INVESTIGATION ON THE ENGINEERING PROPERTIES OF SOIL FOUND IN BISHOFTU TOWN

MINISHAW HAILEGIYORGIES ALI

A Thesis Submitted to

Civil Engineering Department

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Degree of Masters of Science in Civil Engineering (Geotechnical Engineering)

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

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Declaration

I hereby declare that this MSc Thesis entitled "Investigation on the Engineering Properties of Soil found in Bishoftu Town" 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 materials that are used for this thesis have been duly acknowledged through citations.

Minishaw Hailegiyorgies Ali______________________ ____________________

Name of Student Signature date

Recommendation of Advisors

We, the advisor of this research, hereby certify that I have closely advised the student while developing this proposal and read the draft thesis proposal entitled "Investigation on the Engineering Properties of Soil found in Bishoftu Town" prepared under my guidance by Minishaw Hailegiyorgies Ali. Therefore, I recommend the submission of the proposal to the Department for further review and evaluation.

we, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Investigation On the Engineering Properties of Soil Found in Bishoftu Town" prepared under my/our guidance by Minishaw Hailegiyorgies Ali submitted in partial fulfillment of the requirements for the degree of Master's of Science in Civil Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr.Argaw Asha ______________________	______________________	______________________
Major-Advisor	Signature	Date
______________________	______________________	______________________
Co-advisor	Signature	Date

Approval Page of M.Sc. Thesis

we, the advisors of the thesis entitled "Investigation On the Engineering Properties of Soil Found in Bishoftu Town" and developed by Minishaw Hailegiyorgies Ali, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Argaw Asha ________ ______________________ ______________
Major Advisor Signature Date

_________________________ ______________________ _______________
Co-advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Minishaw Hailegiyorgies Ali have read and evaluated the thesis entitled "Investigation On the Engineering Properties of Soil Found in Bishoftu Town" 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 Civil Engineering.

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Internal Examiner Signature Date

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External Examiner Signature Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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School Dean Signature Date

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Symbols and Abbreviations

AASHTO – American Association of state Highway and transportation officials

ASTM – American standard of testing materials

BS- The British Standard Classification system

Gs – Specific gravity

LL – Liquid limit

MDD – Maximum Dry Density

MH – Inorganic silt with high plasticity

NMC – Natural moisture content

PI – Plasticity index

PL – Plastic limit

OMC – Optimum Moisture Content

TP – Test pit

UCS – Unconfined compressive strength

USCS – Unified soil classification system

SM – Silty sand

DEC- Defense Engineering Collage

FS- Free Swell

CH-highly plastic clay soil

OM-organic matter

Φ-internal friction

ω- is the water content

C -cohesion

Abstract

This research focused on investigate the engineering properties of soil found in Bishoftu town. Engineering properties of soils is useful in understanding the properties and behavior of soils for the management especially erosion control, farming activities, building, etc. The objectives of this research is to investigate the engineering properties of soils found in the Bishoftu town by conducting different types of laboratory tests. To achieve its objective disturbed samples from different parts of the town were collected and laboratory tests were done on the collected samples. The number of test pits taken were limited because of that the soil in the entire area of the town is more or less similar. From reconnaissance survey it has been observed that the town is covered by expansive soil. After collecting representative disturbed samples from proposed open test pits by direct manual excavation, laboratory tests were carried out including specific gravity, natural moisture content, Atterberg limit, free swell, sieve analysis, hydrometer tests and direct shear strength test.

Grain size analysis tests indicated that, the clay content range from 29.77% to 46.38%, silt content range from 54.19% to 63.05%, sand content range from 5.08% to 6.72%, and gravel content range from 0.58%to 1.52% therefore the soil in Bishoftu town is mostly silts and caly soil and the specific gravity tests indicated that content range from37.72% to 42.35%.The Atterberg limit test tests indicated that, a liquid limit range from 82%to 90.3%, plastic limit range from 29.61% to 38.38% and plastic index from 44.65% to 58.71%. This indicate that soil of the study area is highly plastic. The free swell soil test indicated that from127% to 209.5% which indicates that the soil is expansive soil. from the compaction test result the maximum dry density (MDD) soil ranges from 1.23 to 1.46 g/cm^3 and the optimum moisture content(OMC) ranges from 38.04 %. Shear strength parameters from the graph of shear stress versus normal stress cohesion(C) ranges from 18.68Kpa to 27.44Kpa and angle of internal friction (Φ) ranges from 10^0 to 15.99^0. Soils of the study area are classified according to USCS and AASHTO.USCS indicates one main type of soils, which is highly plastic silt soil (MH). According to AASHTO classification soils of the study area is A-7-5.

Finally, the pit excavation method of exploration is used, the outcomes would be applicable only for light structures which under lie their foundation up to depth of 2.8m. Therefore, by increasing the depth of the pit excavation additional investigation should be done in the future in order to fully characterize the soil properties of the area.

CHAPTER ONE
INTRODUCTION

1.1. Background of the study

A geotechnical engineering is an essential requirement to the design and construction of civil engineering projects. The proper design of civil engineering structures like foundation of buildings, retaining walls, high ways, etc. requires adequate knowledge of sub surface conditions at the sites of the structures (*2010 Richard P. Weber).* Many damages to buildings, roads and other structures founded on soils are mainly due to the lack of proper investigation of substructure condition. Thus this thesis gives better understanding about some engineering behaviour of the soil in the Bishoftu town. Identifying the soil characteristic is essential to construct economically different types of civil engineering that will serve to the people for various purposes.

The results of the study will be of great importance for the ever growing building construction especially for those yet to be constructed in that area. It can be used as soil property manual as it will have a customized nature to meet the required soil information of the area with regard to the future development programs in the construction sector. Thus this thesis gives better understanding about some engineering behaviour of the soil in the Town. Identifying the soil characteristic is essential to construct economically different types of civil engineering that will serve to the people for various purposes. The results of the study will be of great importance for the ever growing building construction especially for those yet to be constructed in that area. It can be used as soil property manual as it will have a customized nature to meet the required soil information of the area with regard to the future development programs in the construction sector.

Bishoftu is one of the industry zone and recreation centres in the country and also Bishoftu was founded between Dukem and Mojo towns along Addis Ababa-Djibouti road. Due to its location more investors are attracted for different project using construction. Therefor the engineering properties of soil investigation was very important aspect for the development project in Bishoftu town. The town had some industrial facilities like factories (small and large scale), warehouses, resorts and lodges.

Now a day Dukem was merged with Bishoftu town, therefore there will be expected more investments project on construction works.

1.2. Statement of the problem

Investigation of the underground conditions at a site is prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies of the proposed project. As well soil investigation is a must in the present age for the design of foundations of any project. The extent of the investigation depends upon the magnitude and importance of the project. Now a day Bishoftu town developing in construction industries, therefore better information geotechnical investigation data in order to recommend the feasible type of foundation for future construction infrastructure and other related structure with geotechnical engineering.

1.3. General objective of the Study

The main objective of this thesis is to study the Investigating on the engineering properties of soils found in Bishoftu town.

1.3.1. Specific objective of the Study

- To investigate the engineering properties of the Bishoftu soils namely natural moisture content, specific gravity, Atterberg Limits, grain size analysis, swelling values, compaction characteristics and shear strength of soil by direct shear test.
- To determine Classification of soil based on both according to ASHTO and USCS.
- To determine the range of values of index property of soil in some part of the city

1.4. Significance of the Study

Interpretation and analysis of laboratory test results and to determine the natural and relevant physical properties of the soil in the Bishoftu town.

1.5. Limitations of the Study

The Limitations of this study is limited to investigating the index properties, compaction characteristics, and direct shear tests. The depth of investigation in this research is limited to the maximum depth of 2.8 meters and due to lack of material, it was difficult to collect undisturbed soil sample. Therefore, all the laboratory tests are done using disturbed sample of soils.

CHAPTER TWO
LITERATURE REVIEW

2.1. Soil

Soil is the unconsolidated outer layer of the Earth's crust. It appears in a variety of forms (different textures, colour, structure and nutrient content) depending on a number of factors. Although soil is largely variable, there are four main constituents(fragments) that are harmonious with all types of soil mineral, organic matter, water and air. These four fragments fall into two orders solid (mineral and organic matter) and non-solid (water and air).

The solid order

The solid order makes up roughly 50- 70% by volume of the total soil and consists of the mineral and organic matter fragments. Combined, the mineral and organic matter fragments give the soil a characteristic known as texture.

The mineral fraction

The mineral fraction makes up about 95- 99 %of the solid order. It's comprised of the survived remains of parent rocks that are broken down over numerous thousands of times. As the mineral fraction is such a large chance of the total soil volume, the characteristics of soil are generally determined by the type of parent rock(geology) from which it was formed. The mineral fraction is made up of four main particles that are defined by the diameter of the particle:

Gravel> 2 mm

Sand 0.02- 2 mm

silt 0.002-0.02 mm

clay <0.002 mm

The proportion of these particles plays an important part in the fertility of the soil and its response to operation Clay particles are the lowest particles of the mineral fraction. They're an important element of soil as they've a negative electrical charge. This enables them to hold and change nutrients (which also have an electrical charge). Clay particles in soil give an exchange point for plant nutrients. Clay soils are typically more rich than sandy soils.

The type and volume of Clay in the soil can affect the amount of nutrients held for plant use and the ease at which these nutrients are released to the plant. The electrical charge on Clay particles enables them to stick to other Clay particles and also to sand and silt particles (this is the reason why clays are so sticky). This can be good and bad in terms of soil operation as will be explained in Section1.5 of this folder Soil Management and Land Degradation.

Clay, sand and silt particles don't have an electrical charge and have minimum capability to hold and change plant nutrients. They do, still, have other important places similar as aeration of the soil. Clay and coarse sand particles are larger than Clay, silt and fine sand particles, and they've bigger gaps between them. thus, further space is available for movement of water and air through the soil. A good blend of sand, ground and Clay patches will allow the soil to hold sufficient nutrients as well as allowing acceptable exchange of air and water essential for plant growth.

Organic matter fraction

Organic matter occurs in colorful forms from undecomposed to fully decomposed (humus), and all forms give benefits for the soil. Like Clay particles, humus is also electrically charged and is suitable to store and release nutrients. Humus is also suitable to increase the water holding capacity of the soil. This is particularly important for sandy soils which have a low water holding capacity.

Micro-organisms form the living element of the organic fraction. They feed on organic matter putrefying it to humus. Micro-organisms also live on products of living shops, some furnishing benefits to the plant, others creating disease. most soil organisms decompose organic matter and release nutrients for plant growth as well as perfecting soil structure. Micro-organisms in the soil are important for soil health.

The non-solid order

The non-solid order can be divided into two fragments water and air. Water and air should comprise around 30- 50 %of an agricultural soil. This depends on the time of time and the soil type. Water and air are essential for plant growth. In particular, oxygen and carbon dioxide need to be changed between the soil and the atmosphere for root respiration to do.

Characteristics of soil

There are three characteristics of soil that are important for plant growth and productivity physical, biological, and chemical.

Physical

The aspects of the soil that you can see and touch. Physical characteristics particles) and stone include soil texture, soil color, soil depth, soil structure, porosity (spaces between content. The part physical properties play in soil health are:

- ❖ To supply water and air to plant roots and allow acceptable water and air movement into and through the soil profile.
- ❖ To store water for plant growth.
- ❖ To support machine and animal traffic.

Chemical

The capability to supply nutrients for plant growth and store nutrients in the profile without loss by filtering. The capability to keep Clay summations chemically stable which impacts on soil structure.

Biological

The capability to support a healthy microbial population for organic matter breakdown(faeces and crop and pasturage remainders), nutrient cycling and the growth of nitrogen fixing bacteria.

Physical characteristics

Soil texture

As mentioned over, soils are incompletely made up of mineral fraction (gravel, sand, silt and clay particles) and an organic matter fraction. It's these two fragments combined (minus the gravel particles) that give the soil a characteristic known as texture. There are numerous different texture grades depending on which particles (sand, silt Clay or organic matter) are dominant (if any). Soil texture provides a good way of characterising soils and can be described through the behaviour of a moist lump of soil when rubbed between your thumb and forefinger.

Soils of one particle size

Sand -Particles are visible to the eye, feels gritty and sand grains can be heard when rubbed. Sticks together only when moist e.g. beach sand.

Silt - Particles not visible to the eye, feels silky (like talcum powder) and can be rolled when moist to form short rods. Sticks together when moist or dry.

Clay -Particles not visible to the eye, feels smooth and plastic and can be rolled to form long rods when moist. Sticks together when moist or dry e.g. pottery clay.

Water and nutrient holding capacity

In confluence with soil depth and structure, the texture of a soil will determine the implicit water and nutrient holding capacity. Sandy soils, due to their large primary particle sizes, have poor nutrient and water holding capacities. clay soils, on the other hand, are suitable to hold high situations of nutrients due to electrical charges. clay soils are suitable to hold further water but generally don't drain as well as sand.

Soil structure

The solid order of soil, which consists of individual particles (sand, silt, clay and organic matter) can cement together to form summations. aggregates. Sand, silt, clay and organic matter are cemented together by the Clay particles and organic matter (due to electrical magnet). Organic matter is one of the major cementing agents for soil aggregates (particularly in top soils) and one that's explosively affected by soil operation. Organic matter and Clay also bind summations together. The arrangement of aggregates, along with their size and shape, gives soil a characteristic known as soil structure. Sandy soils don't tend to form aggregates and remain as primary sand particles with poor structure. Soils that have enough clay and organic matter to bind the soil particles together to form numerous small aggregates have good structure. summations held together by Clay particles that are unstable in water can be veritably weak and may collapse when wet or over cultivated to form larger aggregates or clods. Good soil structure should have clays that remain stable in water.

Soil structure is important as it affects the movement of water and air through the soil, the growth of plant roots through the soil and the threat of declination (similar as corrosion).

Porosity

Spaces or pores within and between aggregates can be either filled with air or water. The number, size and shape of the pores determines the amount and rate at which water and air can move into and through the soil, and also the amount of water held in the soil. Pores can be divided into two Macro pores and Micro pores.

Macro pores do between the soil aggregates. They're responsible for the rapid-fire movement of air and water into and through the soil but aren't filled with water at low to moderate soil humidity contents. Because of their size, roots grow through macrospores. These pores are typically lesser than0.1 mm in diameter.

Micro pores do within the soil aggregates. They are the spaces formed between the sand, silt, clay and organic matter particles. Micro pores are responsible for the water holding capacity of the soil and are the star point for water birth by roots. These pores are typically lower than 0.1 mm in diameter.

A well-structured soil requires a combination of both macro pores and micro pores. Too numerous macro pores will allow water to move fluently into and through the soil, still very little water will be held for plant use. Sandy soils tend to have a lesser chance of macro pores than silty soils or clays. This means sandy soils are well drained but unfit to hold a great deal of water for plant use. Too numerous micro pores won't allow enough water and air to move into or through the soil freely, performing in runoff or drainage problems. Clays soils generally have further micro pores than macro pores and are suitable to hold further water for plant use but aren't as well drained as sandy soils.

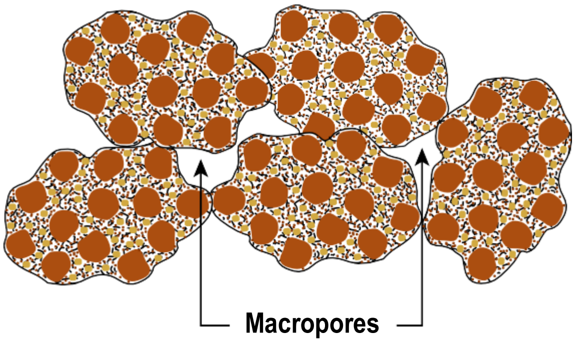

Figure1. *Macro pores between soil aggregates.*

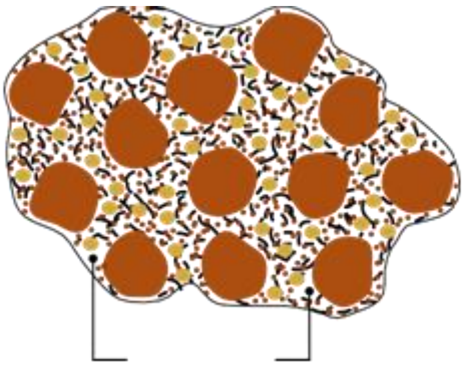

Figure2. *Micro pores within a soil aggregates.*

Slaking

Unstable or disturbed soil aggregates will frequently slake or slump when wet. Slaking occurs when dry soil is wet rapidly. Water enters the soil aggregate through capillary action and traps air inside. The air pressure inside the aggregate increases. If the air pressure inside the aggregate is stronger than the strength of the aggregate, the aggregate will disintegrate into micro-aggregates (slake). A strong aggregate will withstand the pressure and this is a sign of good soil structure. Soil deficient in organic matter will have weak aggregates. Slaked aggregates will block macro pores, drop the movement of water and air into and through the soil, and produce crusts and hard-setting soils

Dispersion

Dispersion is the structural breakdown of soil aggregates in water into the individual soil particles (sand, silt and clay). This is apparent in a muddy puddle or dam where dispersed clay particles are suspended in water. Dispersed clays can block micro pores and macro pores and affect in structural damage to the soil. Clods, surface seals or hardpans are frequently set up in soil with dispersible clay.

The behaviour of the clays when wet depends on which positive ions (sodium, calcium or magnesium) dominate. Dispersion is a chemical process in which the negatively charged clay particles react with positively charged sodium ions in the soil. Clay particles dominated by sodium ions will frequently disperse in rainwater.

Soil colour

Soil colours are related to chemical properties, aeration or drainage, and organic matter. Soil colour is an important specific of the soil as it can give a suggestion of the soil's drainage characteristics. Soil colour may also help you determine the different horizons of the soil.

Red colours suggest the presence of unhydrated iron oxides that are a suggestion of good drainage and aeration. Generally, water can drain relatively quickly through the profile of red soil and oxygen can thus be stored in the macro pores. Brown soils generally have reasonable drainage. The brown colour is frequently (but not always) a suggestion of high quantities of organic matter. Yellow soils have inadequate drainage. The yellow colour generally indicates that the soil remains saturated and is thus starved of oxygen for ages of several weeks after rainfall. Yellow soils may also have a perched water table.

Black soils can indicate high organic matter content or a high Clay content. Black Clay soils can have variable drainage characteristics ranging from relatively well drained to inadequately drained. Light coloured soils (particularly topsoil) are a suggestion that soil has been explosively percolated of nutrients (iron oxides, aluminium and organic matter) which have been moved by water to a lower layer

Chemical characteristics

Nutrients

Plant nutrients can also be added to the soil from the atmosphere. Some nutrients may be dissolved in downfall and gassy nitrogen is converted to solid mineral nitrogen by micro-organisms similar as the rhizobia growing in the nodules on legume roots (e.g. peas, lupine, clover and Lucerne). In the natural environment nutrients are cycled between the vegetation and the soil and many nutrients are lost from the system. These systems of nutrient inputs are normally sufficient to sustain vegetation. In productive agricultural systems however, these sources are not sufficient to supply all of the nutrients required by crops and pastures. Additional nutrient inputs through fertilisers are needed.

Whenever grain, stock or wool is removed from a paddock, nutrients that were stored in the soil are exported. nutrients removed need to be replaced, or the practice of farming will not be sustainable. nutrients such as phosphorus, nitrogen, sulphur and zinc are some of the more common elements that are applied in the form of fertiliser. Without the addition of nutrients, the availability of nutrients for plant growth would be less than optimal and productivity would decline. The importance of plant nutrients can be based on the quantities required for adequate plant growth. The most important are macro-nutrients (needed in larger amounts) which include nitrogen, phosphorus, potassium (potash), sulphur, magnesium and calcium.

Biological characteristics

Micro-organisms are responsible for the breakdown of plant remainders and can control the nutrients released during decomposition. Under high residue loads, micro-organisms can tie up plant available nutrients to increase their own population. nutrients are tied up in the microbial population until such a time that residue situations are dropped and the nutrients also come available for plants. Using this system, micro-organisms can hold nutrients similar as nitrate in an organic form and prevent leaching below the root zone.

Roots and soil organisms (which include earthworms and fungi) are suitable to stabilise soil aggregates with compounds excreted from their cells. These compounds are suitable to stick micro-aggregates together to form water stable macro-aggregates. Roots and earthworms form stable channels through the soil which are known as bio pores. These have the same characteristics as macro pores. In addition to forming channels, earthworms are suitable to cycle nutrients and organic matter through different parts of the soil profile.

Earthworms feed on soil organisms and root exudates. Earthworm activity is concentrated in the root zone when soils are moist. As soils dry over summer, earthworms burrow down through the profile. Following the autumn break, they burrow back to the face. not all soils host earthworms and there is still debate as to acceptable earthworm figures.

References: Introduction to Soils (Nathalie Baxter and John Williamson)

2.2. Soil Formation

Soils are the products of weathering from some parent rocks. All soils originally come from some pre-existing rocks. They're called as ‘parent material’. The Parent Material may be directly below the soil, or at great distances down from it. It's necessary to understand the factors and processes that are responsible for the formation of soils. Soil formation is a long term process. As soil is a complex admixture of colourful factors, its formation is also more complex. The formation of a particular type of soil depends upon the physico-chemical properties of the parent rock, intensity and duration of weathering, climatic and other parameters. Four Soil Forming Processes these are Additions, Losses, Translocations, and Transformation.

Additions: Material added to the soil, similar as putrefying vegetation and organisms (organic matter-- OM), or new mineral materials deposited by wind or water.

Losses: Through the movement of wind or water, or uptake by plants, soil particles (sand, silt, clay, and OM) or chemical composites can be eroded, percolated, or gathered from the soil, altering the chemical and physical makeup of the soil.

Transformation: The chemical weathering of sand and formation of clay minerals, transformation of coarse OM into decay resistant organic compounds (humus).

Translocations: Movement of soil ingredients (organic or mineral) within the profile and/ or between horizons. Over time, this process is one of the more visibly noticeable differences in colour, texture, and structure come apparent.

Factors of Soil forming

Soils are dynamic, forming continuously over a long period of time. Soil types differ, depending on the parent material from which they came and from the girding terrain. The way in which soil forms depends on Parent material, Climate, Topography, Biota (Living organisms), and Time.

Parent Material

Soil parent material is the material that soil develops from, and may be gemstone that has perished in place, or material that has been deposited by wind, water, or ice. The character and chemical composition of the parent material plays an important part in determining soil parcels, especially during the early stages of development. Soils developed on parent material that's coarse grained and composed of minerals resistant to riding are likely to parade coarse grain texture. Fine grain soils develop where the parent material is composed of unstable minerals that readily rainfall.

Climate

Temperature and precipitation influence how fast parent material rainfall and, therefore, soil parcels similar as mineral composition and organic matter content. Temperature directly influences the speed of chemical responses. The warmer the temperature, the briskly responses do. Temperature oscillations increase physical weathering of rocks. precipitation governs water movement in the soil. The amount of water the soil receives and the amount of evapotranspiration that occurs influence water movement.

Evapotranspiration

Evapotranspiration is the combination of water faded from the soil face and water occurred by growing shops. As air temperatures increase, evapotranspiration increases. High evapotranspiration relative to rush means lower water is available to move through the soil.

Topography

This refers to the geography position and the pitches it has. Steep, long pitches mean water will run down briskly and potentially erode the surfaces of slopes. The effect will be poor soils on the slopes, and richer deposits at the bottom of the slopes. Also, pitches may be exposed to more direct sun, which may dry out soil humidity and render it less rich.

Biota(organisms)

Biotic agents have greatly affected the soil conformation process. These include organisms that live in the soil, similar as bacteria and gophers, and vegetation growing on the face. Soil organisms in the soil can speed up or decelerate down soil conformation. For illustration, microorganisms can facilitate chemical responses or excrete organic substances to improve water infiltration in the soil. Other organisms similar as gopher’s slow soil conformation by digging and mixing soil materials, and destroying soil horizon that have formed.

Generally, soils have been formed under two major types of foliage timber and Champaign. Soils formed under timbers tend to be more weathered (aged in soil terms) because timbers grow in advanced downfall areas. There’s more water movement in the root zone, and a lower quantum of organic matter forms. Soils formed in Champaign tend to be in areas with lower rush. Grasses tend to use the handed humidity, reducing the water movement through the soil profile. Organic matter forms in large amounts and to a deeper depth in the soil face than timber soils.

Time

Soils can take numerous times to form. youngish soils have some characteristics from their parent material, but as they progress, the addition of organic matter, exposure to humidity and other environmental factors may change its features. With time, they settle and are buried deeper below the face, taking time to transform. ultimately, they may change from one soil type to another.

References: Processes and Factors of Soil forming (Dr. B. S. Dwivedi)

2.3. Index properties

Index properties are the properties of soil that help in identification and classification of soil for general engineering purpose. These properties are generally determined in the laboratory. The main index properties of soils are Grain-size distribution of soil, Specific gravity, Atterberg Limits tests, Free Swell Test and Moisture Contents.

2.3.1. Grain-size distribution of soil

The grain size analysis test is performed to determine the percentage of each size of grain that is contained within a soil sample, and the results of the test can be used to produce the grain size distribution curve. This information is used to classify the soil and to predict its behaviour. The two methods generally used to find the grain size distribution are: Sieve analysis which is used for particle sizes larger than 0.075 mm in diameter and Hydrometer analysis which is used for particle sizes smaller than 0.075 mm in diameter.

Sieve analysis is a method that is used to determine the grain size distribution of soils that are greater than 0.075 mm in diameter. It is usually performed for sand and gravel but cannot be used as the sole method for determining the grain size distribution of finer soil. The sieves used in this method are made of woven wires with square openings.

The particle size distribution of soil containing a significant number of finer particles (silt and clay) cannot be performed by sieve analysis. The hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the #200 (0.075 mm) sieve to around 0.001 mm. The data are plotted on a semi-log plot of percent finer versus grain diameters to represent the particle size distribution. Both sieve analysis and hydrometer analysis are required to obtain the complete gradation curve of the coarse and fine fraction of many natural soils.

Practical Application

- Hydrometer analysis is essential for obtaining the complete particle size distribution of such soils. Particle size distribution obtained from sieve analysis may be combined with the data from a hydrometer analysis to produce a complete gradation curve. It is possible to approximate the percentage of silt and clay particles present in the finer portion from the hydrometer analysis.
- Particle size is one of the criteria used to determine whether a soil is suitable for building roads, embankments, dams, etc.
- Information obtained from a particle size analysis can be used to predict soil-water movement if a permeability test is not available.

2.3.2. Specific gravity

Specific gravity of the soil solids is useful in the determination of void-ratio and degree of saturation. It is also useful in computing the unit weight of the soil under different conditions and also in the determination of particle size by hydrometer analysis.

2.3.3. Atterberg Limits tests

Atterberg Limits tests are used to confirm visual descriptions. They are performed on fine-grained soils (clays, silts) to determine the amount of water necessary to achieve a range of behavioural states. Atterberg limits tests should be performed on each representative soil, and additional tests are advisable to confirm grouping of apparently similar soils and where project complexity justifies additional testing. These test results have been correlated with other soil properties. The liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) are Atterberg limits but the term Atterberg limits generally refers to the more common liquid and plastic limits only.

The Atterberg limit tests also known as consistency test are types of index property tests and it is used to determine the degree of firmness of the soil. Based on their mode of formation and mineralogical composition, different soils respond differently for the same moisture content. Atterberg limits are empirical formulas developed to determine the soil consistency. These tests are mostly used for cohesive soils by which their strength is highly dependent on the amount of water they have in their voids. The gradual increase of water in a dry cohesive soil sample for example will change the sample from solid to a semi solid state, to a plastic state and finally by adding more water the sample will be changed into a liquid state.

Liquid Limit: The moisture content of a soil at the boundary between the liquid and plastic states. The liquid limit is determined by ascertaining the moisture content at which two halves of a soil cake will flow together for a distance of 0.5 inch along the bottom of the groove separating the halves, when the blows they are in is dropped between 15 to 35 times from a distance of 0.4 inches at the rate of 2 drops/second. A plot of the relationship between the water content and the number of drops is made using the results of the tests. The water content corresponding to the intersection of the line with the 25-drop abscissa is the liquid limit of the soil.

Plastic Limit: The moisture content at the boundary between the plastic and semisolid states. The plastic limit is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 3mm in diameter before crumbling.

Plasticity Index: is simply the numerical difference between the liquid limit and the plastic limit and indicates the magnitude of the range of moisture content over which the soil remains plastic. PI = LL-PL.

The plasticity index is nothing but a measure that gives the amount of water which must be added to change a soil from its plastic limit to its liquid limit. Generally, the behaviour of all soils and specifically clays considerably differs with the presence of water so one needs a reference index to clarify the effects.

2.3.4. Moisture content

Moisture content of a soil is the ratio of weight water present to weight of dry soil in a given soil mass. It is usually expressed as percentage of the dry mass. The water content, which is usually expressed as a percentage, can range from zero (dry soil) to several hundred percent. For many soils, the water content may be an extremely 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. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.

2.4. Compaction of soil

Compaction means pressing the soil particles close to each other by mechanical methods. Air during compaction is expelled from the void space in the soil mass and, therefore the mass density is increased. Compaction of soil mass is done to improve its engineering properties. Compaction generally increases the shear strength of soil, and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil.

2.5. Shear strength

Shear strength is one of the key geotechnical properties of soil which is used in foundation’s design, construction of different structures like pavements, backfill material, and embankments. The stability of civil engineering structures depends on the shear resistance of the soil. Various factors like soil textural properties, past history of soil, the initial state of soil, and permeability characteristics of soil influence the shear strength parameters (cohesion and angle of shearing resistance). The direct shear test has commonly been carried out to determine the shear strength parameters due to its simplicity. Also, construction of direct shear test apparatus is not complex, the test can be performed fast and the output data can be relatively easily processed.

There are many parameters that affect the shear strength of mixtures containing oversize particles like the gravel content, relative density, overburden pressure, and gravel size and gravel shape. The silty sand has disadvantages of poor stability, low strength, easy deformation, and hard compaction. Therefore, it is difficult to meet the requirements of highway and railway subgrade. Improved coarse-grained soil is obtained by adding different proportions of gravel in silty sand. Coarse-grained soil is widely used as filler for highways and railways because of its characteristics of easy compaction, high permeability, high strength, high density, a small settlement, and strong bearing capacity. The strength and deformation parameters of coarse-grained soil are the main parameters to determine the bearing capacity of embankment and calculate the settlement of the embankment, and the particle distribution is the main factor determining the shear strength characteristics. The strength parameters of coarse grained soil can be obtained using in situ or laboratory testing devices. Physical disintegration and chemical decomposition help in the formation of residual soil. Shear strength properties of the residual soil depend on its composition and environmental conditions under which it is formed. Fine grains are found on upper layer and decrease with depth indicates the age of soil deposit. These soils are used commonly in the construction of embankments, pavements, and soil barriers.

Geotechnical design of embankments, cuts, walls, and foundations requires a thorough understanding of the strength properties of soil. The level of effort used to determine soil strength parameters varies, depending on the size and complexity of the project elements and consequences of failure. The shear strength of a soil is the maximum shearing stress the soil structure can resist before failure. Soils generally derive their strength from friction between particles (expressed as the angle of internal friction, Φ) or cohesion between particles (expressed as the cohesion, c in units of force/unit area), or both. These parameters are expressed in the form of total stress (c, Φ) or effective stress (c'', Φ''). The total stress on any soil layer is induced by the overburden pressure plus any applied loads.

2.5.1. Direct shear test

Direct shear test is conducted on a soil specimen in a shear box which is split into two halves along a horizontal plane. The shear box is made of brass or gunmetal. It is square or circular in plan. In situations which need the shearing strength of a soil, direct shear test applied. The test can be performed on an undisturbed sample or remoulded samples. The main advantage of direct shear test is its simplicity and smoothness in operation and the rapidity of testing program. But this test has the disadvantage that lateral pressure and stress on planes other than the plane of shear are not known during test.

2.6. Classification of soils

2.6.1. General

Geotechnical engineers classify soils according to their engineering properties as they relate to use for foundation support or building material. Modern engineering classification systems are designed to allow an easy transition from field observations to basic predictions of soil engineering properties and behaviours.

The most common engineering classification system for soils in North America is the Unified Soil Classification System (USCS). The USCS has three major classification groups: (1) coarse-grained soils (e.g. sands and gravels); (2) fine-grained soils (e.g. silts and clays); and (3) highly organic soils. The USCS further subdivides the three major soil classes for clarification. It distinguishes sands from gravels by grain size, classifying some as "well-graded" and the rest as "poorly-graded".

Other engineering soil classification systems in the United States include the AASHTO Soil Classification System, which classifies soils and aggregates relative to their suitability for pavement construction, and the Modified Burmister system, which works similarly to the USCS but includes more coding for various soil properties.

2.6.2. USCS Classification

It was developed from a system proposed by Casagrande (1948) and referred to as the Airfield Classification System. Coarse-grained soils (sands and gravels) are classified according to their grading, and fine-grained soils (silts and clays) and organic soils are classified according to their plasticity. (Morsi,2010).

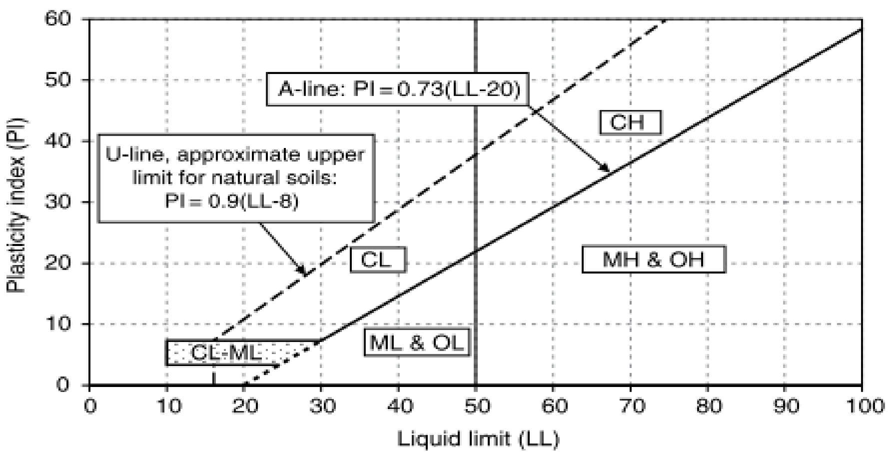

Figure 3. Plasticity chart for the USCS soil classification system

2.6.3. AASHTO Classification

AASHTO (American Association of State Highway and Transportation Officials) does not classify soils by type (e.g. Sands, clays) but simply divides them into seven major groups, essentially classifying soils according to their suitability as subgrades (Morsi, 2010). Soils classified under groups A-1, A-2 and A-3 are granular materials with 35% or less passing through a No. 200 sieve but A-1 & A-3 non-plastic. Soils with more than 35% passing a No. 200 sieve are classified under groups A-4, A-5, A-6 and A-7. (Ameratunga, Sivakugan et al., 2016

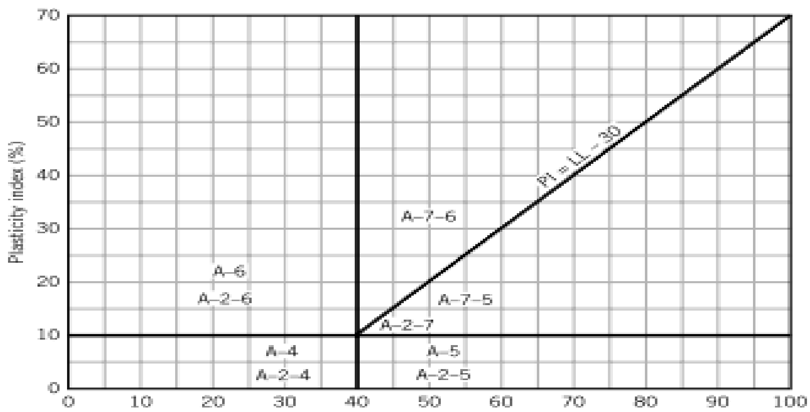

Figure 4. Plasticity chart for the AASHTO soil classification system (Source: Carter, 2016)

CHAPTER THREE

MATERIAL AND METHOD

3.1. Location of the Study Area

The city is located between 8045‟- 8047‟ North latitudes and 38056‟-390 East longitudes and has an altitude that ranges from 1746m to 1995m. It is situated at a distance of 47 km South East of Addis Ababa, and 52 Km from Adama. Formerly known by the name Debre Ziet Bishoftu city is found in east Shoa zonal administration.

3.1.1. Background of the Study Area

Bishoftu city is found in east Shoa zonal administration and it was found in1917 with the coming of Ethio –Djibouti railway. The factors to change the status of urbanization during this period were the development of new system of administration, development of communication and flourishing of commerce. In addition to these the most important reasons for the emergence of urbanization in larger parts of the country in general and in the region in particular was mainly attributed to three major historical events which are south ward expansion, introduction of Djibouti-Finfinnee rail way line and the Italian occupation/1936-1941/ of the country. The period was the completion of Ethio- Djibouti railway. The railway provided an easy and effective means of contact with the outside world. Along the railway a number of small towns were developed: Metahara, Adama, Modjo, Bishoftu, Dukem and Akaki were direct products of the railway line. Based on the above details Bishoftu city is found in east Shoa zonal administration and it was found in1917 with the coming of Ethio –Djibouti railway. The name Bishoftu comes from the Afan Oromo language called “Bishanoftu” which refers to “water bodies”. From the existing of volcanic crater lakes named as, Horaarsade, Babogaya, Bishoftu, Cheleleka /seasonal/, Kilole, Kuriftu and Green lake. On the topic of its growth from 1983-1994 E.C. it was the political centre of Adea District. Beginning from 1995 it renamed as first level city with Mayor, Municipality Administer, city Council's and city cabinet members. Gradually the city had developed from a station centre to a large and big city. The Municipality of the city was founded around 1943 E.C. The Municipality has expanded its horizon to reach out to the people and provide diversified socio-Economic services including the provision of infrastructure development, affordable housing and sanitation, public parks development, fire and emergency services. For administrative simplicity in real circumstances the city is divided in to 14 Kebeles but now using new administrative in to three sub city. The city also hosts large institutions such as the Great Ethiopian Air Force, different higher institutions, Agricultural research centers, galleries and the likes. Bishoftu is a rapidly growing urban city both in terms of population and economy. One can also see the dynamisms of the city in various aspects. The city has been experiencing a high population growth compared to other cities of the region. Various studies have indicated that rural-urban migration accounts to the high increase in population of the city.

Figure 5. Lake Bishoftu *Figure 6. Lake Hora*

3.2. Climatic Condition

3.2.1. Temperature and Precipitation

The climate of the city in general belongs to woina dega (Agro climatic zone). The maximum annual temperature is 29.8 0c and the Minimum is 4.90c. Annual average rainfall of the city is 797.2 mm. April is the hottest month of the year (29.30C), December is the coldest month (4.9 0C) and July is the rainy month (225.3 mm) of the year (Bishoftu city of Lakes,2019). The highest wind speed is registered in May (2.91m/s) and the most common wind direction seen in the city is easterlies (Bishoftu city of Lakes, 2019).

3.2.2. Elevation / Altitude/

The general elevation of the town ranges from 1746m to 1995m. The altitude is generally higher in the south western part of the town and gradually declines to east directions for few distances and then increases again in the same direction. Altitude declines gradually from north to south direction for few distances and then increases again from north to south direction. The greatest proportion of the altitude of the town ranges between 1893 to 1930 meters and almost covers western, northern, and south western parts of the town. The central part of the town where the lakes are found is surrounded by higher elevations ranging from 1856-1893m with few lower altitudes to access the lakes.

3.2.3. Drainage

Surface flow direction is determined by topographic features, nature of soil, vegetation cover and human impacts. Based on the topography of the city, Seasonal streams flow from northern direction to the central part of the town (some draining to the lakes) and then flow to southeast direction. On the other hand, Surface run off from south western parts of the town flows to southeast direction. At the same time, Surface runoff from northeast direction also flows to southwest until it is blocked by the upland areas Located around and near the Lakes. Thus, appropriate watershed management should be carried out to reduce risks of siltation and hence increase the volume of Lakes by timely supervising the watershed and diversion channels.

3.3. Land Cover

Since the first master plan of the city was made in 1961 and revised in 1978, 1992, 2001, and 2004 E.C. In 2001 E.C., the city had area of 14,500 ha. Now a day, the total area of the city incorporated under the master plan is enlarged to 18,278 hectors.

3.4. Sampling and Testing

To achieve the above mentioned objectives five sampling areas were selected. From the selected sampling areas subsurface exploration was performed by boring test pits up to 2.8 m depth using manually. Disturbed samples of soils were collected for laboratory testing. In this thesis work, review of the literatures has been done for understanding the accepted theories like index properties, compaction test, free swell test and shear strength test. In order to have more information about the study area, environmental condition like climate, drainage and altitude elevation of the study area are also being reviewed.

In this work, the type of study was mainly experimental. According to the objective of the research, more emphasis was given to the laboratory test which greatly helps to specific gravity test, atteberg limit test, compaction test grain size test, free swell test, moisture content test, and direct shear strength test of the soil. The laboratory tests are done according to ASTM standards. Disturbed soil samples are collected from different areas of Bishoftu. Based on the theories and laboratory tests performed, the results obtained have been analysed and discussed thoroughly. From the laboratory tests result, to concluded and findings output performed.

3.4.1. Selection of Sampling Sites

A Pit is dug manually in order to reveal the sub surface conditions to the desired depth Sampling was done.

The disturbed soil sample were collected from their respective sites at a depth of 1.5m and 2.8m below ground surface using tight plastic bag with a reference tag to describe the location

N.o	**Station**	Location	Color
1	TPL 1	Cheleleka	Black
2	TPL 2	Zequala	Black
3	TPL 3	Air force	Black
4	TPL 4	Genesis	Black
5	TPL 5	Sunshine	Black

Table 1. The test pits designation, location of test pits and colour of the soil sample.

CHAPTER FOUR
LABORATORY TEST RESULT AND DISCUSSION

4.1. General

The samples were collected; the next step is conducting the required laboratory tests. All the necessary laboratory tests were conducted at Defense Engineering Collage (DEC) soil laboratories. The following laboratory tests were conducted: In order to determine index properties soils tests, moisture content soil test, specific gravity soil test, Atterberg limits soil test grain size distribution Analysis soil test, Compaction soil test, direct shear soil test, and free swell were conducted at 5 test pits and the results of the laboratory tests results will be discussed in this chapter.

4.2. Index Properties

4.2.1. Results of Moisture Content

The weight of the moisture can and the weight of can with moist soil was measured. Then the sample put it in to drying oven at a temperature of 105+5°c for 24 hours. Then after, the natural moisture content was determined. The natural moisture content of the collected samples ranges from (37.72%-42.35%) and the results are summarized in the following table, detail laboratory moisture content results are given in APPENDIX A

No	Location	Depth	ω%
1	TP1	1.5	40.56
2	TP1	2.8	42.09
3	TP2	1.5	39.85
4	TP2	2.8	41.52
5	TP3	1.5	39.94
6	TP3	2.8	42.83
7	TP4	1.5	42.35
8	TP4	2.8	37.72
9	TP5	1.5	40.70
10	TP5	2.8	38.04

Table 2. Summary of Results of Moisture Content

4.2.2. Results of Specific Gravity

Specific Gravity:-of soil is the ratio of weight of a given volume of soil particles in air at a stated temperature to the weight of an equal volume of distilled water at a stated temperature. The specific gravity of a soil is often used in relating a weight of soil to its volume. Summarized Specific gravity test results of the soil at each test pit are shown in table, detail laboratory Specific gravity test results are given in APPENDIX B.

No	Location	Depth	GS
1	TP1	1.5	2.71
2	TP1	2.8	2.68
3	TP2	1.5	2.71
4	TP2	2.8	2.57
5	TP3	1.5	2.71
6	TP3	2.8	2.59
7	TP4	1.5	2.67
8	TP4	2.8	2.61
9	TP5	1.5	2.55
10	TP5	2.8	2.71

Table 3. Summary of Results of Specific Gravity

Figure 7. Specific gravity test in the laboratory (Source: photos taken during Specific gravity test)

4.2.3. Result of Atterberg Limit Tests

Depending on its water content, soil may appear in one of four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behaviour of soil are different, and consequently so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behaviour. The Atterberg limits can be used to distinguish between silt and clay and to distinguish between different types of silts and clays. The water content at which soil changes from one state to the other is known as consistency limits, or Atterberg's limit

The tests are carried out only on the fine fraction of a soil, which is normally material passing the 425 µm sieve, and about 200-gram soil sample are taken.

Liquid Limit: The liquid limit of a soil is the water content at the boundary between the liquid and plastic states. The water content at this boundary is arbitrarily defined as the water content at which, two halves of a soil pat placed in a brass cup, cut with standard groove, and dropped from a height of 1cm will undergo a groove closure of about 1.3 cm when the cup is dropped 25 times at the rate of 2 drops per second.

Plot the water content versus number of blows in semi logarithm paper. A straight line should be drawn through the data points. Obtain the liquid limit, LL, at 25 blows.

Plastic Limit: The plastic limit of a soil is the water content at the boundary between the plastic and semisolid state. The water content at this boundary is arbitrarily defined as the water content at which soil begins to crumble when rolled into threads of specified size (3.2mm).

Plasticity index: The plasticity index is the numerical difference between liquid and plastic limit. It represents the range in water content through a soil is in plastic state. A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample.

Finally, the results are summarized in the following table, detail laboratory Atterberg limit test results are given in APPENDIX D.

No	Location	Depth	LL, %	PL, %	PI,%	Plasticity characteristic
1	TP1	1.5	84.2	38.37	45.83	Very high
2	TP1	2.8	82	37.35	44.65	Very high
3	TP2	1.5	84.2	38.24	45.96	Very high
4	TP2	2.8	86.3	31.58	54.72	Very high
5	TP3	1.5	84	35.58	48.42	Very high
6	TP3	2.8	84.3	33.45	50.85	Very high
7	TP4	1.5	84.3	35.29	49.01	Very high
8	TP4	2.8	88.3	32.6	55.7	Very high
9	TP5	1.5	90.3	31.59	58.71	Very high
10	TP5	2.8	84.5	29.61	54.89	Very high

Table 4. Summary of Atterberg limit test results

Burmister (1947) classified plastic properties of soils according to their plasticity indices as follows:

Plasticity index	Plasticity
0	Non plastic
1 to 5	Slight
5 to 10	Low
10 to 20	Medium
20 to 40	High
> 40	Very high

Table 5. Plasticity characteristic (References: according to Burmister (1947)

Figure 8. Liquid Limit test (Source: photos taken during test)

4.2.4. Result of Liquidity Index

The liquidity index indicates the nearness of natural moisture content of the soil to the liquid limit while as consistency index shows the nearness of water content of the soil to its plastic limit.

When a soil is at its liquid limit, its liquidity index is 100% and it behaves as a liquid. When the soil is at the plastic limit, its liquidity index is zero. Negative values of liquidity index indicate water content smaller than the plastic limit. The soil is then in a hard state.

$LI = ((\omega - PL))/PI$ where ω is the water content

The value of Liquidity Index (LI) varies according to the consistency of soils as follows:

Liquidity Index(LI)	Description of Strength
LI<0	Semisolid state- High strength but brittle i.e. Sudden failure is expected
0<LI<1	Plastic state- Intermediate strength
LI>1	Liquid state- Low strength

Table 6. Liquidity Index Vs Soil Consistency

The results of Liquidity Index for the soil samples are tabulated in the following table.

No	Location	Depth	ω%	Plastic Limit	Plasticity Index	Liquidity index	Description
1	TP1	1.5	40.56	38.37	45.83	0.048	Plastic state
2	TP1	2.8	42.09	37.35	44.65	0.106	Plastic state
3	TP2	1.5	39.85	38.24	45.96	0.035	Plastic state
4	TP2	2.8	41.52	31.58	54.72	0.182	Plastic state
5	TP3	1.5	39.94	35.58	48.42	0.090	Plastic state
6	TP3	2.8	42.83	33.45	50.85	0.184	Plastic state
7	TP4	1.5	42.35	35.29	49.01	0.144	Plastic state
8	TP4	2.8	37.72	32.6	55.7	0.092	Plastic state
9	TP5	1.5	40.70	31.59	58.71	0.155	Plastic state
10	TP5	2.8	38.04	29.61	54.89	0.154	Plastic state

Table 7. Liquidity Index result

4.2.5. Results Grain Size Distribution Analysis

Grain size Analysis test is used to determine the percentage of different grain sizes contained within a soil. The distribution of particle sizes larger than 75μm (retained on the No.200 sieve) is determined by sieving while the distribution of particle size smaller than 75 μ m (usually silt and clay) is determined by the sedimentation process using hydrometer analysis. For different soil types at different depth, analysis can be carried out to determine the ranges of sizes in which the soil samples fall and their relative proportions. After complete grain size analysis, the relative proportion of different size groups in each soil sample can be determined. The ranges of size especially the proportion of clay fraction is very important in case of expansive soils and the results are summarized in the following table and graph, detail laboratory moisture content results are given in APPENDIX- C

No	Location	Depth	Gravel, %	Sand, %	Silt,%	Clay,%
1	TP1	1.5	1.52	5.08	54.19	39.21
2	TP1	2.8	1.18	5.2	54.32	39.3
3	TP2	1.5	1.26	5.52	49.26	43.96
4	TP2	2.8	1.46	5.48	57.68	35.38
5	TP3	1.5	1.18	5.86	46.58	46.38
6	TP3	2.8	1.34	5.86	59.36	33.44
7	TP4	1.5	0.94	6.24	63.05	29.77
8	TP4	2.8	0.78	6.46	48.31	44.45
9	TP5	1.5	0.58	6.72	61.13	31.57
10	TP5	2.8	1.16	6.9	58.81	33.13

Table 8. Summary of Grain size distribution of the study area

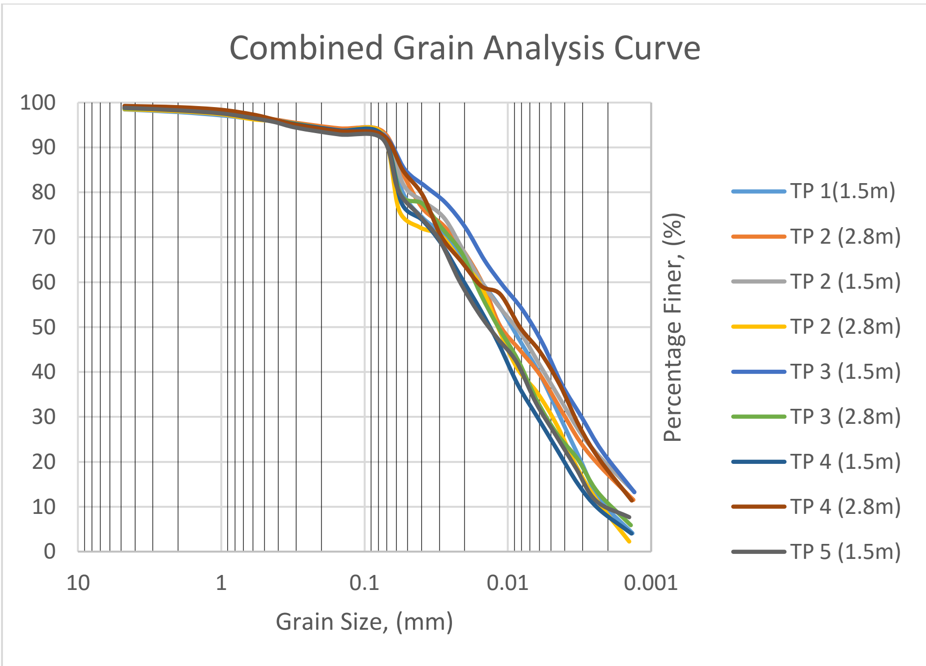

Figure 9. Summary of combined Grain size distribution curve

4.2.6. Results of Free Swell test

One of the easiest ways to know whether a given soil type has potential for swell or not is to measure its free swell. To study the swelling property of the soils, the simplest test conducted is free swell test. This test is performed by slowly pouring 10 ml of oven dry soil which has passed the No. 40(0.425mm) sieve in to 100 ml graduated cylinder filled with distilled water. After 24 hours, final volume of the suspension being read and the results are summarized in the following table, detail laboratory free swell test results are given in APPENDIX-E.

No	Location	Depth	Free Swell, %
1	TP1	1.5	209.50
2	TP1	2.8	195.50
3	TP2	1.5	189.50
4	TP2	2.8	173.50
5	TP3	1.5	211.00
6	TP3	2.8	163.75
7	TP4	1.5	153.75
8	TP4	2.8	153.75
9	TP5	1.5	127.08
10	TP5	2.8	108.75

Table 9. Summary of Results of Free Swell test

Figure 10. Free swell test laboratory (Source: photos taken during test)

4.3. Results of Compaction test

When used Compaction places soils in to construction work in decreases settlement; increases shear strength and decreases permeability. Mechanical compaction is one of the most common and cost effective means of stabilizing soils. During compaction air is expelled from the void spaces. Thus compaction results in an increase in the density of the soil. The optimum water content is the water content that results in the greatest density for a specified compactive effort. In this thesis the Standard Proctor Test is used.

The results are summarized in the following table, and the corresponding compaction curves are included in Appendix-F.

No	Location	Depth	MDD, gm/cm3	OMC,%
1	TP1	1.5	1.23	37.86
2	TP1	2.8	1.29	34.56
3	TP2	1.5	1.37	29.76
4	TP2	2.8	1.47	19.55
5	TP3	1.5	1.41	27.87
6	TP3	2.8	1.46	21.16
7	TP4	1.5	1.37	24.67
8	TP4	2.8	1.34	25.41
9	TP5	1.5	1.39	22.59
10	TP5	2.8	1.23	38.04

Table 10. Summary of Results of Compaction test

Figure 11. Compaction test laboratory (Source: photos taken during test)

4.4. Results of Shear Strength Test

The purpose of shear strength testing is to establish representative values for the shear strength parameters from laboratory and field testes. The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test. For this research work only direct shear test was conducted. The direct shear test is one of the common strength tests for soils. In the laboratory, direct shear device will be used to determine the shear strength of soil angle of internal friction (Φ) and cohesion (C)). The results are summarized in the following table, and the direct shear strength curves are included in Appendix-G.

No	Location	Depth	MDD, gm/cm3	OMC,%	C, kPa	$\Phi,^0$
1	TP1	2.8	1.29	34.56	27.44	15.99
2	TP2	2.8	1.47	19.55	20.39	14.4
3	TP3	2.8	1.46	21.16	24.34	10
4	TP4	2.8	1.34	25.41	22.51	11.44
5	TP5	2.8	1.23	38.04	18.68	12.1

Table 11. Summary of Results of Shear Strength Test

Figure 12. Direct Shear Strength Test laboratory (Source: photos taken during test)

4.5. Soil Classification of the Study Area

There are different soil classification methods. The most widely used soil classification systems are the unified soil classification system (USCS), The American Association for Testing and Materials (ASTM), The British Standard Classification system (BS) and American Association of State Highway and Transportation Officials (AASHTO) system.

4.5.1. Results of USCS Classification

The Unified system classifies fine-grained soils (silts and clays) and organic soils, according to their plasticity. As per the USCS classification system the soil in the study area is categorized under MH region, and because the liquid limit of the samples was greater than 50 the soil is classified as Silty and clayey of higher plasticity of soil. The plasticity chart of the study area according to USCS is given below

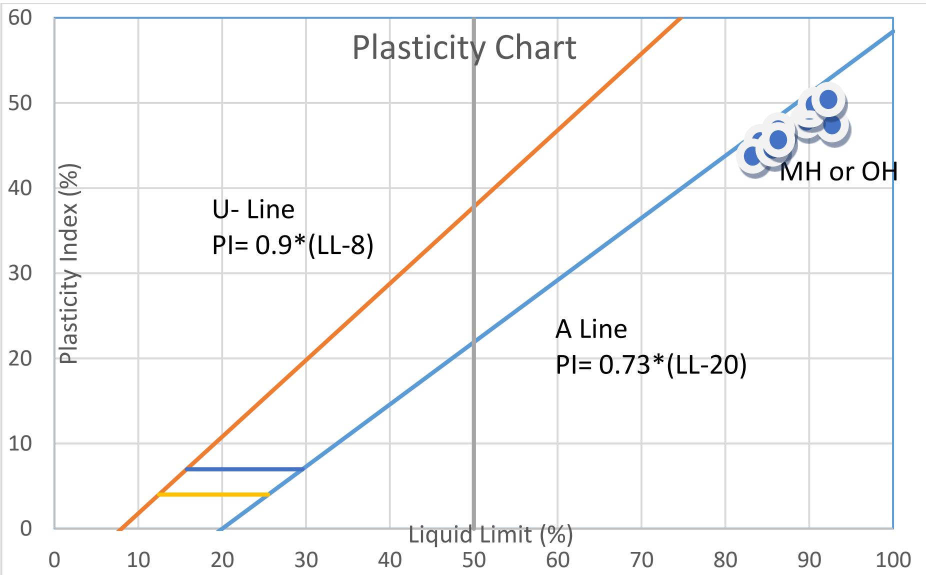

Figure 13. Results of USCS soil classification

S/No	Location	Depth(m)	Liquid Limit(LL)	Plasticity Index(PI)	%passing Sieve #200	USCS
1	TP1	1.5	84.2	45.83	93.4	MH
2	TP1	2.8	82	44.65	93.62	MH
3	TP2	1.5	84.2	45.96	93.22	MH
4	TP2	2.8	86.3	54.72	93.06	MH
5	TP3	1.5	84	48.42	92.96	MH
6	TP3	2.8	84.3	50.85	92.8	MH
7	TP4	1.5	84.3	49.01	92.82	MH
8	TP4	2.8	88.3	55.7	92.76	MH
9	TP5	1.5	90.3	58.71	92.7	MH
10	TP5	2.8	84.5	54.89	91.94	MH

Table 12. Results of USCS soil classification

4.5.2. Results of AASHTO Classification

On this classification system the soil of the study area falls in the region of A-2-7 and A-7-5 but more than 35% passing No. 200 sieve it classified under groups A-7-5. The plasticity chart as per AASHTO classification system is given below.

S/ No	Location	Depth(m)	Liquid Limit(LL)	Plasticity Index(PI)	%passing Sieve #200	AASHTO
1	TP1	1.5	84.2	45.83	93.4	A-7-5
2	TP1	2.8	82	44.65	93.62	A-7-5
3	TP2	1.5	84.2	45.96	93.22	A-7-5
4	TP2	2.8	86.3	54.72	93.06	A-7-5
5	TP3	1.5	84	48.42	92.96	A-7-5
6	TP3	2.8	84.3	50.85	92.8	A-7-5
7	TP4	1.5	84.3	49.01	92.82	A-7-5
8	TP4	2.8	88.3	55.7	92.76	A-7-5
9	TP5	1.5	90.3	58.71	92.7	A-7-5
10	TP5	2.8	84.5	54.89	91.94	A-7-5

Table 13. Results of AASHTO soil classification

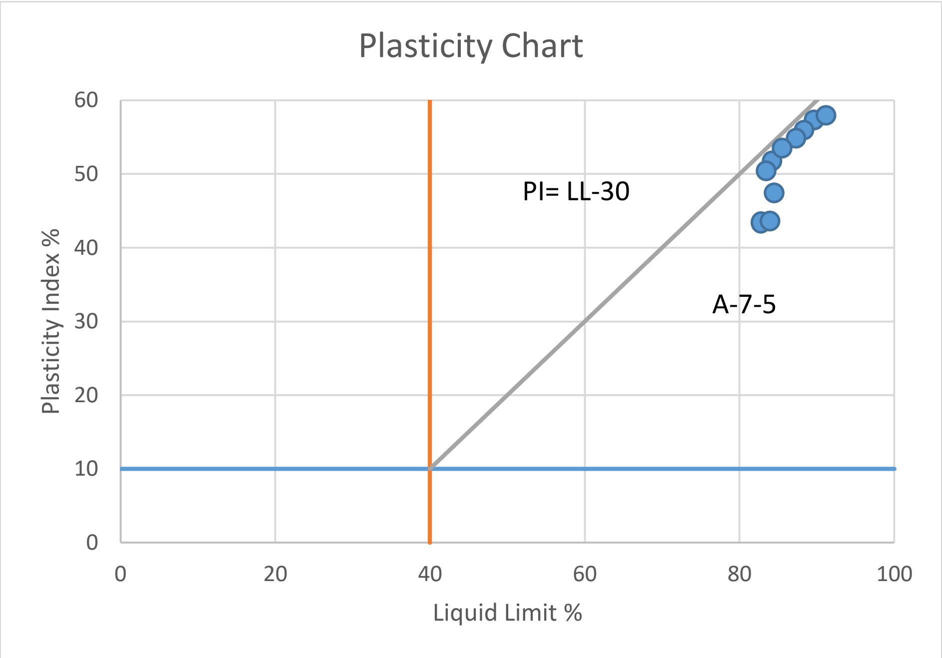

Figure 14. Results of AASHTO soil classification

4.6. Discussion of the laboratory test results

The results of grain size analysis conducted on disturbed soil samples were indicated that the predominant proportion of soil particles in the study area is silt and clay, which have clay content range from 29.77%. to 46.38%, silt content range from 54.19%. to 63.05%, sand content range from 5.08%. to 6.72% and gravel content ranging from 0.58%. to 1.52%. This analysis shows the dominant soil types in the area are Silt and Clay type soils.

The results of specific gravity test indicate that the specific gravity of soils of the study area ranges from 2.55%.to2.71%, which is in the range of typical specific gravity values of inorganic soils are dominant, as most of organic soils contain a value of less than 2.40. This range of specific gravity is similar to most of silty and clayey soils as determined in different literatures.

Test results of Atterberg's limits indicate that soils of the study are have Liquid limit ranging from 82% to 90.3%, plastic limit ranges from 29.61% to 38.38% and plastic index from 44.65%. to 58.71%.

The values of liquidity index ranges from 0.035 to 0.184. This shows that the liquidity index indicated that plastic limit, since liquidity index nearest to zero or between 0 and 1.

The free swell of soils of the study area ranges from 127% to 209.5-55%. This shows that the degree of expansiveness of the soils is very expansive. This showed the infrastructure of structure could be cracks & differential settlements which can lead to total collapse of the structure.

The Compaction test result showed that maximum dry density (MDD) of the study area ranges from 1.23 g/cm3 to 1.47 g/cm3 and the optimum moisture content (OMC) ranges from 19.55% to 38.04%.

Shear strength parameters from the graph of shear stress versus displacement and maximum shear stress versus and applied vertical load respectively gives cohesion(C) and angle of internal friction (Φ), From this results the cohesion of Bishoftu ranges from 18 KPa to 27.44KPa and the angle of internal friction ranges from 10^0 to 15.99^0.

As per the USCS classification system the soil in the study area is categorized under MH region, and because the liquid limit of the samples was greater than 50 the soil is classified as Silty and clayey of higher plasticity of soil.
On the other AASHTO classification system, the soil of the study area falls in the region of A-2-7 and A-7-5 but more than 35% passing No. 200 sieve it classified under groups A-7-5.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Bishoftu is one of the rapidly developing cities in Ethiopia and has a variety of soil types. From the laboratory test performed, it can be observed that the soils in Bishoftu town are expansive. No significant variations of engineering properties within the investigated depths as well as in different pits which were found in the research work. From the results of the investigation we can conclude that:

- Since pit excavation method of exploration is used, the outcomes would be applicable only for light structures which under lie their foundation up to depth of 2.8m.
- The specific gravity of the soil is 2.55%.to2.71%, in between 2.62 and 2.81 which is common for most of soil types and The moisture content of the soil found in Bishoftu town range from 37.72% to 42.09%.
- Grain size analysis result shows the soil under investigation is dominantly silt and clay types through which about 32% is silt soil and 59% clay soils.
- Results of Atterberg limits tests show that soils of Bishoftu town have liquid limit ranging from 82% to 90.3%, plastic limit 29.61% to 38.38% and PI ranging from 44.65%. to 58.71%. This indicates that soils of the study area are highly plastic.
- The grain size distribution indicates all soil samples have clay 29.77%. to 46.38%, silt content range from 54.19%. to 63.05% Therefore silt and clay type of soil is dominantly located in the study area and the Compaction test result showed that maximum dry density (MDD) of the study area ranges from 1.23 g/cm3 to 1.47 g/cm3 and the optimum moisture content (OMC) ranges 19.55% to 38.04%.
- The free swell test result shows between from 127% to 209.5 this indicates that soils of the study area are very high expansive which means the soils is swelling property. Since Expansive soils are those which experience significant volume changes associated with changes in water content. These

volume changes can either be in the form of swell or shrinkage, and are sometimes known as swell–shrink soils this resulted cracks & differential settlements which can lead to total collapse of the structure.

- ❖ Shear strength parameters from the graph of shear stress versus displacement and maximum shear stress versus and applied vertical load respectively gives cohesion(C) and angle of internal friction (Φ), From this results the cohesion of Bishoftu ranges from 18KPa to 27.44KPa and the angle of internal friction ranges from 10^0 to 15.99^0.
- ❖ As per the USCS classification system the soil in the study area is categorized under MH region and AASHTO classification system, the soil of the study area falls in the region of A-7-5.

5.2. Recommendation

- ❖ By new administration plan Dukem town is a part of Bishoftu town, therefore further soil investigation is required for the future as part of Dukem town.
- ❖ The numbers of test pits taken are not enough to generalize the engineering properties of soils found in Bishoftu town. Therefore, by increasing the number of sampling area in-depth investigation should be done in future in order to fully characterize the soil properties of the area.
- ❖ The pit excavation method of exploration is used; the outcomes would be applicable only for light structures which under lie their foundation up to depth of 2.8m. Therefore, by increasing the depth of the pit excavation additional investigation should be done in the future.
- ❖ From laboratory test the soil was expansive. Therefore, it is essential to check for the presence of expansive soil and a suitable treatment method should be adopted before commencing any construction projects.

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Appendix – A
(Moisture Content test result)

Location	Depth	Wt.of wet sample + Container	Wt.of dry sample + Container	Can Weig ht (w1) gm	Weight of Water (Moistur e)	Wt .of dry Sample	Moist ure Conte nt (%)	average
TP1	1.5	113.1	98.3	60.4	14.8	37.9	39.05013	
TP1	1.5	112.3	96.7	60.7	15.6	36	43.33333	
TP1	1.5	116.4	100.6	60.4	15.8	40.2	39.30348	40.56232
TP1	2.8	112	96	60.1	16	35.9	44.56825	
TP1	2.8	117.3	100.7	60.3	16.6	40.4	41.08911	
TP1	2.8	114.3	98.7	60.3	15.6	38.4	40.625	42.09412
TP2	1.5	113	97.8	60.2	15.2	37.6	40.42553	
TP2	1.5	112.3	97.6	60.8	14.7	36.8	39.94565	
TP2	1.5	107	93.8	60.1	13.2	33.7	39.16914	39.84677
TP2	2.8	107	93	60.8	14	32.2	43.47826	
TP2	2.8	114.5	98.6	60.2	15.9	38.4	41.40625	
TP2	2.8	104	91.7	60.7	12.3	31	39.67742	41.52064
TP3	1.5	105.9	92.9	60.9	13	32	40.625	
TP3	1.5	106.2	93.8	60.8	12.4	33	37.57576	
TP3	1.5	106	92.6	60.4	13.4	32.2	41.61491	39.93855
TP3	2.8	109.2	94.9	60.3	14.3	34.6	41.32948	
TP3	2.8	111	95.9	60.7	15.1	35.2	42.89773	
TP3	2.8	114.3	97.7	60.2	16.6	37.5	44.26667	42.83129
TP4	1.5	110.2	94.5	60.1	15.7	34.4	45.63953	
TP4	1.5	113	98.1	60.2	14.9	37.9	39.31398	
TP4	1.5	111.6	96.4	60.3	15.2	36.1	42.10526	42.35293
TP4	2.8	109.9	95.1	60.9	14.8	34.2	43.27485	
TP4	2.8	113.4	100.4	60.8	13	39.6	32.82828	
TP4	2.8	104.2	92.3	60.2	11.9	32.1	37.07165	37.72493

TP5	1.5	102.5	90.3	60.1	12.2	30.2	40.39735	
TP5	1.5	106.1	92.7	60.7	13.4	32	41.875	
TP5	1.5	108.2	94.7	60.8	13.5	33.9	39.82301	40.69845
TP5	2.8	116	100.9	60.2	15.1	40.7	37.10074	
TP5	2.8	112.1	98	60.2	14.1	37.8	37.30159	
TP5	2.8	108.3	94.6	60.1	13.7	34.5	39.71014	38.03749

Appendix – B
(Specific gravity test result)

Specific Gravity Determination test				
Test Pit 1	Depth 1.5m			Total
Pycnometer bottle number	PA1	PA2	PA3	
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, wp+s (g)	67.5	69	68.5	
Weight of pycnometer + soil + water, wp+s+w	146.2	146.9	147.2	
Weight of pycnometer + water,wp+w	130.6	130.2	130.9	
Weight of dry soil,ws	25	26.5	26	
Specific gravity of soil at 20°c.	2.659574	2.704082	2.680412	8.044068
Average specific gravity of soil.	2.681356			

Specific Gravity Determination test				
Test Pit 1	Depth 2.8m			
Pycnometer bottle number	P11	P12	P13	
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, wp+s (g)	66.8	65.4	66.3	
Weight of pycnometer + soil + water, wp+s+w	151	148.6	150.3	
Weight of pycnometer + water,wp+w	135.6	134.3	135.2	
Weight of dry soil,ws	24.3	22.9	23.8	
Specific gravity of soil at 20°c.	2.730337	2.662791	2.735632	8.12876
Average specific gravity of soil.	8.9	8.6	8.7	2.709587

Specific Gravity Determination test				
Test Pit 2	Depth 1.5m			
Pycnometer bottle number	PB1	PB2	PB3	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, wp+s (g)	68.4	67.3	67.6	
Weight of pycnometer + soil + water, wp+s+w	147.9	148.6	148.3	
Weight of pycnometer + water,wp+w	132.4	132.8	133.7	
Weight of dry soil,ws	25.9	24.8	25.1	
Specific gravity of soil at 20°c.	2.490385	2.755556	2.390476	7.636416
Average specific gravity of soil.	2.545472			

Specific Gravity Determination test				
Test Pit 2	Depth 2.8m			
Pycnometer bottle number	P21	P22	P23	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	64.8	63.9	63.2	
Weight of pycnometer + soil + water, wp+s+w	147.8	146.3	145.7	
Weight of pycnometer + water,wp+w	133.7	132.8	132.7	
Weight of dry soil,ws	22.3	21.4	20.7	
Specific gravity of soil at 20°c.	2.719512	2.708861	2.688312	8.116685
Average specific gravity of soil.	2.705562			

Specific Gravity Determination test				
Test Pit 3	Depth 1.5m			
Pycnometer bottle number	PC1	PC2	PC3	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	67.1	67.7	67.5	
Weight of pycnometer + soil + water, wp+s+w	146.8	148.4	148.3	
Weight of pycnometer + water,wp+w	131.5	132.7	133.4	
Weight of dry soil,ws	24.6	25.2	25	
Specific gravity of soil at 20°c.	2.645161	2.652632	2.475248	7.77304
Average specific gravity of soil.	2.591013			

Specific Gravity Determination test				
Test Pit 3	Depth 2.8m			
Pycnometer bottle number	P31	P32	P33	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	68.7	67.8	67.9	
Weight of pycnometer + soil + water, wp+s+w	151	150.6	150.3	
Weight of pycnometer + water,wp+w	134.5	134.7	134.2	
Weight of dry soil,ws	26.2	25.3	25.4	
Specific gravity of soil at 20°c.	2.701031	2.691489	2.731183	8.123703
Average specific gravity of soil.	2.707901			

Specific Gravity Determination test				
Test Pit 4	Depth 1.5m			
Pycnometer bottle number	PD1	PD2	PD3	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	69.8	69.8	70.2	
Weight of pycnometer + soil + water, wp+s+w	148.5	148.9	148.7	
Weight of pycnometer + water,wp+w	131.4	132.5	131.9	
Weight of dry soil,ws	27.3	27.3	27.7	
Specific gravity of soil at 20°c.	2.676471	2.504587	2.541284	7.722342
Average specific gravity of soil.	2.574114			

Specific Gravity Determination test				
Test Pit 4	Depth 2.8m			
Pycnometer bottle number	P41	P42	P43	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	68.3	67.2	67.4	
Weight of pycnometer + soil + water, wp+s+w	153.4	152.3	151.9	
Weight of pycnometer + water,wp+w	137.3	136.7	136.4	
Weight of dry soil,ws	25.8	24.7	24.9	
Specific gravity of soil at 20°c.	2.659794	2.714286	2.648936	8.023016
Average specific gravity of soil.	2.674339			

Specific Gravity Determination test				
Test Pit 5	Depth 1.5m			
Pycnometer bottle number	P51	P52	P53	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, $wp{+}s$ (g)	66.3	65.4	66.4	
Weight of pycnometer + soil + water, wp+s+w	148.5	146.5	146.7	
Weight of pycnometer + water,wp+w	133.7	132.5	132	
Weight of dry soil,ws	23.8	22.9	23.9	
Specific gravity of soil at 20°c.	2.644444	2.573034	2.597826	7.815304
Average specific gravity of soil.	2.605101			

Specific Gravity Determination test				
Test Pit 5	Depth 2.8m			
Pycnometer bottle number	PE1	PE2	PE3	Total
Mass of Pycnometer, wp (g)	42.5	42.5	42.5	
Mass of Pycnometer and dry specimen, wp+s (g)	67.7	67.2	68.8	
Weight of pycnometer + soil + water, wp+s+w	149.3	150.3	149.5	
Weight of pycnometer + water,wp+w	133.4	134.8	132.8	
Weight of dry soil,ws	25.2	24.7	26.3	
Specific gravity of soil at 20°c.	2.709677	2.684783	2.739583	8.134043
Average specific gravity of soil.	2.711348			

Appendix – C
(Sieve Grain Size and Hydrometer Analysis test result)

Weight of Soil	50gm	Test pit 1 @1.5m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	7.6	1.52	1.52	98.48
2	2	2.9	0.58	2.1	97.9
3	1	3.7	0.74	2.84	97.16
4	0.6	4	0.8	3.64	96.36
5	0.425	2.6	0.52	4.16	95.84
6	0.3	3.7	0.74	4.9	95.1
7	0.15	5.3	1.06	5.96	94.04
8	0.075	3.2	0.64	6.6	93.4
9	pan	467	93.4	100	0

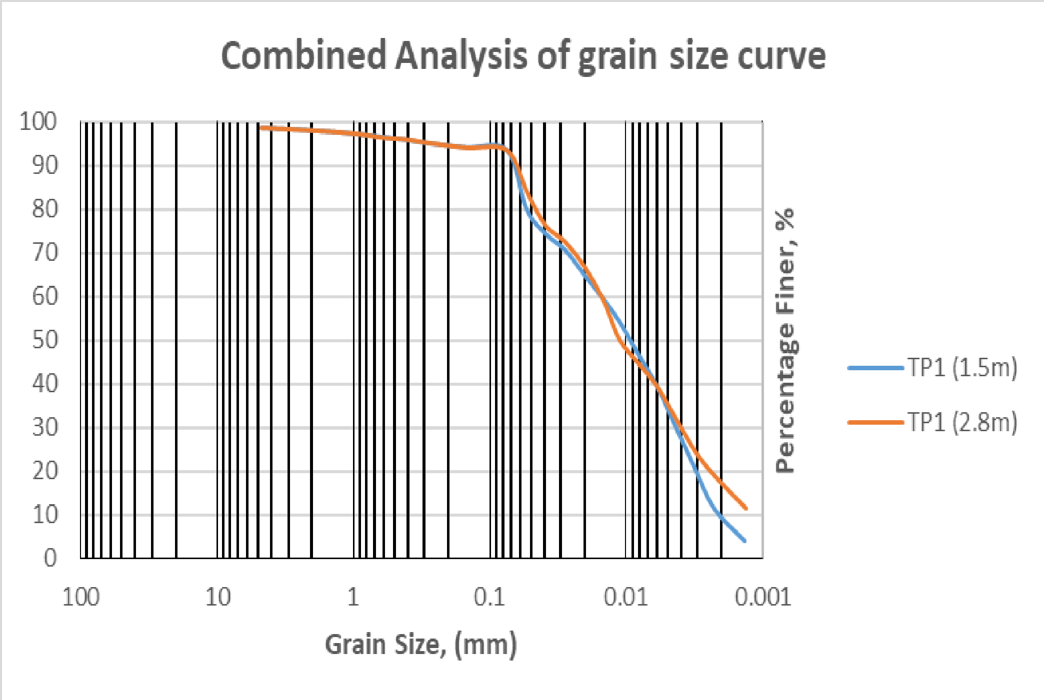
Gravel, %	1.52
Sand%	5.08
sc	93.4

Specific Gravity (Gs)	2.7	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
						T^0 Correction		0.2
Weight of soil sample	50 gm	Zero Correction	5	Test pit 1 @1.5m		% finer # 200 Sieve		93.4
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	48	43.2	49	8.3	0.01328	0.05399	85.54	79.89
1	45	40.2	46	8.8	0.01328	0.03930	79.60	74.34
2	43	38.2	44	9.1	0.01328	0.02830	75.64	70.64
4	40	35.2	41	9.6	0.01328	0.02055	69.70	65.10
8	37	32.2	38	10.1	0.01328	0.01490	63.76	59.55
15	34	29.2	35	10.6	0.01328	0.01114	57.82	54.00
30	30	25.2	31	11.2	0.01328	0.00812	49.90	46.60
60	26	21.2	27	11.9	0.01328	0.00591	41.98	39.21
120	21	16.2	22	12.7	0.01328	0.00432	32.08	29.96
240	16	11.2	17	13.5	0.01328	0.00315	22.18	20.71
480	11	6.2	14	14.0	0.01328	0.00227	12.28	11.47
1440	7	2.2	8	15.0	0.01328	0.00135	4.36	4.07

Weight of Soil	50gm	Test pit 1 @2.8m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	5.9	1.18	1.18	98.82
2	2	3.1	0.62	1.8	98.2
3	1	3.4	0.68	2.48	97.52
4	0.6	4.8	0.96	3.44	96.56
5	0.425	1.7	0.34	3.78	96.22
6	0.3	3.7	0.74	4.52	95.48
7	0.15	6.1	1.22	5.74	94.26
8	0.075	3.2	0.64	6.38	93.62
9	pan	468.1	93.62	100	0

Gravel, %	1.18
Sand%	5.2
sc	93.62

Specific Gravity (Gs)	2.68	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 1 @2.8m		T^0 Correction		0.2
						% finer # 200 Sieve		93.62
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	50	45.2	51	7.9	0.01338	0.05331	89.50	83.79
1	46	41.2	47	8.6	0.01338	0.03922	81.58	76.37
2	44	39.2	45	8.9	0.01338	0.02826	77.62	72.66
4	41	36.2	42	9.4	0.01338	0.02052	71.68	67.10
8	37	32.2	38	10.1	0.01338	0.01501	63.76	59.69
15	32	27.2	33	10.9	0.01338	0.01140	53.86	50.42
30	29	24.2	30	11.4	0.01338	0.00824	47.92	44.86
60	26	21.2	27	11.9	0.01338	0.00595	41.98	39.30
120	22	17.2	23	12.5	0.01338	0.00432	34.06	31.88
240	18	13.2	19	13.2	0.01338	0.00314	26.14	24.47
480	15	10.2	16	13.7	0.01338	0.00226	20.20	18.91
1440	11	6.2	12	14.3	0.01338	0.00133	12.28	11.49



Weight of Soil	50gm	Test pit 2 @1.5m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	6.3	1.26	1.26	98.74
2	2	2.8	0.56	1.82	98.18
3	1	3.7	0.74	2.56	97.44
4	0.6	5.1	1.02	3.58	96.42
5	0.425	1.4	0.28	3.86	96.14
6	0.3	4.5	0.9	4.76	95.24
7	0.15	7.2	1.44	6.2	93.8
8	0.075	2.9	0.58	6.78	93.22
9	pan	466.1	93.22	100	0

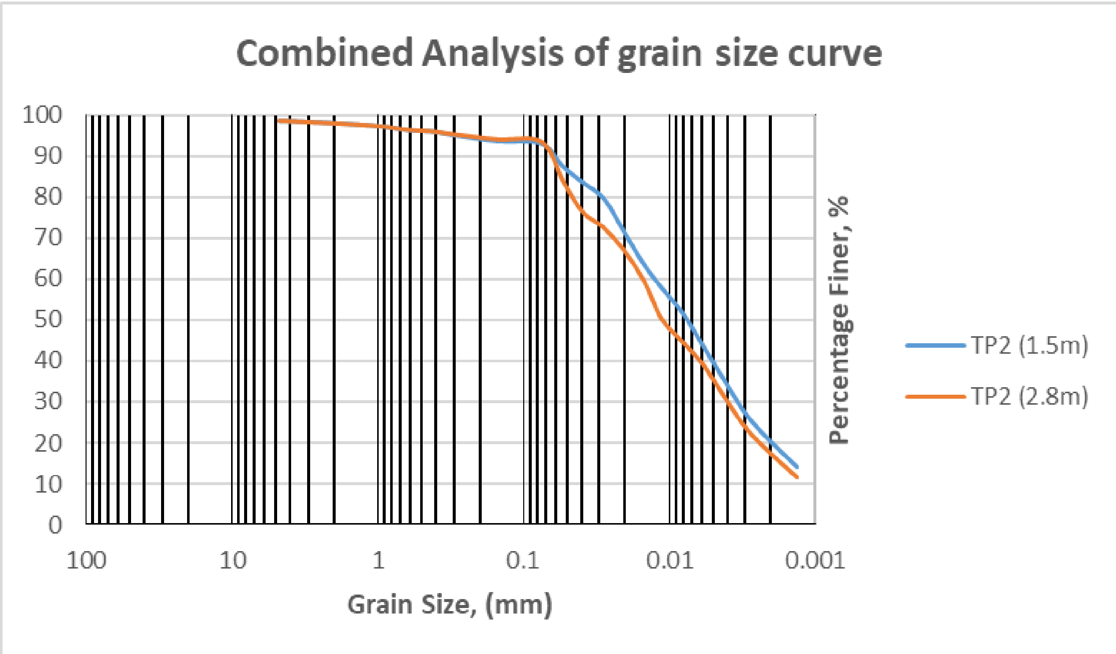
Gravel, %	1.26
Sand%	5.52
sc	93.22

Specific Gravity (Gs)	2.71	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 2 @1.5m		T^0 Correction		0.2
						% finer # 200 Sieve		93.22
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	49	44.2	50	8.1	0.01324	0.05329	87.52	81.58
1	47	42.2	48	8.4	0.01324	0.03844	83.56	77.89
2	45	40.2	46	8.8	0.01324	0.02770	79.60	74.20
4	41	36.2	42	9.4	0.01324	0.02031	71.68	66.82
8	37	32.2	38	10.1	0.01324	0.01485	63.76	59.43
15	34	29.2	35	10.6	0.01324	0.01111	57.82	53.90
30	31	26.2	32	11.1	0.01324	0.00804	51.88	48.36
60	27	22.2	28	11.7	0.01324	0.00585	43.96	40.98
120	23	18.2	24	12.4	0.01324	0.00425	36.04	33.59
240	19	14.2	20	13.0	0.01324	0.00308	28.12	26.21
480	16	11.2	17	13.5	0.01324	0.00222	22.18	20.67
1440	12	7.2	13	14.2	0.01324	0.00131	14.26	13.29

Weight of Soil	50gm	Test pit 2 @2.8m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	7.3	1.46	1.46	98.54
2	2	2.3	0.46	1.92	98.08
3	1	3.4	0.68	2.6	97.4
4	0.6	5.7	1.14	3.74	96.26
5	0.425	1.9	0.38	4.12	95.88
6	0.3	3.8	0.76	4.88	95.12
7	0.15	6.9	1.38	6.26	93.74
8	0.075	3.4	0.68	6.94	93.06
9	pan	465.3	93.06	100	0

Gravel, %	1.46
Sand%	5.48
sc	93.06

Specific Gravity (Gs)	2.57	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 2 @2.8m		T^0 Correction		0.2
						% finer # 200 Sieve		93.06
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	46	41.2	47	8.6	0.01382	0.05729	81.58	75.91
1	44	39.2	45	8.9	0.01382	0.04128	77.62	72.23
2	43	38.2	44	9.1	0.01382	0.02945	75.64	70.39
4	40	35.2	41	9.6	0.01382	0.02138	69.70	64.86
8	37	32.2	38	10.1	0.01382	0.01550	63.76	59.33
15	32	27.2	33	10.9	0.01382	0.01177	53.86	50.12
30	27	22.2	28	11.7	0.01382	0.00863	43.96	40.91
60	24	19.2	25	12.2	0.01382	0.00623	38.02	35.38
120	20	15.2	21	12.9	0.01382	0.00452	30.10	28.01
240	15	10.2	16	13.7	0.01382	0.00330	20.20	18.79
480	11	6.2	12	14.3	0.01382	0.00239	12.28	11.42
1440	6	1.2	7	15.2	0.01382	0.00142	2.38	2.21



Weight of Soil	50gm	Test pit 3 @1.5m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	5.9	1.18	1.18	98.82
2	2	1.9	0.38	1.56	98.44
3	1	3.9	0.78	2.34	97.66
4	0.6	5.4	1.08	3.42	96.58
5	0.425	2.9	0.58	4	96
6	0.3	3.8	0.76	4.76	95.24
7	0.15	7.5	1.5	6.26	93.74
8	0.075	3.9	0.78	7.04	92.96
9	pan	464.8	92.96	100	0

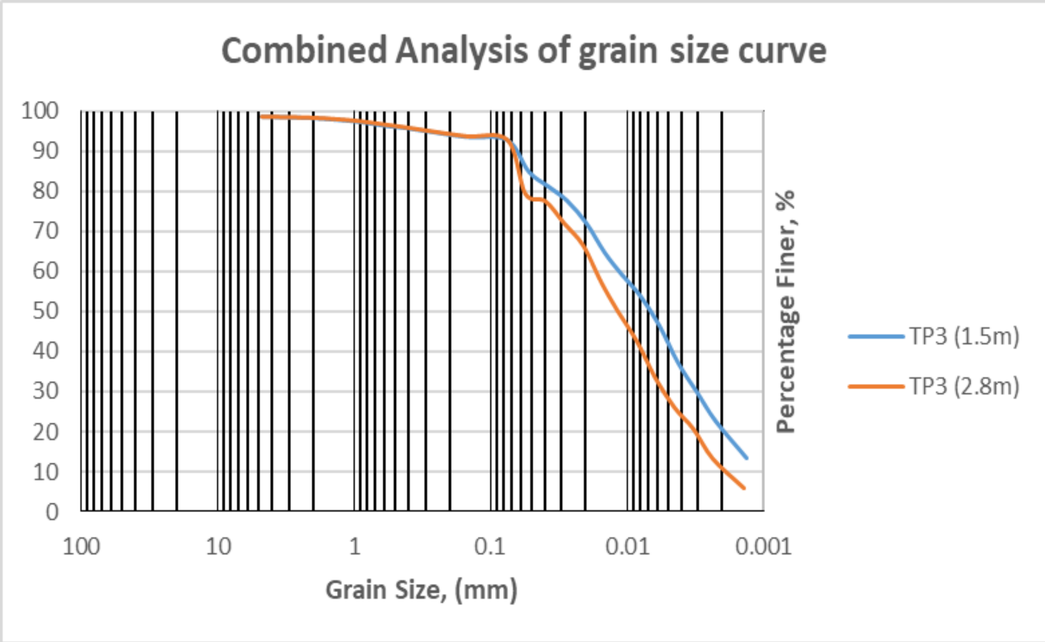
Gravel, %	1.18
Sand%	5.86
sc	92.96

Specific Gravity (Gs)	2.71	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 3 @1.5m		T^0 Correction		0.2
						% finer # 200 Sieve		92.96
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	51	46.2	52	7.8	0.01324	0.05220	91.48	85.04
1	49	44.2	50	8.1	0.01324	0.03768	87.52	81.35
2	47	42.2	48	8.4	0.01324	0.02718	83.56	77.67
4	44	39.2	45	8.9	0.01324	0.01977	77.62	72.15
8	40	35.2	41	9.6	0.01324	0.01449	69.70	64.79
15	37	32.2	38	10.1	0.01324	0.01085	63.76	59.27
30	34	29.2	35	10.6	0.01324	0.00786	57.82	53.75
60	30	25.2	31	11.2	0.01324	0.00572	49.90	46.38
120	25	20.2	26	12.0	0.01324	0.00419	40.00	37.18
240	21	16.2	22	12.7	0.01324	0.00304	32.08	29.82
480	17	12.2	18	13.3	0.01324	0.00221	24.16	22.46
1440	12	7.2	13	14.2	0.01324	0.00131	14.26	13.25

Weight of Soil	50gm	Test pit 3 @2.8m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	6.7	1.34	1.34	98.66
2	2	1.4	0.28	1.62	98.38
3	1	3.5	0.7	2.32	97.68
4	0.6	4.9	0.98	3.3	96.7
5	0.425	3.4	0.68	3.98	96.02
6	0.3	3.9	0.78	4.76	95.24
7	0.15	7.4	1.48	6.24	93.76
8	0.075	4.8	0.96	7.2	92.8
9	pan	464	92.8	100	0

Gravel, %	1.34
Sand%	5.86
sc	92.8

Specific Gravity (Gs)	2.59	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 3 @2.8m		T^0 Correction		0.2
						% finer # 200 Sieve		92.8
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	48	43.2	49	8.264	0.01365	0.05549	85.54	79.38
1	47	42.2	48	8.428	0.01365	0.03963	83.56	77.54
2	44	39.2	45	8.92	0.01365	0.02883	77.62	72.03
4	41	36.2	42	9.412	0.01365	0.02094	71.68	66.52
8	36	31.2	37	10.232	0.01365	0.01544	61.78	57.33
15	32	27.2	33	10.888	0.01365	0.01163	53.86	49.98
30	28	23.2	29	11.544	0.01365	0.00847	45.94	42.63
60	23	18.2	24	12.364	0.01365	0.00620	36.04	33.44
120	19	14.2	20	13.02	0.01365	0.00450	28.12	26.09
240	16	11.2	17	13.512	0.01365	0.00324	22.18	20.58
480	12	7.2	13	14.168	0.01365	0.00235	14.26	13.23
1440	8	3.2	9	14.824	0.01365	0.00138	6.34	5.88



Weight of Soil	50gm	Test pit 4 @1.5m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	4.7	0.94	0.94	99.06
2	2	1.3	0.26	1.2	98.8
3	1	3.1	0.62	1.82	98.18
4	0.6	5.1	1.02	2.84	97.16
5	0.425	5.2	1.04	3.88	96.12
6	0.3	4.7	0.94	4.82	95.18
7	0.15	6.7	1.34	6.16	93.84
8	0.075	5.1	1.02	7.18	92.82
9	pan	464.1	92.82	100	0

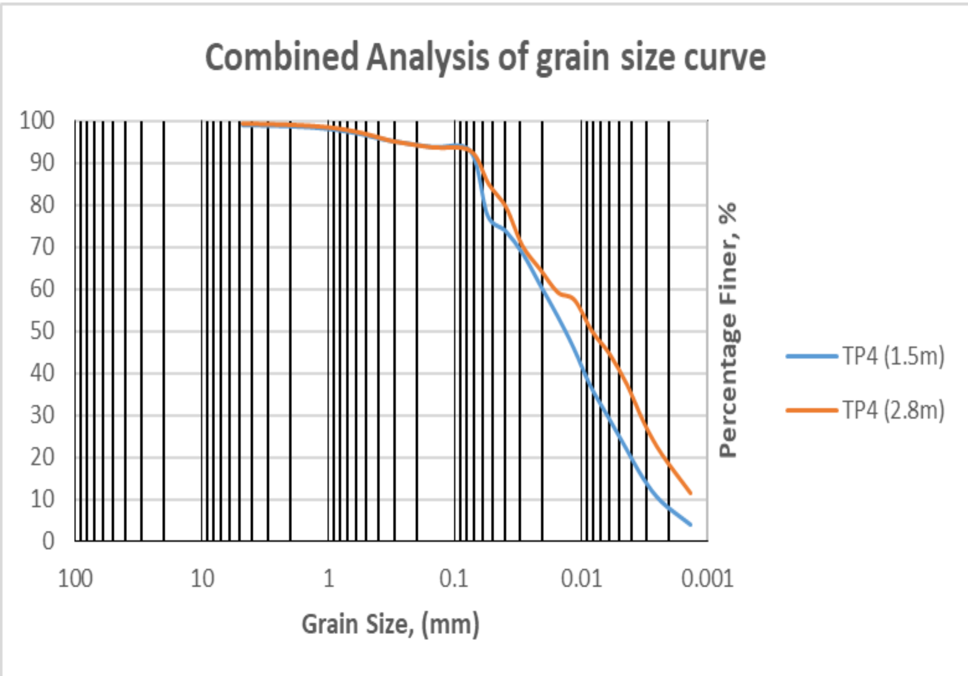
Gravel, %	0.94
Sand%	6.24
sc	92.82

Specific Gravity (Gs)	2.67	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 4 @1.5m		T^0 Correction		0.2
						% finer # 200 Sieve		92.82
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	47	42.2	48	8.428	0.0134	0.05502	83.56	77.56
1	45	40.2	46	8.756	0.0134	0.03965	79.60	73.88
2	42	37.2	43	9.248	0.0134	0.02881	73.66	68.37
4	38	33.2	39	9.904	0.0134	0.02109	65.74	61.02
8	34	29.2	35	10.56	0.0134	0.01540	57.82	53.66
15	30	25.2	31	11.216	0.0134	0.01159	49.90	46.31
30	25	20.2	26	12.036	0.0134	0.00849	40.00	37.12
60	21	16.2	22	12.692	0.0134	0.00616	32.08	29.77
120	17	12.2	18	13.348	0.0134	0.00447	24.16	22.42
240	13	8.2	14	14.004	0.0134	0.00324	16.24	15.07
480	10	5.2	11	14.496	0.0134	0.00233	10.30	9.56
1440	7	2.2	8	14.988	0.0134	0.00137	4.36	4.04

Weight of Soil	50gm	Test pit 4 @2.8m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	3.9	0.78	0.78	99.22
2	2	1.4	0.28	1.06	98.94
3	1	2.9	0.58	1.64	98.36
4	0.6	5.3	1.06	2.7	97.3
5	0.425	5.6	1.12	3.82	96.18
6	0.3	5.9	1.18	5	95
7	0.15	7.1	1.42	6.42	93.58
8	0.075	4.1	0.82	7.24	92.76
9	pan	463.8	92.76	100	0

Gravel, %	0.78
Sand%	6.46
sc	92.76

Specific Gravity (Gs)	2.61	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 4 @2.8		T^0 Correction		0.2
						% finer # 200 Sieve		92.76
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	51	46.2	52	7.772	0.01365	0.05382	91.48	84.85
1	48	43.2	49	8.264	0.01365	0.03924	85.54	79.34
2	43	38.2	44	9.084	0.01365	0.02909	75.64	70.16
4	40	35.2	41	9.576	0.01365	0.02112	69.70	64.65
8	37	32.2	38	10.068	0.01365	0.01531	63.76	59.14
15	36	31.2	37	10.232	0.01365	0.01127	61.78	57.30
30	32	27.2	33	10.888	0.01365	0.00822	53.86	49.96
60	29	24.2	30	11.38	0.01365	0.00594	47.92	44.45
120	25	20.2	26	12.036	0.01365	0.00432	40.00	37.10
240	20	15.2	21	12.856	0.01365	0.00316	30.10	27.92
480	16	11.2	17	13.512	0.01365	0.00229	22.18	20.57
1440	11	6.2	12	14.332	0.01365	0.00136	12.28	11.39



Weight of Soil	50gm	Test pit 5 @1.5m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	2.9	0.58	0.58	99.42
2	2	1.7	0.34	0.92	99.08
3	1	3.1	0.62	1.54	98.46
4	0.6	5.4	1.08	2.62	97.38
5	0.425	4.8	0.96	3.58	96.42
6	0.3	6.7	1.34	4.92	95.08
7	0.15	7.3	1.46	6.38	93.62
8	0.075	4.6	0.92	7.3	92.7
9	pan	463.5	92.7	100	0

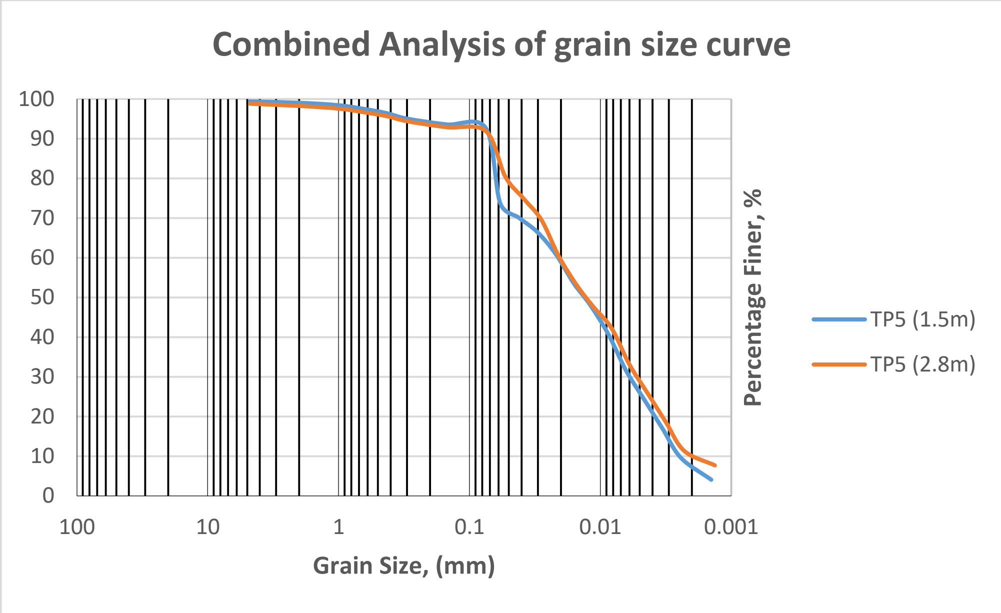
Gravel, %	0.58
Sand%	6.72
sc	92.7

Specific Gravity (Gs)	2.55	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 5 @1.5m		T^0 Correction		0.2
						% finer # 200 Sieve		92.7
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	45	40.2	46	8.756	0.01391	0.05821	79.60	73.79
1	43	38.2	44	9.084	0.01391	0.04192	75.64	70.11
2	41	36.2	42	9.412	0.01391	0.03018	71.68	66.44
4	38	33.2	39	9.904	0.01391	0.02189	65.74	60.94
8	34	29.2	35	10.56	0.01391	0.01598	57.82	53.60
15	31	26.2	32	11.052	0.01391	0.01194	51.88	48.09
30	27	22.2	28	11.708	0.01391	0.00869	43.96	40.75
60	22	17.2	23	12.528	0.01391	0.00636	34.06	31.57
120	18	13.2	19	13.184	0.01391	0.00461	26.14	24.23
240	14	9.2	15	13.84	0.01391	0.00334	18.22	16.89
480	10	5.2	11	14.496	0.01391	0.00242	10.30	9.54
1440	7	2.2	8	14.988	0.01391	0.00142	4.36	4.04

Weight of Soil	50gm	Test pit 5 @2.8m		Sieve Analysis	
No	Sieve opening (mm)	Mass of retained soil (gm	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
1	4.75	5.8	1.16	1.16	98.84
2	2	2.8	0.56	1.72	98.28
3	1	3.4	0.68	2.4	97.6
4	0.6	5.3	1.06	3.46	96.54
5	0.425	4.3	0.86	4.32	95.68
6	0.3	6.3	1.26	5.58	94.42
7	0.15	7.5	1.5	7.08	92.92
8	0.075	4.9	0.98	8.06	91.94
9	pan	459.7	91.94	100	0

Gravel, %	1.16
Sand%	6.9
sc	91.94

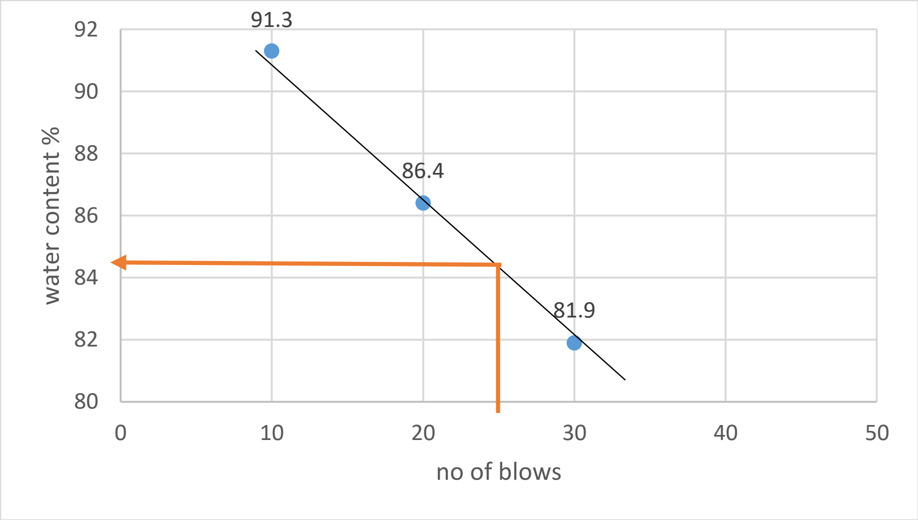
Specific Gravity (Gs)	2.71	Meniscus Correction	1	Hydrometer Analysis		Correction Factor α		0.99
Weight of soil sample	50 gm	Zero Correction	5	Test pit 5 @2.8m		T^0 Correction		0.2
						% finer # 200 Sieve		91.94
Elapsed Time (min)	Hydrometer Reading	Corrected Hydrometer Reading	Hydrometer Correction for Meniscus	Effective Depth	K	Particle Diameter	% finer	Adjusted % finer
0.5	49	44.2	50	8.1	0.01324	0.05329	87.52	80.46
1	46	41.2	47	8.592	0.01324	0.03881	81.58	75.00
2	43	38.2	44	9.084	0.01324	0.02822	75.64	69.54
4	38	33.2	39	9.904	0.01324	0.02083	65.74	60.44
8	34	29.2	35	10.56	0.01324	0.01521	57.82	53.16
15	31	26.2	32	11.052	0.01324	0.01136	51.88	47.69
30	28	23.2	29	11.544	0.01324	0.00821	45.94	42.23
60	23	18.2	24	12.364	0.01324	0.00601	36.04	33.13
120	19	14.2	20	13.02	0.01324	0.00436	28.12	25.85
240	15	10.2	16	13.676	0.01324	0.00316	20.20	18.57
480	11	6.2	12	14.332	0.01324	0.00229	12.28	11.29
1440	9	4.2	10	14.66	0.01324	0.00134	8.32	7.65


Combined Analysis of grain size curve
100
90
80
70
60
50
40
30
20
10
0
100
10
1
0.1
0.01
0.001
Grain Size, (mm)
Percentage Finer, %
TP5 (1.5m)
TP5 (2.8m)

Appendix – D (Atteberg limit results)

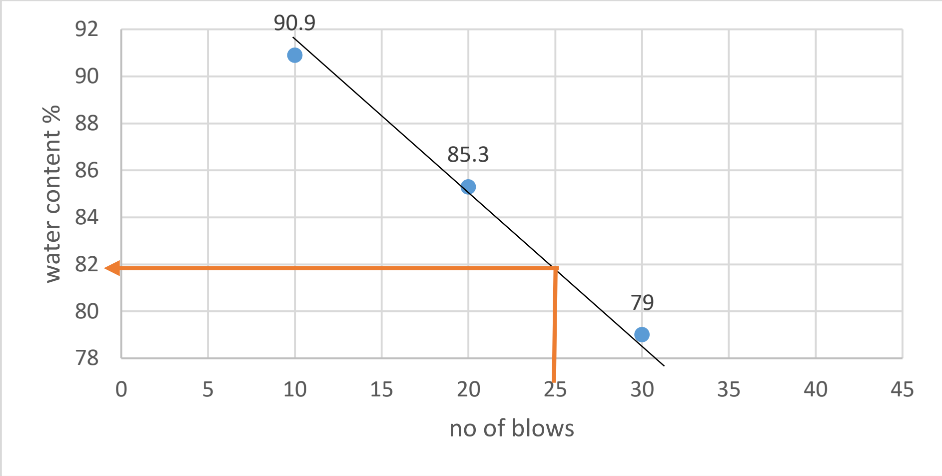
Liquid Limit Determination test			
Test Pit 1	Depth 1.5m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.9	60.1	60.5
Mass of container + Wet soil, g	78.5	79.3	79.6
Mass of container + Dry soil, g	70.1	70.4	71
Mass of water, g	8.4	8.9	8.6
Mass of dry soil, g	9.2	10.3	10.5
NO OF BLOW	13	27	35
Water content, %	0.913043	0.864078	0.819048

LL=84.2

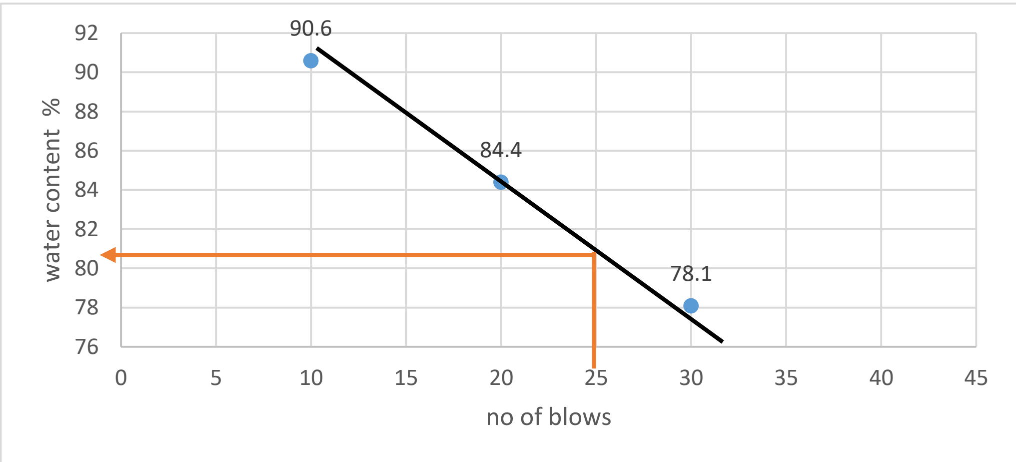


Liquid Limit Determination test			
Test Pit 1	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.2	60.2	60.5
Mass of container + Wet soil, g	79.1	79.1	79.3
Mass of container + Dry soil, g	70.1	70.4	71
Mass of water, g	9	8.7	8.3
Mass of dry soil, g	9.9	10.2	10.5
NO OF BLOW	12	28	34
Water content, %	0.909091	0.852941	0.790476

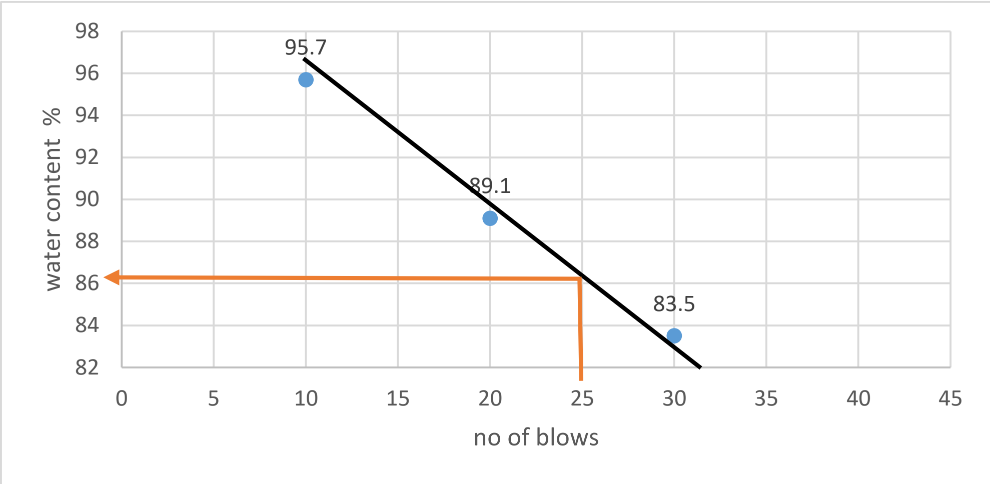
LL=82



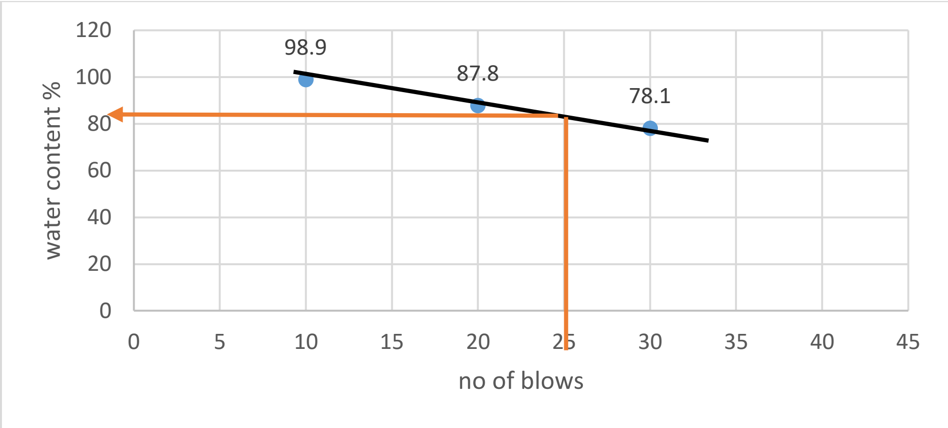
Liquid Limit Determination test			
Test Pit 2	Depth 1.5m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.4	60.8	60.5
Mass of container + Wet soil, g	78.7	78.5	79.2
Mass of container + Dry soil, g	70	70.4	71
Mass of water, g	8.7	8.1	8.2
Mass of dry soil, g	9.6	9.6	10.5
NO OF BLOW	15	26	34
Water content, %	0.90625	0.84375	0.780952
		LL=81.3	



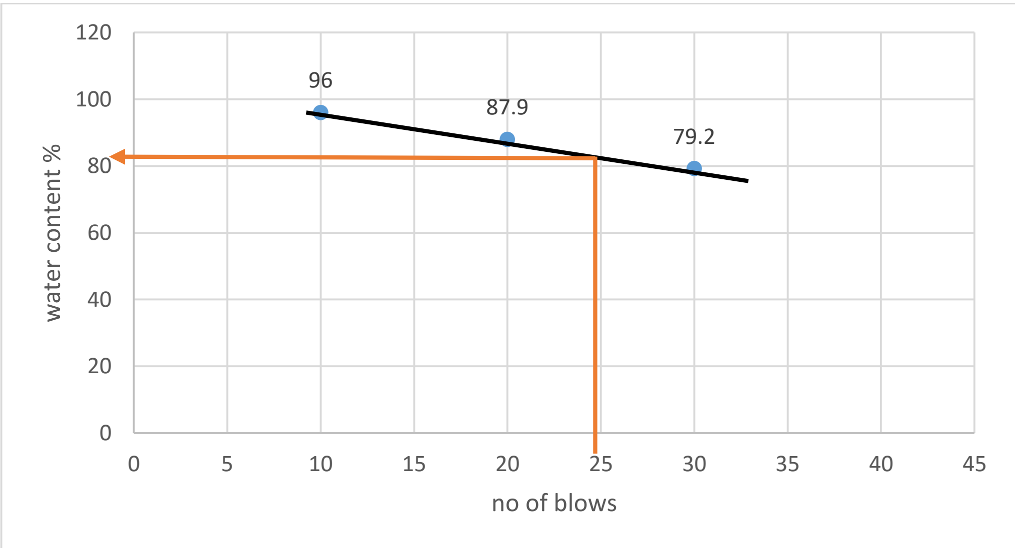
Liquid Limit Determination test			
Test Pit 2	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.9	60.8	60.4
Mass of container + Wet soil, g	79.1	78.2	79.3
Mass of container + Dry soil, g	70.2	70	70.7
Mass of water, g	8.9	8.2	8.6
Mass of dry soil, g	9.3	9.2	10.3
NO OF BLOW	14	26	29
Water content, %	0.956989	0.891304	0.834951
		LL=86.3	



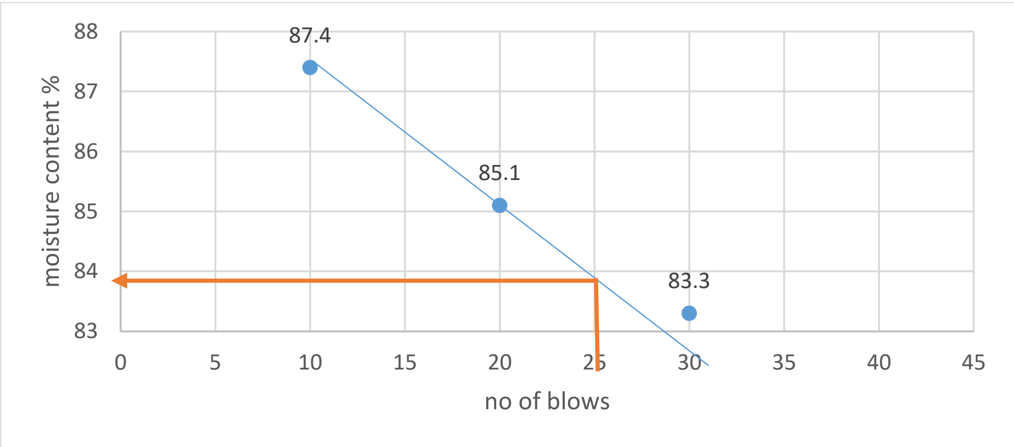
Liquid Limit Determination test			
Test Pit 3	Depth 1.5m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.2	60.7	60.4
Mass of container + Wet soil, g	79.9	79.1	79.1
Mass of container + Dry soil, g	70.1	70.5	70.9
Mass of water, g	9.8	8.6	8.2
Mass of dry soil, g	9.9	9.8	10.5
NO OF BLOW	11	26	35
Water content, %	0.989899	0.877551	0.780952
		LL=84	



Liquid Limit Determination test			
Test Pit 3	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.1	60.5	60.4
Mass of container + Wet soil, g	79.9	79.1	79.4
Mass of container + Dry soil, g	70.2	70.4	71
Mass of water, g	9.7	8.7	8.4
Mass of dry soil, g	10.1	9.9	10.6
NO OF BLOW	14	26	34
Water content, %	0.960396	0.878788	0.792453
		LL=84.3	

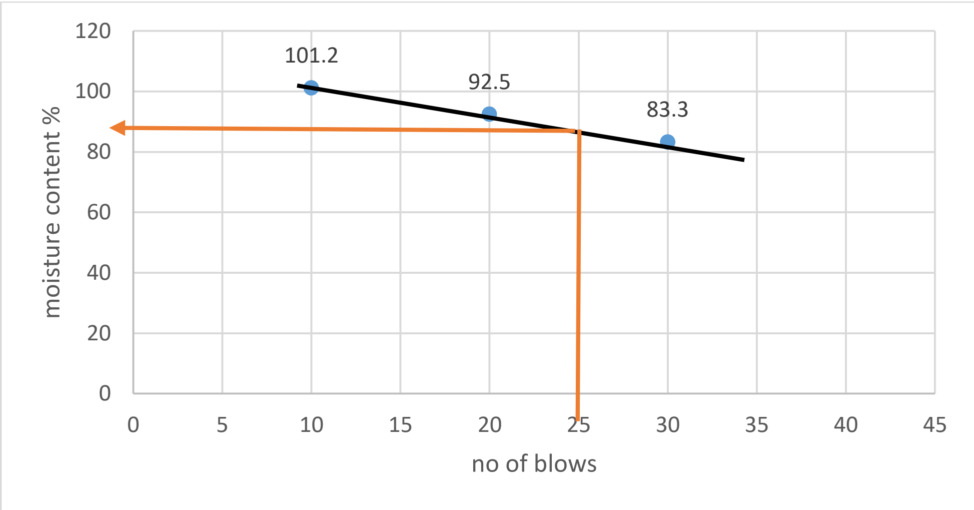


Liquid Limit Determination test			
Test Pit 4	Depth 1.5m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.5	60.4	60.6
Mass of container + Wet soil, g	79.8	79.1	79.3
Mass of container + Dry soil, g	70.8	70.5	70.8
Mass of water, g	9	8.6	8.5
Mass of dry soil, g	10.3	10.1	10.2
NO OF BLOW	13	27	35
Water content, %	0.873786	0.851485	0.833333
		LL=84.3	

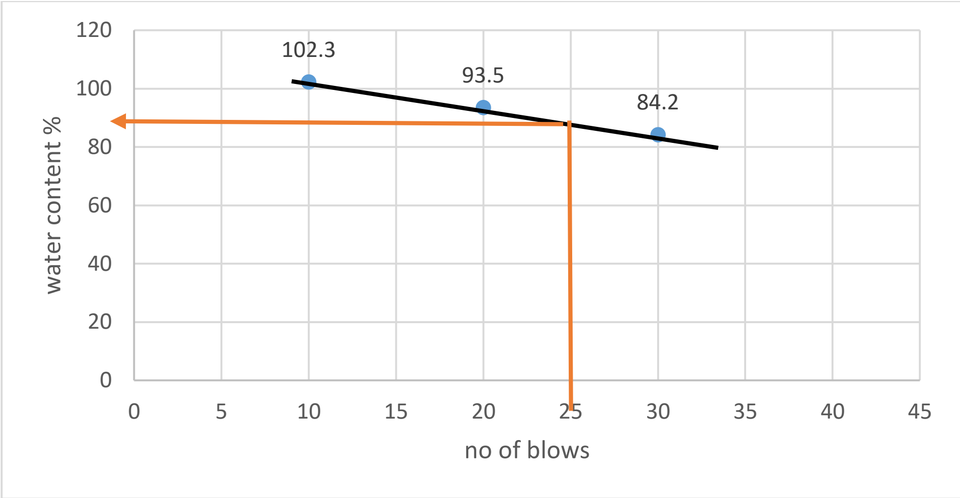


Liquid Limit Determination test			
Test Pit 4	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.8	60.4	60.1
Mass of container + Wet soil, g	77.9	78.3	78.8
Mass of container + Dry soil, g	69.3	69.7	70.3
Mass of water, g	8.6	8.6	8.5
Mass of dry soil, g	8.5	9.3	10.2
NO OF BLOW	12	26	34
Water content, %	1.011765	0.924731	0.833333
		LL=88.3	

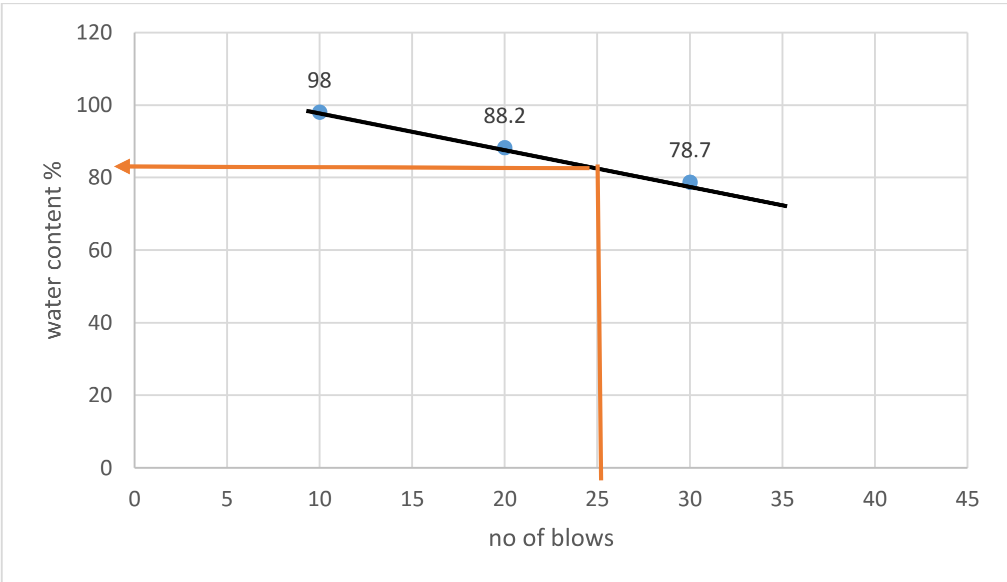
Liquid Limit Determination test			
Test Pit 4	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.8	60.4	60.1
Mass of container + Wet soil, g	77.9	78.3	78.8
Mass of container + Dry soil, g	69.3	69.7	70.3
Mass of water, g	8.6	8.6	8.5
Mass of dry soil, g	8.5	9.3	10.2
NO OF BLOW	12	26	34
Water content, %	1.011765	0.924731	0.833333
		LL=88.3	



Liquid Limit Determination test			
Test Pit 5	Depth 1.5m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.2	60.3	60.8
Mass of container + Wet soil, g	77.8	78.1	78.3
Mass of container + Dry soil, g	68.9	69.5	70.3
Mass of water, g	8.9	8.6	8
Mass of dry soil, g	8.7	9.2	9.5
NO OF BLOW	13	26	35
Water content, %	1.022989	0.934783	0.842105
		LL=90.3	



Liquid Limit Determination test			
Test Pit 5	Depth 2.8m		
Trial No	1	2	3
Container No	K1	L2	M3
Mass of container, g	60.3	60.1	60.5
Mass of container + Wet soil, g	79.7	79.3	79.8
Mass of container + Dry soil, g	70.1	70.3	71.3
Mass of water, g	9.6	9	8.5
Mass of dry soil, g	9.8	10.2	10.8
NO OF BLOW	16	28	34
Water content, %	0.979592	0.882353	0.787037
		LL=84.5	



Plastic Limit Determination test				
Test Pit 1	Depth 1.5m			
Trial No	1	2	3	
Container No	K1	L2	M3	Total
Mass of container, g	60.5	60.2	60.3	
Mass of container + Wet soil, g	79	78.5	79.8	
Mass of container + Dry soil, g	74.4	73.3	74	
Mass of water, g	4.6	5.2	5.8	
Mass of dry soil, g	13.9	13.1	13.7	
Water content	0.330935	0.396947	0.423358	1.151239
Water content, %	0.383746494			

Plastic Limit Determination test				
Test Pit 1	Depth 2.8m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.3	60.4	60.2	
Mass of container + Wet soil, g	78.5	78.5	79.8	
Mass of container + Dry soil, g	73.9	73.4	74.3	
Mass of water, g	4.6	5.1	5.5	
Mass of dry soil, g	13.6	13	14.1	
Water content	0.338235	0.392308	0.390071	1.120614
Water content, %	0.373538			

Plastic Limit Determination test				
Test Pit 2	Depth 1.5m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.9	60.1	60.6	
Mass of container + Wet soil, g	79.1	78.1	79.7	
Mass of container + Dry soil, g	74.3	73.3	74	
Mass of water, g	4.8	4.8	5.7	
Mass of dry soil, g	13.4	13.2	13.4	
Water content	0.358209	0.363636	0.425373	1.147218
Water content, %				0.382406

Plastic Limit Determination test				
Test Pit 2	Depth 2.8m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.2	60.3	60.4	
Mass of container + Wet soil, g	78.5	76.9	78.4	
Mass of container + Dry soil, g	73.7	73.1	74.3	
Mass of water, g	4.8	3.8	4.1	
Mass of dry soil, g	13.5	12.8	13.9	
Water content	0.355556	0.296875	0.294964	0.947395
Water content, %				0.315798

Plastic Limit Determination test				
Test Pit 3	Depth 1.5m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.7	60.5	60.4	
Mass of container + Wet soil, g	78.7	78.4	79.1	
Mass of container + Dry soil, g	74.3	73.3	74.3	
Mass of water, g	4.4	5.1	4.8	
Mass of dry soil, g	13.6	12.8	13.9	
Water content	0.323529	0.398438	0.345324	1.067291
Water content, %				0.355764

Plastic Limit Determination test				
Test Pit 3	Depth 2.8m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.6	60.3	60.2	
Mass of container + Wet soil, g	78.3	77.1	78.3	
Mass of container + Dry soil, g	73	73.3	74.3	
Mass of water, g	5.3	3.8	4	
Mass of dry soil, g	12.4	13	14.1	
Water content	0.427419	0.292308	0.283688	1.003415
Water content, %				0.334472

Plastic Limit Determination test				
Test Pit 4	Depth 1.5m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.6	60.3	60.4	
Mass of container + Wet soil, g	78.5	78.4	79.3	
Mass of container + Dry soil, g	74.3	73.3	74.3	
Mass of water, g	4.2	5.1	5	
Mass of dry soil, g	13.7	13	13.9	
Water content	0.306569	0.392308	0.359712	1.058589
Water content, %				0.352863

Plastic Limit Determination test				
Test Pit 4	Depth 2.8m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.1	60.3	60.3	
Mass of container + Wet soil, g	78	77.3	78.7	
Mass of container + Dry soil, g	73.3	73.3	74.3	
Mass of water, g	4.7	4	4.4	
Mass of dry soil, g	13.2	13	14	
Water content	0.356061	0.307692	0.314286	0.978039
Water content, %				0.326013

Plastic Limit Determination test				
Test Pit 5	Depth 1.5m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.4	60.8	60.5	
Mass of container + Wet soil, g	78.4	78.6	78.9	
Mass of container + Dry soil, g	74.3	74.1	74.5	
Mass of water, g	4.1	4.5	4.4	
Mass of dry soil, g	13.9	13.3	14	
Water content	0.294964	0.338346	0.314286	0.947596
Water content, %				0.315865

Plastic Limit Determination test				
Test Pit 5	Depth 2.8m			
Trial No	1	2	3	
Container No	K1	L2	M3	
Mass of container, g	60.8	60.3	60.4	
Mass of container + Wet soil, g	78.5	78.4	79.3	
Mass of container + Dry soil, g	74.5	74.3	74.9	
Mass of water, g	4	4.1	4.4	
Mass of dry soil, g	13.7	14	14.5	
Water content	0.291971	0.292857	0.303448	0.888276
Water content, %				0.296092

Appendix – E
(Free Swell Test results)

Free Swell Test		
Test Pit -1		
Depth	1.5	
sample no	1	2
Initial volume,ml	10	10
Final volume,ml	30.4	31.5
Free Swell %	204	215
Average FS %	209.5	

Free Swell Test		
Test Pit -1		
Depth	2.8	
sample no	1	2
Initial volume,ml	10	10
Final volume,ml	29.4	29.7
Free Swell %	194	197
Average FS %	195.5	

Free Swell Test		
Test Pit -2		
Depth	1.5	
sample no	1	2
Initial volume,ml	10	10
Final volume,ml	28.6	29.3
Free Swell %	186	193
Average FS %	189.5	

Free Swell Test		
Test Pit -2		
Depth	2.8	
sample no	1	2
Initial volume,ml	10	10
Final volume,ml	27.8	26.9
Free Swell %	178	169
Average FS %	173.5	

Free Swell Test		
Test Pit -3		
Depth	1.5	
sample no	1	2
Initial volume,ml	10	10
Final volume,ml	31.4	30.8
Free Swell %	214	208
Average FS %	211	

Free Swell Test		
Test Pit -3		
Depth	2.8	
sample no	1	2
Initial volume,ml	12	12
Final volume,ml	31.3	32
Free Swell %	160.83	166.7
Average FS %	163.75	

Free Swell Test		
Test Pit -4		
Depth	1.5	
sample no	1	2
Initial volume,ml	12	12
Final volume,ml	30.1	30.8
Free Swell %	150.83	156.67
Average FS %	153.75	

Free Swell Test		
Test Pit -4		
Depth	2.8	
sample no	1	2
Initial volume,ml	12	12
Final volume,ml	28.9	32
Free Swell %	140.83	166.67
Average FS %	153.75	

Free Swell Test		
Test Pit -5		
Depth	1.5	
sample no	1	2
Initial volume,ml	12	12
Final volume,ml	27.6	26.9
Free Swell %	130	124.17
Average FS %	127.08	

Free Swell Test		
Test Pit -5		
Depth	2.8	
sample no	1	2
Initial volume,ml	12	12
Final volume,ml	25.8	24.3
Free Swell %	115	102.5
Average FS %	108.75	

Appendix – F
(Compaction Test Results)

Test pit 1	Depth 1.5m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C11	C12	C13	C14	C15
Mass of Container	60.8	60.2	60.7	60.9	60.8
Mass of Container + Wet Soil	102.5	103.5	106.1	104.6	108.3
Mass of Container + Dry Soil	92.6	92.4	94.1	92.6	95.1
Mass of Water	9.9	11.1	12	12	13.2
Mass of Dry Soil	31.8	32.2	33.4	31.7	34.3
Moisture Content %	34.0836	34.47205	35.92814	37.85489	38.48397
Density Determination					
Moisture Content %	34.0836	34.47205	35.92814	37.85489	38.48397
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5817.2	5908.7	6012.3	6094.7	6076.5
Wt of mold, g	4502.1	4502.4	4503.7	4500	4501.3
Wt of soil in mold, g	1315.1	1406.3	1508.6	1594.7	1575.2
Wet density, g/cc	1.393114	1.489725	1.598093	1.689301	1.668644
Dry density, g/cc	1.038989	1.107832	1.17569	1.22542	1.204937
Test pit 1	Depth 2.8m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C21	C22	C23	C24	C25
Mass of Container	60.9	60.8	60.2	60.1	60.7
Mass of Container + Wet Soil	101.7	104.5	106.1	104.1	107.3
Mass of Container + Dry Soil	92.3	93.8	94.8	92.8	95.3
Mass of Water	9.4	10.7	11.3	11.3	12
Mass of Dry Soil	31.4	33	34.6	32.7	34.6
Moisture Content %	29.93631	32.42424	32.65896	34.55657	34.68208
Density Determination					
Moisture Content %	29.93631	32.42424	32.65896	34.55657	34.68208
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5901.3	5990.4	6104	6136.7	6081.6
Wt of mold, g	4503	4501.7	4503.7	4502	4501.3
Wt of soil in mold, g	1398.3	1488.7	1600.3	1634.7	1580.3
Wet density, g/cc	1.48125	1.577013	1.695233	1.731674	1.674047

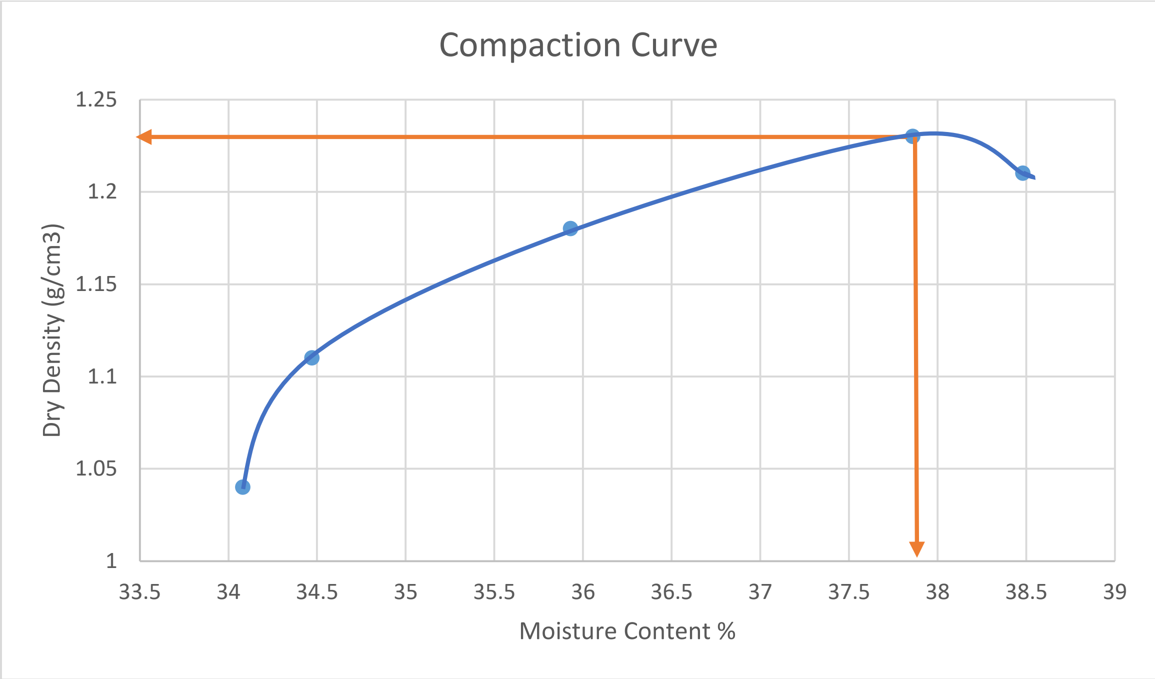
Dry density, g/cc	1.139982	1.190879	1.277888	1.286948	1.242962
Test pit 2	Depth 1.5m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C31	C32	C33	C34	C35
Mass of Container	60.8	60.2	60.7	60.9	60.8
Mass of Container + Wet Soil	98.7	97.6	102.5	103.2	102.5
Mass of Container + Dry Soil	91.4	90.3	93.5	93.5	92.6
Mass of Water	7.3	7.3	9	9.7	9.9
Mass of Dry Soil	30.6	30.1	32.8	32.6	31.8
Moisture Content %	26.33333	26.77966	27.43902	29.7546	31.13208
Density Determination					
Moisture Content %	26.33333	26.77966	27.43902	29.7546	31.13208
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5864.4	5959.3	6105.8	6179.3	6138.9
Wt of mold, g	4503	4502.1	4503.7	4501.8	4504.2
Wt of soil in mold, g	1361.4	1457.2	1602.1	1677.5	1634.7
Wet density, g/cc	1.442161	1.543644	1.69714	1.777013	1.731674
Dry density, g/cc	1.141552	1.21758	1.331727	1.369518	1.320557
Test pit 2	Depth 2.8m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C41	C42	C43	C44	C45
Mass of Container	60.2	60.8	60.1	60.8	60.2
Mass of Container + Wet Soil	97.6	94.2	101.6	102.5	102.4
Mass of Container + Dry Soil	92.3	89.3	94.9	95.7	94.7
Mass of Water	5.3	4.9	6.7	6.8	7.7
Mass of Dry Soil	32.1	28.5	34.8	34.9	34.5
Moisture Content %	16.5109	17.19298	19.25287	19.48424	19.5467
Density Determination					
Moisture Content%	16.5109	17.19298	19.25287	19.48424	19.5467
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5864.2	5947.5	6109.1	6170.3	6163.1

Wt of mold, g	4503	4502.3	4503.7	4503.1	4504.2
Wt of soil in mold, g	1361.2	1445.2	1605.4	1667.2	1658.9
Wet density, g/cc	1.441949	1.530932	1.700636	1.766102	1.757309
Dry density, g/cc	1.237609	1.306334	1.426075	1.478104	1.469977
Test pit 3	Depth 1.5m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C51	C52	C53	C54	C55
Mass of Container	60.8	60.2	60.1	60.7	60.8
Mass of Container + Wet Soil	96.1	95.1	101.8	107.5	102.4
Mass of Container + Dry Soil	90.4	88.9	93.1	97.3	91.7
Mass of Water	5.7	6.2	8.7	10.2	10.7
Mass of Dry Soil	29.6	28.7	33	36.6	30.9
Moisture Content %	19.25676	21.60279	26.36364	27.86885	34.62783
Density Determination					
Moisture Content%	19.25676	21.60279	26.36364	27.86885	34.62783
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5847.9	5970.1	6082.8	6204.4	6188.9
Wt of mold, g	4502.4	4502.3	4505.9	4503.1	4501.6
Wt of soil in mold, g	1345.5	1467.8	1576.9	1701.3	1687.3
Wet density, g/cc	1.425318	1.554873	1.670445	1.802225	1.787394
Dry density, g/cc	1.195167	1.278649	1.321935	1.409432	1.327656
Test pit 3	Depth 2.8m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C61	C62	C63	C64	C65
Mass of Container	60.2	60.1	60.2	60.3	60.9
Mass of Container + Wet Soil	97.2	94.3	102	104.5	97.3
Mass of Container + Dry Soil	92	88.9	95	96.8	90
Mass of Water	5.2	5.4	7	7.7	7.3
Mass of Dry Soil	31.8	28.8	34.8	36.5	29.1
Moisture Content %	16.3522	18.75	20.11494	21.09589	25.08591
Density Determination					
Moisture Content%	16.3522	18.75	20.11494	21.09589	25.08591
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5797.8	5868.6	6082.4	6161.4	6144.3
Wt of mold, g	4501.1	4500.8	4509.1	4503.1	4503.2
Wt of soil in mold, g	1296.7	1367.8	1573.3	1658.3	1641.1
Wet density, g/cc	1.373623	1.448941	1.666631	1.756674	1.738453

Dry density, g/cc	1.180573	1.220161	1.38753	1.450647	1.389808
Test pit 4	Depth 1.5m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C71	C72	C73	C74	C75
Mass of Container	60.2	60.7	60.9	60.8	60.4
Mass of Container + Wet Soil	98.1	94.3	102.5	98.7	97.3
Mass of Container + Dry Soil	92	88.8	94.5	91.2	88.7
Mass of Water	6.1	5.5	8	7.5	8.6
Mass of Dry Soil	31.8	28.1	33.6	30.4	28.3
Moisture Content %	19.18239	19.57295	23.80952	24.67105	30.38869
Density Determination					
Moisture Content%	19.18239	19.57295	23.80952	24.67105	30.38869
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5668.1	5775	6007.5	6110.7	6047.1
Wt of mold, g	4511.2	4507.2	4509.2	4508.4	4510.2
Wt of soil in mold, g	1156.9	1267.8	1498.3	1602.3	1536.9
Wet density, g/cc	1.22553	1.343008	1.587182	1.697352	1.628072
Dry density, g/cc	1.028281	1.123171	1.281955	1.361464	1.24863
Test pit 4	Depth 2.8m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C81	C82	C83	C84	C85
Mass of Container	60.1	60.3	60.3	60.2	60.8
Mass of Container + Wet Soil	97.3	94.3	98.3	98.7	98.4
Mass of Container + Dry Soil	91.7	87.9	90.8	90.9	89.7
Mass of Water	5.6	6.4	7.5	7.8	8.7
Mass of Dry Soil	31.6	27.6	30.5	30.7	28.9
Moisture Content %	17.72152	23.18841	24.59016	25.40717	30.10381
Density Determination					
Moisture Content%	17.72152	23.18841	24.59016	25.40717	30.10381
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5724.5	5891.6	6020.9	6086.2	6055
Wt of mold, g	4511.1	4512.7	4508.2	4508.4	4511
Wt of soil in mold, g	1213.4	1378.9	1512.7	1577.8	1544
Wet density, g/cc	1.285381	1.460699	1.602436	1.671398	1.635593
Dry density, g/cc	1.091883	1.185744	1.286166	1.332777	1.257145
Test pit 5	Depth 1.5m				
Moisture Content Determination					
Sample No	1	2	3	4	5

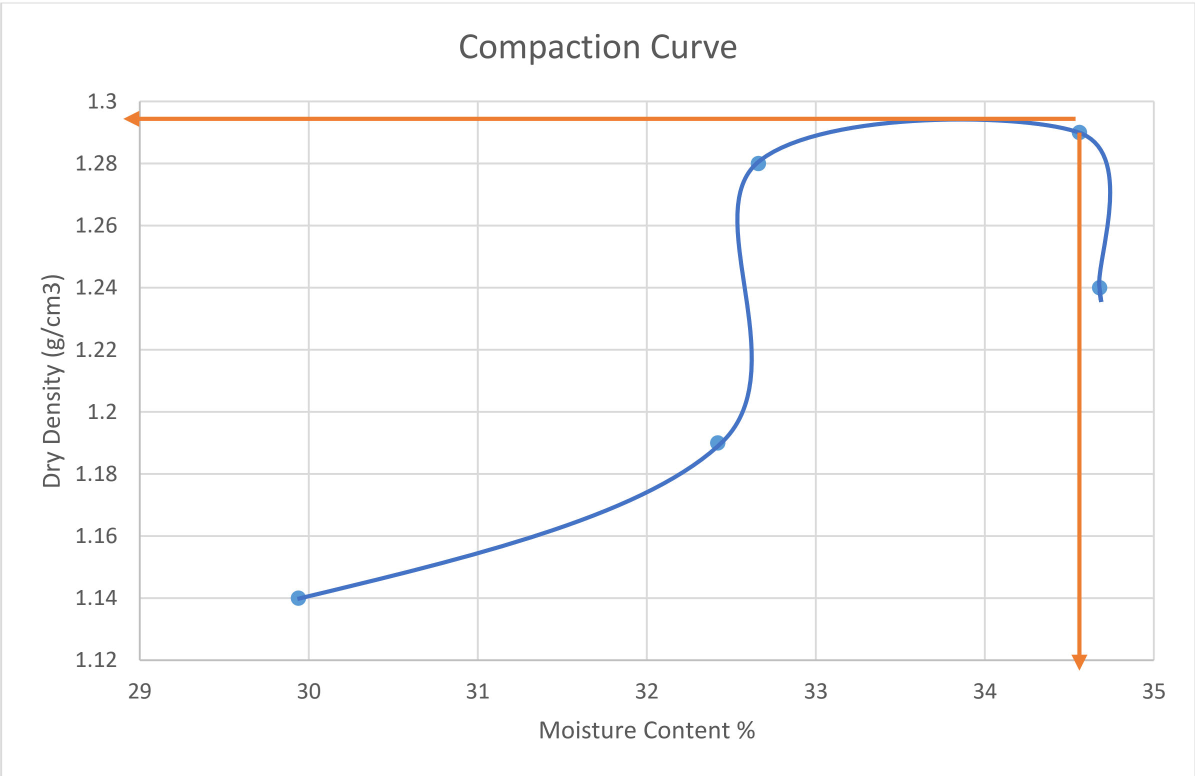
Container No	C91	C92	C93	C94	C95
Mass of Container	60.3	60.9	60.8	60.2	60.1
Mass of Container + Wet Soil	96.5	93.5	98.3	97.1	98
Mass of Container + Dry Soil	90.3	87.9	91.8	90.3	90.2
Mass of Water	6.2	5.6	6.5	6.8	7.8
Mass of Dry Soil	30	27	31	30.1	30.1
Moisture Content %	20.66667	20.74074	20.96774	22.59136	25.91362
Density Determination					
Moisture Content%	20.66667	20.74074	20.96774	22.59136	25.91362
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5757.7	5899.1	6031.2	6118.4	6087.1
Wt of mold, g	4512	4510.3	4508.2	4509.2	4509
Wt of soil in mold, g	1245.7	1388.8	1523	1609.2	1578.1
Wet density, g/cc	1.319597	1.471186	1.613347	1.704661	1.671716
Dry density, g/cc	1.093589	1.218467	1.333701	1.390523	1.327669
Test pit 5	Depth 2.8m				
Moisture Content Determination					
Sample No	1	2	3	4	5
Container No	C101	C102	C103	C104	C105
Mass of Container	60.2	60.7	60.9	60.8	60.4
Mass of Container + Wet Soil	96	94.5	100.3	98.9	98
Mass of Container + Dry Soil	88.3	86.4	89.9	88.4	87.6
Mass of Water	7.7	8.1	10.4	10.5	10.4
Mass of Dry Soil	28.1	25.7	29	27.6	27.2
Moisture Content %	27.40214	31.51751	35.86207	38.04348	38.23529
Density Determination					
Moisture Content%	27.40214	31.51751	35.86207	38.04348	38.23529
Volume of Mold,cm3	944	944	944	944	944
Wt of soil + mold, g	5690.6	5765.4	5931	6107.8	6052.3
Wt of mold, g	4511.7	4508.5	4508	4509.2	4510.3
Wt of soil in mold, g	1178.9	1256.9	1423	1598.6	1542
Wet density, g/cc	1.248835	1.331462	1.507415	1.693432	1.633475
Dry density, g/cc	0.980231	1.012384	1.109519	1.226738	1.181662

Test Pit 1 @ Depth 1.5m



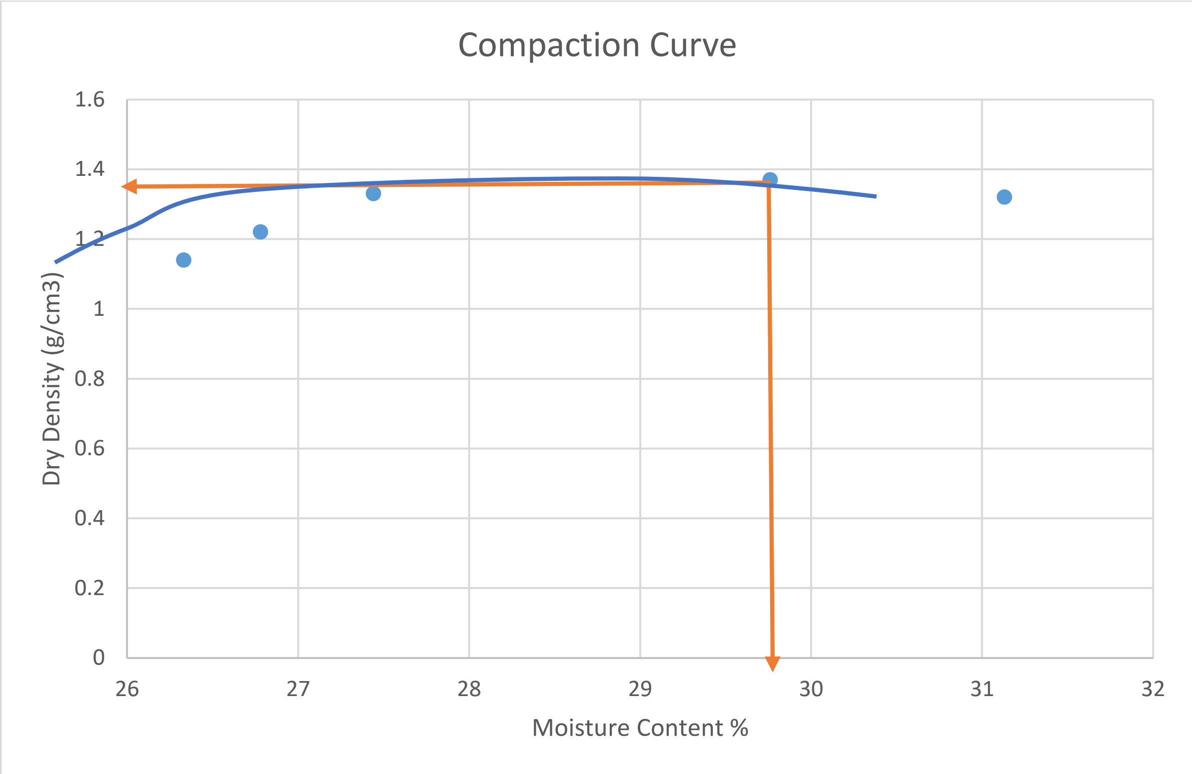
Maximum Dry Density=1.23g/cm3, Optimum Moisture Content %=37.86

Test Pit 1 @ Depth 2.8m



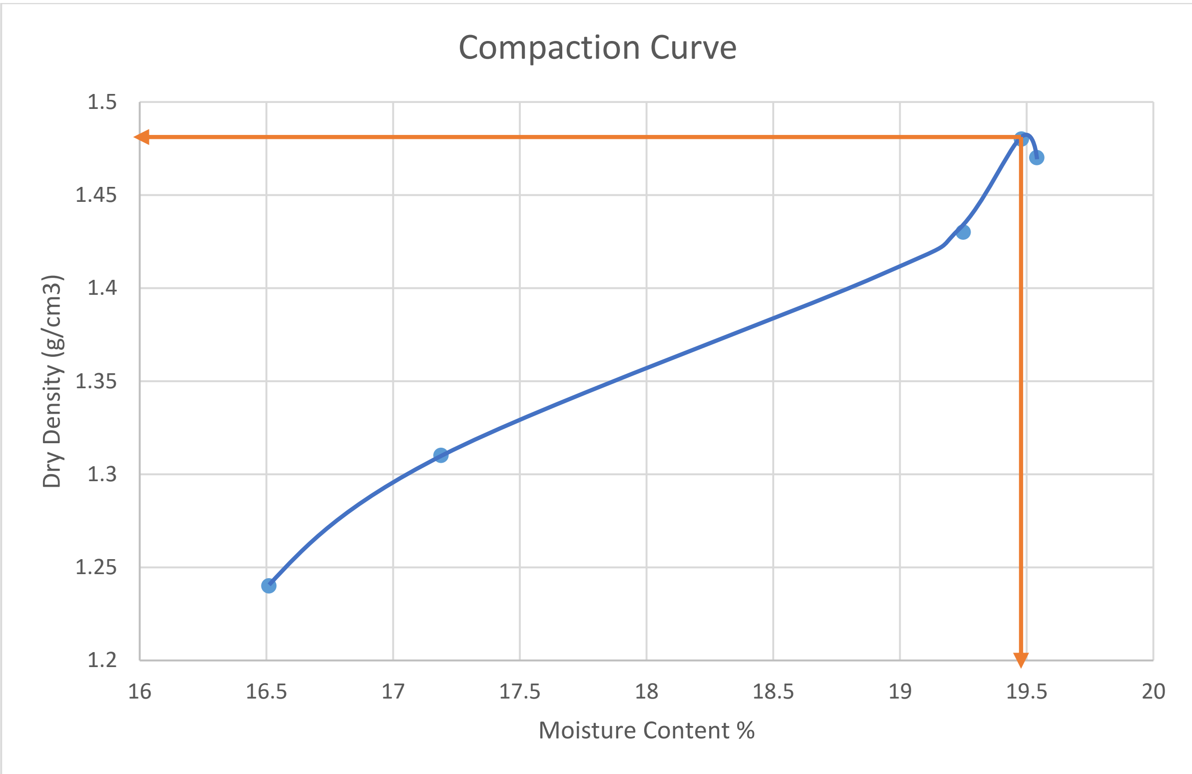
Maximum Dry Density=1.29g/cm^3 Optimum Moisture Content %=34.56

Test Pit 2 @ Depth 1.5m



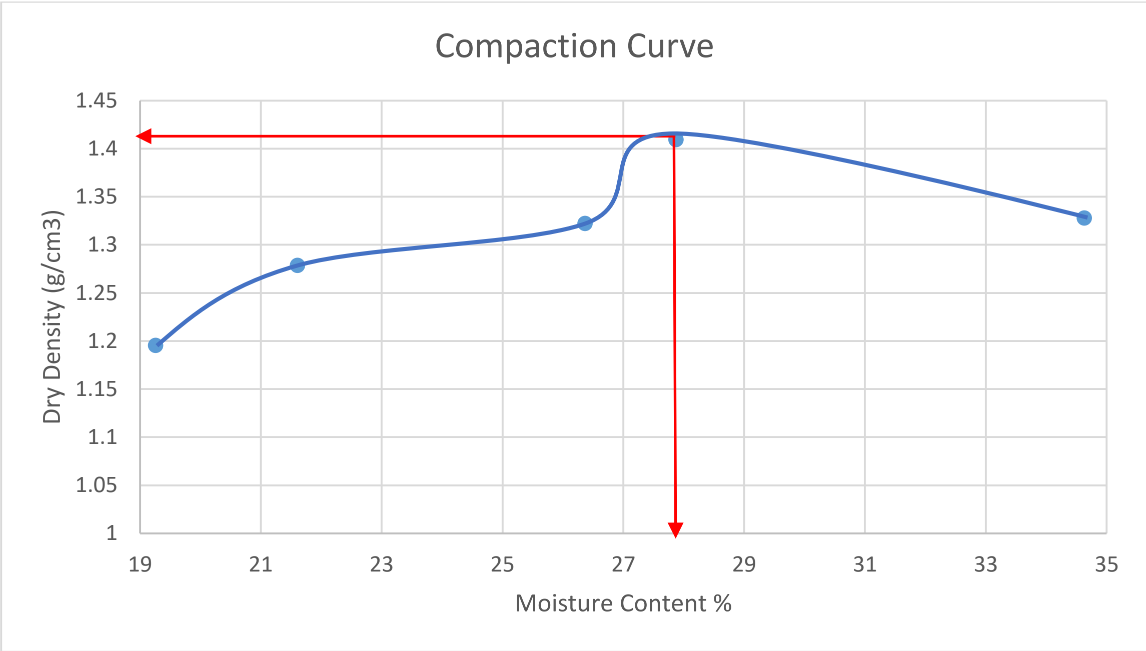
Maximum Dry Density=1.37g/cm3, Optimum Moisture Content %=29.76

Test Pit 2 @ Depth 2.8m



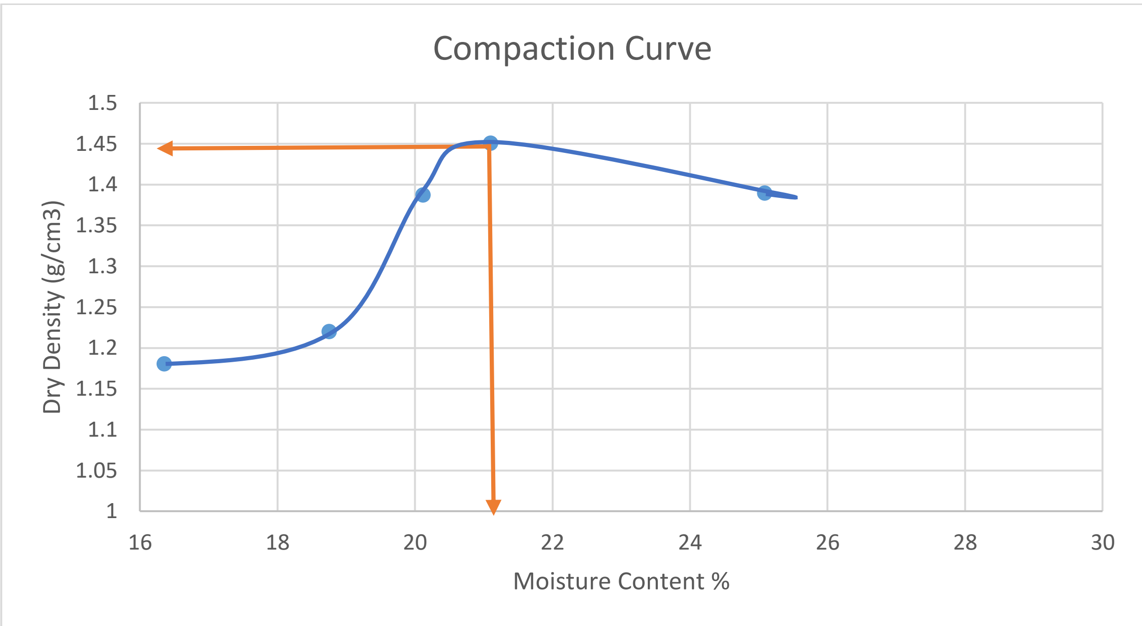
Maximum Dry Density=1.47g/cm3, Optimum Moisture Content %=19.55

Test Pit 3 @ Depth 1.5m



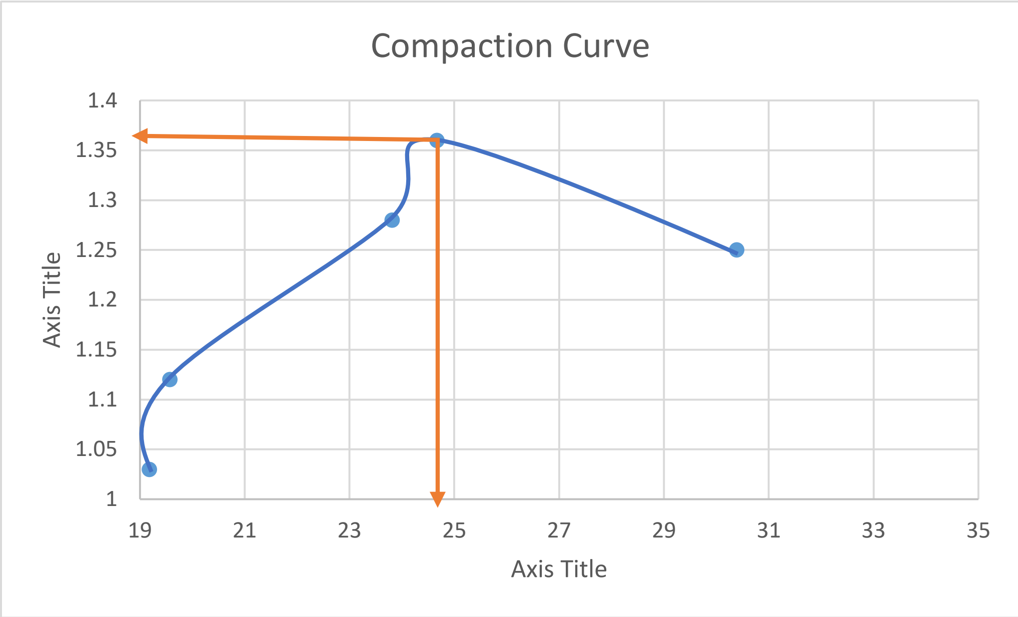
Maximum Dry Density=1.41g/cm3, Optimum Moisture Content %=27.87

Test Pit 3 @ Depth 2.8m



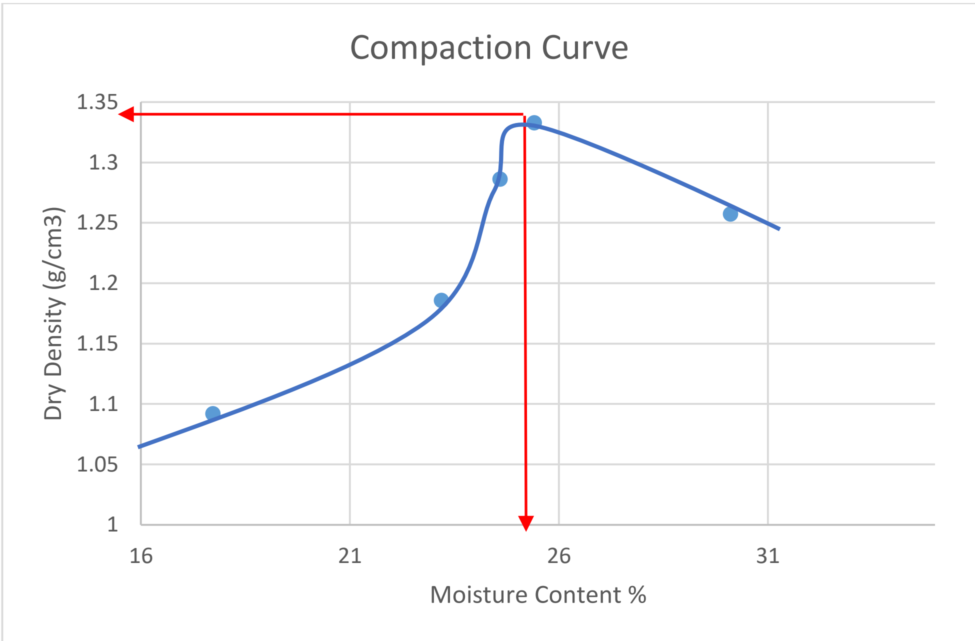
Maximum Dry Density=1.46g/cm3, Optimum Moisture Content %=21.16

Test Pit 4 @ Depth 1.5m



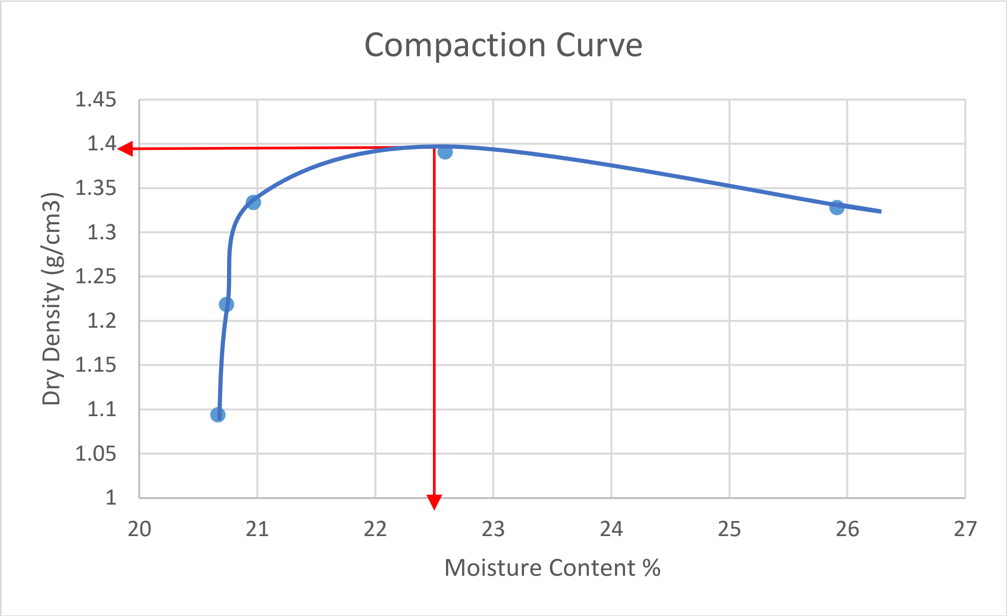
Maximum Dry Density=1.37g/cm3, Optimum Moisture Content %=24.67

Test Pit 4 @ Depth 2.8m



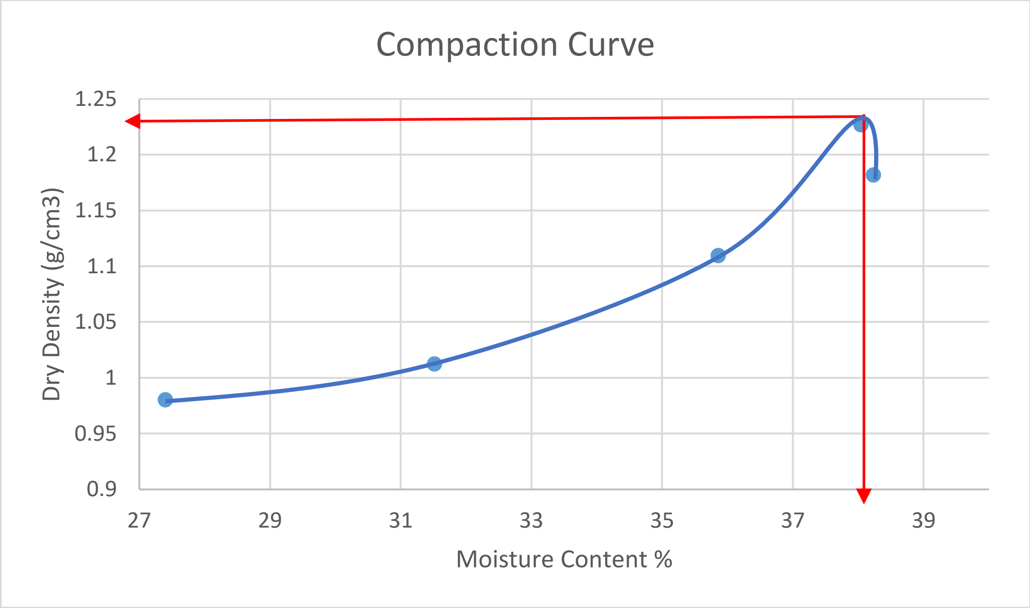
Maximum Dry Density=1.34g/cm3, Optimum Moisture Content %=25.41

Test Pit 5 @ Depth 1.5m



Maximum Dry Density=1.39g/cm3, Optimum Moisture Content %=22.59

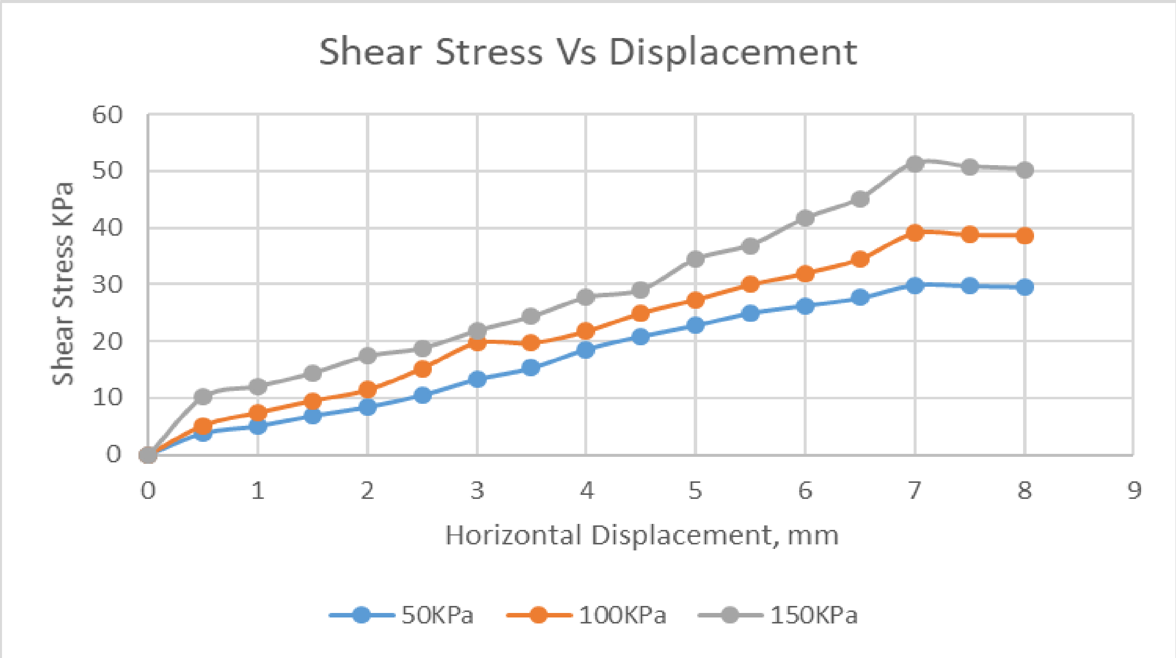
Test Pit 5 @ Depth 2.8m



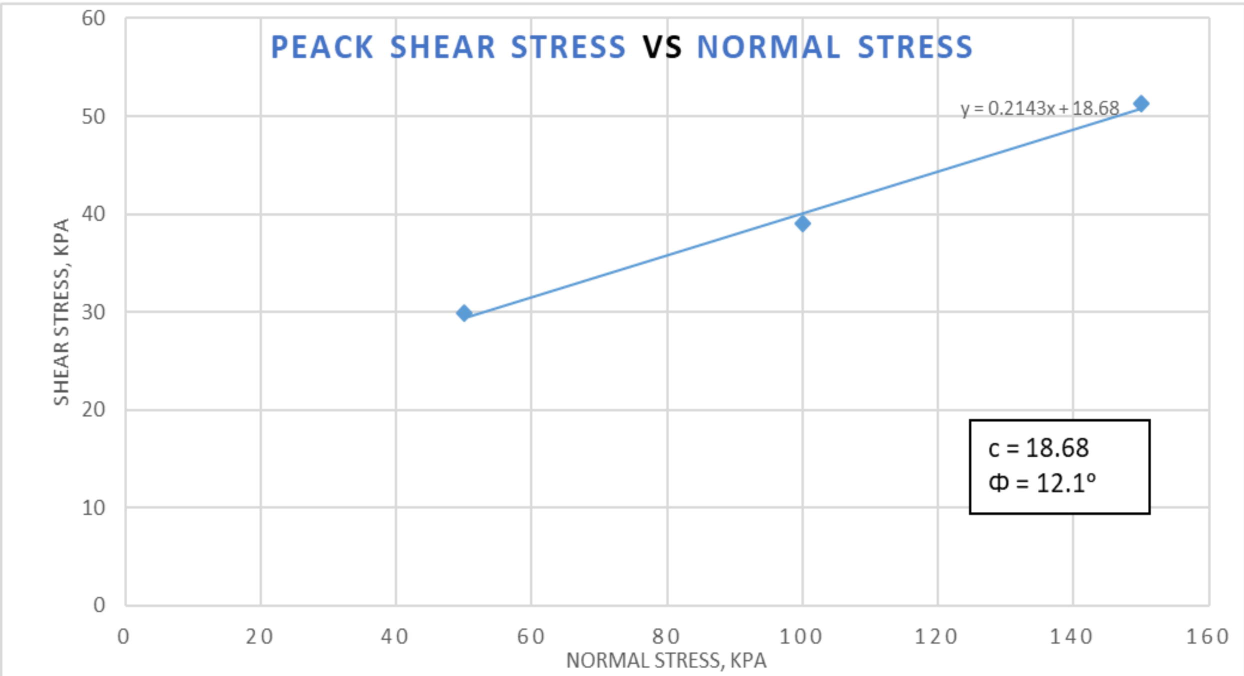
Maximum Dry Density=1.23g/cm3, Optimum Moisture Content %=38.04

Appendix – G
(Direct Shear Strength Test Results)

Test Pit 1 / Depth 3.0 m		Ring Calibration Factor =0.70 N/div	Applied Vertical Stress 50 KPa			Applied Vertical Stress 100KPa			Applied Vertical Stress 150KPa		
Dial Gauge	Horizontal Displacement (mm)	Corrected Area (mm^2)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)
0	0	3600	0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
50	0.5	3570	19	13.5	3.8	26.0	18.5	5.2	51.0	36.2	10.1
100	1	3540	25	17.8	5.0	37.0	26.3	7.4	60.0	42.6	12.0
150	1.5	3510	34	24.1	6.9	47.0	33.4	9.5	71.0	50.4	14.4
200	2	3480	41	29.1	8.4	56.0	39.8	11.4	85.0	60.4	17.3
250	2.5	3450	51	36.2	10.5	74.0	52.5	15.2	91.0	64.6	18.7
300	3	3420	64	45.4	13.3	81.0	66.7	19.7	105.0	74.6	21.8
350	3.5	3390	73	51.8	15.3	94.0	66.7	19.7	116.0	82.4	24.3
400	4	3360	88	62.5	18.6	103.0	73.1	21.8	131.0	93.0	27.7
450	4.5	3330	98	69.6	20.9	117.0	83.1	24.9	136.0	96.6	29.0
500	5	3300	106	75.3	22.8	127.0	90.2	27.3	160.0	113.6	34.4
550	5.5	3270	115	81.7	25.0	138.0	98.0	30.0	170.0	120.7	36.9
600	6	3240	120	85.2	26.3	146.0	103.7	32.0	190.0	134.9	41.6
650	6.5	3210	125	88.8	27.6	156.0	110.8	34.5	204.0	144.8	45.1
700	7	3180	134	95.1	29.9	175.0	124.3	39.1	230.0	163.3	51.4
750	7.5	3150	132	93.7	29.8	172.0	122.1	38.8	225.0	159.8	50.7
800	8	3120	130	92.3	29.6	170.0	120.7	38.7	221.0	156.9	50.3

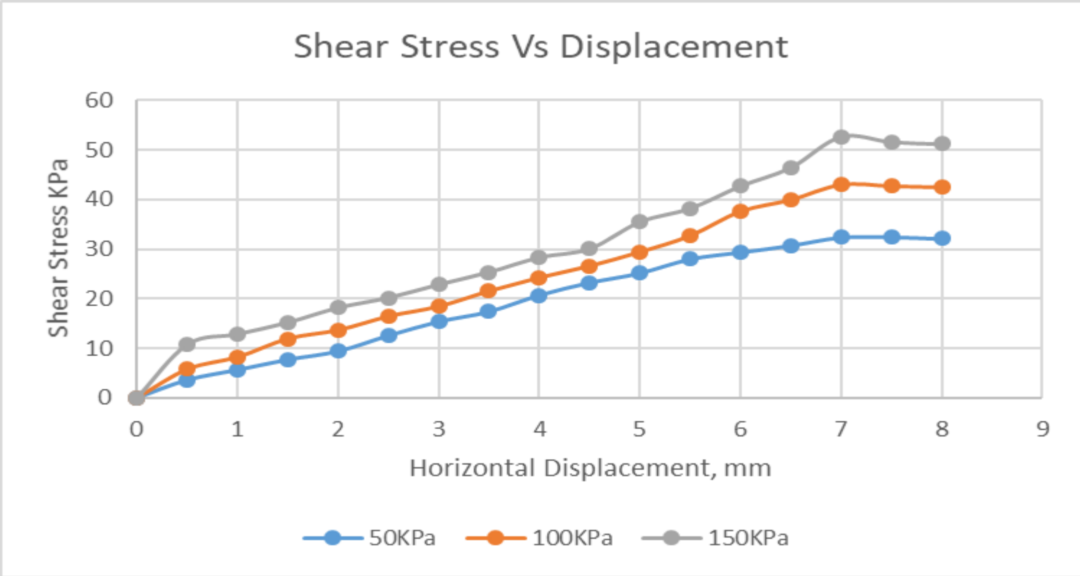


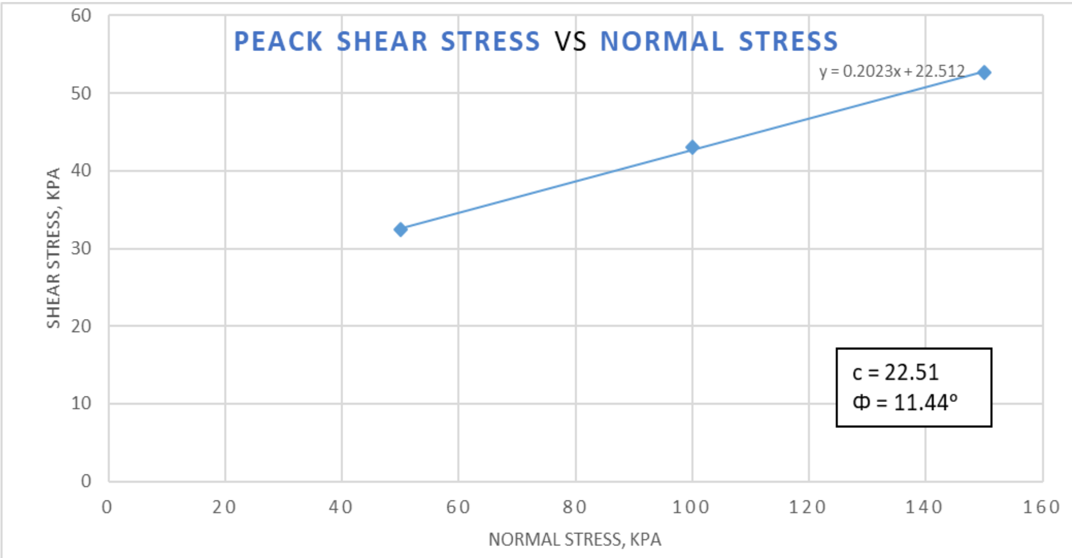
Shear Stress Vs Displacement
Shear Stress KPa
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Horizontal Displacement, mm
50KPa
100KPa
150KPa



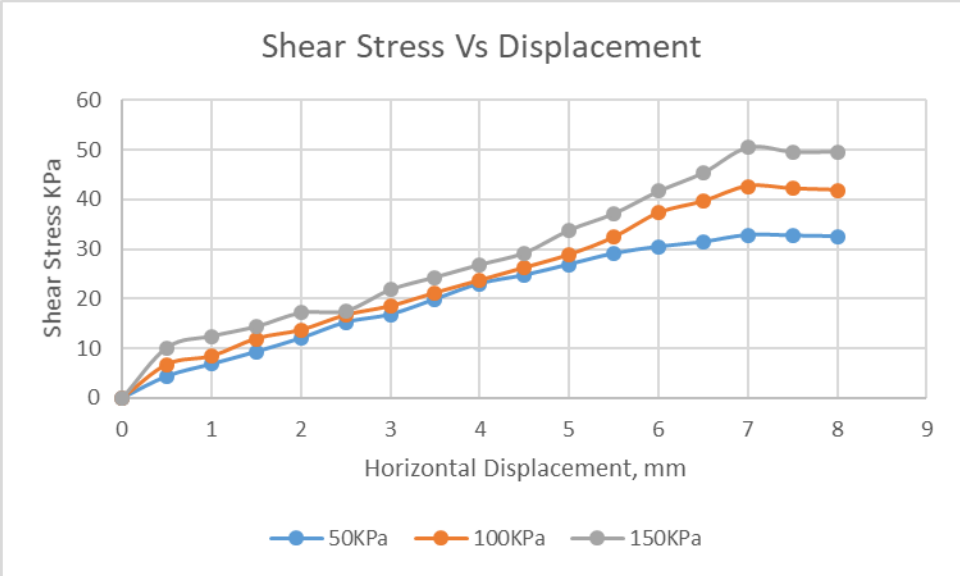
PEACK SHEAR STRESS VS NORMAL STRESS
y = 0.2143x + 18.68
SHEAR STRESS, KPA
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
NORMAL STRESS, KPA
c = 18.68
Φ = 12.1°

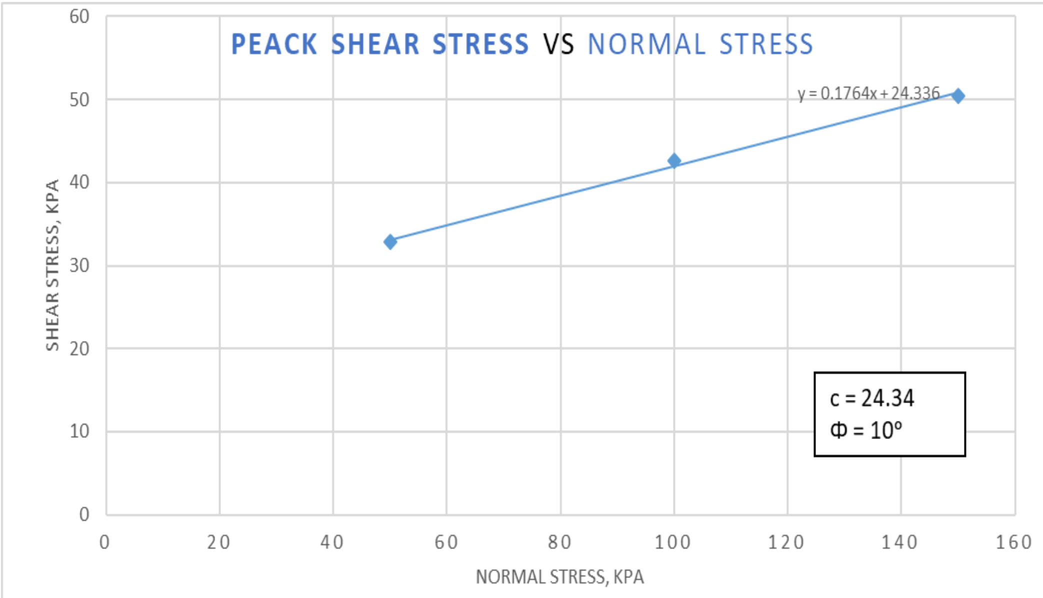
Test Pit 1 Depth 3.0 m		Ring Calibration Factor =0.70 N/div	Applied Vertical Stress 50 KPa			Applied Vertical Stress 100KPa			Applied Vertical Stress 150KPa		
Dial Gauge	Horizontal Displacement (mm)	Corrected Area (mm^2)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)
0	0	3600	0	0	0	0	0	0	0		0
50	0.5	3570	18	12.8	3.6	29	20.6	5.8	54	38.3	10.7
100	1	3540	28	19.9	5.6	41	29.1	8.2	64	45.4	12.8
150	1.5	3510	38	27.0	7.7	59	41.9	11.9	75	53.3	15.2
200	2	3480	46	32.7	9.4	67	47.6	13.7	89	63.2	18.2
250	2.5	3450	61	43.3	12.6	80	56.8	16.5	98	69.6	20.2
300	3	3420	74	52.5	15.4	89	63.2	18.5	110	78.1	22.8
350	3.5	3390	83	58.9	17.4	103	73.1	21.6	121	85.9	25.3
400	4	3360	98	69.6	20.7	115	81.7	24.3	134	95.1	28.3
450	4.5	3330	109	77.4	23.2	125	88.8	26.7	141	100.1	30.1
500	5	3300	117	83.1	25.2	137	97.3	29.5	165	117.2	35.5
550	5.5	3270	129	91.6	28.0	151	107.2	32.8	176	125.0	38.2
600	6	3240	134	95.1	29.4	172	122.1	37.7	195	138.5	42.7
650	6.5	3210	139	98.7	30.7	181	128.5	40.0	210	149.1	46.4
700	7	3180	145	103.0	32.4	193	137.0	43.1	236	167.6	52.7
750	7.5	3150	144	102.2	32.5	190	134.9	42.8	229	162.6	51.6
800	8	3120	141	100.1	32.1	187	132.8	42.6	225	159.8	51.2


Shear Stress Vs Displacement
Shear Stress KPa
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Horizontal Displacement, mm
50KPa
100KPa
150KPa

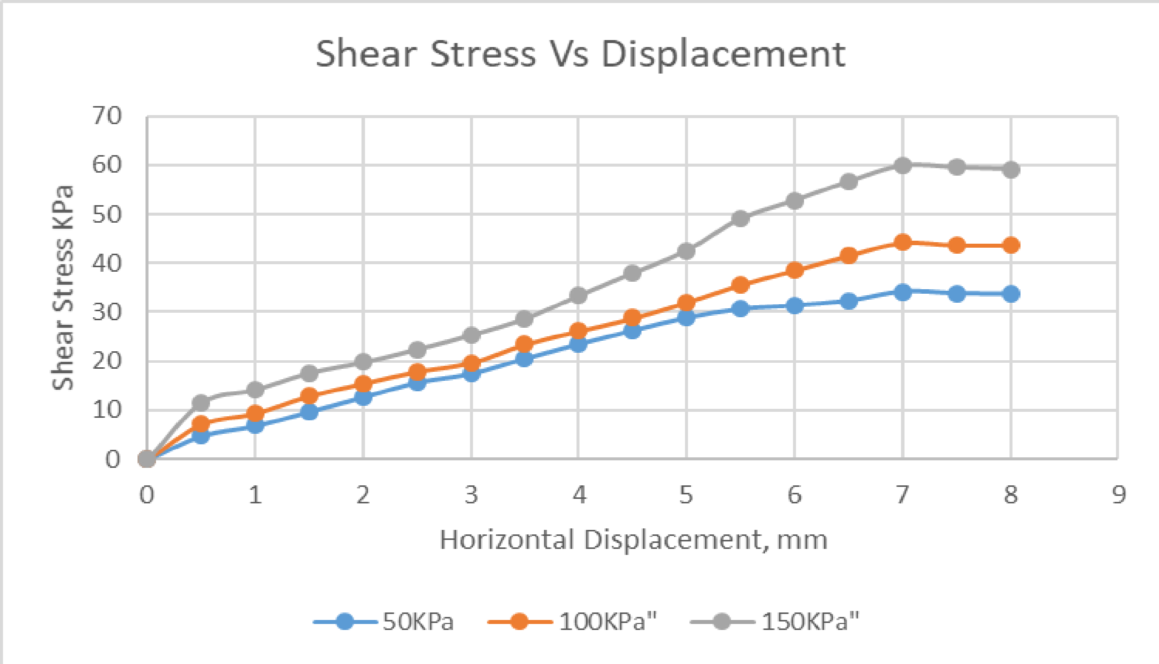

PEACK SHEAR STRESS VS NORMAL STRESS
y = 0.2023x + 22.512
SHEAR STRESS, KPA
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
NORMAL STRESS, KPA
c = 22.51
Φ = 11.44°

Test Pit 1 Depth 3.0 m		Ring Calibration Factor =0.70 N/div	Applied Vertical Stress 50 KPa			Applied Vertical Stress 100KPa			Applied Vertical Stress 150KPa		
Dial Gauge	Horizontal Displacement (mm)	Corrected Area (mm^2)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)
0	0	3600	0	0	0	0	0	0	0		0
50	0.5	3570	22	15.6	4.4	34.0	24.1	6.8	51	36.2	10.1
100	1	3540	34	24.1	6.8	42.0	29.8	8.4	62	44.0	12.4
150	1.5	3510	46	32.7	9.3	59.0	41.9	11.9	71	50.4	14.4
200	2	3480	59	41.9	12.0	67.0	47.6	13.7	84	59.6	17.1
250	2.5	3450	74	52.5	15.2	81.0	57.5	16.7	85	60.4	17.5
300	3	3420	81	57.5	16.8	89.0	63.2	18.5	105	74.6	21.8
350	3.5	3390	95	67.5	19.9	101.0	71.7	21.2	116	82.4	24.3
400	4	3360	109	77.4	23.0	112.0	79.5	23.7	127	90.2	26.8
450	4.5	3330	116	82.4	24.7	123.0	87.3	26.2	137	97.3	29.2
500	5	3300	125	88.8	26.9	134.0	95.1	28.8	157	111.5	33.8
550	5.5	3270	134	95.1	29.1	149.0	105.8	32.4	171	121.4	37.1
600	6	3240	139	98.7	30.5	170.0	120.7	37.3	190	134.9	41.6
650	6.5	3210	142	100.8	31.4	179.0	127.1	39.6	205	145.6	45.3
700	7	3180	147	104.4	32.8	191.0	135.6	42.6	226	160.5	50.5
750	7.5	3150	145	103.0	32.7	187.0	132.8	42.1	220	156.2	49.6
800	8	3120	143	101.5	32.5	184.0	130.6	41.9	218	154.8	49.6

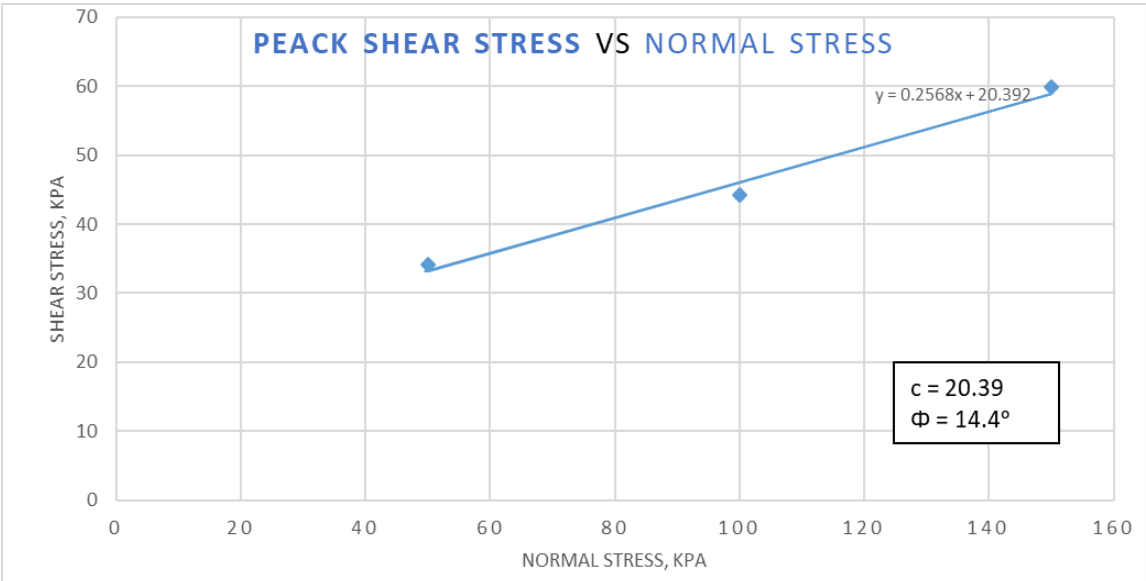

Shear Stress Vs Displacement
Shear Stress KPa
Horizontal Displacement, mm
50KPa
100KPa
150KPa


PEACK SHEAR STRESS VS NORMAL STRESS
y = 0.1764x + 24.336
SHEAR STRESS, KPA
NORMAL STRESS, KPA
c = 24.34
Φ = 10°

Test Pit 1 Depth 3.0 m		Ring Calibration Factor =0.70 N/div	Applied Vertical Stress 50 KPa			Applied Vertical Stress 100KPa			Applied Vertical Stress 150KPa		
Dial Gauge	Horizontal Displacement (mm)	Corrected Area (mm^2)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)
0	0	3600	0	0	0	0	0	0	0		0
50	0.5	3570	24	17.0	4.8	36.0	25.6	7.2	58	41.2	11.5
100	1	3540	34	24.1	6.8	47.0	33.4	9.4	71	50.4	14.2
150	1.5	3510	48	34.1	9.7	64.0	45.4	12.9	87	61.8	17.6
200	2	3480	62	44.0	12.6	76.0	54.0	15.5	97	68.9	19.8
250	2.5	3450	76	54.0	15.6	87.0	61.8	17.9	109	77.4	22.4
300	3	3420	84	59.6	17.4	95.0	67.5	19.7	122	86.6	25.3
350	3.5	3390	98	69.6	20.5	112.0	79.5	23.5	137	97.3	28.7
400	4	3360	111	78.8	23.5	124.0	88.0	26.2	158	112.2	33.4
450	4.5	3330	123	87.3	26.2	135.0	95.9	28.8	178	126.4	38.0
500	5	3300	134	95.1	28.8	149.0	105.8	32.1	198	140.6	42.6
550	5.5	3270	141	100.1	30.6	164.0	116.4	35.6	226	160.5	49.1
600	6	3240	143	101.5	31.3	176.0	125.0	38.6	241	171.1	52.8
650	6.5	3210	146	103.7	32.3	188.0	133.5	41.6	256	181.8	56.6
700	7	3180	153	108.6	34.2	198.0	140.6	44.2	268	190.3	59.8
750	7.5	3150	150	106.5	33.8	194.0	137.7	43.7	264	187.4	59.5
800	8	3120	148	105.1	33.7	192.0	136.3	43.7	260	184.6	59.2

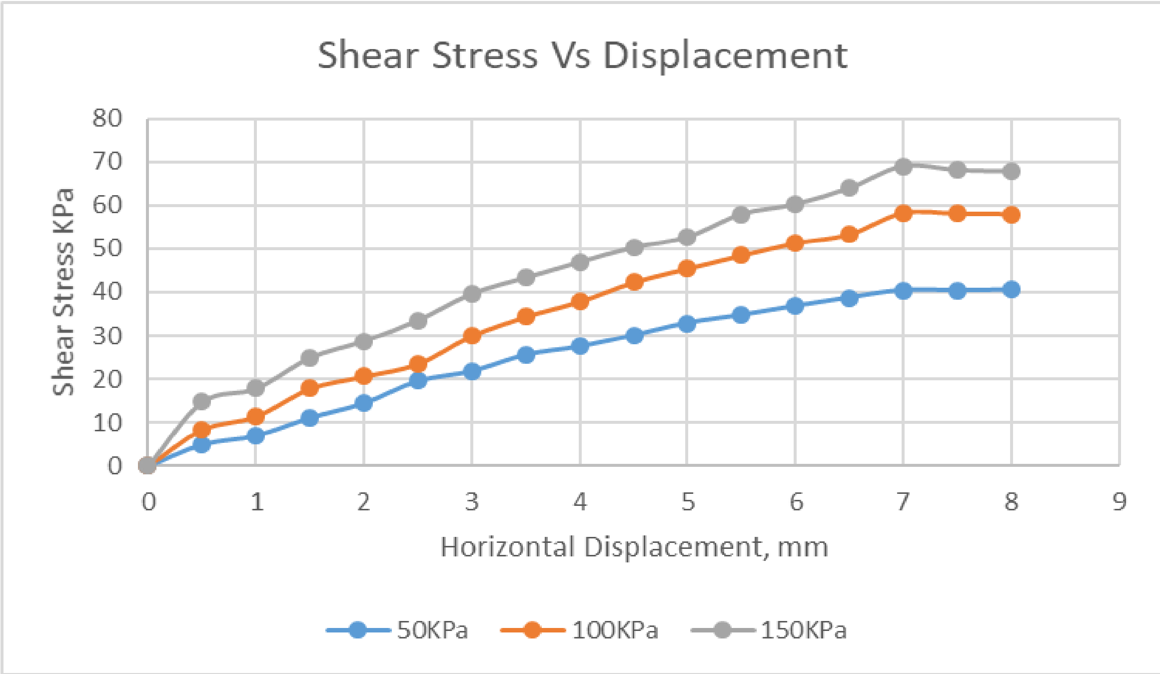


Shear Stress Vs Displacement
Shear Stress KPa
Horizontal Displacement, mm
50KPa
100KPa"
150KPa"

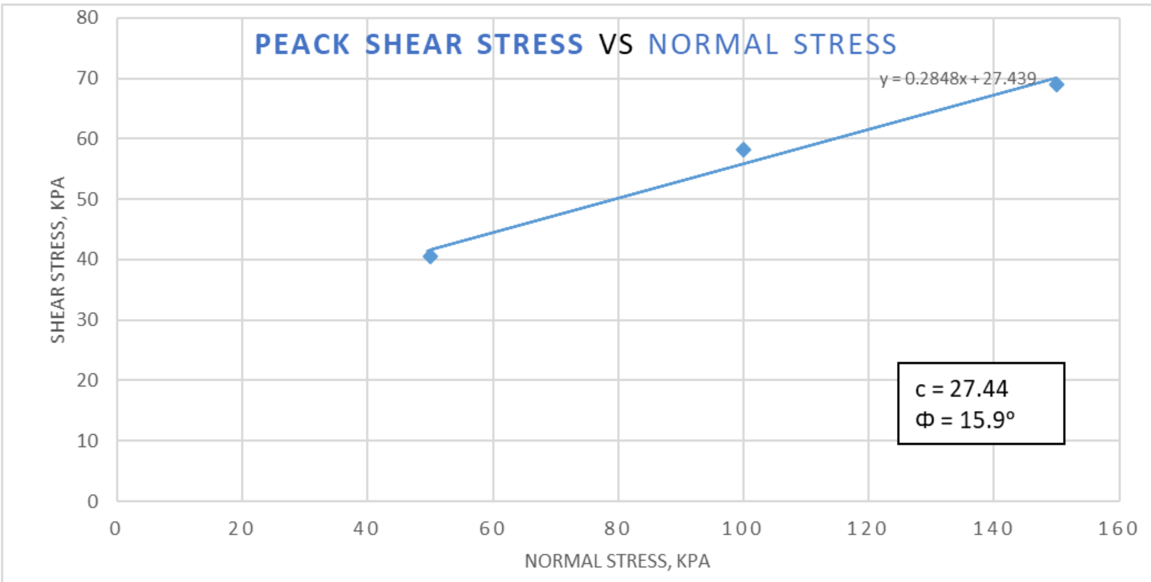


PEACK SHEAR STRESS VS NORMAL STRESS
y = 0.2568x + 20.392
c = 20.39
Φ = 14.4°
SHEAR STRESS, KPA
NORMAL STRESS, KPA

Test Pit 1 / Depth 3.0 m		Ring Calibration Factor =0.70 N/div	Applied Vertical Stress 50 KPa			Applied Vertical Stress 100KPa			Applied Vertical Stress 150KPa		
Dial Gauge	Horizontal Displacement (mm)	Corrected Area (mm^2)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)	Proving Ring Reading	Shear Load (N)	Shear Stress (KPa)
0	0	3600	0	0	0	0	0	0	0	0	0
50	0.5	3570	25	17.8	5.0	42	29.8	8.4	74	52.5	14.7
100	1	3540	35	24.9	7.0	57	40.5	11.4	89	63.2	17.9
150	1.5	3510	55	39.1	11.1	88	62.5	17.8	123	87.3	24.9
200	2	3480	71	50.4	14.5	101	71.7	20.6	141	100.1	28.8
250	2.5	3450	95	67.5	19.6	114	80.9	23.5	163	115.7	33.5
300	3	3420	105	74.6	21.8	144	102.2	29.9	191	135.6	39.7
350	3.5	3390	122	86.6	25.6	164	116.4	34.3	207	147.0	43.4
400	4	3360	130	92.3	27.5	179	127.1	37.8	222	157.6	46.9
450	4.5	3330	141	100.1	30.1	198	140.6	42.2	236	167.6	50.3
500	5	3300	153	108.6	32.9	211	149.8	45.4	245	174.0	52.7
550	5.5	3270	160	113.6	34.7	223	158.3	48.4	267	189.6	58.0
600	6	3240	168	119.3	36.8	234	166.1	51.3	275	195.3	60.3
650	6.5	3210	175	124.3	38.7	241	171.1	53.3	289	205.2	63.9
700	7	3180	181	128.5	40.4	261	185.3	58.3	309	219.4	69.0
750	7.5	3150	179	127.1	40.3	258	183.2	58.2	302	214.4	68.1
800	8	3120	178	126.4	40.5	255	181.1	58.0	298	211.6	67.8



Shear Stress Vs Displacement
Shear Stress KPa
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Horizontal Displacement, mm
50KPa
100KPa
150KPa



PEACK SHEAR STRESS VS NORMAL STRESS
y = 0.2848x + 27.439
c = 27.44
Φ = 15.9°
SHEAR STRESS, KPA
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
NORMAL STRESS, KPA