

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



**Relationship between Water Content Ratio and Undrained
Shear Strength of Fine-Grained Soil**

A Thesis in Geotechnical Engineering

By Tigist Gemechu

July 2023

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

**RELATIONSHIP BETWEEN WATER CONTENT RATIO AND UNDRAINED
SHEAR STRENGTH OF FINE-GRAINED SOIL**

By

Tigist Gemechu Weyuma

A thesis submitted to the school of graduate studies at Addis Ababa institute of
technology in partial fulfillment of the requirement of the degree of masters of Science in
Geotechnical Engineering

Approved by Board of Examiners

Dr.-Ing. Samuel Tadesse Tafesse	_____	_____
Advisor	Signature	Date
Dr.-Ing. Asrat Worku Setegn	_____	_____
Internal Examiner	Signature	Date
Dr. Tezera Ferewu Azmach	_____	_____
External Examiner	Signature	Date
Dr, Abreham Gebre	_____	_____
Chairman	Signature	Date

UNDERTAKING

I certify that research work titled “Relationship between Water Content Ratio and Undrained Shear Strength of Fine-Grained Soil” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

Tigist Gemechu

ACKNOWLEDGMENTS

I am deeply grateful to almighty GOD for helping me all the way throughout this thesis. Nothing would have been possible without him.

Special thanks and respect to my research advisor Dr.-Ing Samuel Tadesse for his critical comments and suggestions in guiding and supervising me throughout all my research work. He has been devoting his precious time to check the work and give me important information to carry out the work.

My grateful thanks also go to laboratory technicians at Addis Ababa institute of technology, geotechnical laboratory for their kindly cooperation in all aspects in doing the laboratory tests.

I would like also to express my deepest gratitude to Tewodros Gemechu for his technical support and sacrifice his valuable time and also all my colleagues and friends with whom i had the opportunity to learn, share and enjoy. It has been a pleasure.

Special and infinite thanks to the most important people in my life goes to Dad (Ato Gemechu Weyuma), Mom (Kumeye) and my sisters for supporting and encouraging in doing this thesis.

Last but not least, I thank all those who directly or indirectly contributed towards the success of this research work.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	III
TABLE OF CONTENTS	IV
LIST OF TABLES	VII
LIST OF FIGURES	VIII
ABSTRACT	X
CHAPTER 1 INTRODUCTION	1
1.1 Background of the Study	1
1.2 Importance	2
1.3 Objective	3
1.4 Statement of the Problem	3
1.5 Methodology	4
1.6 Limitation of the Study	4
1.7 Organization of the Thesis	4
CHAPTER 2 LITERATURE REVIEW	5
2.1 General	5
2.2 Consistency of Red Clay Soils	7
2.2.1 Atterberg Limits	7
2.3 Soil classification Methods	9
2.3.1 Unified Soil Classification System: USCS	9
2.4 Compaction Test	10
2.5 Shear Strength Behavior of Clay	12
2.6 Factor affecting the shear strength of clay soil	13
2.7 Unconfined Compression Strength Test (UCS)	14
2.8 Related Researches	17
2.9 Undrained Shear Strength of Unsaturated Soils under Zero or Low Confining Pressures	22
2.10 List of some of the models equation	23
2.10 Models for Shear Strength of Unsaturated Soils	25
2.10.1 Fredlund et al (1978) Shear Strength Equation	25

2.10.2	Fredlund et al (1996) Shear Strength Equation	26
2.10.3	Fredlund and Xing 1994	26
CHAPTER 3	DESCRIPTION OF THE STUDY AREA	27
3.1	General	27
3.2	Climatic condition.....	29
3.3	Geology and Tectonics of the Study Area	29
CHAPTER 4	LABORATORY SOIL TEST RESULTS	31
4.1	General	31
4.2	Atterberg Limits Tests	32
4.3	Specific Gravity	32
4.4	Grain Size Analysis.....	33
4.5	Unconfined Compression Strength Test (UCS).....	34
4.6	DISCUSSION ON LABOATORY TEST RESULTS.....	37
4.6.1	Soil classification according to USCS of the study areas.....	37
4.6.2	Classifications based on activity number	37
4.6.3	Standard compaction	38
4.6.4	Unconfined compression strength test.....	39
CHAPTER 5	CORRELATION AND ANALYSIS.....	41
5.1	General	41
5.2	Scatter Plot	41
5.3	Regression Analysis	42
5.4	Single regression analysis	42
CHAPTER 6	CONCLUSIONS AND RECOMMENDATIONS	51
6.1	Conclusions.....	51
6.2	Recommendations	52
REFERENCES	53
	Appendix A: Method of Computation for Atterberg Limits.....	57
	Appendix B Specific gravity determination.....	63
	Appendix C Hydrometer and sieve analysis test result.....	65
	Appendix D Method of computation for Compaction test result.....	69

Appendix E Method of determining the mass of soil for remolding in the specimen and
Method of determining UCS test result 73
Appendix G: Aerial photographs 115

LIST OF TABLES

Table 2-1: Properties of Addis Ababa Red clay soils.....	7
Table 2-2: Soil classification methods.....	9
Table 3-1: Location of selected sites	28
Table 4-1: Summary of Atterberg limit test results	32
Table 4-2: Summary of Specific gravity test result	33
Table 4-3: Summary of Grain size analysis results	34
Table 4-4: Mass of soil remolded for Rufael site	35
<i>Table 4-5: Summary of UCS test result</i>	<i>36</i>
Table 4-6: Activity and degree of activity	38
Table 5-1: Degree of Saturation for the selected soil sample.....	43
Table 5-2: Physical properties and shear strength of red clay soil in selected location of Addis Ababa city for saturated soil.	44
Table 5-3: suction value for selected soil samples.....	46
Table 5-4: suction value for selected soil samples	46

LIST OF FIGURES

Figure 2-1: Structure of Kaolinite, Illite, and Montmorillonite.....	6
Figure 2-2: Different state of soil	8
Figure 2-3: Unconfined compression test device	15
Figure 2-4: Relationship between undrained Shear strength and water content normalized by liquid limit.	17
Figure 2-5: WCR and shear strength (on log scale) Tsuchida et al. (1999)	19
Figure 2-6: Water content ratios versus liquidity index	21
Figure 3-1: Location map of the study areas with in Addis Ababa.....	28
Figure 3-2: Geological map of Addis Ababa and its surroundings	30
Figure 4-1: Plasticity chart of the study area.....	37
Figure 4-2: Activity chart of the study area.....	38
Figure 5-1: Water content ratio versus Shear strength curve for saturated soil sample ...	44
Figure 5-2 water content vs suction for kechene	47
Figure 5-3 Undrained shear strength shear strength vs suction for kechene	48
Figure 5-4 water content vs suction for Rufael	48
Figure 5-5 Undrained shear strength shear strength vs suction for Rufael.....	48
Figure 5-6 water content vs suction for Addisu Gebeya	49
Figure 5-7 Undrained shear strength shear strength vs suction for Addisu Gebeya.....	49
Figure 5-8 water content vs suction for British Embassy.....	50
Figure 5-9 Undrained shear strength vs suction for British Embassy	50

LIST OF SYMBOLS AND ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society of Testing and Material
CU	Undrained Shear Strength
CH	Inorganic clays of high plasticity
CL	Inorganic clays of low plasticity
GPS	Global Positioning System
Kpa	kilo Pascal
LL	Liquid Limit
MH	Inorganic silts of high plasticity
ML	Inorganic silts of low plasticity
M	Meter
N	Number of sample
PI	Plasticity Index
R^2	Correlation Coefficient
RP	Plasticity ratio
WCR	Water content ratio
UCS	Unconfined Compression Strength
USCS	Unified Soil Classification System

ABSTRACT

Undrained shear strength of clay soil is a very important feature in geotechnical engineering. Obtaining undisturbed samples and testing them is a tough and time-consuming procedure; any experiment aimed at obtaining correlations between shear strength and consistency limits would be extremely beneficial.

In this thesis, efforts have been made to obtain valid correlations between undrained shear strength and Water content ratio (WCR) for saturated soil samples and for unsaturated soil samples suction values were obtained from previous proposed mode of SWCC then suction value and undrained shear strength were correlate. For this purpose, Red clay soil samples collected from different sites in Addis Ababa city at the depth of 3m were used. In addition to collected soil samples secondary data were used. And for each samples Atterberg limits, Specific gravity, Sieve and hydrometer analysis, Compaction tests were conducted beside that by remolding these samples Unconfined Compressive Strength (UCS) tests were conducted.

The best fit line, correlation, regression analysis, and comparison were performed using EXCEL. The findings are expected to have a wide range of applications in construction, making it easier for designers to produce a solid, cost-effective, and dependable design.

Keywords: - Water content ratio, Undrained shear strength, Liquid limit, Water content.

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

The shear strength of soils is of special relevance among geotechnical soil properties because it is one of the most essential parameters for analyzing and solving variety of stability problems. Its concept is used for estimating bearing capacity of foundations & carrying out stability analysis of structures. Therefore, determining reliable shear strength values of a soil plays a significant role in obtaining a sustainable structure afterwards. Application of shear strength was first done in the 18th century by a French scientist; Coulomb provided the first comprehensive description of soil shear strength. He stated that the limit of soil shear resistance is composed of two components, namely cohesion and friction these basic concepts still holds true to this day & are widely used for design of different structures. Different soil types show different shear resisting characteristics due to their unique nature of formation. The shear strength of fine-grained soils generally can be divided into two parts as drained and undrained shear strengths depending on whether the pore water pressure dissipates or not. In situ shear strength of soils is recorded almost in undrained condition [2].

One of the essential geotechnical metrics is the undrained shear strength (CU) of fine-grained soils, which can be determined in situ and in the laboratory. Soil testing procedures do not take the same amount of time and effort; in fact, some of the equipment is lacking in underdeveloped nations, resulting in unreliable and impractical results. That is why it is critical to create empirical equations that are appropriate for the local environment. Attempts to link shear strength to the Liquidity Index have been undertaken in the past the value of the plastic limit established by the Casagrande thread rolling method is used to calculate the Liquidity index.

The determination of plastic limit is relatively a difficult task in geotechnical engineering practice due to: -

- The rolling method may be inaccurate due to the incorrect judgment of the operator Spagnoli and Feinendegen (2017)
- Incorrect measure of the final thread diameter (Feng 2004)

- The rolling process stopped too soon (Andrade et al. 2011).

The water content ratio (WCR) is the ratio of water content to the liquid limit (LL) and has been proved to be a good substitute for the well-known measure liquidity index (LI) in forecasting fine-grained soil shear strength. The water content ratio reported here has been widely used to study clayey soils' liquid limit behavior (Nagaraj and Jayadeva1981) and compressibility (Nagaraj and Srinivasa Murthy 1983, 1986). Griffiths and Joshi (1988) utilize the non-dimensional measure e/e_L (void ratio/void ratio at liquid limit), which is nothing more than the water content ratio.

Undrained shear strength and the water content ratio have a strong linear relationship. However, while a comparison of moisture content and shear strength reveals no evidence of a link between the two, incorporating the liquid limit values into the analysis reveals clear leanings. With the use of several experimental results, it was shown that the water content ratio used to forecast shear strength instead of the well-known metric liquidity index. This eliminates the need to calculate the plastic limit [10].

1.2 Importance

Geotechnical parameters, which let engineers to specify the engineering qualities of soils, have been determined via sampling from boreholes, laboratory testing, and field tests, and are crucial outfits for predicting the behavior of soils. Empirical correlations have been constructed based on this data in order to determine soil geotechnical design parameters. Correlations are critical for estimating engineering parameters of soils, especially in the early stages of project development.

It can also be utilized for projects with a budget constraint, a lack of test equipment, or a short timeline. The results obtained here relate the undrained shear strength to Water Content Ratio by eliminating the plastic limit, which is inaccurate due to the above-mentioned problems, and provide designers with a simple way to develop a stable, cost-effective, and dependable design with confidence and convenience.

1.3 Objective

1.3.1 General Objective

The general objective of this research is to obtain applicable relation between undrained shear strength and water content ratio for saturated soil sample whose degree of saturation is greater than 95% in selected area of Addis Ababa red clay soil and to correlate undrained shear strength with suction value for unsaturated soil samples whose degree of saturation is less than 95%.

1.3.2 Specific Objective

- To develop appropriate empirical correlations between undrained shear strength and water content ratio for saturated soil samples.
- To obtain suction value from SWCC proposed model equation and correlate that with undrained shear strength for unsaturated soil samples.
- To examine the validity of the correlations with previous proposed model and to draw appropriate conclusions.

1.4 Statement of the Problem

The undrained shear strength of fine-grained soils is the most essential soil attribute. Laboratory and field tests can be used to determine it. However, calculating these tests is a time-consuming and difficult operation. Despite the fact that Addis Ababa is a rapidly expanding metropolis in terms of development activity, there are certain issues with the construction process. For foundations of light weight structures, most design offices and geotechnical investigation service businesses employ presumptive shear strength estimates from codes and standards. Because the real shear strength of the soil has not been considered, this will have a negative impact on the structure's future serviceability. The thesis come up with a correlation of undrained shear strength with water content ratio as one of the important solutions to decrease the time and cost of site inquiry.

1.5 Methodology

The first step in this research was to study previous works of different researches with regard to the study topic. Following that, sites inside Addis Ababa were chosen, and disturbed samples were collected at depth of 3.00m.

Atterberg limit tests, specific gravity tests, sieve and hydrometer tests, standard compaction tests, and UCS testing were conducted to gather relevant data for the relation mentioned in the objective. The UCS was conducted on the remolded disturbed samples. All tests were carried out in accordance with ASTM standards.

Using EXCEL Undrained shear strength was correlated with water content ratio and empirical equations were developed. The reliability of the correlations was examined and conclusion and recommendation were made.

1.6 Limitation of the Study

The area covered in this study is the main factor that limits the applicability of the findings. Since the correlation results are highly material dependent, the applicability will also be limited to the areas of the study. As a result, the results should only be applied to these areas.

1.7 Organization of the Thesis

This project work is organized into six Chapters; the first chapter presents a general description, importance, objectives, scope of the study, methodology and limitation of the project. The second Chapter presents the brief literature review which discusses the Atterberg limit, undrained shear strength, Water content ratio. Chapter three tied up with the data collection and preparation and describes the location of the selected site for investigation. Chapter 4 deals with Laboratory soil test results obtained in the experiment and detail discussion chapter 5 describe correlation and analysis of the selected sites with detail discussion & interpretation Chapter 6 is engaged in the final conclusion & overall recommendations about the study. Detailed test results are presented in the appendices.

CHAPTER 2 LITERATURE REVIEW

2.1 General

Soil is a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. Rock, on the other hand, is thought of as a naturally occurring assemblage of mineral grains bound together by powerful and long-lasting cohesive forces. The weathering of rock reduces the cohesive forces holding the mineral grains together and causes larger masses to break up into smaller and smaller particles.

Clay minerals are known as secondary silicates because they are generated when primary rock-forming minerals weather. Clay minerals are very fine grained and flakes shaped and occur in microscopic particle sizes (0.002 mm); they are differentiated from sand, gravel, and silt by a negative electrical load on the crystal edges and a positive electrical load on the face. Clay minerals are made up of two types of structures. To begin, silicon ions are bonded to oxygen atoms on all four sides to form silica oxygen (tetrahedron). Second, with aluminum and magnesium ions coordinated on eight sides with oxygen and hydroxyl ions, an octagon arises (octahedron).

All clay minerals are made up of octahedral and tetrahedral sheets that contain specific types of cations in various shapes and are connected in a system. As the configurations of the octahedral and tetrahedral sheets vary, different clay minerals emerge. Kaolinite, illite, and smectite (montmorillonite) are some of the most prevalent clay mineral groupings. Kaolinite is made up of silica and alumina plates that are tightly linked due to the stability of kaolin clay. Illite has layers made up of two silica plates and one alumina plate, but it also contains potassium ions between each layer, making the clay's structure stronger than smectite. The layers of smectite are made up of two silica plates and one alumina plate. Large amounts of water can easily enter the structure due to the weak link between the layers, and this event causes the clay to inflate [3].

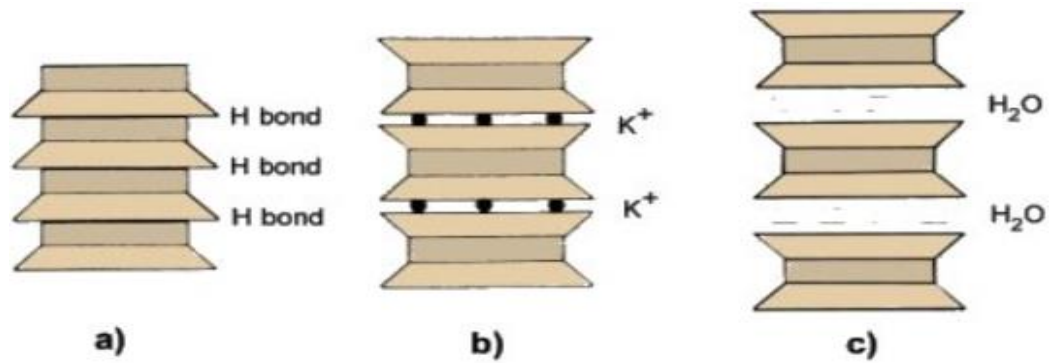


Figure 2-1: Structure of Kaolinite, Illite, and Montmorillonite

Studies on soil behavior that don't take into account the physico-chemical and microstructural features of clay soils may be missing out on crucial information about the soil's physical and mechanical qualities. This is because the physico-chemical and microstructural features of the soil may explain the majority of physical and mechanical behaviors. Clay has plasticity and can be shaped into dough; when cooked, it hardens into a solid with large strength increments. When clay is wet, its volume increases, and when it dries, its volume drops, resulting in many fissures.

Various studies have looked at the formation and mineral makeup of Ethiopian Red Clay soils. The primary source of the red clay soils in Ethiopia is residual volcanic rock weathering. In Ethiopia, olivine basalt, basalt, and trachyte make up the majority of the parent rock for the black and red clays. Kaolinite and halloysite are the main clay minerals found in Ethiopian red clay soils. Ethiopian red clay soils have evolved when rain fall is abundant and drainage is good. The red clay soil type in Ethiopia indicates the presence of iron. It is discovered that the acidity of Ethiopian red clay is comparable to that of other tropical soils. They don't show a wide variety of index qualities they have also small amount of clay, liquid limits, and the overall plasticity indices in compared to other tropical soils. [7].

Red clay soils are widely dispersed in Addis Ababa's Gulele and Kolfe Keranyo sub cities. Red clay soils can also be found in parts of Addis Ketema and Arada sub-cities. Addis Ababa's red clay soil is underlain by rhyolites in places like Kokebe-Tsebah and the British Embassy through Kotebe College of Teachers Education Based on these findings, it may be assumed that Addis Ababa's red clay soils are primarily made up of basalts and rhyolites. The features of Addis Ababa red clay soil are summarized in the table below [21].

Table 2-1: Properties of Addis Ababa Red clay soils

Properties	Hailemariam (1992)	Medhanit (2009)	(Samuel ,1989)		
			Kolfe	Rufael	Semen Gebeya
Location	A.A	A.A	Kolfe	Rufael	Semen Gebeya
Clay content (%)	48-73	55-65	58-70	50-70	53-68
Activity	-	0.11-0.70	-	-	-
LL	54-81	39-106	61-75	56-75	57-76
PL	21-30	9-40	30-43	29-41	33-47
SL	14-21	12-20	15-21	14-20	14-25
Free swell	10-40	5-80	15-45	30-40	15-20
Specific gravity	2.61-2.79	2.6-2.8	2.66-2.73	2.66-2.76	2.7-2.77
UCS (KN/m ²)	49-50	64-213	-	-	-
Plasticity chart	-	CH,CL,MH	CH	CH	CH

It is essential to determine a clay type in geotechnical engineering since the type has a direct impact on important clay parameters as Atterberg's limits, hydraulic conductivity, swelling-shrinkage, settlement (compression), and shear resistance.

2.2 Consistency of Red Clay Soils

2.2.1 Atterberg Limits

Fine-grained soil (silt and clay) can exist in three states of consistency: solid, plastic, and liquid, with Atterberg limits dependent on moisture content defining the borders. The liquid limit (LL) and the plastic limit (PL) are two limits linked with soil plasticity (PL). Atterberg limits are also used to define the shrinkage limit. When an excessive amount of water is added to a cohesive soil, it becomes partly liquid and flows like a viscous liquid. However, as the viscous liquid dries up, it transforms into a plastic condition due to the loss of moisture. The soil will transition from a semisolid to a solid condition when moisture is reduced more.

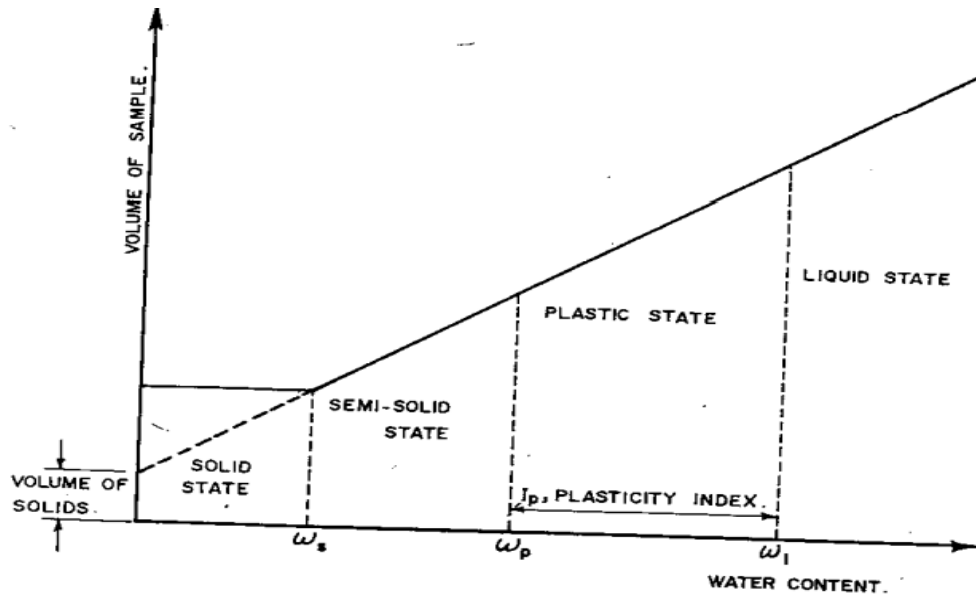


Figure 2-2: Different state of soil

2.2.1.1 Liquid Limit

Liquid limit is the water content at which the soil changes from the liquid state to the plastic state. At the liquid limit the clay is practically like a liquid, but possesses a small shearing strength. The shearing strength at this stage is the smallest value that can be measured in the laboratory. The liquid limit of soil depends upon the clay mineral present in it. To compute the Liquidity index, the liquid limit of the soil must be determined in the laboratory using Casagrande's Liquid Limit device, which consists of a semi-spherical brass cup that is repeatedly dropped from a height of 10 mm on to a hard rubber base by a cam operated mechanism using a test procedure known as the Casagrande cup method. The test was carried out in accordance with ASTM D4318.

2.2.1.2 Plastic Limit

The water concentration below which soil ceases to behave as a plastic substance is known as the plastic limit. When rolled into a 3mm diameter soil thread, it begins to crumble. The soil loses its plasticity and becomes semisolid at this level of water concentration. The plastic limit is also a parameter in calculating the soil's index properties. For determining the plastic limit, ASTM D4318 was used as the standard procedure.

2.2.1.3 Shrinkage Limit

The maximum water content below which a decrease in water content does not result in a decrease in the volume of the soil mass is known as the shrinkage limit. The shrinkage stops when the water content reaches a certain level. Because practically all of the water in the soil has been removed, there is no further volume change in the solid state. The shrinkage limit is the water content at which the soil transforms from a semisolid to a solid. The shrinkage limit is useful for determining the capacity of soils to swell and shrink.

2.3 Soil classification Methods

Soils are made up of weathered rocks, inorganic materials (such as sand, silt, clay, and so on), and organic compounds (such as peat). The coarse grained and fine grained soils are distinguished by soil classification. This also serves as the foundation for a thorough geotechnical examination. Different criteria, such as particle size distribution and Atterberg limits, can be used to classify soil.

Table 2-2: Soil classification methods

Classification system	Grain size (mm)			
	Gravel	Sand	silt	clay
Unified	4.75-75	0.075-4.75	Clay and silt are identified by their plasticity	
AASHTO	2.00-75	0.05-2.00	0.002-0.05	<0.002
MIT	2.00-1.00	0.06-2.00	0.002-0.06	<0.002
USDA	2.00-75	0.05-2.00	0.002-0.05	<0.002

2.3.1 Unified Soil Classification System: USCS

The Unified Soil Classification System is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity and compressibility. It divides soil into three major divisions: coarse-grained soils, fine grained soils, and highly organic (peaty) soils. This classification is based on Unified Soil Classification as given in ASTM D248. Course grained soil can be classified into gravels and sands

Grave (G):- If the percent retained on sieve 4.75mm sieve is greater than 50%, the soil may be represented by GW (Well Graded), GP (Poorly Graded), GM (Silty Gravel) or GC (clayey gravel).

Sand (S):- If the percent on sieve finer than 4.75mm and coarser than 0.075mm sieve is greater than 50%, the soil may be represented by SW(Well graded Sand), SP(poorly graded sand), SM (Silty Sand) and SC(clayey Sand).

Fine grained soil grouped in to silts and clay

Clay(C) or Silt (M):- If the percent on sieve finer than 0.075mm is greater than 50%, the soil may be represented by ML (Inorganic Silty), CL (lean clay), MH (Elastic Silt), OH (organic clay) and CH (Fat clay). In general after analyzing the grain size distribution we can say that if the soil grain size that passes the 0.075mm is more than 50% then the soil is fine grained soil and if the soil grain size that passes the sieve diameter 0.075mm is 50% or less then it is coarse grain soil [2].

2.4 Compaction Test

Compaction is the process of eliminating air voids in soil to make it denser. For a given compaction effort, this test is used to determine the relationship between soil moisture content and dry density. The amount of mechanical energy applied to the soil mass is referred to as compaction effort. The goal of a laboratory compaction test is to find the right amount of water at which the weight of the soil grains in a unit volume of compacted soil is at its maximum; this amount of water is referred to as the Optimum Moisture Content (OMC). The amount of compaction used and the moisture level of the soil determine the dry density that can be obtained.

Compaction of a soil can be accomplished by repeatedly applying loads. Loads can be applied in three ways: statically, dynamically, and through vibration. Different moisture content values and the corresponding dry densities obtained after compaction are plotted on an arithmetic scale in the laboratory, with the former as abscissa and the latter as ordinate. The points are then linked together to form a curve. The curve is used to determine the maximum dry density and the corresponding OMC. It is typical to print

two additional curves in addition to the compaction curve: theoretical curves of the dry unit weight that correspond to 100% and 80% degrees of saturation. The zero air voids curve is the relationship between dry unit weight and compaction moisture content at 100 percent saturation, because a soil compacted to this curve would have all the gaps filled with water and hence contain no air.

Because it is impossible to compact a soil beyond the point when all the air has been eliminated, this curve indicates the theoretical maximum compaction that may be accomplished for any given compaction moisture content. Compacted soils never attain the 100 percent saturation curve in terms of practicality. Any points on the compaction curve that lie to the right of the 100 percent saturation curve must be erroneous, providing a valuable check on test results. The curve indicating dry unit weight at 80% saturation is important to depict since, in practice, most soils reach maximum compaction near 80% saturation. For proctor compaction examinations, there are two separate criteria.

The primary goal of compaction is to enhance the material's engineering qualities by reducing compressibility and so reducing settlement, increasing shear strength and thereby enhancing embankment stability and bearing capacity, or decreasing void ratio and thereby reducing permeability. Soil compaction raises density, shear strength, bearing capacity, reducing voids, settling, and permeability the findings are valuable in determining the stability of field problems such as earthen dams, embankments, highways, and airfields. If the soil is not compacted properly and is heaped loosely, it is likely to settle or wash away easily in the future. As a result, it's critical to compact the soils on the field to the necessary degree. The value of the OMC established by laboratory compaction test is managed in such compacted in the field. The maximum dry density established in the laboratory also influences the compaction energy provided by a compaction unit.

In other words, the findings of laboratory compaction tests are used to create a compaction specification for field soil compaction. The capacity of the compaction mold is approximately 944cm^3 . This test was created by Proctor in 1933 in connection with the construction of earth fill dams in California. He outlines the requirements for conducting the test. A soil with specified water content is layered in three layers into a mold, with each layer compressed by 25 blows and 2.5 Kg hammer. Increase in the dry

density of a soil due to compaction is affected by the moisture content of the soil, the mode and amount of compaction, type of soil and gradation of soil.

2.5 Shear Strength Behavior of Clay

One of the most essential parts of geotechnical engineering is soil shear strength. Soil strength ensures the safety of geotechnical structures. The shear strength of the soils influences the bearing strength, slope stability, and bearing wall of the bases. Shear is a type of failure that occurs in soils. Failure happens when the forces in the soil surpass the shear strength. The interactions between the soil particles determine the soil's shear failure. When clay soils are sheared, these interactions are separated into friction strength and cohesion strength; the volume change in the drainage shear is dependent on the ambient pressure as well as the soil's stress history. In addition, loading on clay soils does not allow water to escape from the pores, and thus, this creates excess water pressure.

Excess water pressure is reduced, consolidation occurs, and volume change is detected if the loading does not induce failure. Due to the clays' low hydraulic conductivity, this volume change takes a long time. Depending on whether the pore water pressure dissipates or not, the shear strength of fine-grained soils can be separated into two categories: drained and undrained shear strengths. One of the most important geotechnical parameters is the undrained shear strength (C_u) of fine-grained soils, which may be determined both in situ and in the laboratory.

Many geotechnical applications, such as pile design and subsurface soil investigations for offshore structures, rely on the remolded undrained shear strength (c_{ur}). The main clay mineral determines the undrained shear strength of a clayey soil. The net attractive forces and the mode of particle arrangement as governed by the interparticle forces are responsible for the undrained shear strength of Kaolinitic soils, whereas the viscous shear resistance of the double-layer water is responsible for the undrained shear strength of montmorillonite soils. A direct shear test, triaxial compression test, vane test, unconfined compression strength test, and standard penetration tests are used to determine the clay's shear strength. For this study Unconfined Compression Test (UCS) is used to determine the shear strength of fine-grained soil.

2.6 Factor affecting the shear strength of clay soil

The shear strength of soil can be defined as the inherent resistance of the soil against deformation due to the action of shear stress. Shear strength of the soil is constituted basically of the following components:

- The structural resistance to displacement of the soil because of the interlocking of the particles.
- The friction between the individual soil particles at their contact points.
- Cohesion or adhesion between the surfaces of the soil particles

There are many factors affecting the shear strength of cohesive soils. Those factors include:

(1) **Structure of clay:** there is a distinct structure to the clay. Due to structural strength, even usually consolidated clay has a small peak. The structural strength of over-consolidated clays takes priority.

(2) **Clay content:** The clay content affects the cohesive soil's ultimate friction angle. The angle reduces as the clay content rises.

(3) **Drainage conditions:** Because cohesive soils have a poor permeability, shear strength will vary depending on whether the soil is drained or not. When undrained conditions exist, cohesive soils have very low strength just after the load is applied.

(4). **Rate of strain:** The influence of rate of strain increase on the angle of shearing resistance is rather minimal in usually cemented clays. The strain rate is reduced by a factor of ten, so the value of may drop by around 10%. However, in other circumstances, the angle increases as the rate of strain decreases. When the rate of strain is reduced in over consolidated clays, some of the shear strength is always lost.

(5) **Plasticity Index:** the value of angle of internal friction decreases with an increase in Plasticity Index of the clay

(6) **Confining pressure:** If there is adequate time for the pore water pressure to dissipate, the shear strength of clays increases with an increase in confining pressure.

(7) **Stress history:** the values of strength parameters depend up on the stress history

(8). **Intermediate principal stress:** the value of cohesion and angle of internal friction are affected very little by the magnitude of the intermediate principal stress [7].

2.7 Unconfined Compression Strength Test (UCS)

Because it is one of the quickest and cheapest techniques of evaluating shear strength, this is the most prevalent method of soil shear testing. The sample is extruded from the sampling tube to perform an unconfined compression test. The ends of a cylindrical sample of soil are trimmed to be reasonably flat, and the length-to-diameter ratio is on the order of two. The soil sample is loaded into a loading frame on a metal plate, and the operator raises the level of the bottom plate by turning a crank.

The top plate, which is linked to a calibrated proving ring, restrains the top of the soil sample. An axial load is applied to the sample as the bottom plate is elevated. The load is gradually increased to shear the sample, and readings of the force applied to the sample and the resulting deformation are collected at regular intervals.

The stress is kept up until the soil forms a clear shearing plane or the deformations become excessive. The measured data are used to calculate the soil specimen's strength and stress-strain properties. The unconfined compressive strength, q_u , is used to calculate the maximum load per unit area. We assume that no pore water is lost from the sample during the set-up or shearing procedure in the unconfined compression test (ASTM D-2166).

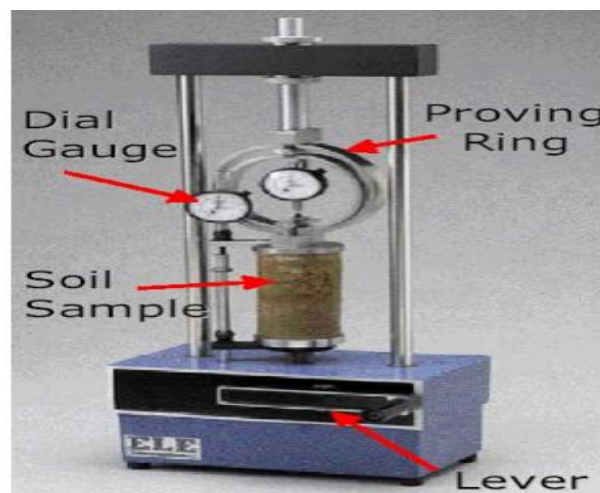


Figure 2-3: Unconfined compression test device

This test's primary goal is to establish the clay's unconfined compressive strength, which is then used to compute the clay's unconsolidated undrained shear strength under unconfined conditions. The undrained shear strength of soils is required for determining the bearing capacity of foundations, dams, and other structures. It's usually calculated using an unconfined compression test, which yields one-half of the unconfined compressive strength (q_u) and angle of internal friction is zero. The most important condition for the soil occurs shortly after construction, when the undrained shear strength is roughly equal to the cohesion (c). This is written as:

$$c_u = \frac{q_u}{2}$$

The unconfined compression test method was used to determine the undrained shear strength around the plastic limit and below the plastic limit moisture content value. The test is carried out on a cylindrical sample that has been extruded from a thin-walled sampling tube or clipped from a block sample. The diameter of the test specimen should be at least 33 mm (1.3 in.) and the length (L) to diameter (D) ratio should be between 2 and 3. Before testing, the length, diameter, and weight of the test specimen should be determined. The specimen is loaded at a strain rate of about one percentage per minute in a strain regulated axial compression system. A calibrated proving ring or force transducer is used to measure the axial load and a dial gage or displacement transducer is used to measure the axial deformation. Data on load displacement is captured continuously with an x-y plotter or manually at regular intervals in order to draw a stress-strain curve. The test is repeated until either the axial load remains constant (or decreases) or the axial strain reaches a predetermined limit.

The item is weighed and its water content is determined when the test is completed. It is well known that the shear strength of cohesive clay varies with its consistency depending on their consistency clay soils and other cohesive soils are classified as soft, medium, stiff, or hard. The force per unit area at which unconfined cylindrical samples of soil fail in compression tests is the most direct quantitative measure of consistency.

Table 2-3 shows general relationship of consistency and Unconfined Compression Strength (UCS) of clays. The table depicts the overall relationship between clay soil consistency and unconfined strength [5].

Table 2-3: Consistency and unconfined strength of clay soil.

Consistency	q_u (KNm ²)	Remark
Very soft	<25	Squishes between finger when squeezed
Soft	25-50	Very easily deformed by squeezing
Medium	50-100	Thumb makes impression to deform
Stiff	100-200	Hard to deform by hand squeezing
Very stiff	200-400	Very hard to deform by hand
Hard	>400	Nearly impossible to deform by hand

2.8 Related Researches

Different authors have investigated the relationship between undrained shear strength and water content ratio. The relationship between the logarithm of the undrained shear strength and the water content normalized by that at the liquid limit is indicated by the equation, proposed by Tsuchida et al. (1999) and shown in Fig. below. The relationship has been used as a dominant parameter for evaluating the characteristic of compressibility of marine clay.

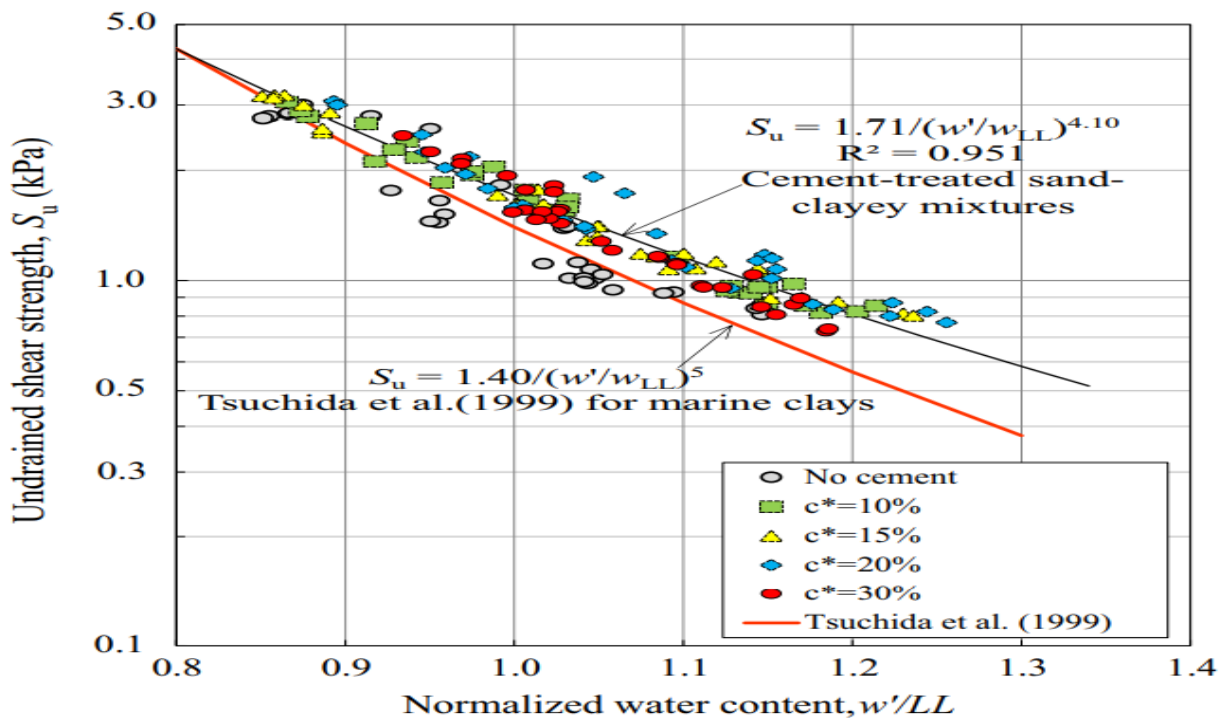


Figure 2-4: Relationship between undrained Shear strength and water content normalized by liquid limit.

It was found that the undrained shear strength has a strong correlation with the normalized water content in a semi-log scale and that a power law fitting has the highest coefficient of determination compared with others. Tsuchida et al. (1999) investigated the relationship of the undrained shear strength versus the water content normalized by the liquid limit for marine clays in Japan proposed the following equation for the relationship.

$$c_{ur} = 1.4 \{WCR\}^{-4.5} \quad (2-1)$$

The undrained shear strength decreases with an increase in the normalized water content.

The Discussion of Water Content Ratio an Effective Substitute for Liquidity Index for Prediction of Shear Strength of Clays by Vardanega and Haigh (2017) presented the water content ratio is somewhat effective in characterizing the changes in undrained strength with water content. For a given soil, any linear link between WCR and the logarithm of undrained strength implies good relationship.

The discussers re-analyzed the large database of fall-cone data that was reported in 2014 using the authors' method the best linear fit to the database relating values of undrained strength with WCR is given as: -

$$c_{ur} = 10^{2.72-2.585wcr} \quad (2-2)$$

Mathews Abraham and Beshy Kuriakose (2017) present Water Content Ratio might replace the well-known Liquidity Index with comparable results. This means that forecasting shear strength does not require determining the plastic limit of the soils. The relationship between undrained shear strength and clay water content ratio was studied using more than 500 data points. The shear strength of remolded representative saturated samples of Cochin marine clays collected from the four locations is presented at various water contents on remolded representative samples of Cochin marine clays taken from the four sites.

Despite the fact that the four sites are all inside Greater Cochin, the sampling locations are around 10–30 kilometers apart. The clays, on the other hand, have the same geological origin. As illustrated in Fig 2.5, the samples produce four distinct curves. The liquid limit value of any clay is determined by the type of clay mineral and its associated cations, as well as the sample's clay concentration (Mitchell 1976). The liquid limit rises in tandem with the clay content. Similarly, percent clay remaining same, clays containing montmorillonite clay mineral will have higher liquid limit than kaolinite clay. Clayey soils' shear strength is influenced by both of these factors. However, the impact of both can be easily accounted for simply normalizing the water content and expressing it as a ratio of liquid limit.

Table 2.4: Physical properties and Shear Strength of Cochin Marine clays from four locations

No	Soil type	Water content w%	Shear strength (KN/m ²)	Liquid limit %	Plastic limit %	Plasticity index %	Water content ratio
1	Marine clay (Parur)	105.6	2.10	108	43	65	0.97
2	Marine clay (maraud)	105.0	1.75	105	45	60	1.0
3	Marine clay elamkulam	105.8	2.36	119	47	72	0.89
4	Marine clay (kumbalam)	98.0	1.90	98	39	59	1.00

For the four soils, good linear connections have been found. The liquid limits of these clays ranged from 98 to 119 %, and their slopes were nearly identical. In the figure, there is also a composite plot for all four soil samples. Although the liquid limit values of the individual samples are different, it can be seen from the plot that a unique linear correlation could be achieved between water content ratio and log of shear strength. With a strong correlation coefficient of 0.990, a statistical fit to the experimental data yields the following connection [13].

$$\log c_u = 2.72 - 2.58wcr \tag{2-3}$$

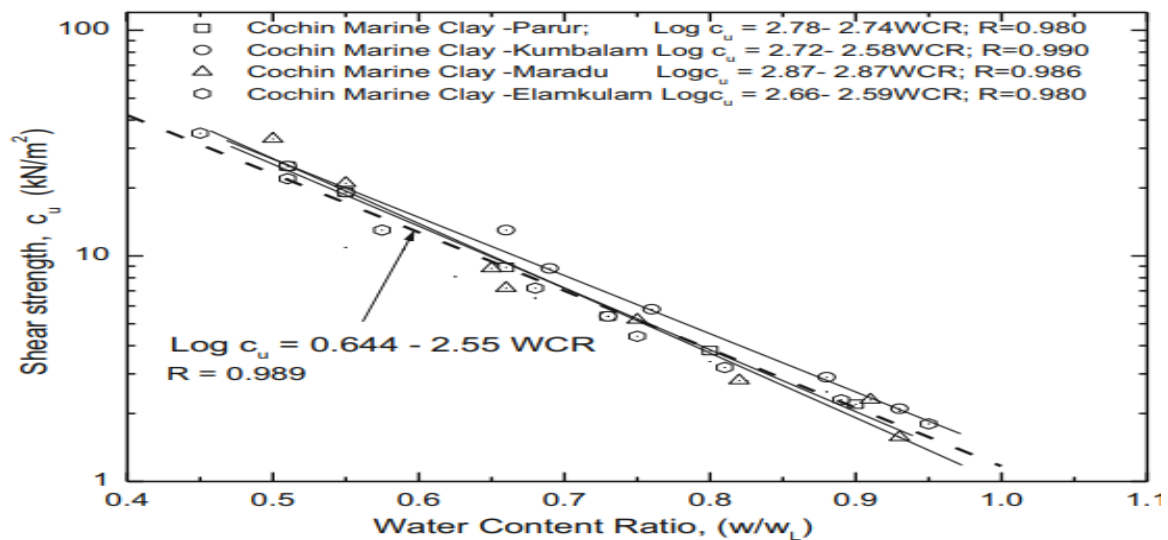


Figure 2-5: WCR and shear strength (on log scale) Tsuchida et al. (1999)

The soil sampling data points are separated in the study, but the clay is of the same geological origin, and a significant linear relationship between log of shear strength and water content ratio is established using experimental results on various types of saturated clay. WCR is also commonly used to determine the swell potential of expansive clays (swell index), the trafficability of construction trucks, and liquefaction resistance.

Satoru Shimobe and Giovanni (2020) considering over 500 data from literature and from laboratory and study the relationship between Undrained shear strength (remolded and undisturbed), liquidity index (IL), and water content ratio (WCR).

The authors conclude CU-IL relationship using both remolded and undisturbed data, as it is possible to state that no unique relationship exists. If only remolded undrained shear strength are used, data follow a more uniform path. Introducing the value parameter Rp (PL/LL), considering the material constants α and β , and substituting IL-WCR relationship in the remolded CU-WCR relation, the CU-IL relation with different Rp values is obtained. Considering however a larger database where undisturbed and remolded undrained shear strength values are considered, the CU-WCR relationship is not as unique as it should be only for WCR values larger than 0.8 a relationship is observed.

Table 2-5: Relationships between undrained shear strength (Cu) and Water content ratio (Wcr)

Authors	Proposed equation	Application
Fedrico (1983)	$c_{ur} = 597.82e^{-5.131wcr}$	Remolded soil
Tsuchida (1999)	$c_{ur} = 1.4(WCR)^{-4.5}$	Remolded soil
Lee(2004)	$c_{ur} = 182.93e^{-2.86wcr}$	Remolded soil
Berilgenetal (2007)	$c_{ur} = 145e^{-2.86wcr}$	Remolded soil
Kangetal (2017)	$c_{ur} = 1.71(WCR)^{-4.1}$	Remolded soil
Vardanega & Haigh (2017)	$c_{ur} = 10^{2.72-2.585wcr}$	Remolded soil

In order to explore the possibility of substituting WCR with IL (wherever relations exist with other geotechnical parameters), attempts were made whether definite relationship can be established between WCR and IL.

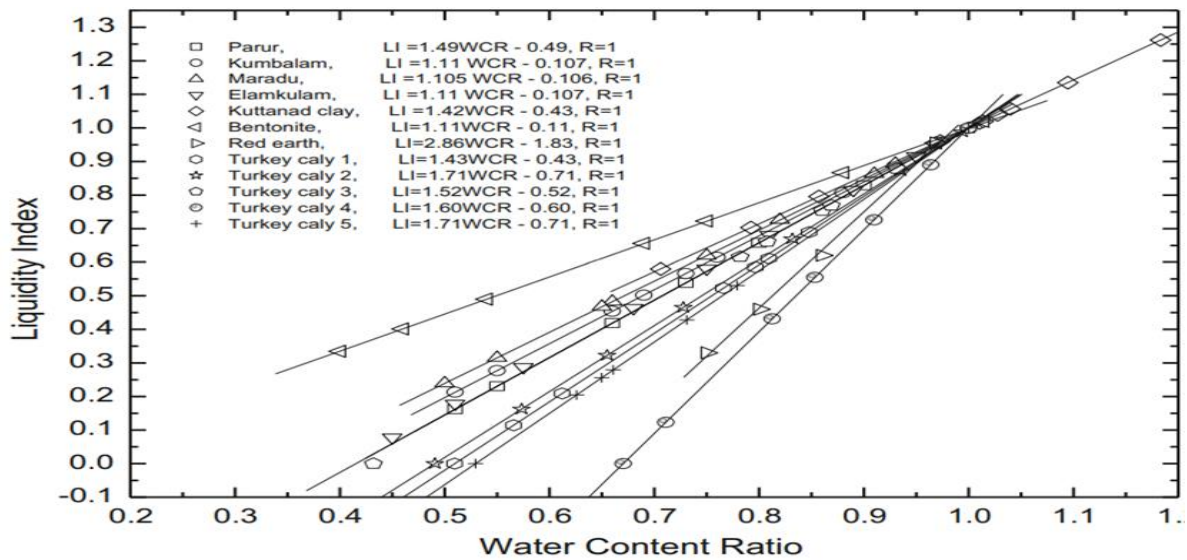


Figure 2-6: Water content ratios versus liquidity index

The slope of the linear relationship between IL and WCR changes with the LL/PL ratio, Figure 2.6 also emphasizes the impact of the LL/PL ratio on the slope of the WCR-IL plots, demonstrating that regardless of the geological origin or the assumed value of the liquid limit to plastic limit ratio, the variation of the slope of the WCR-IL plots follows a clear trend with the LL/PL ratio. Even though excellent relationship between IL and WCR exist for individual soils, the plots do not merge to a single straight line for the different soils [14].

As a result of the above discussion, it is clear that the proposed parameter, Water Content Ratio, could replace the well-known parameter, Liquidity Index, with equal, if not superior, performance. In addition, the slope of the water content ratio–liquidity index plot is highly correlated with the LL/PL ratio.

2.9 Undrained Shear Strength of Unsaturated Soils under Zero or Low Confining Pressures.

In geotechnical practice, compressive strengths are frequently employed to calculate the Undrained Shear Strength (USS) of soils. Under field conditions, environmental variables such water infiltration or evaporation through a soil's surface can alter soil suction, which in turn affects the USS. Therefore, a model that can predict the fluctuation in the USS with respect to soil suction is required in order to numerically model soil behaviors under wetting and drying conditions.

The shear strength of unsaturated coarse-grained soils can be accurately calculated under the presumption that pore air and pore water are in drained conditions. In other words, there is no change in the suction of the soil during the shearing process until the soils near failure conditions. On the other hand, because of their poor air and water permeability, unsaturated fine-grained soils are difficult to anticipate in terms of shear strength (ucs test ends before a failure state is achieved during the shearing procedure). The difference between the initial and failure conditions in soil suction can be positive, negative, or insignificant in this case since soil suction changes constantly during the shearing process.

Instead of using an effective stress approach, a total stress technique should be employed to investigate the mechanical behavior of unsaturated fine-grained soils. Furthermore, it is justifiable to estimate the shear strength of unsaturated soils using half of the unconfined compressive strength (UCS) [29].

It is possible to experimentally evaluate the shear strength of unsaturated soils using a variety of laboratory testing methods, including consolidated drained, constant water content, unconsolidated undrained, and unconfined compression (UC) tests. The most logical method for evaluating the undrained shear strength of unsaturated fine-grained soils is the UC test, which extends the total stress technique. This is due to a number of projects in geotechnical and pavement engineering that includes soils at shallow depths, as well as the fact that the UC test is the simplest and most economical.

Although UC tests are performed under zero confining pressure, it is still challenging to prepare the soil specimens at different soil suction values without causing notable changes to the soil structure.

a semi-empirical model were attempted to predict the undrained shear strength of unsaturated fine-grained soils in vadose zones under zero or low confining pressure as a function of the soil suction based on the UCS of unsaturated fine-grained soils[23].

2.10 List of some of the models equation

Vanapalli and Fredlund (1997)

The shear strength equation for unsaturated soils

$$c_{u(unsat)} = \frac{\sigma_1}{2} = \frac{c' \cos \phi' + (\mu_a - \mu_w)[(\Theta^k) \tan \phi'] \cos \phi'}{1 - \sin \phi'} \quad (2-6)$$

Where Θ is the normalized volumetric water content ($=\theta/\theta_s$ where θ is the volumetric water content and θ_s is the volumetric water content under saturated conditions), and k is a fitting parameter for shear strength.

Equation 2-6 was successfully used to predict the UCS of an unsaturated silty soil (Vanapalli et al., 2000) for suction values in the range of 0 to 10^6 kPa.

Babu et al. (2005) examined the UCS of Red and Black Cotton soils and suggested that the UCS of unsaturated soils can be written in the form.

$$\alpha_0 c_u - \alpha_1 = (\mu_a - \mu_w) (\Theta^k) \alpha_2 \quad (2-7)$$

where, α_0, α_1 and α_2 are functions of the strength parameters of soil.

Chae et al. (2010)

Suggested that there is a unique relationship between the UCS and suction stress at failure. Stress components resulting from bulk water and meniscus water are termed bulk (p_b) and meniscus (p_m) stresses, respectively. The sum of these two stresses is denoted

as the suction stress (p_s) (Karube and Kato, 1996). The suction stress for different suction values can be estimated by adopting the VG model.

$$\rho_s = \rho_b + \rho_m = \left(\frac{1}{1 + (\alpha\psi)^n} \right)^m \psi \quad (2-8)$$

Suction stress is located on the axis of net normal stress as an intercept (Karube et al., 1996; Lu and Likos, 2006). Therefore, if it is assumed that suction stress at failure acts as a confining pressure during a UC test, an equation can be derived based on Mohr's circle at failure.

$$q_{unsat} = \frac{4 \sin \phi^f}{1 - \sin \phi^f} p_{sf} \quad (2-9)$$

Where, p_{sf} is the suction stress at failure.

The internal friction angle in Eq. [2-9] is based on the net normal stress. There is a limitation to the use of Eq. [2-9] because predicting the suction stress at failure is still challenging.

The predicted USS using the equation proposed by Vanapalli and Fredlund (1997) is too sensitive to the fitting parameter k . Lastly, the methodologies proposed by Chae et al. (2010) and Zhou et al. (2016) require the soil suction at failure, which is impossible to predict.

Chae et al model requires the USS under saturated conditions and the soil-water characteristic curve along with two fitting parameters, n and m . However, since $n = 2$ provides good comparisons when compared with the measured USS for a wide range of I_p , only one fitting parameter (i.e., m) is required.

The predicted USS from the Chae et al model showed good agreement with the measured USS using the degree of saturation and soil suction under both initial and failure conditions. In other words, the proposed model does not require the degree of saturation and soil suction at failure. The reason for the good agreement between the predicted USS under both initial and failure conditions is that the change in the soil suction at failure is compensated by the change in the degree of saturation.

2.10 Models for Shear Strength of Unsaturated Soils

Empirical models for the shear strength of unsaturated soils have been proposed using different estimation procedures which can be used to approximate the shear strength envelope of the soils. Most of the estimated shear strength equations are based on the SWCC of the soil and the saturated shear strength parameters, cohesion (c') and angle of internal friction (ϕ'), as well as other soil properties used to predict the shear strength function for an unsaturated soil (Fredlund, 1999).

Some models use the entire soil suction range for shear strength prediction, others apply at residual suction, and some others were developed from zero suction to the air-entry value of the soil. Basically, in geotechnical engineering practice usually the range of suction below the residual suction is the greatest interest to determine the change in shear strength.

2.10.1 Fredlund et al (1978) Shear Strength Equation

Fredlund et al (1978) proposed a linear shear strength equation for unsaturated soils shear strength using two independent stress state variables, equation 5.1. It resembled a progression of the Mohr-Coulomb failure criterion and become the basis for subsequent nonlinear equations.

$$\tau_f = c' + (\sigma - u_a) \tan \phi' + (u_a - u_w) \tan \phi^b \quad (2-10)$$

where, τ_f is the shear strength of unsaturated soil, c' is the effective cohesion of saturated soil, ϕ' is the effective angle of shearing resistance for a saturated soil, ϕ^b is the angle of shearing resistance with respect to matric suction, $(\sigma_n - u_a)$ is the net normal stress on the plane of failure ; and $(u_a - u_w)$ is the matric suction of the soil on the plane of failure.

The friction angle ϕ^b was assumed to be independent of net normal stress and the friction angle, ϕ' associated with net normal stress is independent of soil suction. It is then further showed by Fredlund and Rahardjo (1993) that since the intercept of the failure envelop intersects the shear stress vs. matric suction plane, the relationship between shear stress with matric suction can be explained in the form of: -

$$c = c' + (u_a - u_w) \tan \phi^b \quad (2-11)$$

Where, c represents the intercept of the Mohr-Coulomb failure envelope for zero net normal stress and for a specific matric suction value.

2.10.2 Fredlund et al (1996) Shear Strength Equation

Fredlund et al (1996) proposed a non-linear shear strength equation for unsaturated soils shear strength at any given value of suction and incorporated the SWCC written in terms of dimensionless water content, θ into the equation written as follows: -

$$\tau = c' + (\sigma - u_a) \tan \phi' + (u_a - u_w)(\theta_d^k) \tan \phi' \quad (2-12)$$

where, $\theta_d =$ dimensionless water content defined as $\frac{\theta}{\theta_s}$; θ is any volumetric water content; θ_s is the saturated volumetric water content.

The first part of equation 5-3 is the saturated shear strength, expressed as a function of normal stress. The second part of equation 5-3 is the shear strength contribution due to suction, which can be computed using the soil-water characteristics curve.

The equation is useful to predict the shear strength of unsaturated soils over the entire range of suction from 0 kPa to 106 kPa and it can also be expressed in terms of degree of saturation, S , or gravimetric water content, an empirical relationship is provided by Garven and Vanapalli (2006) between the plasticity index of the soil, PI and the fitting parameter κ , equation 5.4 as follows: -

$$k = -0.0016(PI)^2 + 0.0975PI + 1 \quad (2-13)$$

As a result, the Fredlund et al (1996) shear strength equations become an estimation equation which was originally a best-fit equation.

2.10.3 Fredlund and Xing 1994

It assumed as the soil may be regarded as a set of interconnected pores that are randomly distributed. The air-entry value of the soil is the matric suction where the air starts to enter the largest pores in the soil. The SWCC is divided into three zones by changes in slope: the "boundary effect zone" in the lower suction range, the "transition zone" between the air-entry and residual values, and the "residual zone" at high soil suctions reaching up to 1,000,000 kPa.

CHAPTER 3 DESCRIPTION OF THE STUDY AREA

3.1 General

Addis Ababa is located in the western margin of the Main Ethiopian Rift Valley. The margin exhibits Mio-Pliocene volcanic features and is distinguished by normal faults thrown downward in the direction of the rift. The major fault running roughly east-west just to the north of the Addis Ababa-Ambo route serves as the upper (outer) boundary of the margin. From Nazareth to Awash Station, the lower boundary runs northeast to southwest parallel to the main systems of fissures of the rift-floor.

The majority of the soil formation in the Addis Ababa area is caused by the physical disintegration and chemical decomposition of volcanic rocks; the weathering by products are either transported and deposited in low lying flat lands and depressions or remain in place and create residual soils. Residual Red soils are widely distributed in North, North western and in the central parts of the city [14].

The topography of the study areas, along with its drainage situation, had a significant impact on the soils' color and distribution. Light brown to yellowish brown soils are typical on both relatively mild and steep slopes in the city's northern, northeastern, and northwest regions. To the benefit of the topography, these locations have good drainage. Dark colored (dark grey) soils predominate in low-lying regions of the city (south, central, southeastern, and western parts), where surface drainage is poor and frequently wet logged.

Soil samples were taken in different location Addis Ababa city, which are dominated by red fine-grained soils. This soil has a larger surface area and necessitates a thorough geotechnical analysis. For this investigation, four locations were chosen. The sites are located at the global UTM [by hand held GPS] coordinates to determine the exact location of the test pit as well as its elevation above sea level.

These sites are:-

- Kechene Medehaniyalem
- Rufael
- Addisu Gebeya
- British Embassy

Table 3-1: Location of selected sites

No.	Location	Easting	Northing	Elevation (m)
1	Kechene Medhaniyalem	384591	933190	2359
2	Rufael	384356	933043	2358
3	Addisu Gebeya	384413	943392	2427
4	British Embassy	354573	857311	2205



Figure 3-1: Location map of the study areas with in Addis Ababa

3.2 Climatic condition

Addis Ababa's climate is cold to temperate, with an average annual temperature of 16 degrees Celsius and 1200–1600mm of rainfall (Environmental Management Authority). The main wet season in the area is winter, which lasts from June until mid-September. While the autumn rains come between February and April, with some showers lasting until mid-May. During both rainy seasons, heavy and torrential rainfall that last anywhere from a few minutes to several hours are prevalent.

As the strength of foundation materials decreases with increasing moisture content, the fluctuation in moisture content has a higher effect on the engineering properties of earth materials. Therefore, understanding the impact of a region's rainfall variation on changes in the ground water table and making wise decisions on the design and long-term safety of engineering structures are made possible.

Addis Ababa is not just Ethiopia's capital, but also the country's largest and most densely inhabited metropolis. Due to the city's rapid growth and the need to build more houses, there is currently a lot of development going on in all directions of the city, including parts of the study areas.

3.3 Geology and Tectonics of the Study Area

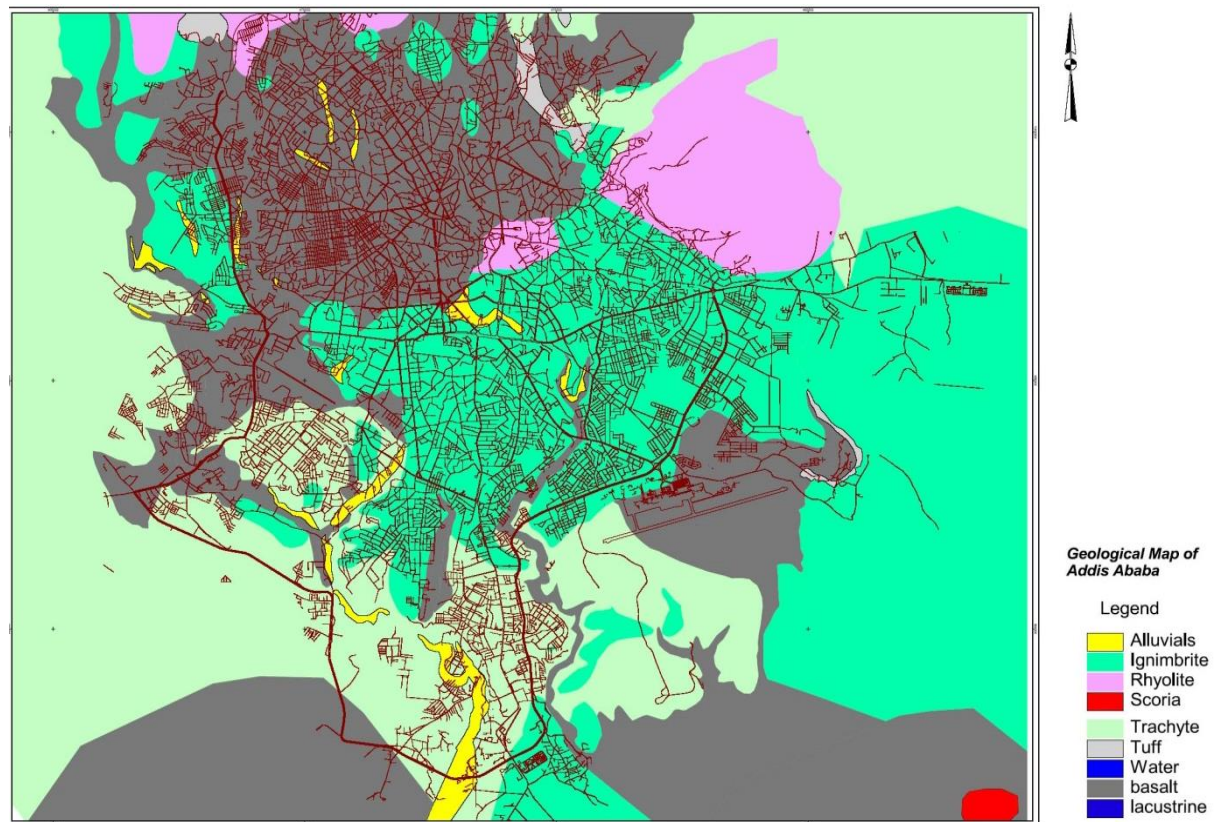
According to geological map of Addis Ababa Trachy-basalts, Ignimbrites and Basalts are the major outcrops in the western north east and central parts of Addis Ababa. The trachy-basalts cover places around General Wingate School. They are slightly weathered and intersected by fractures. The red soil, which is formed on ignimbrite rock, as observed around Asko Condominium site to a shallower depth of up to 2m during sampling has two layers based on color variations: the lower light red soil and the upper dark red soil. The change in color between the two layers is not sharp but gradual.

The study areas' geology are dominated by Addis Ababa basalt, which is primarily alkaline and olivine basalt, and Addis Ababa ignimbrite, which covers portions of Gulele, Addis Ketema, and Arada subcity. Most of Kolfe Keraniyo Sub city is covered with pyroclastic trachytic lava flows from the core volcanics of Wechecha, Entoto. Furthermore, the formation and thickness of the soil horizon above the aphanitic basalts

are significantly influenced by the area's topography, weathering, and fracture severity. Along the surface of the joint sets, physical disintegration and chemical breakdown become increasingly obvious.

The vicinity of the city is surrounded by trachyte and rhyolite hills and mountains. In the northern part, the Entoto mountain chains are composed of rhyolite and trachyte which are called the Entoto silicic of the Addis Ababa area. They are associated with the Alaji formation and rest on older basalts. Volcanism initiating the Alaji cycle occurred in late Oligocene - early Miocene times (Tamiru, 2001). Volcanic mountains such as Wachecha in southwest, Furi in the southern and Yerer in the southeastern parts of Addis Ababa are mainly trachyte in composition. The basalts are outcropping in the central part of Addis Ababa and to the south and north of the Entoto hills some small patches of basalts are capping the Entoto silicic.

Figure 3-2: Geological map of Addis Ababa and its surroundings



CHAPTER 4 LABORATORY SOIL TEST RESULTS

4.1 General

In nature, there are many different types of soils. On the other hand, similar-behaving soils can be gathered together to form a particular group. Engineers are constantly searching for quick tests that will enable them to gain more knowledge about soils than they can from a visual assessment without having to expend money, time, and effort necessary for engineering characteristics tests. These streamlined tests are referred to as index tests since they offer oblique information about the soil's engineering qualities.

In order to determine whether the soil is fine-grained or coarse-grained the first step is identifying the soil under investigation in field. The sample is first spread on a flat surface if more than 50% of the particles are visible to the naked eye, the soil is coarsegrained; otherwise, it is fine-grained. Color is also another important factor used to distinguish the red clay soil from expansive black or gray clay soils.

Representative test pits were excavated to a maximum depth of 3m to gather disturbed soil samples after a preliminary reconnaissance of the study completed. Representative soil samples were obtained from the test pits and packaged in plastic bags according to ASTM requirements for various laboratory procedures.

To ascertain the relationship between undrained shear strength and water content ratio, several laboratory tests were carried out after the samples were collected and transported to the AAiT Geotechnical laboratory. All laboratory tests are conducted according to ASTM standards.

The laboratory testing included: -

- Atterberg limits tests
- Specific gravity test
- Grain size analysis test (sieve analysis and hydrometer test)
- Standard compaction test
- Unconfined Compression Strength test

A detail test results are presented in the Appendix. Below are the summary of the test results.

4.2 Atterberg Limits Tests

Atterberg limits were determined using soil samples that passed a 425-micrometer sieve. The Liquid Limit was determined using the Casagrand device. The difference between the Liquid Limit (LL) and the Plastic Limit (PL) is the Plasticity Index (PI). The Casagrande plasticity chart is based on the plasticity index, which is useful for identifying fine-grained soils. Shrinkage limit (SL) is the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass. At the water content, the shrinkage ceases. Because practically all of the water in the soil has been removed, there is no further volume change in the solid state. The shrinkage limit is useful for the determination of the swelling and shrinking capacity of soils. Detail test results for Atterberg limit tests are presented in Appendix A.

Table 4-1: Summary of Atterberg limit test results

No	Location	Depth, (m)	Liquid limit %	Plastic limit%	Plasticity index %	Shrinkage limit %
1	Kechene Medhaniyalem	3	60	30	30	20
2	Rufael	3	53	28	25	18.7
3	Addisu Gebeya	3	69	33	36	20.2
4	British Embassy	3	54	28	26	19.2

4.3 Specific Gravity

The specific gravity of a soil is used in calculating the phase relationships of soils that is, the relative volumes of solids to water and air in a given volume of soil. Soil sample that passed through a 2.00-mm (No. 10) sieve and was oven dried at 105 degrees Celsius was used to calculate the weight of the soil particles using a small Pycnometer device. It is

intended to perform the specific gravity test on that portion of the sample using the values of specific gravity that were acquired for calculations related to the hydrometer analysis. Detail test results are presented in Appendix B.

Table 4-2: Summary of Specific gravity test result

No	Location	Specific gravity
1	Kechene	2.64
2	Rufael	2.71
3	Addisu Gebeya	2.66
4	British Embassy	2.75

4.4 Grain Size Analysis

The grain size distribution of the soil in the study area is assessed since grain size analysis is one of the index property tests. Based on the size of the grains, soil is categorized into two basic categories: fine-grained soil and coarse-grained soil. Fine-grained soil particles, such silt and clay, are smaller than coarse-grained soil particles, which are defined as those with a diameter more than 0.075 mm. The property of coarse-grained soil is influenced by the grain size distribution, whereas the property of fine-grained soil is influenced by inter-particle force.

Two methods were used to find the particle-size distribution of the soil samples: sieve analysis, for particle sizes larger than 0.075 mm (No. 200) in diameter; and hydrometer analysis for particle-sizes smaller than 0.075 mm in diameter. During hydrometer analysis sodium hexametaphosphate ($\text{Na}_6\text{P}_6\text{O}_{18}$) was used as a dispersion agent, To check whether the soil is clay or not analysis is done on each four sites at a depth of 3.0m. The sample preparation and test procedure was according to ASTM D 421 and ASTM D 422 respectively. Detail results of grain-size analysis are presented in Appendix C.

No	Depth(m)	Location	Percentage Amount of Particle Size (%)				% finer than 0.0075 mm
			Gravel	Sand	Silt	Clay	
1	3	Kechene	2	24.7	21	52.3	94.97
2	3	Rufael	1.04	10	1.09	87.9	89.53
3	3	Addisu Gebyea	1	4.3	10.6	85	94.97
4	3	British Embassy	3	7.7	2.8	86.4	86.8

Table 4-3: Summary of Grain size analysis results

4.5 Unconfined Compression Strength Test (UCS)

Since the sample is disturbed soil, it was remolded before the Ucs test was performed. Samples having a diameter of 38 mm and a height of 76 mm were created for stress-strain since varying height-to-diameter ratio produced different results.

Standard compaction test of each soil sample was computed according to ASTM standard. Ten water contents from Shrinkage Limit up to Plastic State were selected and their respective dry density was known from standard compaction graph. The bulk density of the soil was calculated using equation 4-1.

$$\gamma_d = \frac{\gamma_b}{1+w} \quad (4-1)$$

where, γ_d is dry density, γ_b is the bulk density and w is the moisture content

Table 4-4: Mass of soil remolded for Rufael site

w%	Mass of soil to be remolded for Rufael site			
	Dry density	Bulk density	Volume	Mass
18.00	1.28	1.51	86.19	130.19
19.00	1.29	1.54	86.19	132.31
20.00	1.32	1.58	86.19	136.43
22.00	1.35	1.64	86.19	141.64
25.00	1.38	1.73	86.19	149.11
28.00	1.43	1.83	86.19	157.66
30.00	1.44	1.87	86.19	161.35
33.00	1.40	1.86	86.19	160.49
35.00	1.38	1.86	86.19	160.58
38.00	1.32	1.82	86.19	157.01
40.00	1.29	1.80	86.19	155.06
42.00	1.26	1.79	86.19	154.22

The mass of the soil which is remolded is known by multiplying bulk density with the volume of the specimen and it is presented in Appendix E. The remolding and the Ucs test start from the water content around SL and proceeds up to Plastic state. The following is a summary of the UCS test results.

Table 4-5: Summary of UCS test result

Location	W%	LL%	WCR%	qu(Kpa)	Cu(Kpa)	Soil Type
Kechene	20.5	60	34.17	349.36	174.68	Disturbed
	22	60	36.67	319.92	159.96	
	25	60	41.67	278.80	139.40	
	27	60	45.00	250.10	125.05	
	30	60	50.00	184.64	92.32	
	32	60	53.33	171.28	85.64	
	34	60	56.67	146.68	73.34	
	36	60	60.00	111.02	55.51	
	38	60	63.33	88.06	44.03	
Rufael	40	60	66.67	71.12	35.56	Disturbed
	19	53	35.85	485.12	242.56	
	22	53	41.51	450.04	225.02	
	25	53	47.17	346.60	173.30	
	28	53	52.83	307.80	153.90	
	30	53	56.60	263.68	131.84	
	33	53	62.26	240.22	120.11	
	35	53	66.04	195.22	97.61	
	38	53	71.70	166.52	83.26	
Addisu Gebeya	40	53	75.47	144.04	72.02	Disturbed
	42	53	79.25	126.48	63.24	
	18	69	26.09	363.42	181.71	
	20	69	28.99	328.32	164.16	
	23	69	33.33	280.84	140.42	
	25	69	36.23	250.10	125.05	
	27	69	39.13	201.08	100.54	
	30	69	43.48	160.20	80.10	
	33	69	47.83	121.36	60.68	
British Embassy	35	69	50.72	91.38	45.69	Disturbed
	38	69	55.07	73.86	36.93	
	40	69	57.97	61.32	30.66	
	21	54	38.89	344.54	172.27	
	23	54	42.59	324.62	162.31	
	26	54	48.15	266.68	133.34	
	28	54	51.85	219.24	109.62	
	30	54	55.56	208.68	104.34	
	32	54	59.26	190.90	95.45	
34	54	62.96	169.84	84.92		
37	54	68.52	140.28	70.14		
39	54	72.22	121.30	60.65		
42	54	77.78	101.78	50.89		

4.6 DISCUSSION ON LABOATORY TEST RESULTS

Soil samples were collected from known areas of Addis Ababa where red clay soil is found. The laboratory tests were done on four different sites. The detail discussions of laboratory test results are presented below.

4.6.1 Soil classification according to USCS of the study areas

The basis for Unified Soil Classification System (USCS) is Liquid Limit and Plasticity Index of a soil. An “A-line” which is defined by an equation (i.e. $0.73*(LL-20)$) separates the ‘MH or OH’ and the ‘CH or OH’ designation. In USCS MH means elastic silt, CH means inorganic clay of high plasticity and OH means organic clay or silt.

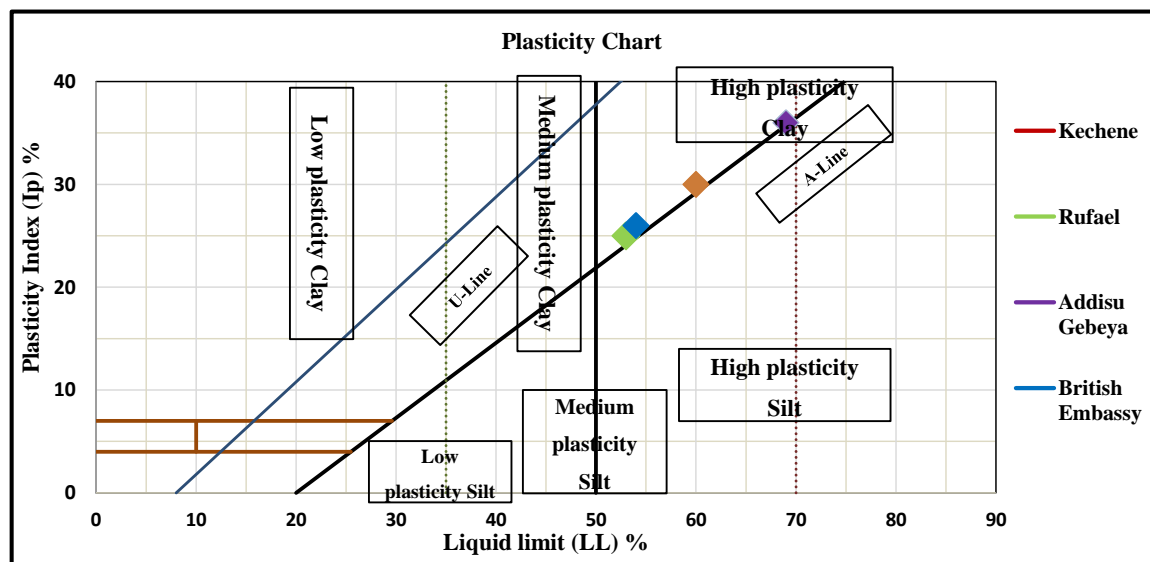


Figure 4-1: Plasticity chart of the study area

According to this classification scheme the soil of the study areas falls in CH/OH region, which shows that the soil is inorganic clay of highly plastic (CH).

4.6.2 Classifications based on activity number

The significant change in volume of a clay soil during shrinking or swelling is related to both the plasticity index and the quantity of colloidal clay particles present in the soil [24]. Clay soil can be categorized as inactive, normal, or active and is used to calculate swelling potential of a given class. In terms of potential expansiveness soils with activity less than 0.75 are inactive, 0.75-1.25 normal and those with greater than 1.25 are active or highly expansive [25]. Using Line, A Chart the activity of clay is expressed as:

$$\text{Activity } A = (\text{Plasticity index (PI)}) / (\text{Percent finer than 2 micron})$$

Location	plasticity index	Clay	Activity
Kechene Medhaniyalem	30.00	52.30	0.57
Rufael	25.00	87.90	0.28
Addisu Gebyea	36.00	85.00	0.42
British Embassy	26.00	86.40	0.30

Table 4-6: Activity and degree of activity

Based on activity number the soil in the study areas are non-expansive or inactive. These values are presented in the form of chart, which is called Activity Chart, and the soil of the study areas are compared to the values and it falls in the range of inactive clay.

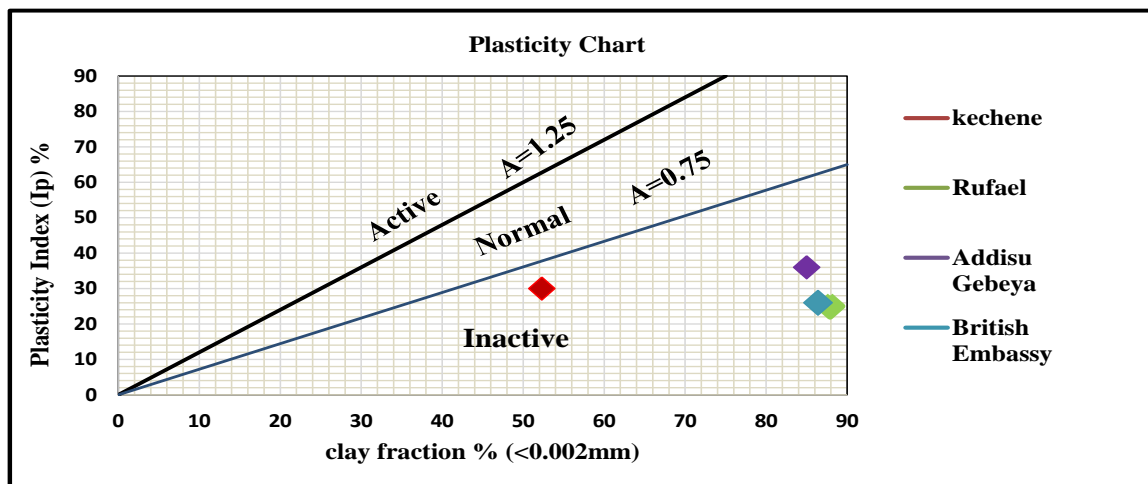


Figure 4-2: Activity chart of the study area

According to this classification scheme the soil of the study areas non- expansive (inactive nature).

4.6.3 Standard compaction

Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. In this thesis standard compaction according to method A was done for all the four sites. Hence, the prepared samples are weighted and sieved on #4 sieve and the amount of soil retained on sieve number 4 is less than 20%. The soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops with a volume of about 944 cm³.

Table 4.7 Alternative proctor test methods

	Standard proctor ASTM698		
	Method A	Method B	Method C
Material	≤20%Retained on No.4 Sieve	>20% Retained on No.4 ≤ 20%Retained on	>20%Retained on 3/8” < 30%Retained on 3/4” Sieve
For test sample, use soil passing	Sieve No.4	3/8” Sieve	3/4” Sieve
Mold size	4”	4”	6”
No. of Layers	3	3	3
No. of blows/layer	25	25	56

To identify the dry densities for each soil that correspond to the water content levels within the shrinkage limit and above plastic limit range, the Standard Compaction test was carried out. By multiplying the bulk density with the volume of the specimen, the mass of the soil that is to be remolded was methodically determined using the dry density obtained from compaction and its corresponding water content. Appendix D contains the tables and graphs for the standard compaction test.

4.6.4 Unconfined compression strength test

The unconfined compression strength of soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in simple compression test. It used to calculate the unconsolidated undrained shear strength of the soil under unconfined conditions.

The choice between total and effective stress analysis depends on the load application, which is by considering and comparing the soil response during and after construction, after construction effective stresses or shear strength increased due to excess pore pressures dissipated as of the soil consolidated. Thus, the immediate total stress response of the soil during construction is most critical. This is the justification for the use of quick undrained shear strength tests rather than effective stress analysis for foundation design.

To measure the resistance of the soil by compressibility or shearing deformation, UCS test gives the shear strength of the soil that is useful parameters for computing safe bearing capacity of soil as well as strength of soil. The undrained shear strength is

necessary for the determination of the bearing capacity of foundations, dams, etc. It is basically equal to the cohesion, hence the soil angle of internal friction zero; undrained conditions represent the most critical condition for the soil usually occurs immediately after construction.

Different authors have investigated the shear strength of red clay soil in Addis Ababa. Haile Mariam (1992) stated that unconfined compressive strength of Addis Ababa is 89 KN/m^2 . and undrained shear strength is 45 KN/m^2 at an average moisture content of 29% and the unconfined compressive strength ranges between 49-250 kPa with moisture of 22-34 %. Sisay (2005) explained the unconfined compressive strength of red clay samples collected from Kolfe area were in the range of 127-317 kPa. Soressa (2016) states that UCS values for sample collected from Bethel area range from 429.28 – 440.99 kPa at 3m depth below the ground respectively.

In this study a total of 40 UCS tests were conducted for each type of soil sample the tests were conducted at 10 levels of water content to determine undrained shear strength of the soil. From summary of UCS test result in table 4.5 and from the previous studies it is clearly observed that the unconfined compressive strength values differ from site to site. The difference may be due to initial moisture content, compaction density, type and properties of the soil, testing method, sampling time and depth also affects the result obtained from tests.

In performing unconfined compression strength test, the clay sample fails in one of two ways. A unique failure plane emerges in stiffer clays. The measurement of a peak followed by a decrease in load is likely to reveal the point of failure for this sort of failure. Softer clays are more prone to "barreling" failure. A discrete failure plane does not appear in this sort of failure; instead, the sample bulges in the center.

As a result, different failure features emerged during and after the UCS test. The failure pattern seen in red clay soil samples collected from selected locations for this study indicates that the samples are stiff clay soil. However, failure evolved differently in specimens with variable moisture content. Single diagonal and localized bulging were observed for the moisture content at shrinkage limit and above plastic limit respectively.

CHAPTER 5 CORRELATION AND ANALYSIS

5.1 General

Finding the strength of a linear or nonlinear link between two continuous variables and interpreting the findings are the goals of correlation analysis. The scatter plot and regression analysis are presented here to show how two variables relate to one another.

In these analysis approaches, undrained shear strength measurements are typically considered as dependent variables whereas WCR values are treated as independent variables.

Table 5-1: Variables in the research

Dependent Variable	Independent Variable	Extraneous variable	Control Variable	Control methods	Continuous variable	Discrete Variable
Undrained Shear Strength	Water content ratio	Temperature	Liquid Limit	Carefully following standardized procedures	Temperature	Number of data points
		Experimentation error		obtaining different tests to see if they give similar results	LL, SL and WCR	Number of test pit
		Interpretation error	Water Content	Keeping the environment as natural as possible	Cu	Number of soil samples

5.2 Scatter Plot

The scatter plot, correlation, and regression are calculated using an MS Excel spreadsheet during the statistical analysis. Each correlation's best fit curve is chosen, with the one having the highest R^2 value. Undrained shear strength, water content, and liquid limit were among the parameters taken into account throughout the analysis. The major source of all the test results used in this study is direct laboratory testing, and all

the data gathered were used to examine the relationship between undrained shear strength and water content ratio.

5.3 Regression Analysis

A statistical method for modeling and examining the relationship between two or more variables is regression analysis. In order to solve many technical and scientific challenges, it is often necessary to examine and use the relationships between two or more variables. Depending on the trend that may exist between the dependent and independent variables, regression analysis may take the form of a linear, parabolic, logarithmic, etc. graph.

Depending on how many variables are present in the system, regression analysis is either single regression or multiple regression analysis. Single regression models are those that only have one independent variable or regressor.

Dependent variable or response refers to a variable whose value is anticipated. Independent or regressor variables are those that are used to forecast the value of the dependent variable (s). Calculating the decrease in the sum of squared deviations that can be assigned to regressor variables and this quantity is known as the coefficient of determination, or R^2 . It is a practical technique to assess how well the regression model performs as a predictor of the dependent variable. R is a constant between -1 and +1, hence the value of R^2 is always between 0 and 1.

5.4 Single regression analysis

In order to analyze the relation formed between undrained shear strength and water content ratio, the first step in creating correlations is the generation of a scatter plot using an Excel spreadsheet. Using a Microsoft Excel spreadsheet, a single correlation data set is plotted in the best fit graph (linear, semi-log, or log-log) to determine the best model equation.

In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points (Taylor, 1990). According to the values of R^2 , the relationship between any two parameters can be classified as ($R^2 < 0.30$) are

considered to have no correlation, (R^2 of 0.30 to 0.499) are considered to be a mild relationship, (R^2 of 0.50 to 0.699) are considered to be a moderate relationship and (R^2 of 0.70 to 1.0) are considered to be a strong relationship.

In the analysis secondary data were used to make the empirical equation more accurate. Atari 1, Atari2 and Addis Ketema sites were included from thesis document Anteneh Getachewu (2012) in his thesis he use Ucs test to conduct shear strength of red clay soil. The degree of saturation for the selected soil samples are above 95%. Degrees of saturation of selected sites including Anteneh Getachewu are presented in Table 5.1.

Location	water content %	Saturation(%)	C_u
kechene	32	98	85.64
	34	98	73.34
	36	98	55.51
	38	95	44.03
Rufael	33	96	120.11
	35	98	97.61
	38	98	83.26
	40	98	72.02
	42	99	63.24
Addisu Gebeya	33	95	60.68
	35	97	37.94
	38	96	36.93
	40	94	30.66
British Embassy	34	94	84.92
	37	94	70.14
	39	94	60.65
	42	95	50.89
Atari1	29.2	95.68	108.26
Atari2	30.2	95.91	181.27

Table 5-1: Degree of Saturation for the selected soil sample

Table 5-2: Physical properties and shear strength of red clay soil in selected location of Addis Ababa city for saturated soil.

Location	Water content%	LL	WCR	C_u
kechene	32	60	53.33	85.64
	34		56.67	73.34
	36		60.00	55.51
	38		63.33	44.03
Rufael	33	53	62.26	120.11
	35		66.04	97.61
	38		71.70	83.26
	40		75.47	72.02
	42		79.25	63.24
Addisu Gebeya	33	69	47.83	60.68
	35		50.72	37.94
	38		55.07	36.93
	40		57.97	30.66
British Embassy	34	54	62.96	84.92
	37		68.52	70.14
	39		72.22	60.65
	42		77.78	50.89
Atari1	29.2	70.3	41.54	108.26
Atari2	30.2	66	45.76	181.27
Addis Ketema	32.5	60	54.17	222.92

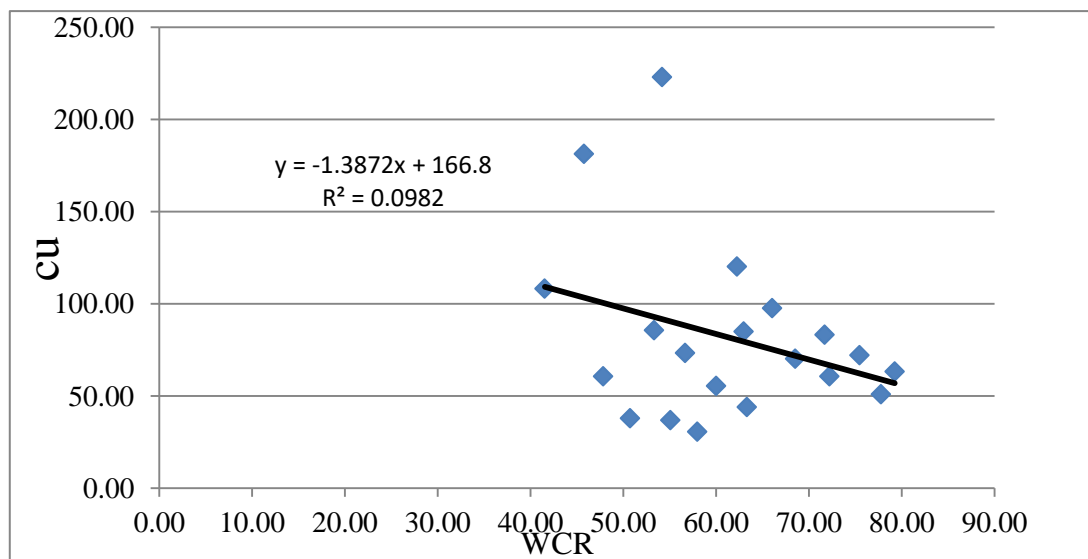


Figure 5-1: Water content ratio versus Shear strength curve for saturated soil sample

Figure 5.1 gives a plot between WCR and undrained shear strength for the selected sites of Addis Ababa saturated red clay soil. Their liquid limits varied from 53 to 70 %. A statistical fit to the experimental data gives equation $y = -1.3872x + 166.8$ with correlation coefficient of 0.0982. The correlation findings of the analysis are presented and analyzed. The results were shown using the best fitting method while taking account for the correlation coefficient (R^2). The purpose of applying this statistical technique is to develop a statistic known as the correlation coefficient, which is a summary value of a significant coefficient of regression indicating the strength of the linear link between two measured variables.

The area covered under unsaturated soil samples are the soil found in North, North West and Central part of Addis Ababa with degree of saturation is below 94%. Even though the selected sites are with in Addis Ababa city the sampling location are different but the clay are of the same geological origin. The liquid limit value varied from 53-69. The equations for determining suction values were obtained from Master's thesis work of Sinishawu. (2022) "soil-water characteristic curve for red clay soils of Addis Ababa" to conduct the relation between undrained shear strength and suction using Fredlund and Xing 1994 equation.

$$w(\psi) = c(\psi) \frac{w_s}{\{\ln[e + (\psi / a_f)^{n_f}]\}^{m_f}} \quad (5.5)$$

$$c(\psi) = 1 - \frac{\ln[1 + \psi / \psi_r]}{\ln[1 + 10^6 / \psi_r]} \quad (5.6)$$

w_s Saturated moisture content of soil

a_f Fitting parameter which is primarily a function of air-entry value of soil

n_f Fitting parameter which is primarily a function of the rate of water extraction from the soil once air-entry value has been exceeded,

m_f Fitting parameter which is primarily a function of residual water content

e is constant equal to 2.71828

$C(\psi)$ Correction factor which is primarily a function of suction corresponding to residual water content.

$w(\psi)$ Gravimetric Water Content to the Corresponding Matric Suction, %

ψ Matric Suction, kPa

Equation 5.5 and 5.6 are Fredlund and Xing(1994) model equations from this equation sinishawu estimated the following parameters

$$a_f = 375.33 - 368.03eo + 975.41(eo - 0.88)^2 + 645.19(eo - 0.88)^3$$

$$n_f = -14.73 + 0.84wPI + 0.01(wpl - 24.1)^2 - 0.003(wpl - 24.1)^3$$

$$m_f = 0.39 - 0.03 n_f + 0.004(n_f - 6.04)^2 - 0.0002 (n_f - 6.04)^3$$

$$\psi_r = 766596.78 + 3792.94PL + 170.07(PL - 34.24)^2 - 66.27 (PL - 34.24)^3$$

Using the above equations and parameters suction value for selected soil sample were obtained table 5.3 shows the suction value of four selected sites.

Table 5-3: suction value for selected soil samples

location	a_f (Kpa)	n_f	m_f	ψ_r (Kpa)
kechene	573.49	9.14	0.148	888493.8
Rufael	573.49	4.11	0.283	895522.88
Addisu Gebeya	565.74	11.93	0.13	892151.65
British Embassy	565.74	4.263	0.276	895522.88

Table 5-4: suction value for selected soil samples

for unsaturated soil sample			
	w	(ua-uw)	c_u
Kechene	20.5	230	174.68
	22	189	159.96
	25	130	139.4
	27	104	125.05
	30	76	92.32
Rufael	19	880	242.56
	22	692	225.02
	25	309	173.3
	28	151	153.9
	30	97	131.84
Addisu Gebeya	18	774	181.71
	20	647	164.16
	23	247	140.42
	25	139	125.05
	27	100	100.54
	30	77	80.1
British Embassy	21	646	172.27
	23	381	162.31
	26	186	133.34
	28	121	109.62
	30	82	104.34

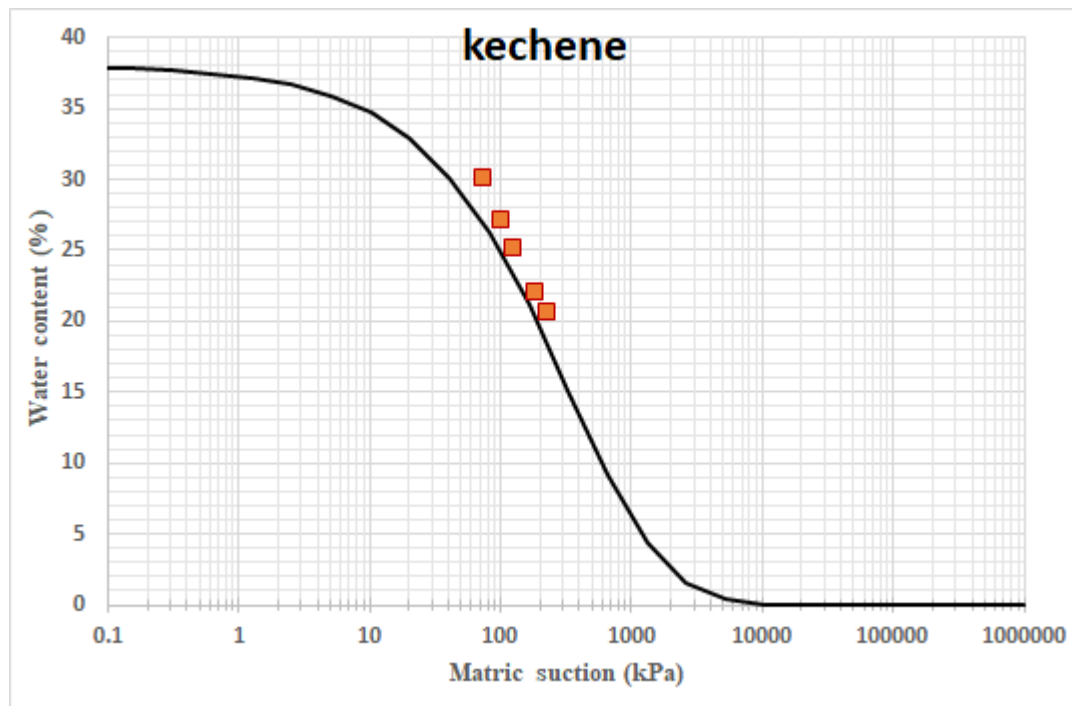


Figure 5-2 water content vs suction for kechene

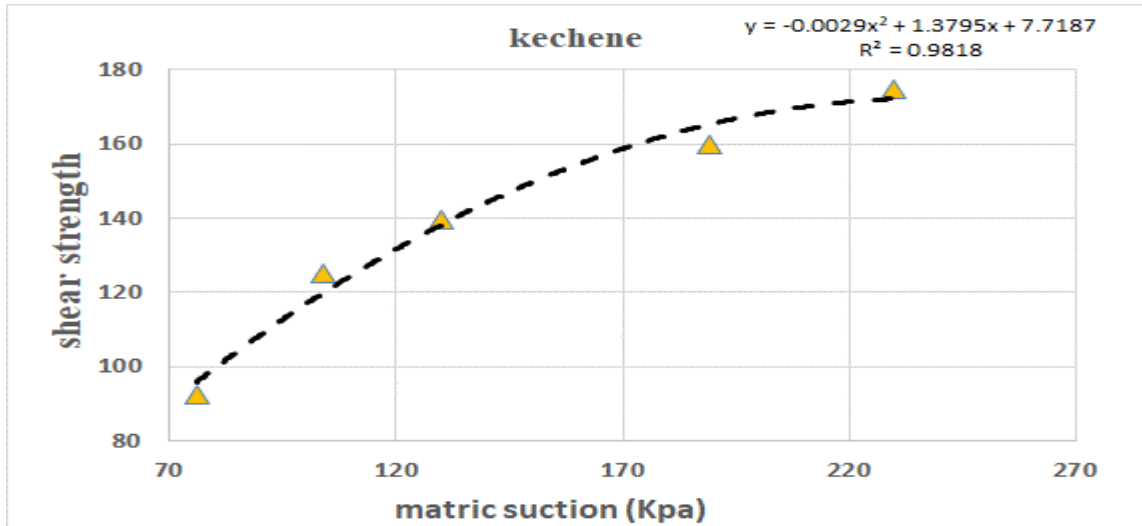


Figure 5-3 Undrained shear strength vs suction for kechene

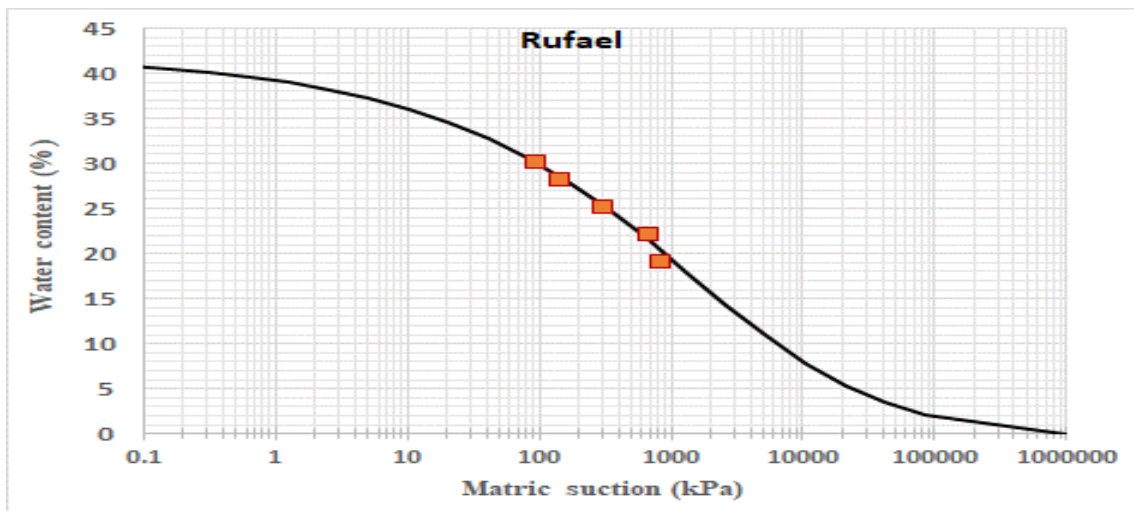


Figure 5-4 water content vs suction for Rufael

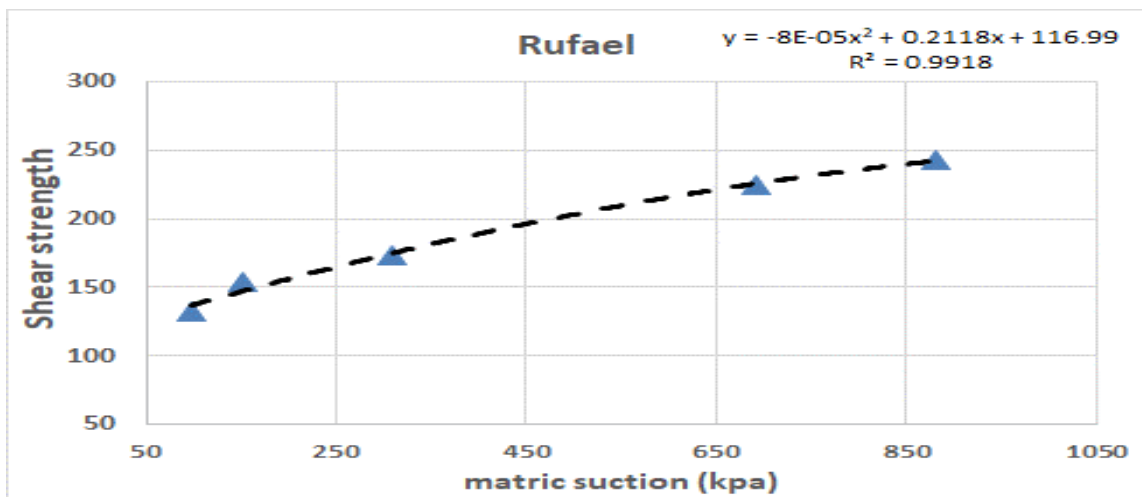


Figure 5-5 Undrained shear strength vs suction for Rufael

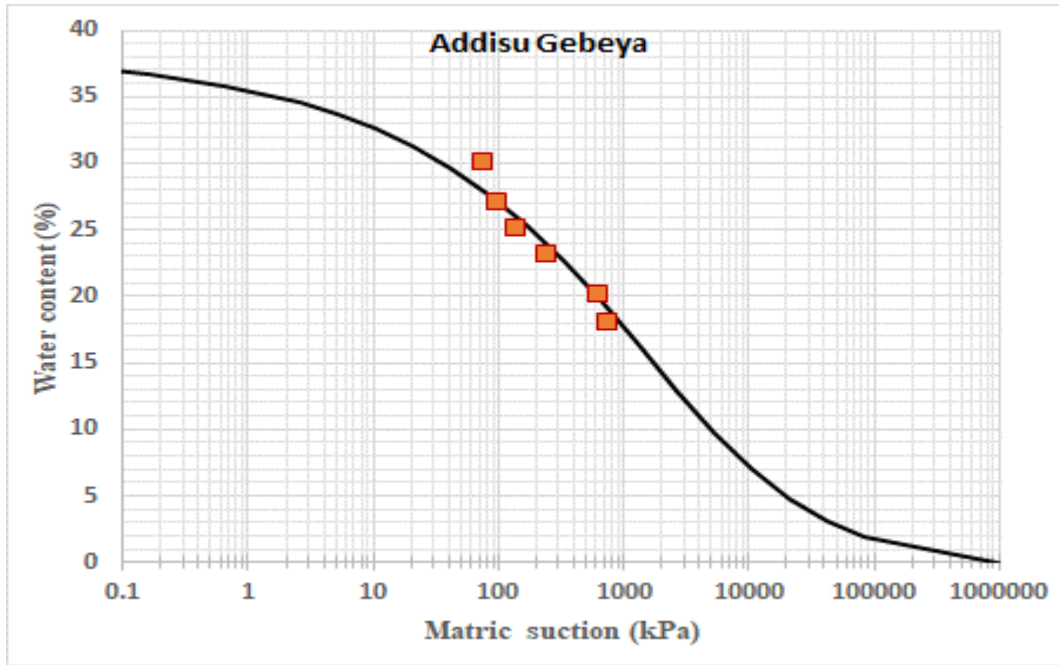


Figure 5-6 water content vs suction for Addisu Gebeya

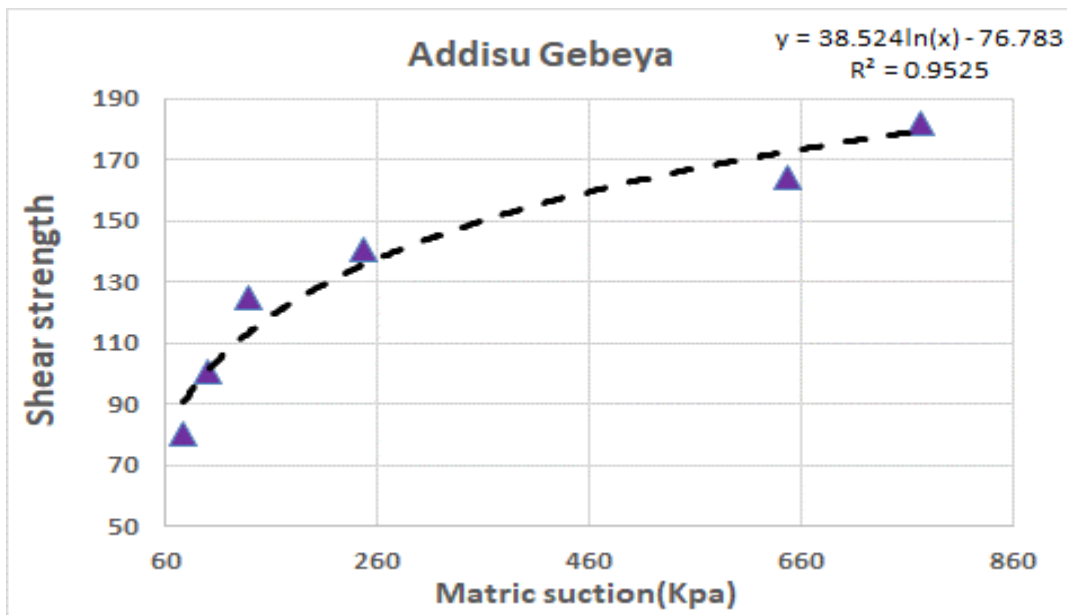


Figure 5-7 Undrained shear strength vs suction for Addisu Gebeya

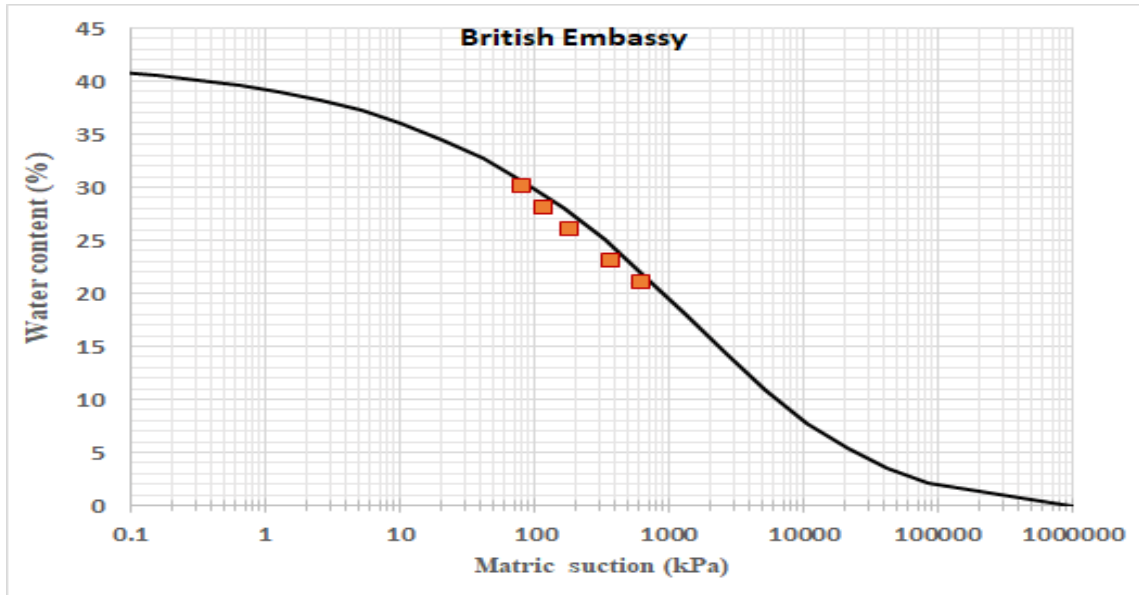


Figure 5-8 water content vs suction for British Embassy

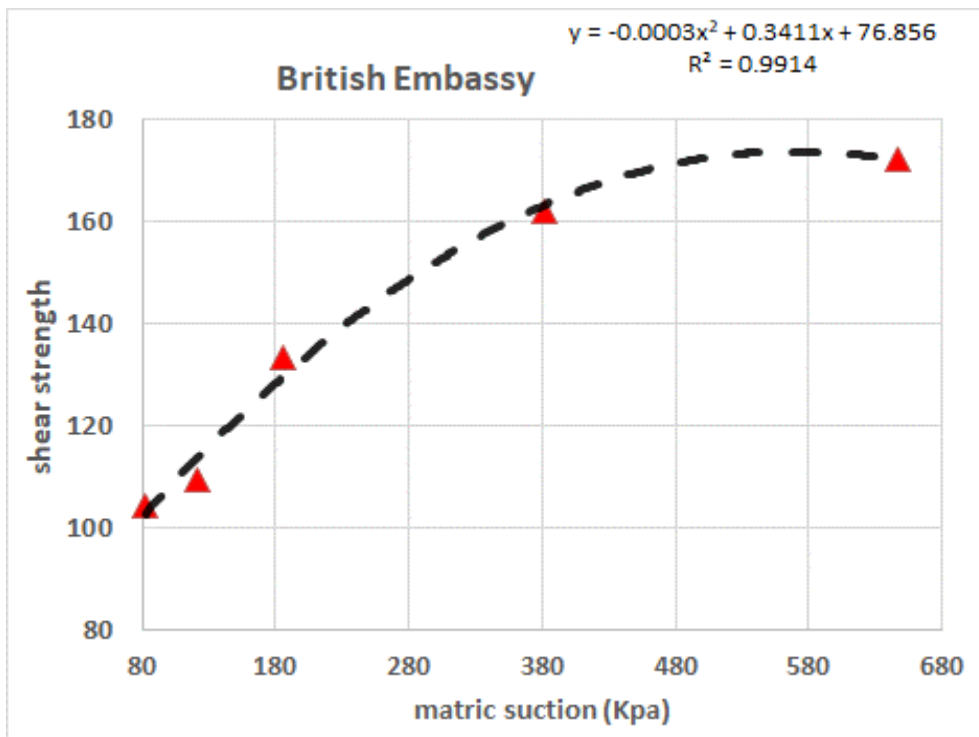


Figure 5-9 Undrained shear strength vs suction for British Embassy

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

In this section, the main conclusions and observations are presented. This study looked for a suitable relationship between the Water content Ratio to Undrained shear strength. Based on the findings from the analysis of the study's discussion, the following conclusions are drawn.

6.1 Conclusions

- The soils of the chosen areas are categorized as clay with high plasticity based on visual observations and field tests. These soils can be classified as clay with a high plastic and firm consistency according to the classification criteria for indices. According to activity number, the soil in the studied areas is non-expanding or inactive, and the soil in the chosen locations is classed as CH (inorganic clay with high plasticity) under the Unified Soil Classification System.
- The values of specific gravity ranges from 2.64 to 2.75, liquid limit ranges 46 to 72 %, plastic limit ranges 28% to 33%, and Shrinkage limit ranges 18.7% to 20.2%. These values are within the same ranges of the red clay soils of previous studies.
- According to grain size analysis, more than 90% of the total masses pass through a sieve with a size of 75 μm . As a result, it can be concluded that practically all soils are fine-grained soils.
- The value of undrained shear strength of the selected soil samples around semi solid (shrinkage limit) is higher than the soil sample around plastic state and during Ucs test. The failure pattern was compression (bulging) and failure near in shear at ultimate stress for around plastic state and semi solid state respectively.
- The correlation coefficient between undrained shear strength and water content ratio including secondary data from Antheneh Getachewu thesis document were conducted
- The relation between undrained shear strength and suction value were obtained by using the proposed model of Fredlund and Xing(1994) model equation and sinishawu estimated parameters.

6.2 Recommendations

Here are a few suggestions in regard to the subject of study:

- This study considered a correlation between Undrained shear strength (C_u) and water content ratio (WCR) for saturated red clay soils in some selected areas of Addis Ababa city with the addition of secondary data from previous studies. Further research should be conducted in different areas with other types of soil.
- The relation between Undrained shear strength (C_u) and suction value that is obtained from proposed model were estimated for unsaturated red clay soils in some selected areas of Addis Ababa city on different densities. Further research should be conducted by considering the effect of density on SWCC.
- The accuracy of developed equations for undrained shear strength may be further modified by taking many soil samples and decreasing expected errors during sampling and testing time.

REFERENCES

- [1] **Atsbeha Nerea, (2012)**, “Prediction of compaction characteristics from Atterberg limits for fine-grained soils.”
- [2] **Anteneh Getachewu, (2012)**, “correlating Dynamic cone penetration index with undrained shear strength of clayey soils.”
- [3] **Braja M.Das.2016**. “Soil mechanics laboratory manual.”
- [4] **Cernica, John N. (1995)**. “Geotechnical Engineering: Soil mechanics”. John Willey and Sons, Inc., USA.
- [5] **Conduto, D.P, (2001)**. “Foundation Design Principles and Practices”. Prentice-Hall, New Jersey.
- [6] **Das, B., Taylor and Francis, United State of America, (1997)**, “Advanced Soil mechanics”, Second edition,
- [7] **Dereje, Megersa. (2017)**, “Correlation between undrained shear strength,swelling pressure and standard penetration test with liquidity index.”
- [8] **Dr K. R. Arora, (2004)**, “Soil Mechanics and Foundation Engineering.”
- [9] **Dr P. J. Vardanega and Dr S. K. Haigh, (2014)**, “The undrained strength – liquidity index relationship.” Can. Geotech J. 51:9, 1073-1086.
- [10] **Dunn IS, Anderson LR, Kiefer FW**, “Fundamentals of Geotechnical Analysis. New York, United states of America: John Wiley & Sons; 1980. 414 p”.
- [11] **Giovanni, Spagnoli and Martin Feinendegen(2017)**, “Relationship between measured plastic limit and plastic limit estimated from undrained shear strength, water content ratio and liquidity index.”
- [12] **Giovanni, Spagnolin. (2019)**.”Some relations among fall cone penetration, Liquidity index and undrained shear strength of clays considering the sensitivity ratio.”

- [13] **Haigh S. K., Vardanega P. J. and Bolton M. D. (2013)**, “The plastic limit of clays.” *Geotechnique* 63, 435-440.
- [14] **Joseph E. Bowels, (1988)**, “Foundation Analysis and Design.” Fifth Edition.
- [15] **Jara Mengistu.(2017)**, "Correlating Liquidity Index with vane-shear strength of Clays in Addis Ababa" [Report].
- [16] **Kayabali K. and Tufenkci O. (2010)**, “Undrained Shear Strength of Remolded Soils at Consistency Limits.” *Can. Geotech J.*, 47(3):b259-266.
- [17] **Kangetal and Tsuchida. (2017)**,“Consistency measurement of cement-treated marine clay using fall cone test and Casagrande liquid limit test.”
- [18] **Kim Borden. (2012)**, “Influence of soil type and stress state on predicting shear strength of unsaturated soils using the soil-water characteristic curve.”
- [19] **Kuriakose, Jose. (2017)**. “Water Content Ratio: An Effective Substitute for Liquidity Index for Prediction of Shear Strength of Clays.”
- [20] **Nagraj, T.S &Jayadeva, M.S (1981)**, “Re-examination of one point methods of liquid limit determination.”
- [21] **O’Kelly, B. C. (2013)**, “Atterberg limits and remolded strength-water content relationships.”*Geotechnical Testing Journal*,(36&6), 939-947.
- [22] **Rabia Hussien (2018)**, “Effect of Strain rate on Undrained Shear Strength and sensitivity of Red clay soil found in Addis Ababa”
- [23] **Samuel, T. (1989)**, “Investigation in to some Engineering Properties of Addis Ababa Red clay soil”. A thesis presented to School of Graduate Study, Addis Ababa University
- [24] **Satoru Shimobe,Giovanni.(2020)**,“Relationships between undrained shear strength, liquidity index and water content ratio of clays.”
- [25] **Sinishawu Shaweno.(2022)**,“Soil-Water Charactrestics of red clay soil of Addis Ababa.”

[26] **Sharma, B. and Bora, P. K., (2003)**, “Plastic limit, liquid limit and Undrained Shear Strength of Soil-reappraisal.” J. Geotechnical and Geoenvironmental Engineering, ASCE, 129(8)

[27] **Skempton, A.W., and D.J. Petley. (1967)**,“The strength along structural discontinuities in stiff clays”, Proc. Geotechnical Conference, Oslo, Norway, Vol. 2, 29-46.

[28] **Teferra, A., and M. Leikun. (1999)**, “Soil Mechanics”, Addis Ababa University Press, AA.


[29] **Won Taek Oh* and Sai Vanapalli (2018)**, “Undrained Shear Strength of Unsaturated Soils under Zero or Low Confining Pressures in the Vadose Zone”, Addis Ababa University Press, AA.

[30] **Wroth, C. P., and Wood, D. M., (1978)**, “The correlation of index properties with some basic engineering properties of soils.” Can Geotech J., 15(2), 137-145.

[31] **Youssef, M. F., El Ramli, A. H., and El Demery M. (1965)**, “Relationships between shear strength, consolidation, liquid limit and plastic limit for remolded clays.” Proc. 6th Int. Conf. Soil Mech. Found. Eng., Montreal, 1, 126-12.

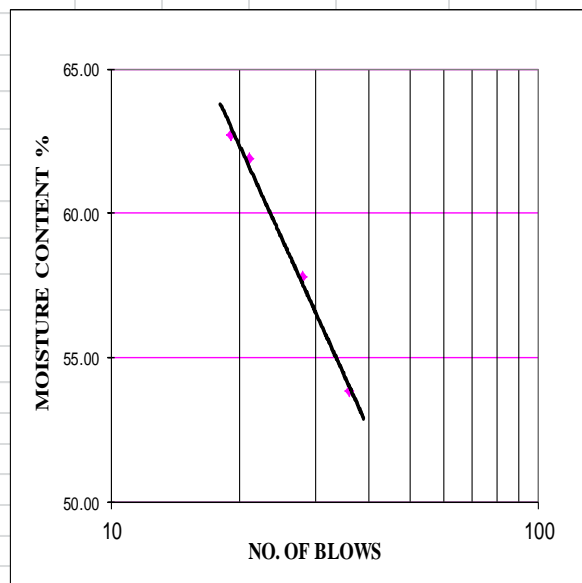
Appendices


Appendix A: Method of Computation for Atterberg Limits

 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY አዲስ አበባ ቴክኖሎጂ ሳ.ገ.ቤ.ት ADDIS ABABA UNIVERSITY አዲስ አበባ ዩኒቨርሲቲ</small>	Addis Ababa Institute of Technology Civil Engineering Department Geotechnical Laboratory Atterberg Limits ASTM D4318-10	
	Project Name: <u>Geotechnical investigation program</u> Location: <u>Kechene</u> Sample Depth: <u>3m</u>	Tested By: <u>Tigist Gemechu</u> Date: <u>15/03/22</u> Sample Type: <u>Disturbed Sample</u>

TEST			LIQUID LIMIT				PLASTIC LIMIT			
Variable	NO		1	2	3	4	1	2	3	4
	Var.	Units								
Number of Blows	N	blows	19	21	28	36				
Can Name	---	---	A8	AG4	D17	CD2	D19	D20	D21	D22
Mass of Empty Can	M _C	(g)	15.90	16.00	15.00	15.50	15.80	15.70	15.80	14.70
Mass Can & Soil (Wet)	M _{CMS}	(g)	25.50	22.80	25.10	23.50	20.20	19.00	19.40	18.70
Mass Can & Soil (Dry)	M _{CDS}	(g)	21.80	20.20	21.40	20.70	19.20	18.20	18.20	17.70
Mass of Soil	M _S	(g)	5.90	4.20	6.40	5.20	3.40	2.50	4.20	3.00
Mass of Water	M _W	(g)	3.70	2.60	3.70	2.80	1.00	0.80	1.20	1.00
Water Content	w	(%)	62.7	61.9	57.8	53.8	29.4	32.0	28.6	33.3
									30.8	

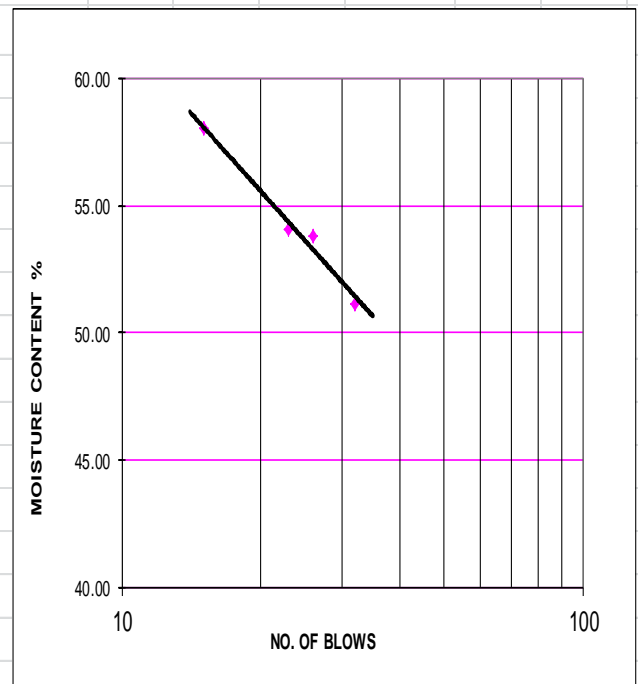
Liquid Limit (LL or w_L) (%):	60
Plastic Limit (PL or w_P) (%):	30
Plasticity Index (PI) (%):	30
USCS Classification:	CH




 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ቴክኖሎጂ ኢንስቲትዩት</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>	Addis Ababa Institute of Technology Civil Engineering Department Geotechnical Laboratory Atterberg Limits ASTM D4318-10	
	Project Name: <u>Geotechnical investigation program</u>	Tested By: <u>Tigist Gemechu</u>
	Location: <u>Rufael</u>	Date: <u>16/03/22</u>
	Boring No: <u>1</u>	Test Number: <u>1</u>
Sample Depth: <u>3m</u>	Sample Type: <u>Disturbed Sample</u>	

Number of Blows	N	blows	15	23	26	32				
Can Name	---	---	APL2	D13	E18	E16	E17	E18	E19	E20
Mass of Empty Can	M_C	(g)	15.97	15.80	15.80	15.90	14.60	15.80	13.90	15.00
Mass Can & Soil (Wet)	M_{CMS}	(g)	26.18	25.20	23.80	28.90	19.10	20.60	18.10	19.70
Mass Can & Soil (Dry)	M_{CDS}	(g)	22.43	21.90	21.00	24.50	18.10	19.60	17.20	18.60
Mass of Soil	M_S	(g)	6.46	6.10	5.20	8.60	3.50	3.80	3.30	3.60
Mass of Water	M_W	(g)	3.75	3.30	2.80	4.40	1.00	1.00	0.90	1.10
Water Content	w	(%)	58.0	54.1	53.8	51.2	28.6	26.3	27.3	30.6
									28.2	

Liquid Limit (LL or w_L) (%):	53
Plastic Limit (PL or w_p) (%):	28
Plasticity Index (PI) (%):	25
USCS Classification:	CH

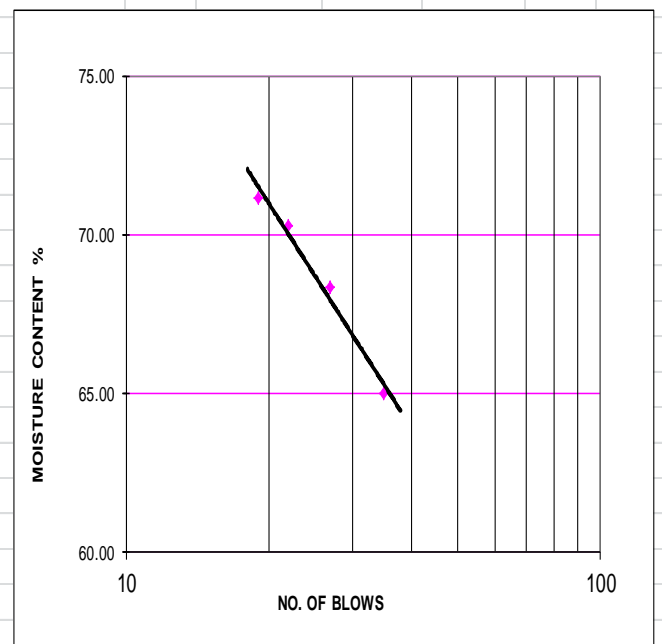



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ቴክኖሎጂ ሲቪል ሲንጅሎጅ</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>	Addis Ababa Institute of Technology Civil Engineering Department Geotechnical Laboratory	
	Atterberg Limits ASTM D4318-10	
Project Name:	<u>Geotechnical investigation program</u>	Tested By: <u>Tigist Gemechu</u>
Location:	<u>Addisu Gebeya</u>	Date: <u>17/03/22</u>
Sample Depth:	<u>3m</u>	Sample Type: <u>Disturbed Sample</u>

TEST			LIQUID LIMIT				PLASTIC LIMIT			
Variable	NO		1	2	3	4	1	2	3	4
	Var.	Units								
Number of Blows	N	blows	19	22	27	35				
Can Name	---	---	P23	A3	D16	A2	A5	A6	A7	A8
Mass of Empty Can	M_C	(g)	15.90	15.80	15.60	15.50	16.00	15.40	13.40	15.90
Mass Can & Soil (Wet)	M_{CMS}	(g)	24.80	28.40	25.70	25.40	21.40	20.10	19.00	20.50
Mass Can & Soil (Dry)	M_{CDS}	(g)	21.10	23.20	21.60	21.50	20.13	18.91	17.65	19.33
Mass of Soil	M_S	(g)	5.20	7.40	6.00	6.00	4.13	3.51	4.20	3.43
Mass of Water	M_W	(g)	3.70	5.20	4.10	3.90	1.27	1.19	1.35	1.17
Water Content	w	(%)	71.2	70.3	68.3	65.0	30.8	33.9	32.1	34.1
							32.7			

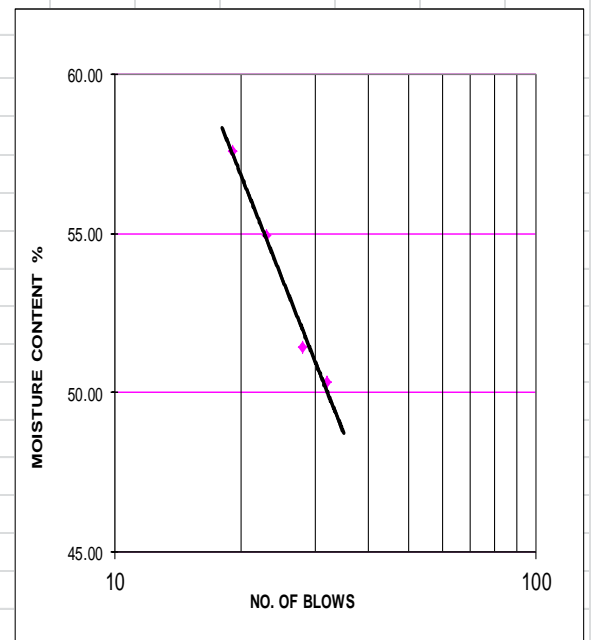
Liquid Limit (LL or w_L) (%):	69
Plastic Limit (PL or w_P) (%):	33
Plasticity Index (PI) (%):	36
USCS Classification:	CH





 AAiT ADDIS ABABA INSTITUTE OF TECHNOLOGY አዲስ አበባ ተክኖሎጂ ሲቨርስቲቲ ADDIS ABABA UNIVERSITY አዲስ አበባ ዩኒቨርሲቲ	Addis Ababa Institute of Technology
	Civil Engineering Department Geotechnical Laboratory
Atterberg Limits ASTM D4318-10	
Project Name: <u>Geotechnical investigation program</u>	Tested By: <u>Tigist Gemechu</u>
Location: <u>British Embassy</u>	Date: <u>18/03/22</u>
Sample Depth: <u>3m</u>	Sample Type: <u>Disturbed Sample</u>


TEST	NO		LIQUID LIMIT				PLASTIC LIMIT				
			1	2	3	4	1	2	3	4	
	Variable	Var.	Units								
Number of Blows	N	blows	19	23	28	32					
Can Name	---	---	D19	E17	D19	A5	C15	C16	C17	C18	
Mass of Empty Can	M _C	(g)	15.30	14.60	15.30	15.30	15.50	15.70	15.80	16.00	
Mass Can & Soil (Wet)	M _{CMS}	(g)	27.00	25.60	25.50	32.80	19.60	21.30	19.80	19.70	
Mass Can & Soil (Dry)	M _{CDS}	(g)	22.97	21.70	21.90	26.94	18.72	20.12	18.90	18.89	
Mass of Soil	M _S	(g)	7.00	7.10	7.00	11.64	3.22	4.42	3.10	2.89	
Mass of Water	M _W	(g)	4.03	3.90	3.60	5.86	0.88	1.18	0.90	0.81	
Water Content	w	(%)	57.6	54.9	51.4	50.3	27.3	26.7	29.0	28.0	
											27.8


Liquid Limit (LL or w_L) (%):	54
Plastic Limit (PL or w_P) (%):	28
Plasticity Index (PI) (%):	26
USCS Classification:	CH




 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ተገናኝ ሊቀ-ሰብሰብ</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>		Shrinkage Limit ASTM D422-63(2007)	
Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu
Location:	Kechene	Date	14/03/22
Sample Depth:	3m		
Determination No.		1	2
Dish No			
Mass of dish coated with petroleum jelly ,(g)		24.50	24.20
Mass of dish coated with petroleum jelly + wet pat,(g)		100.7	97.80
Mass of dish coated with petroleum + oven-dried soil pat,(g)		68.90	67.50
Mass of oven-dried soil sample,(g)		44.40	42.95
Mass of water in wet soil,(g)		31.80	30.30
Water content of wet soil pat		71.62	70.55
Volume of wet pat ,(cm ³)		46.73	45.78
Volume of oven-dried soil pat ,(cm ³)		24.00	23.90
Shrinkage limit,%		20.43	19.60
Average Shrinkage limit,%		20.02	


 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ተገናኝ ሊቀ-ሰብሰብ</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>		Shrinkage Limit ASTM D422-63(2007)	
Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu
Location:	Rufael	Date	15/03/22
Sample Depth:	3m		
Determination No.		1	2
Dish No			
Mass of dish coated with petroleum jelly ,(g)		24.50	24.20
Mass of dish coated with petroleum jelly + wet pat,(g)		95.4	94.20
Mass of dish coated with petroleum + oven-dried soil pat,(g)		64.20	62.80
Mass of oven-dried soil sample,(g)		39.45	38.60
Mass of water in wet soil,(g)		31.20	31.40
Water content of wet soil pat		79.09	81.35
Volume of wet pat ,(cm ³)		46.73	45.78
Volume of oven-dried soil pat ,(cm ³)		20.70	21.00
Shrinkage limit,%		17.62	19.73
Average Shrinkage limit,%		18.7	

 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ቴክኖሎጂ ሳ.ገ.ቤ.ት</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>		Shrinkage Limit ASTM D422-63(2007)			
Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu		
Location:	Addisu Gebeya	Date	13/03/22		
Sample Depth:	3m				
Determination No.				1	2
Mass of dish coated with petroleum jelly ,(g) w ₀ "				24.50	24.20
Mass of dish coated with petroleum jelly + wet pat,(g)				95.6	96.30
Mass of dish coated with petroleum + oven-dried soil pat,(g) w ₂ "				62.99	63.79
Mass of oven-dried soil sample,(g)				38.49	39.59
Mass of water in wet soil,(g)				32.61	32.51
Water content of wet soil pat w _i				84.72	82.12
Volume of wet pat ,(cm ³) V _i				46.73	45.78
Volume of oven-dried soil pat ,(cm ³) V _f				22.20	20.98
Shrinkage limit,% $w_i - ((v_i - v_f) / w_2 - w_0) * 100$				20.99	19.47
Average Shrinkage limit,% =					20.2


 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>አዲስ አበባ ቴክኖሎጂ ሳ.ገ.ቤ.ት</small> <small>ADDIS ABABA UNIVERSITY</small> <small>አዲስ አበባ ዩኒቨርሲቲ</small>		Shrinkage Limit ASTM D422-63(2007)			
Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu		
Location:	British Embassy	Date	16/03/22		
Sample Depth:	3m				
Determination No.				1	2
Dish No					
Mass of dish coated with petroleum jelly ,(g)				24.50	24.20
Mass of dish coated with petroleum jelly + wet pat,(g)				100	98.00
Mass of dish coated with petroleum + oven-dried soil pat,(g)				68.10	67.00
Mass of oven-dried soil sample,(g)				44.03	42.95
Mass of water in wet soil,(g)				31.90	31.00
Water content of wet soil pat				72.00	71.85
Volume of wet pat ,(cm ³)				46.73	45.78
Volume of oven-dried soil pat ,(cm ³)				23.89	23.00
Shrinkage limit,%				19.61	18.81
Average Shrinkage limit,%					19.2


Appendix B Specific gravity determination

		Specific Gravity			
Project	Geotechnical Investigation Program				
location	Kechene				
depth	3m				
					
[A] Calibration of pycnometer					
Pycnometer No.				A	B
Weight of dry, clean pycnometer, w1				58.48	58.48
Weight of pycnometer + water, m4				159.39	159.39
Observed temperature of water, T _i (oc)				22	22
[B] Specific Gravity Determination					
Determination No.				1	2
Weight of Pycnometer + dry soil , m2				83.48	83.48
Weight of pycnometer + soil + water, m3				175.01	174.81
Specific gravity of soil $GS=(m2-m1)/(m2-m1)+(m4-m3)$				2.67	2.61
Average specific gravity of soil .					2.64


		Specific Gravity			
Project	Geotechnical Investigation Program				
location	Rufael				
boring number	1				
depth	3m				
					
[A] Calibration of pycnometer					
Pycnometer No.				A	B
Weight of dry, clean pycnometer, w1				64.19	64.19
Weight of pycnometer + water, m4				163.5	163.61
Observed temperature of water, T _i (oc)				22	22
[B] Specific Gravity Determination					
Determination No.				1	2
Weight of Pycnometer + dry soil , m2				88.71	88.69
Weight of pycnometer + soil + water, m3				179.13	178.89
Specific gravity of soil $GS=(m2-m1)/(m2-m1)+(m4-m3)$				2.76	2.66
Average specific gravity of soil .					2.71

Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

		Specific Gravity		
Project	Geotechnical Investigation Program			
location	Addisu Gebeya			
boring number	1			
depth	3m			
[A] Calibration of pycnometer				
Pycnometer No.			A	B
Weight of dry, clean pycnometer, w1			58.21	58.18
Weight of pycnometer + water, m4			159.12	158.86
Observed temperature of water, T _i (oc)			22	22
[B] Specific Gravity Determination				
Determination No.			1	2
Weight of Pycnometer + dry soil , m2			83.25	82.64
Weight of pycnometer + soil + water, m3			174.69	174.15
Specific gravity of soil $GS=(m2-m1)/(m2-m1)+(m4-m3)$			2.64	2.67
Average specific gravity of soil .				2.66

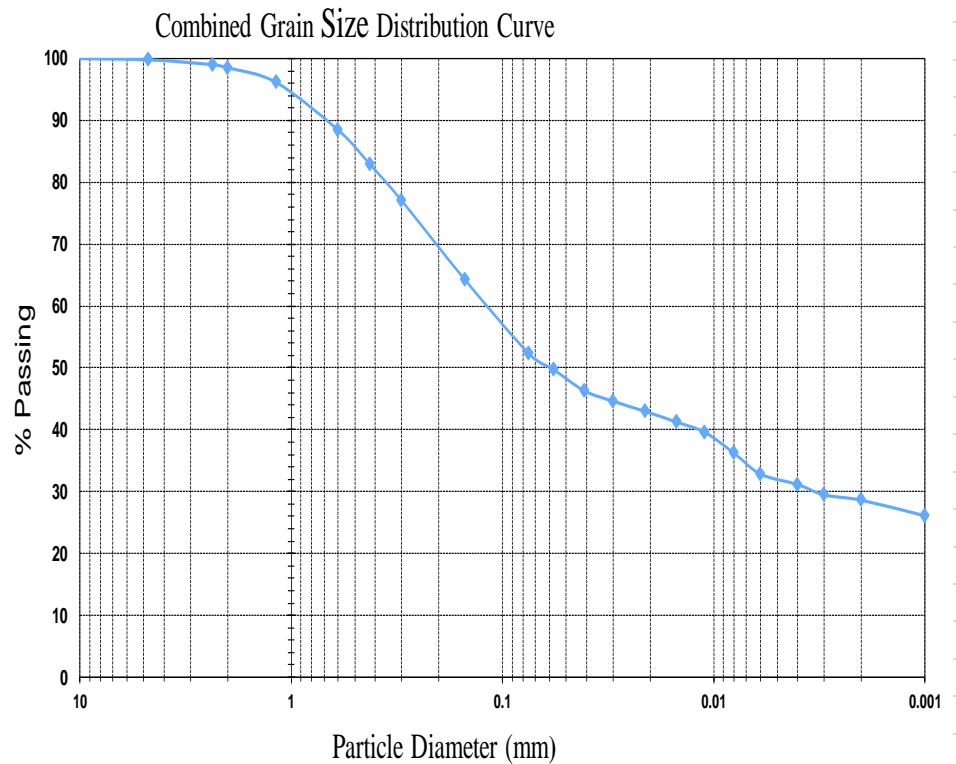
		Specific Gravity		
Project	Geotechnical Investigation Program			
location	British Embassy			
boring number	1			
depth	3m			
[A] Calibration of pycnometer				
Pycnometer No.			A	B
Weight of dry, clean pycnometer, w1			64.19	64.15
Weight of pycnometer + water, m4			163.5	163.61
Observed temperature of water, T _i (oc)			22	22
[B] Specific Gravity Determination				
Determination No.			1	2
Weight of Pycnometer + dry soil , m2			89.19	88.81
Weight of pycnometer + soil + water, m3			179.59	179.13
Specific gravity of soil $GS=(m2-m1)/(m2-m1)+(m4-m3)$			2.81	2.70
Average specific gravity of soil .				2.75

Appendix C Hydrometer and sieve analysis test result


	Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu
	Location:	Kechene	Date:	20/03/22
	Boring No:	1		CD= 2.5
	Sample Depth:	3m		SG=2.64

time (minute)	T	Actual hydrometer	correction	effective length mm	k value	D mm	CT	a	corrected hydrometer reading	%age remaining in the suspen	% passing
0.5	20	1.032	1.033	76	0.01369	0.057	0	1	1.0295	94.972	49.67
1	20	1.03	1.031	81	0.01369	0.041	0	1	1.0275	88.533	46.3
2	20	1.029	1.03	84	0.01369	0.03	0	1	1.0265	85.533	44.62
4	20	1.028	1.029	86	0.01369	0.0212	0	1	1.0255	82.094	42.94
8	20	1.027	1.028	89	0.01369	0.015	0	1	1.0245	78.875	41.25
15	20	1.026	1.027	92	0.01369	0.011	0	1	1.0235	75.656	39.57
30	20	1.024	1.025	97	0.01369	0.0082	0	1	1.0215	69.217	36.2
60	20	1.022	1.023	102	0.01369	0.006	0	1	1.0195	62.778	32.83
120	20	1.021	1.022	105	0.01369	0.004	0	1	1.0185	59.559	31.15
240	20	1.02	1.021	105	0.01369	0.003	0	1	1.0175	56.339	29.47
480	20	1.02	1.021	107	0.01369	0.002	0	1	1.017	54.73	28.62
1440	20	1.018	1.019	113	0.01369	0.001	0	1	1.0155	49.901	26.1

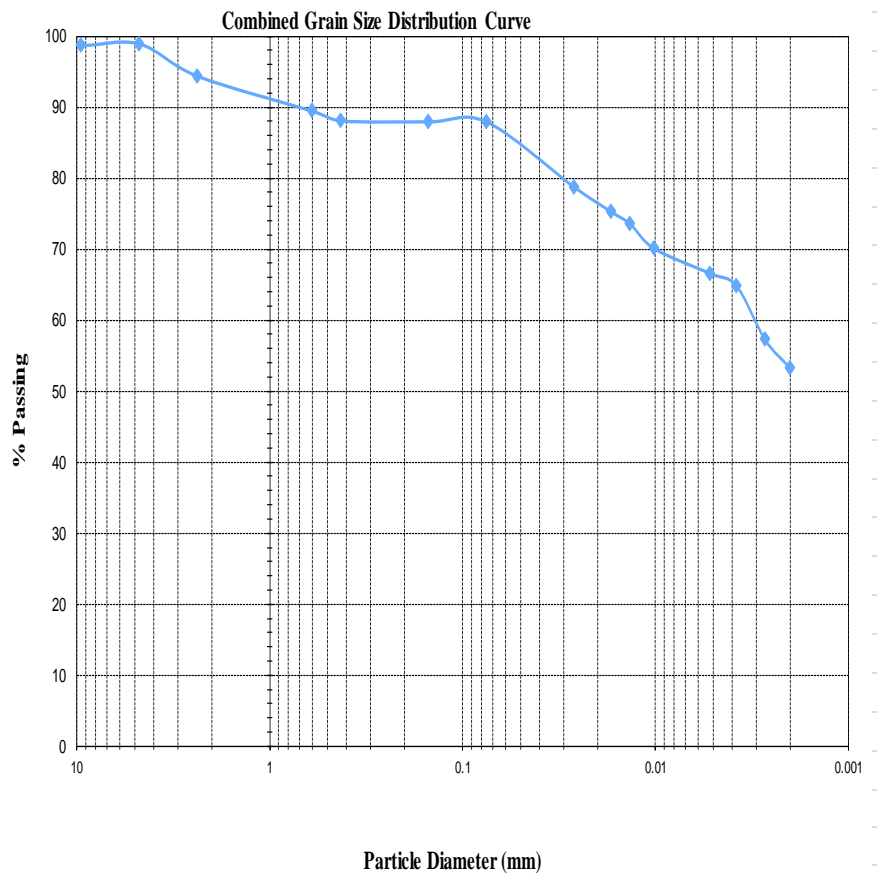
sieve sizes	% passing
19	100
12.5	100
4.75	99.78
2.36	98.99
2	98.5
1.18	96.13
0.6	88.42
0.425	82.92
0.3	77
0.15	64.16
0.075	52.3
0.057	49.67
0.041	46.3
0.03	44.62
0.021	42.94
0.015	41.25
0.011	39.57
0.008	36.2
0.006	32.83
0.004	31.15
0.003	29.47
0.002	28.62
0.001	26.1




Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

	Project Name:	Geotechnical Investigation Program		Tested By:	Tigist Gemechu						
	Location:	Rufael		Date:	21/03/22						
	Boring No:	1			CD=5						
	Sample Depth:	3m									
SG=2.71											
time (minute)	Tempratur	Actual hydrom	mensicus correc	effective depth	k value	D mm	CT	a	corrected hydrometer	%age remaining in the susper	%passing
2	22	1.031	1.032	81	0.01305	0.0263	0.4000	0.986	45.4	89.53	78.7
5	22	1.03	1.031	84	0.01305	0.0169	0.4000	0.986	43.4	85.58	75.23
8	22	1.029	1.03	86	0.01305	0.0135	0.4000	0.986	42.4	83.61	73.5
15	22	1.028	1.029	89	0.01305	0.0101	0.4000	0.986	40.4	79.67	70.03
60	22	1.027	1.028	92	0.01305	0.0052	0.4000	0.986	38.4	75.72	66.56
120	22	1.026	1.027	94	0.01305	0.0038	0.4000	0.986	37.4	73.75	64.83
240	22	1.024	1.025	100	0.01305	0.0027	0.4000	0.986	33.02	65.11	57.23
480	22	1.022	1.023	105	0.01305	0.0020	0.4000	0.986	30.7	60.54	53.22

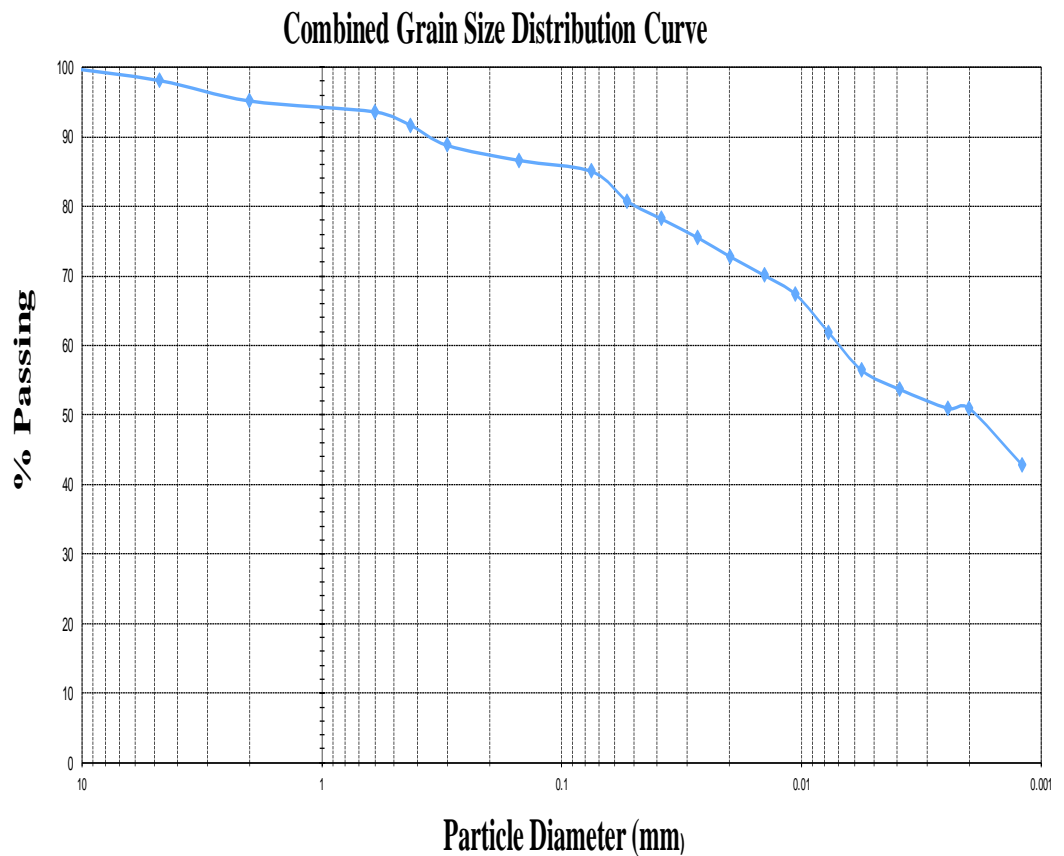
sieve sizes	%passing
9.5	98.63
4.750	98.9
2.360	94.33
0.600	89.42
0.425	88.05
0.150	87.92
0.075	87.91
0.0263	78.7
0.0169	75.23
0.0135	73.5
0.0101	70.03
0.0052	66.56
0.0038	64.83
0.0027	57.23
0.0020	53.22




Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

	Project Name:	Geotechnical Investigation Program			Tested By:	Tigist Gemechu					
	Location:	Addisu Gebeya			Date:	22/03/22					
	Boring No:	1									
	Sample Depth:	3m									
			SG= 2.66		CD =2.5						
time(minute)	Temperature	Actual hydrometer	correction for meniscus	effective length mm	k value	D mm	CT	a	corrected hydrometer	%age remaining	%passing
0.5	21	1.032	1.033	78	0.01348	0.0532	0.2	0.99	1.0297	94.972	80.73
1	21	1.031	1.032	81	0.01348	0.0384	0.2	0.99	1.0287	91.978	78.18
2	21	1.03	1.031	84	0.01348	0.027	0.2	0.99	1.0277	88.773	75.46
4	21	1.029	1.03	86	0.01348	0.0198	0.2	0.99	1.0267	85.569	72.73
8	21	1.028	1.029	89	0.01348	0.0142	0.2	0.99	1.0257	82.364	70.01
15	21	1.027	1.028	92	0.01348	0.01056	0.2	0.99	1.0247	79.159	67.29
30	21	1.025	1.026	97	0.01348	0.0077	0.2	0.99	1.0227	72.749	61.84
60	21	1.023	1.024	102	0.01348	0.0056	0.2	0.99	1.0207	66.340	56.39
120	21	1.022	1.023	105	0.01348	0.00389	0.2	0.99	1.0197	63.135	53.66
240	21	1.021	1.022	107	0.01348	0.00245	0.2	0.99	1.0187	59.930	50.94
480	21	1.021	1.022	107	0.01348	0.002	0.2	0.99	1.0187	59.930	50.94
1440	21	1.018	1.019	115	0.01348	0.0012	0.2	0.99	1.0157	50.316	42.77

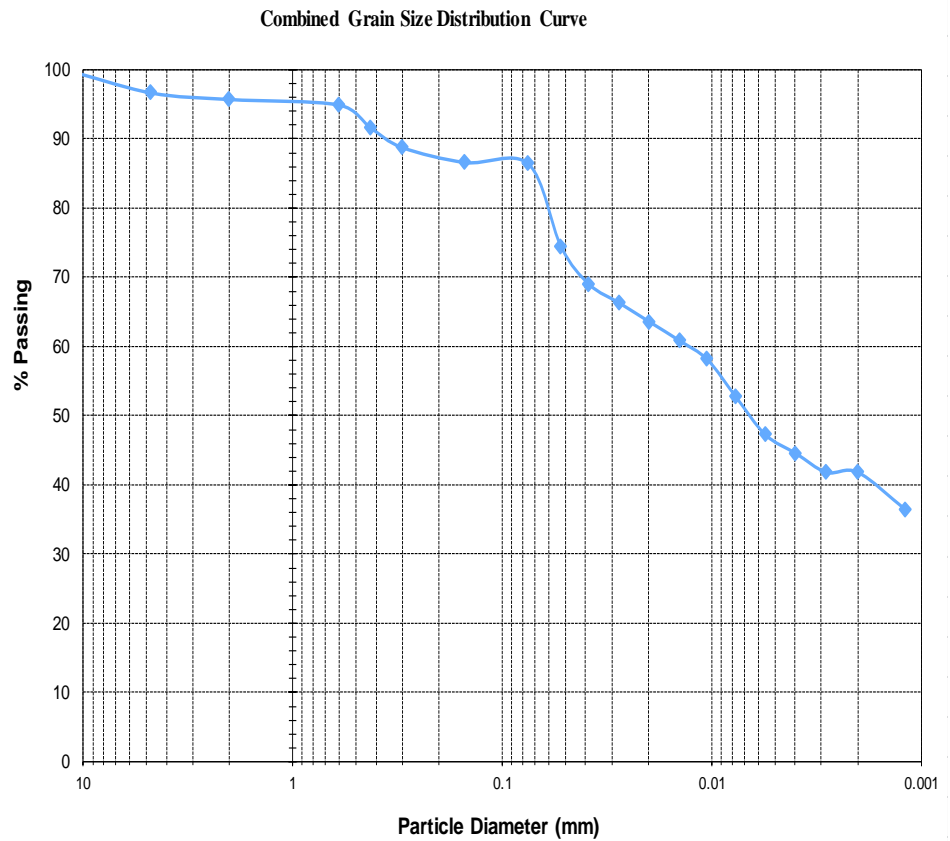
Diameter (mm)	Soil Passing (%)
19	100
12.5	100
4.750	98.1
2.000	95.2
0.600	93.6
0.425	91.6
0.300	88.8
0.150	86.6
0.075	85.0
0.0532	80.73
0.0384	78.18
0.027	75.46
0.0198	72.73
0.0142	70.01
0.01056	67.29
0.0077	61.84
0.0056	56.39
0.00389	53.66
0.00245	50.94
0.002	50.94
0.0012	42.77




Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

	Project Name:	Geotechnical Investigation Program		Tested By	Tigist Gemechu							
	Location:	British Embassy		Date	21/03/22							
	Boring No:	1			CD							
	Sample Depth:	3m			4.6							
GS= 2.75												
Time (minute)	Temperature	Actual hydrometer	meniscus correction	effective depth	k value	D mm	CT	a	corrected hydrometer	bage remaining in the suspension	% passing	
0.5	20	1.032	1.033	78	0.01325	0.0523	0	0.98	1.0274	86.114	74.4027	
1	20	1.03	1.031	84	0.01325	0.0384	0	0.98	1.0254	79.829	68.9719	
2	20	1.029	1.03	86	0.01325	0.0275	0	0.98	1.0244	76.686	66.2565	
4	20	1.028	1.029	89	0.01325	0.0198	0	0.98	1.0234	73.543	63.5410	
8	20	1.027	1.028	92	0.01325	0.0142	0	0.98	1.0224	70.400	60.8256	
15	20	1.026	1.027	94	0.01325	0.0105	0	0.98	1.0214	67.257	58.1102	
30	20	1.024	1.025	100	0.01325	0.0076	0	0.98	1.0194	60.971	52.6793	
60	20	1.022	1.023	105	0.01325	0.0055	0	0.98	1.0174	54.686	47.2485	
120	20	1.021	1.022	107	0.01325	0.0040	0	0.98	1.0164	51.543	44.5330	
240	20	1.02	1.021	110	0.01325	0.0028	0	0.98	1.0154	48.400	41.8176	
480	20	1.02	1.021	110	0.01325	0.0020	0	0.98	1.0154	48.400	41.8176	
1440	20	1.018	1.019	115	0.01325	0.0012	0	0.98	1.0134	42.114	36.3867	

sieve sizes	% passing
19	100
12.5	100
4.750	96.7
2.000	95.7
0.600	94.9
0.425	91.6
0.300	88.8
0.150	86.6
0.075	86.4
0.0523	74.40274
0.0384	68.97189
0.0275	66.25646
0.0198	63.54103
0.0142	60.8256
0.0105	58.11017
0.0076	52.67931
0.0055	47.24846
0.0040	44.53303
0.0028	41.8176
0.0020	41.8176
0.0012	36.38674



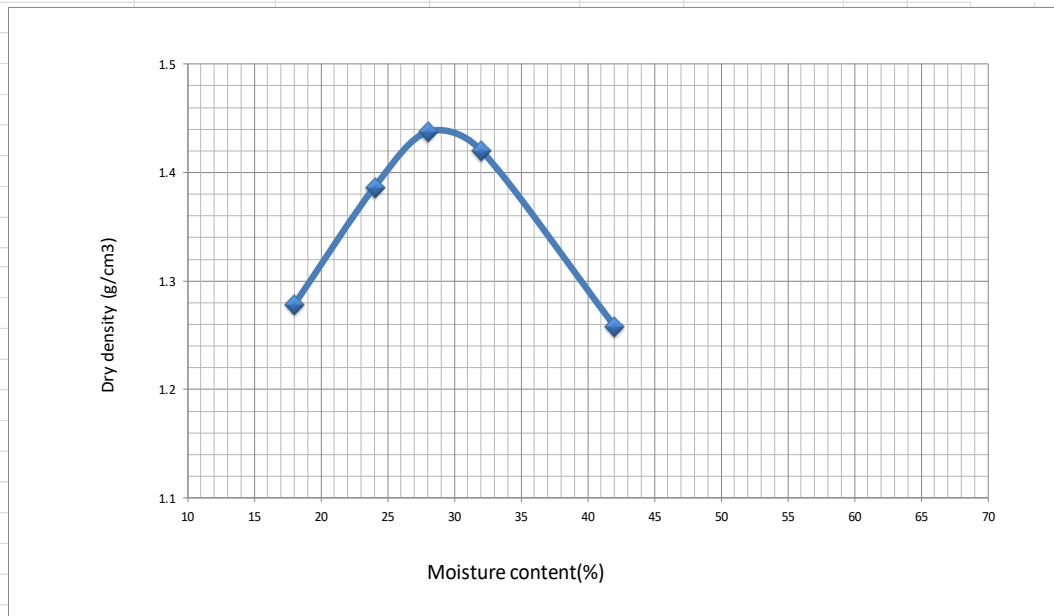
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

 AAiT <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small> <small>የአዲስ አበባ ቴክኖሎጂ ስራ ቤቅ</small> <small>ADDIS ABABA INSTITUTE OF TECHNOLOGY</small>	Standard Compaction Test ASTM D698-91 Using Standard Effort of 600kN-m/m ³			
	Project Name:	Geotechnical Investigation Program	Tested By:	Tigist Gemechu
	Location:	Rufael	Date	20/03/22
	Boring No:	1		
	Sample Depth:	3m		


Moisture content Vs dry density computation table

Determination No.	1	2	3	4	5		
Mass of Mold, g	4376	4376	4376	4376	4376		
Mass of mold + Compact	5800	5999	6113	6166	6063		
Mass of Compacted soil,	1424	1623	1737	1770	1687		
Volume of Mold, cm ³	944	944	944	944	944		
Bulk density, g/cm ³	1.51	1.72	1.84	1.88	1.79		
Water Content, %	18.00	24.00	28.00	32.00	42.00		
Dry density, g/cm ³	1.28	1.39	1.44	1.42	1.26		

Water Content										
Conatiner No	18		24		28		32		42	
Mass of container, g	D16	C13	M1	M2	M3	M4	M5	M6	M7	M8
Can weight	15.6	15.3	15.3	14.6	15.6	15.5	15.8	14.7	15.7	14.6
Mass of container + wet s	35.5	44.4	43.7	35.5	38	46	44.6	38.9	47.6	44.4
Mass of ontainer + Dry s	32.7	39.7	38.2	31.6	33.3	39.5	36.7	33.8	38.2	35.6
Mass of Water, g	2.8	4.7	5.5	3.9	4.7	6.5	7.9	5.1	9.4	8.8
Mass of Dry soil, g	17.1	24.4	22.9	17	17.7	24	20.9	19.1	22.5	21
Water content, %	16.37	19.26	24.02	22.94	26.55	27.08	37.80	26.70	41.78	41.90
Avarage	17.82		23.5		26.8		32.3		41.8	



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

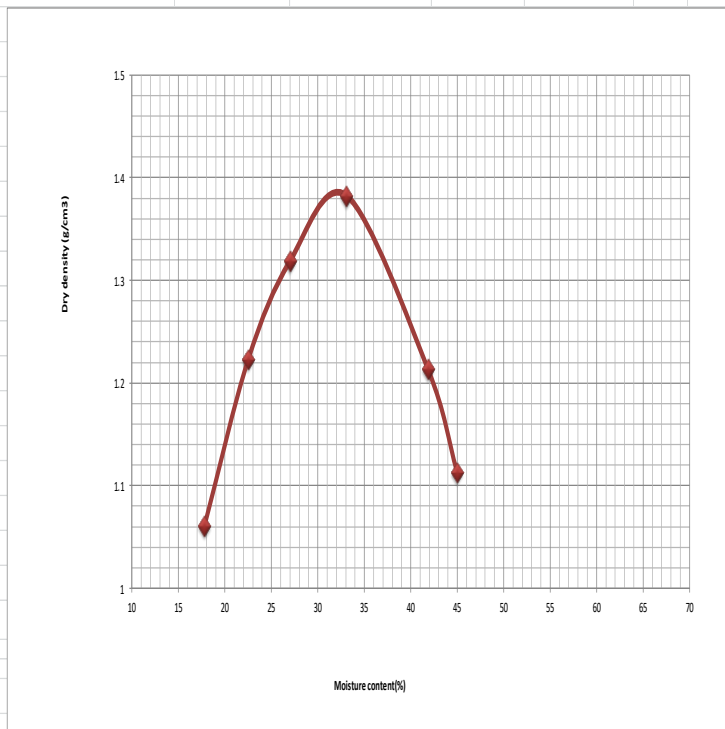
	Standard Compaction Test	
	ASTM D698-91 Using Standard Effort of 600kN-m/m ³	
Project Name:	Geotechnical Investigation Program	Tested By: Tigist Gemechu
Location:	Addisu Gebeya	Date: 18/03/22
Boring No:	1	
Sample Depth:	3m	

Moisture content Vs dry density computation table


Determination No.	1	2	1	2	3	4	1
Mass of Mold, g	4376	4376	4376	4376	4376	4376	4376
Mass of mold + Compacted Soil, g	5555	5555	5790	5957	6113	6001	5899
Mass of Compacted soil, g	1179	1179	1414	1581	1737	1625	1523
Volume of Mold, cm ³	944	944	944	944	944	944	944
Bulk density, g/cm ³	1.25	1.25	1.50	1.67	1.84	1.72	1.61
Water Content, %	12.92	17.78	22.50	27.00	33.10	41.84	45.00
Dry density, g/cm ³	1.11	1.06	1.22	1.32	1.38	1.21	1.11

Water Content determination

Conatiner No	12	16	20	27	32	40	45							
Mass of container, g	D19	D20	D16	C13	C15	E18	C11	C14	C18	E19	C16	E17	a1	a2
Can weight	15.8	15.7	15.6	15.3	15.5	15.8	15.6	15.5	16	13.9	15.7	14.6	15.6	15.5
Mass of container + wet soil, g	45.5	49.8	35.5	44.4	51.8	47.3	38	46	47.8	42.8	47.6	44.4	47.6	44.4
Mass of ontainer + Dry soil, g	42.1	45.9	32.5	40	44.5	42.1	33.31	39.42	40	35.5	38.2	35.6	37.8	35.3
Mass of Water, g	3.4	3.9	3	4.4	7.3	5.2	4.69	6.58	7.8	7.3	9.4	8.8	9.8	9.1
Mass of Dry soil, g	26.3	30.2	16.9	24.7	29	26.3	17.71	23.92	24	21.6	22.5	21	22.2	19.8
Water content, %	12.93	12.91	17.75	17.81	25.17	19.77	26.48	27.51	32.5	33.80	41.78	41.90	44.14	45.96
Avarage	12.92		17.78		22.47		27.00		33.15		41.84		45.05	



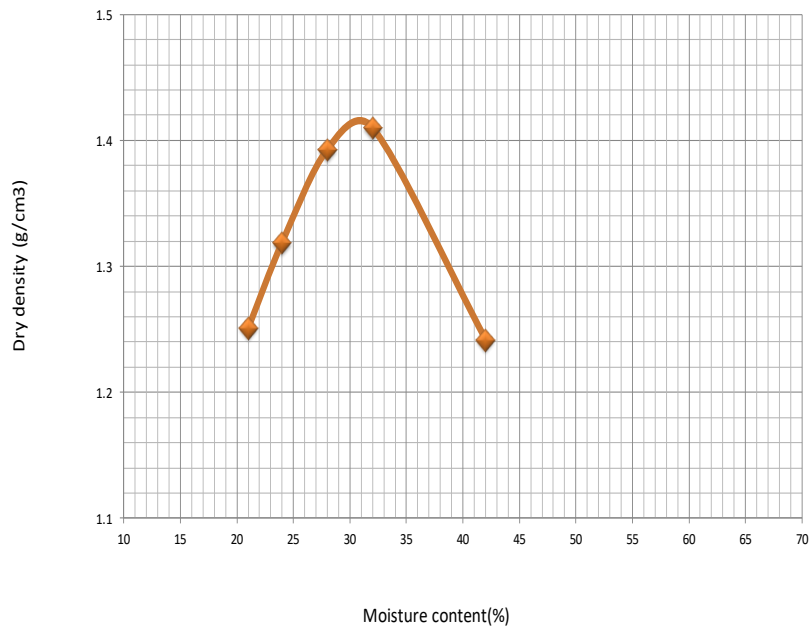
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

	Standard Compaction Test			
	ASTM D698-91			
	Using Standard Effort of 600kN-m/m ³			
	Project Name: Geotechnical Investigation Program		Tested By: Tigist Gemechu	
Location: British Embassy		Date: 21/03/22		
Boring No: 1				
Sample Depth: 3m				

Moisture content Vs dry density computation table

Determination No.	1	2	3	4
Mass of Mold, g	4376	4376	4376	4376
Mass of mold + Compacted Soil, g	5805	5920	6059	6133
Mass of Compacted soil, g	1429	1544	1683	1757
Volume of Mold, cm ³	944	944	944	944
Bulk density, g/cm ³	1.51	1.64	1.78	1.86
Water Content, %	21.00	24.00	28.00	32.00
Dry density, g/cm ³	1.25	1.32	1.39	1.41

Water Content										
Container No	19		24		28		32		42	
Mass of container, g	b1	b2	B1	B2	B3	B4	B5	B6	B7	B8
Can weight	15.3	14.6	15.3	14.6	15.6	15.5	15.8	14.7	15.7	14.6
Mass of container + wet soil, g	40.7	34.6	43.7	35.5	38	46	44.6	38.9	47.6	44.4
Mass of container + Dry soil, g	36.4	31.02	38.2	31.6	33.3	39.5	36.7	33.8	38.2	35.6
Mass of Water, g	4.3	3.58	5.5	3.9	4.7	6.5	7.9	5.1	9.4	8.8
Mass of Dry soil, g	21.1	16.42	22.9	17	17.7	24	20.9	19.1	22.5	21
Water content, %	20.38	21.80	24.02	22.94	26.55	27.08	37.80	26.70	41.78	41.90
Average	21.1		23.5		26.8		32.3		41.8	



Appendix E Method of determining the mass of soil for remolding in the specimen and Method of determining UCS test result

Mass of soil to be remolded for Kechene					
	w%	Dry density	Bulk density	Volume	Mass
	20.50	1.09	1.31	86.19	112.69
	22.00	1.18	1.44	86.19	124.08
SL	25.00	1.32	1.65	86.19	142.22
	27.00	1.39	1.76	86.19	151.61
	30.00	1.42	1.85	86.19	159.11
PL	32.00	1.42	1.87	86.19	161.56
	34.00	1.38	1.85	86.19	159.39
	36.00	1.34	1.82	86.19	157.08
	38.00	1.29	1.77	86.19	152.85
	40.00	1.24	1.74	86.19	149.63

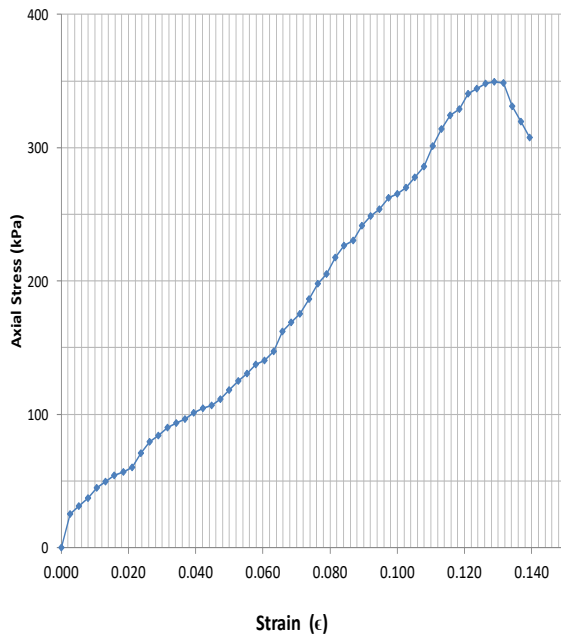
Mass of soil to be remolded for Rufael site					
	w%	Dry density	Bulk density	Volume	Mass
	18.00	1.28	1.51	86.19	130.19
	19.00	1.29	1.54	86.19	132.31
	20.00	1.32	1.58	86.19	136.43
SL	22.00	1.35	1.64	86.19	141.64
	25.00	1.38	1.73	86.19	149.11
	28.00	1.43	1.83	86.19	157.66
	30.00	1.44	1.87	86.19	161.35
	33.00	1.40	1.86	86.19	160.49
PL	35.00	1.38	1.86	86.19	160.58
	38.00	1.32	1.82	86.19	157.01
	40.00	1.29	1.80	86.19	155.06
	42.00	1.26	1.79	86.19	154.22

Mass of soil to be remolded for Addisu Gebeya					
	w%	Dry density	Bulk density	Volume	Mass
	18	1.06	1.25	86.19	107.81
	20	1.14	1.37	86.19	117.91
SL	23	1.24	1.52	86.19	131.25
	25	1.28	1.60	86.19	137.91
	27	1.32	1.68	86.19	144.49
	30	1.35	1.75	86.19	151.04
	33	1.38	1.84	86.19	158.43
	35	1.36	1.84	86.19	158.25
PL	38	1.30	1.79	86.19	154.51
	40	1.25	1.74	86.19	150.23
	42	1.21	1.72	86.19	148.10
	45	1.10	1.60	86.19	137.48

Mass of soil to be remolded for British Embassy					
	w%	Dry density	Bulk density	Volume	Mass
	21.00	1.25	1.51	86.19	129.85
	23.00	1.29	1.58	86.19	136.23
	26.00	1.36	1.71	86.19	147.70
SL	28.00	1.39	1.77	86.19	152.80
	30.00	1.42	1.84	86.19	158.78
	32.00	1.41	1.87	86.19	160.88
	34.00	1.38	1.85	86.19	159.39
	37.00	1.32	1.81	86.19	156.23
PL	39.00	1.28	1.78	86.19	153.71
	42.00	1.24	1.76	86.19	151.77

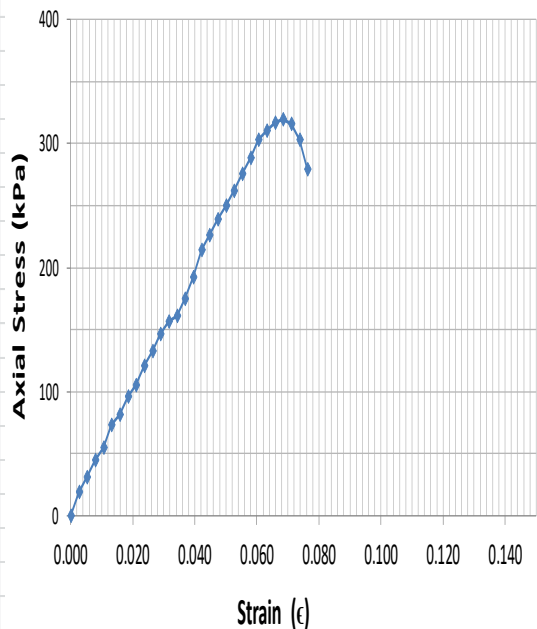
Method of determining UCS test for Kechene site

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		11/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program Location : kechene Sample ID TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : kechene Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	112.69	Length (mm)	76.00	20	20.0	0.20	0.003	0.263	1137.10	0.028	24.98
Wt of Dry Sample + Container(gm)	96.30	Area, A ₀ (mm ²)	1134.11	40	25.0	0.40	0.005	0.526	1140.08	0.036	31.14
Wt. Of Water(gm)	16.39	Volume, (mm ³)	86192.74	60	30.0	0.60	0.008	0.789	1143.07	0.043	37.27
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.307	80	36.0	0.80	0.011	1.053	1146.05	0.051	44.61
Wt of Dry Sample (gm)	80.00	Dry density(gm/cm ³)	1.085	100	40.0	1.00	0.013	1.316	1149.04	0.057	49.43
Water Content(%)	20.49	Rate (mm/min):	2.00	120	44.0	1.20	0.016	1.579	1152.02	0.062	54.24
		Ring Factor	0.00142	140	46.0	1.40	0.018	1.842	1155.01	0.065	56.55
				160	49.0	1.60	0.021	2.105	1157.99	0.070	60.09
				180	58.0	1.80	0.024	2.368	1160.98	0.082	70.94
				200	65.0	2.00	0.026	2.632	1163.96	0.092	79.30
				220	69.0	2.20	0.029	2.895	1166.94	0.098	83.96
				240	74.0	2.40	0.032	3.158	1169.93	0.105	89.82
				260	77.0	2.60	0.034	3.421	1172.91	0.109	93.22
				280	80.0	2.80	0.037	3.684	1175.90	0.114	96.61
				300	84.0	3.00	0.039	3.947	1178.88	0.119	101.18
				320	87.0	3.20	0.042	4.211	1181.87	0.124	104.53
				340	89.0	3.40	0.045	4.474	1184.85	0.126	106.66
				360	93.0	3.60	0.047	4.737	1187.84	0.132	111.18
				380	99.0	3.80	0.050	5.000	1190.82	0.141	118.05
				400	105.0	4.00	0.053	5.263	1193.81	0.149	124.89
				420	110.0	4.20	0.055	5.526	1196.79	0.156	130.52
				440	116.0	4.40	0.058	5.789	1199.77	0.165	137.29
				460	119.0	4.60	0.061	6.053	1202.76	0.169	140.49
				480	125.0	4.80	0.063	6.316	1205.74	0.178	147.21
				500	138.0	5.00	0.066	6.579	1208.73	0.196	162.12
				520	144.0	5.20	0.068	6.842	1211.71	0.204	168.75
				540	150.0	5.40	0.071	7.105	1214.70	0.213	175.35
				560	160.0	5.60	0.074	7.368	1217.68	0.227	186.58
				580	170.0	5.80	0.076	7.632	1220.67	0.241	197.76
				600	177.0	6.00	0.079	7.895	1223.65	0.251	205.40
				620	188.0	6.20	0.082	8.158	1226.63	0.267	217.64
				640	196.0	6.40	0.084	8.421	1229.62	0.278	226.35
				660	200.0	6.60	0.087	8.684	1232.60	0.284	230.41
				680	210.0	6.80	0.089	8.947	1235.59	0.298	241.34
				700	217.0	7.00	0.092	9.211	1238.57	0.308	248.79
				720	222.0	7.20	0.095	9.474	1241.56	0.315	253.91
				740	230.0	7.40	0.097	9.737	1244.54	0.327	262.43
				760	233.0	7.60	0.100	10.000	1247.53	0.331	265.21
				780	238.0	7.80	0.103	10.263	1250.51	0.338	270.26
				800	245.0	8.00	0.105	10.526	1253.50	0.348	277.54
				820	253.0	8.20	0.108	10.789	1256.48	0.359	285.93
				840	267.0	8.40	0.111	11.053	1259.46	0.379	301.03
				860	279.0	8.60	0.113	11.316	1262.45	0.396	313.82
				880	289.0	8.80	0.116	11.579	1265.43	0.410	324.30
				900	294.0	9.00	0.118	11.842	1268.42	0.417	329.13
				920	305.0	9.20	0.121	12.105	1271.40	0.433	340.65
				940	309.0	9.40	0.124	12.368	1274.39	0.439	344.31
				960	313.0	9.60	0.126	12.632	1277.37	0.444	347.95
				980	315.0	9.80	0.129	12.895	1280.36	0.447	349.36
				1000	315.0	10.00	0.132	13.158	1283.34	0.447	348.54
				1020	300.0	10.20	0.134	13.421	1286.33	0.426	331.18
				1040	290.0	10.40	0.137	13.684	1289.31	0.412	319.40
				1060	280.0	10.60	0.139	13.947	1292.29	0.398	307.67
										qu	349.36
										CU	174.68



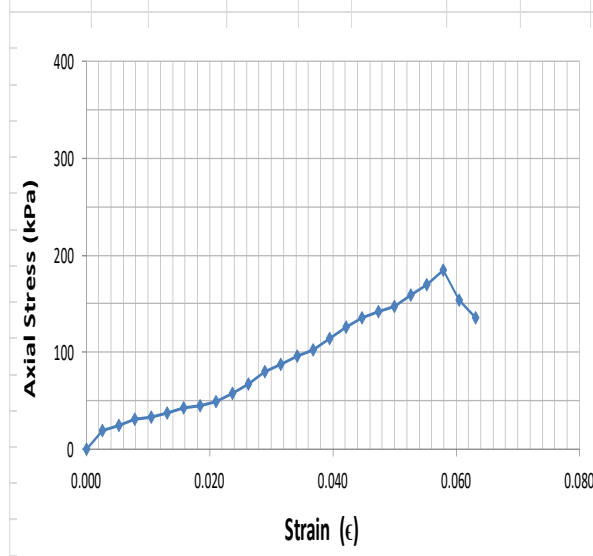
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	11/4/2022	Disturbed									
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : kechene				Location : kechene							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	124.08	Length(mm)	76.00	20	15.0	0.20	0.003	0.263	1137.10	0.021	18.73
Wt of Dry Sample + Container(gm)	104.50	Area, A_0 (mm ²)	1134.11	40	25.0	0.40	0.005	0.526	1140.08	0.036	31.14
Wt. Of Water(gm)	19.58	Volume,(mm ³)	86192.74	60	36.0	0.60	0.008	0.789	1143.07	0.051	44.72
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.440	80	44.0	0.80	0.011	1.053	1146.05	0.062	54.52
Wt of Dry Sample (gm)	88.20	Dry density(gm/cm ³)	1.178	100	59.0	1.00	0.013	1.316	1149.04	0.084	72.91
Water Content(%)	22.20	Rate (mm/min):	2.00	120	66.0	1.20	0.016	1.579	1152.02	0.094	81.35
		Ring Factor	0.00142	140	78.0	1.40	0.018	1.842	1155.01	0.111	95.90
				160	86.0	1.60	0.021	2.105	1157.99	0.122	105.46
				180	99.0	1.80	0.024	2.368	1160.98	0.141	121.09
				200	109.0	2.00	0.026	2.632	1163.96	0.155	132.98
				220	120.0	2.20	0.029	2.895	1166.94	0.170	146.02
				240	129.0	2.40	0.032	3.158	1169.93	0.183	156.57
				260	133.0	2.60	0.034	3.421	1172.91	0.189	161.02
				280	145.0	2.80	0.037	3.684	1175.90	0.206	175.10
				300	160.0	3.00	0.039	3.947	1178.88	0.227	192.72
				320	178.0	3.20	0.042	4.211	1181.87	0.253	213.86
				340	189.0	3.40	0.045	4.474	1184.85	0.268	226.51
				360	200.0	3.60	0.047	4.737	1187.84	0.284	239.09
				380	210.0	3.80	0.050	5.000	1190.82	0.298	250.42
				400	220.0	4.00	0.053	5.263	1193.81	0.312	261.68
				420	232.0	4.20	0.055	5.526	1196.79	0.329	275.27
				440	244.0	4.40	0.058	5.789	1199.77	0.346	288.79
				460	257.0	4.60	0.061	6.053	1202.76	0.365	303.42
				480	264.0	4.80	0.063	6.316	1205.74	0.375	310.91
				500	270.0	5.00	0.066	6.579	1208.73	0.383	317.19
				520	273.0	5.20	0.068	6.842	1211.71	0.388	319.93
				540	270.0	5.40	0.071	7.105	1214.70	0.383	315.63
				560	260.0	5.60	0.074	7.368	1217.68	0.369	303.20
				580	240.0	5.80	0.076	7.632	1220.67	0.341	279.19
										qu	319.93
										CU	159.96



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test								
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample					
		11/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program								
Location : kechene				Location : kechene								
Sample ID : TP -1				Sample ID : TP -1								
Depth (m) : 3.00				Depth (m) : 3.00								
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)	
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00	
Wt of Wet Sample + Container(gm)	159.11	Length (mm)	76.00	20	15.0	0.20	0.003	0.263	1137.10	0.021	18.73	
Wt of Dry Sample + Container(gm)	126.00	Area, A_0 (mm ²)	1134.11	40	20.0	0.40	0.005	0.526	1140.08	0.028	24.91	
Wt. Of Water(gm)	33.11	Volume, (mm ³)	86192.74	60	25.0	0.60	0.008	0.789	1143.07	0.036	31.06	
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.846	80	27.0	0.80	0.011	1.053	1146.05	0.038	33.45	
Wt of Dry Sample (gm)	109.70	Dry density(gm/cm ³)	1.418	100	30.0	1.00	0.013	1.316	1149.04	0.043	37.07	
Water Content(%)	30.18	Rate (mm/min):	2.00	120	35.0	1.20	0.016	1.579	1152.02	0.050	43.14	
		Ring Factor	0.00142	140	36.0	1.40	0.018	1.842	1155.01	0.051	44.26	
				160	40.0	1.60	0.021	2.105	1157.99	0.057	49.05	
				180	47.0	1.80	0.024	2.368	1160.98	0.067	57.49	
				200	55.0	2.00	0.026	2.632	1163.96	0.078	67.10	
				220	66.0	2.20	0.029	2.895	1166.94	0.094	80.31	
				240	72.0	2.40	0.032	3.158	1169.93	0.102	87.39	
				260	79.0	2.60	0.034	3.421	1172.91	0.112	95.64	
				280	85.0	2.80	0.037	3.684	1175.90	0.121	102.64	
				300	95.0	3.00	0.039	3.947	1178.88	0.135	114.43	
				320	105.0	3.20	0.042	4.211	1181.87	0.149	126.16	
				340	113.0	3.40	0.045	4.474	1184.85	0.160	135.43	
				360	119.0	3.60	0.047	4.737	1187.84	0.169	142.26	
				380	123.0	3.80	0.050	5.000	1190.82	0.175	146.67	
				400	134.0	4.00	0.053	5.263	1193.81	0.190	159.39	
				420	143.0	4.20	0.055	5.526	1196.79	0.203	169.67	
				440	156.0	4.40	0.058	5.789	1199.77	0.222	184.63	
				460	130.0	4.60	0.061	6.053	1202.76	0.185	153.48	
				480	115.0	4.80	0.063	6.316	1205.74	0.163	135.44	
											qu	184.63
											CU	92.32

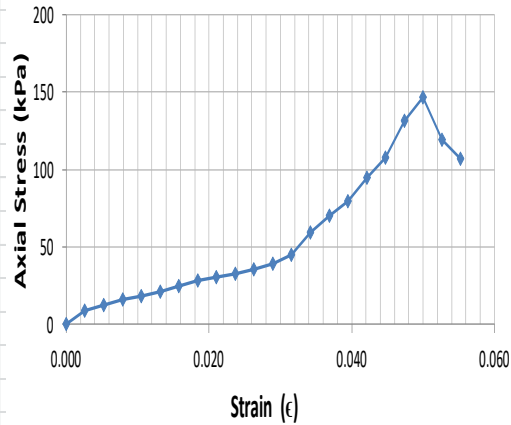


Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date 11/4/2022	Sample Disturbed		Soil UCS Test (ASTM D2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : kechene				Location : kechene							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	161.56	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.099	0.014	12.49
Wt of Dry Sample + Container(gm)	126.30	Area, A ₀ (mm ²)	1134.11	40	15.0	0.40	0.005	0.526	1140.084	0.021	18.68
Wt. Of Water(gm)	35.26	Volume, (mm ³)	86192.74	60	20.0	0.60	0.008	0.789	1143.068	0.028	24.85
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.874	80	25.0	0.80	0.011	1.053	1146.053	0.036	30.98
Wt of Dry Sample (gm)	110.00	Dry density(gm/cm ³)	1.419	100	30.0	1.00	0.013	1.316	1149.038	0.043	37.07
Water Content(%)	32.05	Rate (mm/min):	2.00	120	35.0	1.20	0.016	1.579	1152.022	0.050	43.14
		Ring Factor	0.00142	140	36.0	1.40	0.018	1.842	1155.007	0.051	44.26
				160	40.0	1.60	0.021	2.105	1157.991	0.057	49.05
				180	47.0	1.80	0.024	2.368	1160.976	0.067	57.49
				200	55.0	2.00	0.026	2.632	1163.960	0.078	67.10
				220	67.0	2.20	0.029	2.895	1166.945	0.095	81.53
				240	75.0	2.40	0.032	3.158	1169.929	0.107	91.03
				260	79.0	2.60	0.034	3.421	1172.914	0.112	95.64
				280	88.0	2.80	0.037	3.684	1175.898	0.125	106.27
				300	95.0	3.00	0.039	3.947	1178.883	0.135	114.43
				320	107.0	3.20	0.042	4.211	1181.867	0.152	128.56
				340	111.0	3.40	0.045	4.474	1184.852	0.158	133.03
				360	120.0	3.60	0.047	4.737	1187.836	0.170	143.45
				380	130.0	3.80	0.050	5.000	1190.821	0.185	155.02
				400	144.0	4.00	0.053	5.263	1193.805	0.204	171.28
				420	125.0	4.20	0.055	5.526	1196.790	0.178	148.31
				440	110.0	4.40	0.058	5.789	1199.774	0.156	130.19
										qu	171.28
										CU	85.64

Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		11/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : kechene				Location : kechene							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	159.39	Length (mm)	76.00	20	7.0	0.20	0.003	0.263	1137.099	0.010	8.74
Wt of Dry Sample + Container(gm)	123.00	Area, A_0 (mm ²)	1134.11	40	10.0	0.40	0.005	0.526	1140.084	0.014	12.46
Wt. Of Water(gm)	36.39	Volume, (mm ³)	86192.74	60	13.0	0.60	0.008	0.789	1143.068	0.018	16.15
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.849	80	15.0	0.80	0.011	1.053	1146.053	0.021	18.59
Wt of Dry Sample (gm)	106.70	Dry density(gm/cm ³)	1.379	100	17.0	1.00	0.013	1.316	1149.038	0.024	21.01
Water Content(%)	34.10	Rate (mm/min):	2.00	120	20.0	1.20	0.016	1.579	1152.022	0.028	24.65
		Ring Factor	0.00142	140	23.0	1.40	0.018	1.842	1155.007	0.033	28.28
				160	25.0	1.60	0.021	2.105	1157.991	0.036	30.66
				180	27.0	1.80	0.024	2.368	1160.976	0.038	33.02
				200	29.0	2.00	0.026	2.632	1163.960	0.041	35.38
				220	32.0	2.20	0.029	2.895	1166.945	0.045	38.94
				240	37.0	2.40	0.032	3.158	1169.929	0.053	44.91
				260	49.0	2.60	0.034	3.421	1172.914	0.070	59.32
				280	58.0	2.80	0.037	3.684	1175.898	0.082	70.04
				300	66.0	3.00	0.039	3.947	1178.883	0.094	79.50
				320	79.0	3.20	0.042	4.211	1181.867	0.112	94.92
				340	90.0	3.40	0.045	4.474	1184.852	0.128	107.86
				360	110.0	3.60	0.047	4.737	1187.836	0.156	131.50
				380	123.0	3.80	0.050	5.000	1190.821	0.175	146.67
				400	100.0	4.00	0.053	5.263	1193.805	0.142	118.95
				420	90.0	4.20	0.055	5.526	1196.790	0.128	106.79
											qu 146.67
											CU 73.34



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		11/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : kechene				Location : kechene							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	157.08	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.10	0.014	12.49
Wt of Dry Sample + Container(gm)	119.80	Area, A_0 (mm ²)	1134.11	40	12.0	0.40	0.005	0.526	1140.08	0.017	14.95
Wt. Of Water(gm)	37.28	Volume, (mm ³)	86192.74	60	15.0	0.60	0.008	0.789	1143.07	0.021	18.63
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.822	80	20.0	0.80	0.011	1.053	1146.05	0.028	24.78
Wt of Dry Sample (gm)	103.50	Dry density(gm/cm ³)	1.340	100	26.0	1.00	0.013	1.316	1149.04	0.037	32.13
Water Content(%)	36.02	Rate (mm/min):	2.00	120	38.0	1.20	0.016	1.579	1152.02	0.054	46.84
		Ring Factor	0.00142	140	49.0	1.40	0.018	1.842	1155.01	0.070	60.24
				160	60.0	1.60	0.021	2.105	1157.99	0.085	73.58
				180	72.0	1.80	0.024	2.368	1160.98	0.102	88.06
				200	91.0	2.00	0.026	2.632	1163.96	0.129	111.02
				220	80.0	2.20	0.029	2.895	1166.94	0.114	97.35
				240	60.0	2.40	0.032	3.158	1169.93	0.085	72.82
											qu 111.02
											CU 55.51

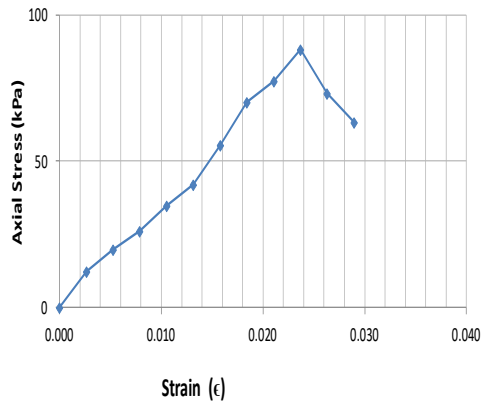
Axial Stress (kPa)

Strain (ϵ)

Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
20	10.0	0.20	0.003	0.263	1137.10	0.014	12.49
40	12.0	0.40	0.005	0.526	1140.08	0.017	14.95
60	15.0	0.60	0.008	0.789	1143.07	0.021	18.63
80	20.0	0.80	0.011	1.053	1146.05	0.028	24.78
100	26.0	1.00	0.013	1.316	1149.04	0.037	32.13
120	38.0	1.20	0.016	1.579	1152.02	0.054	46.84
140	49.0	1.40	0.018	1.842	1155.01	0.070	60.24
160	60.0	1.60	0.021	2.105	1157.99	0.085	73.58
180	72.0	1.80	0.024	2.368	1160.98	0.102	88.06
200	91.0	2.00	0.026	2.632	1163.96	0.129	111.02
220	80.0	2.20	0.029	2.895	1166.94	0.114	97.35
240	60.0	2.40	0.032	3.158	1169.93	0.085	72.82

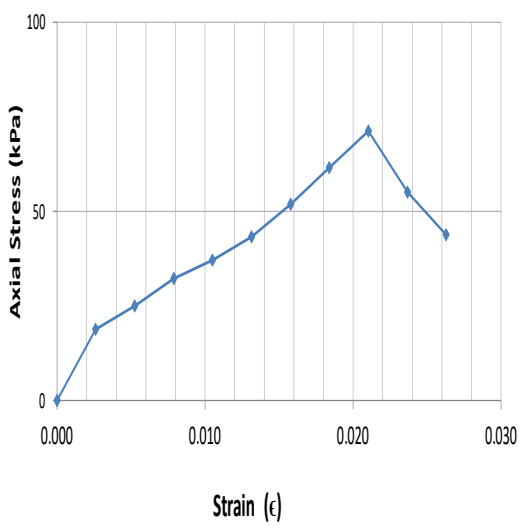
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test										
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample								
	11/4/2022	Disturbed				Disturbed								
Project : Geotechnical Investigation program Location : kechene Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : kechene Sample ID : TP -1 Depth (m) : 3.00										
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)			
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00			
Wt of Wet Sample + Container(gm)	152.85	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.099	0.014	12.49			
Wt of Dry Sample + Container(gm)	115.12	Area, A_0 (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.084	0.023	19.93			
Wt. Of Water(gm)	37.73	Volume, (mm ³)	86192.74	60	21.0	0.60	0.008	0.789	1143.068	0.030	26.09			
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.773	80	28.0	0.80	0.011	1.053	1146.053	0.040	34.69			
Wt of Dry Sample (gm)	98.82	Dry density(gm/cm ³)	55.182	100	34.0	1.00	0.013	1.316	1149.038	0.048	42.02			
Water Content(%)	38.18	Rate (mm/min):	2.00	120	45.0	1.20	0.016	1.579	1152.022	0.064	55.47			
		Ring Factor	0.00142	140	57.0	1.40	0.018	1.842	1155.007	0.081	70.08			
			1.283	160	63.0	1.60	0.021	2.105	1157.991	0.089	77.25			
			2.00	180	72.0	1.80	0.024	2.368	1160.976	0.102	88.06			
			0.00142	200	60.0	2.00	0.026	2.632	1163.960	0.085	73.20			
				220	52.0	2.20	0.029	2.895	1166.945	0.074	63.28			
<table border="1" style="float: right; margin-top: 10px;"> <tr> <td style="padding: 2px;">qu</td> <td style="padding: 2px;">88.06</td> </tr> <tr> <td style="padding: 2px;">CU</td> <td style="padding: 2px;">44.03</td> </tr> </table>											qu	88.06	CU	44.03
qu	88.06													
CU	44.03													



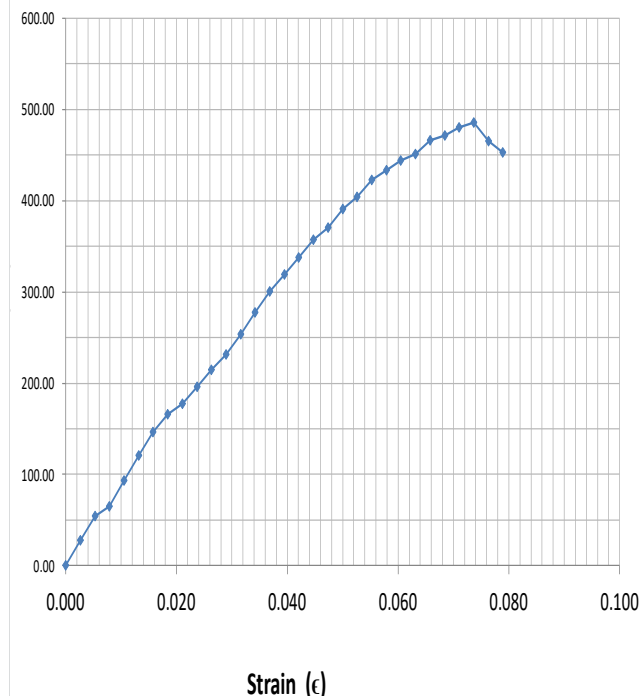
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
	Date	Sample			Date	Sample					
Soil UCS Test (ASTM D2166)	11/4/2022	Disturbed		Soil UCS Test (ASTM D2166)		Disturbed					
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : kechene				Location : kechene							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	149.63	Length (mm)	76.00	20	15.0	0.20	0.003	0.263	1137.10	0.021	18.73
Wt of Dry Sample + Container(gm)	111.50	Area, A_0 (mm ²)	1134.11	40	20.0	0.40	0.005	0.526	1140.08	0.028	24.91
Wt. Of Water(gm)	38.13	Volume, (mm ³)	86192.74	60	26.0	0.60	0.008	0.789	1143.07	0.037	32.30
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.736	80	30.0	0.80	0.011	1.053	1146.05	0.043	37.17
Wt of Dry Sample (gm)	95.20	Dry density(gm/cm ³)	1.240	100	35.0	1.00	0.013	1.316	1149.04	0.050	43.25
Water Content(%)	40.05	Rate (mm/min):	2.00	120	42.0	1.20	0.016	1.579	1152.02	0.060	51.77
		Ring Factor	0.00142	140	50.0	1.40	0.018	1.842	1155.01	0.071	61.47
				160	58.0	1.60	0.021	2.105	1157.99	0.082	71.12
				180	45.0	1.80	0.024	2.368	1160.98	0.064	55.04
				200	36.0	2.00	0.026	2.632	1163.96	0.051	43.92
										qu	71.12
										CU	35.56



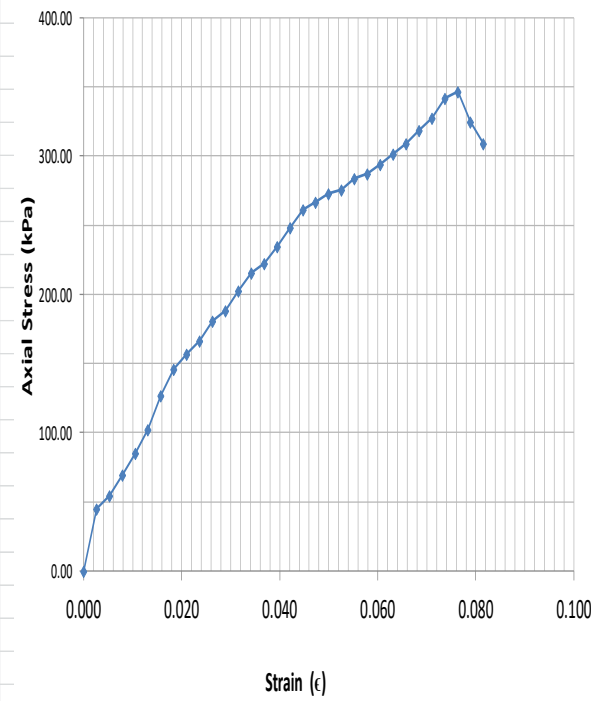
Ucs test result for Rufael

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	15/04/2022	Disturbed red clay soil				Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	132.31	Length (mm)	76.00	20	22.0	0.20	0.003	0.263	1137.10	0.031	27.47
Wt of Dry Sample + Container(gm)	113.80	Area, A_0 (mm ²)	1134.11	40	44.0	0.40	0.005	0.526	1140.08	0.062	54.80
Wt. Of Water(gm)	18.51	Volume, (mm ³)	86192.74	60	52.0	0.60	0.008	0.789	1143.07	0.074	64.60
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.535	80	75.0	0.80	0.011	1.053	1146.05	0.107	92.93
Wt of Dry Sample (gm)	97.50	Dry density(gm/cm ³)	1.290	100	98.0	1.00	0.013	1.316	1149.04	0.139	121.11
Water Content(%)	18.98	Rate (mm/min):	2.00	120	119.0	1.20	0.016	1.579	1152.02	0.169	146.68
		Ring Factor	0.00142	140	135.0	1.40	0.018	1.842	1155.01	0.192	165.97
				160	145.0	1.60	0.021	2.105	1157.99	0.206	177.81
				180	160.0	1.80	0.024	2.368	1160.98	0.227	195.70
				200	176.0	2.00	0.026	2.632	1163.96	0.250	214.72
				220	190.0	2.20	0.029	2.895	1166.94	0.270	231.20
				240	209.0	2.40	0.032	3.158	1169.93	0.297	253.67
				260	229.0	2.60	0.034	3.421	1172.91	0.325	277.24
				280	249.0	2.80	0.037	3.684	1175.90	0.354	300.69
				300	265.0	3.00	0.039	3.947	1178.88	0.376	319.20
				320	281.0	3.20	0.042	4.211	1181.87	0.399	337.62
				340	298.0	3.40	0.045	4.474	1184.85	0.423	357.14
				360	310.0	3.60	0.047	4.737	1187.84	0.440	370.59
				380	328.0	3.80	0.050	5.000	1190.82	0.466	391.13
				400	340.0	4.00	0.053	5.263	1193.81	0.483	404.42
				420	356.0	4.20	0.055	5.526	1196.79	0.506	422.40
				440	366.0	4.40	0.058	5.789	1199.77	0.520	433.18
				460	376.0	4.60	0.061	6.053	1202.76	0.534	443.91
				480	383.0	4.80	0.063	6.316	1205.74	0.544	451.06
				500	397.0	5.00	0.066	6.579	1208.73	0.564	466.39
				520	402.0	5.20	0.068	6.842	1211.71	0.571	471.10
				540	411.0	5.40	0.071	7.105	1214.70	0.584	480.47
				560	416.0	5.60	0.074	7.368	1217.68	0.591	485.12
				580	400.0	5.80	0.076	7.632	1220.67	0.568	465.32
				600	390.0	6.00	0.079	7.895	1223.65	0.554	452.58
				620	350.0	6.20	0.082	8.158	1226.63	0.497	405.17
										qu	485.12
										CU	242.56



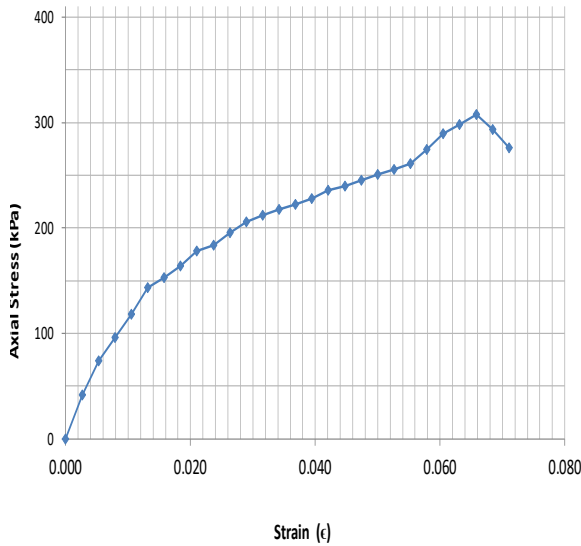
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	15/04/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	149.11	Length (mm)	76.00	20	36.0	0.20	0.003	0.263	1137.10	0.051	44.96
Wt of Dry Sample + Container(gm)	122.50	Area, A ₀ (mm ²)	1134.11	40	44.0	0.40	0.005	0.526	1140.08	0.062	54.80
Wt. Of Water(gm)	26.61	Volume, (mm ³)	86192.74	60	56.0	0.60	0.008	0.789	1143.07	0.080	69.57
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.730	80	69.0	0.80	0.011	1.053	1146.05	0.098	85.49
Wt of Dry Sample (gm)	106.20	Dry density(gm/cm ³)	1.383	100	83.0	1.00	0.013	1.316	1149.04	0.118	102.57
Water Content(%)	25.06	Rate (mm/min):	2.00	120	103.0	1.20	0.016	1.579	1152.02	0.146	126.96
		Ring Factor	0.00142	140	119.0	1.40	0.018	1.842	1155.01	0.169	146.30
				160	128.0	1.60	0.021	2.105	1157.99	0.182	156.96
				180	136.0	1.80	0.024	2.368	1160.98	0.193	166.34
				200	148.0	2.00	0.026	2.632	1163.96	0.210	180.56
				220	155.0	2.20	0.029	2.895	1166.94	0.220	188.61
				240	167.0	2.40	0.032	3.158	1169.93	0.237	202.70
				260	178.0	2.60	0.034	3.421	1172.91	0.253	215.50
				280	184.0	2.80	0.037	3.684	1175.90	0.261	222.20
				300	195.0	3.00	0.039	3.947	1178.88	0.277	234.88
				320	207.0	3.20	0.042	4.211	1181.87	0.294	248.71
				340	218.0	3.40	0.045	4.474	1184.85	0.310	261.26
				360	223.0	3.60	0.047	4.737	1187.84	0.317	266.59
				380	229.0	3.80	0.050	5.000	1190.82	0.325	273.07
				400	232.0	4.00	0.053	5.263	1193.81	0.329	275.96
				420	239.0	4.20	0.055	5.526	1196.79	0.339	283.58
				440	243.0	4.40	0.058	5.789	1199.77	0.345	287.60
				460	249.0	4.60	0.061	6.053	1202.76	0.354	293.97
				480	256.0	4.80	0.063	6.316	1205.74	0.364	301.49
				500	263.0	5.00	0.066	6.579	1208.73	0.373	308.97
				520	272.0	5.20	0.068	6.842	1211.71	0.386	318.76
				540	280.0	5.40	0.071	7.105	1214.70	0.398	327.32
				560	293.0	5.60	0.074	7.368	1217.68	0.416	341.68
				580	298.0	5.80	0.076	7.632	1220.67	0.423	346.66
				600	280.0	6.00	0.079	7.895	1223.65	0.398	324.93
				620	267.0	6.20	0.082	8.158	1226.63	0.379	309.09
										qu	346.66
										cu	173.3



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		15/04/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Diameter (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	157.66	Length (mm)	76.00	20	33.0	0.20	0.003	0.263	1137.10	0.047	41.21
Wt of Dry Sample + Container(gm)	126.60	Area, A ₀ (mm ²)	1134.11	40	59.0	0.40	0.005	0.526	1140.08	0.084	73.49
Wt. Of Water(gm)	31.06	Volume, (mm ³)	86192.74	60	77.0	0.60	0.008	0.789	1143.07	0.109	95.65
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.829	80	95.0	0.80	0.011	1.053	1146.05	0.135	117.71
Wt of Dry Sample (gm)	110.30	Dry density(gm/cm ³)	1.427	100	116.0	1.00	0.013	1.316	1149.04	0.165	143.35
Water Content(%)	28.16	Rate (mm/min):	2.00	120	124.0	1.20	0.016	1.579	1152.02	0.176	152.84
		Ring Factor	0.00142	140	133.0	1.40	0.018	1.842	1155.01	0.189	163.51
				160	145.0	1.60	0.021	2.105	1157.99	0.206	177.81
				180	150.0	1.80	0.024	2.368	1160.98	0.213	183.47
				200	160.0	2.00	0.026	2.632	1163.96	0.227	195.20
				220	169.0	2.20	0.029	2.895	1166.94	0.240	205.65
				240	175.0	2.40	0.032	3.158	1169.93	0.249	212.41
				260	180.0	2.60	0.034	3.421	1172.91	0.256	217.92
				280	184.0	2.80	0.037	3.684	1175.90	0.261	222.20
				300	189.0	3.00	0.039	3.947	1178.88	0.268	227.66
				320	196.0	3.20	0.042	4.211	1181.87	0.278	235.49
				340	200.0	3.40	0.045	4.474	1184.85	0.284	239.69
				360	205.0	3.60	0.047	4.737	1187.84	0.291	245.07
				380	210.0	3.80	0.050	5.000	1190.82	0.298	250.42
				400	215.0	4.00	0.053	5.263	1193.81	0.305	255.74
				420	220.0	4.20	0.055	5.526	1196.79	0.312	261.03
				440	232.0	4.40	0.058	5.789	1199.77	0.329	274.58
				460	245.0	4.60	0.061	6.053	1202.76	0.348	289.25
				480	253.0	4.80	0.063	6.316	1205.74	0.359	297.96
				500	262.0	5.00	0.066	6.579	1208.73	0.372	307.79
				520	250.0	5.20	0.068	6.842	1211.71	0.355	292.97
				540	236.0	5.40	0.071	7.105	1214.70	0.335	275.89
										c _u	307.79
										q _u	153.90



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTMD2166)	Date 15/04/2022	Sample Disturbed		Soil UCS Test (ASTMD2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container (gm)	161.35	Length (mm)	76.00	20	12.0	0.20	0.003	0.263	1137.10	0.017	14.99
Wt of Dry Sample + Container (gm)	127.80	Area, A_0 (mm ²)	1134.11	40	28.0	0.40	0.005	0.526	1140.08	0.040	34.87
Wt. Of Water (gm)	33.55	Volume, (mm ³)	86192.74	60	39.0	0.60	0.008	0.789	1143.07	0.055	48.45
Wt. Of Container (gm)	16.30	Bulk density (gm/cm ³)	1.872	80	50.0	0.80	0.011	1.053	1146.05	0.071	61.95
Wt of Dry Sample (gm)	111.50	Dry density (gm/cm ³)	1.439	100	64.0	1.00	0.013	1.316	1149.04	0.091	79.09
Water Content (%)	30.09	Rate (mm/min):	2.00	120	74.0	1.20	0.016	1.579	1152.02	0.105	91.21
		Ring Factor	0.00142	140	87.0	1.40	0.018	1.842	1155.01	0.124	106.96
				160	95.0	1.60	0.021	2.105	1157.99	0.135	116.49
				180	104.0	1.80	0.024	2.368	1160.98	0.148	127.20
				200	110.0	2.00	0.026	2.632	1163.96	0.156	134.20
				220	116.0	2.20	0.029	2.895	1166.94	0.165	141.15
				240	125.0	2.40	0.032	3.158	1169.93	0.178	151.72
				260	132.0	2.60	0.034	3.421	1172.91	0.187	159.81
				280	140.0	2.80	0.037	3.684	1175.90	0.199	169.06
				300	146.0	3.00	0.039	3.947	1178.88	0.207	175.86
				320	156.0	3.20	0.042	4.211	1181.87	0.222	187.43
				340	163.0	3.40	0.045	4.474	1184.85	0.231	195.35
				360	170.0	3.60	0.047	4.737	1187.84	0.241	203.23
				380	177.0	3.80	0.050	5.000	1190.82	0.251	211.06
				400	185.0	4.00	0.053	5.263	1193.81	0.263	220.05
				420	191.0	4.20	0.055	5.526	1196.79	0.271	226.62
				440	199.0	4.40	0.058	5.789	1199.77	0.283	235.53
				460	206.0	4.60	0.061	6.053	1202.76	0.293	243.21
				480	212.0	4.80	0.063	6.316	1205.74	0.301	249.67
				500	218.0	5.00	0.066	6.579	1208.73	0.310	256.10
				520	225.0	5.20	0.068	6.842	1211.71	0.320	263.68
				540	210.0	5.40	0.071	7.105	1214.70	0.298	245.49
				560	190.0	5.60	0.074	7.368	1217.68	0.270	221.57

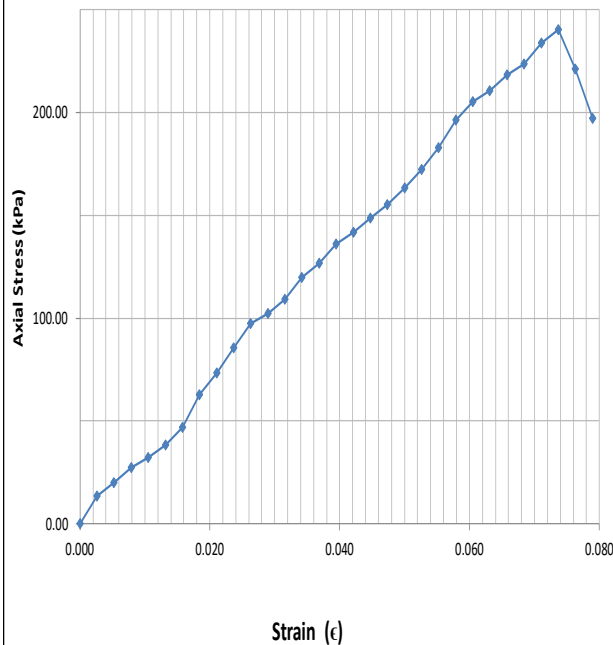
Axial Stress (kPa)

Strain (ϵ)

qu	263.68
CU	131.84

Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil



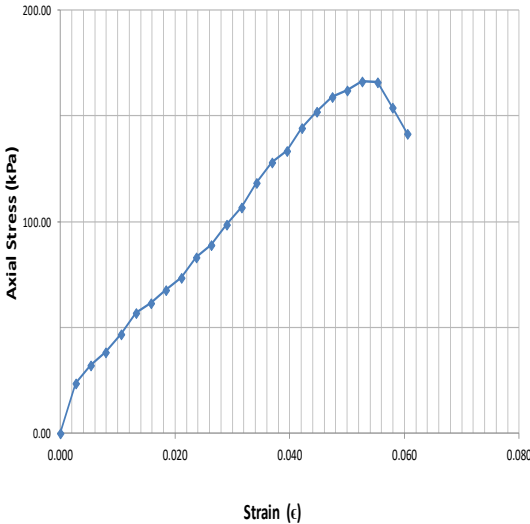
Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date 15/04/2022	Sample Disturbed		Soil UCS Test (ASTM D2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading g	Sample Deformation ΔL(mm)	Strain (ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container (gm)	160.49	Length (mm)	76.00	20	11.0	0.20	0.003	0.263	1137.10	0.016	13.74
Wt of Dry Sample + Container (gm)	124.40	Area, A ₀ (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water (gm)	36.09	Volume, (mm ³)	86192.74	60	22.0	0.60	0.008	0.789	1143.07	0.031	27.33
Wt. Of Container (gm)	16.30	Bulk density (gm/cm ³)	1.862	80	26.0	0.80	0.011	1.053	1146.05	0.037	32.21
Wt of Dry Sample (gm)	108.10	Dry density (gm/cm ³)	1.396	100	31.0	1.00	0.013	1.316	1149.04	0.044	38.31
Water Content (%)	33.39	Rate (mm/min):	2.00	120	38.0	1.20	0.016	1.579	1152.02	0.054	46.84
		Ring Factor	0.00142	140	51.0	1.40	0.018	1.842	1155.01	0.072	62.70
				160	60.0	1.60	0.021	2.105	1157.99	0.085	73.58
				180	70.0	1.80	0.024	2.368	1160.98	0.099	85.62
				200	80.0	2.00	0.026	2.632	1163.96	0.114	97.60
				220	84.0	2.20	0.029	2.895	1166.94	0.119	102.22
				240	90.0	2.40	0.032	3.158	1169.93	0.128	109.24
				260	99.0	2.60	0.034	3.421	1172.91	0.141	119.86
				280	105.0	2.80	0.037	3.684	1175.90	0.149	126.80
				300	113.0	3.00	0.039	3.947	1178.88	0.160	136.11
				320	118.0	3.20	0.042	4.211	1181.87	0.168	141.78
				340	124.0	3.40	0.045	4.474	1184.85	0.176	148.61
				360	130.0	3.60	0.047	4.737	1187.84	0.185	155.41
				380	137.0	3.80	0.050	5.000	1190.82	0.195	163.37
				400	145.0	4.00	0.053	5.263	1193.81	0.206	172.47
				420	154.0	4.20	0.055	5.526	1196.79	0.219	182.72
				440	166.0	4.40	0.058	5.789	1199.77	0.236	196.47
				460	174.0	4.60	0.061	6.053	1202.76	0.247	205.43
				480	179.0	4.80	0.063	6.316	1205.74	0.254	210.81
				500	186.0	5.00	0.066	6.579	1208.73	0.264	218.51
				520	191.0	5.20	0.068	6.842	1211.71	0.271	223.83
				540	200.0	5.40	0.071	7.105	1214.70	0.284	233.80
				560	206.0	5.60	0.074	7.368	1217.68	0.293	240.23
				580	190.0	5.80	0.076	7.632	1220.67	0.270	221.03
				600	170.0	6.00	0.079	7.895	1223.65	0.241	197.28
										qu	240.23
										CU	120.11



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

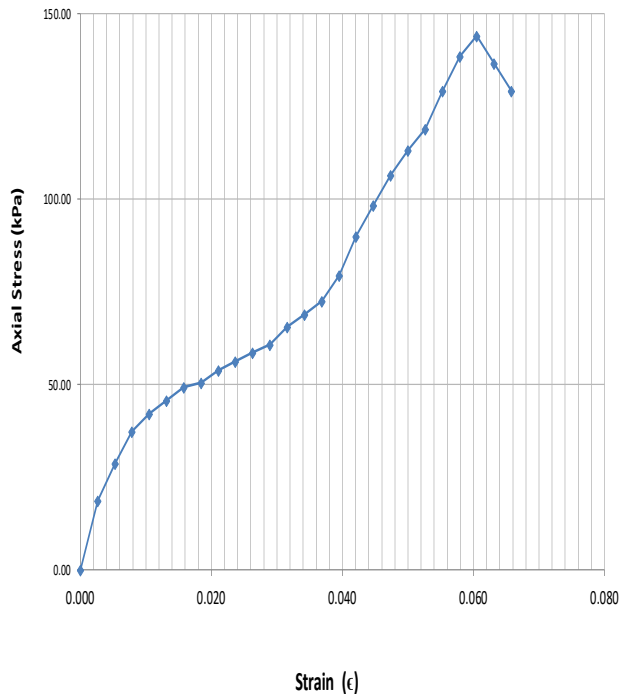
Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date 15/04/2022	Sample Disturbed		Soil UCS Test (ASTM D2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	160.58	Length (mm)	76.00	20	25.0	0.20	0.003	0.263	1137.10	0.036	31.22
Wt of Dry Sample + Container(gm)	122.90	Area, A ₀ (mm ²)	1134.11	40	32.0	0.40	0.005	0.526	1140.08	0.045	39.86
Wt. Of Water(gm)	37.68	Volume, (mm ³)	86192.74	60	39.0	0.60	0.008	0.789	1143.07	0.055	48.45
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.863	80	45.0	0.80	0.011	1.053	1146.05	0.064	55.76
Wt of Dry Sample (gm)	106.60	Dry density(gm/cm ³)	1.376	100	54.0	1.00	0.013	1.316	1149.04	0.077	66.73
Water Content(%)	35.34	Rate (mm/min):	2.00	120	58.0	1.20	0.016	1.579	1152.02	0.082	71.49
		Ring Factor	0.00142	140	64.0	1.40	0.018	1.842	1155.01	0.091	78.68
				160	70.0	1.60	0.021	2.105	1157.99	0.099	85.84
				180	75.0	1.80	0.024	2.368	1160.98	0.107	91.73
				200	79.0	2.00	0.026	2.632	1163.96	0.112	96.38
				220	80.0	2.20	0.029	2.895	1166.94	0.114	97.35
				240	87.0	2.40	0.032	3.158	1169.93	0.124	105.60
				260	97.0	2.60	0.034	3.421	1172.91	0.138	117.43
				280	105.0	2.80	0.037	3.684	1175.90	0.149	126.80
				300	111.0	3.00	0.039	3.947	1178.88	0.158	133.70
				320	118.0	3.20	0.042	4.211	1181.87	0.168	141.78
				340	126.0	3.40	0.045	4.474	1184.85	0.179	151.01
				360	133.0	3.60	0.047	4.737	1187.84	0.189	158.99
				380	137.0	3.80	0.050	5.000	1190.82	0.195	163.37
				400	143.0	4.00	0.053	5.263	1193.81	0.203	170.09
				420	147.0	4.20	0.055	5.526	1196.79	0.209	174.42
				440	151.0	4.40	0.058	5.789	1199.77	0.214	178.72
				460	154.0	4.60	0.061	6.053	1202.76	0.219	181.82
480	157.0	4.80	0.063	6.316	1205.74	0.223	184.90				
500	162.0	5.00	0.066	6.579	1208.73	0.230	190.32				
520	165.0	5.20	0.068	6.842	1211.71	0.234	193.36				
540	167.0	5.40	0.071	7.105	1214.70	0.237	195.23				
560	155.0	5.60	0.074	7.368	1217.68	0.220	180.75				
										qu	195.23
										CU	97.61

Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

 Addis Ababa Institute of Technology Unconfined Compression Strength Test				 Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	15/04/2022	Disturbed									
Project : Geotechnical Investigation program Location : Rufael Sample ID :TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID :TP -1 Depth (m) 3.00							
Moisture content Determination		specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	157.01	Length (mm)	76.00	20	19.0	0.20	0.003	0.263	1137.10	0.027	23.73
Wt of Dry Sample + Container(gm)	118.10	Area, A_0 (mm ²)	1134.11	40	26.0	0.40	0.005	0.526	1140.08	0.037	32.38
Wt. Of Water(gm)	38.91	Volume, (mm ³)	86192.74	60	31.0	0.60	0.008	0.789	1143.07	0.044	38.51
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.822	80	38.0	0.80	0.011	1.053	1146.05	0.054	47.08
Wt of Dry Sample (gm)	101.80	Dry density(gm/cm ³)	1.318	100	46.0	1.00	0.013	1.316	1149.04	0.065	56.85
Water Content(%)	38.22	Rate (mm/min):	2.00	120	50.0	1.20	0.016	1.579	1152.02	0.071	61.63
		Ring Factor	0.00142	140	55.0	1.40	0.018	1.842	1155.01	0.078	67.62
				160	60.0	1.60	0.021	2.105	1157.99	0.085	73.58
				180	68.0	1.80	0.024	2.368	1160.98	0.097	83.17
				200	73.0	2.00	0.026	2.632	1163.96	0.104	89.06
				220	81.0	2.20	0.029	2.895	1166.94	0.115	98.57
				240	88.0	2.40	0.032	3.158	1169.93	0.125	106.81
				260	98.0	2.60	0.034	3.421	1172.91	0.139	118.64
				280	106.0	2.80	0.037	3.684	1175.90	0.151	128.00
				300	111.0	3.00	0.039	3.947	1178.88	0.158	133.70
				320	120.0	3.20	0.042	4.211	1181.87	0.170	144.18
				340	127.0	3.40	0.045	4.474	1184.85	0.180	152.20
				360	133.0	3.60	0.047	4.737	1187.84	0.189	158.99
				380	136.0	3.80	0.050	5.000	1190.82	0.193	162.17
				400	140.0	4.00	0.053	5.263	1193.81	0.199	166.53
				420	140.0	4.20	0.055	5.526	1196.79	0.199	166.11
				440	130.0	4.40	0.058	5.789	1199.77	0.185	153.86
				460	120.0	4.60	0.061	6.053	1202.76	0.170	141.67
										qu	166.53
										CU	83.26

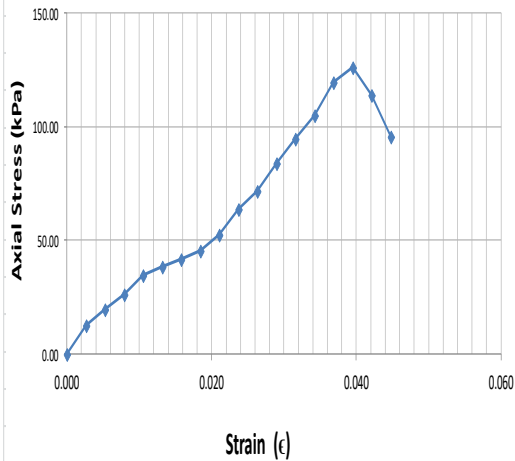
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date 15/04/2022	Sample Disturbed		Soil UCS Test (ASTM D2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID :TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID :TP -1 Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain (ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	155.06	Length (mm)	76.00	20	15.0	0.20	0.003	0.263	1137.10	0.021	18.73
Wt of Dry Sample + Container(gm)	115.20	Area, A ₀ (mm ²)	1134.11	40	23.0	0.40	0.005	0.526	1140.08	0.033	28.65
Wt. Of Water(gm)	39.86	Volume, (mm ³)	86192.74	60	30.0	0.60	0.008	0.789	1143.07	0.043	37.27
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.799	80	34.0	0.80	0.011	1.053	1146.05	0.048	42.13
Wt of Dry Sample (gm)	98.90	Dry density(gm/cm ³)	1.282	100	37.0	1.00	0.013	1.316	1149.04	0.053	45.73
Water Content(%)	40.30	Rate (mm/min):	2.00	120	40.0	1.20	0.016	1.579	1152.02	0.057	49.30
		Ring Factor	0.00142	140	41.0	1.40	0.018	1.842	1155.01	0.058	50.41
				160	44.0	1.60	0.021	2.105	1157.99	0.062	53.96
				180	46.0	1.80	0.024	2.368	1160.98	0.065	56.26
				200	48.0	2.00	0.026	2.632	1163.96	0.068	58.56
				220	50.0	2.20	0.029	2.895	1166.94	0.071	60.84
				240	54.0	2.40	0.032	3.158	1169.93	0.077	65.54
				260	57.0	2.60	0.034	3.421	1172.91	0.081	69.01
				280	60.0	2.80	0.037	3.684	1175.90	0.085	72.46
				300	66.0	3.00	0.039	3.947	1178.88	0.094	79.50
				320	75.0	3.20	0.042	4.211	1181.87	0.107	90.11
				340	82.0	3.40	0.045	4.474	1184.85	0.116	98.27
				360	89.0	3.60	0.047	4.737	1187.84	0.126	106.40
				380	95.0	3.80	0.050	5.000	1190.82	0.135	113.28
				400	100.0	4.00	0.053	5.263	1193.81	0.142	118.95
				420	109.0	4.20	0.055	5.526	1196.79	0.155	129.33
				440	117.0	4.40	0.058	5.789	1199.77	0.166	138.48
				460	122.0	4.60	0.061	6.053	1202.76	0.173	144.04
				480	116.0	4.80	0.063	6.316	1205.74	0.165	136.61
				500	110.0	5.00	0.066	6.579	1208.73	0.156	129.23
										qu	144.04
										CU	72.02



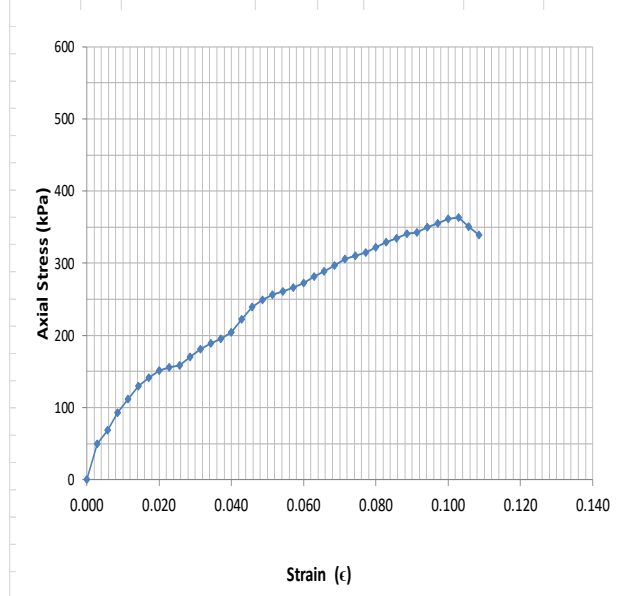
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	15/04/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Rufael Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	154.22	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.10	0.014	12.49
Wt of Dry Sample + Container(gm)	113.20	Area, A_0 (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water(gm)	41.02	Volume, (mm ³)	86192.74	60	21.0	0.60	0.008	0.789	1143.07	0.030	26.09
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.789	80	28.0	0.80	0.011	1.053	1146.05	0.040	34.69
Wt of Dry Sample (gm)	96.90	Dry density(gm/cm ³)	1.257	100	31.0	1.00	0.013	1.316	1149.04	0.044	38.31
Water Content(%)	42.33	Rate (mm/min):	2.00	120	34.0	1.20	0.016	1.579	1152.02	0.048	41.91
		Ring Factor	0.00142	140	37.0	1.40	0.018	1.842	1155.01	0.053	45.49
				160	43.0	1.60	0.021	2.105	1157.99	0.061	52.73
				180	52.0	1.80	0.024	2.368	1160.98	0.074	63.60
				200	59.0	2.00	0.026	2.632	1163.96	0.084	71.98
				220	69.0	2.20	0.029	2.895	1166.94	0.098	83.96
				240	78.0	2.40	0.032	3.158	1169.93	0.111	94.67
				260	87.0	2.60	0.034	3.421	1172.91	0.124	105.33
				280	99.0	2.80	0.037	3.684	1175.90	0.141	119.55
				300	105.0	3.00	0.039	3.947	1178.88	0.149	126.48
				320	95.0	3.20	0.042	4.211	1181.87	0.135	114.14
				340	80.0	3.40	0.045	4.474	1184.85	0.114	95.88
qu 126.48 CU 63.24											



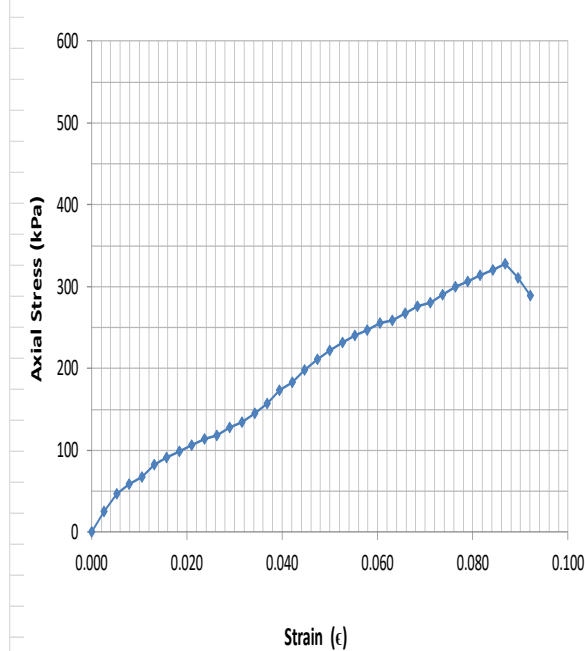
UCS test result for Addisu gebeya

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		8/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location Addisu Gebeya				Location Addisu Gebeya							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	107.81	Length (mm)	70.00	20	40.0	0.20	0.003	0.286	1137.36	0.057	49.94
Wt of Dry Sample + Container(gm)	93.65	Area, A ₀ (mm ²)	1134.11	40	55.0	0.40	0.006	0.571	1140.60	0.078	68.47
Wt. Of Water(gm)	14.16	Volume, (mm ³)	86192.74	60	75.0	0.60	0.009	0.857	1143.84	0.107	93.11
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.251	80	90.0	0.80	0.011	1.143	1147.08	0.128	111.41
Wt of Dry Sample (gm)	77.35	Dry density(gm/cm ³)	1.057	100	105.0	1.00	0.014	1.429	1150.32	0.149	129.62
Water Content(%)	18.31	Rate (mm/min):	2.00	120	115.0	1.20	0.017	1.714	1153.56	0.163	141.56
		Ring Factor	0.00142	140	123.0	1.40	0.020	2.000	1156.80	0.175	150.99
				160	127.0	1.60	0.023	2.286	1160.04	0.180	155.46
				180	130.0	1.80	0.026	2.571	1163.28	0.185	158.69
				200	140.0	2.00	0.029	2.857	1166.52	0.199	170.42
				220	149.0	2.20	0.031	3.143	1169.76	0.212	180.87
				240	156.0	2.40	0.034	3.429	1173.00	0.222	188.85
				260	162.0	2.60	0.037	3.714	1176.24	0.230	195.57
				280	170.0	2.80	0.040	4.000	1179.48	0.241	204.67
				300	185.0	3.00	0.043	4.286	1182.72	0.263	222.12
				320	200.0	3.20	0.046	4.571	1185.96	0.284	239.47
				340	209.0	3.40	0.049	4.857	1189.20	0.297	249.56
				360	215.0	3.60	0.051	5.143	1192.44	0.305	256.03
				380	220.0	3.80	0.054	5.429	1195.68	0.312	261.27
				400	225.0	4.00	0.057	5.714	1198.92	0.320	266.49
				420	231.0	4.20	0.060	6.000	1202.16	0.328	272.86
				440	239.0	4.40	0.063	6.286	1205.40	0.339	281.55
				460	246.0	4.60	0.066	6.571	1208.64	0.349	289.02
				480	253.0	4.80	0.069	6.857	1211.88	0.359	296.45
				500	262.0	5.00	0.071	7.143	1215.12	0.372	306.17
				520	266.0	5.20	0.074	7.429	1218.36	0.378	310.02
				540	271.0	5.40	0.077	7.714	1221.60	0.385	315.01
				560	278.0	5.60	0.080	8.000	1224.84	0.395	322.29
				580	285.0	5.80	0.083	8.286	1228.08	0.405	329.54
				600	290.0	6.00	0.086	8.571	1231.32	0.412	334.44
				620	296.0	6.20	0.089	8.857	1234.57	0.420	340.46
				640	299.0	6.40	0.091	9.143	1237.81	0.425	343.01
				660	306.0	6.60	0.094	9.429	1241.05	0.435	350.12
				680	311.0	6.80	0.097	9.714	1244.29	0.442	354.92
				700	318.0	7.00	0.100	10.000	1247.53	0.452	361.96
				720	320.1	7.20	0.103	10.286	1250.77	0.455	363.41
				740	310.0	7.40	0.106	10.571	1254.01	0.440	351.03
				760	300.0	7.60	0.109	10.857	1257.25	0.426	338.84
											qu 363.41
											CU 181.71



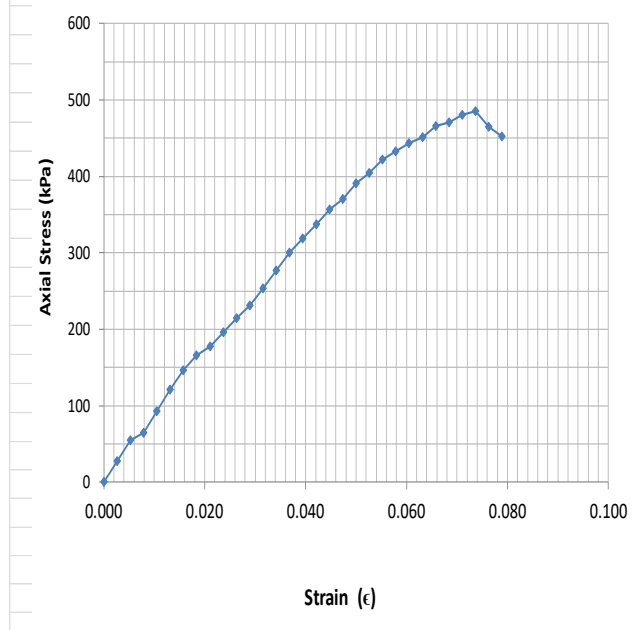
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	8/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	117.91	Length (mm)	76.00	20	20.0	0.20	0.003	0.263	1137.099	0.028	24.98
Wt of Dry Sample + Container(gm)	100.70	Area, A ₀ (mm ²)	1134.11	40	38.0	0.40	0.005	0.526	1140.084	0.054	47.33
Wt. Of Water(gm)	17.21	Volume, (mm ³)	86192.74	60	47.0	0.60	0.008	0.789	1143.068	0.067	58.39
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.368	80	54.0	0.80	0.011	1.053	1146.053	0.077	66.91
Wt of Dry Sample (gm)	84.40	Dry density(gm/cm ³)	1.136	100	67.0	1.00	0.013	1.316	1149.038	0.095	82.80
Water Content(%)	20.39	Rate (mm/min):	2.00	120	74.0	1.20	0.016	1.579	1152.022	0.105	91.21
		Ring Factor	0.00142	140	80.0	1.40	0.018	1.842	1155.007	0.114	98.35
				160	87.0	1.60	0.021	2.105	1157.991	0.124	106.68
				180	93.0	1.80	0.024	2.368	1160.976	0.132	113.75
				200	97.0	2.00	0.026	2.632	1163.960	0.138	118.34
				220	105.0	2.20	0.029	2.895	1166.945	0.149	127.77
				240	111.0	2.40	0.032	3.158	1169.929	0.158	134.73
				260	120.0	2.60	0.034	3.421	1172.914	0.170	145.28
				280	130.0	2.80	0.037	3.684	1175.898	0.185	156.99
				300	144.0	3.00	0.039	3.947	1178.883	0.204	173.45
				320	152.0	3.20	0.042	4.211	1181.867	0.216	182.63
				340	165.0	3.40	0.045	4.474	1184.852	0.234	197.75
				360	177.0	3.60	0.047	4.737	1187.836	0.251	211.59
				380	186.0	3.80	0.050	5.000	1190.821	0.264	221.80
				400	195.0	4.00	0.053	5.263	1193.805	0.277	231.95
				420	203.0	4.20	0.055	5.526	1196.790	0.288	240.86
				440	209.0	4.40	0.058	5.789	1199.774	0.297	247.36
				460	216.0	4.60	0.061	6.053	1202.759	0.307	255.01
				480	220.0	4.80	0.063	6.316	1205.743	0.312	259.09
				500	228.0	5.00	0.066	6.579	1208.728	0.324	267.85
				520	236.0	5.20	0.068	6.842	1211.712	0.335	276.57
				540	240.0	5.40	0.071	7.105	1214.697	0.341	280.56
				560	249.0	5.60	0.074	7.368	1217.681	0.354	290.37
				580	258.0	5.80	0.076	7.632	1220.666	0.366	300.13
				600	264.0	6.00	0.079	7.895	1223.650	0.375	306.36
				620	271.0	6.20	0.082	8.158	1226.635	0.385	313.72
				640	277.0	6.40	0.084	8.421	1229.619	0.393	319.89
				660	285.0	6.60	0.087	8.684	1232.604	0.405	328.33
				680	270.0	6.80	0.089	8.947	1235.588	0.383	310.30
				700	252.0	7.00	0.092	9.211	1238.573	0.358	288.91
										qu	328.33
										CU	164.16



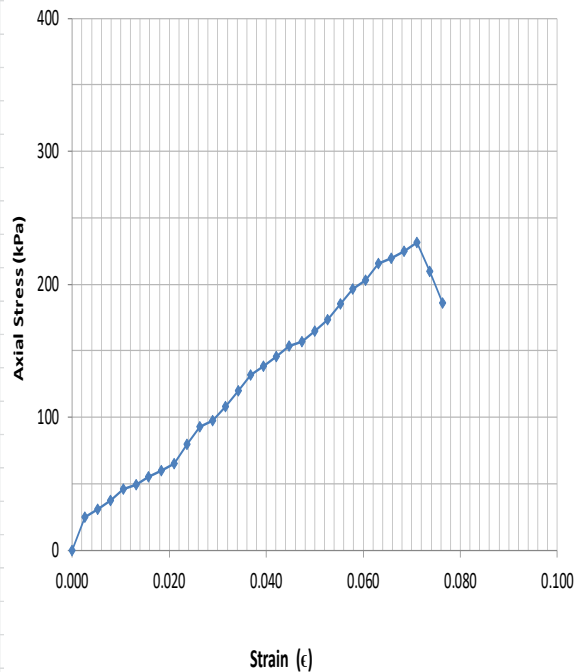
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		8/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain (ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	131.25	Length (mm)	76.00	20	15.0	0.20	0.003	0.263	1137.10	0.021	18.73
Wt of Dry Sample + Container(gm)	109.50	Area, A_0 (mm ²)	1134.11	40	29.0	0.40	0.005	0.526	1140.08	0.041	36.12
Wt. Of Water(gm)	21.75	Volume, (mm ³)	86192.74	60	40.0	0.60	0.008	0.789	1143.07	0.057	49.69
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.523	80	55.0	0.80	0.011	1.053	1146.05	0.078	68.15
Wt of Dry Sample (gm)	93.20	Dry density(gm/cm ³)	1.235	100	65.0	1.00	0.013	1.316	1149.04	0.092	80.33
Water Content(%)	23.34	Rate (mm/min):	2.00	120	80.0	1.20	0.016	1.579	1152.02	0.114	98.61
		Ring Factor	0.00142	140	89.0	1.40	0.018	1.842	1155.01	0.126	109.42
				160	97.0	1.60	0.021	2.105	1157.99	0.138	118.95
				180	100.0	1.80	0.024	2.368	1160.98	0.142	122.31
				200	109.0	2.00	0.026	2.632	1163.96	0.155	132.98
				220	110.0	2.20	0.029	2.895	1166.94	0.156	133.85
				240	114.0	2.40	0.032	3.158	1169.93	0.162	138.37
				260	120.0	2.60	0.034	3.421	1172.91	0.170	145.28
				280	125.0	2.80	0.037	3.684	1175.90	0.178	150.95
				300	130.0	3.00	0.039	3.947	1178.88	0.185	156.59
				320	136.0	3.20	0.042	4.211	1181.87	0.193	163.40
				340	144.0	3.40	0.045	4.474	1184.85	0.204	172.58
				360	152.0	3.60	0.047	4.737	1187.84	0.216	181.71
				380	160.0	3.80	0.050	5.000	1190.82	0.227	190.79
				400	172.0	4.00	0.053	5.263	1193.81	0.244	204.59
				420	182.0	4.20	0.055	5.526	1196.79	0.258	215.94
				440	196.0	4.40	0.058	5.789	1199.77	0.278	231.98
				460	206.0	4.60	0.061	6.053	1202.76	0.293	243.21
				480	213.0	4.80	0.063	6.316	1205.74	0.302	250.85
				500	217.0	5.00	0.066	6.579	1208.73	0.308	254.93
				520	220.0	5.20	0.068	6.842	1211.71	0.312	257.82
				540	224.0	5.40	0.071	7.105	1214.70	0.318	261.86
				560	228.0	5.60	0.074	7.368	1217.68	0.324	265.88
				580	235.0	5.80	0.076	7.632	1220.67	0.334	273.38
				600	242.0	6.00	0.079	7.895	1223.65	0.344	280.83
				620	228.0	6.20	0.082	8.158	1226.63	0.324	263.94
				640	210.0	6.40	0.084	8.421	1229.62	0.298	242.51
											qu 280.83
											CU 140.42



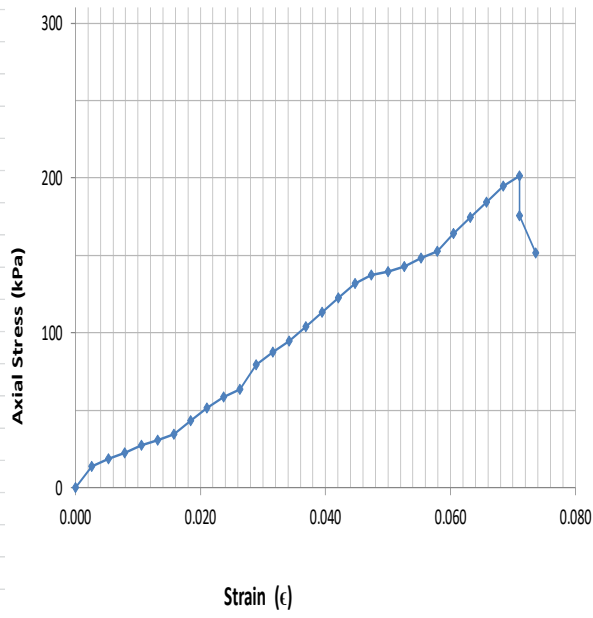
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		8/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : Addisu Gebeya				Location : Addisu Gebeya							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	137.91	Length (mm)	76.00	20	20.0	0.20	0.003	0.263	1137.10	0.028	24.98
Wt of Dry Sample + Container(gm)	113.80	Area, A ₀ (mm ²)	1134.11	40	25.0	0.40	0.005	0.526	1140.08	0.036	31.14
Wt. Of Water(gm)	24.11	Volume, (mm ³)	86192.74	60	30.0	0.60	0.008	0.789	1143.07	0.043	37.27
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.600	80	37.0	0.80	0.011	1.053	1146.05	0.053	45.84
Wt of Dry Sample (gm)	97.50	Dry density(gm/cm ³)	1.283	100	40.0	1.00	0.013	1.316	1149.04	0.057	49.43
Water Content(%)	24.73	Rate (mm/min):	2.00	120	45.0	1.20	0.016	1.579	1152.02	0.064	55.47
		Ring Factor	0.00142	140	49.0	1.40	0.018	1.842	1155.01	0.070	60.24
				160	53.0	1.60	0.021	2.105	1157.99	0.075	64.99
				180	65.0	1.80	0.024	2.368	1160.98	0.092	79.50
				200	76.0	2.00	0.026	2.632	1163.96	0.108	92.72
				220	80.0	2.20	0.029	2.895	1166.94	0.114	97.35
				240	89.0	2.40	0.032	3.158	1169.93	0.126	108.02
				260	99.0	2.60	0.034	3.421	1172.91	0.141	119.86
				280	109.0	2.80	0.037	3.684	1175.90	0.155	131.63
				300	115.0	3.00	0.039	3.947	1178.88	0.163	138.52
				320	121.0	3.20	0.042	4.211	1181.87	0.172	145.38
				340	128.0	3.40	0.045	4.474	1184.85	0.182	153.40
				360	131.0	3.60	0.047	4.737	1187.84	0.186	156.60
				380	138.0	3.80	0.050	5.000	1190.82	0.196	164.56
				400	146.0	4.00	0.053	5.263	1193.81	0.207	173.66
				420	156.0	4.20	0.055	5.526	1196.79	0.222	185.10
				440	166.0	4.40	0.058	5.789	1199.77	0.236	196.47
				460	172.0	4.60	0.061	6.053	1202.76	0.244	203.07
				480	183.0	4.80	0.063	6.316	1205.74	0.260	215.52
				500	187.0	5.00	0.066	6.579	1208.73	0.266	219.69
				520	192.0	5.20	0.068	6.842	1211.71	0.273	225.00
				540	198.0	5.40	0.071	7.105	1214.70	0.281	231.47
				560	180.0	5.60	0.074	7.368	1217.68	0.256	209.91
				580	160.0	5.80	0.076	7.632	1220.67	0.227	186.13
											qu 231.47
											CU 115.73



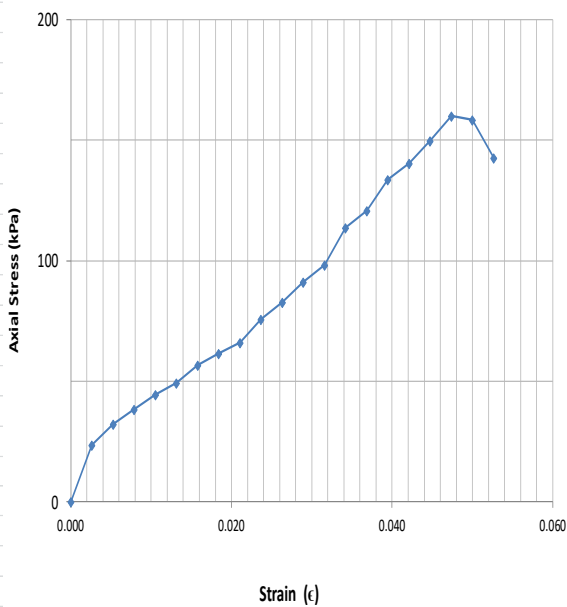
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	8/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID TP -1 Depth (m) 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID TP -1 Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	144.49	Length (mm)	76.00	20	11.0	0.20	0.003	0.263	1137.099	0.016	13.74
Wt of Dry Sample + Container(gm)	117.00	Area, A ₀ (mm ²)	1134.11	40	15.0	0.40	0.005	0.526	1140.084	0.021	18.68
Wt. Of Water(gm)	27.49	Volume, (mm ³)	86192.74	60	18.0	0.60	0.008	0.789	1143.068	0.026	22.36
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.676	80	22.0	0.80	0.011	1.053	1146.053	0.031	27.26
Wt of Dry Sample (gm)	100.70	Dry density(gm/cm ³)	1.317	100	25.0	1.00	0.013	1.316	1149.038	0.036	30.90
Water Content(%)	27.30	Rate (mm/min):	2.00	120	28.0	1.20	0.016	1.579	1152.022	0.040	34.51
		Ring Factor	0.00142	140	35.0	1.40	0.018	1.842	1155.007	0.050	43.03
				160	42.0	1.60	0.021	2.105	1157.991	0.060	51.50
				180	48.0	1.80	0.024	2.368	1160.976	0.068	58.71
				200	52.0	2.00	0.026	2.632	1163.960	0.074	63.44
				220	65.0	2.20	0.029	2.895	1166.945	0.092	79.10
				240	72.0	2.40	0.032	3.158	1169.929	0.102	87.39
				260	78.0	2.60	0.034	3.421	1172.914	0.111	94.43
				280	86.0	2.80	0.037	3.684	1175.898	0.122	103.85
				300	94.0	3.00	0.039	3.947	1178.883	0.133	113.23
				320	102.0	3.20	0.042	4.211	1181.867	0.145	122.55
				340	110.0	3.40	0.045	4.474	1184.852	0.156	131.83
				360	115.0	3.60	0.047	4.737	1187.836	0.163	137.48
				380	117.0	3.80	0.050	5.000	1190.821	0.166	139.52
				400	120.0	4.00	0.053	5.263	1193.805	0.170	142.74
				420	125.0	4.20	0.055	5.526	1196.790	0.178	148.31
				440	129.0	4.40	0.058	5.789	1199.774	0.183	152.68
				460	139.0	4.60	0.061	6.053	1202.759	0.197	164.11
				480	148.0	4.80	0.063	6.316	1205.743	0.210	174.30
				500	157.0	5.00	0.066	6.579	1208.728	0.223	184.44
				520	166.0	5.20	0.068	6.842	1211.712	0.236	194.53
				540	172.0	5.40	0.071	7.105	1214.697	0.244	201.07
				540	150.0	5.40	0.071	7.105	1214.697	0.213	175.35
				560	130.0	5.60	0.074	7.368	1217.681	0.185	151.60
										qu	201.07
										CU	100.54



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date 8/4/2022	Sample Disturbed	Soil UCS Test (ASTM D2166)		Date	Sample Disturbed				
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen data									
Wt of Dry Sample + Container(gm)	119.60	Length (mm)	76.00	Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain (ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Wt. Of Water(gm)	31.44	Area, A ₀ (mm ²)	1134.11	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt. Of Container (gm)	16.30	Volume, (mm ³)	86192.74	20	19.0	0.20	0.003	0.263	1137.099	0.027	23.73
Wt of Dry Sample (gm)	103.30	Bulk density(gm/cm ³)	1.752	40	26.0	0.40	0.005	0.526	1140.084	0.037	32.38
Water Content(%)	30.44	Dry density(gm/cm ³)	1.343	60	31.0	0.60	0.008	0.789	1143.068	0.044	38.51
		Rate (mm/min):	2.00	80	36.0	0.80	0.011	1.053	1146.053	0.051	44.61
		Ring Factor	0.00142	100	40.0	1.00	0.013	1.316	1149.038	0.057	49.43
				120	46.0	1.20	0.016	1.579	1152.022	0.065	56.70
				140	50.0	1.40	0.018	1.842	1155.007	0.071	61.47
				160	54.0	1.60	0.021	2.105	1157.991	0.077	66.22
				180	62.0	1.80	0.024	2.368	1160.976	0.088	75.83
				200	68.0	2.00	0.026	2.632	1163.960	0.097	82.96
				220	75.0	2.20	0.029	2.895	1166.945	0.107	91.26
				240	81.0	2.40	0.032	3.158	1169.929	0.115	98.31
				260	94.0	2.60	0.034	3.421	1172.914	0.133	113.80
				280	100.0	2.80	0.037	3.684	1175.898	0.142	120.76
				300	111.0	3.00	0.039	3.947	1178.883	0.158	133.70
				320	117.0	3.20	0.042	4.211	1181.867	0.166	140.57
				340	125.0	3.40	0.045	4.474	1184.852	0.178	149.81
				360	134.0	3.60	0.047	4.737	1187.836	0.190	160.19
				380	133.0	3.80	0.050	5.000	1190.821	0.189	158.60
				400	120.0	4.00	0.053	5.263	1193.805	0.170	142.74
										qu	160.19
										CU	80.10



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
		Date	Sample			Date	Sample				
Soil UCS Test (ASTM D2166)		8/4/2022	Disturbed	Soil UCS Test (ASTM D2166)			Disturbed				
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformati on Dial Reading	Load Dial Readin g	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	158.43	Length (mm)	76.00	20	22.0	0.20	0.003	0.263	1137.099	0.031	27.47
Wt of Dry Sample + Container(gm)	123.00	Area, A_0 (mm ²)	1134.11	40	25.0	0.40	0.005	0.526	1140.084	0.036	31.14
Wt. Of Water(gm)	35.43	Volume, (mm ³)	86192.74	60	28.0	0.60	0.008	0.789	1143.068	0.040	34.78
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.838	80	35.0	0.80	0.011	1.053	1146.053	0.050	43.37
Wt of Dry Sample (gm)	106.70	Dry density(gm/cm ³)	1.380	100	45.0	1.00	0.013	1.316	1149.038	0.064	55.61
Water Content(%)	33.20	Rate (mm/min):	2.00	120	53.0	1.20	0.016	1.579	1152.022	0.075	65.33
		Ring Factor	0.00142	140	60.0	1.40	0.018	1.842	1155.007	0.085	73.77
				160	67.0	1.60	0.021	2.105	1157.991	0.095	82.16
				180	70.0	1.80	0.024	2.368	1160.976	0.099	85.62
				200	74.0	2.00	0.026	2.632	1163.960	0.105	90.28
				220	79.0	2.20	0.029	2.895	1166.945	0.112	96.13
				240	87.0	2.40	0.032	3.158	1169.929	0.124	105.60
				260	93.0	2.60	0.034	3.421	1172.914	0.132	112.59
				280	100.5	2.80	0.037	3.684	1175.898	0.143	121.36
				300	90.0	3.00	0.039	3.947	1178.883	0.128	108.41
				320	78.0	3.20	0.042	4.211	1181.867	0.111	93.72
											qu 121.36
											CU 60.68

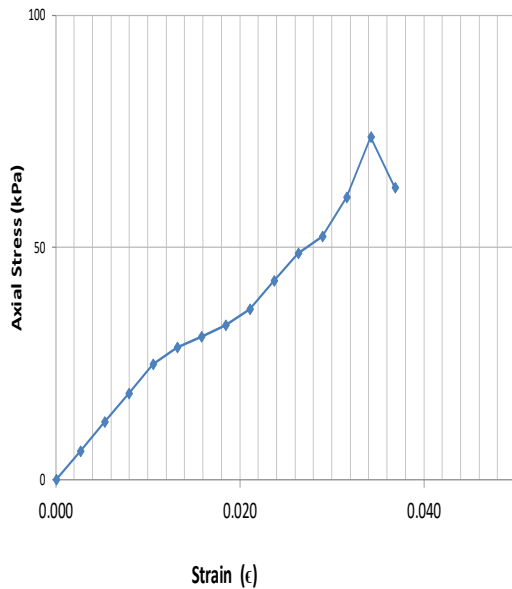
Axial Stress (kPa)

Strain (ϵ)

Deformati on Dial Reading	Load Dial Readin g	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
20	22.0	0.20	0.003	0.263	1137.099	0.031	27.47
40	25.0	0.40	0.005	0.526	1140.084	0.036	31.14
60	28.0	0.60	0.008	0.789	1143.068	0.040	34.78
80	35.0	0.80	0.011	1.053	1146.053	0.050	43.37
100	45.0	1.00	0.013	1.316	1149.038	0.064	55.61
120	53.0	1.20	0.016	1.579	1152.022	0.075	65.33
140	60.0	1.40	0.018	1.842	1155.007	0.085	73.77
160	67.0	1.60	0.021	2.105	1157.991	0.095	82.16
180	70.0	1.80	0.024	2.368	1160.976	0.099	85.62
200	74.0	2.00	0.026	2.632	1163.960	0.105	90.28
220	79.0	2.20	0.029	2.895	1166.945	0.112	96.13
240	87.0	2.40	0.032	3.158	1169.929	0.124	105.60
260	93.0	2.60	0.034	3.421	1172.914	0.132	112.59
280	100.5	2.80	0.037	3.684	1175.898	0.143	121.36
300	90.0	3.00	0.039	3.947	1178.883	0.128	108.41
320	78.0	3.20	0.042	4.211	1181.867	0.111	93.72

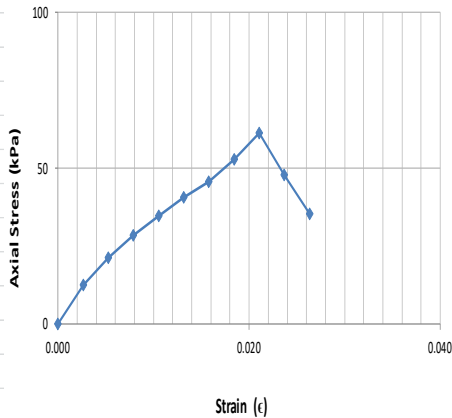
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	8/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00
Wt of Wet Sample + Container(gm)	154.51	Length (mm)	76.00	20	5.0	0.20	0.003	0.263	1137.099	0.007	6.24
Wt of Dry Sample + Container(gm)	116.30	Area, A_0 (mm ²)	1134.11	40	10.0	0.40	0.005	0.526	1140.084	0.014	12.46
Wt. Of Water(gm)	38.21	Volume, (mm ³)	86192.74	60	15.0	0.60	0.008	0.789	1143.068	0.021	18.63
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.793	80	20.0	0.80	0.011	1.053	1146.053	0.028	24.78
Wt of Dry Sample (gm)	100.00	Dry density(gm/cm ³)	1.297	100	23.0	1.00	0.013	1.316	1149.038	0.033	28.42
Water Content(%)	38.21	Rate (mm/min):	2.00	120	25.0	1.20	0.016	1.579	1152.022	0.036	30.82
		Ring Factor	0.00142	140	27.0	1.40	0.018	1.842	1155.007	0.038	33.19
				160	30.0	1.60	0.021	2.105	1157.991	0.043	36.79
				180	35.0	1.80	0.024	2.368	1160.976	0.050	42.81
				200	40.0	2.00	0.026	2.632	1163.960	0.057	48.80
				220	43.0	2.20	0.029	2.895	1166.945	0.061	52.32
				240	50.0	2.40	0.032	3.158	1169.929	0.071	60.69
				260	61.0	2.60	0.034	3.421	1172.914	0.087	73.85
				280	52.0	2.80	0.037	3.684	1175.898	0.074	62.79
										qu	73.85
										CU	36.93



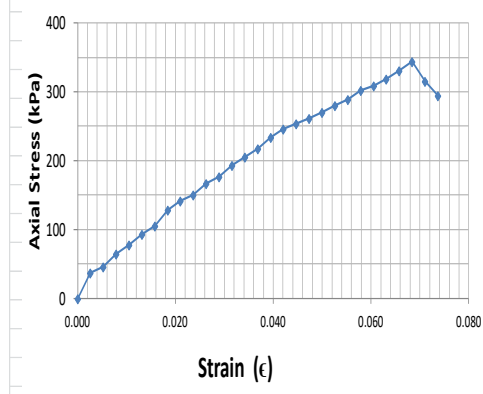
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test								
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample						
	8/4/2022	Disturbed				Disturbed						
Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : Addisu Gebeya Sample ID : TP -1 Depth (m) : 3.00								
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)	
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.115	0.000	0.00	
Wt of Wet Sample + Container(gm)	150.23	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.099	0.014	12.49	
Wt of Dry Sample + Container(gm)	111.99	Area, A ₀ (mm ²)	1134.11	40	17.0	0.40	0.005	0.526	1140.084	0.024	21.17	
Wt. Of Water(gm)	38.24	Volume, (mm ³)	86192.74	60	23.0	0.60	0.008	0.789	1143.068	0.033	28.57	
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.743	80	28.0	0.80	0.011	1.053	1146.053	0.040	34.69	
Wt of Dry Sample (gm)	95.69	Dry density(gm/cm ³)	1.245	100	33.0	1.00	0.013	1.316	1149.038	0.047	40.78	
Water Content(%)	39.97	Rate (mm/min):	2.00	120	37.0	1.20	0.016	1.579	1152.022	0.053	45.61	
		Ring Factor	0.00142	140	43.0	1.40	0.018	1.842	1155.007	0.061	52.87	
				160	50.0	1.60	0.021	2.105	1157.991	0.071	61.31	
				180	39.0	1.80	0.024	2.368	1160.976	0.055	47.70	
				200	29.0	2.00	0.026	2.632	1163.960	0.041	35.38	
											qu	61.31
											CU	30.66



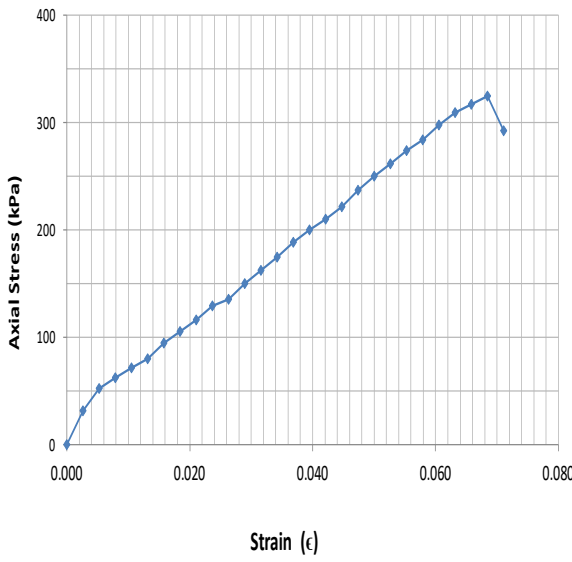
UCS TEST RESULT FOR BRITISH EMBASSY

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test						
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample			
		12/4/2022	Disturbed				Disturbed			
Project : Geotechnical investigation Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00				Project : program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00						
Moisture content Determination		Specimen Data		Deformation on Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	129.84	Length (mm)	76.00	20	30.0	0.20	0.263	1137.10	0.043	37.46
Wt of Dry Sample + Container(gm)	110.10	Area, A_0 (mm ²)	1134.11	40	37.0	0.40	0.526	1140.08	0.053	46.08
Wt. Of Water(gm)	19.74	Volume, (mm ³)	86192.74	60	52.0	0.60	0.789	1143.07	0.074	64.60
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.506	80	63.0	0.80	1.053	1146.05	0.089	78.06
Wt of Dry Sample (gm)	93.80	Dry density(gm/cm ³)	1.244	100	75.0	1.00	1.316	1149.04	0.107	92.69
Water Content(%)	21.04	Rate (mm/min):	2.00	120	85.0	1.20	1.579	1152.02	0.121	104.77
		Ring Factor	0.00142	140	104.0	1.40	1.842	1155.01	0.148	127.86
				160	115.0	1.60	2.105	1157.99	0.163	141.02
				180	123.0	1.80	2.368	1160.98	0.175	150.44
				200	137.0	2.00	2.632	1163.96	0.195	167.14
				220	145.0	2.20	2.895	1166.94	0.206	176.44
				240	159.0	2.40	3.158	1169.93	0.226	192.99
				260	170.0	2.60	3.421	1172.91	0.241	205.81
				280	180.0	2.80	3.684	1175.90	0.256	217.37
				300	194.0	3.00	3.947	1178.88	0.275	233.68
				320	205.0	3.20	4.211	1181.87	0.291	246.31
				340	212.0	3.40	4.474	1184.85	0.301	254.07
				360	219.0	3.60	4.737	1187.84	0.311	261.80
				380	227.0	3.80	5.000	1190.82	0.322	270.69
				400	236.0	4.00	5.263	1193.81	0.335	280.72
				420	244.0	4.20	5.526	1196.79	0.346	289.51
				440	255.0	4.40	5.789	1199.77	0.362	301.81
				460	262.0	4.60	6.053	1202.76	0.372	309.32
				480	271.0	4.80	6.316	1205.74	0.385	319.16
				500	282.0	5.00	6.579	1208.73	0.400	331.29
				520	294.0	5.20	6.842	1211.71	0.417	344.54
				540	270.0	5.40	7.105	1214.70	0.383	315.63
				560	253.0	5.60	7.368	1217.68	0.359	295.04
qu										344.54
CU										172.27



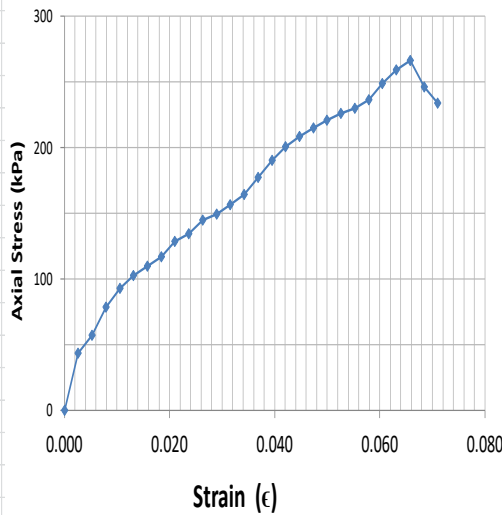
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading g	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	136.23	Length (mm)	76.00	20	25.0	0.20	0.003	0.263	1137.10	0.036	31.22
Wt of Dry Sample + Container(gm)	113.60	Area, A ₀ (mm ²)	1134.11	40	42.0	0.40	0.005	0.526	1140.08	0.060	52.31
Wt. Of Water(gm)	22.63	Volume, (mm ³)	86192.74	60	50.0	0.60	0.008	0.789	1143.07	0.071	62.11
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.581	80	58.0	0.80	0.011	1.053	1146.05	0.082	71.86
Wt of Dry Sample (gm)	97.30	Dry density(gm/cm ³)	1.282	100	65.0	1.00	0.013	1.316	1149.04	0.092	80.33
Water Content(%)	23.26	Rate (mm/min):	2.00	120	77.0	1.20	0.016	1.579	1152.02	0.109	94.91
		Ring Factor	0.00142	140	86.0	1.40	0.018	1.842	1155.01	0.122	105.73
				160	95.0	1.60	0.021	2.105	1157.99	0.135	116.49
				180	106.0	1.80	0.024	2.368	1160.98	0.151	129.65
				200	111.0	2.00	0.026	2.632	1163.96	0.158	135.42
				220	123.0	2.20	0.029	2.895	1166.94	0.175	149.67
				240	134.0	2.40	0.032	3.158	1169.93	0.190	162.64
				260	144.0	2.60	0.034	3.421	1172.91	0.204	174.34
				280	156.0	2.80	0.037	3.684	1175.90	0.222	188.38
				300	166.0	3.00	0.039	3.947	1178.88	0.236	199.95
				320	175.0	3.20	0.042	4.211	1181.87	0.249	210.26
				340	185.0	3.40	0.045	4.474	1184.85	0.263	221.72
				360	198.0	3.60	0.047	4.737	1187.84	0.281	236.70
				380	210.0	3.80	0.050	5.000	1190.82	0.298	250.42
				400	220.0	4.00	0.053	5.263	1193.81	0.312	261.68
				420	231.0	4.20	0.055	5.526	1196.79	0.328	274.08
				440	240.0	4.40	0.058	5.789	1199.77	0.341	284.05
				460	252.0	4.60	0.061	6.053	1202.76	0.358	297.52
				480	263.0	4.80	0.063	6.316	1205.74	0.373	309.73
				500	270.0	5.00	0.066	6.579	1208.73	0.383	317.19
				520	277.0	5.20	0.068	6.842	1211.71	0.393	324.62
				540	250.0	5.40	0.071	7.105	1214.70	0.355	292.25
				560	230.0	5.60	0.074	7.368	1217.68	0.327	268.21
				580	220.0	5.80	0.076	7.632	1220.67	0.312	255.93
										qu	324.62
										CU	162.31



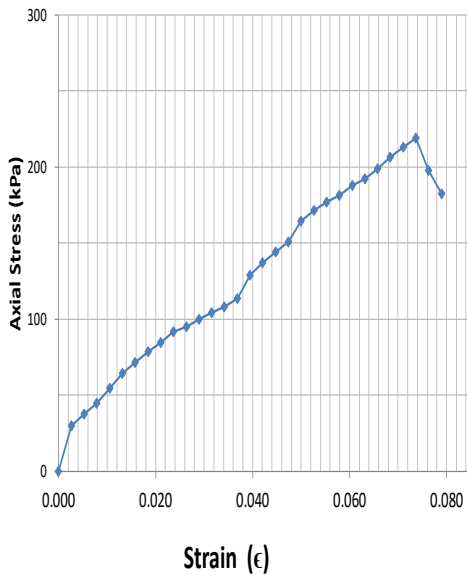
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample Disturbed		Soil UCS Test (ASTM D2166)	Date	Sample Disturbed					
Project : Geotechnical Investigation program	12/4/2022			Project : Geotechnical Investigation program							
Location : British Embassy				Location : British Embassy							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading g	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	147.70	Length (mm)	76.00	20	35.0	0.20	0.003	0.263	1137.10	0.050	43.71
Wt of Dry Sample + Container(gm)	120.50	Area, A ₀ (mm ²)	1134.11	40	46.0	0.40	0.005	0.526	1140.08	0.065	57.29
Wt. Of Water(gm)	27.20	Volume, (mm ³)	86192.74	60	63.0	0.60	0.008	0.789	1143.07	0.089	78.26
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.714	80	75.0	0.80	0.011	1.053	1146.05	0.107	92.93
Wt of Dry Sample (gm)	104.20	Dry density(gm/cm ³)	1.359	100	83.0	1.00	0.013	1.316	1149.04	0.118	102.57
Water Content(%)	26.10	Rate (mm/min):	2.00	120	89.0	1.20	0.016	1.579	1152.02	0.126	109.70
		Ring Factor	0.00142	140	95.0	1.40	0.018	1.842	1155.01	0.135	116.80
				160	105.0	1.60	0.021	2.105	1157.99	0.149	128.76
				180	110.0	1.80	0.024	2.368	1160.98	0.156	134.54
				200	119.0	2.00	0.026	2.632	1163.96	0.169	145.18
				220	123.0	2.20	0.029	2.895	1166.94	0.175	149.67
				240	129.0	2.40	0.032	3.158	1169.93	0.183	156.57
				260	136.0	2.60	0.034	3.421	1172.91	0.193	164.65
				280	147.0	2.80	0.037	3.684	1175.90	0.209	177.52
				300	158.0	3.00	0.039	3.947	1178.88	0.224	190.32
				320	167.0	3.20	0.042	4.211	1181.87	0.237	200.65
				340	174.0	3.40	0.045	4.474	1184.85	0.247	208.53
				360	180.0	3.60	0.047	4.737	1187.84	0.256	215.18
				380	185.0	3.80	0.050	5.000	1190.82	0.263	220.60
				400	190.0	4.00	0.053	5.263	1193.81	0.270	226.00
				420	194.0	4.20	0.055	5.526	1196.79	0.275	230.18
				440	200.0	4.40	0.058	5.789	1199.77	0.284	236.71
				460	211.0	4.60	0.061	6.053	1202.76	0.300	249.11
				480	220.0	4.80	0.063	6.316	1205.74	0.312	259.09
				500	227.0	5.00	0.066	6.579	1208.73	0.322	266.68
				520	210.0	5.20	0.068	6.842	1211.71	0.298	246.10
				540	200.0	5.40	0.071	7.105	1214.70	0.284	233.80
											qu 266.68
											CU 133.34



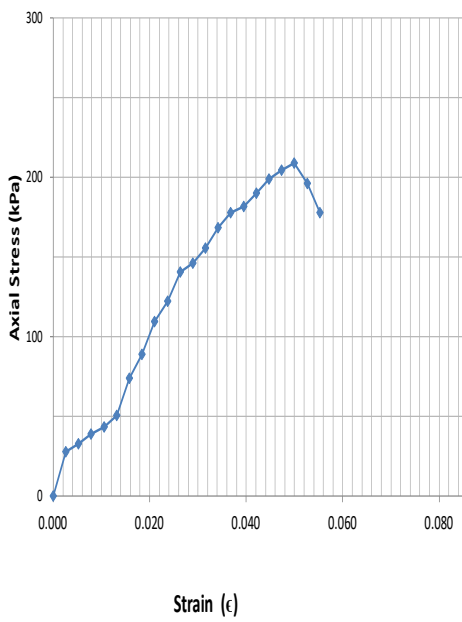
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	152.80	Length (mm)	76.00	20	24.0	0.20	0.003	0.263	1137.10	0.034	29.97
Wt of Dry Sample + Container(gm)	122.69	Area, A_0 (mm ²)	1134.11	40	30.0	0.40	0.005	0.526	1140.08	0.043	37.37
Wt. Of Water(gm)	30.11	Volume, (mm ³)	86192.74	60	36.0	0.60	0.008	0.789	1143.07	0.051	44.72
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.773	80	44.0	0.80	0.011	1.053	1146.05	0.062	54.52
Wt of Dry Sample (gm)	106.39	Dry density(gm/cm ³)	1.382	100	52.0	1.00	0.013	1.316	1149.04	0.074	64.26
Water Content(%)	28.30	Rate (mm/min):	2.00	120	58.0	1.20	0.016	1.579	1152.02	0.082	71.49
		Ring Factor	0.00142	140	64.0	1.40	0.018	1.842	1155.01	0.091	78.68
				160	69.0	1.60	0.021	2.105	1157.99	0.098	84.61
				180	75.0	1.80	0.024	2.368	1160.98	0.107	91.73
				200	78.0	2.00	0.026	2.632	1163.96	0.111	95.16
				220	82.0	2.20	0.029	2.895	1166.94	0.116	99.78
				240	86.0	2.40	0.032	3.158	1169.93	0.122	104.38
				260	89.0	2.60	0.034	3.421	1172.91	0.126	107.75
				280	94.0	2.80	0.037	3.684	1175.90	0.133	113.51
				300	107.0	3.00	0.039	3.947	1178.88	0.152	128.88
				320	114.0	3.20	0.042	4.211	1181.87	0.162	136.97
				340	120.0	3.40	0.045	4.474	1184.85	0.170	143.82
				360	126.0	3.60	0.047	4.737	1187.84	0.179	150.63
				380	138.0	3.80	0.050	5.000	1190.82	0.196	164.56
				400	144.0	4.00	0.053	5.263	1193.81	0.204	171.28
				420	149.0	4.20	0.055	5.526	1196.79	0.212	176.79
				440	153.0	4.40	0.058	5.789	1199.77	0.217	181.08
				460	159.0	4.60	0.061	6.053	1202.76	0.226	187.72
				480	163.0	4.80	0.063	6.316	1205.74	0.231	191.96
				500	169.0	5.00	0.066	6.579	1208.73	0.240	198.54
				520	176.0	5.20	0.068	6.842	1211.71	0.250	206.25
				540	182.0	5.40	0.071	7.105	1214.70	0.258	212.76
				560	188.0	5.60	0.074	7.368	1217.68	0.267	219.24
				580	170.0	5.80	0.076	7.632	1220.67	0.241	197.76
				600	157.0	6.00	0.079	7.895	1223.65	0.223	182.19
											qu 219.24
											CU 109.62



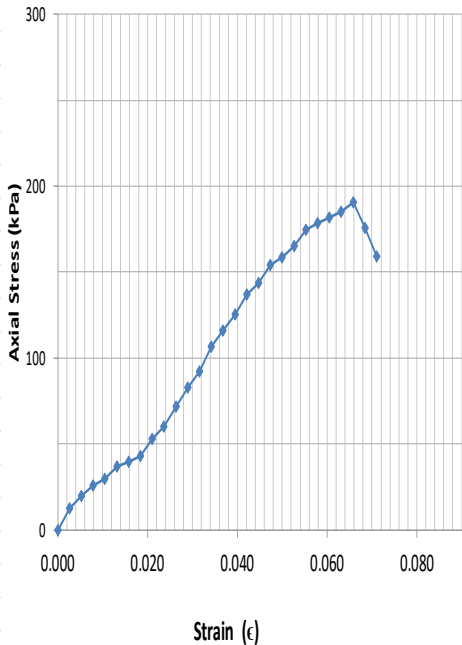
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	158.78	Length (mm)	76.00	20	22.0	0.20	0.003	0.263	1137.10	0.031	27.47
Wt of Dry Sample + Container(gm)	125.80	Area, A ₀ (mm ²)	1134.11	40	26.0	0.40	0.005	0.526	1140.08	0.037	32.38
Wt. Of Water(gm)	32.98	Volume, (mm ³)	86192.74	60	31.0	0.60	0.008	0.789	1143.07	0.044	38.51
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.842	80	35.0	0.80	0.011	1.053	1146.05	0.050	43.37
Wt of Dry Sample (gm)	109.50	Dry density(gm/cm ³)	1.416	100	41.0	1.00	0.013	1.316	1149.04	0.058	50.67
Water Content(%)	30.12	Rate (mm/min):	2.00	120	60.0	1.20	0.016	1.579	1152.02	0.085	73.96
		Ring Factor	0.00142	140	72.0	1.40	0.018	1.842	1155.01	0.102	88.52
				160	89.0	1.60	0.021	2.105	1157.99	0.126	109.14
				180	100.0	1.80	0.024	2.368	1160.98	0.142	122.31
				200	115.0	2.00	0.026	2.632	1163.96	0.163	140.30
				220	120.0	2.20	0.029	2.895	1166.94	0.170	146.02
				240	128.0	2.40	0.032	3.158	1169.93	0.182	155.36
				260	139.0	2.60	0.034	3.421	1172.91	0.197	168.28
				280	147.0	2.80	0.037	3.684	1175.90	0.209	177.52
				300	151.0	3.00	0.039	3.947	1178.88	0.214	181.88
				320	158.0	3.20	0.042	4.211	1181.87	0.224	189.84
				340	166.0	3.40	0.045	4.474	1184.85	0.236	198.94
				360	171.0	3.60	0.047	4.737	1187.84	0.243	204.42
				380	175.0	3.80	0.050	5.000	1190.82	0.249	208.68
				400	165.0	4.00	0.053	5.263	1193.81	0.234	196.26
				420	150.0	4.20	0.055	5.526	1196.79	0.213	177.98
											qu 208.68
											CU 104.34



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : British Embassy				Location : British Embassy							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	160.87	Length (mm)	76.00	20	10.0	0.20	0.003	0.263	1137.10	0.014	12.49
Wt of Dry Sample + Container(gm)	125.90	Area, A_0 (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water(gm)	34.97	Volume, (mm ³)	86192.74	60	21.0	0.60	0.008	0.789	1143.07	0.030	26.09
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.866	80	24.0	0.80	0.011	1.053	1146.05	0.034	29.74
Wt of Dry Sample (gm)	109.60	Dry density(gm/cm ³)	1.415	100	30.0	1.00	0.013	1.316	1149.04	0.043	37.07
Water Content(%)	31.91	Rate (mm/min):	2.00	120	32.0	1.20	0.016	1.579	1152.02	0.045	39.44
		Ring Factor	0.00142	140	35.0	1.40	0.018	1.842	1155.01	0.050	43.03
				160	43.0	1.60	0.021	2.105	1157.99	0.061	52.73
				180	49.0	1.80	0.024	2.368	1160.98	0.070	59.93
				200	59.0	2.00	0.026	2.632	1163.96	0.084	71.98
				220	68.0	2.20	0.029	2.895	1166.94	0.097	82.75
				240	76.0	2.40	0.032	3.158	1169.93	0.108	92.24
				260	88.0	2.60	0.034	3.421	1172.91	0.125	106.54
				280	96.0	2.80	0.037	3.684	1175.90	0.136	115.93
				300	104.0	3.00	0.039	3.947	1178.88	0.148	125.27
				320	114.0	3.20	0.042	4.211	1181.87	0.162	136.97
				340	120.0	3.40	0.045	4.474	1184.85	0.170	143.82
				360	129.0	3.60	0.047	4.737	1187.84	0.183	154.21
				380	133.0	3.80	0.050	5.000	1190.82	0.189	158.60
				400	139.0	4.00	0.053	5.263	1193.81	0.197	165.34
				420	147.0	4.20	0.055	5.526	1196.79	0.209	174.42
				440	151.0	4.40	0.058	5.789	1199.77	0.214	178.72
				460	154.0	4.60	0.061	6.053	1202.76	0.219	181.82
				480	157.0	4.80	0.063	6.316	1205.74	0.223	184.90
				500	162.5	5.00	0.066	6.579	1208.73	0.231	190.90
				520	150.0	5.20	0.068	6.842	1211.71	0.213	175.78
				540	136.0	5.40	0.071	7.105	1214.697	0.193	158.99
											qu 190.90
											CU 95.45



Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
		Date	Sample			Date	Sample				
Soil UCS Test (ASTM D2166)		12/4/2022	Disturbed	Soil UCS Test (ASTM D2166)			Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : British Embassy				Location : British Embassy							
Sample ID : TP -1				Sample ID : TP -1							
Depth (m) : 3.00				Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	0.0	0.00	0.00	0.000	1134.11	0.000	0.00
Wt of Wet Sample + Container(gm)	159.39	Length (mm)	76.00	20	30.0	0.20	0.003	0.263	1137.10	0.043	37.46
Wt of Dry Sample + Container(gm)	122.90	Area, A ₀ (mm ²)	1134.11	40	44.0	0.40	0.005	0.526	1140.08	0.062	54.80
Wt. Of Water(gm)	36.49	Volume, (mm ³)	86192.74	60	56.0	0.60	0.008	0.789	1143.07	0.080	69.57
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.849	80	72.0	0.80	0.011	1.053	1146.05	0.102	89.21
Wt of Dry Sample (gm)	106.60	Dry density(gm/cm ³)	1.378	100	79.0	1.00	0.013	1.316	1149.04	0.112	97.63
Water Content(%)	34.23	Rate (mm/min):	2.00	120	93.0	1.20	0.016	1.579	1152.02	0.132	114.63
		Ring Factor	0.00142	140	99.0	1.40	0.018	1.842	1155.01	0.141	121.71
				160	105.0	1.60	0.021	2.105	1157.99	0.149	128.76
				180	110.0	1.80	0.024	2.368	1160.98	0.156	134.54
				200	114.0	2.00	0.026	2.632	1163.96	0.162	139.08
				220	118.0	2.20	0.029	2.895	1166.94	0.168	143.59
				240	125.0	2.40	0.032	3.158	1169.93	0.178	151.72
				260	130.0	2.60	0.034	3.421	1172.91	0.185	157.39
				280	136.0	2.80	0.037	3.684	1175.90	0.193	164.23
				300	141.0	3.00	0.039	3.947	1178.88	0.200	169.84
				320	130.0	3.20	0.042	4.211	1181.87	0.185	156.19
				340	119.0	3.40	0.045	4.474	1184.85	0.169	142.62
										qu	169.84
										CU	84.92

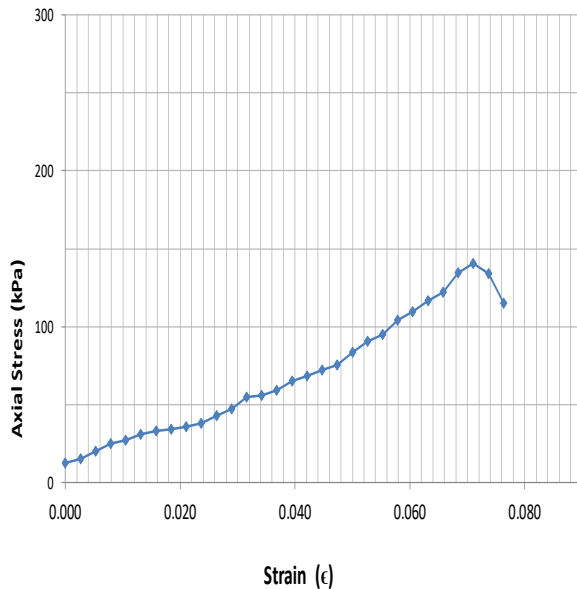
Axial Stress (kPa)

Strain (ε)

qu	169.84
CU	84.92

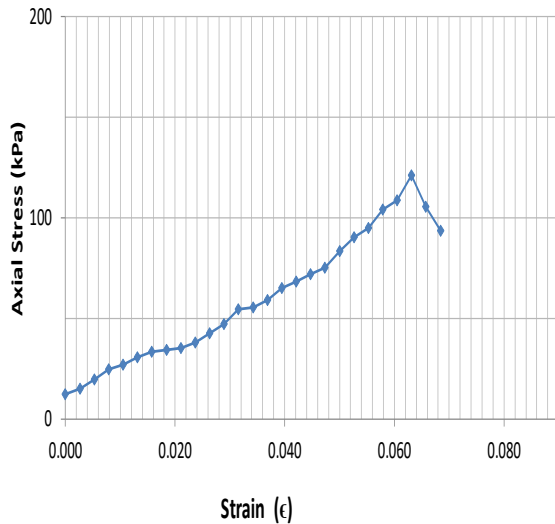
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00				Project : Geotechnical Investigation program Location : British Embassy Sample ID : TP -1 Depth (m) : 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading g	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	10.0	0.00	0.00	0.000	1134.11	0.014	12.52
Wt of Wet Sample + Container(gm)	156.23	Length (mm)	76.00	20	12.0	0.20	0.003	0.263	1137.10	0.017	14.99
Wt of Dry Sample + Container(gm)	118.50	Area, A_0 (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water(gm)	37.73	Volume, (mm ³)	86192.74	60	20.0	0.60	0.008	0.789	1143.07	0.028	24.85
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.813	80	22.0	0.80	0.011	1.053	1146.05	0.031	27.26
Wt of Dry Sample (gm)	102.20	Dry density(gm/cm ³)	1.324	100	25.0	1.00	0.013	1.316	1149.04	0.036	30.90
Water Content(%)	36.91	Rate (mm/min):	2.00	120	27.0	1.20	0.016	1.579	1152.02	0.038	33.28
		Ring Factor	0.00142	140	28.0	1.40	0.018	1.842	1155.01	0.040	34.42
				160	29.0	1.60	0.021	2.105	1157.99	0.041	35.56
				180	31.0	1.80	0.024	2.368	1160.98	0.044	37.92
				200	35.0	2.00	0.026	2.632	1163.96	0.050	42.70
				220	39.0	2.20	0.029	2.895	1166.94	0.055	47.46
				240	45.0	2.40	0.032	3.158	1169.93	0.064	54.62
				260	46.0	2.60	0.034	3.421	1172.91	0.065	55.69
				280	49.0	2.80	0.037	3.684	1175.90	0.070	59.17
				300	54.0	3.00	0.039	3.947	1178.88	0.077	65.04
				320	57.0	3.20	0.042	4.211	1181.87	0.081	68.48
				340	60.0	3.40	0.045	4.474	1184.85	0.085	71.91
				360	63.0	3.60	0.047	4.737	1187.84	0.089	75.31
				380	70.0	3.80	0.050	5.000	1190.82	0.099	83.47
				400	76.0	4.00	0.053	5.263	1193.81	0.108	90.40
				420	80.0	4.20	0.055	5.526	1196.79	0.114	94.92
				440	88.0	4.40	0.058	5.789	1199.77	0.125	104.15
				460	93.0	4.60	0.061	6.053	1202.76	0.132	109.80
				480	99.0	4.80	0.063	6.316	1205.74	0.141	116.59
				500	104.0	5.00	0.066	6.579	1208.73	0.148	122.18
				520	115.0	5.20	0.068	6.842	1211.71	0.163	134.77
				540	120.0	5.40	0.071	7.105	1214.70	0.170	140.28
				560	115.0	5.60	0.074	7.368	1217.68	0.163	134.11
				580	99.0	5.80	0.076	7.632	1220.67	0.141	115.17
										qu	140.28
										CU	70.14





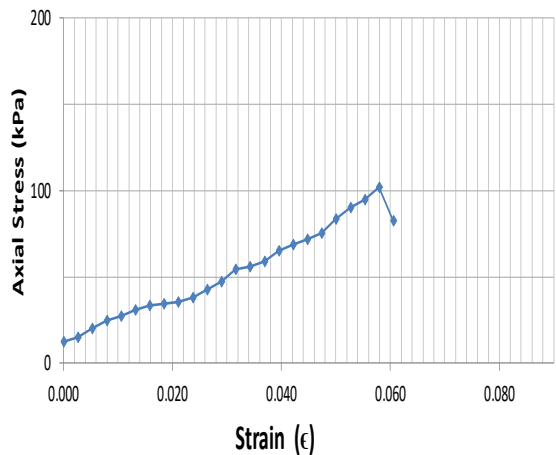
Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

Addis Ababa Institute of Technology Unconfined Compression Strength Test				Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)	Date	Sample		Soil UCS Test (ASTM D2166)	Date	Sample					
	12/4/2022	Disturbed				Disturbed					
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location : British Embassy				Location : British Embassy							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading g	Sample Deformation ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	10.0	0.00	0.00	0.000	1134.11	0.014	12.52
Wt of Wet Sample + Container(gm)	153.71	Length (mm)	76.00	20	12.0	0.20	0.003	0.263	1137.10	0.017	14.99
Wt of Dry Sample + Container(gm)	114.87	Area, A ₀ (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water(gm)	38.84	Volume, (mm ³)	86192.74	60	20.0	0.60	0.008	0.789	1143.07	0.028	24.85
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.783	80	22.0	0.80	0.011	1.053	1146.05	0.031	27.26
Wt of Dry Sample (gm)	98.57	Dry density(gm/cm ³)	1.279	100	25.0	1.00	0.013	1.316	1149.04	0.036	30.90
Water Content(%)	39.41	Rate (mm/min):	2.00	120	27.0	1.20	0.016	1.579	1152.02	0.038	33.28
		Ring Factor	0.00142	140	28.0	1.40	0.018	1.842	1155.01	0.040	34.42
				160	29.0	1.60	0.021	2.105	1157.99	0.041	35.56
				180	31.0	1.80	0.024	2.368	1160.98	0.044	37.92
				200	35.0	2.00	0.026	2.632	1163.96	0.050	42.70
				220	39.0	2.20	0.029	2.895	1166.94	0.055	47.46
				240	45.0	2.40	0.032	3.158	1169.93	0.064	54.62
				260	46.0	2.60	0.034	3.421	1172.91	0.065	55.69
				280	49.0	2.80	0.037	3.684	1175.90	0.070	59.17
				300	54.0	3.00	0.039	3.947	1178.88	0.077	65.04
				320	57.0	3.20	0.042	4.211	1181.87	0.081	68.48
				340	60.0	3.40	0.045	4.474	1184.85	0.085	71.91
				360	63.0	3.60	0.047	4.737	1187.84	0.089	75.31
				380	70.0	3.80	0.050	5.000	1190.82	0.099	83.47
				400	76.0	4.00	0.053	5.263	1193.81	0.108	90.40
				420	80.0	4.20	0.055	5.526	1196.79	0.114	94.92
				440	88.0	4.40	0.058	5.789	1199.77	0.125	104.15
				460	92.0	4.60	0.061	6.053	1202.76	0.131	108.62
				480	103.0	4.80	0.063	6.316	1205.74	0.146	121.30
				500	90.0	5.00	0.066	6.579	1208.73	0.128	105.73
				520	80.0	5.20	0.068	6.842	1211.71	0.114	93.75
										qu	121.30
										CU	60.65

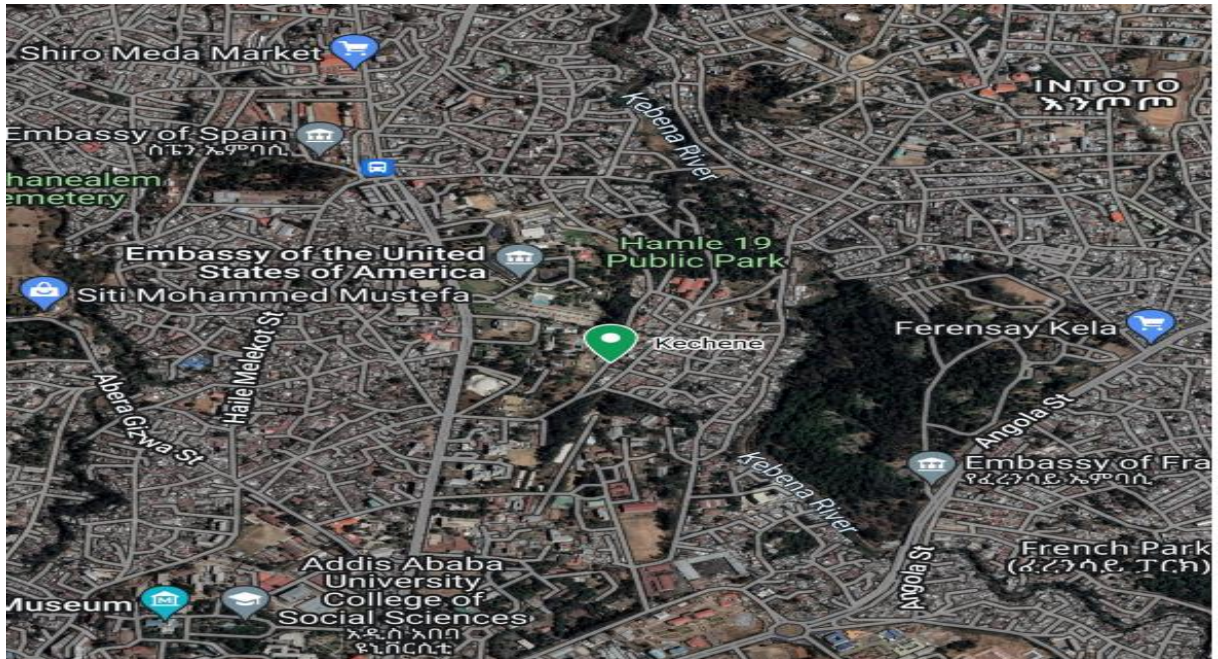


Relationship Between Water content ratio and Undrained Shear Strength of Fine grained Soil

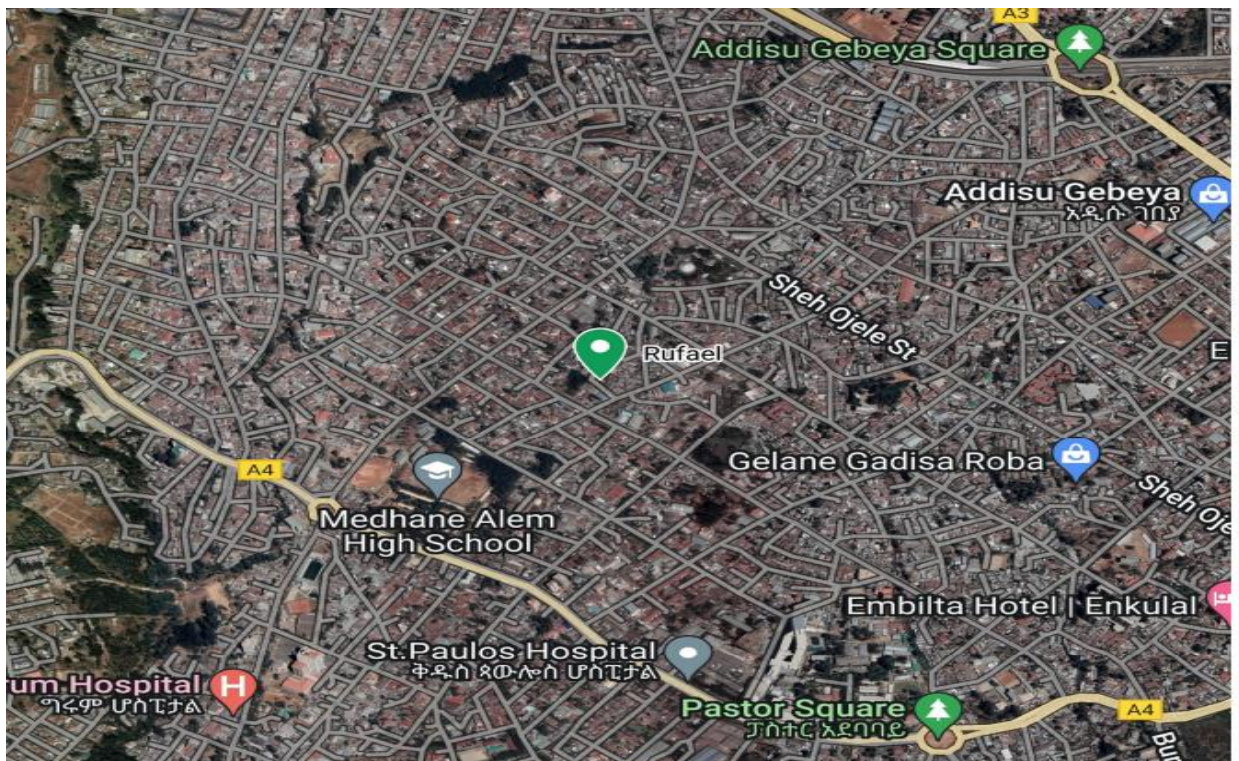
 Addis Ababa Institute of Technology Unconfined Compression Strength Test				 Addis Ababa Institute of Technology Unconfined Compression Strength Test							
Soil UCS Test (ASTM D2166)		Date	Sample	Soil UCS Test (ASTM D2166)		Date	Sample				
		12/4/2022	Disturbed				Disturbed				
Project : Geotechnical Investigation program				Project : Geotechnical Investigation program							
Location British Embassy				Location British Embassy							
Sample ID TP -1				Sample ID TP -1							
Depth (m) 3.00				Depth (m) 3.00							
Moisture content Determination		Specimen Data		Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	Strain(ϵ)	% Strain	Corrected Area A'	Load (kN)	Stress (kPa)
Container No		Dia (mm)	38.00	0	10.0	0.00	0.00	0.000	1134.11	0.014	12.52
Wt of Wet Sample + Container(gm)	151.77	Length (mm)	76.00	20	12.0	0.20	0.003	0.263	1137.10	0.017	14.99
Wt of Dry Sample + Container(gm)	111.45	Area, A_0 (mm ²)	1134.11	40	16.0	0.40	0.005	0.526	1140.08	0.023	19.93
Wt. Of Water(gm)	40.32	Volume, (mm ³)	86192.74	60	20.0	0.60	0.008	0.789	1143.07	0.028	24.85
Wt. Of Container (gm)	16.30	Bulk density(gm/cm ³)	1.761	80	22.0	0.80	0.011	1.053	1146.05	0.031	27.26
Wt of Dry Sample (gm)	95.15	Dry density(gm/cm ³)	1.237	100	25.0	1.00	0.013	1.316	1149.04	0.036	30.90
Water Content(%)	42.37	Rate (mm/min):	2.00	120	27.0	1.20	0.016	1.579	1152.02	0.038	33.28
		Ring Factor	0.00142	140	28.0	1.40	0.018	1.842	1155.01	0.040	34.42
				160	29.0	1.60	0.021	2.105	1157.99	0.041	35.56
				180	31.0	1.80	0.024	2.368	1160.98	0.044	37.92
				200	35.0	2.00	0.026	2.632	1163.96	0.050	42.70
				220	39.0	2.20	0.029	2.895	1166.94	0.055	47.46
				240	45.0	2.40	0.032	3.158	1169.93	0.064	54.62
				260	46.0	2.60	0.034	3.421	1172.91	0.065	55.69
				280	49.0	2.80	0.037	3.684	1175.90	0.070	59.17
				300	54.0	3.00	0.039	3.947	1178.88	0.077	65.04
				320	57.0	3.20	0.042	4.211	1181.87	0.081	68.48
				340	60.0	3.40	0.045	4.474	1184.85	0.085	71.91
				360	63.0	3.60	0.047	4.737	1187.84	0.089	75.31
				380	70.0	3.80	0.050	5.000	1190.82	0.099	83.47
				400	76.0	4.00	0.053	5.263	1193.81	0.108	90.40
				420	80.0	4.20	0.055	5.526	1196.79	0.114	94.92
				440	86.0	4.40	0.058	5.789	1199.77	0.122	101.79
				460	70.0	4.60	0.061	6.053	1202.76	0.099	82.64
											qu 101.79
											CU 50.89



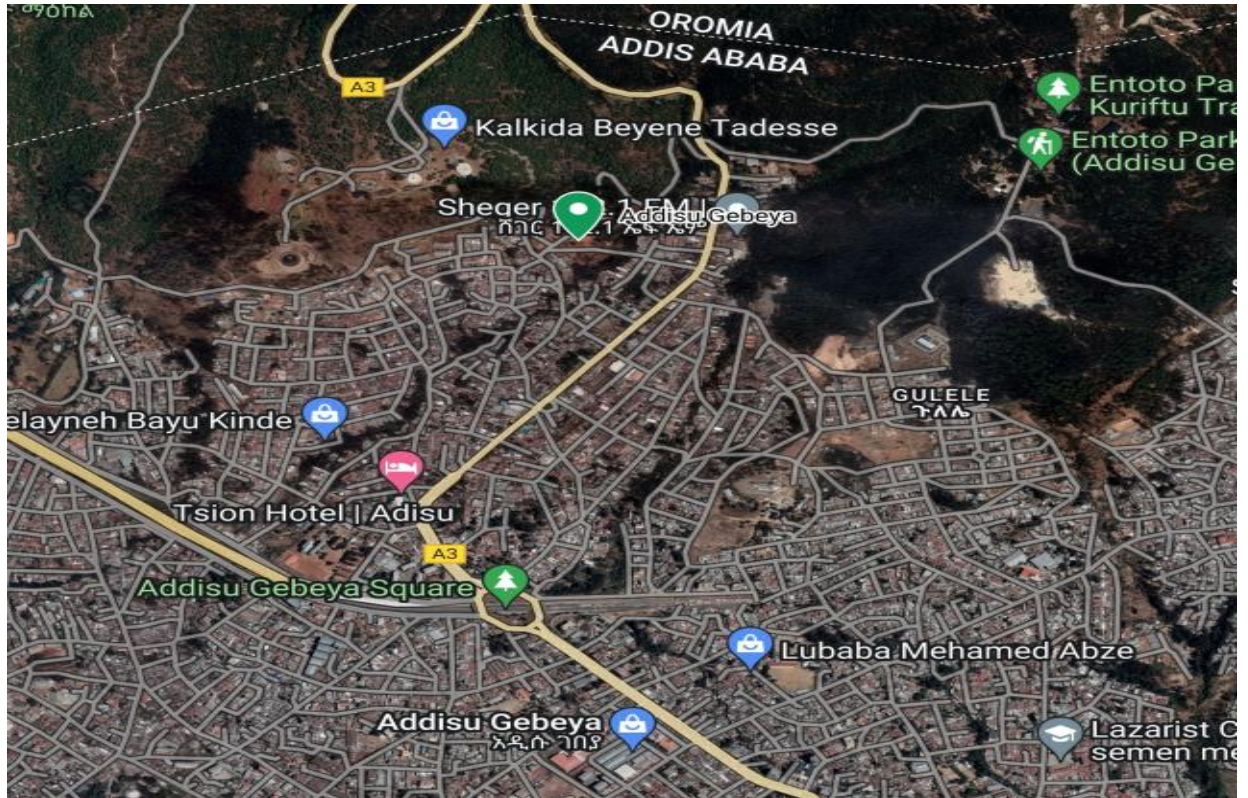
Appendix G: Aerial photographs



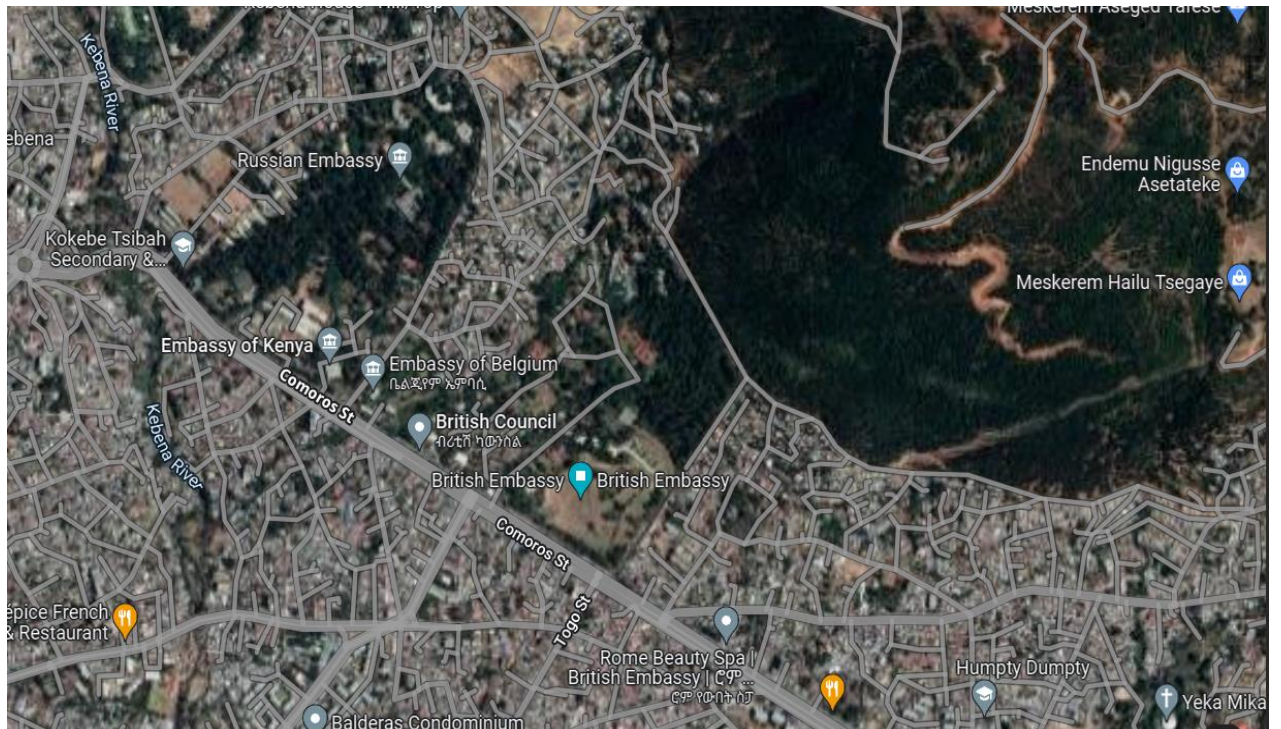
Kechene typical location using GPS from Google Earth



Rufael typical location using GPS from Google Earth



Addisu Gebeya typical location using GPS from Google Earth



British Embassy typical location using GPS from Google Earth