

**Determination of using Standard Penetration Test in Predicting
Index Properties and shear strength Parameters of fine-grained
Soils: In Case of Kombolcha Bypass Road**



Bontu Tegege

A Thesis Submitted to Department of Civil Engineering

School of Civil and Architecture

**Presented in Partial Fulfillment of the Requirement for the award of Degree
of Master's in Civil Engineering (Specialization in Geotechnical Engineering)**

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

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Advisor: Argaw Asha (PhD)

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DECLARATION

I declare that this thesis entitled **Determination of using Standard Penetration Test in Predicting Index Properties and shear strength parameters of fine-grained Soils: In Case of Kombolcha Bypass Road** is my work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **Determination of using Standard Penetration Test in Predicting Index Properties and shear strength parameters of fine-grained Soils: In Case of Kombolcha Bypass Road** prepared under my guidance by Bontu Tegege submitted in partial fulfillment of the requirement for the award of degree of Master of Science in Civil Engineering (Geotechnical Engineering). Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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I/we, the advisors of the thesis entitled “Determination of using Standard Penetration Test in Predicting Index Properties and shear strength parameters of fine-grained Soils: In Case of Kombolcha Bypass Road” developed by Bontu Tegene, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Abbreviation

AASHTO American Association of State Highway and Transportation

ASTM American Society for Testing and Materials

SPT-Standard Penetration Test

SG Specific gravity

NMC Natural Moisture Content

PI Plasticity Index

PL Plasticity Limit

LL Liquid Limit

Abstract

Soil properties can be determined through field and laboratory tests, with special techniques like undisturbed samples and initial overburden pressures needed. Field tests, like SPT, are conducted in original field soil, and soil strength and compressibility are crucial issues. Correlation between soil characteristics and load tests is essential for selecting appropriate tests. The prediction of index characteristics and shear strength parameters of fine-grained soils for the Kombolcha Bypass Road using the Standard Penetration Test is presented in this study. Soil properties are important for a variety of geotechnical engineering tasks. To determine these characteristics' values, certain techniques should be applied, such as using undisturbed samples and taking the original overburden pressures into account. It is difficult to get completely undisturbed samples due to handling, shipping, overburden pressure release, and poor laboratory conditions. Consequently, without the need for further laboratory testing, the standard penetration test (SPT) provides an excellent method to estimate some characteristics, such as the shear strength parameters (c & ϕ), for dry silty clay with sand soil. Standard penetration tests provide a general estimate of the soil's strength. The inexpensiveness and simplicity of use of this test is its biggest advantages and the main reasons it is so widely used. When appropriate-quality borehole samples are hard to come by, such those with clay and sand or gravel, the estimated shear strength parameters that may be calculated can come in handy. The main objective of this study is to determine the use of Standard Penetration Test in estimating the shear strength parameters (c & ϕ) and index properties (LL , PL , PI) of silty clay with sand soil. The relationship between the soils' shear strength characteristics and index properties in the research region is ascertained using linear regression analysis. To find the correlation required the standard penetration test (SPT) was corrected for field and dilatancy effect. The results of the study showed that the SPT number is a good estimator of the shear strength parameters of soil. This suggests that the SPTN-values can be used as indicator of the strength characteristics of fine-grained soils.

Key word: Fine-grained soil, (c & ϕ), LL , PL , PI , SPT, correction

1. INTRODUCTION

1.1. Back ground

Numerous methods have been developed for determination the soil properties. These methods include the field and laboratory tests. Also, to determine the real values of these properties, special techniques should be followed such as undisturbed samples and initial overburden pressures should be taken into consideration. On the other hand, field test such as SPT does not depend on undisturbed sample because it is carried out in original field soil. Most problems in soils and construction involve either the strength of the in-situ soil or the compressibility of the soil mass. People tend to have a negative opinion of clay soils. These soils may not drain quickly after heavy rain and often harden when dry. Most soils contain a mixture of clay, organic matter, sand and silt. A variety of tests are conducted to determine the properties of soils, especially for deep foundations. Correlation of soil characteristics, from soil investigation reports and corresponding load tests from actual projects constructed, is essential to decide the type of soil tests to be performed.

The Standard Penetration Test (SPT) is a common in situ dynamic testing method used to determine the geotechnical engineering properties of subsurface soils. It is a simple and inexpensive test to estimate the relative density of soils and approximate shear strength parameters. The test is carried out within a borehole. The results can be used to determine the relative density, bearing capacity, and settlement of granular soil. The results can also be used to correlate the approximate strength of cohesive soil.

SPT gives only the N value, which is not directly representative of any soil property, unless the N Value is correlated to the particular property under testing, such as density. Sometimes, multiple correlations must be resorted to, which makes the results susceptible to low quality. Apart from using rough correlations, there is a need to normalize the data to account for overburden pressure, sampling technique, and other factors. Although there are several correlations available in the literature to predict the properties and behavior of cohesive soils (clays/silts) by standard penetration test, the use of SPT values for predicting properties of cohesive soils is not considered very reliable

Moreover, for loose soils and soft clay soils, the blow count value will be very low and the sample gets significantly disturbed during SPT, giving rise to results under disturbed conditions, rather than under the original the intact soil conditions.

Soil characteristics vary from region to region sometimes its characteristics changes with few meters or kilometers. Every structure whether it is small or big on the earth, requires a strong and permanent base or support on which it stands firmly for a period. Soil fulfills that requirement of structure and the permanent and strong base as well as it provides stability of the structure. So, this is always big challenge to Geotechnical Engineer to analysis the engineering as well as Index property of the soil.

Index properties are known as the inductive of the engineering properties. Simple tests are required for index properties are known as classification test. The geotechnical engineer will be well known about the soil properties which of the engineering properties without conducting elaborate test. Based on the index properties, some information about engineering properties such as permeability, compressibility and shear strength can be estimated. It is also assumed that soils with like index properties have identical engineering properties.

The study area was defined in terms of soils and geology, physiography and drainage, climate, hydrogeology and seismicity. Common factors required for the prediction of soil type are rock type, climate, and topography. (Roy, 2006)

1.2. Statement of the problem

Estimation of engineering characteristics of soil are important parts in geotechnical works. As part of design stage, an engineer needs to determine the average value and variability of soil properties. The importance of in-situ testing in geotechnical engineering is undeniably increasing because most of laboratory tests are laborious, time consuming and costly (Mair R J and Wood D M , 1987). However, sometimes the outcomes are not accurate due the poor laboratory condition (Venkatasubramanian C and Dhinakaran G, 2011) Another long discussion is that the result of strength values determined from laboratory testing is not applicable to the in-situ soil mass due the scale effect.

Standard Penetration Test (SPT) is the one of the most common in-situ tests to identify soil type and stratigraphy along with being a relative measure of strength during site investigation. The SPT number could provide useful in-situ test data (K, Terzaghi and RB, Peck, 1967). The number of SPT might correlated with the consistency and density the soils encountered. Many studies have been developed to investigate the correlations between the number of blows, N with different soil properties including the relative density of sands, consistency and unconfined compressive strength of clays and allowable bearing pressure on sands and clays. According to (Kulhawy & Mayne, 1990), SPT data have been used to correlate the shear strength parameter such as cohesion and angle of friction angle of soil but (Bowels, 1997) and (Sherif Aggour & Rose Radding, 2014), recommend that the measured N value is standardized by multiplying it by the ratio between the measured energy transferred to the rod and 60 % of the theoretical free fall energy of the hammer. In this study, the relationships between SPT number and soil parameters such as Atterberg limit and shear strength parameters have been discussed to ensure that which of these parameters affect the SPT number.

1.3. Objective of the study

1.3.1. General objective

The major objective of this thesis is the use of standards penetration test in predicting the index properties and shear strength parameters of soil found in the study area.

1.3.2. Specific objective

- ❖ Effect of soil depth (D) below ground surface on SPT Number in determining shear strength parameters and index properties fine grained soils.
- ❖ Assessing the correlation between SPTN-values and Atterberg limits (LL, PL and PI) of fine-grained soils.
- ❖ Develop empirical equations to predict the shear strength parameters of soil using SPTN-value.

1.4. Significance of the study

The findings of this research are expected to provide valuable insights into the reliability of the standards penetration test in predicting the index properties and shear strength of fine-grained soils. Such knowledge will help geotechnical engineers better understand the properties of fine-grained soils and predict their behaviors during engineering projects. The results will also inform better procedures for using the standards penetration test in geotechnical investigations and soil behavior modeling.

1.5. Scope and Limitations of study

To study the reliability of using SPT test in predicting properties of clay and silty with sand soil, many boreholes and SPT at different depths were carried out. Many samples were obtained to determine experimentally the properties of soil. There are different parameters were taken into consideration such as depth of sample (D) below ground surface, SPT number (N), liquid limit (LL), Plastic limit (PL), plasticity index (PI) and shear strength parameters (c & ϕ). In this study, the relationships between corrected SPT number (N_{60}) and all previous parameters have been discussed to make sure that which of these parameters affect the SPT. The effect of mineral content and percent of fineness of clay soil is not the scope of this study. And, the analysis method is limited to linear regression.

2. LITERATURE REVIEW

2.1. Standard penetration testing

The standard penetration test, commonly known as ‘SPT, was developed to provide geotechnical engineering properties for foundation design purposes. The test is carried out within a borehole. The results can be used to determine the relative density, bearing capacity, and settlement of granular soil. The results can also be used to correlate the approximate strength of cohesive soil.

Standard penetration test is an in-situ dynamic penetration test that measures the resistance of the soil to penetration of the sampler. The SPT is a simple and rugged test suitable for most soil types and is usually performed using a conventional geotechnical drill rig (Sabatini & Bachus, 2002)

It is made by dropping a free-falling hammer onto the drill rods from a specific height to achieve the penetration of a standard sample tube to the soil (Mwajuma I.L., 2015)

In cohesive soil the test involves driving a 50mm diameter split-barrel (spoon) sample tube into the ground to recover a disturbed sample. In granular soil, a solid 60-degree cone replaces the split-barrel. The split-barrel or solid cone is driven using a sliding hammer with a mass of 63.5kg falling through 760mm. The test is advanced in six 75mm increments and the number of blows required to drive the last 300mm of penetration is termed the “standard penetration resistance” or “N-value”. The penetration resistance during the first 150mm of penetration is ignored, because the soil is considered to have been disturbed by the action of boring the hole. In cases where 50 blows are insufficient to advance the sample tube through a 300mm interval the penetration after 50 blows is recorded.

According to (Aggour & Radding, 2000) the earliest credits for the SPT are attributed to Mohr and to Terzaghi. The standard penetration test, developed around 1927, is currently the most popular and economical means to obtain subsurface information (Bowels, 1997). The split soon Harry Mohr (a subsidiary of the Raymond concrete pile) first introduced sampler, and the other by Sprague and Henwood. The sample tube has a 2-in diameter and were driven into the bottom of the borehole by repeated blows of a weight lifted by two men by hand, without the use of any powdered winch equipment (Clayton, 1995)

In cohesive soil, the sample remaining inside the split-barrel is recovered after the test. The sample is only suitable for visual examination and identification. If engineering properties like strength or compressibility parameters are, required undisturbed samples of the cohesive soil will be recovered. If very silt clay, very sandy clay or hard clay, is encountered the undisturbed sampling should be alternated with standard penetration tests to correlate the soil strength.

In granular soils if the test is carried out below the groundwater level, the N-values may indicate the relative density is loose. In these circumstances, it may be appropriate to continue driving the sampler beyond the specified distance. This additional drive is not a standard test, but it does provide an indication as to whether the deposit is as loose as the initial N-value has indicated.

The SPT has been used in almost every part of the world. The Standard penetration test was first “standardized” by the American Society for Testing Materials in the USA in 1958 with periodic revisions to date (Clayton, 1995). The method was further standardized with the most recent update in 1999.

Ethiopia has not established its own SPT standard and as a result, companies are adopting different standards from other country practice. The standards widely applied in Ethiopia are American standard (ASTM D1586: 2008) and Britain standard (BS 1377: 1975). Applying other’s country SPT standards, which have different soil types, climate and hydrogeology leads to untrustworthy result. To reduce the significant variability of the SPT N-value due to the large variation in energy delivered and other factors, it has been recommended that the N-value be standardized to a specific value using correction factors.

Bowles also describes SPT test procedures and correction factors in Foundation Analysis and Design presented in 1997. The other literature that reviewed is Standard Penetration Test Correction presented by (Aggour & Radding, 2000) which mainly describe about the correction factors that mainly applied in the adjustment of standard penetration test.

Many researchers were investigating on the performance of the SPT for evaluating the sources of uncertainty including (Schmertmann, 1975) and (Kulhawy & Mayne, 1990), are mentioned that sources of uncertainty which includes sources depending on encountered soil, due to presence of water, sources related to equipment and its maintenance and site investigation procedure (Rabie & Albata, 2012)

2.1.1. Procedure of SPT

- ❖ The bore hole is to be drilled up to the desired depth
- ❖ The drilling tools are removed and sampler is lowered to the bottom of the hole
- ❖ Three markings at 150mm are made on the rod of sampler
- ❖ The sampler is driven into the soil by the drop hammer falling through the height of 150mm at 30 blow/minimum
- ❖ The number of blows required to drive each 150mm of the sampler is counted
- ❖ The number of blows recorded for the first 150mm is disregarded
- ❖ The number of blows recorded for the last two 150mm intervals are added to give the standard penetration number(N)
- ❖ Likewise, another sample of soil are collected at the interval of 1.67m or where the soil profile or strata changes

One advantage of the SPT tests is that the drillers can collect samples for further classification and laboratory testing. Another advantage of this simple and economical test is the significant body of research that has been done to correlate empirically the SPT N values with geotechnical design parameters such as soil density, consistency, friction angles, undrained shear strength, Young's modulus, shear modulus, settlement of shallow and deep foundations in sand, bearing capacity values, and to provide an index of soil liquefaction resistance. Thus, the N value saves money by reducing laboratory testing. Unfortunately, the SPT test is anything but standard. (Sherif Aggour & Rose Radding, 2014)

It is important to point out that several factors contribute to the variation of the standard penetration number "N" at a given depth for similar soil profiles. Among these factors are the SPT hammer efficiency, borehole diameter, sampling method, rod length, water table and overburden pressure important. The most two common types of SPT hammers used in the field are the safety hammer and donut hammer. They are usually dropped using a rope with two wraps around a pulley.

Usually, SPT is conducted at every 1.5 m or 2 m depth or at the change of stratum. In hard formations, the testing is discontinued if N value is found to be over 100 and it is termed refusal.

2.1.2. Termination of Standard Penetration Test (SPT)

The test can be terminated if the following three conditions appear in the field.

- ❖ A total of 50 blows have been applied during any one of the three 150 mm increments.
- ❖ A total of 100 blows have been applied.
- ❖ There is no observed advance of the sampler during the application of 10 successive blows of the hammer.

2.1.3. Correction of Standard Penetration Test (SPT)

The use of SPT correction factor is often confusing. Corrections for field procedures (Energy Correction) are always appropriate, but the overburden pressure correction may or may not be appropriate depending on the procedures by those who developed the analysis method under consideration.

2.1.4. Correction of SPT Value for Field Procedures

Based on field observations, it appears reasonable to standardize the field SPT number as a function of the input driving energy and its dissipation around the sampler around the surrounding soil. The variations in testing procedures may be at least partially compensated by converting the measured N to N_{60} as follows (Skempton, 1986).

$$N_{60} = \frac{E_H C_B C_S C_R N}{0.60} \dots \dots \dots \text{Equation 2.1}$$

Where, N_{60} = Corrected SPT N – value for field procedures

E_H = Hammer efficiency

C_B = Borehole diameter correction

C_S = Sampler correction

C_R = Rod length correction

N = Measured SPT N – value in field

This correction is to be done irrespective of the type of soil.

Table 2.1: Correction table for field procedure of SPT N-value

| SPT Hammer Efficiencies (BNBC 2015 Table 6.D.4) | | |
|---|---|-------------------------------------|
| Hammer Type | Hammer Release Mechanism | Efficiency, E_H |
| Automatic | Trip | 0.70 |
| Donut | Hand dropped | 0.60 |
| Donut | Cathead+2 turns | 0.50 |
| Safety | Cathead+2 turns | 0.55-0.60 |
| Drop/Pin | Hand dropped | 0.45 |
| Borehole, Sampler and Rod Correction Factors (BNBC 2015 Table 6.D.5) | | |
| Factor | Equipment Variables | Correction Factor |
| Borehole Dia Factor, C_B | 65 – 115 mm (2.5-4.5 in) | 1.00 |
| | 150 mm (6 in) | 1.05 |
| | 200 mm (8 in) | 1.15 |
| Sampler Correction, C_S | Standard sampler | 1.00 |
| | Sampler without liner (not recommended) | 1.20 |
| Rod Length Correction, C_R | 3 – 4 m (10-13 ft) | 0.75 |
| | 4 – 6 m (13-20 ft) | 0.85 |
| | 6 – 10 m (20-30 ft) | 0.95 |
| | >10 m (>30 ft) | 1.00 |

2.1.5. Correction of SPT Value for Overburden Pressure

In cohesionless soils, the overburden pressure affects the penetration resistance. For SPT made at shallow levels, the values are usually too low. At a greater depth, the same soil at the same density index would give higher penetration resistance. It was only as late as in 1957 that Gibbs & Holtz (1957) suggested that corrections should be made for field SPT values for depth.

As the correction factor came to be considered only after 1957, all empirical data published before 1957 like those by Terzaghi is for uncorrected values of SPT. Since then, several investigators have suggested overburden correction. Gibbs & Holtz took standard pressure of 280 kN/m^2 (corresponding to a depth of 14 m) and duly made overburden correction for other overburdens. Thornburn suggested a standard pressure of 138 kN/m^2 (corresponding to a depth

of 7 m). Finally, Peck et. al. (1974) suggested a standard pressure of 100 kN/m² (Equivalent to 1 tsf or 1 kg/cm² overburden corresponding to a depth of 5 m). As such, all field SPT values are to be corrected by the correction factor given by them as

$$(N_1)_{60} = C_N \times N_{60} \leq N_{60} \dots\dots\dots Equation 2.2$$

C_N =Overburden pressure correction factor

$$C_N = \sqrt{\frac{100}{\sigma'_0}}$$

Where, σ'_0 is in kPa

2.1.6. Correction of SPT Value for Water Table

In addition to corrections of overburden, investigators suggested corrections of SPT-value for water table in the case of fine sand or silt below water table. Apparently, high N-values may be observed especially when observed value is higher than 15 due to dilatancy effect. In saturated, fine or silty, dense or very dense sand the N-values may be abnormally great because of the tendency of such materials to dilate during shear under undrained conditions. The pore pressure affects the resistance of the soil and hence the N value. In such cases, following correction is recommended (Terzaghi and Peck, 1948).

$$(N_1)_{60(CORR)} = 15 + 1/2[(N_1)_{60} - 15] \dots\dots\dots Equation 2.3$$

For coarse sand this correction is not required. In applying this correction, overburden correction is applied first and then this dilatancy correction is used.

2.2. Index property tests

In nature, soil occurs in a large variety. Engineers are continually searching for simplified tests that will increase their knowledge of soils by employing a simple and rapid soil test. These simplified tests which are indicative of the engineering properties of soils are called index properties (Arora, 2004) Index properties of cohesive soils are used to characterize the physical and mechanical behavior of soils by making use of parameters such as moisture content, specific gravity, particle size distribution, Atterberg limits and moisture-density relationships. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties (ASTM D 2166: 2004) the strength and compressibility characteristics of cohesive

soils are functions of water content. As such, water content is an important factor in understanding the aggregate behavior of cohesive soils (Murthy, 1977)

2.2.1. Soil classification

Soils exhibiting similar behavior can be grouped together to form a particular group under different standardized classification systems. A classification scheme provides a method of identifying soils in a particular group that would likely exhibit similar characteristics. There are different classification schemes such as USCS and AASHTO classification systems, which are used to specify a certain soil type that is best suitable for a specific application. These classification systems divide the soil into two groups: cohesive or fine-grained soils and cohesion-less or coarse-grained soils.

2.2.2. Grain size analysis

For coarse grained materials, the grain size distribution is determined by passing soil sample either by wet or dry shaken through a series of sieves placed in order of decreasing standard opening sizes and a pan at the bottom of the stack. Then the percent passing on each sieve is used for further identifying the distribution and gradation of different grain sizes. Particle size analysis tests are carried out in accordance to AASHTO.

2.2.3. Moisture content

Change in moisture content is the most influential parameter that affects the property of soils. Moisture content is defined as the ratio expressed as a percentage of mass of water to mass of soil solids. The moisture content test is carried out in laboratory as per the procedures of AASHTO T 265 or ASTM D 2216 and in field according to AASHTO T 217.

2.2.4. Atterberg limits

The three Atterberg limits, which are liquid limit, plastic limit, and shrinkage limits are the boundary between each of the two consecutive states of the soil-water phases.

Liquid limit: The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state. The liquid limit of a soil highly depends upon the

clay mineral present. The conventional liquid limit test is carried out in accordance of test procedures of AASHTO T 89 or ASTM D 4318. A soil containing high water content is in the liquid state and it offers no shearing resistance (Fredrics, 1983)

Plastic limit: The plastic limit (PL) is the water content, expressed in percentage, below which the soil stops behaving as a plastic material and it begin to crumble when rolled into a thread of soil of 3.0 mm diameter. The conventional plastic limit test is carried out as per the procedure of AASHTO T 90 or ASTM D 4318. The soil in the plastic state can be remolded into different shapes. When the water content is reduced the plasticity of the soil decreases changing into semisolid state and it cracks when remolded.

Plastic index: is defined as the difference between liquid limit and plastic limit. Plasticity index is the range of water content over which the soil remains in the plastic state. When ether liquid limit or plastic limit cannot determine, the soil is non-plastic. When the plastic limit is greater than the liquid limits the plasticity index is reported as zero (not negative). The test is carried out as per the procedure of AASHTO T 92 or ASTM D 427.

The amount of water, which must be added to change a soil from its plastic limit to liquid limit, is an indication of the plasticity of the soil. The degree of plasticity is measured by the plasticity index (PI), which is the numerical difference between liquid limit and plastic limit ($PI=LL - PL$). The greater the plasticity index means that the soil is more plastic, compressible and the greater volume change characteristic of the soil.

The liquid limit, plastic limit and plasticity index parameters are an integral part of several engineering properties and characterize the fine-grained fractions of construction materials. The shear strength of a fine-grained soil mainly depends on the consistency of the soil.

Effective Stress: It is the stress transferred via grain to grain at the contact point by soil mass and is indicated by'. Whenever a soil mass is pressed, the weight is transmitted to the soil grains via their point of contact. Whereas if effective load at the point of contact is higher than the resistance of the grains, the soil mass will compress. This is owing to elastic compression of the grains just at site of contact, and relative particle sliding. Effective stress is the load per unit area of soil mass that is prone to soil mass displacement.

Cohesive strength(C) of a soil is a crucial aspect of soil consistency. It refers to the cohesive force that takes place between adjacent particles. Cohesion means "the shear strength (S_u) when the compressive stresses are equal to zero". Here we have taken the unconfined compressive strength (q_u) also in consideration. We are taking the half value of q_u as Cohesion (C)

The frictional angle (ϕ) is also a crucial parameter for its uses in finding the lateral pressure and bearing resistance of soil.

2.3. Existing Correlation between SPTN & Cohesion C

First study to determine the relationship between C and SPT-N was done by (K, Terzaghi and RB, Peck, 1967). They proposed following equation for fine grained soil

$$C = 6.25 N$$

Where, C = Cohesion in KPa

(Here N=field SPT N value for limited range)

Table 2.2: Relation of Consistency of Clay, Number of Blows N_{60} on Sampling Spoon and Unconfined Compressive Strength (K, Terzaghi and RB, Peck, 1967)

| Consistency | q_u (kPa) | | | | | |
|-------------|-------------|-------|--------|---------|------------|------|
| | Very Soft | Soft | Medium | Stiff | Very Stiff | Hard |
| N_{60} | <2 | 2-4 | 4-8 | 8-15 | 15-30 | >30 |
| q_u | <25 | 25-50 | 50-100 | 100-200 | 200-400 | >400 |

Stroud (1974) examined different relationships and proposed correlation in terms of Plasticity Index (PI) for the first time.

This research shows increase in Plasticity Index decreases the value of Cohesion (C)

$$C = (6-7) N, \text{ When } PI < 20$$

$$C = (4-5) N, \text{ When } 20 < PI < 30$$

$$C = 4.2 N, \text{ When } PI > 30$$

Where, C = Cohesion in kPa and PI = Plasticity Index (Here N=field SPT N value for limited range)

In 2013 Mostafa Abdou Abdel Naiem Mahmoud studied the reliability of using SPT test to predict the properties of silty clay with sandy soil. Standard penetration test was carried out in 100 locations to depths between 10-15m below ground surface. Specimens with different field SPT numbers have been taken for laboratory test. To determine the shear strength parameters (C & Ø), direct shear test was done. From the regression analysis the following equation was found:

$$C = 0.014 N^{0.18}$$

Where, C = Cohesion in Kg/cm², N' = Corrected N value.

In 2016 Kumar proposed a relation using random number generation method between field SPT-N value & Cohesion KPa.

$$C = -2.2049 + 6.484N$$

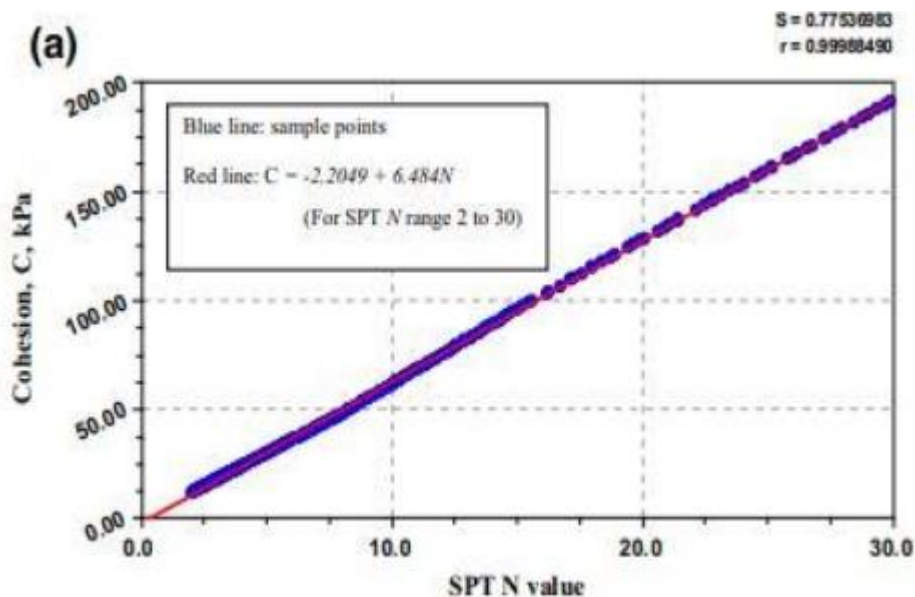


Figure 2.1: plot of 200 pair of data points of SPT-N & Cohesion of Cohesive Soil (Kumar,2016).

In 2018 N.Q.A.M. Yusof & H. Zabidi studied the soil of Pahang, Malaysia to check the reliability of predicting properties of soil from SPT-N.

The study area is in the State of Pahang, in the district of Cameron Highlands. Samples collected from 14 boreholes. Borehole depth was 1.5 to 15m. Triaxial test was conducted in the laboratory

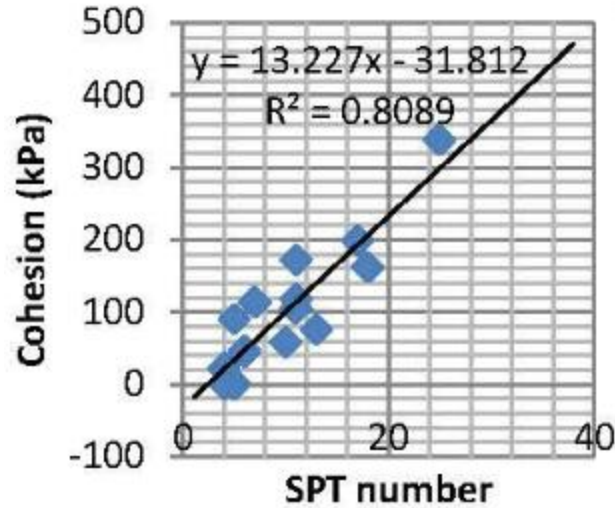


Figure 2.2: After performing regression analysis using the test results between SPT-N & Cohesion (N.Q.A.M. Yusof, H.Zabidi, 2018)

After performing regression analysis using the test results, the regression co-efficient was found more than 0.7 which Indicates the reliability of pretending cohesion from SPT-N.

In 2021 Mustafa Najdat Kasim and Aram Mohammed Raheem proposed a relation using random number generation method between field SPT-N value & Cohesion KPa.

Based on the used random number generation technique, around 300 data point has been created to simulate the relation between the cohesion versus the SPT-N values. A correlation has been built between the random generated values of soil cohesion with their corresponding SPT-N values as follows:

$$C(kPa) = 6.5808 * N - 9.079 (R^2 = 0.9942)$$

Where: C is the cohesion (kPa), and N is SPT-values.

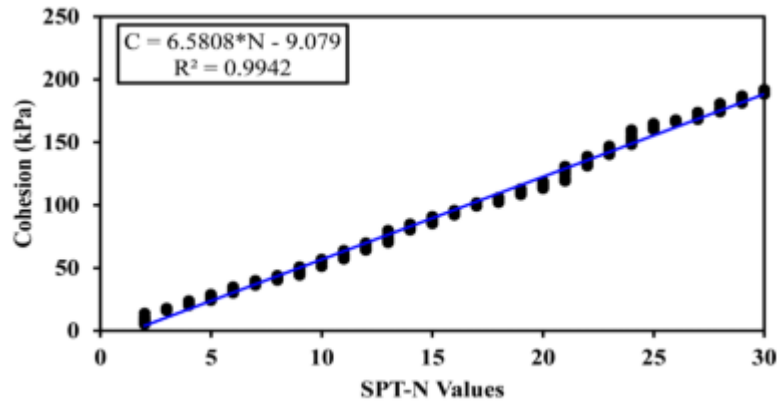


Figure 2.3: The random distribution of soil cohesion with SPT-N values (Mustafa Najdat Kasim and Aram Mohammed Raheem, 2021).

2.4. Existing Correlations between SPT N & frictional angle

The angle of friction is estimated by using empirical equation using the SPT N value from field. The existing equations on this parameter are mentioned below:

The empirical equation developed by Peck in 1953.

$$\Phi = (0.3N)^{0.5} + 27 \text{ (Here } N = \text{field SPT N value for limited range)}$$

In 1989 Wolf approximated the equation of Peck (1974). Which is-

$$\Phi = 27.1 + 0.3N_{60} - 0.00054(N_{60})^2$$

(N_{60} = Corrected SPTN value for 60% hammer efficiency)

In 2016 Kumar proposed relation using random number generation & curve expert for 200 samples and obtained the relation based on field SPT N value ranging 4 to 50.

$$\phi = 0.2857 * N + 27.12 \text{ (} R^2 = 0.998 \text{)}$$

The higher R^2 value represents higher predictability of the model.

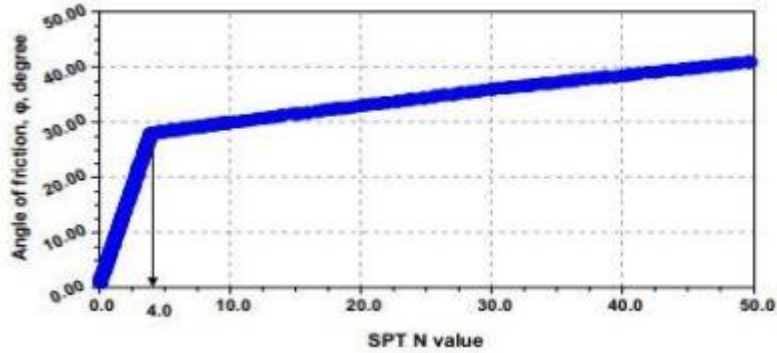


Figure 2.4: plot of 200 data points of SPT-N value & angle of friction (Kumar et.al.,2016).

In 2018 Yusof conducted study on 32 samples obtained from 14 boreholes of Malaysia’s Pahang state.

The relation was proposed based on field SPT-N value.

$$\Phi = 0.481 N + 29.174, R^2 = 0.7903$$

The higher R^2 value indicates higher predictability of proposed model.

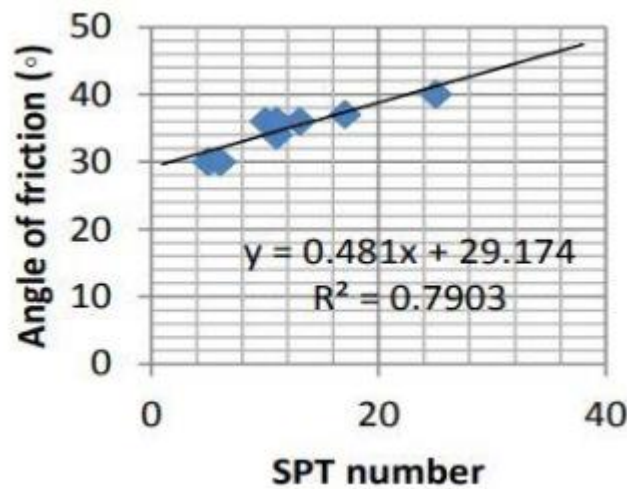


Figure 2.5: the relation between SPT-N number & angle of internal friction (**N.Q.A.M. Yusof, H.Zabidi, 2018**).

In 2021 Mustafa Najdat Kasim and Aram Mohammed Raheem proposed a relation using random number generation method between field SPT-N value & Cohesion KPa.

Based on the used random number generation technique, around 300 data point has been created to simulate the relation between the angles of internal friction versus the SPT-N values. A correlation has been developed between the random generated values of soil angle of internal friction with their corresponding SPT-N values as follows:

$$\phi(\text{°}) = 0.8531 * N + 0.1581, (R^2 = 0.9963)$$

Where: ϕ (°) is the angle of internal friction, and N is SPT-values.

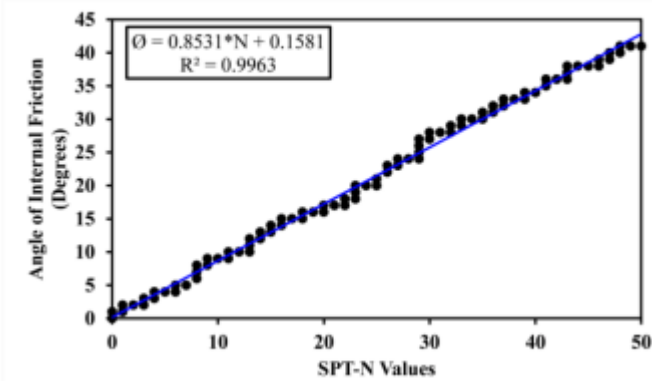


Figure 2.6: The random distribution of soil angles of internal friction with SPT-N values (Mustafa Najdat Kasim and Aram Mohammed Raheem, 2021).

3. Materials and Methods

3.1. General Description of the Study Area

The project is in Amhara Regional State, South Wollo Zone, Kombolcha Town. Kombolcha is a town and district in north-central Ethiopia. Located in the Debub Wollo Zone of the Amhara Region, it has a latitude and longitude of with an elevation between 1842 and 1915 meters above sea. Some guide books describe Kombolcha as the twin town of Dessie which lies some 12 kilometers (7.5 mi) to the northwest. The road traverse mainly through rolling terrain above 90% is inaccessible section. The project road crosses Borkena River, Railway Bridge, agricultural lands and settlements having steep gradients at some location bypassing the town at the LHS. The location Map of the project is presented in Figure 3.1 below.

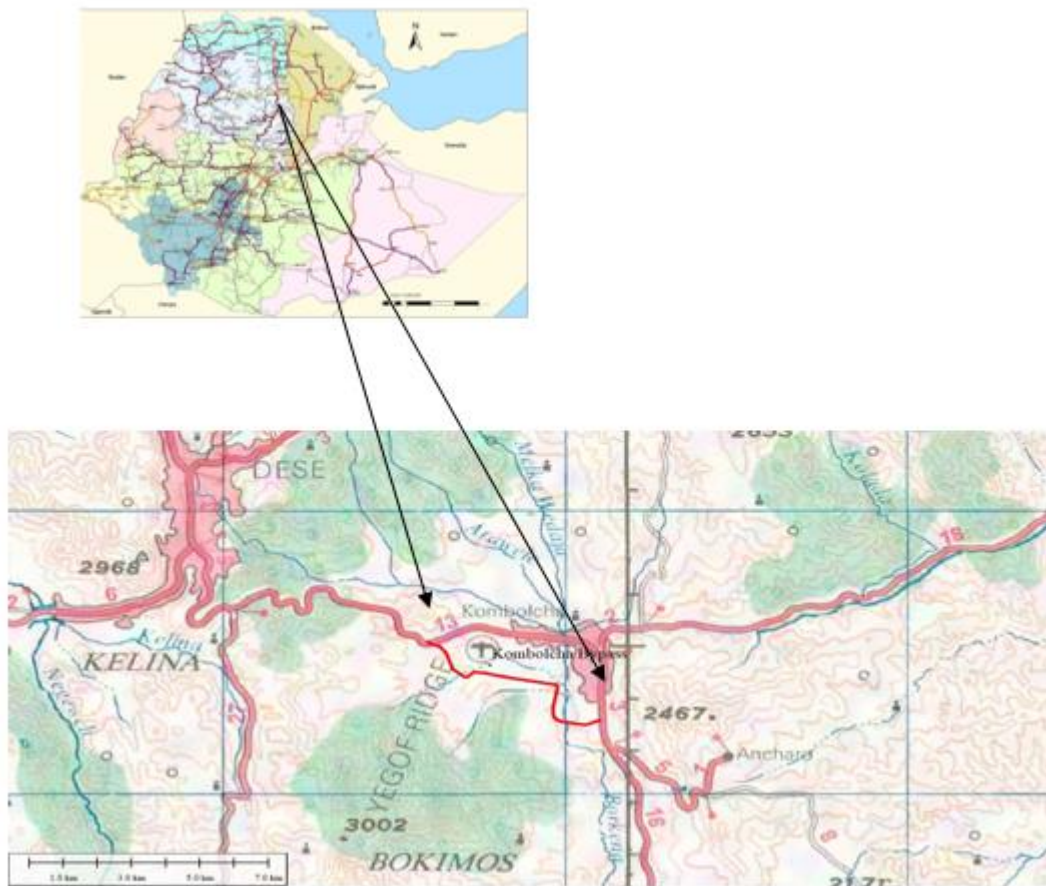


Figure 3.1: Location of the study area.

3.1.1. Topography and Climate

The project area has dominantly traversed through rolling terrain.

Based on climatic classification in Ethiopia, the project corridor is in C3 weina Dega climatic zone. The mean monthly annual rainfall varies from 12mm to 299mm in the project area. It receives relatively light rainfall in the month of October to June. The main rainy season in the area is from July to October and its average annual rainfall ranges from 500mm to 1000mm. According to Ethiopian Metrological data, the monthly maximum temperature ranges between 23 °C to 30 °C, and the minimum between 8 °C to 14 °C.

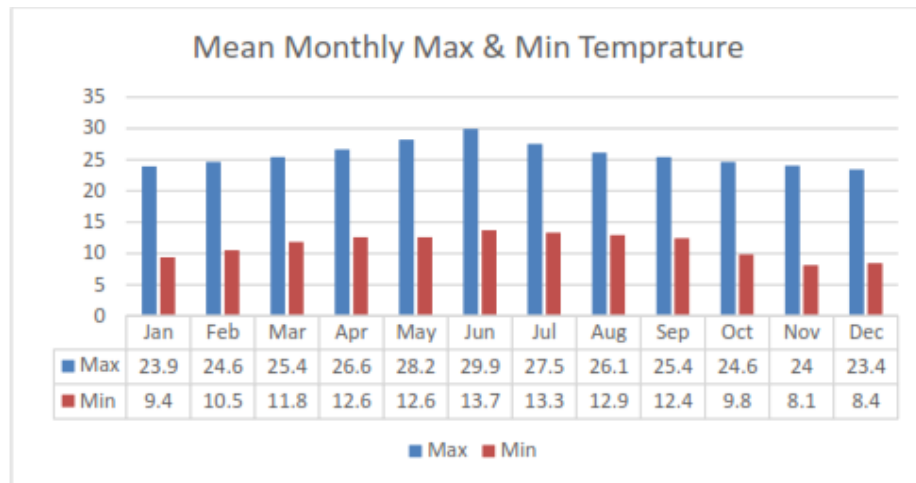


Figure 3.2: Maximum and Minimum Temperature of Kombolcha.

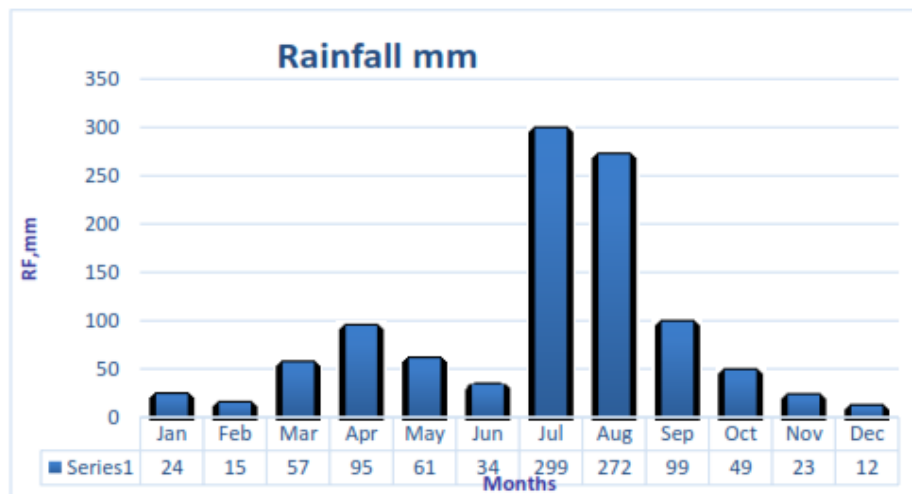


Figure 3.3: Mean Monthly rainfall for Kombolcha.

3.1.2. Regional and Local Geology

According to the Geological Map of Desie Sheet compiled by Lulu Tsige et.al 2007 with a scale of 1: 250,000, the geology of the project area is described below.

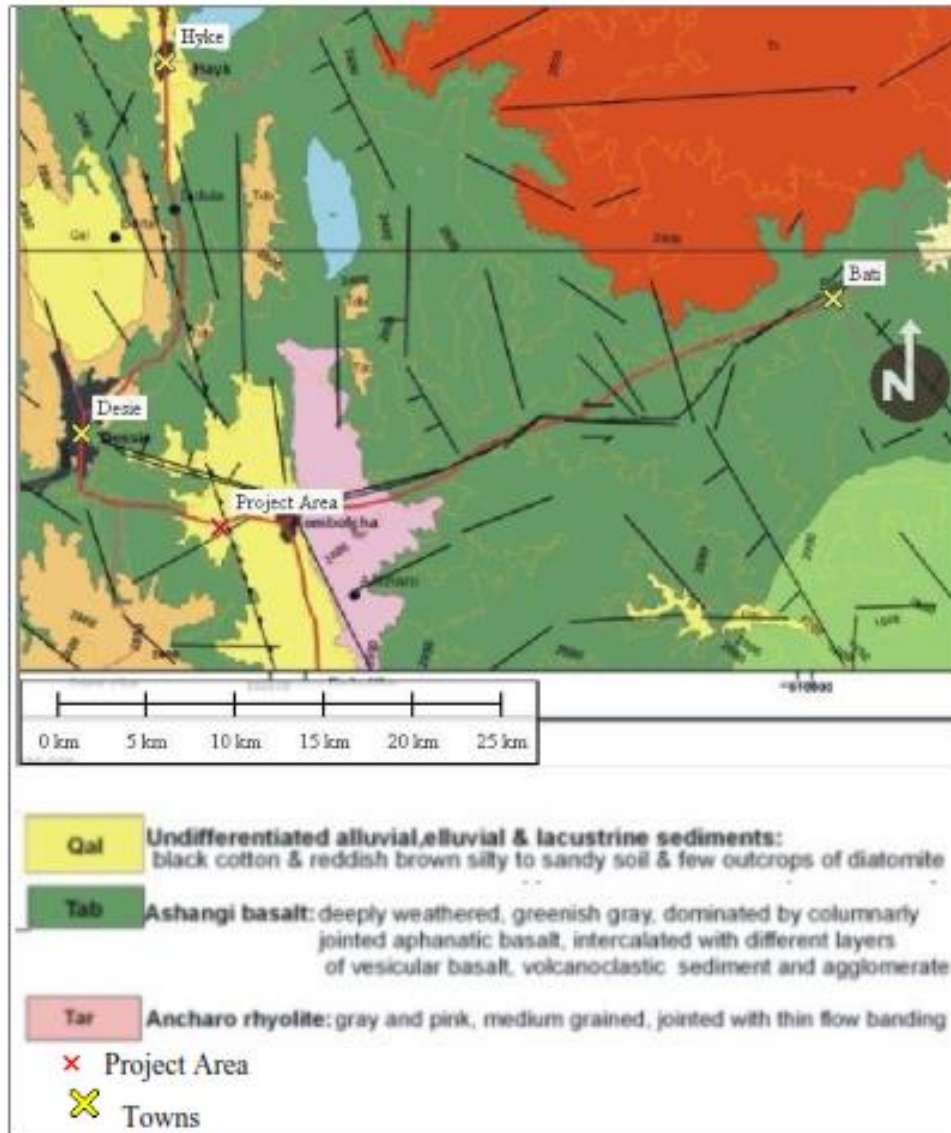


Figure 3.4: Regional geological map of the study area

The regional geologies of the area are classified as follows:

A. Undifferentiated Alluvial, Elluvial and Lacustrine Sediments (Qal)

These are exposed in the eastern low land plain and in the central part along the western Afar marginal basin. They are represented by black cotton and reddish brown silty to sandy soil with

few outcrops of diatomite. The black cotton soil is commonly seen along the western marginal basins. The thickness of the soil is more than 3 m as observed along the main road. Reddish brown sandy soil is mainly seen on the plain on the top of the western plateau and on the eastern low land plain of the Afar rift floor. The lacustrine sediment is 1m thick weathered gray, horizontally thinly laminated to thickly laminated and bedded diatomite exposed along the Afar rift floor in the southeastern part.

B. Ashange basalt (Tab)

The Ashangie basalts represent the earliest fissural volcanism in the Dessie area (e.g. Tefera et al., 1996). They are exposed in the western plateau and the western Afar marginal area. The basalts attain a maximum thickness of ~1000 m along Beshilo river section. Its thickness decreases towards south (< 200m) along Dessie Kombolcha Road. These basalt flows represent the lower most parts of volcanic successions. They are exposed along the deep river gorges of NE-SW trending Zita and Beshilo and NWSE trending Gerado rivers and their tributary streams in the western plateau area.

The Ashangie basalts are also exposed as faulted block along NW-SE trending escarpment. They are found as continuous and patchy outcrops with sheet and blocky forms. The Ashangie basalt is exposed along road cuts, stream beds, gentle and steep slopes of undulating mountain chains and low-lying flat plains. Its lower contact with the underlying unit is not seen in the area. The unit is unconformably overlain by the Wegel Tena rhyolite and / or ignimbrite and Dessie basalt formation. Their contact with the Wegel Tena rhyolite is clearly observed on Wegel Tena and Kombolcha and Dessie-Hayk Road at an elevation ~2300-2500 m a. s. l. This paleosoil has undulating nature related to the paleotopography and sometimes faulted. The basalts are characterized by strong weathering, different directional tilting, columnar jointing, intense fracturing and crushing. In many of its exposure it is dominated by inclined columnarly jointed aphanatic basalts. The unit also contains intercalated layers of agglomerate and volcanoclastic sediments on the Beshilu section.

Megascopically the rock is black, dark gray and greenish gray in color. Texturally it varies from the aphanatic, medium to coarse grained. It has greenish alteration zones seen along the fracture

zones, in the pyroclasts and along its contact with the overlying rhyolite. The vesicles (3-5 cm in size) are common in this unit filled by the secondary calcite.

Petrographically, the Ashangie basalt unit is classified in to three sequences. These are Vesicular augite-plagioclase phyric basalt, Vesicular augite phyric basalts and Aphanatic basalts.

C. Ancharo Rhyolitic Ignimbrite (Tar)

This unit forms a north-south trending hill in south central part, which is named after the locality called Ancharo. It is well exposed on the Quarry site along Kombolcha Bati Road, where the exposed thickness is about 50m. The rock is white, pink, gray and medium to coarse grained. On the above quarry site, the unit is columnarly jointed and shows three major layers. The bottom part (~ 5 m thick) is pink, yellowish white and massive.

This part contains plagioclase, alkali feldspar phenocrysts, glass shards and pumice rock fragments. Here the unit also shows inclined layering. It is affected by two major joint sets. The middle part (~ 20 m thick) is vesicular and the vesicles are mostly rounded with maximum diameter of 15 cm. The top part (~ 15 m thick) is white and compositionally similar with the bottom one, except that it sometimes contains secondary calcite. The southern part of this unit strongly weathered and found as fragmental outcrop. Petrographically, it consists of (< 10 %) fine alkaline feldspar and plagioclase feldspar, (5 %) pumice rock fragment and (< 5 %) opaque minerals. The phenocrysts are found within (80-85 %) brown ashy matrix.

Local Geology

The local geology near to the river bridge at Km 5+585 and 6+327.24 sites is Dark gray medium to very dense silty gravel with sand and Dark gray medium dense gravelly sand soil which is covered by the top Dark brown clay this top soil is occurred above the borehole reference elevation which is useful for agricultural purpose and the local geology near to the river bridge at Km Old borkena and Berbere river is Dark brown soft to hard silty clay with some sandy gravel soil and Variegated color very loose to loose clay sand with silty gravel soil.

3.2. Methodology

The research methodology comprises a review of existing experimental and analytical, laboratory experiments, and data analysis. Literature on the standards penetration test, its applications, limitations, and optimization techniques will be reviewed to determine the current state of knowledge regarding this test method. A comprehensive understanding of the factors that affect the reliability of the test will be established. The laboratory experiment will involve the application of standard penetration test, and direct shear test on soil samples collected from sites. The data obtained from these tests will be subjected to regression and correlation analyses to determine the relationships between penetration resistance and the index properties and shear strength of the soil samples. Cross-validation will also be used to test the test's accuracy and reliability in predicting index properties and shear strength.

3.3. Materials

3.3.1. Data collection

118 Samples of clay and silty clay soil are collected from Jurassic Consulting Engineers PLC. The data contains SPT, cohesion, liquid limit and plastic limit results. Furthermore, sieve analysis, dry density and moisture content are included for the samples. The SPT-N values were between 2 and 100. Also, the cohesion values varied between 8 and 66 kPa. While the liquid limit values vary between 21 and 92% and the plasticity index values vary between 5 and 70%.

3.3.2. Data preparation:

Accurate measurement of the N-value and correcting those values with the appropriate correction factor is extremely important in engineering design. The observed SPT N-values as measured in the field are not reliable due to several factors such as the energy efficiency, split spoon sampler design, diameter of the borehole and rod length and other factors (Aggour & Radding, 2000). Thus, corrections are needed to apply in SPT blow counts to achieve a normalized value prior to use.

Various authors have proposed correction factors to account the above factors; (Bowels, 1997), listed five correction factors comprises hammer efficiency, sampler, rod length, and borehole

diameter and depth correction. While recent papers (Mostafa, A. and Mahmoud N, 2013) has been applied seven correction factors includes anvil and blow rate correction. The SPT-N values are corrected for field procedures and corrections are applied using the following equation.

$$N_{cor} = C_N \times N \times n_1 \times n_2 \times n_3 \times n_4 \dots \dots \dots \text{Equation 3.1}$$

Where

N_{cor} = adjusted N

CN = adjustment for overburden pressure $\left(\frac{P'_o}{P''_o}\right)^{1/2}$

P'_o = overburden pressure

P''_o = reference overburden pressure (95.76 kPa or 1.0 kg/cm²)

n_1 = Er/Erb (where Er is average energy ratio that depends on the drill system and Erb is the standard energy ratio).

n_2 = Rod length correction

Rod length > 10 m = 1,

Rod length 6-10 m = 0.95,

Rod length 4-6 m = 0.85,

Rod length 0-4 m = 0.75

n_3 = sampler correction (1.00 in our case)

n_4 = borehole diameter correction (1.00 in our case)

The regression analysis is used to find the proposed equation for cohesion and SPT-N. liquid limit and plasticity index equation is found by regression analysis as well. The linear relationship is selected based on previous comprehensive studies.

3.3.3. Coefficient of Determination, R²: SPT versus LL, PI, Shear Strength Parameters

In this study, the best fitting among the calculated and the predicted results suggested by various researchers is plotted and the correlation coefficient represented as R² is determined. The R² coefficient of determination is a statistical measure of how well the regression line approximates the actual data points (Taylor, 1990). As indicated by the estimations of R², the relationship between any two parameters can be grouped as:

$R^2 < 0.30$ considered to have no connection,

R^2 of 0.30 to 0.499 are thought to be a mild relationship,

R^2 of 0.50 to 0.699 are thought to be a moderate relationship and,

R^2 of 0.70 to 1.0 are regarded to be a strong relationship (Mostafa, A. and Mahmoud N, 2013).

Finally, figures have been plotted to analyses and show the relationship between field and experimented results which include the measured SPT number (N_{cor}), depth of test sample (D) from the ground surface, the shear strength parameters (C and ϕ) and the Atterberg limits.

4. Details of Collected Data and regression analysis

4.1. Introduction

SPT is currently the most popular and economical means to characterize in-situ soil strength. It provided the resistance of the soils in the form of number of blows (N-value), from which the bearing capacities of foundation material can be calculated. It is made by dropping a free-falling hammer onto the drill rods from a specific height to achieve the penetration of a standard sample tube to the soil (Mwajuma I.L., 2015).

Although great effort has been put into standardizing the SPT procedure, variability is inherent in present procedures. The standard penetration resistance is, in fact, conventionally measured using different kinds of hammers, drill rig types, drill rod lengths, drill rod types, hammer blow rates, different energy delivery systems with different degrees of efficiency, different borehole fluids, and different kinds of sampling tubes. Thus, the test is performed by different equipment and testing procedures as well as different operators (Clayton, 1995).

Due to the above-mentioned factors the consistency of standard penetration tests is questionable. This research was designed to measure its reliability for a fine-grained soil in Kombolcha. In doing so, SPT measurements were carried out at different depths in selected area where fine grained soils are prominent. Corresponding samples were also obtained to determine shear strength and other physical and engineering properties of soil in the laboratory.

The SPT variables which are considered in this study are N-value, hammer and anvil type, penetration interval, hammer blow rate, drill rod type, rod length, and drill rig type. Accordingly, borings were used in this study at different site.

The boreholes were drilled for foundation investigation purpose by private geotechnical firms and representative fine-grained soils have been investigated for this research work. Automatic cathead hammer type was used in performing the SPT test.

4.2. SPT Equipment Details

Standard penetration test tools composed of SPT hammer system (hammer, anvil and lifting head), split spoon sampler, and drill rod. Deploying inappropriate use and damaged tools have a great impact on the result of SPT blow count and on overall processes to determine the bearing capacity (Clayton, 1995). The different equipment used in this study has been described briefly as follows.

4.2.1. SPT hammer system

SPT hammer system is comprised of the hammer itself, the mechanism that lifts and drops the hammer, the anvil stem and anvil or drive-head (Aggour & Radding, 2000). The use of SPT has grown rapidly; three different types hammer systems have been developed: donut hammer, safety hammer, and automatic hammer. Herein the tests were conducted by automatic cathead hammer system. The donut hammer system is the weight centered on a guide pipe which strikes an external anvil above the drill rods and the weight is raised and dropped by the operator and relatively it increases the risk of injury (Lamb.R, 1997). Unlike the donut type of hammer, the automatic hammer system is a hydraulically powered chain lift device; the only thing that operator does is to open the hydraulic valve to start the lifting and dropping sequences and weight which slides over the drill rods and impacts against an internal anvil.

Due to its difficulty of measure the hammer weight in the field, the hammer weight data was collected from drilling rig manual and specifications. Most of the hammers were fall on the range between 62 kg to 63 kg qualified the ASTM standards. The drill rigs used for was HZ-130YY spindle type China rigs with a donut hammer. The hammer drop system the donut hammer used the cathead and rope system whereas the semiautomatic or automatic hammers have a trip system.

The anvil is that portion of the hammer system through which the hammer energy is transmitted to the drill rods as it is impacted by the falling hammer. The hammer and anvil are designed for steel-on-steel contact when the hammer is dropped. During field observation the anvils have different shape and size.

The hammer type is the most influential due to the variability in energy delivered to the drill rods. Researchers have shown that energy transfer efficiency can be varies from 30% to 90% depending on the type of hammer used. Thus, different drill rig hammer systems give different N values. Hammer efficiency highly depends on equipment and operator skill. It has been found that an inverse relationship exists between the N measured and the efficiency of the hammer (Sherbiny R. M. and Salem M. A., 2013). These findings and the recognition of the direct impact of this inconsistency on geotechnical design.

(Bowels, 1997), listed the energy ratio of different counties practice, is between the range of 40% to 60% and 60% to 100% for donut hammer and automatic hammer, respectively. It is evident from the above-mentioned values that energy efficiency for each type of hammer varies widely with the local practice in different parts of the world.

In fact, in this study, the actual energy delivered to drill rod is not measured and there are no available data on hammer efficiency of either type for local practice in Ethiopia. Thus, the energy ratio, from other countries practice, was adopted considering the drilling rig, hammer type and lifting mechanism.

The length of drill rod is one of the factors that affects the hammer efficiency, manual cathead hammers are influenced by short rod lengths and rod stiffness that may reduce the energy transferred. When the length of the drill rod is less than 10 m, energy is reflected in the rod reducing the energy transmitted to the split spoon penetrating the soil (Bowels, 1997). The SPT data were measured using cathead hammers systems as presented in table 4.1.

4.3. Correction of SPT N-values

Accurate measurement of the N-value and correcting those values with the appropriate correction factor is extremely important in engineering design. The observed SPT N-values as measured in the field are not reliable due to several factors such as the energy efficiency, split spoon sampler design, diameter of the borehole and rod length and other factors (Aggour & Radding, 2000). Thus, corrections are needed to apply in SPT blow counts to achieve a normalized value prior to use.

Various authors have proposed correction factors to account the above factors; (Bowels, 1997), listed five correction factors comprises hammer efficiency, sampler, rod length, and borehole diameter and depth correction. While recent papers (Mostafa, A. and Mahmoud N, 2013) has been applied correction factors includes anvil and blow rate correction. In this research, the following equation is employed to adjust the SPT values.

$$N_{cor} = C_N \times N \times n_1 \times n_2 \times n_3 \times n_4 \dots \dots \dots \text{Equation 4.1}$$

There are several publications recommending that a standard energy ratio (Erb) should be adopted for SPT investigations in to allow reproducible and consistent blow counts. (Seed et al.,1985), suggested instead that 60% be used since it is associated with the safety hammer whereas, (Bowels, 1997), has recommended 70% be used (Aggour & Radding, 2000). These estimates are the basis for the proposed correction factors for hammer types. In this study it is adopted 70% as the standard energy ratio since it will greatly minimize field data (N-value) and it is more recent suggestion using current drilling equipment with a donut or an automatic hammer technology. In most cases, local practices were usually employed to estimate the energy efficiency; and the energy ratio often assumed 45% and 60% of donut hammer and automatic hammer, respectively.

$$\text{Energy efficiency} = \frac{E_r}{E_{rb}} \dots \dots \dots \text{Equation 4.2}$$

Where, E_r = mean energy ratio, E_{rb} = standard energy ratio

E_r is taken as 45 and E_{rb} = 60%

$$\text{Where, } E_r = \frac{\text{actual hammer energy to sampler, } E_a}{\text{input energy, } E_{in}} \times 100$$

$$\text{Energy efficiency} = \frac{45}{60} \times 100 = 0.75$$

The final adjustment of measured SPT (N-values) is presented in the table 4.1 by applying various corrections as mention earlier.

Table 4.1: Adjusted SPTN for five Bridge sites along Kombolcha bypass Road project

| Adjusted SPTN | | | | | | | | | | | |
|--|------------|-------------|------------------|-----------------|----------|----------|----------|----------|------|---------------|------------|
| BH No | Dept h (m) | N_{field} | $\gamma, (kN^3)$ | $\sigma_v(kPa)$ | η_1 | η_2 | η_3 | η_4 | CN | N60 Corrected | N60 Approd |
| Km 5+585 BH-1 (A.A Side Abut) | 1.5 | 50 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 53.693 | 54 |
| | 3 | 100 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 75.933 | 76 |
| | 4.5 | 100 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 70.266 | 70 |
| | 6 | 28 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 17.039 | 17 |
| | 7.5 | 11 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 6.691 | 7 |
| | 9 | 12 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 6.664 | 7 |
| | 10.5 | 21 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 11.365 | 11 |
| | 12 | 19 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 9.618 | 10 |
| | 13.5 | 27 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 12.886 | 13 |
| Km 5+585, BH-ID: BH-2 (Dessie Side Abutment) | 1.5 | 16 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 17.182 | 17 |
| | 3 | 100 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 75.933 | 76 |
| | 4.5 | 100 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 70.266 | 70 |
| | 6 | 8 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 4.868 | 5 |
| | 7.5 | 10 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 6.083 | 6 |
| | 9 | 28 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 15.549 | 16 |
| | 10.5 | 18 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 9.741 | 10 |
| | 12 | 14 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 7.087 | 7 |
| | 13.5 | 15 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 7.159 | 7 |
| Km6+3 27.24 BH-ID: BH-1 | 1.5 | 17 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 18.256 | 18 |
| | 3 | 100 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 75.933 | 76 |

| | | | | | | | | | | | |
|--|------|-----|------|--------|------|------|---|---|------|--------|----|
| | 4.5 | 100 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 70.266 | 70 |
| | 6 | 18 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 10.953 | 11 |
| | 7.5 | 23 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 13.991 | 14 |
| | 9 | 15 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 8.330 | 8 |
| | 10.5 | 18 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 9.741 | 10 |
| | 12 | 37 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 18.730 | 19 |
| | 13.5 | 45 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 21.477 | 21 |
| Km 6+327.24 BH-ID: BH-2 (Dessie Side Abutment) | 1.5 | 2 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 2.148 | 2 |
| | 3 | 100 | 17.5 | 52.5 | 0.75 | 0.85 | 1 | 1 | 1.35 | 86.057 | 86 |
| | 4.5 | 100 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 70.266 | 70 |
| | 6 | 16 | 17.5 | 105 | 0.75 | 0.95 | 1 | 1 | 0.95 | 10.882 | 11 |
| | 7.5 | 10 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 6.083 | 6 |
| | 9 | 22 | 17.5 | 157.5 | 0.75 | 1 | 1 | 1 | 0.78 | 12.860 | 13 |
| | 10.5 | 13 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 7.035 | 7 |
| | 12 | 25 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 12.656 | 13 |
| | 13.5 | 30 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 14.318 | 14 |
| Berbere river bridge, BH-ID: BH-1 (AA Side Abut) | 1.5 | 50 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 53.693 | 54 |
| | 3 | 50 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 37.967 | 38 |
| | 4.5 | 50 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 35.133 | 35 |
| | 6 | 12 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 7.302 | 7 |
| | 7.5 | 12 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 7.300 | 7 |
| | 9 | 13 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 7.219 | 7 |
| | 10.5 | 46 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 24.894 | 25 |
| | 12 | 31 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 15.693 | 16 |
| | 13.5 | 25 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 11.932 | 12 |

| | | | | | | | | | | | |
|---|------|------|--------|--------|------|------|---|---|--------|--------|----|
| | 15 | 20 | 17.5 | 262.5 | 0.75 | 1 | 1 | 1 | 0.60 | 9.056 | 9 |
| | 16.5 | 23 | 17.5 | 288.75 | 0.75 | 1 | 1 | 1 | 0.58 | 9.929 | 10 |
| | 18 | 25 | 17.5 | 315 | 0.75 | 1 | 1 | 1 | 0.55 | 10.333 | 10 |
| | 19.5 | 40 | 17.5 | 341.25 | 0.75 | 1 | 1 | 1 | 0.53 | 15.884 | 16 |
| | 21 | 22 | 17.5 | 367.5 | 0.75 | 1 | 1 | 1 | 0.51 | 8.419 | 8 |
| | 22.5 | 18 | 17.5 | 393.75 | 0.75 | 1 | 1 | 1 | 1 | 13.500 | 14 |
| Berbere river bridge BH-ID: BH-2 (Dessie Side Abutment) | 1.5 | 10 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 10.739 | 11 |
| | 3 | 50 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 37.967 | 38 |
| | 4.5 | 50 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 35.133 | 35 |
| | 6 | 50 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 30.426 | 30 |
| | 7.5 | 9 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 5.475 | 5 |
| | 9 | 15 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 8.330 | 8 |
| | 10.5 | 15 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 8.118 | 8 |
| | 12 | 27 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 13.668 | 14 |
| | 13.5 | 23 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 10.977 | 11 |
| | 15 | 18 | 17.5 | 262.5 | 0.75 | 1 | 1 | 1 | 0.60 | 8.150 | 8 |
| | 16.5 | 14 | 17.5 | 288.75 | 0.75 | 1 | 1 | 1 | 0.58 | 6.044 | 6 |
| | 18 | 18 | 17.5 | 315 | 0.75 | 1 | 1 | 1 | 0.55 | 7.440 | 7 |
| | 19.5 | 21 | 17.5 | 341.25 | 0.75 | 1 | 1 | 1 | 0.53 | 8.339 | 8 |
| | 21 | 26 | 17.5 | 367.5 | 0.75 | 1 | 1 | 1 | 0.51 | 9.949 | 10 |
| 22.5 | 41 | 17.5 | 393.75 | 0.75 | 1 | 1 | 1 | 1 | 30.750 | 31 | |
| Borkena old bridge BH-ID: BH-1 (AA Side Abut) | 1.5 | 18 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 19.329 | 19 |
| | 3 | 28 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 21.261 | 21 |
| | 4.5 | 50 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 35.133 | 35 |
| | 6 | 64 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 38.945 | 39 |
| | 7.5 | 50 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 30.415 | 30 |

| | | | | | | | | | | | |
|---|------|------|--------|--------|------|------|---|------|--------|--------|----|
| Borkena old bridge BH-ID: BH-2 (pier-1) | 9 | 8 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 4.442 | 4 |
| | 10.5 | 11 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 5.953 | 6 |
| | 12 | 12 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 6.075 | 6 |
| | 13.5 | 28 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 13.364 | 13 |
| | 15 | 15 | 17.5 | 262.5 | 0.75 | 1 | 1 | 1 | 0.60 | 6.792 | 7 |
| | 16.5 | 26 | 17.5 | 288.75 | 0.75 | 1 | 1 | 1 | 0.58 | 11.224 | 11 |
| | 18 | 29 | 17.5 | 315 | 0.75 | 1 | 1 | 1 | 0.55 | 11.986 | 12 |
| | 19.5 | 30 | 17.5 | 341.25 | 0.75 | 1 | 1 | 1 | 0.53 | 11.913 | 12 |
| | 21 | 50 | 17.5 | 367.5 | 0.75 | 1 | 1 | 1 | 0.51 | 19.133 | 19 |
| | 1.5 | 50 | 17.5 | 26.25 | 0.75 | 0.75 | 1 | 1 | 1.91 | 53.693 | 54 |
| | 3 | 50 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 37.967 | 38 |
| | 4.5 | 50 | 17.5 | 78.75 | 0.75 | 0.85 | 1 | 1 | 1.10 | 35.133 | 35 |
| | 6 | 50 | 17.5 | 105 | 0.75 | 0.85 | 1 | 1 | 0.95 | 30.426 | 30 |
| | 7.5 | 10 | 17.5 | 131.25 | 0.75 | 0.95 | 1 | 1 | 0.85 | 6.083 | 6 |
| | 9 | 25 | 17.5 | 157.5 | 0.75 | 0.95 | 1 | 1 | 0.78 | 13.883 | 14 |
| | 10.5 | 9 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 4.871 | 5 |
| | 12 | 7 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 3.544 | 4 |
| | 13.5 | 8 | 17.5 | 236.25 | 0.75 | 1 | 1 | 1 | 0.64 | 3.818 | 4 |
| | 15 | 50 | 17.5 | 262.5 | 0.75 | 1 | 1 | 1 | 0.60 | 22.639 | 23 |
| 16.5 | 50 | 17.5 | 288.75 | 0.75 | 1 | 1 | 1 | 0.58 | 21.585 | 22 | |
| 18 | 20 | 17.5 | 315 | 0.75 | 1 | 1 | 1 | 0.55 | 8.267 | 8 | |
| 19.5 | 8 | 17.5 | 341.25 | 0.75 | 1 | 1 | 1 | 0.53 | 3.177 | 3 | |
| 21 | 19 | 17.5 | 367.5 | 0.75 | 1 | 1 | 1 | 0.51 | 7.271 | 7 | |
| 22.5 | 4 | 17.5 | 393.75 | 0.75 | 1 | 1 | 1 | 0.49 | 1.479 | 1 | |
| 24 | 10 | 17.5 | 420 | 0.75 | 1 | 1 | 1 | 0.48 | 3.580 | 4 | |
| Borkena | 1.7 | 13 | 17.5 | 29.75 | 0.75 | 0.75 | 1 | 1 | 1.79 | 13.113 | 13 |

| | | | | | | | | | | |
|------|----|------|--------|------|------|---|---|------|--------|----|
| 3 | 9 | 17.5 | 52.5 | 0.75 | 0.75 | 1 | 1 | 1.35 | 6.834 | 7 |
| 10.5 | 25 | 17.5 | 183.75 | 0.75 | 1 | 1 | 1 | 0.72 | 13.529 | 14 |
| 12 | 50 | 17.5 | 210 | 0.75 | 1 | 1 | 1 | 0.67 | 25.311 | 25 |
| 15 | 32 | 17.5 | 262.5 | 0.75 | 1 | 1 | 1 | 0.60 | 14.489 | 14 |
| 16.5 | 20 | 17.5 | 288.75 | 0.75 | 1 | 1 | 1 | 0.58 | 8.634 | 9 |
| 18 | 26 | 17.5 | 315 | 0.75 | 1 | 1 | 1 | 0.55 | 10.747 | 11 |
| 19.5 | 29 | 17.5 | 341.25 | 0.75 | 1 | 1 | 1 | 0.53 | 11.516 | 12 |
| 21 | 26 | 17.5 | 367.5 | 0.75 | 1 | 1 | 1 | 0.51 | 9.949 | 10 |
| 22.5 | 30 | 17.5 | 393.75 | 0.75 | 1 | 1 | 1 | 0.49 | 11.091 | 11 |

4.4. Laboratory and Field Test Analysis

4.4.1. Laboratory Index Properties and Sieve Analyses

The field and laboratory tests have been used for determination engineering and physical properties of the fine-grained soils. These tests include direct shear test, Atterberg limits, moisture content and standard penetration test. Most problems in construction involve either the strength of the in-situ soil or the compressibility of the soil.

In this study representative soil samples (both disturbed and undisturbed) collected from the boreholes for laboratory tests. Undisturbed samples were taken for conducted direct shear test in determining cohesion (c) and friction angle (ϕ) and disturbed samples for classification tests.

The direct shear test is suited to the relatively rapid determination of consolidated drained strength properties because the drainage paths through the test specimen are short, allowing excess pore pressure to dissipate more rapidly than other drained stress tests. The test can be made on any type of soil material. It is applicable for testing intact, remolded, or reconstituted specimens.

The test results are applicable to assessing strength in a field situation where complete consolidation has occurred under the existing normal stresses. According to ASTM D-3080 failure is reached slowly under drained conditions so that excess pore pressures are dissipated

In fine grained soils the penetration resistance is broadly a function of undrained shear strength. The undrained shear strength of soils is necessary for the determination of the bearing capacity of foundations and other civil structures.

On the other hand, sieve analysis, Atterberg limits and moisture content were carried out from disturbed samples. Plasticity index (PI) and liquid limit (LL) can be used to determine the swelling characteristics of fine grain soil.

The result from Atterberg limits show that the site is made of a typical of weathered granitic materials. The samples tested are classed according to the Unified Soil Classification System (USCS) as clays and silts of low to high liquid limit (CL to CH and ML to MH). The results

obtained from field and laboratory tests are presented in Table 4.2 and discussed in detail under this section.

The results of the index and grain size analysis tests are summarized below in Tables 4.2 and 4.3

Table 4.2: Summary of soil field and laboratory tests at Km 5+585, 6+327.24, Old Borkena and Berbere River Bridge

| Station (Km) | BH.No | Depth (m) | N _f | Atterberg Limit | | | SG | NMC, % |
|--------------------------|-------|-------------|----------------|-----------------|----|------|------|--------|
| | | | | LL | PL | PI | | |
| Old Borkena River Bridge | BH-1 | 4.50-4.95 | 50 | 40 | 22 | 19 | 2.58 | 8.6 |
| | | 6.00-6.45 | 64 | 30 | 19 | 11 | 2.56 | 10.38 |
| | | 9.00-9.45 | 8 | 49 | 29 | 20 | 2.33 | 28.6 |
| | | 15.00-15.45 | 15 | 72 | 27 | 44 | 2.40 | 24.8 |
| | BH-2 | 3.00-3.45 | 50 | 32 | 16 | 16 | 2.63 | 9.8 |
| | | 6.00-6.45 | 50 | 30 | 17 | 13 | 2.75 | 11.4 |
| | | 9.00-9.45 | 25 | 44 | 20 | 25 | 2.60 | 18.5 |
| | | 12.00-12.45 | 7 | 62 | 32 | 31 | 2.37 | 30 |
| | | 15.00-15.35 | 50 | 60 | 28 | 33 | 2.65 | 24.6 |
| | | 18.00-18.45 | 20 | 53 | 22 | 31 | 2.44 | 8.6 |
| | | 21.00-21.45 | 19 | 70 | 36 | 34 | 2.41 | 28.8 |
| | BH-3 | 4.50-4.95 | 50 | 31 | 17 | 14 | 2.59 | 6.4 |
| | | 7.50-7.95 | 22 | 64 | 33 | 31 | 2.36 | 27 |
| | | 10.50-10.95 | 19 | 63 | 31 | 33 | 2.47 | 21.8 |
| | | 13.50-13.95 | 4 | 64 | 33 | 31 | 2.59 | 25.3 |
| | | 16.50-16.95 | 50 | 37 | 19 | 18 | 2.61 | 12.1 |
| | | 19.50-19.95 | 16 | 55 | 27 | 28 | 2.44 | 26.1 |
| | BH-4 | 10.50-10.95 | 25 | NP | | | 2.54 | 39.3 |
| | | 12.00-12.45 | 50 | 28 | 15 | 13 | 2.71 | 39.3 |
| | | 15.00-15.45 | 32 | 43 | 20 | 23 | 2.69 | 8.5 |
| 16.50-16.95 | | 20 | 82 | 36 | 46 | 2.34 | 27.1 | |
| 19.50-19.95 | | 29 | 54 | 24 | 31 | 2.43 | 21.9 | |

| | | | | | | | | |
|----------------------|------|-------------|-----|----|----|----|------|------|
| | | 22.50-22.95 | 30 | 85 | 38 | 47 | 2.36 | 28.5 |
| 5+585 | BH-1 | 3.00-3.45 | 100 | 44 | 28 | 16 | 2.42 | 28.4 |
| | | 4.50-4.95 | 100 | 44 | 28 | 17 | 2.56 | 18 |
| | | 6.00-6.45 | 28 | 38 | 24 | 13 | 2.53 | 47 |
| | | 9.00-9.45 | 12 | 59 | 31 | 28 | 2.51 | 32 |
| | | 12.00-12.30 | 19 | 46 | 28 | 18 | 2.56 | 29 |
| | BH-2 | 2.00-2.45 | 16 | 40 | 28 | 13 | 2.35 | 19 |
| | | 4.50-4.95 | 100 | 40 | 26 | 14 | 2.42 | 23.4 |
| | | 7.70-8.15 | 10 | 54 | 33 | 21 | 2.40 | 38.5 |
| | | 10.50-10.95 | 18 | 64 | 33 | 30 | 2.55 | 29 |
| | | 13.50-13.95 | 15 | 52 | 32 | 21 | 2.36 | 28 |
| 6+327.24 | BH-1 | 3.00-3.45 | 100 | 38 | 16 | 21 | 2.65 | 8.8 |
| | | 6.00-6.45 | 18 | 67 | 37 | 31 | 2.32 | 26.1 |
| | | 9.00-9.45 | 15 | 44 | 24 | 20 | 2.40 | 26 |
| | | 12.00-12.45 | 37 | 54 | 39 | 15 | 2.47 | 22.1 |
| | BH-2 | 1.50-1.95 | 2 | 78 | 35 | 43 | 2.57 | 36.6 |
| | | 4.50-4.95 | 100 | 94 | 35 | 59 | 2.33 | 40.3 |
| | | 7.50-7.95 | 10 | 46 | 24 | 23 | 2.38 | 29.2 |
| | | 10.50-10.95 | 13 | 63 | 37 | 27 | 2.33 | 28 |
| | | 13.50-13.95 | 30 | 62 | 28 | 34 | 2.35 | 30.6 |
| | | | | | | | | |
| Berbere river bridge | BH-1 | 3.00-3.45 | 50 | 40 | 22 | 18 | 2.64 | 29.7 |
| | | 4.50-4.95 | 50 | 37 | 20 | 17 | 2.62 | 27 |
| | | 6.00-6.45 | 12 | 49 | 25 | 24 | 2.47 | 30.4 |
| | | 9.00-9.45 | 13 | 51 | 28 | 23 | 2.50 | 28.8 |
| | | 12.00-12.45 | 31 | 59 | 25 | 34 | 2.47 | 29.6 |
| | | 15.00-15.45 | 20 | 52 | 23 | 29 | 2.54 | 27.4 |
| | | 18.00-18.45 | 25 | 64 | 29 | 35 | 2.55 | 29.4 |
| | | 21.00-21.45 | 22 | 54 | 21 | 33 | 2.61 | 12.1 |
| | | 22.50-22.95 | 18 | 54 | 29 | 25 | 2.45 | 32.9 |
| | BH-2 | 4.50-4.95 | 50 | 60 | 29 | 31 | 2.36 | 31.6 |
| | | 6.00-6.45 | 50 | 52 | 28 | 24 | 2.45 | 33.3 |
| | | 7.50-7.95 | 9 | 53 | 33 | 20 | 2.48 | 31.4 |
| | | 10.50-10.95 | 15 | 46 | 25 | 21 | 2.51 | 26.2 |

Table 4.3: Sieve Analysis Results

| Station Old Borkena River Bridge | | | | | |
|----------------------------------|------------|---------|-------|-------|------------------------------------|
| Borehole No | Depth(m) | %Gravel | %Sand | %Fine | USC classification |
| BH-1 | 9-9.45 | 3 | 2 | 95 | CL Lean Clay |
| BH-1 | 15-15.45 | 6 | 19 | 75 | CL Lean Clay with sand |
| BH-2 | 12-12.45 | 16 | 15 | 69 | CH Gravelly fat Clay sand |
| BH-2 | 15-15.45 | 22 | 24 | 54 | CH sandy fat Clay with gravel |
| BH-2 | 18-18.45 | 17 | 17 | 66 | CH sandy fat Clay with gravel |
| BH-2 | 21-21.45 | 24 | 17 | 59 | MH Gravelly elastic silt with sand |
| BH-3 | 7.5-7.95 | 2 | 10 | 88 | MH elastic silt |
| BH-3 | 10.5-10.95 | 18 | 15 | 67 | CH Gravelly fat Clay with sand |
| BH-4 | 16.5-16.95 | 1 | 6 | 93 | MH elastic silt |
| BH-4 | 19.5-19.95 | 2 | 10 | 78 | CH fat Clay with sand |
| BH-4 | 22.5-22.95 | 0 | 7 | 93 | MH elastic silt |
| Station 5+585 | | | | | |
| BH-1 | 3-3.45 | 1 | 18 | 81 | CL Lean Clay with sand |
| BH-1 | 4.5-4.95 | 6 | 24 | 70 | CL Sandy Lean Clay |
| BH-1 | 6-6.45 | 3 | 42 | 55 | CL Sandy Lean Clay |
| BH-1 | 9-9.45 | 0 | 11 | 89 | MH elastic silt |
| BH-1 | 12-12.45 | 0 | 19 | 81 | CL Lean Clay with sand |
| BH-2 | 2-2.45 | 1 | 29 | 70 | CL Sandy Lean Clay |
| BH-2 | 4.5-4.95 | 2 | 34 | 64 | CL Sandy Lean Clay |
| BH-2 | 7.7-8.15 | 0 | 15 | 85 | MH elastic silt with sand |
| BH-2 | 10.5-10.95 | 6 | 16 | 78 | MH elastic silt with sand |
| BH-2 | 13.5-13.95 | 11 | 19 | 70 | MH sandy elastic silt |
| Station 6+327 | | | | | |
| BH-1 | 6-6.45 | 0 | 8 | 92 | MH elastic silt |
| BH-1 | 9-9.45 | 0 | 13 | 87 | CL Lean Clay |
| BH-2 | 1.5-1.95 | 2 | 14 | 84 | CH fat Clay with sand |
| BH-2 | 4.5-4.95 | 3 | 9 | 88 | CH fat Clay |
| BH-2 | 7.5-7.95 | 0 | 18 | 82 | CL Lean Clay with sand |
| BH-2 | 10.5-10.95 | 0 | 2 | 98 | MH elastic silt |
| BH-2 | 13.5-13.95 | 0 | 3 | 97 | CH fat Clay |
| Station Berbere river bridge | | | | | |
| BH-1 | 3-3.45 | 1 | 31 | 68 | CL Sandy Lean Clay |
| BH-1 | 4.5-4.95 | 0 | 28 | 72 | CL Lean Clay with sand |
| BH-1 | 6-6.45 | 1 | 13 | 86 | CL Lean Clay |

| | | | | | |
|------|------------|---|----|----|---------------------------|
| BH-1 | 9-9.45 | 1 | 2 | 97 | CH fat Clay |
| BH-1 | 12-12.45 | 1 | 5 | 94 | CH fat Clay |
| BH-1 | 15-15.45 | 6 | 23 | 71 | CH Sandy fat Clay |
| BH-1 | 18-18.45 | 0 | 5 | 95 | CH fat Clay |
| BH-1 | 22.5-22.95 | 2 | 12 | 86 | CH fat Clay |
| BH-2 | 4.5-4.95 | 2 | 14 | 84 | CH fat Clay with sand |
| BH-2 | 6-6.45 | 2 | 13 | 85 | MH elastic silt with sand |
| BH-2 | 7.5-7.95 | 0 | 3 | 97 | MH elastic silt |
| BH-2 | 10.5-10.95 | 1 | 13 | 86 | CL Lean Clay |
| BH-2 | 13.5-13.95 | 3 | 21 | 76 | CH fat Clay with sand |
| BH-2 | 16.5-16.95 | 0 | 5 | 95 | CH fat Clay |
| BH-2 | 19.5-19.95 | 0 | 4 | 96 | CH fat Clay |
| BH-2 | 24-24.45 | 0 | 16 | 84 | CH fat Clay with sand |

4.4.2. Correlation between cohesion and SPT-N values

(Karol.RH, 1960) has proposed a correlation between the soil cohesion and SPT-N values based on the soil conditions that vary from very soft to hard conditions corresponding to SPT-N and cohesion values as summarized in Tables A.1 and A2. Attached to this document respectively.

For the effective cohesion value, the method recommended by

$$C' = 0.1 * C_u \text{ (Danish Standard DS 415)}$$

$$C' = 0.2 * C_u \text{ (Sorensen KK and Okkels N, 2013)}$$

$$\text{where } C_u = 29N_{60}^{0.72}$$

4.4.3. Correlation between angle of internal friction and SPT-N value

(K, Terzaghi and RB, Peck, 1967) have given a wide range of soil angle of internal friction with SPT-N values for various soil conditions as summarized in Table A.3 of Appendix A.

5. Analysis of results and discussions

The outcomes of laboratory and field testing will be presented and thoroughly explained in the sections that follow. The data have been shown with the best fit considering the correlation coefficient (R^2). This statistical method's goal is to provide us with a statistic called the correlation coefficient, which is a large-scale data summary value that indicates the degree of linear relationship between two measured variables. The quality of fit of a relationship can be inferred from the R^2 value. According to (Taylor, 1990), the R^2 coefficient of determination in regression is a statistical indicator of how closely the regression line resembles the actual data points. Any two parameters' relationship can be categorized based on the values of R^2 , with $R^2 < 0.30$ indicating no correlation, R^2 of 0.30 to 0.499 indicating a mild relationship, R^2 of 0.50 to 0.699 indicating a moderate relationship, and R^2 of 0.70 to 1.0 indicating a strong relationship.

Plotting of numerous Figures, such as the corrected SPT number (N_{60}), the depth of sample (D) measured from the ground surface, the Atterberg limits (LL), the plastic limit (PL), the principal component of shear strength (c & ϕ), and other correlations between field and experimental data have been analyzed and illustrated. The following three research focuses have been carried out to determine the impact and connection between the parameters:

5.1. Effect of soil depth (D) below ground surface

The correlations between the depth of the sample (D) below the surface and the various parameters under investigation, such as the corrected SPT number (N_{60}) and the Atterberg limits of silty and clay with sand LL, PL, and PI, respectively, are depicted in Figures 5.1 through 5.4. The correlations between adjusted SPT number (N_{60}) and soil depth below ground surface (D) are depicted in Figure 5.1. The adjusted SPT number (N_{60}) decreases as the sample's depth below the surface drops which shows that the soil is collapsible and softer. Based on the correlation coefficient value ($R^2 = 0.266$), Figure 5.1 illustrates a there is no association /relationship.

The correlations between soil depth (D) and the Atterberg limits (LL), (PL), and (PI), on the other hand, are depicted in Figures 5.2 to 5.4. These Figures make it abundantly evident that sample depth (D) has no bearing on the Atterberg limits of soil as these characteristics are based on the mechanical and physical characteristics of soil particles and are tested on samples that

have been disturbed. Additionally, given the correlation coefficient values ($R^2 < 0.30$), it concludes that there is no correlation between these relationships and that the observed behavior is merely the result of unintended (refer to Figures 5.2, 5.3, and 5.4). This leads to the conclusion that the physical and mechanical characteristics of the soil particles themselves determine the Atterberg limits rather than soil depth.

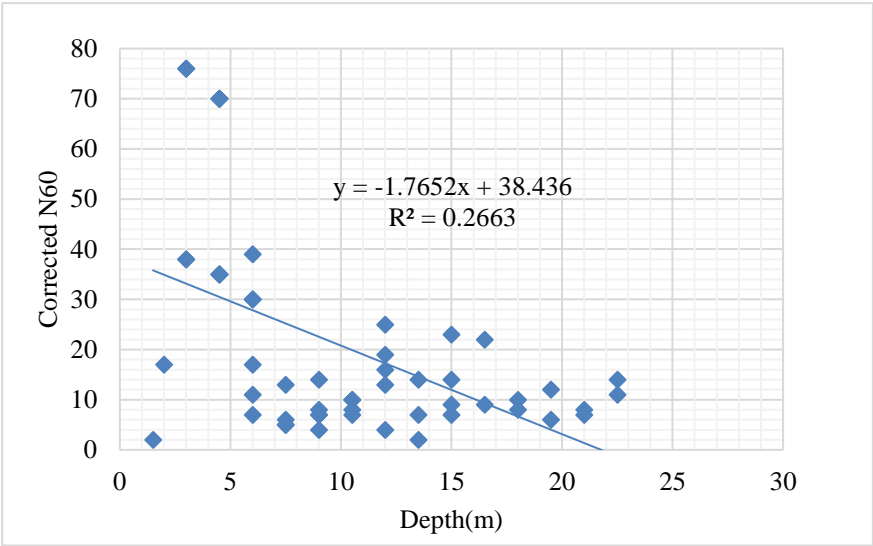


Figure 5.1: Depth of Sample below ground surface versus corrected SPT number (N_{60})

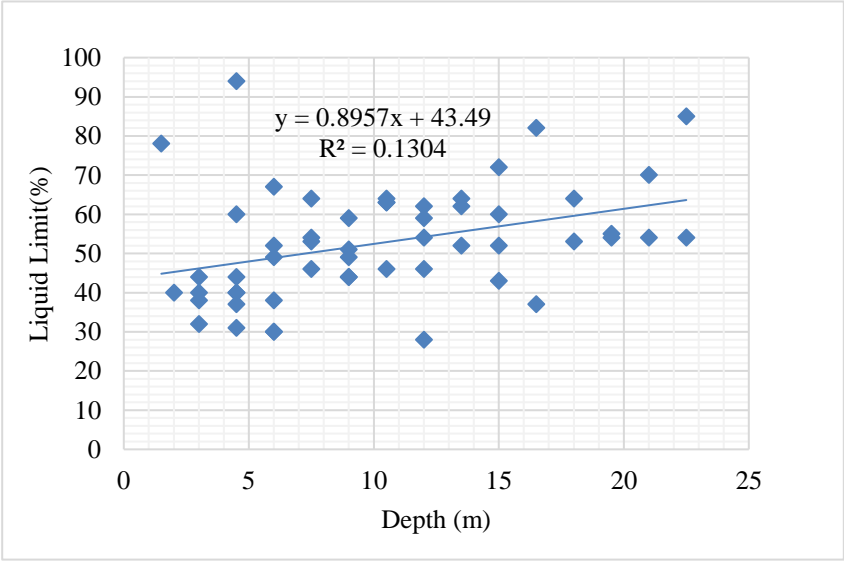


Figure 5.2: Depth of Sample below ground surface versus liquid limit (LL)

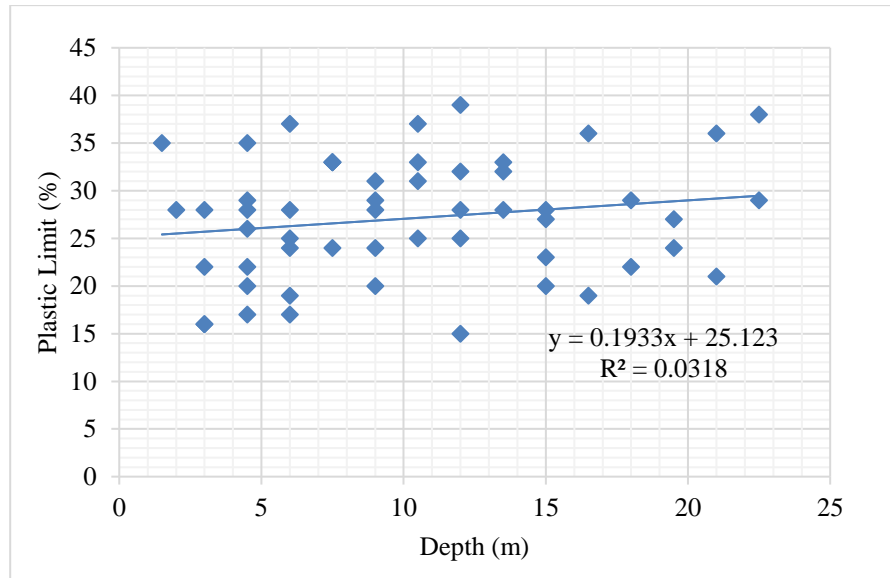


Figure 5.3: Depth of Sample below ground surface versus plastic limit (PL)

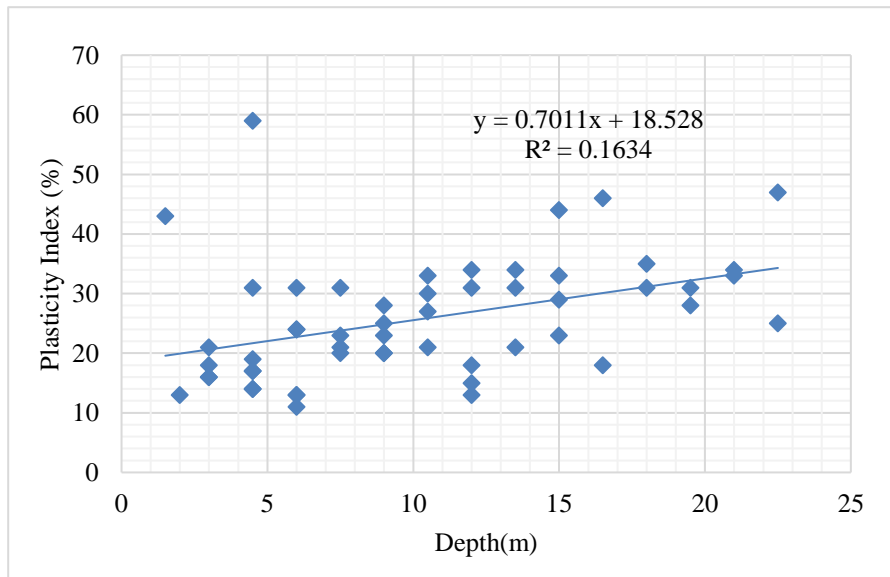


Figure 5.4: Depth of Sample below ground surface versus plasticity index (PI)

5.2. SPT versus Atterberg limits LL, PL and PI

The relationships between the corrected SPT number (N_{60}) and the Atterberg limits LL, PL, and PI, respectively, are illustrated in Figures 5.5, 5.6, and 5.7. These Figures show that, since SPT is dependent on the relative density of the soil layer, the Atterberg limits have no effect on SPT number (N_{60}). It finds out that in accordance with the procedures of these laboratory

experiments, the Atterberg limits of soil are primarily determined by the mechanical and physical characteristics of soil particles and are conducted on disturbed samples, as was previously indicated. Additionally, given the correlation coefficient values ($R^2 < 0.30$), it may be concluded that there is no correlation among these variables and that the observed behavior is likely the result of chance.

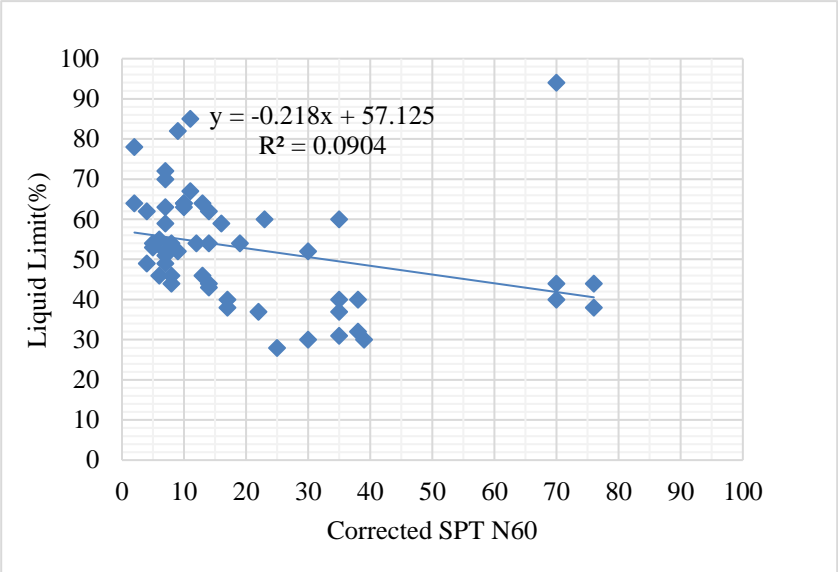


Figure 5.5: Corrected SPT number (N_{60}) versus liquid limit (LL)

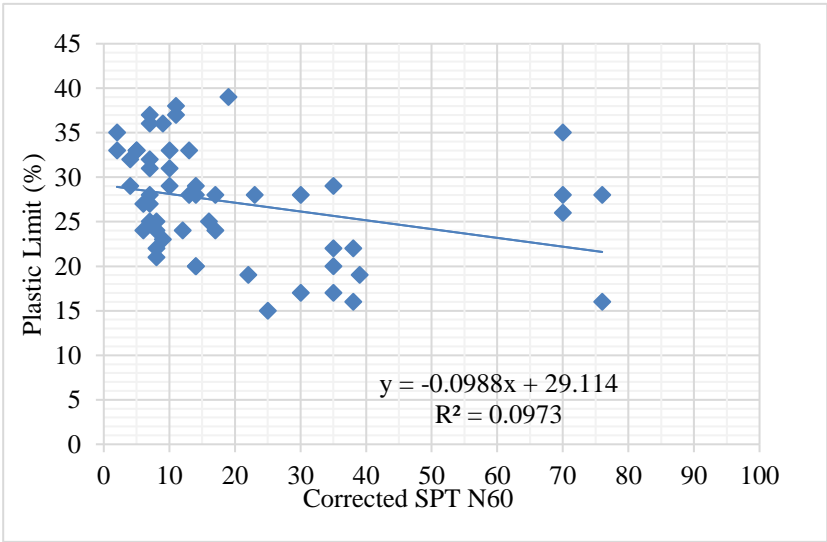


Figure 5.6: Corrected SPT number (N_{60}) versus plastic limit (PL)

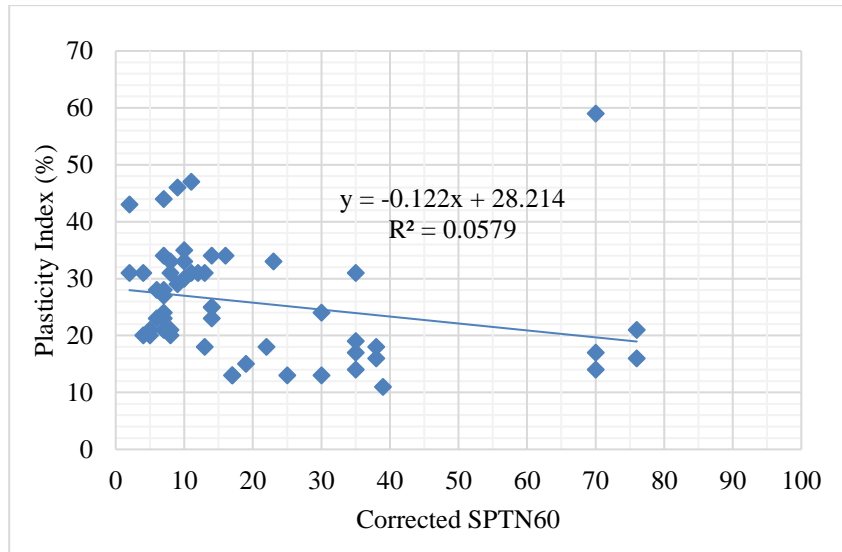


Figure 5.7: Corrected SPT number (N_{60}) versus plasticity index (PI)

5.3. SPT versus shear strength parameters (c & ϕ)

Figures 5.7 and 5.8 show the relationships between corrected SPT number (N_{60}) and shear strength parameters of silty, clay with sand soil, angle of internal friction (ϕ) and cohesion (c), respectively. From these Figures, it can be noticed that corrected SPT number (N_{60}) increases as shear strength of soil increases. The increasing of shear strength parameters of soil is due to increasing in relative density which leads to increasing in corrected SPT number (N_{60}). This may be due to the insertion of fine soil particles in the voids between sand particles to make the specimens are less voids and the friction surface increases too. Also, this means that the surface of shear behaves as a general shear failure and leads to shear strength increases to make SPT number increases too.

From Figure 5.7, a high correlation coefficient ($R^2 = 0.9902$) can be an indication of a good correlation between corrected SPT number (N_{60}) and angle of internal friction (ϕ). Also, in Figure 5.8, a correlation coefficient ($R^2 = 0.9901$) of this figure can be an indication of a good correlation between corrected SPT number (N_{60}) and cohesion (c). This means that the relationships between SPT number (N_{60}) and shear strength parameters (c & ϕ) are considered to a strong relationship. This leads to conclude that the shear strength parameters (c & ϕ) have strongly affected on SPT number.

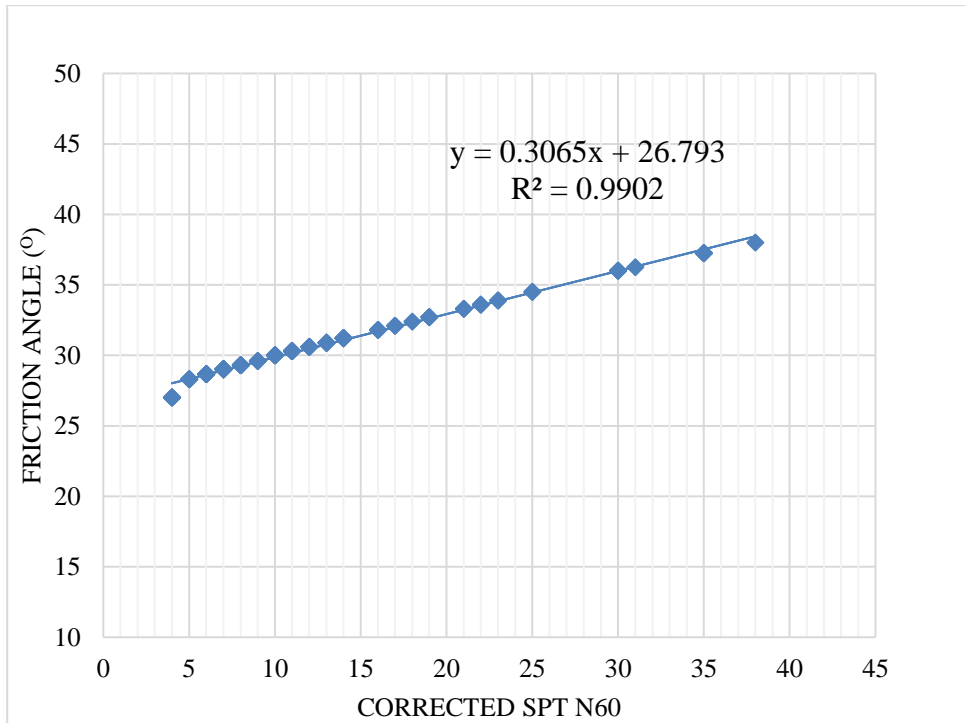


Figure 5.8: Corrected SPT number (N_{60}) versus angle of internal friction (ϕ)

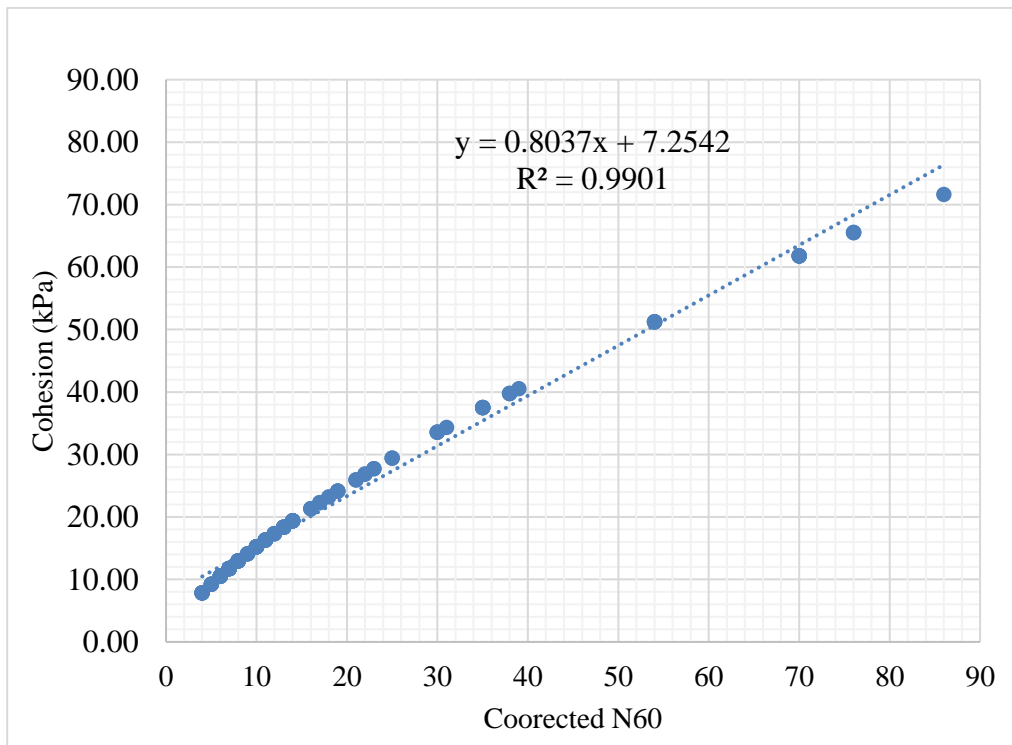


Figure 5.9: Corrected SPT number (N_{60}) versus cohesion (c)

Also, from the previous analysis, it can be found that the SPT number (N_{60}) has strongly correlated with shear strength of soil which can be expressed in parameters (c & ϕ). So, the shear strength parameters (c & ϕ) can be reasonably predicted from field with the help of corrected SPT number (N_{60}).

5.4. Empirical equations to predict the shear strength parameters (c & ϕ)

From the results and relationships shown in Figures 5.7 and 5.8 and regression analysis, empirical equations to estimate the shear strength parameters (c & ϕ) for silty and clay with sand soil with the help of corrected SPT number (N_{60}) as follows:

$$\phi = 0.3065N_{60} + 26.793 \dots\dots\dots \text{Equation 5.1}$$

$$c = 0.8037N_{60} + 7.2542 \dots\dots\dots \text{Equation 5.2}$$

Where, N_{60} is the corrected SPT number, ϕ is the angle of internal friction in degree and c is the cohesion in kPa.

The equations (5.1) and (5.2) have correlation coefficients (R^2) equal to 0.9902 and 0.9901, respectively, are strong relationships. This means that a very good correlation between SPT number N_{60} and shear strength parameters (c & ϕ) of silty and clay with sand soil.

5.5. Comparison with results from laboratory shear strength parameters (c & ϕ) correlations with SPT N

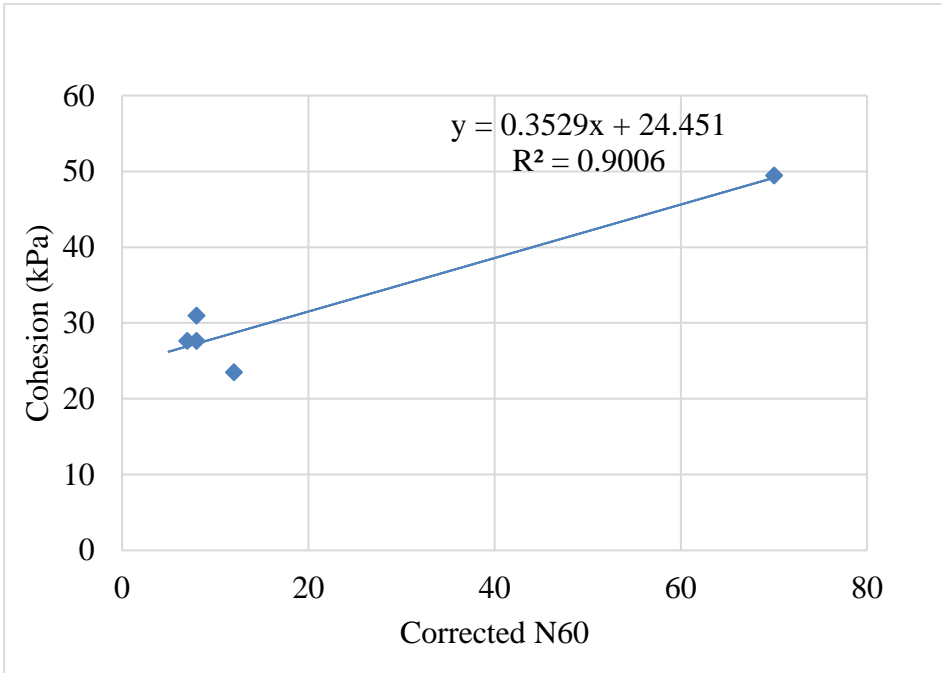


Figure 5.10: Corrected SPT number (N₆₀) versus cohesion (c) of laboratory.

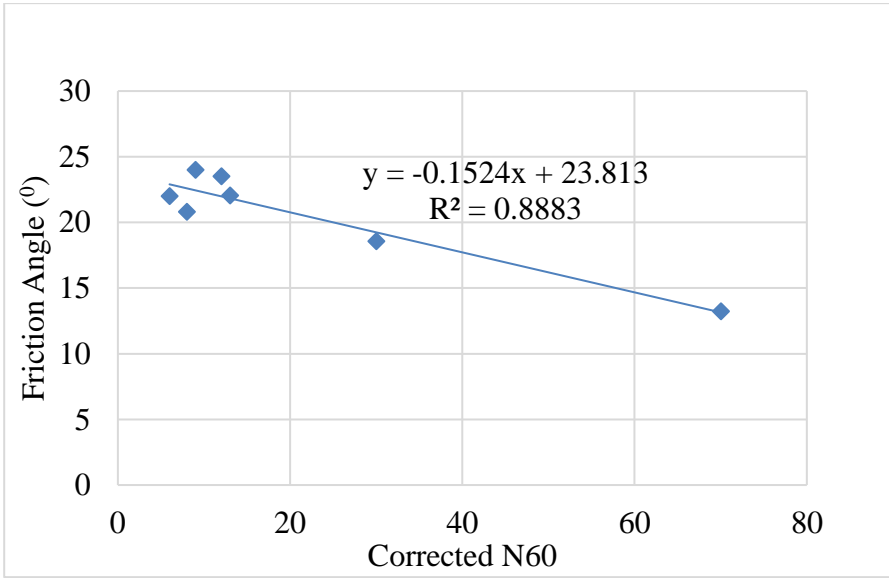


Figure 5.11: Corrected SPT number (N₆₀) versus angle of internal friction (ϕ) of laboratory.

From Figure 5.10, a high correlation coefficient ($R^2= 0.9006$) can be an indication of a good correlation between corrected SPT number (N_{60}) and cohesion (c). Also, in Figure 5.11, a correlation coefficient ($R^2= 0.8883$) of this figure can be an indication of a good correlation between corrected SPT number (N_{60}) and angle of internal friction (ϕ). This means that the relationships between SPT number (N_{60}) and shear strength parameters (c & ϕ) are considered to a strong relationship.

5.6. Comparison of the estimated cohesions and internal friction angles from SPTN-Value with laboratory results.

Table 5.1: shear strength parameters from developed equation and primary data (direct shear test)

| Station (km) | BH.NO | Depth (m) | LL (%) | PI (%) | Developed Estimated Cohesion (kPa) | Developed Estimated Friction angle (phi) | Cohesion (kPa) From Direct shear test (Lab) | Friction angle (phi) From Direct shear test (Lab) |
|--------------------------|-------|-------------|--------|--------|------------------------------------|--|---|---|
| Old Borkena River Bridge | BH-2 | 18.00-18.45 | 53 | 31 | 19.31 | 31.39 | 31 | 17.4 |
| | BH-3 | 7.50-7.95 | 64 | 31 | 17.70 | 30.78 | 40.5 | 22.05 |
| | BH-4 | 16.50-16.95 | 82 | 46 | 14.49 | 29.55 | 16.5 | 23.99 |
| | | 19.50-19.95 | 54 | 31 | 16.90 | 30.47 | 23.5 | 23.51 |
| 5+585 | BH-1 | 12.00-12.30 | 46 | 18 | 17.70 | 30.78 | 10.5 | 31 |
| | BH-2 | 7.70-8.15 | 54 | 21 | 11.27 | 28.33 | 31.59 | 9.5 |
| | | 10.50-10.95 | 64 | 30 | 15.29 | 29.86 | 10.5 | 30.75 |
| 6+327.24 | BH-1 | 9.00-9.45 | 44 | 20 | 13.68 | 29.25 | 13 | 20.81 |
| | BH-2 | 7.50-7.95 | 46 | 23 | 12.08 | 28.63 | 30.5 | 22 |
| | | 10.50-10.95 | 63 | 27 | 16.90 | 30.47 | 59 | 15 |
| Berbere river bridge | BH-1 | 6.00-6.45 | 49 | 24 | 12.88 | 28.94 | 21.73 | 12.26 |
| | | 9.00-9.45 | 51 | 23 | 12.88 | 28.94 | 27.65 | 11.17 |
| | BH-2 | 6.00-6.45 | 52 | 24 | 31.37 | 35.99 | 21.73 | 18.56 |
| | | 10.50-10.95 | 46 | 21 | 13.68 | 29.25 | 27.65 | 17.54 |
| 4+072 | BH-1 | 4.50-4.95 | 60 | 33 | — | — | 35 | 21 |
| | BH-2 | 11.50-11.95 | 32 | 16 | — | — | 36 | 20.8 |

6. Conclusions and Recommendations

6.1. Conclusions

Determining the soils' geotechnical parameters and proposing practical relations using in-situ tests such as SPT could reduce the costs of construction projects considerably. Based on the geotechnical investigations conducted on the Kombolcha bypass road project, the study area has been mainly covered with fine-grained soil (CL to CH & MH).

The following results are concluded based on the results and on the discussion and analysis presented in this research:

- ❖ The depth of soil (D) below ground surface insignificantly affects the SPT number.
- ❖ The Atterberg limits LL, PL, and PI do not affect the SPT number.
- ❖ The shear strength of soil strongly affects the SPT number.
- ❖ For identification of shear strength parameters (c & ϕ) of silty and clay with sand soil using SPT is adequate rather than using laboratory tests because SPT carries out in the field on undisturbed soil.
- ❖ Empirical equations to predict the shear strength parameters (c & ϕ) of silty clay with sand soil using SPT have been presented as mentioned in equations (5.1) and (5.2). The accuracy of these equations proved to be strong relationships.
- ❖ The standard penetration test (SPT) is considered reliable in predicting of shear strength parameters (c & ϕ) of silty and clay with sand soil.

6.2. Recommendations

SPT is one of the most effective and common tests used for quick and inexpensive estimation of mechanical properties of soil. Correlation of cohesion, angle of friction of soils in terms of SPT N value that have been established correlation generated.

Based on the conclusion made above, the appropriate recommendations are given here under:

- ❖ In this study the percentage fines were not considered but the SPT N-value of fine grain soils especially clay soils may vary significantly with seasonal fluctuations in the water

table. So, it is better in the future if the effect of fineness of clay soil considered since the correlations are not as meaningful for sensitive soft clays where effects of disturbance during sampler penetration may cause a lowering in the SPT N-value.

Ultimately, as the results of this study are based on a restricted number of in-situ and laboratory tests as well as limited criteria, they should only be regarded as indicative. There should be more thorough research done. Before implementing the findings of this study, more thorough sample and field testing would be required.

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APPENDIX -A: Borehole log sheet and Correlation Tables

Table A. 1: Various soil cohesion and SPT-N values for highly cohesive soils (Karol.RH, 1960)






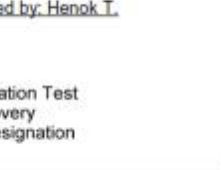
| Soil Conditions | Hard | Very Stiff | Stiff | Firm | Soft | Very Soft |
|-----------------|------|------------|-------|-------|-------|-----------|
| Cohesion (kPa) | 192 | 96-192 | 48-96 | 24-48 | 12-24 | 12 |
| SPT-N Values | >30 | 15-30 | 8-15 | 4-8 | 2-4 | <2 |

Table A. 2: Various soil cohesion and SPT-N values for intermediate soils (Karol.RH, 1960)

| Soil Conditions | Dense | Medium | Loose |
|-----------------|-------|--------|-------|
| Cohesion (kPa) | 48 | 5-48 | 5 |
| SPT-N Values | >30 | 10-30 | <10 |

Table A. 3: Various angle of internal friction and SPT-N values for different soils (K, Terzaghi and RB, Peck, 1967)

| Soil Conditions | Very Good | Good | Fair | Poor | Very Poor |
|---|-----------|-------|-------|-------|-----------|
| Angle of Internal Friction ($^{\circ}$) | >41 | 36-41 | 30-36 | 28-30 | <28 |
| SPT-N Values | >50 | 30-50 | 10-30 | 4-10 | 0-4 |

| Project | | Contractor | | Subcontractor | | Consultant | | | | | |
|--|--|----------------------------------|----------|---|---------|------------------------------------|--------------|-------------|-----|---|---|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | |
| Location/Chainage: Borkena Old Bridge | | | | Drilling Method: Dry/Wash Drilling | | Water level: 5.10m | | | | | |
| Coordinates (E/N): 579996.306 1225525.928 | | | | Core diameter (mm): 110,89,75 mm (0.0 -22.5m) | | Sheet: 1 of 1 | | | | | |
| Ground Elevation (masl.): 1818.927 | | | | Casing type & depth: 110mm | | BH Inclination: 90° | | | | | |
| Borehole No.: BH-1 (A.A side Abut) | | | | Date Started: 27-05-2022 | | Bit type: Carbide/Diamond | | | | | |
| Total Depth (m): 22.50 | | | | Date Completed: 28-05-2022 | | Type of Rig: HZ-130YY Drilling | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs |
| 5.50 | Dark brown soft to hard silty clay with some sandy gravel soil | 0 | 0.50 | 100 | | | | | | |  |
| | | 1 | 1.00 | 100 | | | | | | | |
| | | 2 | 1.50 | 100 | | | | | | | |
| | | 3 | 2.00 | 100 | | | | | | | |
| | | 4 | 2.50 | 100 | | | | | | | |
| | | 5 | 3.00 | 100 | | | | | | | |
| | | 6 | 3.45 | 100 | | | | | | | |
| | | 7 | 3.70 | 100 | | | | | | | |
| | | 8 | 4.00 | 100 | | | | | | | |
| | | 9 | 4.50 | 100 | | | | | | | |
| 5.00 | Variegated color medium to very dense silty gravel sand soil | 6 | 5.00 | 100 | | | | | | |  |
| | | 7 | 6.00 | 100 | | | | | | | |
| | | 8 | 6.45 | 100 | | | | | | | |
| | | 9 | 7.00 | 100 | | | | | | | |
| | Dark brown soft to hard silty clay with some sandy gravel soil | 10 | 7.50 | 100 | | | | | | |  |
| | | 11 | 8.00 | 100 | | | | | | | |
| | | 12 | 9.00 | 100 | | | | | | | |
| | | 13 | 9.45 | 100 | | | | | | | |
| | | 14 | 10.50 | 100 | | | | | | | |
| | | 15 | 11.00 | 100 | | | | | | | |
| | | 16 | 11.50 | 100 | | | | | | | |
| | | 17 | 11.70 | 100 | | | | | | | |
| | | 18 | 12.00 | 100 | | | | | | | |
| | | 19 | 12.45 | 100 | | | | | | | |
| | | 20 | 13.00 | 100 | | | | | | | |
| | | 21 | 13.50 | 100 | | | | | | | |
| | | 22 | 14.00 | 100 | | | | | | | |
| | | 23 | 14.40 | 100 | | | | | | |  |
| | | 24 | 15.00 | 100 | | | | | | | |
| | | 25 | 15.45 | 100 | | | | | | | |
| | | 26 | 16.00 | 100 | | | | | | | |
| | | 27 | 16.50 | 100 | | | | | | | |
| | | 28 | 17.00 | 100 | | | | | | | |
| | | 29 | 18.00 | 100 | | | | | | | |
| | | 30 | 18.45 | 100 | | | | | | | |
| | | 31 | 19.00 | 100 | | | | | | | |
| | | 32 | 19.50 | 100 | | | | | | | |
| | | 33 | 20.00 | 100 | | | | | | |  |
| | | 34 | 20.70 | 100 | | | | | | | |
| | | 35 | 21.40 | 100 | | | | | | |  |
| | | 36 | 22.50 | 100 | | | | | | | |
| | | | | | | | | | | | |
| Driller: Destaw T | | Logged by: Eshetie K. | | Checked by: Henok T. | | | | | | | |
| Note: | | D=Disturbed Sample (Split spoon) | | SPT=Standard Penetration Test | | | | | | | |
| | | UD=Undisturbed Sample | | SCR=Solid Core Recovery | | | | | | | |
| | | RC=Rock Core Sample | | RQD=Rock Quality Designation | | | | | | | |
| | | | | HF= Highly Fractured | | | | | | | |

| Project | | Contractor | | Subcontractor | | Consultant | | | | | |
|--|--|---------------------------|----------|--|---------|--|--------------|-------------|---------|---------|------------------|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | |
| Location/Chainage: Old Borkena Bridge | | | | Drilling Method: Dry/Wash Drilling | | Water level: 0.8 | | | | | |
| Coordinates (E/N): 579972.201 1225528.447 | | | | Core diameter (mm): 75 mm (0.0 -20.0m) | | Sheet: 1 of 1 | | | | | |
| Ground Elevation (masl.): 1814.781 | | | | Casing type & depth: 110mm | | BH Inclination: 90° | | | | | |
| Borehole No.: BH-2(Pier-1) | | | | Date Started: 20-06-2022 | | Bit type: Carbide/Diamond | | | | | |
| Total Depth (m): 25 | | | | Date Completed: 25-06-2022 | | Type of Rig: HZ-130YY Drilling | | | | | |
| Soil/Rock symbol | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs |
| | Variegated color medium to very dense silty gravel sand soil | 0 | 0.50 | 100 | | | | | | | |
| | | 1 | 1.00 | 100 | | | | | | | |
| | | 2 | 1.50 | 100 | | | | | | | |
| | | 3 | 2.00 | 100 | | | | 1.5 | D | 13,34,R | R |
| | | 4 | 2.50 | 100 | | | | 1.9 | | | |
| | | 5 | 3.00 | 100 | | | | | | | |
| | | 6 | 3.30 | 100 | | | | 3 | D | 12,26,R | R |
| | | 7 | 3.70 | 100 | | | | | | | |
| | | 8 | 4.00 | 100 | | | | 3.3 | | | |
| | | 9 | 4.50 | 100 | | | | | | | |
| | 10 | 5.00 | 100 | | | | 4.5 | D | 10,30,R | R | |
| | 11 | 5.40 | 100 | | | | 4.0 | | | | |
| | 12 | 6.00 | 100 | | | | | | | | |
| | 13 | 6.50 | 100 | | | | 6 | D | 19,R | R | |
| | 14 | 7.00 | 100 | | | | 6.2 | | | | |
| | 15 | 7.50 | 100 | | | | | | | | |
| | 16 | 8.00 | 100 | | | | 7.5 | D | 3,4,6 | 10 | |
| | 17 | 8.50 | 100 | | | | 7.95 | | | | |
| | 18 | 9.00 | 100 | | | | | | | | |
| | 19 | 9.40 | 100 | | | | 9 | D | 5,10,15 | 25 | |
| | 20 | 10.00 | 100 | | | | 9.45 | | | | |
| | 21 | 10.50 | 100 | | | | | | | | |
| | 22 | 11.00 | 100 | | | | 10.5 | D | 2,4,5 | 9 | |
| | 23 | 11.30 | 100 | | | | 10.95 | | | | |
| | 24 | 11.50 | 100 | | | | | | | | |
| | 25 | 11.70 | 100 | | | | 12 | D | 1,2,5 | 7 | |
| 26 | 12.00 | 100 | | | | 12.45 | | | | | |
| 27 | 12.30 | 100 | | | | | | | | | |
| 28 | 13.00 | 100 | | | | | | | | | |
| 29 | 13.50 | 100 | | | | 13.5 | D | 1,3,5 | 6 | | |
| 30 | 13.80 | 100 | | | | 13.95 | | | | | |
| 31 | 14.00 | 100 | | | | | | | | | |
| 32 | 14.35 | 100 | | | | 15 | D | 4,15,R | R | | |
| 33 | 15.00 | 100 | | | | 15.35 | | | | | |
| 34 | 15.50 | 100 | | | | | | | | | |
| 35 | 15.45 | 100 | | | | | | | | | |
| 36 | 16.00 | 100 | | | | 16.5 | D | 15,R | R | | |
| 37 | 16.50 | 100 | | | | 16.7 | | | | | |
| 38 | 16.95 | 100 | | | | | | | | | |
| 39 | 17.50 | 100 | | | | 18 | D | 5,9,11 | 20 | | |
| 40 | 18.00 | 100 | | | | 18.45 | | | | | |
| 41 | 19.00 | 100 | | | | 19 | UD | | | | |
| 42 | 19.50 | 100 | | | | 19.2 | D | 2,3,5 | 6 | | |
| 43 | 19.95 | 100 | | | | 19.5 | | | | | |
| 44 | 20.50 | 100 | | | | 19.95 | | | | | |
| 45 | 21.00 | 100 | | | | 21 | D | 5,5,10 | 19 | | |
| 46 | 21.60 | 100 | | | | 21.45 | | | | | |
| 47 | 22.00 | 100 | | | | | | | | | |
| 48 | 22.50 | 100 | | | | | | | | | |
| 49 | 22.95 | 100 | | | | 22.5 | D | 2,2,2 | 4 | | |
| 50 | 23.70 | 100 | | | | 22.95 | | | | | |
| 51 | 24.00 | 100 | | | | | | | | | |
| 52 | 24.45 | 100 | | | | 24 | D | 4,4,6 | 10 | | |
| 53 | 25.00 | 100 | | | | 24.45 | | | | | |
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| Project | | Contractor | | Subcontractor | | Consultant | | | | | | |
|--|--|---------------------------|----------|--|---------|------------------------------------|--------------|-------------|---------|-----------|------------------|--|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | | |
| Location/Chainage: Old Borkena Bridge | | | | Drilling Method: Dry/Wash Drilling | | Water level: 0.65 | | | | | | |
| Coordinates (E/N): 579956.862 1225533.023 | | | | Core diameter (mm): 75 mm (0.0 -20.0m) | | Sheet: 1 of 1 | | | | | | |
| Ground Elevation (masl.): 1814.603 | | | | Casing type & depth: 110mm | | BH Inclination: 90° | | | | | | |
| Borehole No.: BH-3(Pire-2) | | | | Date Started: 26-06-2022 | | Bit type: Carbide/Diamond | | | | | | |
| Total Depth (m): 20.00 | | | | Date Completed: 30-06-2022 | | Type of Rig: GXY 200BXY-2B | | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| | Dark brown to gray loess to very dense sandy gravel material and old bridge retaining wall structure | 0 | 0.50 | 100 | | | | | | | | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 2 | 2.00 | 100 | | | | | | | | |
| | | 3 | 3.50 | 100 | | | | | | | | |
| | Variegated color medium to very dense silty gravel sand soil | 4 | 4.00 | 100 | | | | 4 | D | 14, 17, R | R | |
| | | 5 | 4.25 | 100 | | | | 4.9 | | | | |
| | | 6 | 4.50 | 100 | | | | | | | | |
| | | 7 | 4.90 | 100 | | | | | | | | |
| | | 8 | 5.40 | 100 | | | | | | | | |
| | | 9 | 6.00 | 100 | | | | | | | | |
| | | 10 | 6.50 | 100 | | | | | | | | |
| | Dark brown soft to hard silty clay with some sandy gravel soil | 11 | 7.00 | 100 | | | | 7.3 | HF | 9,9,13 | 22 | |
| | | 12 | 7.30 | 100 | | | | 7.5 | D | | | |
| | | 13 | 7.50 | 100 | | | | 7.5 | | | | |
| | | 14 | 7.95 | 100 | | | | 7.95 | | | | |
| | | 15 | 9.00 | 100 | | | | 9 | D | 2,6,11 | 17 | |
| | | 16 | 9.45 | 100 | | | | 9.45 | | | | |
| | | 17 | 10.00 | 100 | | | | 10.5 | D | 9,9,10 | 19 | |
| | | 18 | 10.50 | 100 | | | | 10.95 | | | | |
| | | 19 | 10.95 | 100 | | | | 12 | D | 2,2,5 | 7 | |
| 20 | | 12.00 | 100 | | | | 12.45 | | | | | |
| Variegated color medium to very dense silty gravel sand soil | 21 | 13.00 | 100 | | | | 13.5 | D | 1,1,3 | 4 | | |
| | 22 | 13.50 | 100 | | | | 13.95 | | | | | |
| | 23 | 13.95 | 100 | | | | 15 | D | 50,R | R | | |
| | 24 | 14.50 | 100 | | | | 15.07 | | | | | |
| | 25 | 15.00 | 100 | | | | 15.50 | | | | | |
| | 26 | 15.07 | 100 | | | | 16.00 | | | | | |
| Dark brown soft to hard silty clay with some sandy gravel soil | 27 | 16.00 | 100 | | | | 16.50 | D | 17,23,R | R | | |
| | 28 | 16.50 | 100 | | | | 16.85 | | | | | |
| | 29 | 16.85 | 100 | | | | 17.10 | | | | | |
| | 30 | 17.10 | 100 | | | | 18.00 | | | | | |
| | | 18.00 | 100 | | | | 18.45 | D | 2,5,7 | 12 | | |
| | | 18.45 | 100 | | | | 19.00 | | | | | |
| | | 19.00 | 100 | | | | 19.50 | | | | | |
| | | 19.50 | 100 | | | | 19.5 | D | 3,7,9 | 16 | | |
| | | 20.00 | 100 | | | | | | | | | |

Driller: Destaw T.

Logged by: Mulugeta M.

Checked by: Henok T.



Note:




D=Disturbed Sample (Split spoon)
UD=Undisturbed Sample
RC=Rock Core Sample

SPT=Standard Penetration Test
SCR=Solid Core Recovery
RQD=Rock Quality Designation
HF= Highly Fractured




| Project | | Contractor | | Subcontractor | | Consultant | | | | | | |
|--|---|---------------------------|--|--|---------|------------------------------------|--------------|-------------|----------|---------|------------------|----|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | | |
| Location/Chainage: Old Borkena Bridge | | | Drilling Method: Dry/Wash Drilling | | | Water level: 11 | | | | | | |
| Coordinates (E/N): 579925.565 1225533.624 | | | Core diameter (mm): 75 mm (0.0 -20.0m) | | | Sheet: 1 of 1 | | | | | | |
| Ground Elevation (masl.): 1821.452 | | | Casing type & depth: 110mm | | | BH Inclination: 90° | | | | | | |
| Borehole No.: BH-4(Desie Side Abut) | | | Date Started: 28-06-2022 | | | Bit type: Carbide/Diamond | | | | | | |
| Total Depth (m): 23.40 | | | Date Completed: 01-07-2022 | | | Type of Rig: HZ-130YY Drilling | | | | | | |
| Soil/Rock symbol | Soil/Rock description | Depth (m) | Core run | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| | Dark brown to gray loos to very dense sandy gravel material and old bridge retaining wall structure | 0 | 0.30 | 100 | | | | | | | | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 2 | 1.70 | 100 | | | | 1.7 | D | 4,6,7 | | 13 |
| | | 3 | 2.15 | 100 | | | | 2.15 | | | | |
| | | 4 | 2.60 | 100 | | | | | | | | |
| | | 5 | 3.00 | 100 | | | | 3 | D | 2,3,6 | | 9 |
| | | 6 | 3.45 | 100 | | | | | | | | |
| | | 7 | 3.70 | 100 | | | | 3.45 | | | | |
| | | 8 | 4.00 | 100 | | | | | | | | |
| | | 9 | 4.30 | 100 | | | | | | | | |
| | | 10 | 4.90 | 100 | | | | | | | | |
| | Variegated color medium to very dense silty gravel sand soil | 11 | 5.40 | 100 | | | | | | | | |
| | | 12 | 5.70 | 100 | | | | | | | | |
| | | 13 | 6.10 | 100 | | | | | | | | |
| | | 14 | 6.40 | 100 | | | | | | | | |
| | | 15 | 7.00 | 100 | | | | | | | | |
| | Dark brown soft to hard silty clay with some sandy gravel soil | 16 | 7.30 | 100 | | | | | | | | |
| | | 17 | 7.80 | 100 | | | | | | | | |
| | | 18 | 8.00 | 100 | | | | | | | | |
| | | 19 | 8.45 | 100 | | | | | | | | |
| | | 20 | 8.80 | 100 | | | | | | | | |
| | | 21 | 10.00 | 100 | | | | | | | | |
| | | 22 | 10.50 | 100 | | | | 10.5 | D | 5,10,15 | 25 | |
| | | 23 | 10.95 | 100 | | | | 10.95 | | | | |
| 24 | | 11.50 | 100 | | | | | | | | | |
| | | 12.00 | 100 | | | | | | | | | |
| | | 12.15 | 100 | | | | 12 | D | 32,R | R | | |
| | | 12.60 | 100 | | | | 12.45 | | | | | |
| | | 13.00 | 100 | | | | | | | | | |
| | | 13.40 | 100 | | | | | | | | | |
| | | 13.80 | 100 | | | | 13.5 | | | | | |
| | | 14.00 | 100 | | | | 13.95 | | | | | |
| | | 14.20 | 100 | | | | | | | | | |
| | | 14.50 | 100 | | | | | | | | | |
| | | 14.80 | 100 | | | | 15 | D | 12,14,18 | 32 | | |
| | | 15.00 | 100 | | | | 15.45 | | | | | |
| | | 15.45 | 100 | | | | | | | | | |
| | | 16.00 | 100 | | | | 16 | UD | | | | |
| | | 16.20 | 100 | | | | 16.2 | D | 7,9,11 | 20 | | |
| | | 16.50 | 100 | | | | 16.5 | | | | | |
| | | 16.95 | 100 | | | | 16.95 | | | | | |
| | | 18.00 | 100 | | | | 18 | D | 5,12,14 | 26 | | |
| | | 18.45 | 100 | | | | 18.45 | | | | | |
| | | 19.00 | 100 | | | | 19 | UD | | | | |
| | | 19.50 | 100 | | | | 19.5 | D | 5,12,17 | 29 | | |
| | | 19.95 | 100 | | | | 19.95 | | | | | |
| | | 21.00 | 100 | | | | 21 | D | 5,12,14 | 26 | | |
| | | 21.45 | 100 | | | | 21.45 | | | | | |
| | | 22.00 | 100 | | | | | | | | | |
| | | 22.50 | 100 | | | | | | | | | |
| | | 22.95 | 100 | | | | 22.5 | D | 10,13,17 | 30 | | |
| | | 23.40 | 100 | | | | | | | | | |
| Driller: Destaw T. | | Logged by: Mulugeta M. | | Checked by: Henok T. | | | | | | | | |
| Note: | | | | | | | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SPT=Standard Penetration Test | | | | | | |
| UD=Undisturbed Sample | | | | | | SCR=Solid Core Recovery | | | | | | |
| RC=Rock Core Sample | | | | | | RQD=Rock Quality Designation | | | | | | |
| | | | | | | HF= Highly Fractured | | | | | | |

| Project | | Contractor | | Subcontractor | | Consultant | | | | | | |
|--|---|---------------------------|--|--|---------|------------------------------------|--------------|------------------|-----|------------|------------------|---|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | | |
| Location/Chainage: Km5+585 | | | Drilling Method: Dry/Wash Drilling | | | Water level: 0.5m | | | | | | |
| Coordinates (E/N): 576885.882 1224128.418 | | | Core diameter (mm): 75 mm (0.0 -15.0m) | | | Sheet: 1 of 1 | | | | | | |
| Ground Elevation (masl.): 1907.33 | | | Casing type & depth: 110mm | | | BH Inclination: 90° | | | | | | |
| Borehole No.: BH-1 (A.A side Abut) | | | Date Started: 3-07-2022 | | | Bit type: Carbide/Diamond | | | | | | |
| Total Depth (m): 15 | | | Date Completed: 5-07-2022 | | | Type of Rig: HZ-130YY Drilling | | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| | Dark gray medium to very dense silty gravel with sand | 0 | | 100 | | | | | | | | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 2 | 1.50 1.80 2.00 | 100 100 100 | | | | 1.5 1.8 | D | 6, 8, R | | R |
| | Dark brown medium to very stiff sandy silty clay soil | 3 | 3.00 | 100 | | | | | | | | |
| | | 4 | 3.45 | 100 | | | | 3 3.45 | D | 9, 9, 12 | 21 | |
| | | 5 | 4.00 4.50 | 100 100 | | | | 4.5 | D | 11, 11, 14 | 25 | |
| | | 6 | 5.00 5.20 | 100 100 | | | | 4.95 5 5.2 | UD | | | |
| | | 7 | 6.00 | 100 | | | | 6 | D | 12, 13, 15 | 26 | |
| | | 8 | 6.45 | 100 | | | | 6.45 | D | | | |
| | | 9 | 7.00 | 100 | | | | 7 | D | 4, 5, 6 | 11 | |
| | | 10 | 7.50 | 100 | | | | 7.5 | D | | | |
| | | 11 | 8.00 | 100 | | | | 7.95 | D | | | |
| | | 12 | 9.00 | 100 | | | | 9 | D | 3, 5, 7 | 12 | |
| | | 13 | 9.45 | 100 | | | | 9.45 | D | | | |
| | | 14 | 10.00 10.50 | 100 100 | | | | | | | | |
| 15 | 11.00 11.20 11.40 | 100 100 100 | | | | 10.5 | D | 7, 9, 12 | 21 | | | |
| | 12.00 12.45 | 100 100 | | | | 10.95 11.20 11.40 | UD | | | | | |
| | 12 | 12 | 100 | | | 12 | D | 7, 8, 11 | 19 | | | |
| | 13 | 13.00 | 100 | | | 12.45 | | | | | | |
| | 14 | 13.50 | 100 | | | | | | | | | |
| | 15 | 14.00 | 100 | | | 13.5 | D | 5, 6, 9 | 17 | | | |
| | 15.00 | 15.00 | 100 | | | 13.95 | | | | | | |
| Driller: Destaw T. | | Logged by: Mulugeta M. | | Checked by: Henok T. | | | | | | | | |
| Note: | | | | | | SPT=Standard Penetration Test | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SCR=Solid Core Recovery | | | | | | |
| UD=Undisturbed Sample | | | | | | RQD=Rock Quality Designation | | | | | | |
| RC=Rock Core Sample | | | | | | HF= Highly Fractured | | | | | | |

| Project | | Contractor | | Subcontractor | | | | Consultant | | | | | | | |
|--|---|---------------------------|---|--|---------|-------------------------------|--------------|------------------------------------|-----|-----------|---|----|------------|--|----|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | | | ETHIO INFRA ENGINEERING PLC | | | | | | | |
| Location/Chainage: Km6+327.24 | | | | Drilling Method: Dry/Wash Drilling | | | | Water level: *0.80m | | | | | | | |
| Coordinates (E/N): 576530.046 1224744.542 | | | | Core diameter (mm): 75 mm (0.0 -15.0m) | | | | Sheet: 1 of 1 | | | | | | | |
| Ground Elevation (masl.): 1895.054 | | | | Casing type & depth: 110mm | | | | BH Inclination: 90° | | | | | | | |
| Borehole No.: BH-1(A.A Side Abut) | | | | Date Started: 17-06-2022 | | | | Bit type: Carbide/Diamond | | | | | | | |
| Total Depth (m): 15 | | | | Date Completed: 18-06-2022 | | | | Type of Rig: HZ-130YY Drilling | | | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | | | | |
| 4.00 | Dark gray medium dense gravelly sand soil | 0.55 | | 100 | | | | | | |  | | | | |
| | | 1.00 | | 100 | | | | | | | | | | | |
| | | 1.50 | | 100 | | | | | | | | | | | |
| | | 1.95 | | 100 | | | | 1.50 | D | 17, 7, 10 | | 17 | | | |
| | | 2.60 | | 100 | | | | 1.95 | | | | | | | |
| | | 3.00 | | 100 | | | | | | | | | | | |
| | | 3.45 | | 100 | | | | 3.00 | D | 9, 10, 10 | | 20 | | | |
| | | 4.00 | | 100 | | | | 3.45 | | | | | | | |
| | | 15.00 | Dark brown to gray soft to hard silty clay soil | 4.50 | | 100 | | | | | | | |  | |
| | | | | 4.95 | | 100 | | | | 4.50 | | D | 2, 2, 3 | | 5 |
| | | | | 6.00 | | 100 | | | | 4.95 | | | | | |
| | | | | 6.45 | | 100 | | | | 6.00 | | D | 4, 7, 11 | | 18 |
| | | | | 7.20 | | 100 | | | | 6.45 | | | | | |
| | | | | 7.50 | | 100 | | | | | | | | | |
| | | | | 7.95 | | 100 | | | | 7.50 | | D | 11, 12, 11 | | 23 |
| 8.80 | | | | 100 | | | | 7.95 | | | | | | | |
| 9.00 | | | | 100 | | | | 8.80 | UD | | | | | | |
| 9.45 | | | | 100 | | | | 9.00 | D | 3, 5, 10 | 15 | | | | |
| 10.00 | | | | 100 | | | | 9.45 | | | | | | | |
| 10.50 | | | | 100 | | | | | | | | | | | |
| 10.95 | | | | 100 | | | | 10.50 | D | 4, 10, 8 | 18 | | | | |
| 11.30 | | | | 100 | | | | 10.95 | | | | | | | |
| 11.50 | | | | 100 | | | | 11.30 | UD | | | | | | |
| 12.00 | | 100 | | | | 11.50 | | | | | | | | | |
| 12.45 | | 100 | | | | 12.00 | D | 13, 16, 21 | 37 | | | | | | |
| 12.70 | | 100 | | | | 12.45 | | | | | | | | | |
| 13.50 | | 100 | | | | | | | | | | | | | |
| 13.95 | | 100 | | | | 13.50 | D | 12, 20, 25 | 45 | | | | | | |
| 15.00 | | 100 | | | | 13.95 | | | | | | | | | |
| Driller: destaw_T | | Logged by: Mulugeta_M | | | | Checked by: Henok_T | | | | | | | | | |
| Note: | | | | | | SPT=Standard Penetration Test | | | | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SCR=Solid Core Recovery | | | | | | | | | |
| UD=Undisturbed Sample | | | | | | RQD=Rock Quality Designation | | | | | | | | | |
| RC=Rock Core Sample | | | | | | HF= Highly Fractured | | | | | | | | | |

| Project | | Contractor | | Subcontractor | | Consultant | | | | | | |
|--|---|---------------------------|----------|--|---------|------------------------------------|--------------|-------------|-----------|----|--|--|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | | |
| Location/Chainage: Km6+327.24 | | | | Drilling Method: Dry/Wash Drilling | | Water level: *0.70m | | | | | | |
| Coordinates (E/N): 576526.237 1224754.86 | | | | Core diameter (mm): 75 mm (0.0 -15.0m) | | Sheet: 1 of 1 | | | | | | |
| Ground Elevation (masl.): 1894.94 | | | | Casing type & depth: 110mm | | BH Inclination: 90° | | | | | | |
| Borehole No.: BH-2 | | | | Date Started: 6/18/2022 | | Bit type: Carbide/Diamond | | | | | | |
| Total Depth (m): 15 | | | | Date Completed: 6/19/2022 | | Type of Rig: HZ-130YY Drilling | | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| | Dark brown to gray soft to hard silty clay soil | 0 | 0.50 | 100 | | | | | | |  <p style="text-align: center;">5.0</p>  <p style="text-align: center;">10.0</p>  <p style="text-align: center;">15.0</p> | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 1.50 | 100 | | | | | | | | | |
| | | 1.95 | 100 | | | | 1.50 | D | 1, 1, 1 | 2 | | |
| | | 2 | | 100 | | | 1.95 | | | | | |
| | | 3 | 3.00 | | | | | | | | | |
| | | 3.45 | 100 | | | | 3.00 | D | 1, 1, 2 | 3 | | |
| | | 4 | 4.00 | | | | 3.45 | | | | | |
| | | 4.50 | 100 | | | | | | | | | |
| | | 4.95 | 100 | | | | 4.50 | D | 1, 2, 4 | 6 | | |
| | | 5 | | 100 | | | 4.95 | | | | | |
| | | 5.70 | | 100 | | | | | | | | |
| | | 6.00 | 100 | | | | 6.00 | D | 6, 7, 9 | 16 | | |
| | | 6.45 | 100 | | | | | | | | | |
| | | 6.70 | 100 | | | | 6.45 | UD | | | | |
| | | 6.90 | 100 | | | | 6.70 | | | | | |
| | | 7 | | 100 | | | 6.90 | | | | | |
| | | 7.50 | 100 | | | | 7.50 | D | 5, 5, 5 | 10 | | |
| | | 8 | | 100 | | | 7.95 | | | | | |
| | | 8.40 | 100 | | | | 7.95 | UD | | | | |
| | | 8.60 | 100 | | | | 8.40 | | | | | |
| | | 9 | | 100 | | | 8.60 | | | | | |
| | | 9.00 | 100 | | | | 9.00 | D | 5, 10, 12 | 22 | | |
| | | 9.45 | 100 | | | | 9.45 | | | | | |
| | | 10 | | 100 | | | | | | | | |
| | | 10.50 | 100 | | | | | | | | | |
| | | 10.95 | 100 | | | | 10.50 | D | 7, 6, 7 | 13 | | |
| | | 11 | | 100 | | | 10.95 | | | | | |
| | | 11.50 | 100 | | | | | | | | | |
| | | 12 | | 100 | | | 12.00 | D | 7, 11, 14 | 25 | | |
| 12.45 | 100 | | | | 12.45 | | | | | | | |
| 13 | | 100 | | | | | | | | | | |
| 13.50 | 100 | | | | 13.50 | D | 8, 14, 16 | 30 | | | | |
| 14 | | 100 | | | 13.95 | | | | | | | |
| 15 | | 100 | | | 15.00 | | | | | | | |
| Driller: Destaw. T | | Logged by: Mulugeta. M | | Checked by: Henok. T | | | | | | | | |
| Note: | | | | | | SPT=Standard Penetration Test | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SCR=Solid Core Recovery | | | | | | |
| UD=Undisturbed Sample | | | | | | RQD=Rock Quality Designation | | | | | | |
| RC=Rock Core Sample | | | | | | HF= Highly Fractured | | | | | | |

| Project | | Contractor | | Subcontractor | | | | Consultant | | | | |
|--|--|---------------------------|----------|--|---------|-------------------------------|--------------|------------------------------------|-----|------------|------------------|--|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | | | ETHIO INFRA ENGINEERING PLC | | | | |
| Location/Chainage: Berbere River Bridge | | | | Drilling Method: Dry/Wash Drilling | | | | Water level: 3.00m | | | | |
| Coordinates (E/N): 580031.202 1225554.698 | | | | Core diameter (mm): 75 mm (0.0 -25.0m) | | | | Sheet: 1 of 1 | | | | |
| Ground Elevation (masl.): 1819.953 | | | | Casing type & depth: 110mm | | | | BH Inclination: 90° | | | | |
| Borehole No.: BH-1 (A.A side Abut) | | | | Date Started: 25-07-2022 | | | | Bit type: Carbide/Diamond | | | | |
| Total Depth (m): 25 | | | | Date Completed: 28-07-2022 | | | | Type of Rig: HZ-130YY Drilling | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| [Soil/Rock symbol] | Variegated color very loose to loose clay sand with silty gravel | 0 | 0.50 | 100 | | | | | | | | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 2 | 1.50 | 100 | | | | | | | | |
| | Dark brown to dark gray soft to hard silty clay soil | 2 | 2.30 | 100 | | | | | | | | |
| | | 3 | 3.00 | 100 | | | | 3.00 | D | 4, 5, 6 | 11 | |
| | | 4 | 3.45 | 100 | | | | 3.45 | | | | |
| | | 4 | 4.00 | 100 | | | | | | | | |
| | | 4 | 4.50 | 100 | | | | | | | | |
| | | 5 | 4.95 | 100 | | | | 4.50 | D | 2, 5, 7 | 12 | |
| | | 5 | 5.50 | 100 | | | | 4.95 | | | | |
| | | 6 | 5.70 | 100 | | | | 5.50 | UD | | | |
| | | 6 | 6.00 | 100 | | | | 5.70 | D | 4, 5, 6 | 11 | |
| | | 7 | 6.45 | 100 | | | | 6.00 | | | | |
| | | 7 | 7.00 | 100 | | | | 6.45 | | | | |
| | | 8 | 7.50 | 100 | | | | 7.00 | D | 4, 5, 7 | 12 | |
| | | 8 | 7.95 | 100 | | | | 7.50 | | | | |
| | | 9 | 8.60 | 100 | | | | 7.95 | | | | |
| | | 9 | 9.00 | 100 | | | | 8.60 | HF | 3, 5, 7 | 12 | |
| | | 10 | 9.45 | 100 | | | | 9.00 | | | | |
| | | 10 | 10.00 | 100 | | | | 9.45 | | | | |
| | | 11 | 10.50 | 100 | | | | 10.00 | D | 4, 5, 6 | 13 | |
| | | 11 | 10.95 | 100 | | | | 10.50 | UD | | | |
| | | 12 | 11.20 | 100 | | | | 10.95 | | | | |
| | | 12 | 11.40 | 100 | | | | 11.20 | D | 13, 22, 24 | 46 | |
| | | 13 | 12.00 | 100 | | | | 11.40 | | | | |
| 13 | 12.45 | 100 | | | | 12.00 | | | | | | |
| 14 | 13.00 | 100 | | | | 12.45 | D | 13, 15, 16 | 31 | | | |
| 14 | 13.30 | 100 | | | | 13.00 | | | | | | |
| 15 | 13.95 | 100 | | | | 13.30 | | | | | | |
| 15 | 15.00 | 100 | | | | 13.95 | | | | | | |
| 16 | 15.45 | 100 | | | | 15.00 | D | 11, 12, 13 | 25 | | | |
| 16 | 16.00 | 100 | | | | 15.45 | | | | | | |
| 17 | 16.30 | 100 | | | | 16.00 | | | | | | |
| 17 | 16.95 | 100 | | | | 16.30 | D | 4, 9, 11 | 20 | | | |
| 18 | 16.00 | 100 | | | | 16.95 | | | | | | |
| 18 | 16.45 | 100 | | | | 16.00 | | | | | | |
| 19 | 19.00 | 100 | | | | 16.45 | D | 5, 11, 12 | 23 | | | |
| 19 | 19.50 | 100 | | | | 19.00 | | | | | | |
| 20 | 20.00 | 100 | | | | 19.50 | D | 6, 10, 15 | 25 | | | |
| 20 | 21.00 | 100 | | | | 20.00 | | | | | | |
| 21 | 21.45 | 100 | | | | 21.00 | D | 10, 19, 21 | 40 | | | |
| 22 | 22.50 | 100 | | | | 21.45 | | | | | | |
| 23 | 22.95 | 100 | | | | 22.50 | D | 10, 11, 11 | 22 | | | |
| 23 | 23.30 | 100 | | | | 22.95 | | | | | | |
| 24 | 24.00 | 100 | | | | 23.30 | | | | | | |
| 24 | 24.45 | 100 | | | | 24.00 | D | 5, 8, 10 | 16 | | | |
| 25 | 25.00 | 100 | | | | 24.45 | | | | | | |
| | | | | | | | | | | | | |
| Driller: destaw_T | | Logged by: Mulugeta_M | | | | Checked by: Henok_T | | | | | | |
| Note: | | | | | | SPT=Standard Penetration Test | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SCR=Solid Core Recovery | | | | | | |
| UD=Undisturbed Sample | | | | | | RQD=Rock Quality Designation | | | | | | |
| RC=Rock Core Sample | | | | | | HF= Highly Fractured | | | | | | |

| Project | | Contractor | | Subcontractor | | Consultant | | | | | | |
|--|--|---------------------------|-----------------------|--|---------|------------------------------------|--------------|-------------|-----|-----------|---|---|
| Consulting Services for the Geotechnical investigation of five bridges along Kombolcha Bypass Road project | | Yonab Construction | | Jurassic Consulting Engineers PLC | | ETHIO INFRA ENGINEERING PLC | | | | | | |
| Location/Chainage: Berbere River Bridge | | | | Drilling Method: Dry/Wash Drilling | | Water level: 3.00m | | | | | | |
| Coordinates (E/N): 580015.995 1225577.281 | | | | Core diameter (mm): 75 mm (0.0 -25.0m) | | Sheet: 1 of 1 | | | | | | |
| Ground Elevation (masl.): 1819.589 | | | | Casing type & depth: 110mm | | BH Inclination: 90° | | | | | | |
| Borehole No.: BH-2 (Dessie Side Abut) | | | | Date Started: 7/21/2022 | | Bit type: Carbide/Diamond | | | | | | |
| Total Depth (m): 25 | | | | Date Completed: 7/24/2022 | | Type of Rig: HZ-130YY Drilling | | | | | | |
| Soil/Rock symbole | Soil/Rock description | Depth (m) | Core num | TCR (%) | SCR (%) | RQD (%) | Sample Depth | Sample Type | SPT | N | Core photographs | |
| 2.00  | Variegated color very loose to loose clay sand with silty gravel | 0 | 0.30 | 100 | | | | | | |  | |
| | | 1 | 1.00 | 100 | | | | | | | | |
| | | 2 | 1.50 | 100 | | | | | | | | |
| | | 3 | 1.95 | 100 | | | | 1.50 | D | 6, 5, 5 | | 10 |
| | | 4 | 3.00 | 100 | | | | 1.95 | | | | |
| | | 5 | 3.45 | 100 | | | | 3.00 | D | 2, 2, 3 | | 5 |
| | | 6 | 4.50 | 100 | | | | 3.45 | | | | |
| | | 7 | 4.95 | 100 | | | | 4.50 | D | 2, 2, 3 | | 5 |
| | | 8 | 5.80 | 100 | | | | 4.95 | | | | |
| | | 9 | 6.00 | 100 | | | | 5.80 | HF | | | |
| | Dark brown to dark gray soft to hard silty clay soil | 10 | 6.45 | 100 | | | | 6.00 | D | 3, 4, 5 | 9 |  |
| | | 11 | 7.00 | 100 | | | | 6.45 | | | | |
| | | 12 | 7.50 | 100 | | | | 7.00 | D | 3, 3, 6 | 9 | |
| | | 13 | 7.95 | 100 | | | | 7.50 | | | | |
| | | 14 | 8.80 | 100 | | | | 7.95 | HF | | | |
| | | 15 | 9.00 | 100 | | | | 8.80 | | 5, 6, 9 | 15 | |
| | | 16 | 9.45 | 100 | | | | 9.00 | | | | |
| | | 17 | 10.00 | 100 | | | | 9.45 | D | | | |
| | | 18 | 10.50 | 100 | | | | 10.00 | | 6, 7, 8 | 15 | |
| | | 19 | 10.95 | 100 | | | | 10.50 | | | | |
| | | 20 | 12.00 | 100 | | | | 10.95 | | | | |
| | | 21 | 12.45 | 100 | | | | 12.00 | D | 9, 13, 14 | 27 | |
| | | 22 | 13.00 | 100 | | | | 12.45 | | | | |
| | | 23 | 13.50 | 100 | | | | 13.00 | D | 9, 10, 13 | 23 | |
| | | 24 | 13.95 | 100 | | | | 13.50 | | | | |
| 25 | 15.00 | 100 | | | | 13.95 | | | | | | |
| 26 | 15.45 | 100 | | | | 15.00 | D | 6, 5, 10 | 18 | | | |
| 27 | 16.00 | 100 | | | | 15.45 | | | | | | |
| 28 | 16.50 | 100 | | | | 16.00 | D | 4, 6, 6 | 14 | | | |
| 29 | 16.95 | 100 | | | | 16.50 | | | | | | |
| 30 | 18.00 | 100 | | | | 16.95 | | | | | | |
| 31 | 18.45 | 100 | | | | 18.00 | D | 7, 9, 9 | 18 | | | |
| 32 | 19.55 | 100 | | | | 18.45 | | | | | | |
| 33 | 20.00 | 100 | | | | 19.55 | D | 9, 10, 11 | 21 | | | |
| 34 | 20.60 | 100 | | | | 20.00 | | | | | | |
| 35 | 21.00 | 100 | | | | 20.60 | | | | | | |
| 36 | 21.45 | 100 | | | | 21.00 | D | 10, 15, 21 | 26 | | | |
| 37 | 22.50 | 100 | | | | 21.45 | | | | | | |
| 38 | 22.95 | 100 | | | | 22.50 | D | 13, 16, 25 | 41 | | | |
| 39 | 23.30 | 100 | | | | 22.95 | | | | | | |
| 40 | 24.00 | 100 | | | | 24.00 | D | | | | | |
| 41 | 24.45 | 100 | | | | 24.45 | | | | | | |
| 42 | 25.00 | 100 | | | | | | | | | | |
| 25.0 | | | | | | | | | | | | |
| Driller: destaw_T | | | Logged by: Mulugeta_M | | | Checked by: Henok_T | | | | | | |
| Note: | | | | | | | | | | | | |
| D=Disturbed Sample (Split spoon) | | | | | | SPT=Standard Penetration Test | | | | | | |
| UD=Undisturbed Sample | | | | | | SCR=Solid Core Recovery | | | | | | |
| RC=Rock Core Sample | | | | | | RQD=Rock Quality Designation | | | | | | |
| | | | | | | HF= Highly Fractured | | | | | | |

APPENDIX-B: Index Properties Results



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ETHIO Infra Engineering Private Limited Company

CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
(Location: In front of Sami Building Geri)
SUMMARY OF TEST RESULTS

P.O.Box 14487

Bole Sub city

Kebele 25 House No. 259

Tel. 011 429 2916

Addis Ababa, Ethiopia

PROJECT: Combolcha Bypass Road Project
CHAINAGE: Old Borkena Bridge
BORE HOLE NO: BH-1 (A A Side Abutment)
TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC.
SAMPLED BY: Client

| Sr. No | chainage | Location | Material Des. | Atterberg's Limit (AASHTO T 89 T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification. | Unified Classification. | Soil | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|--------------------|-------------|-----------------------------------|--------------------------------------|-----|-----|--|------|----------|----------|-----------------------------|--------------------------------|------|---------------------------------|----------|
| | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | | |
| 7 | Old Borkena Bridge | 4.50-4.95 | Dark Gray silty sandy clay | 40 | 22 | 19 | 79 | 69 | 51 | 36 | A-6(8) | CL Sandy Lean clay with gravel | | 2.575 | 8.6 |
| 8 | >> | 6.00-6.45 | Dark gray clayey gravel sand soil | 30 | 19 | 11 | 68 | 59 | 36 | 19 | A-2-6(0) | CL Sandy Lean clay with gravel | | 2.561 | 10.36 |
| 9 | >> | 9.00-9.45 | Dark brown cohesive clay soil | 49 | 29 | 20 | 97 | 97 | 96 | 95 | A-7-6(23) | CL Lean clay | | 2.326 | 28.6 |
| 10 | >> | 15.00-15.45 | Dark brown cohesive clay soil | 72 | 27 | 44 | 94 | 88 | 80 | 75 | A-7-6(43) | CL Lean clay with sand | | 2.401 | 24.8 |



REMARK:

Tested by: *Yohannes Gebret*

Lab. Engineer: *[Signature]*

Reported By: *[Signature]*

Material Engineer: *[Signature]*

Head Office
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ETHIO Infra Engineering Private Limited Company

CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
 (Location: In front of Sami Building Geri)
SUMMARY OF TEST RESULTS

P.O.Box 14487
 Bole Sub city
 Kebele 25 House No. 259
 Tel. 011 629 2916
 Addis Ababa, Ethiopia

PROJECT Combolcha Bypass Road Project
 CHAINAGE Borkena Old Bridge
 Bore Hole No BH- 2
 TESTS ORDERED Atterberg limit, Grading, Sp. Gravity & NMC,
 SUBMITTED BY Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89/ T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification. | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|--------------------|---------------|-------------|------------------------------------|---------------------------------------|-----|-----|--|------|----------|----------|----------------------------|------------------------------------|---------------------------------|----------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 11 | Borkena Old Bridge | BH-2(Pier 1) | 3.00-3.45 | Dark gray sandy gravel with bolder | 32 | 16 | 16 | 36 | 26 | 15 | 9 | A-2-6(1) | CL Gravelly lean clay with sand | 2.632 | 9.8 |
| 12 | >> | >> | 6.00-6.45 | Dark gray sandy gravel with bolder | 30 | 17 | 13 | 45 | 35 | 21 | 14 | A-2-6(0) | CL Gravelly Lean clay with sand | 2.750 | 11.4 |
| 13 | >> | >> | 9.00-9.45 | Dark gray silty sand with gravel | 44 | 20 | 25 | 74 | 65 | 34 | 22 | A-2-7(10) | CL sandy Lean Clay with gravel | 2.598 | 18.5 |
| 14 | >> | >> | 12.00-12.45 | Dark gray silty clay soil | 62 | 32 | 31 | 84 | 80 | 77 | 69 | A-7-5(28) | CH Gravelly fat clay sand | 2.371 | 30.0 |
| 15 | >> | >> | 15.00-15.35 | Dark gray silty clay soil | 60 | 28 | 33 | 78 | 71 | 64 | 54 | A-7-6(25) | CH sandy fat Clay with gravel | 2.653 | 24.6 |
| 16 | >> | >> | 18.00-18.45 | Dark gray silty clay soil | 53 | 22 | 31 | 83 | 78 | 71 | 66 | A-7-6(26) | CH Sandy fat clay with gravel | 2.442 | 8.6 |
| 17 | >> | >> | 21.00-21.50 | Dark gray silty clay soil | 70 | 36 | 34 | 76 | 67 | 63 | 59 | A-7-5(29) | MH Gravelly elastic silt with sand | 2.410 | 28.8 |

REMARK:

Tested by: Yohannes Getnet
 Lab. Engineer: ff

Reported By: [Signature]
 Material Engineer: [Signature]

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 Bole Sub-city Kebele 12/13
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ETHIO Infra Engineering Private Limited Company

CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
 (Location: In front of Sami Building Geri)
SUMMARY OF TEST RESULTS

P.O.Box 14487
 Bole Sub city
 Kebele 25 House No. 259
 Tel. 011 429 2914
 Addis Ababa, Ethiopia

PROJECT: Combolicha Bypass Road Project
 CHAINAGE: Borkena Old Bridge
 Bore Hole No: BH- 3
 TESTS ORDERED: Atterberg limit, Grading , Sp. Gravity & NMC.
 SUBMITTED BY: Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89) (90) | | | Grain size analysis % Pass (AASHTO T 27) | | | AASHTO Soil Classification | Unified Soil Classification | Specific Gravity (AASHTO T 100) | NMC In % | |
|--------|--------------------|----------------|-------------|-------------------------------------|--------------------------------------|-----|-----|--|------|----------|----------------------------|-----------------------------|---------------------------------|----------|----------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | | | | | 0.075 mm |
| 18 | Borkena Old Bridge | BH-3 (Pier 2) | 4.50-4.95 | Dark gray sandy gravel | 31 | 17 | 14 | 36 | 26 | 16 | 10 | A-2-6(0) | CL Gravelly lean clay with sand | 2.586 | 6.4 |
| 19 | >> | >> | 7.50-7.95 | Dark gray silty clay soil with sand | 64 | 33 | 31 | 98 | 96 | 92 | 88 | A-7-5(34) | MH Elastic Silt | 2.363 | 27.0 |
| 20 | >> | >> | 10.50-10.95 | Dark gray silty clay soil with sand | 63 | 31 | 33 | 82 | 77 | 72 | 67 | A-7-5(29) | CH Gravelly fat clay with sand | 2.473 | 21.8 |
| 21 | >> | >> | 13.50-13.95 | Dark gray silty clay soil with sand | 64 | 33 | 31 | 56 | 53 | 48 | 42 | A-7-5(20) | CH Gravelly fat Clay | 2.586 | 25.3 |
| 22 | >> | >> | 16.50-16.95 | Dark gray silty gravel | 37 | 19 | 18 | 64 | 56 | 44 | 35 | A-2-6(7) | CL Gravelly lean clay with sand | 2.609 | 12.1 |
| 23 | >> | >> | 19.50-19.95 | Dark gray silty clay soil | 55 | 27 | 28 | 59 | 56 | 47 | 36 | A-7-6(16) | CH Gravelly fat clay with sand | 2.436 | 26.1 |

REMARK:

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CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
 (Location: In front of Sami Building Geri)
SUMMARY OF TEST RESULTS

P.O.Box 14487
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 Addis Ababa, Ethiopia

PROJECT: Combolicha Bypass Road Project
 CHAINAGE: Borkena Old Bridge
 Bore Hole No: BH- 4
 TESTS ORDERED: Atterberg limit, Grading , Sp. Gravity & NMC,
 SUBMITTED BY: Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 99/ T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification. | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|--------------------|---------------------------|-------------|--------------------------------------|---------------------------------------|-----|-----|--|------|----------|----------|----------------------------|--------------------------------|---------------------------------|----------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 24 | Borkena Old Bridge | Bh-4 Dessie Side Abutment | 10.50-10.95 | Dark brown sand (back fill material) | | | N.P | 97 | 96 | 86 | 20 | A-1-b(0) | ML sandy silt | 2.540 | 39.3 |
| 25 | >> | >> | 12.00-12.45 | Dark gray silty gravel | 28 | 15 | 13 | 64 | 55 | 34 | 25 | A-2-6(1) | CL Sandy lean clay with gravel | 2.709 | 39.3 |
| 26 | >> | >> | 15.00-15.45 | Variegated color silty clay soil | 43 | 20 | 23 | 77 | 67 | 53 | 41 | A-7-6-(12) | CL Sandy lean clay with gravel | 2.693 | 8.5 |
| 27 | >> | >> | 16.50-16.95 | Variegated color silty clay soil | 82 | 36 | 46 | 99 | 96 | 94 | 93 | A-7-5-(54) | MH Elastic silt | 2.337 | 27.1 |
| 28 | >> | >> | 19.50-19.95 | Variegated color silty clay soil | 54 | 24 | 31 | 98 | 93 | 87 | 78 | A-7-6-(29) | CH Fat clay with sand | 2.432 | 21.9 |
| 29 | >> | >> | 22.50-22.95 | Variegated color silty clay soil | 85 | 38 | 47 | 100 | 98 | 96 | 93 | A-7-5-(56) | MH Elastic silt | 2.360 | 28.5 |

REMARK :

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CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
(Location: In front of Sami Building Geri)
SUMMARY OF TEST RESULTS

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Addis Ababa, Ethiopia

PROJECT Combolicha Bypass Road Project
CHAINAGE S+585
Bore Hole No BH- 1 A.A Side Abutment
TESTS ORDERED Atterberg limit, Grading , Sp. Gravity & NMC,
SUMMITTED BY Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89/ T 99) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification. | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|----------|--------------------|-------------|--|---------------------------------------|-----|-----|--|------|----------|----------|----------------------------|------------------------------|---------------------------------|----------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 1 | S+585 | A.A Side Abutment. | 3.00-3.45 | Dark brown silty sand (Alluvial deposit) | 44 | 28 | 16 | 99 | 98 | 95 | 81 | A-7-6(15) | CL Lean clay with Sand | 2.421 | 28.4 |
| 2 | >> | >> | 4.50-4.95 | Dark brown silty sand (Alluvial deposit) | 44 | 28 | 17 | 94 | 90 | 81 | 70 | A-7-6(13) | CL sandy lean Clay | 2.564 | 18.0 |
| 3 | >> | >> | 6.00-6.45 | Dark brown silty sand (Alluvial deposit) | 36 | 24 | 13 | 97 | 97 | 90 | 55 | A-6(7) | CL sandy lean Clay | 2525 | 47.0 |
| 4 | >> | >> | 9.00-9.45 | Dark brown silty Clay | 59 | 31 | 28 | 100 | 99 | 97 | 89 | A-7-5(31) | BH Elastic silt | 2.514 | 32.0 |
| 5 | >> | >> | 12.00-12.45 | Dark brown Clay Soil | 46 | 28 | 18 | 100 | 100 | 97 | 81 | A-7-6(17) | CL Lean Clay with Sand | 2.555 | 29.0 |

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SUMMARY OF TEST RESULTS

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 Addis Ababa, Ethiopia

PROJECT: Combolcha Bypass Road Project
 CHAINAGE: 5+585
 Bore Hole No: BH- 2
 TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC.
 SUBMITTED BY: Jurassic Consulting Engineers

MH Elastic silt with sand

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89: T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification. | Specific Gravity | NMC |
|--------|----------|----------------------|-------------|-------------------------------------|---------------------------------------|------|-----|--|------|----------|----------|----------------------------|------------------------------|------------------|------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| | | | | | (AASHTO T 100) | In % | | | | | | | | | |
| 6 | 5+585 | Dessie Side Abutment | 2.00-2.45 | Light brown Clayey sand | 40 | 28 | 13 | 99 | 97 | 88 | 70 | A-6(9) | CL sandy Lean Clay | 2.346 | 19.0 |
| 7 | >> | >> | 4.50-4.95 | Light brown Clayey sand | 40 | 26 | 14 | 98 | 96 | 85 | 64 | A-6-(9) | CL sandy Lean Clay | 2.418 | 23.4 |
| 8 | >> | >> | 7.70-8.15 | Light brown silty Clay | 54 | 33 | 21 | 100 | 100 | 96 | 85 | A-7-5(23) | MH Elastic silt with sand | 2.395 | 38.5 |
| 9 | >> | >> | 10.50-10.95 | Variegated color gravelly sand | 64 | 33 | 30 | 94 | 93 | 90 | 78 | A-7-5(31) | MH Elastic silt with sand | 2.549 | 29.0 |
| 10 | >> | >> | 13.50-13.95 | Light brown to Dark brown clay soil | 52 | 32 | 21 | 89 | 89 | 83 | 70 | A-7-5(19) | MH Sandy Elastic Silt | 2.362 | 28.0 |

REMARK:

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SUMMARY OF TEST RESULTS

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PROJECT: Combolcha Bypass Road Project
 CHAINAGE: 6+327
 Bore Hole No: BH-1
 TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC
 SUBMITTED BY: Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89/ T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|----------|------------------------|-------------|---------------------------------------|---------------------------------------|-----|-----|--|------|----------|----------|----------------------------|---------------------------------|---------------------------------|----------|
| | | | | | LL% | PL% | PP% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 30 | 6+327 | Bh-1 A.A Side Abutment | 3.00-3.45 | Dark gray gravelly sand with boulders | 38 | 16 | 21 | 40 | 29 | 21 | 15 | A-2-6(6) | CL Gravelly lean clay with sand | 2.648 | 8.8 |
| 31 | >> | >> | 6.00-6.45 | Dark brown silty sand with clay | 67 | 37 | 31 | 100 | 99 | 96 | 92 | A-7-5(36) | MH Elastic silt | 2.317 | 26.1 |
| 32 | >> | >> | 9.00-9.45 | Dark brown silty sand with clay | 44 | 24 | 20 | 100 | 100 | 97 | 87 | A-7-6(20) | CL Lean Clay | 2.399 | 26.0 |
| 33 | >> | >> | 12.00-12.45 | Dark brown silty sand with clay | 54 | 39 | 15 | 99 | 86 | 50 | 39 | A-7-5(5) | MH sandy elastic silt | 2.474 | 22.1 |

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Central Laboratory
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SUMMARY OF TEST RESULTS

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Addis Ababa, Ethiopia

PROJECT: Combolicha Bypass Road Project
CHAINAGE: 6+327
Bore Hole No: BH-2
TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC
SUMMITTED BY: Jurassic Consulting Engineers

| Sr. No | chainage | Location | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 99 / T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Soil Classification | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|----------|---------------------------|-------------|---------------------------------|--|-----|-----|--|------|----------|----------|----------------------------|-----------------------------|---------------------------------|----------|
| | | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 34 | 6+327 | Bh-2 Dessie Side Abutment | 1.50-1.95 | Dark gray organic clay | 78 | 35 | 43 | 98 | 96 | 92 | 84 | A-7-5(47) | CH Fat clay with Sand | 2.572 | 36.6 |
| 35 | >> | >> | 4.50-4.95 | Dark gray organic clay | 94 | 35 | 59 | 97 | 94 | 91 | 88 | A-7-5(66) | CH Fat clay | 2.330 | 40.3 |
| 36 | >> | >> | 7.50-7.95 | Dark brown silty sand with clay | 46 | 24 | 23 | 100 | 99 | 94 | 82 | A-7-6(21) | CL Lean clay with sand | 2.382 | 29.2 |
| 37 | >> | >> | 10.50-10.95 | Dark brown silty sand with clay | 63 | 37 | 27 | 100 | 100 | 99 | 98 | A-7-5(34) | MH Elastic silt | 2.334 | 28.0 |
| 38 | >> | >> | 13.50-13.95 | Dark brown silty sand with clay | 62 | 28 | 34 | 100 | 100 | 99 | 97 | A-7-6(40) | CH Fat Clay | 2.348 | 30.6 |

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SUMMARY OF TEST RESULTS

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Addis Ababa, Ethiopia

PROJECT: Combolcha Bypass Road Project
CHAINAGE: Berebere River Bridge
BORE HOLE NO: BH - 1 A A Side Abutment
TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC
SAMPLED BY: Client

| Sr. No | chainage | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89/ T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification. | Unified Soil Classification. | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|-----------------------|-------------|--|---------------------------------------|-----|-----|--|------|----------|----------|-----------------------------|-------------------------------|---------------------------------|----------|
| | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | |
| 1 | Berebere River Bridge | 3.00-3.45 | Dark brown medium dense clayey sand soil | 40 | 22 | 18 | 99 | 97 | 89 | 68 | A-6(13) | CL Sandy Lean clay | 2.644 | 29.7 |
| 2 | >> | 4.50-4.95 | Dark brown medium dense clayey sand soil | 37 | 20 | 17 | 100 | 98 | 92 | 72 | A-6(13) | CL Lean clay with Sand | 2.622 | 27.0 |
| 3 | >> | 6.00-6.45 | Dark brown to dark gray clay soil | 49 | 25 | 24 | 99 | 97 | 91 | 86 | A-7-6(24) | CL Lean clay | 2.474 | 30.4 |
| 4 | >> | 9.00-9.45 | Dark brown to dark gray clay soil | 51 | 28 | 23 | 99 | 99 | 98 | 97 | A-7-6(26) | CH Fat clay | 2.499 | 28.8 |
| 5 | >> | 12.00-12.45 | Dark gray hard sandy clay soil | 59 | 25 | 34 | 99 | 98 | 96 | 94 | A-7-6(38) | CH Fat clay | 2.473 | 29.6 |
| 6 | >> | 15.00-15.45 | Dark gray hard sandy clay soil | 52 | 23 | 29 | 94 | 87 | 79 | 71 | A-7-6(25) | CH sandy fat clay | 2.541 | 27.4 |
| 7 | >> | 18.00-18.45 | Black to dark gray very stiff to hard clay soil | 64 | 29 | 35 | 100 | 99 | 98 | 95 | A-7-6(40) | CH Fat clay | 2.553 | 29.4 |
| 8 | >> | 21.00-21.45 | Black to dark gray very stiff clayey Gravel soil | 54 | 21 | 33 | 76 | 64 | 50 | 40 | A-7-6(21) | CH sandy Fat clay with Gravel | 2.611 | 12.1 |
| 9 | >> | 22.50-22.95 | Black to dark gray very stiff to hard clay soil | 54 | 29 | 25 | 98 | 96 | 93 | 86 | A-7-6(26) | CH Fat clay | 2.445 | 32.9 |

REMARK :

Tested by: Yohannes Getachew
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Reported By: Mesfin H. Mesfin
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CONSULTING ENGINEERS - PLANNING, DESIGN AND CONSTRUCTION MANAGEMENT

Central Laboratory
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SUMMARY OF TEST RESULTS

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PROJECT: Combolcha Bypass Road Project
 CHAINAGE: Berebere River Bridge
 BORE HOLE NO: BH - 2 Dessie Side Abutment
 TESTS ORDERED: Atterberg limit, Grading, Sp. Gravity & NMC
 SAMPLED BY: Client

| Sr. No | chainage | Depth (m) | Material Des. | Atterberg's Limit (AASHTO T 89/ T 90) | | | Grain size analysis % Pass (AASHTO T 27) | | | | AASHTO Soil Classification | Unified Classification | Soil | Specific Gravity (AASHTO T 100) | NMC In % |
|--------|-----------------------|-------------|--|---------------------------------------|-----|-----|--|------|----------|----------|----------------------------|------------------------|------------------------|---------------------------------|----------|
| | | | | LL% | PL% | PI% | 4.75 mm | 2 mm | 0.425 mm | 0.075 mm | | | | | |
| 10 | Berebere River Bridge | 4.50-4.95 | Dark Brown Stiff Clay With Silt | 60 | 29 | 31 | 98 | 95 | 90 | 84 | A-7-6(32) | CH | Fat clay with sand | 2.362 | 31.6 |
| 11 | >> | 6.00-6.45 | Dark brown to dark gray stiff to very stiff clay soil | 52 | 28 | 24 | 96 | 96 | 93 | 85 | A-7-6(24) | MH | Elastic silt with sand | 2.445 | 33.3 |
| 12 | >> | 7.50-7.95 | Dark brown to dark gray stiff to very stiff clay soil | 53 | 33 | 20 | 100 | 99 | 99 | 97 | A-7-5(25) | MH | Elastic silt | 2.479 | 31.4 |
| 13 | >> | 10.50-10.95 | Dark brown to dark gray stiff to very stiff clay soil | 46 | 25 | 21 | 99 | 98 | 95 | 86 | A-7-6(21) | CL | Lean clay | 2.511 | 26.2 |
| 14 | >> | 13.50-13.95 | Dark gray very stiff clay with silt and sand | 59 | 28 | 31 | 97 | 93 | 87 | 76 | A-7-6(29) | CH | Fat clay with sand | 2.54 | 25.4 |
| 15 | >> | 16.50-16.95 | Variegated color very stiff to hard clay with trace of sand and silt | 71 | 29 | 42 | 100 | 100 | 99 | 95 | A-7-6(48) | CH | Fat clay | 2.441 | 29.4 |
| 16 | >> | 19.50-19.95 | Variegated color very stiff to hard clay with trace of sand and silt | 79 | 30 | 49 | 100 | 99 | 98 | 96 | A-7-5(57) | CH | Fat clay | 2.514 | 31.0 |
| 17 | >> | 24.00-24.45 | Variegated color very stiff to hard clay with trace of sand and silt | 55 | 27 | 28 | 100 | 99 | 93 | 84 | A-7-6(29) | CH | Fat clay with sand | 2.432 | 33.1 |

REMARK:

Tested by: Yohannes Gebret
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APPENDIX -C: Direct shear test results and Index Properties from Primary Data

| GEOTECHNICAL ENGINEERING LABORATORY | | | | | | | | | | | | |
|--|-----------------------------------|------------------------------------|--------------------------|--------------------|------------------------------------|----------------|--------------------|------------------------------------|----------------|----------------------------------|--|---------------|
| Attachment 3 =Unconsolidated Undrained Direct Shear Test | | | | | | | | | | | | |
| Project: | | | | | | | | | | | | |
| Owner: | | | | | | | | | | | | |
| Client: | | | | | | | | | | | | |
| Location: | | | | | | | | | | | | |
| Sample No. | GTL-044 | | Sample Source: | Test Pit | | Depth, m : | 4.5 | | | | | |
| Thickness of sample: | 25 mm | | Ring Calibration Factor: | 1.610 N/div | | | | | | | | |
| Length of sample : | 60 mm | | | | | | | | | | | |
| Width of sample: | 60 mm | | | | | | | | | | | |
| Horizontal Displacement [mm] | Corrected Area [mm ²] | Applied Vertical Stress 100 kpa | | | Applied Vertical Stress 200 kpa | | | Applied Vertical Stress 300 kpa | | | | |
| | | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| 0.3 | 3583 | 20.00 | 32.00 | 8.93 | 50.00 | 80.50 | 22.45 | 10.00 | 16.10 | 4.49 | | |
| 0.5 | 3570 | 60.00 | 96.00 | 26.89 | 130.00 | 209.30 | 58.63 | 100.00 | 161.00 | 45.10 | | |
| 0.8 | 3555 | 70.00 | 112.00 | 31.50 | 140.00 | 225.40 | 63.40 | 120.00 | 193.20 | 54.35 | | |
| 1.0 | 3540 | 90.00 | 144.00 | 40.68 | 160.00 | 257.60 | 72.77 | 130.00 | 209.30 | 59.12 | | |
| 1.5 | 3510 | 100.00 | 160.00 | 45.58 | 180.00 | 289.80 | 82.56 | 150.00 | 241.50 | 68.80 | | |
| 2.0 | 3480 | 105.00 | 168.00 | 48.28 | 200.00 | 322.00 | 92.53 | 160.00 | 257.60 | 74.02 | | |
| 2.5 | 3450 | 110.00 | 176.00 | 51.01 | 210.00 | 338.10 | 98.00 | 170.00 | 273.70 | 79.33 | | |
| 3.0 | 3420 | 115.00 | 184.00 | 53.80 | 215.00 | 346.15 | 101.21 | 200.00 | 322.00 | 94.15 | | |
| 3.5 | 3390 | 115.00 | 184.00 | 54.28 | 220.00 | 354.20 | 104.48 | 220.00 | 354.20 | 104.48 | | |
| 4.0 | 3360 | 115.00 | 184.00 | 54.76 | 230.00 | 370.30 | 110.21 | 230.00 | 370.30 | 110.21 | | |
| 4.5 | 3330 | 115.00 | 184.00 | 55.26 | 240.00 | 386.40 | 116.04 | 245.00 | 394.45 | 118.45 | | |
| 5.0 | 3300 | 120.00 | 192.00 | 58.18 | 250.00 | 402.50 | 121.97 | 260.00 | 418.60 | 126.85 | | |
| 5.5 | 3270 | 120.00 | 192.00 | 58.72 | 255.00 | 410.55 | 125.55 | 260.00 | 418.60 | 128.01 | | |
| 6.0 | 3240 | 120.00 | 192.00 | 59.26 | 260.00 | 418.60 | 129.20 | 265.00 | 426.65 | 131.68 | | |
| 6.5 | 3210 | 120.00 | 192.00 | 59.81 | 260.00 | 418.60 | 130.40 | 270.00 | 434.70 | 135.42 | | |
| 7.0 | 3180 | 120.00 | 192.00 | 60.38 | 265.00 | 426.65 | 134.17 | 270.00 | 434.70 | 136.70 | | |
| 7.5 | 3150 | 120.00 | 192.00 | 60.95 | 260.00 | 418.60 | 132.89 | 270.00 | 434.70 | 138.00 | | |
| 8.0 | 3120 | 120.00 | 192.00 | 61.54 | 260.00 | 418.60 | 134.17 | 265.00 | 426.65 | 136.75 | | |
| | | <i>Maximum shear stress, kPa</i> | | | 61.54 | | | | 134.17 | <i>Maximum shear stress, kPa</i> | | 138.00 |

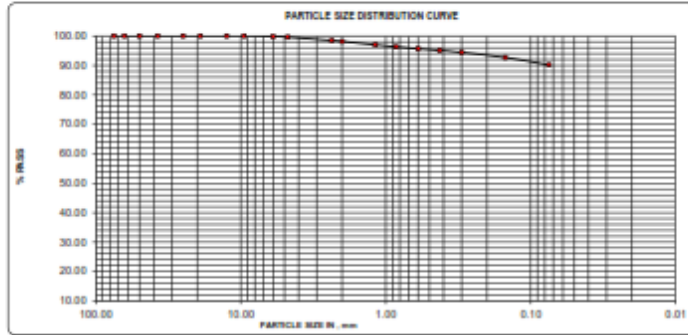
Shear Stress Vs Displacement

Maximum Shear Stress Vs Applied Vertical Load

$y = 0.38x + 34.77$

| | |
|--|--------------------|
| Angle of internal friction, $\phi =$ | 21 |
| Cohesion, C (kN/m²) = | 35 |
| <i>Tested by</i> | <i>Verified by</i> |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 100 |
| 2.000 | 98 |
| 0.425 | 95 |
| 0.075 | 90 |

| Soil Description | |
|-----------------------|----|
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 80 |
| PI | 33 |
| <u>Classification</u> | |
| USCS | CH |

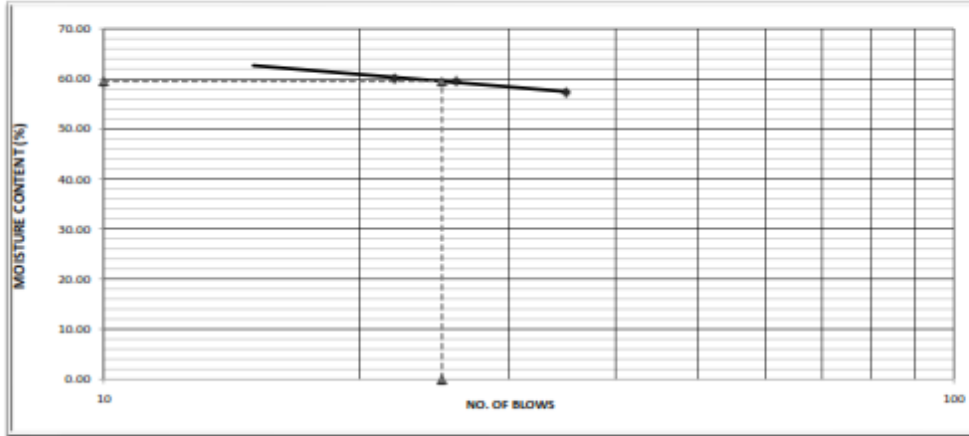
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | NIL | 10 | 90 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 1' |
| SAMPLE DEPTH(m) | : | 4.50 - 4.95m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 35 | 26 | 22 | | |
| Wt. wet soil (g.) | 17.75 | 20.37 | 22.29 | 5.75 | 5.05 |
| Wt. dry soil (g.) | 11.30 | 12.77 | 13.92 | 4.56 | 4.02 |
| Moisture content (%) | 57.35 | 59.51 | 60.13 | 26.75 | 26.37 |
| | | | | AV. PL (%) | 26.6 |

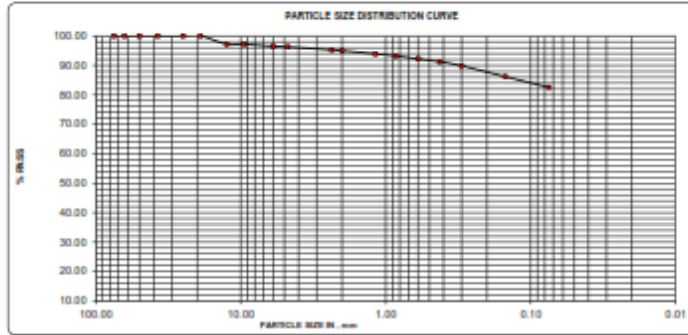
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|-----------|-----------|
| | | | 2mm | 0.425mm | 0.075mm |
| 60 | 27 | 33 | 100 | 98 | 98 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 1' |
| SAMPLE DEPTH(m) | : | 4.50 - 4.95m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 96 |
| 2.000 | 95 |
| 0.425 | 91 |
| 0.075 | 83 |

| Soil Description | |
|-----------------------|----|
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 53 |
| PI | 24 |
| <u>Classification</u> | |
| USCS | CH |

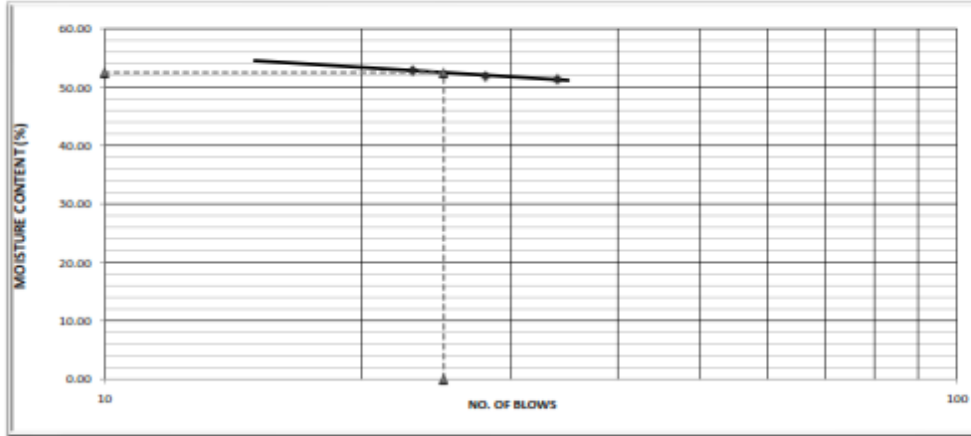
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | 1 | 8 | 91 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 1' |
| SAMPLE DEPTH(m) | : | 9.00 - 9.43m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 34 | 25 | 23 | | |
| Wt. wet soil (g.) | 16.86 | 19.34 | 20.56 | 5.66 | 6.10 |
| Wt. dry soil (g.) | 11.14 | 12.73 | 13.46 | 4.43 | 4.74 |
| Moisture content (%) | 51.35 | 51.92 | 52.90 | 25.22 | 26.69 |
| | | | | AV. PL (%) | 25.5 |

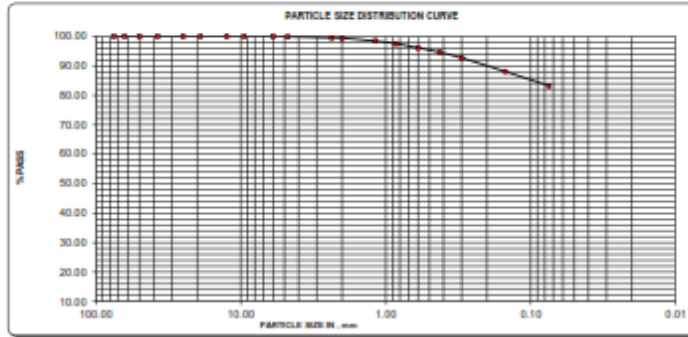
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 53 | 28 | 24 | 96 | 95 | 95 |

REPORTED BY

APPROVED BY

| | |
|--|--|
| | TEST OBJECT : Disturbed soil SAMPLE SOURCE : BH - 1' SAMPLE DEPTH(m) : 9.00 - 9.45m |
|--|--|

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM) | % PASSED |
|-----------------|----------|
| 4.750 | 100 |
| 2.000 | 99 |
| 0.425 | 95 |
| 0.075 | 83 |

| | |
|------------------|-------|
| Soil Description | |
| DUAL | |
| Atterberg Limit | |
| LL | 45 |
| PI | 21 |
| Classification | |
| USCS | CL-ML |

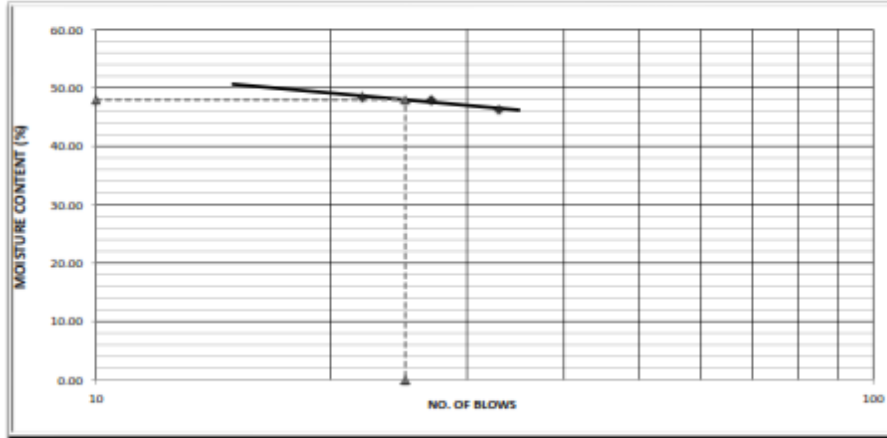
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | 0 | 17 | 83 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 1' |
| SAMPLE DEPTH(m) | : | 10.50 - 10.95m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 33 | 27 | 22 | | |
| Wt. wet soil (g.) | 21.30 | 22.95 | 24.60 | 5.48 | 6.26 |
| Wt. dry soil (g.) | 14.56 | 15.51 | 16.71 | 4.33 | 4.93 |
| Moisture content (%) | 46.29 | 47.97 | 48.41 | 26.56 | 26.98 |
| | | | | AV. PL (%) | 26.6 |

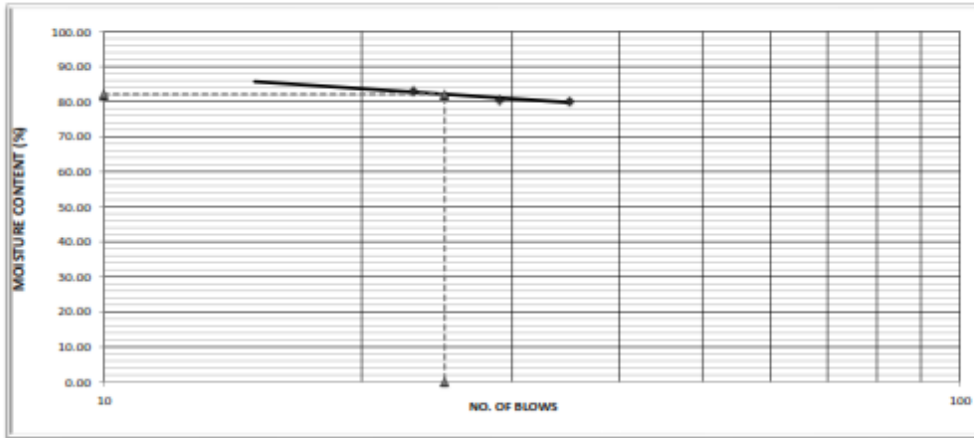
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 48 | 27 | 21 | 100 | 100 | 99 |

REPORTED BY

APPROVED BY

| | | |
|------------------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 1' |
| SAMPLE DEPTH(m) | : | 10.50 - 10.95m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 35 | 29 | 23 | | |
| Wt. wet soil (g.) | 15.61 | 15.16 | 15.90 | 4.31 | 4.47 |
| Wt. dry soil (g.) | 5.75 | 10.06 | 10.33 | 3.49 | 3.67 |
| Moisture content (%) | 80.07 | 80.52 | 82.96 | 23.50 | 21.00 |
| | | | | AV. PL (%) | 22.6 |

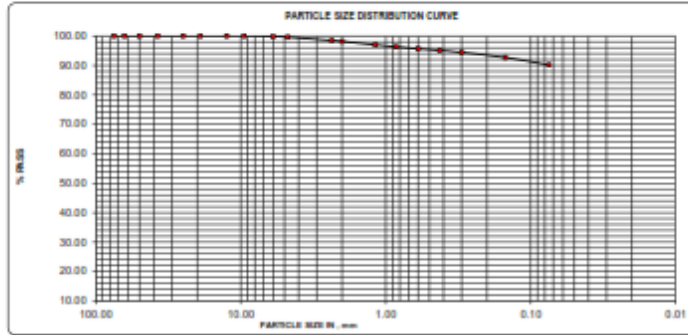
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 82 | 23 | 59 | 99 | 98 | 98 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 4.00 - 4.50m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 100 |
| 2.000 | 98 |
| 0.425 | 95 |
| 0.075 | 90 |

| Soil Description | |
|-----------------------|----|
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 86 |
| PI | 57 |
| <u>Classification</u> | |
| USCS | CH |

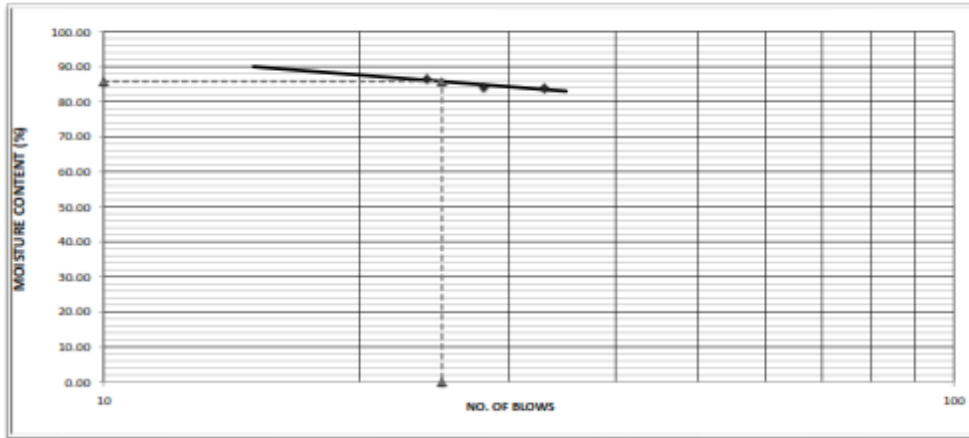
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | NIL | 10 | 90 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 4.50 - 4.95m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|------------------------|-------|
| | 33 | 25 | 24 | 5.60 | 4.97 |
| Wt. wet soil (g.) | 17.19 | 19.21 | 21.00 | 4.33 | 3.65 |
| Wt. dry soil (g.) | 9.35 | 10.44 | 11.26 | 29.33 | 29.09 |
| Moisture content (%) | 83.85 | 84.00 | 86.50 | AV. PL (%) 29.2 | |

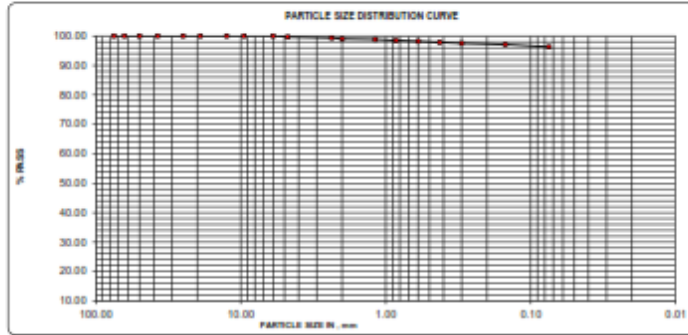
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 86 | 29 | 57 | 98 | 93 | 90 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 4.50 - 4.95m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 100 |
| 2.000 | 99 |
| 0.425 | 99 |
| 0.075 | 96 |

| | |
|-------------------------|----|
| <u>Soil Description</u> | |
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 82 |
| PI | 59 |
| <u>Classification</u> | |
| USCS | CH |

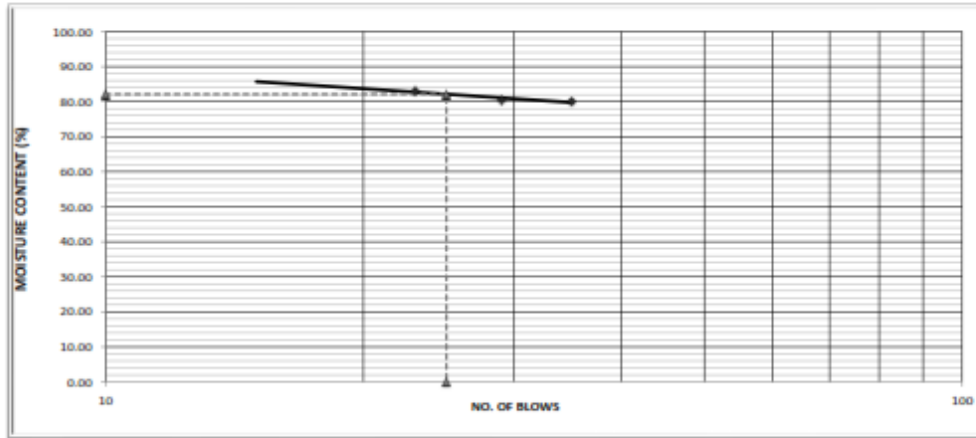
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | NIL | 4 | 96 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 0.00 - 0.50m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 35 | 29 | 23 | | |
| Wt. wet soil (g.) | 15.81 | 15.16 | 15.90 | 4.31 | 4.47 |
| Wt. dry soil (g.) | 5.75 | 10.06 | 10.33 | 3.49 | 3.67 |
| Moisture content (%) | 80.07 | 80.52 | 82.96 | 23.50 | 21.80 |
| | | | | AV. PL (%) | 22.6 |

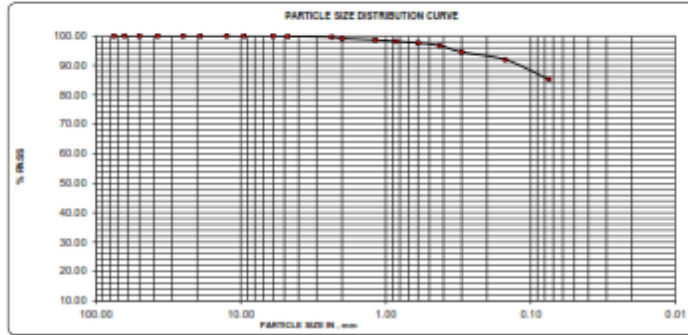
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 82 | 23 | 59 | 100 | 99 | 99 |

REPORTED BY

APPROVED BY

| | |
|--|--|
| | TEST OBJECT : Disturbed soil SAMPLE SOURCE : BH - 2' SAMPLE DEPTH(m) : 6.00 - 6.50m |
|--|--|

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 100 |
| 2.000 | 99 |
| 0.425 | 97 |
| 0.075 | 85 |

| Soil Description | |
|-----------------------|----|
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 86 |
| PI | 32 |
| <u>Classification</u> | |
| USCS | CH |

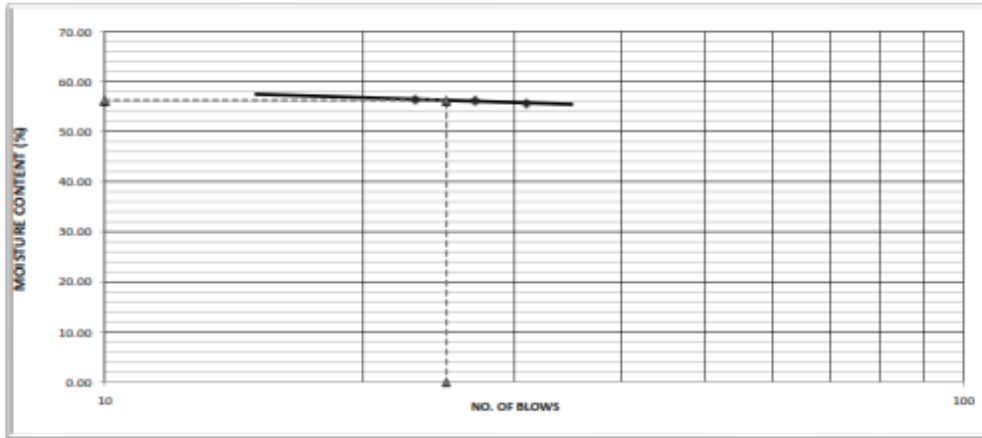
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | NIL | 15 | 85 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 7.50 - 7.95m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 31 | 27 | 23 | | |
| Wt. wet soil (g.) | 16.51 | 20.61 | 23.10 | 4.76 | 5.16 |
| Wt. dry soil (g.) | 11.89 | 13.32 | 14.77 | 3.62 | 4.14 |
| Moisture content (%) | 55.68 | 56.23 | 56.40 | 24.61 | 24.64 |
| | | | | AV. PL (%) | 24.6 |

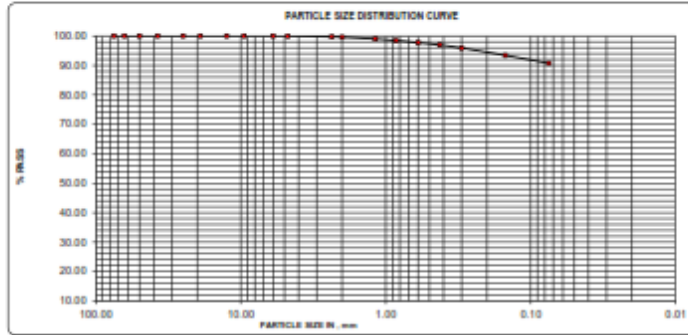
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|------------|-----------|
| | | | 2mm | 0.425mm | 0.075mm |
| 56 | 25 | 32 | 100 | 100 | 99 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 7.50 - 7.95m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 100 |
| 2.000 | 100 |
| 0.425 | 97 |
| 0.075 | 91 |

| Soil Description | |
|-----------------------|----|
| CLAY | |
| <u>Aterberg Limit</u> | |
| LL | 52 |
| PI | 26 |
| <u>Classification</u> | |
| USCS | CH |

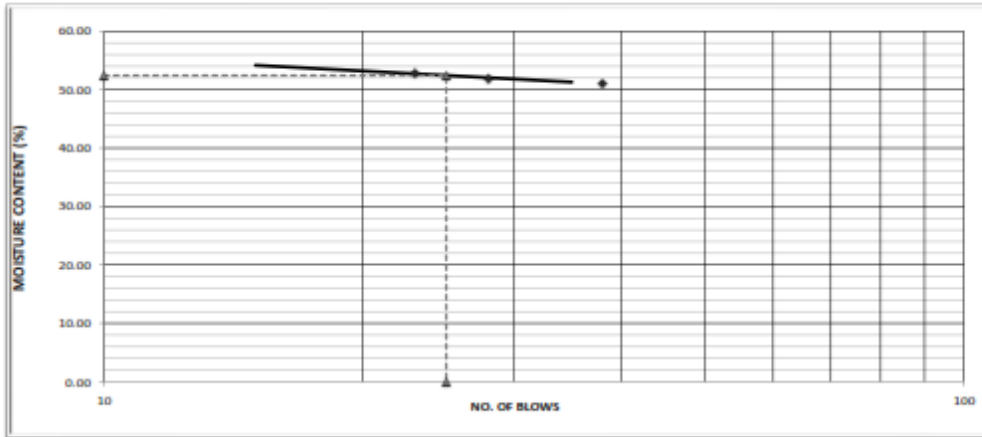
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | NIL | 9 | 91 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 14.50 - 15.00m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 35 | 25 | 23 | | |
| Wt. wet soil (g.) | 21.09 | 23.15 | 24.97 | 5.65 | 4.79 |
| Wt. dry soil (g.) | 13.96 | 15.24 | 16.34 | 4.47 | 3.76 |
| Moisture content (%) | 51.07 | 51.90 | 52.82 | 27.07 | 26.72 |
| | | | | AV. PL (%) | 26.9 |

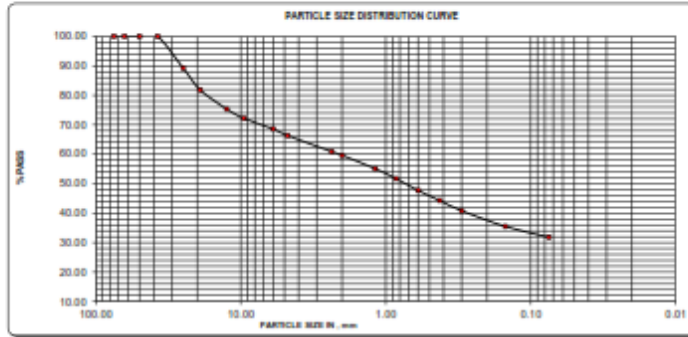
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 52 | 27 | 25 | 100 | 100 | 100 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 9.00 - 9.50m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM) | % PASSED |
|-----------------|----------|
| 4.750 | 86 |
| 2.000 | 60 |
| 0.425 | 44 |
| 0.075 | 32 |

| | |
|-------------------------|----|
| Soil Description | |
| CLAY | |
| Atterberg Limit | |
| LL | 32 |
| PI | 16 |
| Classification | |
| USCS | CL |

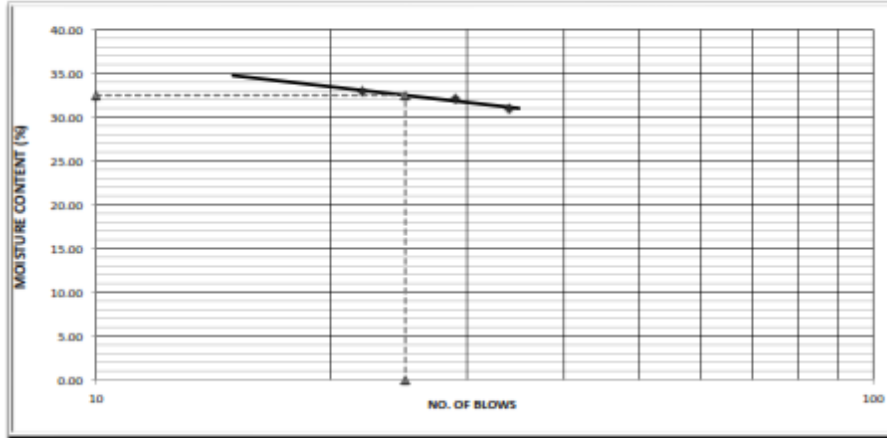
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | 34 | 34 | 32 |

REPORTED BY

APPROVED BY

TEST OBJECT : Disturbed soil
 SAMPLE SOURCE : BH - 2'
 SAMPLE DEPTH(m) : 12.50 - 13.00m

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------------|
| | 34 | 29 | 22 | | |
| Wt. wet soil (g.) | 20.35 | 21.77 | 24.09 | 6.41 | 6.74 |
| Wt. dry soil (g.) | 15.54 | 16.48 | 18.12 | 5.52 | 5.80 |
| Moisture content (%) | 30.95 | 32.10 | 32.95 | 16.12 | 16.21 |
| | | | | AV. PL (%) | 16.2 |

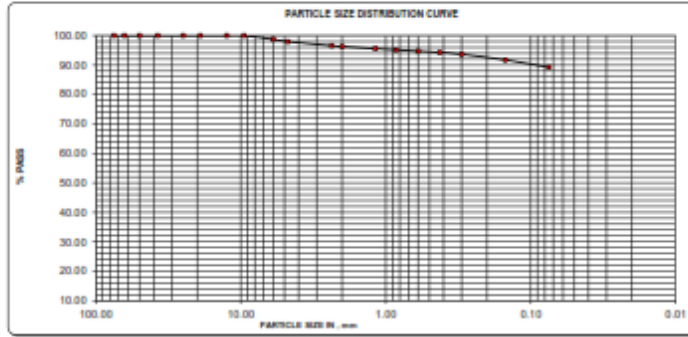
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 32 | 16 | 16 | 66 | 61 | 60 |

REPORTED BY _____

APPROVED BY _____

TEST OBJECT : Disturbed soil
 SAMPLE SOURCE : BH - 2'
 SAMPLE DEPTH(m) : 12.50 - 13.00m

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 98 |
| 2.000 | 98 |
| 0.425 | 94 |
| 0.075 | 89 |

| | |
|-------------------------|----|
| <u>Soil Description</u> | |
| CLAY | |
| <u>Atterberg Limit</u> | |
| LL | 77 |
| PI | 49 |
| <u>Classification</u> | |
| USCS | CH |

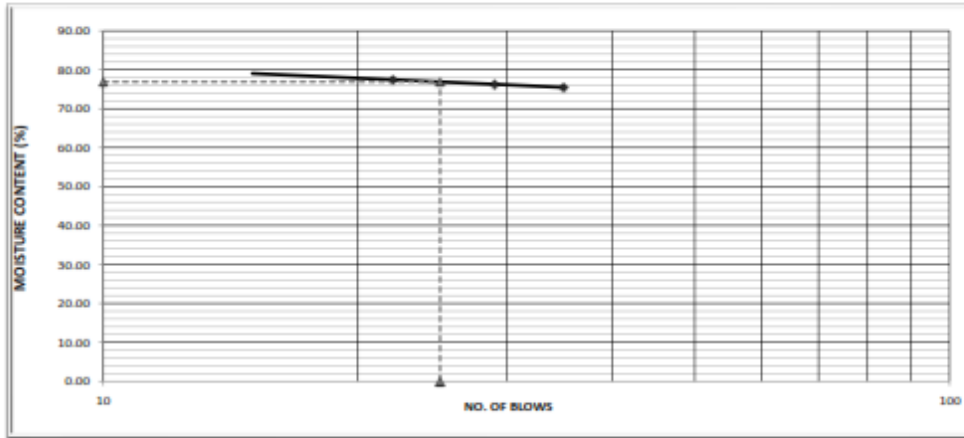
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | 2 | 9 | 89 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 14.50 - 15.00m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-----------------|-------|
| | | 35 | 29 | 22 | |
| Wt. wet soil (g.) | 16.32 | 19.76 | 22.41 | 4.61 | 5.13 |
| Wt. dry soil (g.) | 10.44 | 11.21 | 12.63 | 3.77 | 4.02 |
| Moisture content (%) | 75.46 | 76.27 | 77.43 | 27.59 | 27.61 |
| | | | | AV. PL (%) 27.6 | |

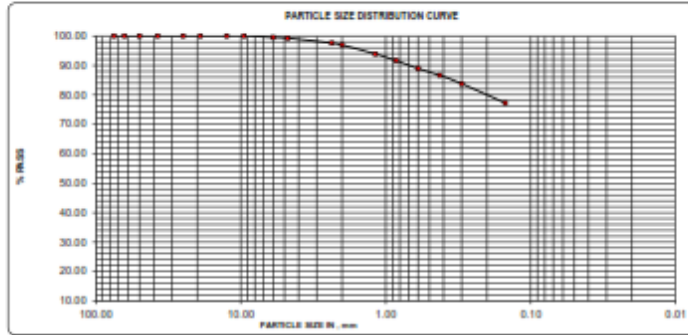
| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 77 | 28 | 49 | 98 | 97 | 96 |

REPORTED BY

APPROVED BY

| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 14.50 - 15.00m |

PARTICLE SIZE DISTRIBUTION REPORT



| SIEVE SIZE (MM.) | % PASSED |
|------------------|----------|
| 4.750 | 99 |
| 2.000 | 97 |
| 0.425 | 97 |
| 0.075 | 70 |

| Soil Description | |
|-----------------------|------|
| DUAL | |
| <u>Aterberg Limit</u> | |
| LL | 37 |
| PI | 15 |
| <u>Classification</u> | |
| USCS | CLML |

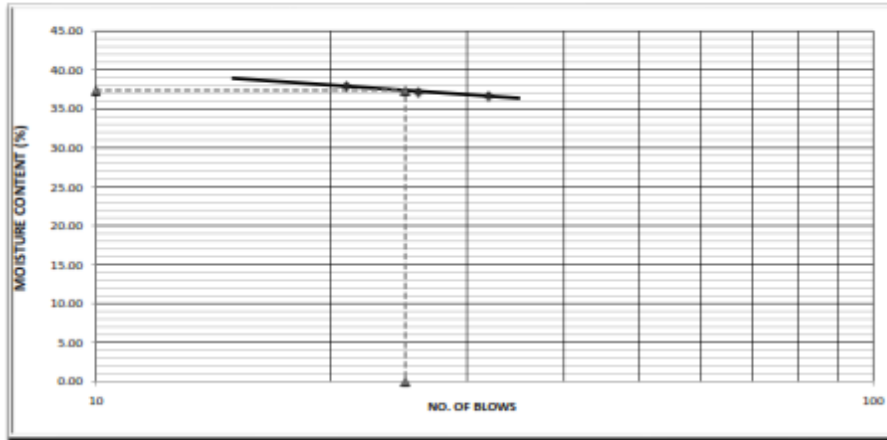
| % COBBLE | % GRAVEL | % SAND | % FINE |
|----------|----------|--------|--------|
| - | 1 | 29 | 70 |

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| | | |
|-----------------|---|----------------|
| TEST OBJECT | : | Disturbed soil |
| SAMPLE SOURCE | : | BH - 2' |
| SAMPLE DEPTH(m) | : | 18.00 - 18.45m |

LIQUID AND PLASTIC LIMITS TEST REPORT



| No. Blows | LIQUID LIMIT | | | PLASTIC LIMIT | |
|----------------------|--------------|-------|-------|-------------------|-------|
| | 32 | 25 | 21 | | |
| Wt. wet soil (g.) | 19.56 | 21.66 | 23.77 | 6.07 | 6.41 |
| Wt. dry soil (g.) | 14.31 | 15.79 | 17.23 | 4.96 | 5.25 |
| Moisture content (%) | 36.69 | 37.18 | 37.96 | 22.36 | 22.10 |
| | | | | AV. PL (%) | 22.2 |

| Liquid Limit LL(%) | Plastic Limit PL(%) | Plasticity Index PI | WET SEIVE ANALYSIS, % PASS | | |
|-----------------------|------------------------|------------------------|----------------------------|---------|---------|
| | | | 2mm | 0.425mm | 0.075mm |
| 37 | 22 | 15 | 99 | 98 | 97 |

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TEST OB : Disturbed soil
 SAMPLE : BH - 2'
 SAMPLE : 18.00 - 18.45m