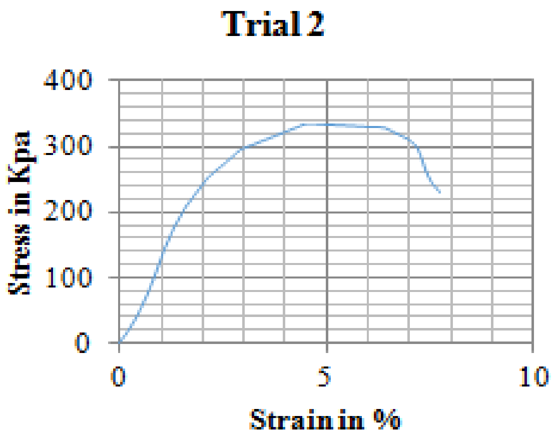
Stress - strain curve



Test pit designation	TP- 2	
Depth(m)	3	3
Height of sample(mm)	83	83
Diameter of sample(mm)	38	38
Mass of specimen (gm)	165.12	162.4
Unit weight(KN/m^3)	18.06	18.01
Moisture content (%)	50.54	50.52
Dry unit weight(KN/m^3)	11.99	11.96
Unconfined compressive strength(qu (kPa)	323	334
Shear strength cu = qu /2 (kPa)	161	167

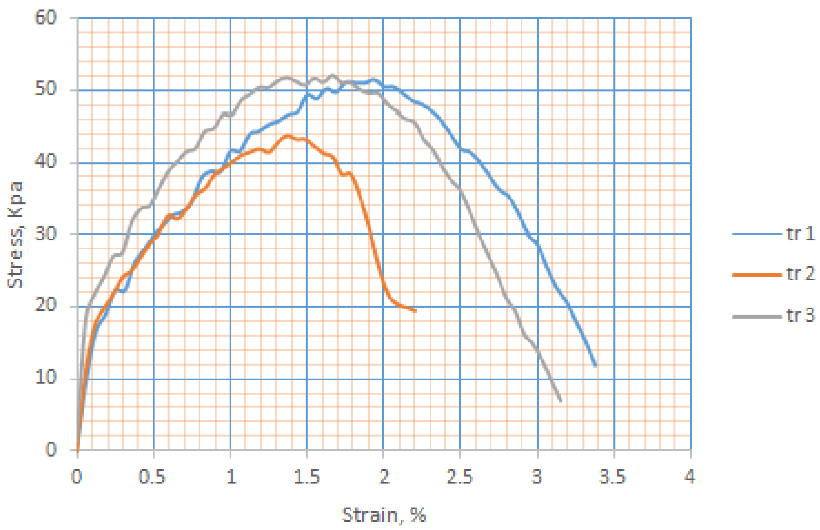
Stress-strain curve





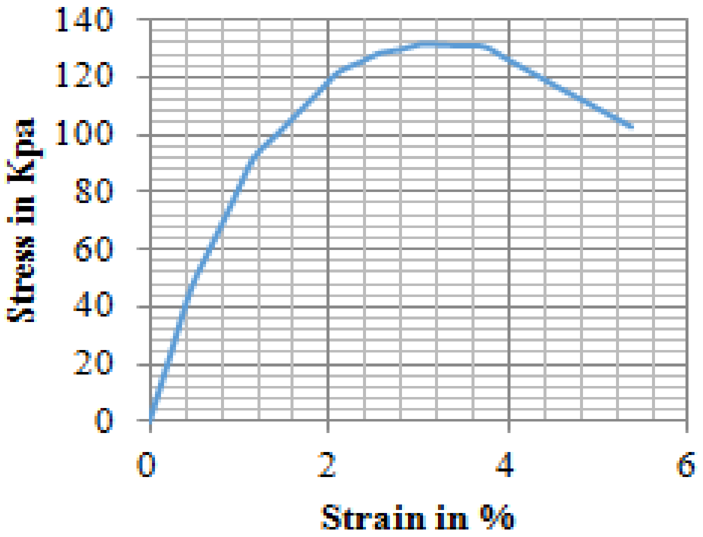
Test pit designation	TP- 3		
Depth(m)	3	3	3
Height of sample(mm)	80	34	82
Diameter of sample(mm)	38	38	38
Mass of specimen (gm)	148.17	148.86	148.63
Unit weight(KN/m^3)	16.03	15.34	15.69
Moisture content(%)	64.69	58.96	63.70
Dry unit weight(KN/m^3)	9.73	9.65	9.58
Unconfined compressive strength(qu (kPa)	51.52	43.81	52.13
Shear strength cu = qu /2 (kPa)	25.76	21.90	26.06

Stress-strain curve

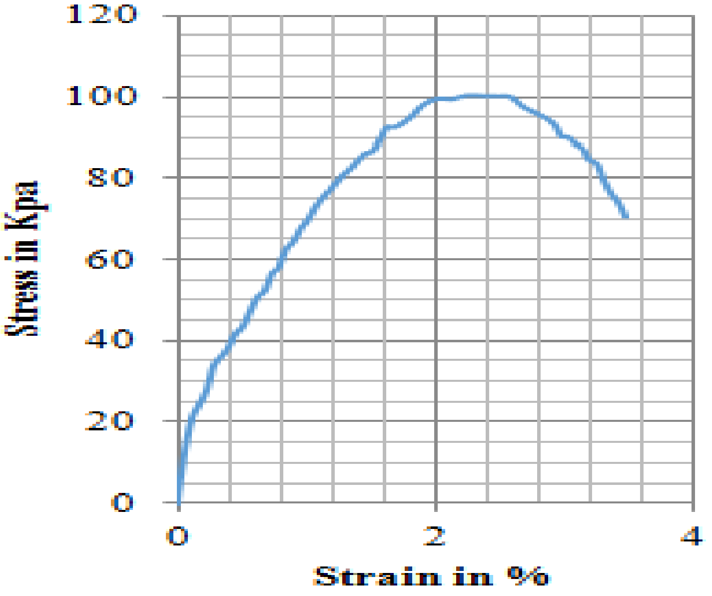


Test pit designation	TP-4
Depth(m)	3
Height of sample(mm)	87
Diameter of sample(mm)	38
Mass of specimen (gm)	145
Unit weight(KN/m^3)	17.17
Moisture content (%)	54.10
Dry unit weight(KN/m^3)	11.14
Unconfined compressive strength(qu (kPa)	132
Shear strength cu = qu /2 (kPa)	66

Stress-strain curve

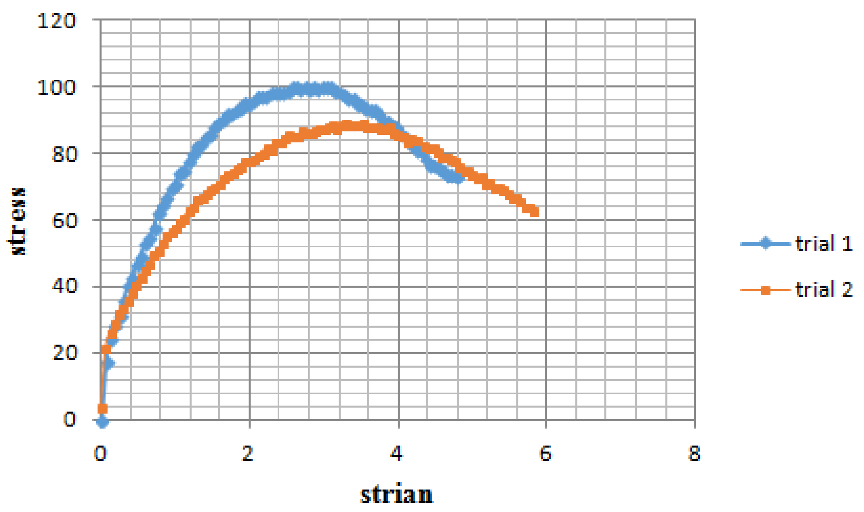


Test pit designation	TP-5
Depth(m)	3
Height of sample(mm)	82
Diameter of sample(mm)	38
Mass of specimen (gm)	148
Unit weight(KN/m^3)	16.83
Moisture content (%)	45.57
Dry unit weight(KN/m^3)	11.56
Unconfined compressive strength(qu (kPa)	47
Shear strength cu = qu /2 (kPa)	27



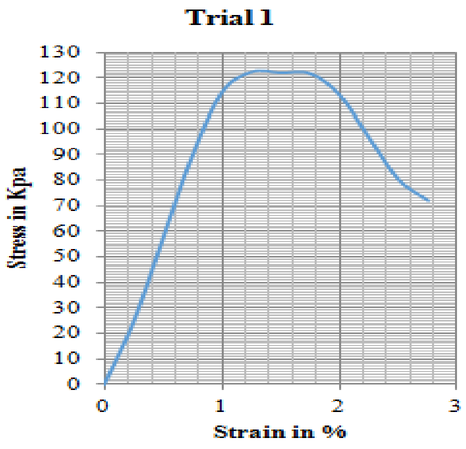
Test pit designation	TP-6	
Depth(m)	3	3
Height of sample(mm)	86	85
Diameter of sample(mm)	38	38
Mass of specimen (gm)	165.56	152.51
Unit weight(KN/m^3)	16.66	16.55
Moisture content (%)	39.37	46.48
Dry unit weight(KN/m^3)	11.95	11.30
Unconfined compressive strength(qu (kPa)	100.51	89.38
Shear strength cu = qu /2 (kPa)	50.25	44.69

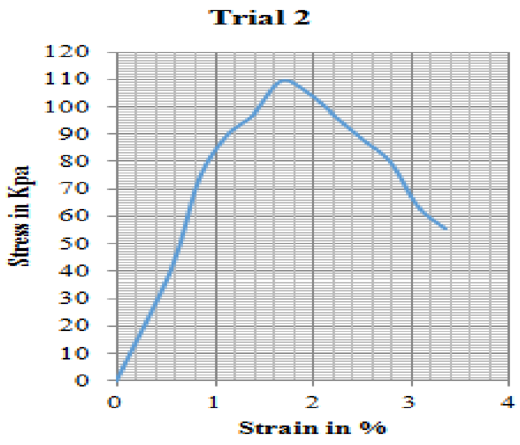
Stress-strain curve



Test pit designation	TP-7	
Depth(m)	3	3
Height of sample(mm)	86	85
Diameter of sample(mm)	38	38
Mass of specimen (gm)	164.6	150.8
Unit weight(KN/m^3)	19.53	19.31
Moisture content (%)	48.38	48.84
Dry unit weight(KN/m^3)	13.04	12.97
Unconfined compressive strength(qu (kPa)	122.30	109.61
Shear strength cu = qu /2 (kPa)	61.15	54.80

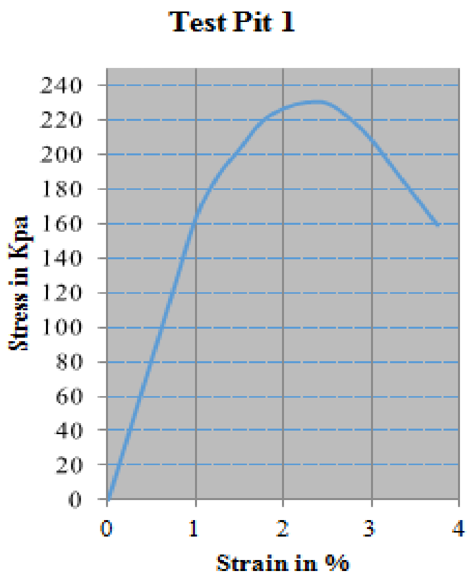
Stress-strain curve

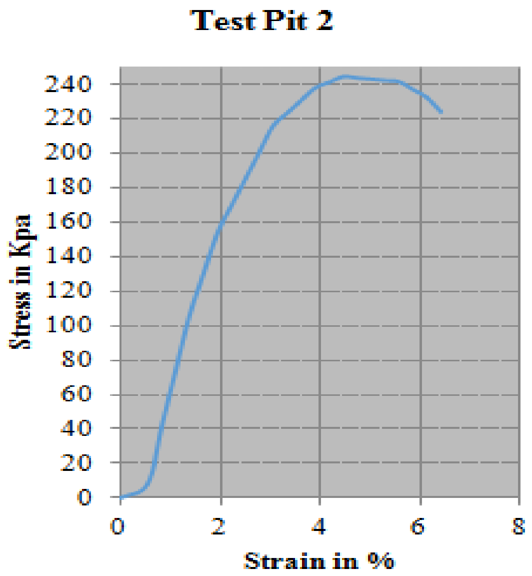




Test pit designation	TP-8	
Depth(m)	3	3
Height of sample(mm)	86	85
Diameter of sample(mm)	38	38
Mass of specimen (gm)	163	160
Unit weight(KN/m^3)	18.42	18.89
Moisture content (%)	47.26	47.73
Dry unit weight(KN/m^3)	12.51	12.79
Unconfined compressive strength(qu (kPa)	230.02	244.58
Shear strength cu = qu /2 (kPa)	115.01	122.29

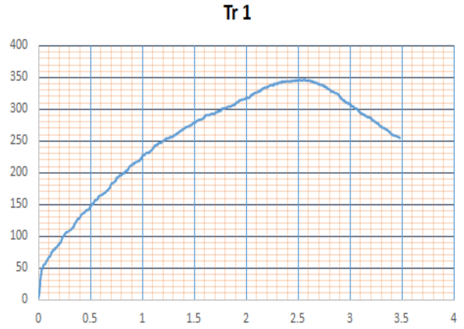
Stress-strain curve

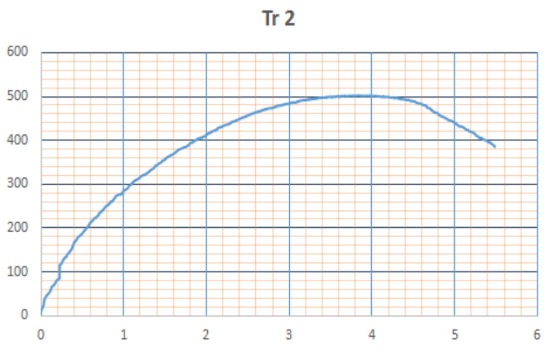




Test pit designation	TP-9	
Depth(m)	3	3
Height of sample(mm)	85	88
Diameter of sample(mm)	38	38
Mass of specimen (gm)	167.12	167.61
Unit weight(KN/m^3)	17.02	17.06
Moisture content (%)	44.96	43.49
Dry unit weight(KN/m^3)	11.74	11.89
Unconfined compressive strength(qu (kPa)	329.95	352.95
Shear strength cu = qu /2 (kPa)	164.97	176.47

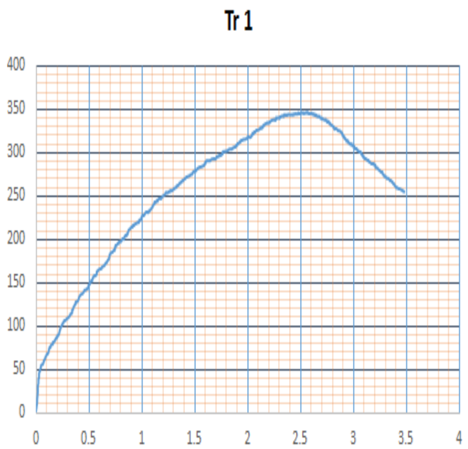
Stress-strain curve

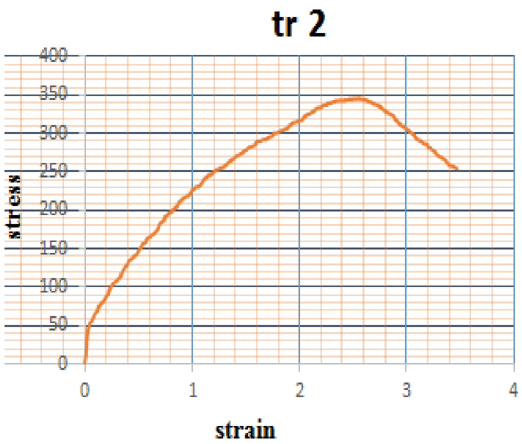




Test pit designation	TP-10	
Depth(m)	3	3
Height of sample(mm)	88	88
Diameter of sample(mm)	38	38
Mass of specimen (gm)	169.73	172.90
Unit weight(KN/m^3)	16.69	17.00
Moisture content (%)	45.93	43.71
Dry unit weight(KN/m^3)	11.44	11.83
Unconfined compressive strength(qu (kPa)	348.09	346.58
Shear strength cu = qu /2 (kPa)	174.04	173.29

Stress-strain curve





APPENDIX-F

Schmidt Hammer Test Result

Easting	Northing	Elevation	Rock type	Rebound value	unconfined compressive strength (Mpa)
267303	850720	1968	Basalt	58.5	194.98
				57.7	181.97
				49.5	131.82
267363	851038	1978	Basalt	51.8	165.95
				56.7	89.12
				55.1	107.15
262725	851499	1836	Ignimbrite	52.5	162.18
				53.3	144.54
				52.6	50.118
262670	847250	1750	Ignimbrite	53.4	169.82
				48.2	128.82
				48.1	58.88
257860	849233	1740	Ignimbrite	55.9	35.48
				55.1	43.65
				56.0	165.95

APPENDIX-G

Lithological Log of Boreholes

Borehole-1

Location: X= 264841m, Y= 852239m, Z= 1767.97m

Site Name: Ginjo School

Ground Water Level: 1764.17m

No.	Depth range (m)	Geological description
1	0-6	Clay soils
2	6-10	Sandy clay soil
3	10-26	Clayey silt soil
4	26-30	Well sorted fine sand
5	30-38	Moderately weathered basalt
6	38-46	Massive basalt
7	46-52	Slightly fractured basalt
8	52-8	Moderately fractured and slightly weathered basalt
9	58-68	Slightly fractured basalt
10	68-80	Moderately fractured basalt
11	80-88	Slightly fractured basalt
12	88-92	Clay soils
13	92-96	Moderately weathered basalt
14	96-100	Clayey sand soil
15	100-108	Slightly fractured basalt
16	108-116	Highly fractured basalt
17	116-122	Slightly fractured basalt
18	122-134	Highly fractured basalt
19	134-142	Slightly fractured basalt
20	142-148	Highly fractured basalt
21	148-154	Moderately fractured basalt
22	154-160	Highly fractured basalt

Borehole-2

Location: X= 263366 m, Y= 851619m, Z= 1756.98m

Site Name: Kito-Furdisa

Static Water Level: 1753.98m

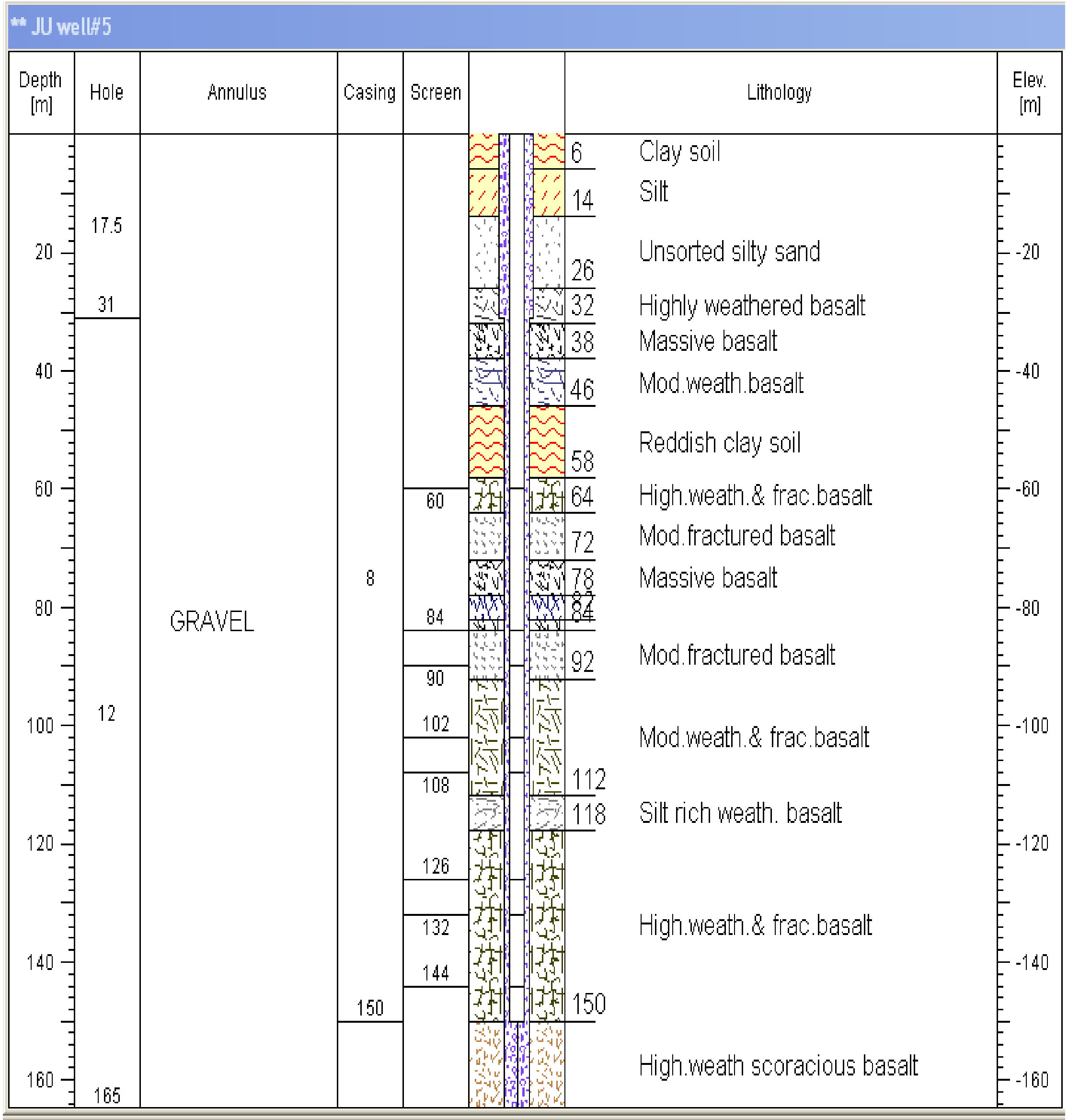
No.	Depth range (m)	Geological description
1	0-12	Sticky clay
2	12-20	Sandy clay
3	20-36	Fine-grained sand
4	36-50	Volcanic ash(gray)
5	50-94	Grey colored clay
6	94-100	Erosional debris
7	100-110	Clay with rock fragment
8	110-130	Highly fractured basalt
9	130-136	Clay (reddish)
10	136-148	Light-colored volcanic ash
11	148-159	Slightly fractured ignimbrite
12	159-164	Fractured ignimbrite
13	164-170	Volcanic tuff(light colored)
14	170-174	Fractured ignimbrite
15	174-178	Volcanic tuff(light colored)
16	178-180	Fractured ignimbrite
17	180-187	Rhyolitic tuff

Borehole-3

Location: X= 260398m, Y= 852256m, Z= 1744.85m

Site Name: JU Sport Field

Static Water Level: 1742.65m



Borehole-4

Location: X= 262846m, Y= 849088m, Z= 1737.2m

Site Name: Main Campus 1

Static Water Level: 1736m

No.	Depth range	Geological description
1	0-2	Top soil
2	2-16	Volcanic ash(light color)
3	16-32	Sticky black clay to gray color
4	32-42	Sticky black clay light color
5	42-48	Clay soil with fine-grained sand
6	48-56	Moderately fractured basalt
7	56-66	Scoriaceous basalt
8	66-80	Highly fractured basalt
9	80-88	Slightly fractured basalt
10	88-102	Massive basalt
11	102-108	Slightly fractured basalt
12	108-121.50	Moderately fractured basalt

Borehole-5

Location: X= 263265m, Y=848836m, Z= 1736.24

Site Name: Main Campus 2

Static Water Level: 1735.44m

No.	Depth range	Geological description
1	0-24	Reddish clay soil
2	24-70	Fine sand
3	70-90	Massive basalt/ slightly fractured
4	90-94	Silt
5	94-112	Fractured ignimbrite
6	112-116	Silt
7	116-132	Grey colored volcanic ash/tuff
8	132-138	Semi consolidated reddish clay
9	138-143	Rhyolitic tuff
10	143-152	Massive basalt/ slightly fractured