



ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INDEX AND COMPRESSIBILITY CHARACTERISTICS OF SOIL IN ADAMA TOWN

**A Thesis Submitted to
School of Graduate Studies of Adama science and Technology University
In Partial Fulfillment of the Requirement for the Degree of
Master of Science in Civil Engineering**

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ABSTRACT

Adama is one of the most developing towns in Ethiopia as a conference and a tourist resort center. A lot of construction work is constructed at present. It is also expected that much more construction is going to be done in the future. However, very little work is done in investigating the engineering properties of soils of Adama town

The objective of this research was to determine index and compressibility characteristics of soil found in Adama town. To achieve the objective a total of ten samples were taken from different parts of the town and laboratory tests were carried out.

The laboratory tests performed were index test such as moisture content, sieve analysis, Atterberg limits, specific gravity, free swell and engineering test that was one dimensional consolidation.

One of the most important engineering properties of soil is its compressibility characteristics or ability to resist settlement along internal surfaces within a soil mass. All stability analyses in the field of geotechnical engineering, whether they relate to foundation, slopes of cuts or earth dams, involve a basic knowledge of this engineering property of the soils.

From the laboratory output and according to the Unified Soil Classification System, the soils in adama town are categorized as silt and silty sand. One-dimensional consolidation tests show that the area under investigation is over consolidated in its natural state, meanwhile the ranges of different properties is determined as: compression index from 0.33 to 0.40, recompression index from 0.017 to 0.066, coefficient of permeability from 10^{-7} to 10^{-8} cm/sec and modulus of compressibility ranges from 3920 to 7500kPa.

Key words

Index properties, value of permeability and compressibility

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SYMBOLS AND ABBREVIATIONS

AASHTO - American Association of Highway and Transportation Officials

ASTM - American Society for Testing Materials standard

Cc - Compression index

CL - Lean clay

Cr - Recompression index

Cv - Coefficient of consolidation

EAEA - Journal of the Ethiopian Association of Engineers and Architects

Es - Modulus of compressibility

K - Modulus of Permeability

LL - Liquid limit

MDD - Maximum dry density

MH - Inorganic Elastic silt

ML - Inorganic Silt

NMC - Natural moisture content

OMC - Optimum moisture content

OCR - Over-consolidation ratio

Pc - Pre-consolidation pressure

Po - Over burden pressure

PI - Plastic Index

PL - Plastic limit

SM - Silty sand

TP - Test pit

USCS - Unified Soil Classification System

γ_d - Dry unit weight

γ_w - Wet unit weight

1. INTRODUCTION

1.1. Back ground of the problem

Investigation of the underground conditions of a site is prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies of the proposed project. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit, particularly if there is a chance that the project will endanger the public health or safety or degrade the environment [4]. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of substandard borrow material, environmental damage to the site, post construction remedial work, and even failure of a structure and subsequent litigation [26]. Therefore, to obtain information on type, characteristics and distributions of a soil, geotechnical investigations should be done on soil and rock underlying (and sometimes adjacent to) a site of proposed structures.

In a country like Ethiopia, which is developing at fastest growing rate and which needs many construction works in the future, geotechnical investigation on the engineering properties of soils is very essential. Because these data are very important for civil engineers in preliminary design and in designing foundations, pavement, retaining structures, etc for future construction projects in the country.

Many researches were done and there are ongoing researches in most big cities of the country like Ziway, Hawassa, Adama, etc. To mention some of the researches undertaken are: ‘Investigation into some of the engineering properties of soils in Ziway (Bezza, T., 2015), ‘Investigation into some of the engineering properties of soils in Hawasa (Eyob, T., 2011), ‘Shear strength characteristics of soil in Adama’ (Genet, K., 2013), ‘Shear modulus & damping ratio values of soils found in Adama soils’(Abu, G., 2011), etc.

Adama is one of the fastest growing cities in the country and there is huge volume of construction works. Since it is the transit way on the road from Addis Ababa to Djibouti, the growth of trade and commerce is very high in the city. The government attention of industrial park at Adama town escalates the investment opportunities within and nearby areas. In addition to this Adama is very close to Addis Ababa and Business hub of Ethiopia. This research is therefore directed to the study of the physical and mechanical properties of soils i.e. investigating the index property and consolidation characteristic, identifying the characteristics of the soil and may be helpful in preparing soil map of the city.

1.2. Objectives of the Study

The objectives of this thesis work are the following:

To investigate index and compressibility characteristics of soils in Adama.

- To determine the index properties of soils such as Atterberg limits, grain size distribution, and specific gravity.
- To determine the compaction characteristics of soils such as Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
- To determine index properties and compressibility characteristics of soils such as coefficient of consolidation (c_v), compression (c_c).

1.3. Methodology

Disturbed samples of soils are collected from ten sampling areas at a depth of three meter below the ground surface.

GPS readings have been taken in the field to locate the ordinate of sampling area. Visual classification, field density and natural moisture content tests are conducted in the field. The natural moisture content test is done by taking balance and moisture can to the field. After measuring the samples are carefully taken to the laboratory drying oven.

The laboratory tests were carried out for the following tests:

- Specific gravity test
- Atterberg limit tests
 - Liquid limit
 - Plastic limit
- Grain size analysis
 - Sieve analysis(wet method)
 - Hydrometer
- Standard compaction test
- One-dimensional consolidation test

All the above tests were carried out according to respective American Society for Testing Materials (ASTM) standard.

1.4. Scope of the Study

This thesis work is carried out on soils found in Adama town. Disturbed and undisturbed sample of soils from ten different test pits was taken at a depth of 1.5-3m. The thesis is limited to determining the index properties and compressibility of the town.

1.5. Structure of the Thesis

This thesis work is divided in to six Chapters, each covering a specific topic of the research work. In this introductory chapter the background of the problem, objective, methodology and scope of the thesis work and structure of the thesis are presented. Chapter two deals with a brief literature review.

Chapter three describes the area in which this research has taken place. The fourth chapter is briefing about in-situ properties of soils with sample description and the types of laboratory tests conducted and results obtained. The discussion on the laboratory results obtained from this work and comparison with previously work is covered in chapter five. Chapter six is the conclusions and recommendations drawn from the research. Finally, detail calculation of the consolidation test results, for each test pits are included in appendix.

2. LITERATURE REVIEW

2.1. Soil formation and soil deposits

Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. The properties of the soil materials depend upon the properties of the rocks from which they are derived [15].

The variety of soil materials encountered in engineering problems are almost limitless, ranging from hard, dense, large pieces of rock through to gravel, sand, silt, and clay to organic deposits of soft compressible peat. To compound the complexity, all of these materials may occur over a range of densities and water contents. At any given site, a number of different soil types may be present, and the composition may vary over intervals of a little as a few inches [11].

It has long been appreciated that the engineering classification of soils is greatly facilitated by taking into account the soil-forming processes by which nature has created the various types of soil conditions. Similar combinations of soil-forming processes in different parts of the world have been found to lead to materials of similar index properties and similar engineering characteristics [21]. The main factors affecting the formations of soil are: Parent materials i.e. geology of the area, topography and drainage, climate and vegetation cover.

2.1.1. Parent materials

There are two main variables in parent materials that affect soils: grain size and composition. Grain size is the main determinant of soil texture. Texture influences the soil structure, consistency, cation exchange capacity, profile drainage, moisture retaining capacity and organic content [9].

2.1.2. Topography and Drainage

Topography has a major influence on drainage characteristics which in turn is known to have major effect on soil mineralogy. Its control over soil properties is particularly strong in tropical environment reflecting the importance of lateral movement of water and soil materials [21].

2.1.3. Climate

Climate is the principal factor governing the rate and type of soil formation. The two important components of climate are the amount and distribution of precipitation, and temperature. The temperature variable is adequately represented by mean annual temperature, which doesn't differ greatly from the nearly constant temperature in the lower part of the regolith. According to Van's Hoff's principle the velocity of a chemical reaction increases by a factor of 2 or 3 for every 10 °c rise of temperature [25].

The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and

the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system [8].

2.2. General types of soils

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75 mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075 mm. Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials [15].

2.3. Soil particle size and shape

The size of particles may range from gravel to the finest size possible. Their characteristics vary with the size. Soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lens. They constitute the coarser fractions of the soils. The coarser fractions of soils consist of gravel and sand. The individual particles of gravel, which are fragments of rock, are composed of one or more minerals, whereas sand grains contain mostly one mineral which is usually quartz. The Individual grains of gravel and sand may be angular, sub angular, sub-rounded, rounded or well-rounded. Gravel may contain grains which may be flat. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity.

Silt and clay constitute the finer fractions of the soil. Any one grain of this fraction generally consists of only one mineral. The particles may be angular, flake-shaped or sometimes needle-like [15].

2.4. Soil mineralogical composition

Mineral particles are inorganic materials derived from rocks and minerals. They are extremely variable in size and composition.

- Primary minerals: present in original rock from which soil is formed. These occur predominantly in sand and silt fractions, and are weathering resistant (quartz, feldspars).
- Secondary minerals: formed by decomposition of primary minerals, and their subsequent weathering and decomposition into new ones (clay minerals).

2.5. Review of related previous researches in Ethiopia

Sand and silty soils of some parts Ethiopia were studied by (Abu G, 2011; Genet K, 2013; Bezza T, 2015 and Eyob T, 2011) respectively. The research areas covered Adama, Hawasa, and Zeway which are geographically the same and near to the interest area of this research. The respective researches were focused on determining the shear strength characteristics and mineralogical contents of the soils.

(Genet, 2013) studied shear strength characteristics of soils of Adama area, from the investigation soil type and moisture content have significant effect on shear strength property of soil. The laboratory work of (Genet, 2005), involved grain size analysis and index property determination to classify soil samples. Atterberg limit test, Proctor test and consolidation tests were used to evaluate properties of soils. The grain size analysis test result showed that the dominant proportion of soil particle in the research area is silt, which have the research area showed a liquid limit ranging from 38 – 73%, plastic limit ranging from 21 – 39% and plastic index from 5 – 34%. The Specific Gravity ranges from 2.45 to 2.70. It compared with this research liquid limit ranging from 28 – 73%, plastic limit ranging from 21 – 37% and plastic index from 5 – 37%. The Specific Gravity ranges from 2.4 to 2.70.

(Bezza, 2015) studied the Engineering properties of soils of Ziway area. The behavior of silt and silty sand soils in the study area were compared with similar soils from other parts of Ethiopia. It compared with this research liquid limit ranging from 28 – 73%, plastic limit ranging from 21 – 37% and plastic index from 5 – 37%. The Specific Gravity ranges from 2.4 to 2.70.

The study was focused for silty soils of ziway town which have clay content ranging from 6.72 to 10.93%, silt fraction 51.45 to 73.03%, sand fraction 15.16 to 40.4%, and gravel content from 0.84 to 1.88% and for silty sand soils clay content ranging from 0.66 to 4.41%, silt fraction 17.15 to 42.18%, sand fraction 52.06 to 81.3%, and gravel content from 0.89 to 1.6% and the specific gravity of the town ranges from 2.40 to 2.62.

(Abu, 2011) studied the values of shear modulus and damping ratio of soils found in Adama city. From comparison of shear modulus and damping ratio curves based on consolidation pressure, it is observed that the confining pressure has less influence on the values of shear modulus and damping ratio at 2.5% and 5% strain than smaller strains.

(Eyob, 2011) studied unsaturated shear strength characteristics and stress-strain behavior of silt soils of Hawassa. This thesis provides the results of triaxial tests which were carried out to study the unsaturated shear strength characteristics of Hawassa silty soil with suction measurement. The soil tested was reconstituted using dynamic compaction. Consolidated undrained (CU) triaxial tests were performed on both saturated and unsaturated samples. In this work, disturbed silt soil samples were collected from test pits dug to a depth of 2.5m and the shear strength tests were conducted on compacted samples. The saturated shear tests were carried out for consolidation pressures of 100 kPa, 200 kPa and 300 kPa.

3. DESCRIPTION OF THE STUDY AREA

3.1 General

Adama is located in East Showa Zone in Oromiya Regional State [10]. It is one of the largest and most populated towns in the Region. It is located at $8^{\circ}33'35''\text{N} - 8^{\circ}3'46''\text{N}$ latitude and $39^{\circ}11'57''\text{E} - 39^{\circ}21'15''\text{E}$ longitude. It is about 99kilometer away from Addis Ababa in southeast direction. Adama has a total area of about 13,000 hectares, which has been subdivided into 21 urban kebele (least administrative structure) administrations.

Available documents evidenced that Adama had been known as Nazareth (the name given to it by Emperor Haile Sellasie-I) for most of the 20th century up until it was officially reverted to its original Oromo language name, Adama, in 2000. Adama had been serving as the capital city of Oromiya National Regional State during 2000-2005.

On the 10th of June 2005 that the Oromiya National Regional Government announced the move of the regional capital back to Addis Ababa [14]. The location of the research area, i.e. Adama, on the map of Ethiopia is shown in figure 3.1.

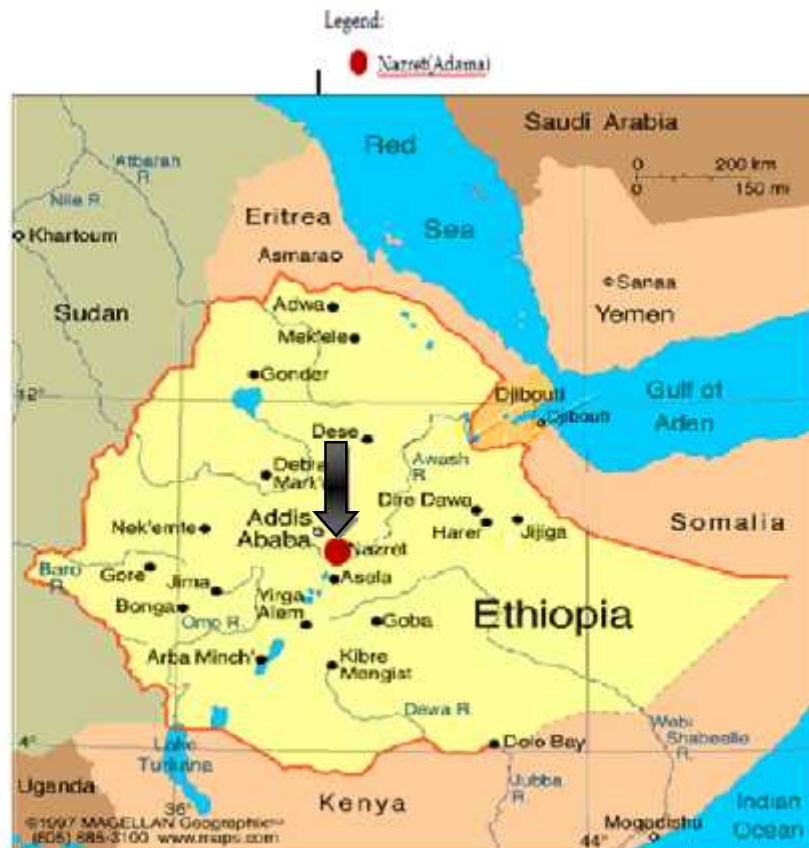


Figure 3.1: Location of the research area on the map of Ethiopia

3.2. Soil and Geology

The Ethiopian rift system which is part of the East African Rift System may be sub- divided into three main sections namely; the south western rift zone, the main Ethiopian rift, and Afar. Adama is part of the central Rift Valley and dominated by flatlands stretching between the escarpments bordering the eastern and western sides of the Rift Valley [10].

Adama is found within the Wonji Fault Belt, which is one of the main structural systems in the Ethiopian Rift Valley. Its physiographic condition is, therefore, mainly the result of volcano tectonic activities that occurred in the past and also partly the result of the deposition of sediments, which are considered largely of fluvial and lacustrine origin. Adama is regarded as seismically active area concerning earthquake hazards with the probability occurrence of 0.99 in every 100 years [After Messay, 2010].

Adama has three types of soil: andosols, fluvisols and lithosols. The dominant type is mollic andosols (Anm), with a water-holding capacity of 144mm for a 1m depth [10].

3.3. Topography and drainage conditions

The altitude of Adama varies from about 1500m to 1670m above mean sea level. The only perennial river in the vicinity of Adama is awash into which all the streams in the town join [After Messay, 2010].

3.4 Rainfall and Temperature

The records of National Meteorological Service Agency from Adama observatory substation show that the mean annual rainfall for thirty three years i.e. from 1977 to 2009 at an altitude of 1622m above mean sea level, latitude of 39°17' and longitude of 8°33' is 881.9mm. As shown in Fig 3.1, the rainy season is only in months of July and August followed by rainfall of almost equal to or below evaporation rate of the city. Around 50% of the rainfall arrives in these two months.

In a mountainous tropical country like Ethiopia altitude is by far the most important factor in controlling climate. It affects distribution of both temperature and rainfall. Generally, regions between 1500 - 2300 meters a.m.s.l. (categorized as 'woina dega' or sub-tropical climate) have temperatures that range between 15 - 20°C, areas between 500 – 1500 meters a.m.s.l. (i.e. 'kola' or tropical climate) have 20 -30°C and areas below 500meters a.m.s.l. (i.e. 'bereha' or desert climate) have a temperature of 30°C and above[16]. The town of Adama, with an altitude ranging from 1500-1670meters a.s.l., has a mean minimum, mean maximum and mean average monthly temperatures of 14.3, 28.1 and 21.2°C respectively. The highest temperature records are during months of March, April, May and June whereas November, December and January have low temperature. From Fig3.3 the Mean monthly average temperature ranges from 19.33°C to 23.54°C. This shows the temperature variation is almost the same throughout the year.

4. IN-SITU CHARACTERISTICS AND LABORATORY TEST RESULTS

4.1. In-situ properties

4.1.1. Identification of Soil in the Study Area

Before selecting sampling areas, visual site investigation and information from resident, and construction firms were collected to consider the different soil types and to take representative samples evenly in the whole town. Accordingly, ten sampling areas were selected from different locations of the town. Pits were excavated to the maximum depth of three meters, but in some areas boulders were encountered making the digging difficult. Only disturbed samples were taken because of the silt nature of the soil which makes recovering of undisturbed sample difficult. In the field visual soil description was made and samples for laboratory testing were collected. The global coordinates of sampling locations i.e. northing, easting and elevations are shown in Table 4.1.

Table 4.1: Global coordinates of sampling areas

Test Pits	Location	Northing	Easting	Elevation
TP1	Kebele 14(Around Adama University)	531952	945566	1653
TP2	Kebele 01(Kechema)	527123	946671	1641
TP3	Kebele 02 (Migira)	531531	941108	1603
TP4	Kebele 03 (Boku)	531368	940736	1633
TP5	Kebele 04 (Bole)	517635	945365	1634
TP6	Kebele 09 (WenjiMazoria)	526686	941386	1612
TP7	Kebele 10 (Pekok)	515545	941382	1628
TP8	Kebele 11(Muger)	527866	941223	1636
TP9	Kebele12(Municipality)	528675	943465	1615
TP10	Kebele 16 (Aba Geda)	531468	946866	1646

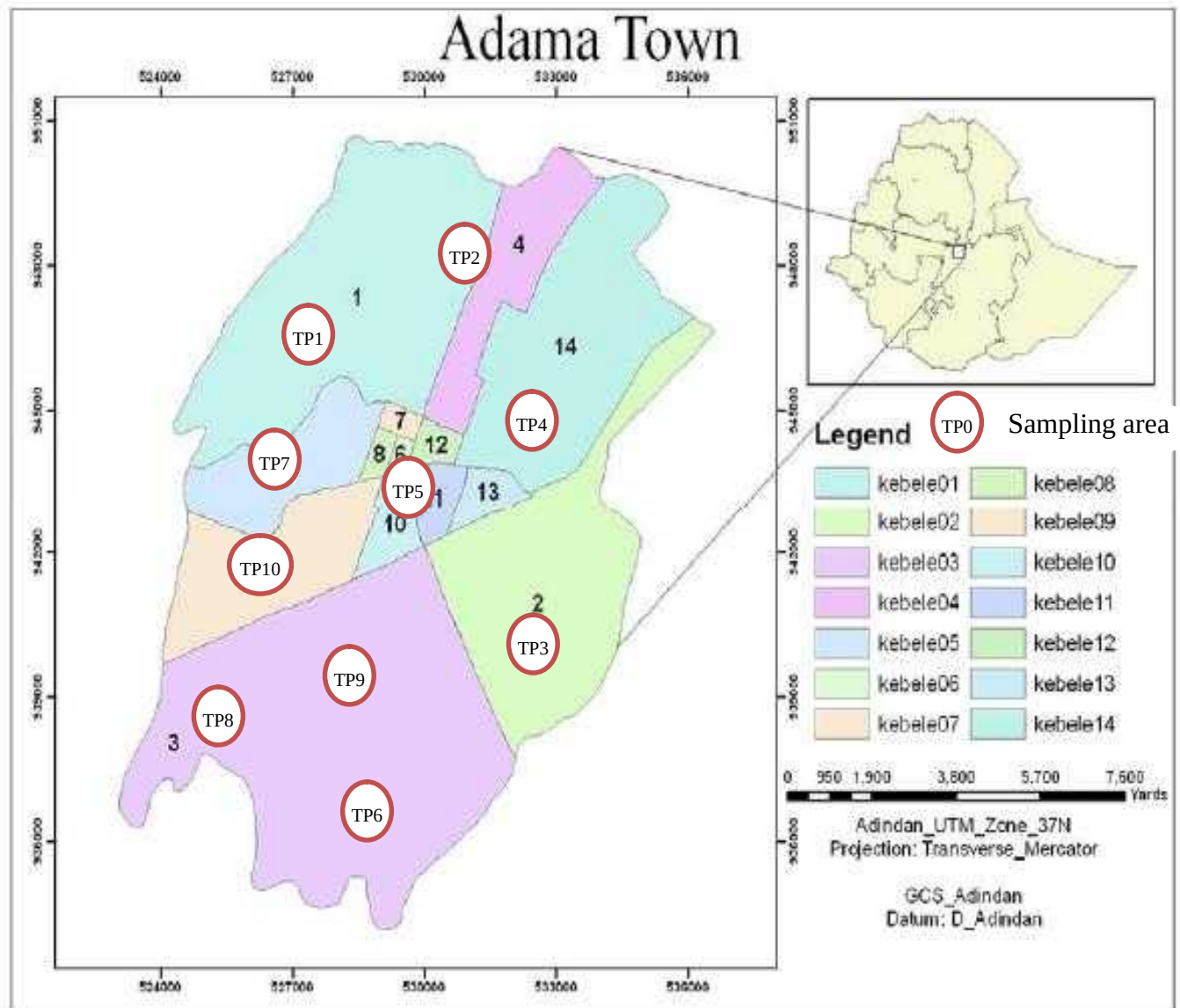


Figure 4.1: Location of sampling areas shown on map of Adama town

(from Google earth map)

4.1.2. In-situ properties Description

From the entire test pits two basic properties were identified as; the top layer is brown clayey silt and at deeper level reddish white clay silt with very small amount of sand was found (see App A. for soil profiles of each test pits). In the field part of the natural moisture content and field density tests were done.

4.1.2.1. Natural moisture content

The natural moisture content test were carried in accordance with **ASTM D2216**, the water content may be an important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water

content is also used to express the phase relationships of air, water, and solids in a given volume of soil [13].

Since it was difficult to bring undisturbed samples to the laboratory, this test was done by taking moisture can and balance to the field. The weight of the moisture can and the weight of can with moist soil was measured in the site. Then the sample was brought to the laboratory and put it in to drying oven at a temperature of 105+5°C for 24 hours. Then after, the natural moisture content was determined. The natural moisture content of the ten pits for each profile is shown in Table 4.2.

Table 4.2: The In-situ density and natural moisture contents of soil samples

Test Pit No.	Depth (m)	Natural moisture content (%)	In-situ density (g/cm ³)	Dry density (g/cm ³)
TP-1	0.00-1.00	12.18	-	-
	1.00-1.50	10.20	-	-
	1.50-3.00	18.50	1.48	1.12
TP-2	0.00-1.00	19.20	-	-
	1.00-1.50	22.60	-	-
	1.50-3.00	20.08	1.32	1.18
TP-3	0.00-0.80	12.60	-	-
	0.80-1.50	16.10	-	-
	1.50-3.00	15.42	1.20	1.10
TP-4	0.00-1.50	16.43	-	-
	1.50-3.00	29.60	1.36	1.06
TP-5	0.00-0.80	Fill	-	-
	0.80-1.50	34.30	-	-
	1.50-3.00	27.21	1.42	1.12
TP-6	0.00-1.50	27.00	-	-
	1.50-3.00	37.00	1.45	1.05
TP-7	0.00-1.50	16.40	-	-
	1.50-3.00	23.54	1.38	1.11
TP-8	0.00-0.80	Fill	-	-
	0.80-1.50	14.62	-	-
	1.50-3.00	22.36	1.35	1.08
TP-9	0.00-0.80	Fill	-	-
	0.80-1.50	16.40	-	-
	1.50-3.00	27.50	1.36	1.07
TP-10	0.00-1.50	25.04	-	-
	1.50-3.00	25.64	1.28	1.00

4.1.2.2. In situ density

By using sand replacement method in-situ density were calculated, natural moisture content and dry density. This test has been conducted in accordance with the Standard Reference: ASTM D 2937-00 – Standard Test for Density of Soil in Place by the Drive-Cylinder Method. The in situ density of the samples around three meter is shown in Table 4.2. Field densities were taken only around three meters because these values were required for remolding sample in consolidation test.

4.2. Index properties

The properties and characteristics of soils vary from point to point. The tests required for determination of engineering properties are generally elaborate and time consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties [2].

The index properties of soils are water content, specific gravity, particle size distribution, consistency limits, in-situ density, free- swell and density index.

4.2.1. Specific gravity

According to ASTM D 854-98, two procedures for performing specific gravity are provided. These are Method-A, procedure for oven dried specimen and Method-B, procedure for moist specimen. For specimens of organic soils and highly plastic, fine-grained soils, procedure B shall be the preferred method. But in this research the specific gravities are determined using both procedures. The test results are shown in Table 4.3, and values determined on Method-B were used in other calculations like hydrometer analysis. Within the depth of exploration, the top layer which is brown clayey silt has a specific gravity as low as 2.40 but as excavation goes deeper it becomes between 2.60 to 2.70.

4.2.2. Grain-size distribution of soil

Grain size Analysis test is used to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. The test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μ m (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μ m is determined by a sedimentation process, using a hydrometer to secure the necessary data.

Table 4.3: Specific Gravity of the Soil of the Study Area

Serial No	Designation	Depth (m)	Specific Gravity using		Water used for testing
			Method A	Method B	
1	TP-1-1	1.00-1.50	2.54	2.55	Tap water
2	TP-1-2	1.50-3.00	2.64	2.67	„
3	TP-2-1	1.00-1.50	2.50	2.40	„
4	TP-2-2	1.50-3.00	2.56	2.65	„
5	TP-3-1	0.80-1.50	2.46	2.55	„
6	TP-3-2	1.50-3.00	2.64	2.68	„
7	TP-4-1	0.00-1.50	2.44	2.46	„
8	TP-4-2	1.50-3.00	2.55	2.70	„
9	TP-5-1	0.80-1.50	2.48	2.45	„
10	TP-5-2	1.50-3.00	2.58	2.58	„
11	TP-6-1	0.00-1.50	2.54	2.48	„
12	TP-6-2	1.50-3.00	2.62	2.65	„
13	TP-7-1	0.00-1.50	2.50	2.50	„
14	TP-7-2	1.50-3.00	2.56	2.66	„
15	TP-8-1	0.00-0.80	2.52	2.58	„
16	TP-8-2	0.80-3.00	2.46	2.64	„
17	TP-9-1	0.00-0.80	2.60	2.56	„
18	TP-9-2	0.80-1.50	2.53	2.66	„
19	TP-10-1	0.00-1.50	2.62	2.67	„
20	TP-10-2	1.50-3.00	2.55	2.57	„

4.2.2.1. Test Results

The procedures followed to run this test are in accordance with ASTM D422-63 and ASTM D1140-97. According to ASTM D422-63 the distribution of particles, finer than 75 μ m can be done by hydrometer test and coarser than 75 μ m by mechanical sieve. Therefore, the samples collected from the site were air dried first and representative samples were taken by quartering. The existing moisture content of the air dried sample was measured which was used for hygroscopic correction. The weight of the sample was measured and then after it was washed on sieve No. 200. Mechanical sieve was carried out on samples of soil retained on sieve No. 200, after oven drying for 24 hours. The sample of soil passing No. 200 was transferred to large dish and soaked until the water becomes clean, then the clean water was decanted. After the sample has been dried in room temperature, it's pulverized and 50 grams of soil was taken for hydrometer test.

In the hydrometer test, 50grams of soil were taken and soaked for 24 hours by adding dispersing agent. At the end of soaking, the sample was dispersed further using stirring apparatus. Then it's poured into 1000ml cylinder and stirred again for a period of 1 min by covering it with the palm.

The actual hydrometer reading and test temperature was taken for 0.1, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, 1440 minutes.

The procedures mentioned above were followed for grain size analysis for all the twenty samples. The combined grain size distribution curve for particles retained on No.200 sieve and passing No.200 sieve is shown in Fig 4.2 and 4.3 respectively. The gradation of soils in the study area varies considerably (Table 4.4). From the grain size analysis result clay content range from 5.4 to 30.2%, silt fraction 16.7 to 61.3%, sand fraction 15 to 51.8% and gravel content from 0.0 to 25.6%.

Table 4.4: Summary of grain size analysis results

Serial No	Designation	Depth (m)	Percent amount of particle size			
			Gravel	Sand	Silt	Clay
1	TP-1-1	1.00-1.50	25.62	51.80	16.72	5.42
2	TP-1-2	1.50-3.00	5.96	45.22	33.92	16.32
3	TP-2-1	1.00-1.50	0.02	26.83	50.02	22.91
4	TP-2-2	1.50-3.00	0.62	15.06	53.85	29.99
5	TP-3-1	0.80-1.50	9.42	34.03	28.62	28.21
6	TP-3-2	1.50-3.00	0.00	30.11	40.01	30.23
7	TP-4-1	0.00-1.50	0.00	41.22	46.93	11.24
8	TP-4-2	1.50-3.00	4.43	26.88	46.87	21.48
9	TP-5-1	0.80-1.50	2.75	19.96	60.62	16.20
10	TP-5-2	1.50-3.00	0.00	22.96	58.83	17.28
11	TP-6-1	0.00-1.50	0.29	29.88	52.23	17.45
12	TP-6-2	1.50-3.00	14.26	47.15	31.32	5.65
13	TP-7-1	0.00-1.50	0.00	34.21	52.23	15.01
14	TP-7-2	1.50-3.00	1.25	36.75	47.33	14.80
15	TP-8-1	0.80-1.50	6.24	33.51	42.66	18.24
16	TP-8-2	1.50-3.00	4.55	28.44	36.56	14.86
17	OTP-9-1	0.80-1.50	1.68	35.82	42.74	11.21
18	TP-9-2	1.50-3.00	0.88	26.52	56.32	7.62
19	TP-10-1	0.00-1.50	0.92	24.92	41.31	14.53
20	TP-10-2	1.50-3.00	0.00	35.89	30.61	14.01

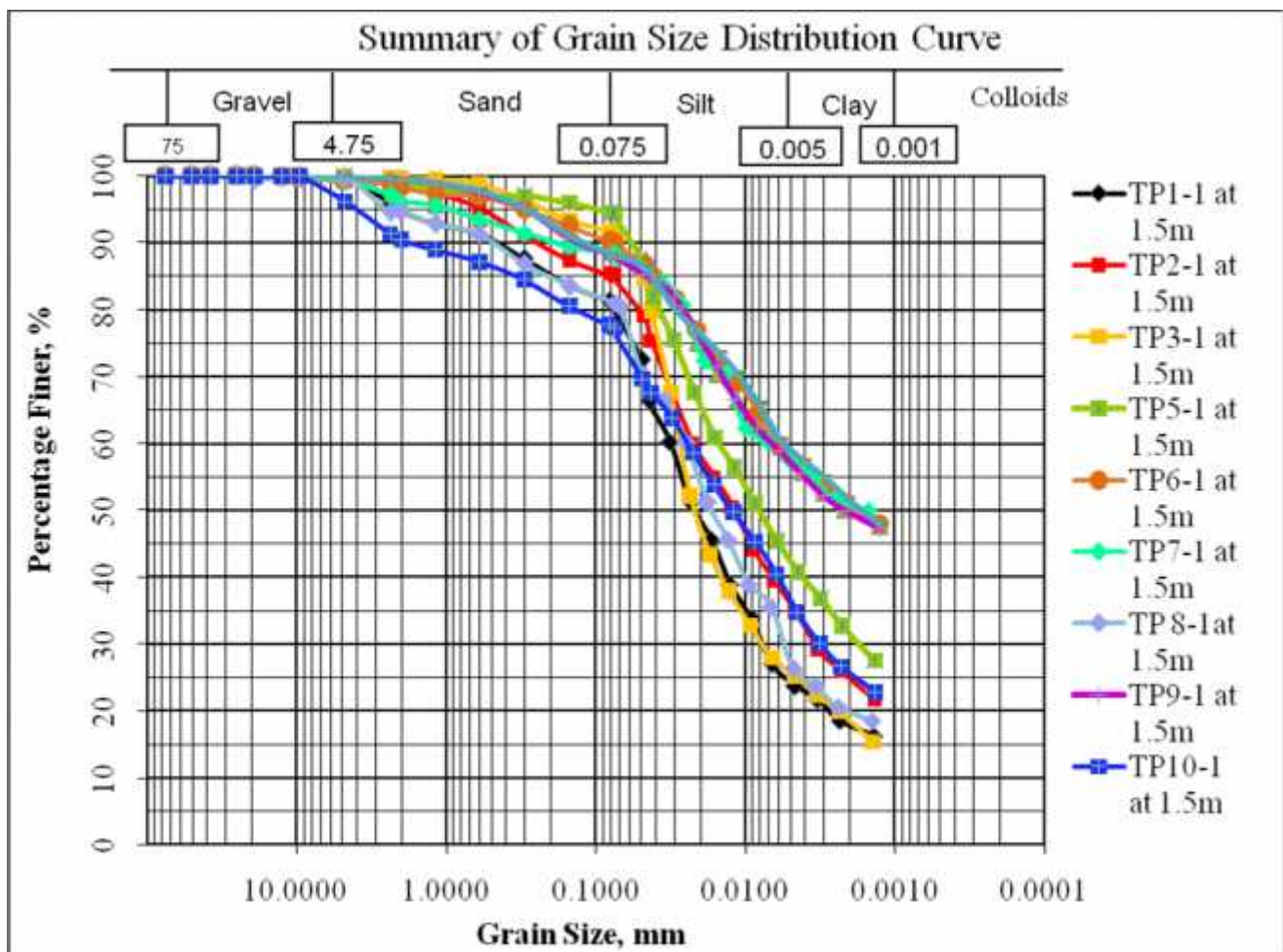


Figure 4.2: Grain size distribution for samples from test pits 1 to 10 at 1.5m

4.2.3. Atterberg limits

The liquid limit and plastic limit of soils (along with the shrinkage limit) are collectively referred to as the Atterberg Limits. The liquid limit is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm diameter threads without crumbling. The term shrinkage limit, expressed as moisture content in percent, represents the amount of water required just to fill all of the voids of a given cohesive soil at its minimum void ratio obtained by oven drying. The shrinkage limit can be used to evaluate the shrinkage potential, crack development potential, and swell potential of earthwork involving cohesive soils [3].

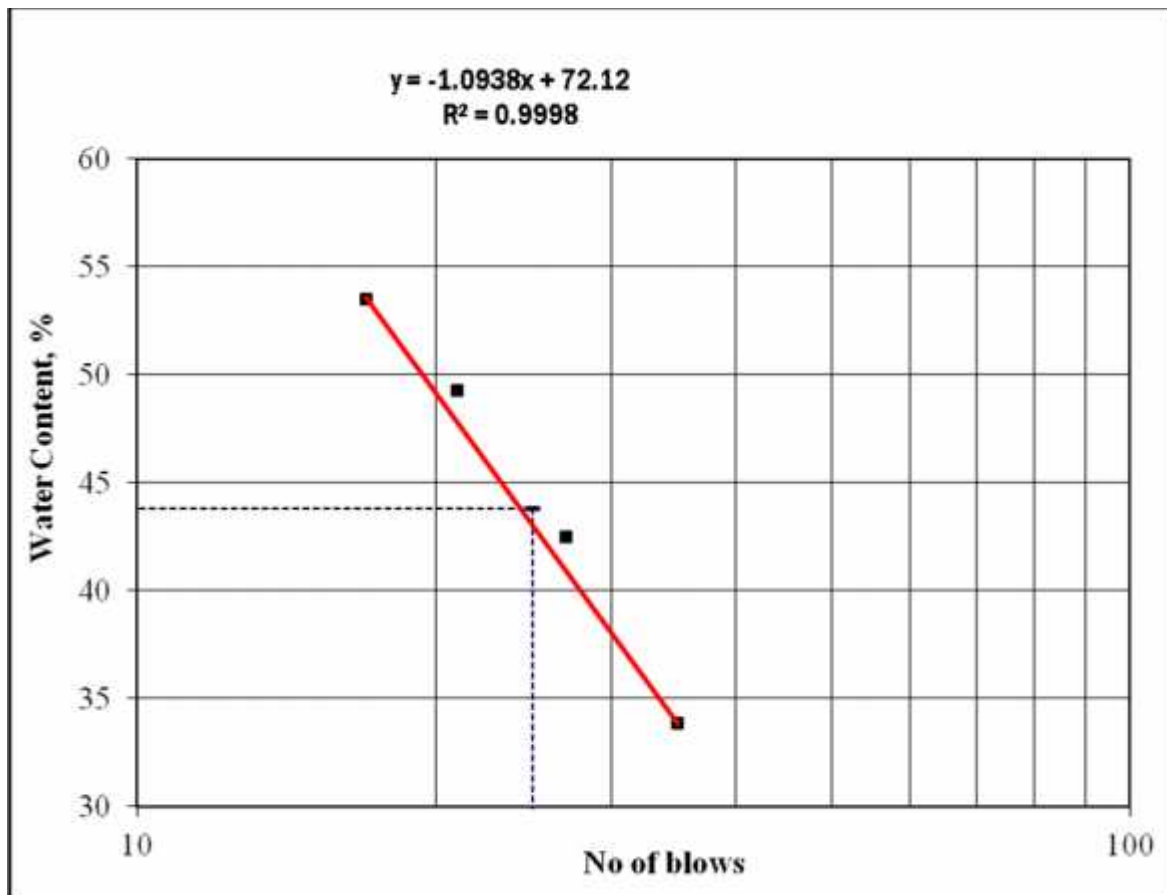


Figure 4.3 Liquid limit test results

The different states and consistencies through which the soil sample passes with the decrease in the moisture content are depicted in Fig 4.3.

States	Limit	Consistency	Volume change
LiquidW _L	Liquid Limit	Very Soft	
PlasticW _p	Plastic Limit	Soft	
Semi SolidW _s	Shrinkage Limit	Stiff	
Solid		Very Stiff	
		Extremely Stiff	
		Hard	

Figure 4.4: consistencies through which the soil sample passes with the decrease in the moisture content. (ARORA) Soil mechanics and foundation engineering.

Table 4.5: Atterberg Limit Result Summary for air dried soil samples

Serial No	Designation	Liquid Limit	Plastic Limit	Plasticity Index
1	TP-1-1	28	21	7
2	TP-1-2	39	25	14
3	TP-2-1	43	27	16
4	TP-2-2	37	31	6
5	TP-3-1	44	32	12
6	TP-3-2	30	25	5
7	TP-4-1	42	32	10
8	TP-4-2	31	26	5
9	TP-5-1	53	36	17
10	TP-5-2	59	30	29
11	TP-6-1	50	25	25
12	TP-6-2	75	38	37
13	TP-7-1	46	31	15
14	TP-7-2	46	34	12
15	TP-8-1	42	30	12
16	TP-8-2	56	35	21
17	TP-9-1	42	28	14
18	TP-9-2	52	33	19
19	TP-10-1	47	26	21
20	TP-10-2	70	37	33

4.2.3.1. Test procedure and results

The liquid limit test on oven dry sample was carried out only on five representative samples. These values are required to know the ratio of liquid limit on oven dried and air dried sample, which will in turn used to classify the soil as organic and inorganic. The oven drying samples were prepared by putting the sample in an oven for 24 hours at a temperature of $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$.

The Atterberg limits for soil in Adama town are summarized in Table 4.5 and the liquid limits for oven dried samples are given in Table 4.6. From this we can observe that liquid limit ranges from 28% to 75%, plastic limit ranges from 21% to 37% and plastic index from 5 – 37%.

Table 4.6: The ratio of liquid limits on oven dried and air dried representative samples

Test pit	Depth	Liquid limit (%)	
		Oven dried	Air dried
TP-03-2	1.50-3.00	62	75
TP-07-2	1.50-3.00	35	37
TP-08-2	1.50-3.00	30	30
TP-09-1	0.00-1.50	49	53
TP-09-2	1.50-3.00	58	59

4.3. Compaction test

The two types of compaction tests routinely performed are: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. In the Standard Proctor test, the soil is compacted by a 24.4N hammer falling a distance of 0.305meters into a soil filled mold.

From the test results the maximum dry density (MDD) of Adama ranges from 1.25 to 1.62 g/cm³ and the optimum moisture content ranges from 16.3 to 34.8%. The summary of the test results is shown in Table 4.7.

Generally coarse grained soils can be compacted to a higher dry density than fine grained soils for the same compaction effort. When some fines are added to the coarse grained soils to fill the voids, the maximum dry density further increases, but if the amount of fines is too much, more than required to fill the voids, it results in reduction of dry density; well graded soils can attain higher dry density than poorly graded soils.

High plasticity clays attain much less dry density than low plasticity clays for the same effort. This can also be observed from Table 4.4 and Table 4.7 i.e. as the amount of coarser particles increases the dry density will increase too. That is why samples with designation TP-1-1 and TP-6-2 show higher dry density as compared to other samples.

Table 4.7: Summary of Optimum moisture content and the maximum dry density

Serial No	Designation	Depth (m)	MDD (g/cm ³)	OMC(%)
1	TP-1-1	1.00-1.50	1.53	16.3
2	TP-1-2	1.50-3.00	1.52	16.8
3	TP-2-1	1.00-1.50	1.25	31
4	TP-2-2	1.50-3.00	1.47	25.5
5	TP-3-1	0.80-1.50	1.25	34.8
6	TP-3-2	1.50-3.00	1.39	26.50
7	TP-4-1	0.00-1.50	1.39	28.50
8	TP-4-2	1.50-3.00	1.52	24.75
9	TP-5-1	0.80-1.50	1.44	25
10	TP-5-2	1.50-3.00	1.35	30
11	TP-6-1	0.00-1.50	1.36	28
12	TP-6-2	1.50-3.00	1.62	22.4
13	TP-7-1	0.00-1.50	1.39	23.6
14	TP-7-2	1.50-3.00	1.46	25
15	TP-8-1	0.80-1.50	1.22	24
16	TP-8-2	1.50-3.00	1.48	26.6
17	TP-9-1	0.80-1.50	1.34	23.5
18	TP-9-2	1.50-3.00	1.47	26.9
19	TP-8-1	0.00-1.50	1.45	24.6
20	TP-8-2	1.50-3.00	1.29	32.5

4.4. Classification of the Soils

4.4.1. Classification of soils based on Unified soil classification (USC) system

This system describes a system for classifying minerals and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required [3].

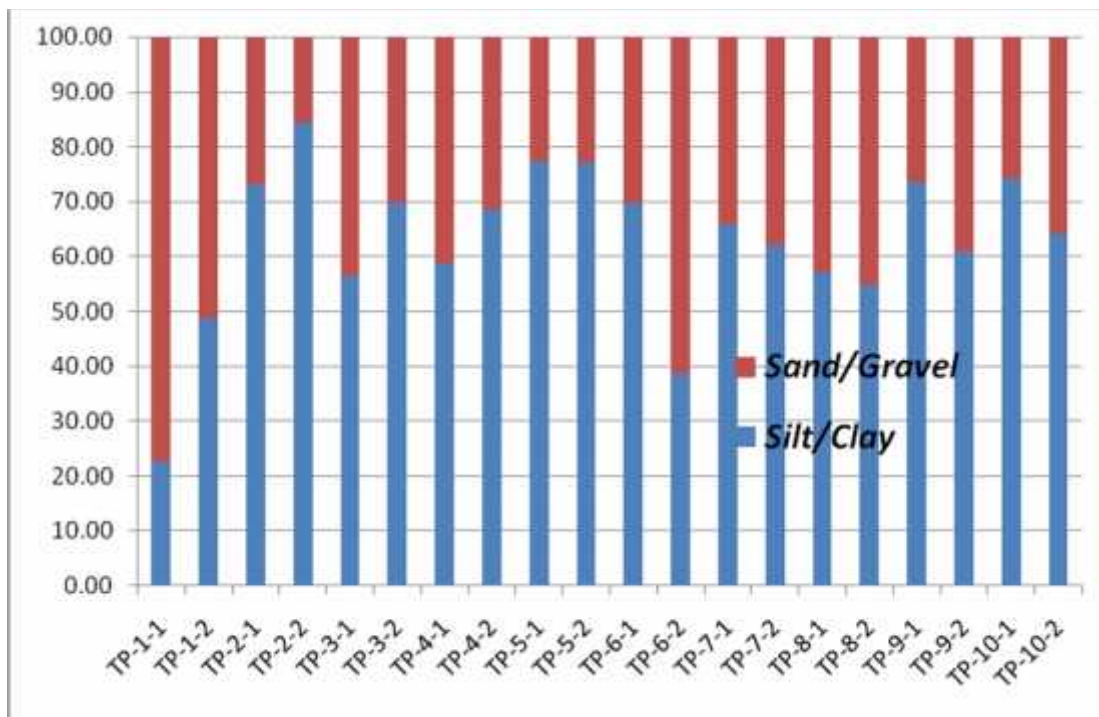


Figure 4.5. % of fines and test pit

Table 4.8: Classifications of soils based on USC system

Serial No	Designation	Depth (m)	Percent amount of particle size				LL (%)	PI (%)	Classification According to USCS
			Gravel	Sand	Silt	Clay			
1	TP-1-1	1.00-1.50	25.62	51.80	16.72	5.42	28	7	SM
2	TP-1-2	1.50-3.00	5.96	45.22	33.92	16.32	39	14	SM
3	TP-2-1	1.00-1.50	0.02	26.83	50.02	22.91	43	16	ML
4	TP-2-2	1.50-3.00	0.62	15.06	53.85	29.99	37	6	MH
5	TP-3-1	0.80-1.50	9.42	34.03	28.62	28.21	44	12	ML
6	TP-3-2	1.50-3.00	0.00	30.11	40.01	30.23	30	5	MH
7	TP-4-1	0.00-1.50	0.00	41.22	46.93	11.24	42	10	ML
8	TP-4-2	1.50-3.00	4.43	26.88	46.87	21.48	31	5	SM
9	TP-5-1	0.80-1.50	2.75	19.96	60.62	16.20	53	17	ML
10	TP-5-2	1.50-3.00	0.00	22.96	58.83	17.28	59	29	MH
11	TP-6-1	0.00-1.50	0.29	29.88	52.23	17.45	50	25	MH
12	TP-6-2	1.50-3.00	14.26	47.15	31.32	5.65	75	37	MH
13	TP-7-1	0.00-1.50	0.00	34.21	52.23	15.01	46	15	ML
14	TP-7-2	1.50-3.00	1.25	36.75	47.33	14.80	46	12	ML
15	TP-8-1	0.80-1.50	1.52	41.33	42.66	14.63	42	12	ML
16	TP-8-2	1.50-3.00	12.6	32.65	36.56	18.42	56	21	MH
17	TP-9-1	0.80-1.50	0.78	25.67	42.74	13.23	42	14	ML
18	TP-9-2	1.50-3.00	4.25	34.86	56.32	14.22	52	19	MH
19	TP-10-1	0.00-1.50	0.92	24.92	41.31	14.53	47	21	MH
20	TP-10-2	1.50-3.00	0.00	35.89	30.61	14.01	70	33	MH

According to USC scheme most of the soil of the study area falls in ML or MH region, which shows that the soil is non-expansive. From the plot of plasticity chart in figure 4.4 and the classification soils on table 4.8 the soils found in Adama town are silt, elastic silt and silty sand.

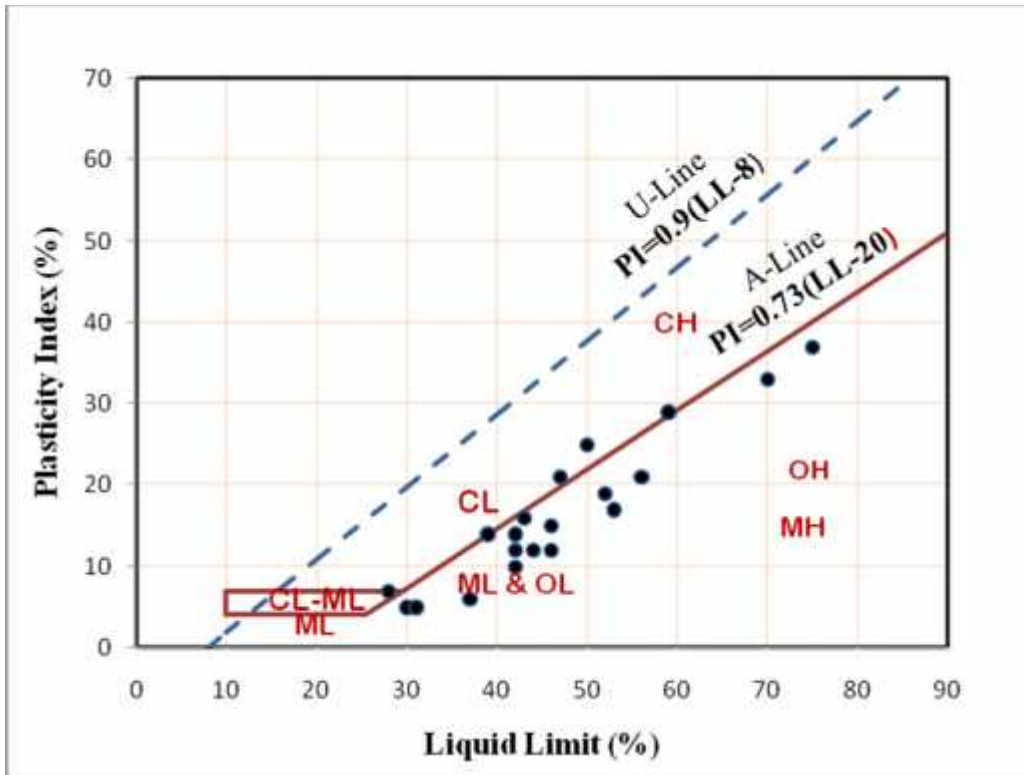


Figure4.6: Plasticity chart of the study area according to Unified Soil Classification System

4.5. Consolidation

Consolidation is a time-dependent decrease in the volume of a soil mass due to dissipation of water under applied loading.

Generally, the volume change in a soil deposit can be divided in to three stages:

- Initial consolidation
- Primary consolidation
- Secondary consolidation

4.5.1. Test procedure and results

This test was done according to the procedure called standard test method for one-dimensional consolidation properties of soils on the ASTM standard, Designation D2435-96.

The sample for which field density and natural moisture content already determined was air dried. From the air dried sample existing moisture content was taken. The required sample of soils passing

sieve number 4.75mm was taken. By quartering the sample is compacted on a compaction mold in three layers. Finally after extruding the sample it has been taken on to the consolidation ring.

After carefully trimming the soil sample at its top and bottom, it was placed inside the metal ring with porous stone at its top and bottom. A setting load of 5 kPa was applied until the soil get fully saturated. Load was applied through the lever arm and compression dial reading was taken at a time intervals of 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30, minutes and 1, 2, 4, 8, and 24hours. The load was doubled every 24 hours starting from 25kpa to 1600kPa. This procedure was followed for all the samples. The plot of void ratio versus logarithm of pressure and pressure for all the samples is shown in fig 4.7 and 4.8 respectively (see App. C for detail calculations of the consolidation test result).

4.5.1.1. Pre-consolidation pressure

There are a few graphical methods for determining the pre-consolidation pressure based on laboratory test data. No suitable criteria exist for appraising the relative merits of the various methods. The earliest and the most widely used method was the one proposed by Casagrande (1936). The method involves locating the point of maximum curvature, B, on the laboratory e - $\log p$ curve of an undisturbed sample as shown in Fig 4.5. From B, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure, P_c [15].

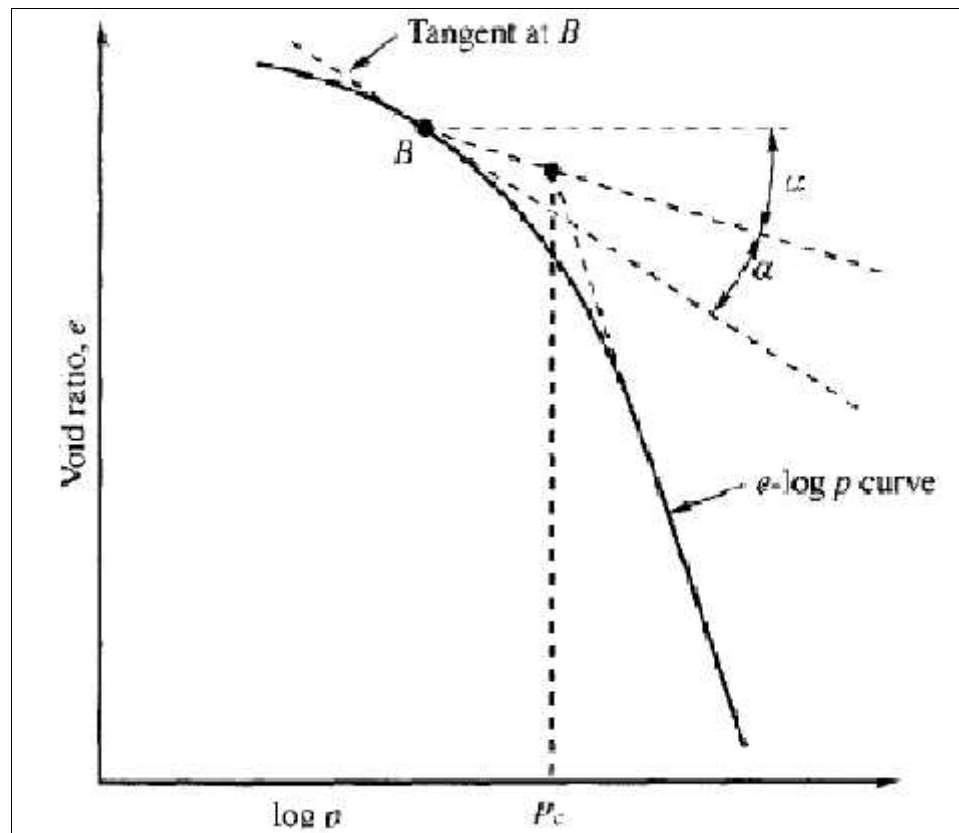


Figure 4.7: Method of determining P_c by Casagrande method [15]

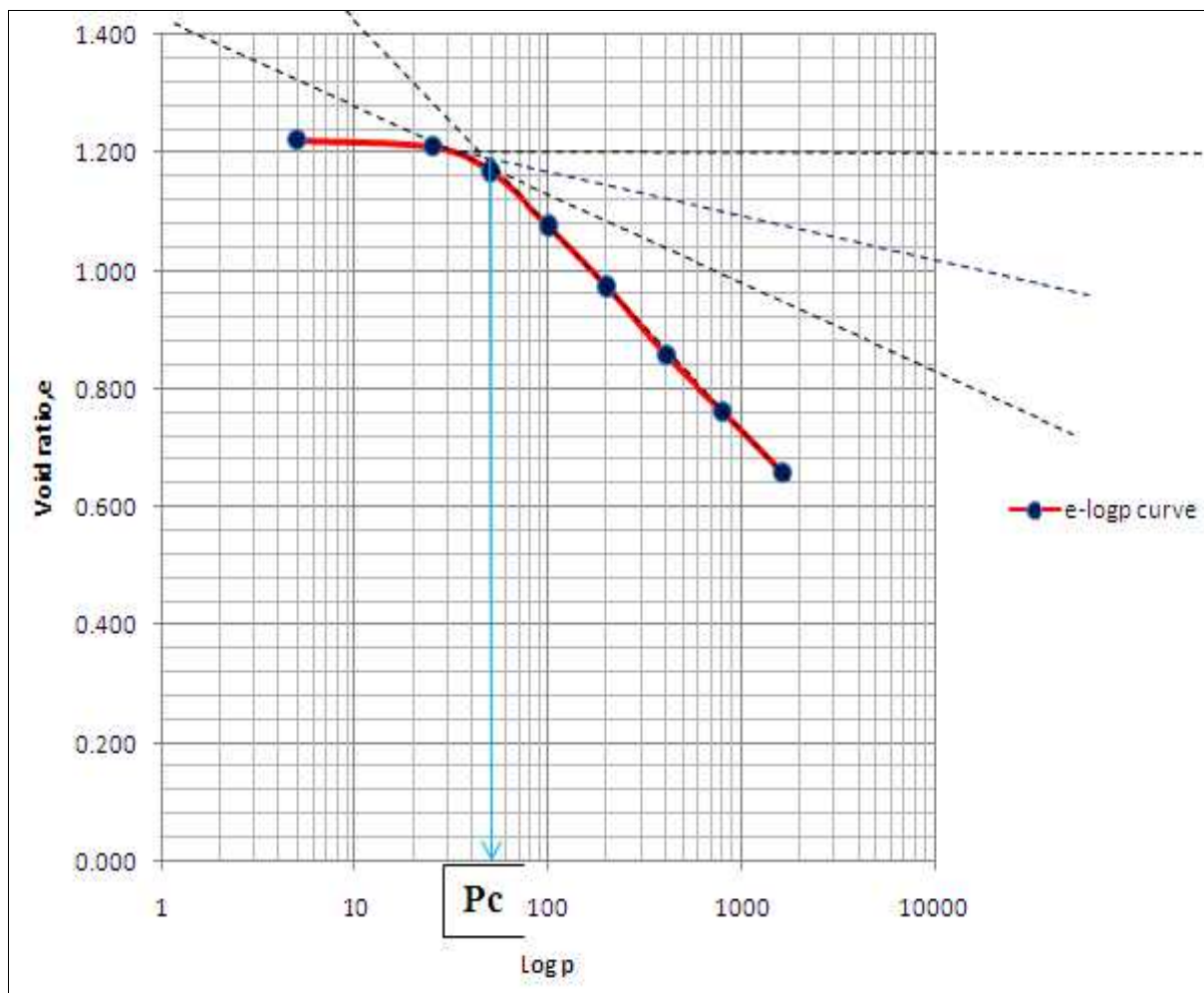


Figure 4.8: Typical void ratio versus pressure curve to determine P_c

The relative amount of pre-consolidation is usually reported as the over-consolidation ratio (OCR) defined as

$$\text{OCR} = \frac{P_c}{P_a} \dots\dots\dots(4.2)$$

The pre-consolidation pressure for the four samples is determined as shown in fig4.6 and table 4.7. From Fig 4.8 and 4.9 all the samples has almost similar pre-consolidation pressure.

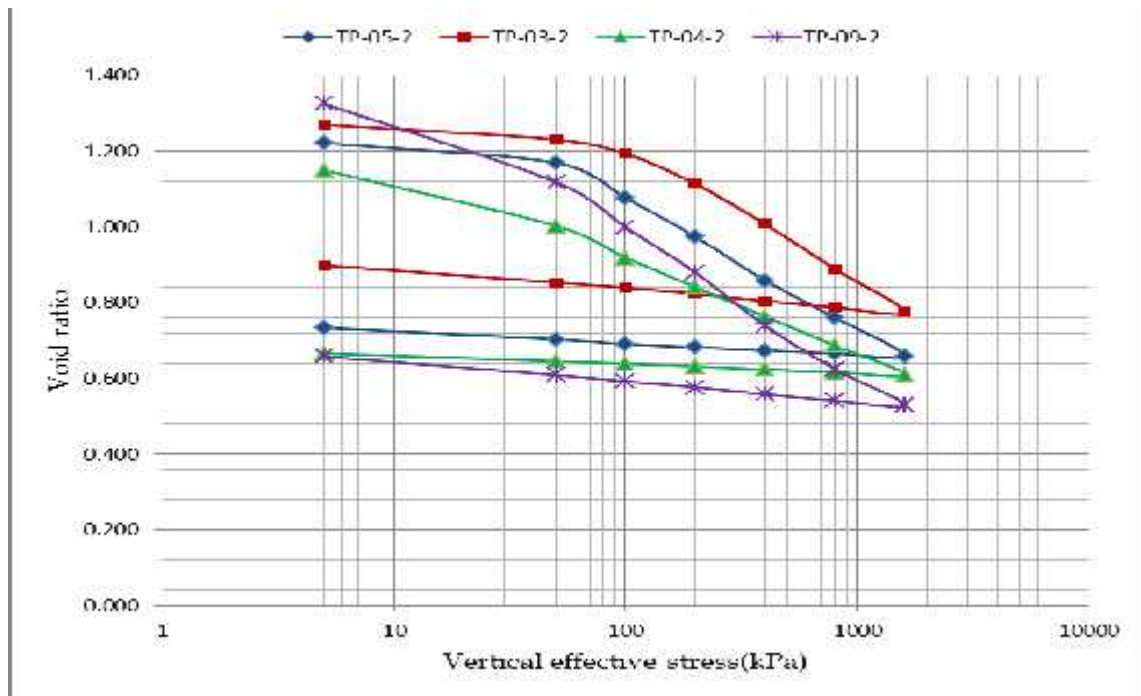


Figure 4.9: Plot of vertical effective stress versus void ratio on semi-log scale

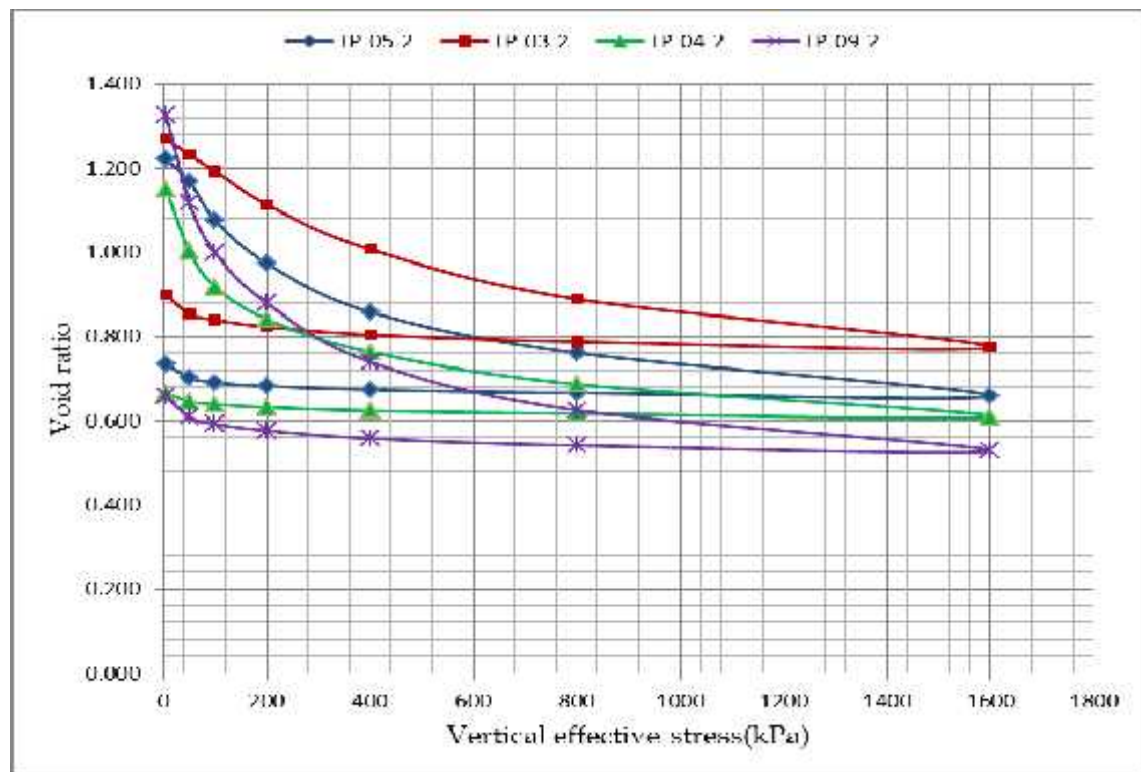


Figure 4.10: Plot of vertical effective stress versus void ratio on linear scale

4.5.1.2 Compression index

The compression index, C_c , is equal to the slope of the linear portion of the void ratio versus log pressure plot. Thus:

$$C_c = \frac{\Delta e}{\log\left(\frac{p_o + \Delta p}{p_o}\right)} \dots\dots\dots (4.3)$$

The compression index is useful for the determination of the settlement in the field.

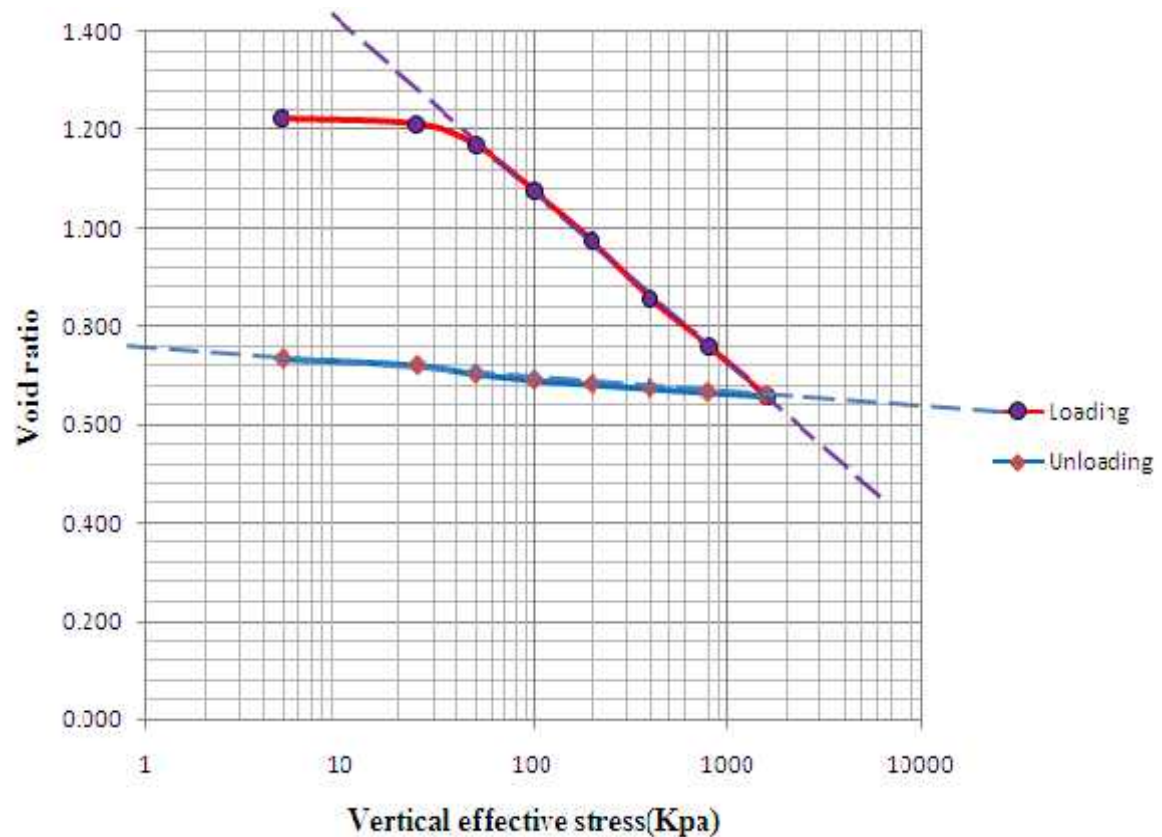


Figure 4.11: Typical loading-unloading curve to calculate the coefficient of consolidation and the recompression index

Table 4.9: Summary of Consolidation test results

Test Pit Designation	Natural Moisture Content (%)	Total Unit weight in kPa (γ)	Pressure kPa	Void ratio E_f	Coefficient of Consolidation C_v $10^{-3} \text{cm}^2/\text{sec}$	Compression Index	Over-burden pressure P_o (kPa)	Pre-consolidation pressure P_c (kPa)	Over-consolidation ratio (OCR)
TP-03-2	38	14.7	5	1.270	-	0.360	43.3	103	2.4
			50	1.231	-				
			100	1.193	2.79				
			200	1.114	9.05				
			400	1.007	9.05				
			800	0.889	1.87				
			1600	0.775	0.883				
TP-04-2	21	13.8	5	1.150	-	0.327	40.6	60	1.5
			50	1.003	-				
			100	0.919	9.81				
			200	0.841	14.1				
			400	0.763	9.05				
			800	0.687	7.48				
			1600	0.610	6.28				
TP-05-2	32	13.4	5	1.222	-	0.335	39.4	56	1.3
			25	1.211	-				
			50	1.169	-				
			100	1.077	9.050				
			200	0.974	11.70				
			400	0.858	9.050				
			800	0.761	5.350				
			1600	0.659	4.610				

4.5.1.3 Coefficient of consolidation

From those increments of load where time-deformation readings are obtained, two alternative procedures are provided to present the data, determine the end-of-primary consolidation and compute the rate of consolidation [3].

i. Logarithm-of-time-fitting method

A straight line is drawn through the points representing the final readings which exhibit a straight line trend and constant slope. A second straight line is drawn tangent to the steepest part of the deformation-log time curve. The intersection represents the deformation, d_{100} , and time, t_{100} , corresponding to 100% primary consolidation. Compression in excess of the above estimated 100% primary consolidation is defined as secondary compression.

The deformation representing 0% primary consolidation is selected by choosing any two points that have a time ratio of 1 to 4. The deformation at the larger of the two times should be greater than $\frac{1}{4}$, but less than $\frac{1}{2}$ of the total deformation for the load increment. The deformation corresponding to 0% primary consolidation is equal to the deformation at the smaller time, less the difference in the deformation for the two selected times.

The deformation, d_{50} , corresponding to 50% primary consolidation is equal to the average of the deformations corresponding to the 0 and 100% deformations. The time, t_{50} , required for 50% consolidation may be found graphically from the deformation-log time curve by observing the time that corresponds to 50% of primary consolidation on the curve.

ii. Square-root-of-time fitting method

A straight line is drawn through the points representing the initial readings that exhibit a straight line trend. Then the line is extrapolated back to $t=0$ and the deformation ordinate representing 0% primary consolidation is obtained.

A second straight line through the 0% ordinate is drawn so that the abscissa of this line is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the deformation-square root of time curve is the deformation, d_{90} , and time, t_{90} , corresponding to 90% primary consolidation.

The deformation at 100% consolidation is $\frac{1}{9}$ more than the difference in deformation between 0 and 90% consolidation. The time of primary consolidation, t_{100} , may be taken as the intersection of the deformation-square root of time curve and this deformation ordinate. The deformation, d_{50} , corresponding to 50% consolidation is equal to the deformation at $\frac{5}{9}$ of the difference b/n 0 and 90% consolidation.

From the measured data and the data obtained from either of the above two methods, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre-consolidation pressure (or

maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil [13].

Because of the fact that during the process of consolidation k and H are assumed to be constant, the coefficient of consolidation during the process of consolidation of the clay is constant [12].

The coefficient of consolidation as determined by Casagrande's semi logarithmic plot method is given by:

$$C_v = \frac{0.197 H^2 d_r}{t_{50}} \dots \dots \dots (4.4)$$

The C_v Value as determined by Taylor's square root of time fitting method is

$$C_v = \frac{0.848 H^2 d_r}{t_{90}} \dots \dots \dots (4.5)$$

4.5.1.4 Coefficient of permeability

The coefficient of permeability can be measured using field tests, or tests conducted in the laboratory. Permeability is sometimes also estimated from one dimensional consolidation test. The coefficient of permeability can be obtained from the following relationship [23].

$$K = \frac{c_v * a_v * \gamma_w}{1 + e} \dots \dots \dots (4.6)$$

- Where: c_v - Coefficient of consolidation
 a_v - Coefficient of compressibility
 γ_w - Unit weight of water
 e - Void ratio

Using the above equation, the coefficient of permeability as the function of void ratio was calculated from the consolidation test results and shown in Table4.9. It is noted that a_v , the ratio of change in void ratio to change in pressure, was obtained from Fig 4.10. As shown in Table4.10, the range of values of coefficient of permeability lies between 10^{-7} and 10^{-8} cm/sec, which indicates that the soils are practically impervious or have low permeability. In general, void ratio versus log coefficient of permeability is close to a straight line nearly for all soils [13].

Table 4.10: Relationship between Void ratio and coefficient of permeability

Test Pit Designation	Depth (m)	Pressure P Kpa	Void ratio e_f	Coefficient of consolidation C_v $10^{-3}\text{cm}^2/\text{sec}$	Coefficient of compressibility a_v $10^{-5}\text{cm}^2/\text{kN}$	Coefficient of permeability k $10^{-8}\text{cm}/\text{sec}$
TP-03-2	3.0	100	1.193	2.79	78.50	9.98
		200	1.114	9.05	66.72	28.57
		400	1.007	9.05	40.00	18.04
		800	0.889	1.87	30.00	2.97
		1600	0.775	0.883	12.45	0.62
TP-04-2	3.0	100	0.919	9.81	107.81	55.12
		200	0.841	14.1	70.00	53.60
		400	0.763	9.05	50.00	25.67
		800	0.687	7.48	10.00	4.43
		1600	0.610	6.28	3.55	1.38
TP-05-2	3.0	100	1.077	9.05	130.00	56.66
		200	0.974	11.7	88.00	52.16
		400	0.858	9.05	40.00	19.48
		800	0.761	5.35	20.00	6.08
		1600	0.659	4.61	10.35	2.88
TP-09-2	3.0	100	0.999	-	-	-
		200	0.879	0.513	99.5	2.72
		400	0.739	1.34	50	3.85
		800	0.625	0.883	15	0.82
		1600	0.529	0.427	10.64	0.30

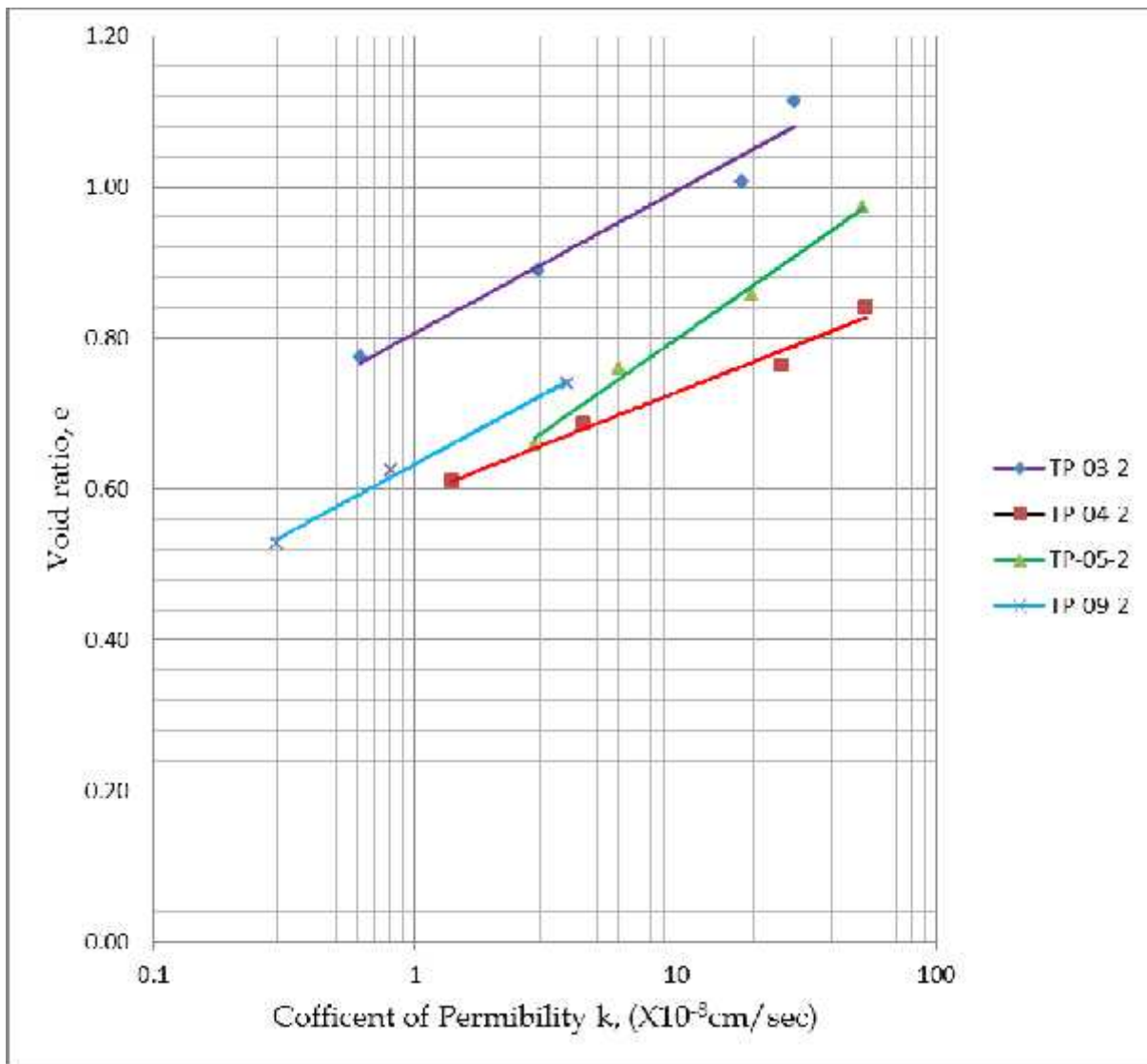


Figure 4.12: Void ratio versus Log Coefficient of Permeability

4.5.1.5. Modulus of compressibility

As stated in the journal of EAEA [20] the compressibility curve obtained from consolidation test may be expressed with sufficient accuracy by the equation of Ohde is;

$$E_s = \frac{\partial \sigma'}{\partial s'} v (\sigma')^w \dots \dots \dots (4.7)$$

In the above equation, s' is the relative settlement, v and w , are coefficients where v has units of kPa. It depends on the void ratio, water (moisture) content and consistency of the sample. It could have values ranging from 50 to 30000 kPa.

Table 4.11: Effective stress, total compression and relative settlements of samples

Test Pit Designation	Depth (m)	Effective stress s' (kN/m ²)	Total compression ΔH (mm)	Relative settlement $s' = \Delta H/H$	Modulus of compressibility kN/m ²
TP-03-2	3.0	5	0.000	0.000	4910
		50	0.352	0.018	
		100	0.689	0.034	
		200	1.408	0.070	
		400	2.366	0.118	
		800	3.431	0.172	
		1600	4.454	0.223	
TP-04-2	3.0	5	0.000	0.000	7512
		50	1.324	0.066	
		100	2.080	0.104	
		200	2.779	0.139	
		400	3.483	0.174	
		800	4.171	0.209	
		1600	4.860	0.243	
TP-05-2	3.0	5	0.000	0.000	4651
		25	0.139	0.007	
		50	0.516	0.026	
		100	1.349	0.067	
		200	2.272	0.114	
		400	3.315	0.166	
		800	4.191	0.210	
		1600	5.104	0.255	
TP-09-2	3.0	5	0.000	0.000	3680
		50	1.863	0.093	
		100	2.939	0.147	
		200	4.019	0.201	

The coefficient 'w' is a dimensionless quantity which depends on the soil type. It could have values ranging from 0 to 1. The tangent of the compressibility curve, which is a function of σ' gives the modulus of compressibility E_s .

From Eq. 4.7,

$$\frac{\partial s'}{\partial \sigma'} = \frac{1}{v(\sigma')^w} \dots \dots \dots (4.8)$$

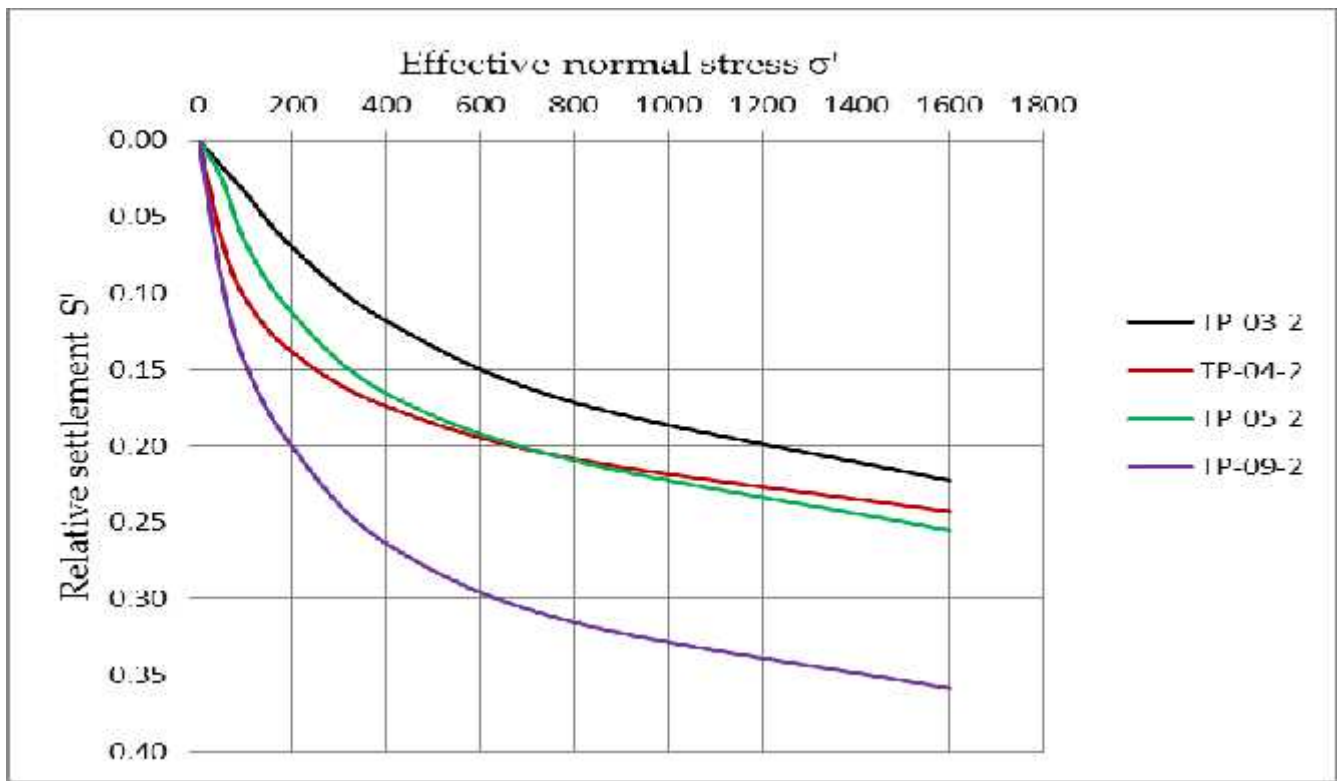


Figure 4.13: Effective normal stress versus relative settlements of the samples

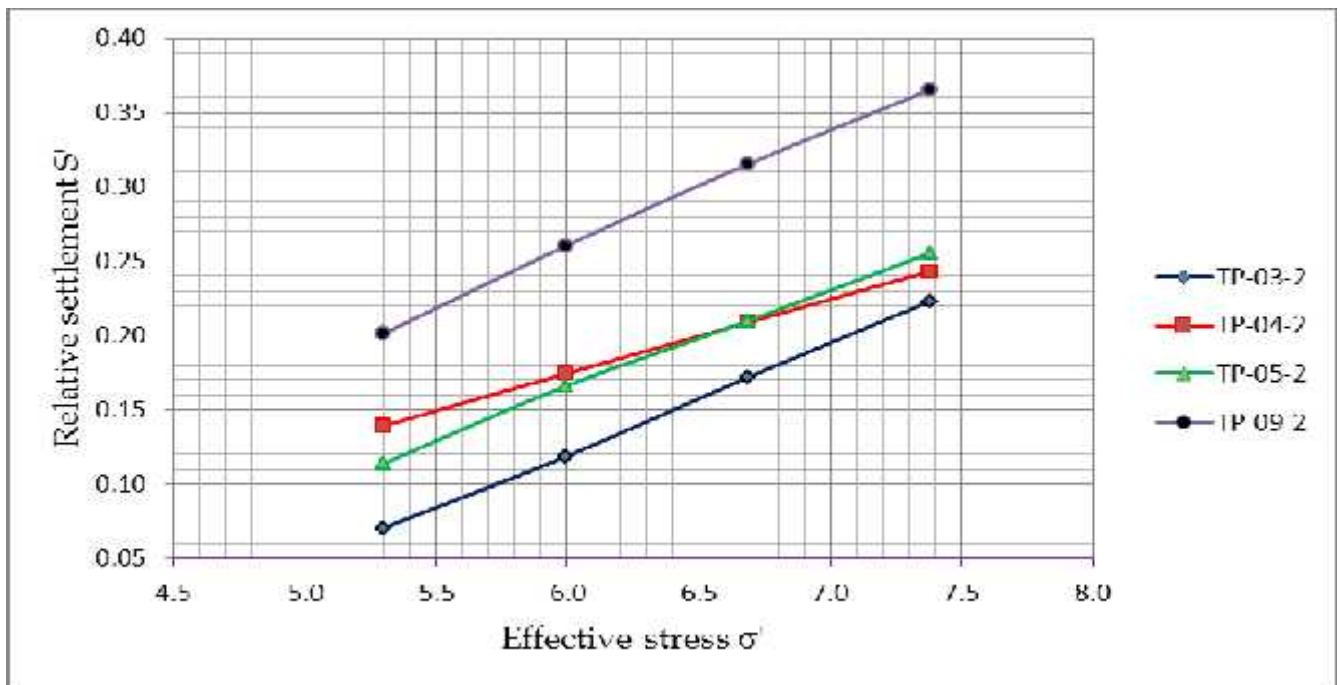


Figure 4.14: Effective normal stress versus Relative settlements of the samples ($\ln \sigma'$ versus σ')

Table 4.12: Coefficients, v and w , and equation of the modulus of compressibility

Test Pit Designation	Depth (m)	v kN/m ²	w	Modulus of compressibility, E_s kN/m ²
TP-03-2	3.0	850	1.0	$850(\sigma')$
TP-04-2	3.0	437	1.0	$437(\sigma')$
TP-05-2	3.0	536	1.0	$536(\sigma')$
TP-09-2	3.0	2396	1.0	$2396(\sigma')$

Table 4.13: Variation of Modulus of compressibility with depth

Sample No.	TP-03-2	TP-04-2	TP-05-2	TP-09-2
Depth (m)	3.00	3.00	3.00	3.00
σ'	Es kN/m ²	Es kN/m ²	Es kN/m ²	Es kN/m ²
0	0	0	0	0
100	85000	43700	53600	239600
200	170000	87400	107200	479200
300	255000	131100	160800	718800
400	340000	174800	214400	958400
500	425000	218500	268000	1198000
600	510000	262200	321600	1437600
700	595000	305900	375200	1677200
800	680000	349600	428800	1916800
900	765000	393300	482400	2156400
1000	850000	437000	536000	2396000
1100	935000	480700	589600	2635600
1200	1020000	524400	643200	2875200
1300	1105000	568100	696800	3114800
1400	1190000	611800	750400	3354400
1500	1275000	655500	804000	3594000
1600	1360000	699200	857600	3833600

5. DISCUSSIONS OF THE LABORATORY RESULTS AND COMPARISONS WITH PREVIOUSLY DONE RESEARCHES

5.1. Discussions of the laboratory test results

The results obtained from the grain size analyses indicate that the dominant proportions of soil particle in the research area are sand and silty soil that have clay content in the extent from 5.4 to 40.5%, silt fraction 17.6 to 60.7%, sand fraction 14.5 to 54.6% and gravel content from 0.0 to 24.8%.

The soil in the research area has liquid limit fluctuating from 28 to 75%, plastic limit from 21 to 37% and plastic index from 5 to 37%.

Within the depth of exploration, the top layer which is brown silty clay as classified visually has a specific gravity as low as 2.40. The specific gravity of soil becomes lower when it contains organic matter. That is why soil from upper layers of the pit has specific gravity around 2.40. But as excavated deeper it becomes extends from 2.60 to 2.70. This specific gravity is proven in literatures for silt and silty sand soils.

Fig 4.4 shows plasticity chart of the study area according to Unified Soil Classification System. This chart shows that the soil under investigation lies below the A-line in the region of inorganic silt and inorganic elastic silt. That means inorganic silt with low to high plasticity. Additionally it contains line above A-line because of the presence of organic content in the sample.

Optimum moisture content and the maximum dry density of the soil is summarized in Table 4.7. From the test results, the maximum dry density (MDD) of Adama varies from 1.20 to 1.62 g/cm³ and the optimum moisture content is from 17.5 to 36.5 percent.

Figure 4.8 and 4.9 show the plots of vertical effective stress against void ratio on semi-log and linear scale. Except their variation in initial void ratio, the plots show similar curvature for all the samples. The soil has a pre-consolidation pressure of 50-100 kPa. Over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in its natural state.

The coefficient of consolidation, C_v , calculated from curve of compression dial reading versus square root of time for each incremental loading is plotted as a function of effective stress. The shapes of the curves for three samples are almost similar and the same is true for value of coefficient of consolidation for each incremental loading. But one of the samples has slightly different shape and value of coefficient of consolidation for each incremental loading. This is because the compressibility of any soil type varies with density.

For all the samples, the modulus of compressibility varies linearly with effective normal stress. The effective normal stress also shows linear relationship with relative settlements of the samples.

The coefficient of permeability of soil under investigation calculated from the test results of consolidation test has values from 10^{-7} to 10^{-8} cm/sec (Table 4.12). The result shows that the soil

under investigation is practically impermeable to very low permeability. As shown in Fig 4.9 the plot of void ratio versus log permeability coefficient shows straight line.

Modulus of compressibility of the area ranges from 3920 to 7500 kPa. As stated in [23], the modulus of compressibility for silt soil ranges from 3000 to 10000 kPa. Therefore, the test result agrees with this range.

The variation of modulus of compressibility, E_s , with effective stress, σ' can be observed for a given value of effective stress as the corresponding value of E_s varies from place to place. This is because of the non- uniformity of the degree of stiffness of the soil samples.

5.2. Comparisons with previously research works

The index and compressibility characteristic of soils in Adama is studied and a comparison has been made with known silt and silty sand soils. Researchers have been found done on Adama silt and silty sand soils by Abu Gemechu (2011) and Genet Kassahun (2013). Meanwhile, Beza Tesfaye (2015) and Eyob Teferi (2011) have studied in Ziway area and Hawasa. The relevant results of findings by these studies are summarized in table 5.1.

As shown in the following table, the average values of various tests done at different countries, i.e., Liquid Limit, Plastic Index and Gradation for silt and silty sand show different properties.

As discussed in the literature, the soil of Adama when compared with the previous tested silt and silty sand soils of Ethiopia show considerable similarities with the silt and silty sand soils: More similarity is observed with respect to the index tests shown in Tables 5-1. Moreover, the test result shows that the value of plasticity is low as these soils due to the mode of formation, i.e., they are formed at relatively wet climatic conditions. Generally, the soil of Adama could be classified as silty sand, with almost close characteristics with Zeway, Meki, and Hawasa soils having high plasticity; Adama soil has high percentage of sand fraction.

Comparisons with previous studies were made with a research done by Genet K. a small variation in index properties were observed which is due to variation in test pit location, but this research reinforce the investigation done on the town since we did on different engineering property of the soils.

Table 5.1 shows that the average values of Sieve analysis, Liquid Limit, Plastic Index and specific gravities. As it can be easily noticed, Adama soils show lower plasticity (clay content) next to Ziway town soils.

Table 5.1: Index property Test Results in different parts of the country

<i>Parameters</i>	<i>(Abu,2011)</i>	<i>(Bezza, 2015)</i>	<i>(Genet, 2013)</i>	<i>(Eyob,2011)</i>	<i>This Research</i>
<i>Soil type</i>	Silt & Silty Sand	Silt & Silty Sand	Silt & Silty Sand	Silt & Silty Sand	Silt & Silty Sand
<i>Location</i>	Adama	Ziway	Adama	Hawasa	Adama
<i>Clay Content (%)</i>	14-58	0.66-10.93	-	2.1 – 3.2	5.4-30.2
<i>Liquid Limit (%)</i>	39-49.4	27-37	30-37	0-38	28-37
<i>Plasticity Index (%)</i>	10-15	4-8	5-34	0-6	5-37
<i>Free swell (%)</i>		20-52	16-48	0	18-50
<i>Specific gravity</i>	2.61-2.7	2.4-2.62	2.45-2.7	2.48-2.51	2.4-2.7
<i>From plasticity chart</i>	ML & SM	SM & ML	SM , ML & MH	ML and SM	SM ,ML & MH

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

1. The soil in Adama town is mostly silt, and silty sand soil in which the percentage of clay ranges from 5 to 32 %, silt from 18 to 62 %, sand from 15 to 55 % and gravel 0 to 25%.
2. From the consistency limit test results, the liquid limit assorts from 28 to 75%, plastic limit from 21 to 37 % and plasticity index from 5 to 37%.
3. As determined from the one-dimensional consolidation test conducted on remolded soil samples, compression index, C_c , ranges from 0.33 to 0.40, recompression index, C_r , from 0.017 to 0.066, coefficient of consolidation, C_v , from $1.63-44.7(\times 10^{-11})\text{cm}^2/\text{year}$, Coefficient of permeability from $0.3-56.7(\times 10^{-8})\text{cm/sec}$ and the modulus of compressibility from 3920 to 7500 kPa.
4. The value of the consolidation parameters of the soil is high, this means the soil has relatively high compressibility and rate of consolidation is also high.

6.2. Recommendation

-  In this research samples of soil were collected only from ten test pits; by taking more number of samples and the tests are conducted over a wide range to see more effects.
-  It is recommended if the correlation of compressibility characteristics with CBR will be done in the future.
-  In evaluating the engineering properties of soil, visual observation of soil in the field is necessary

7. REFERENCE

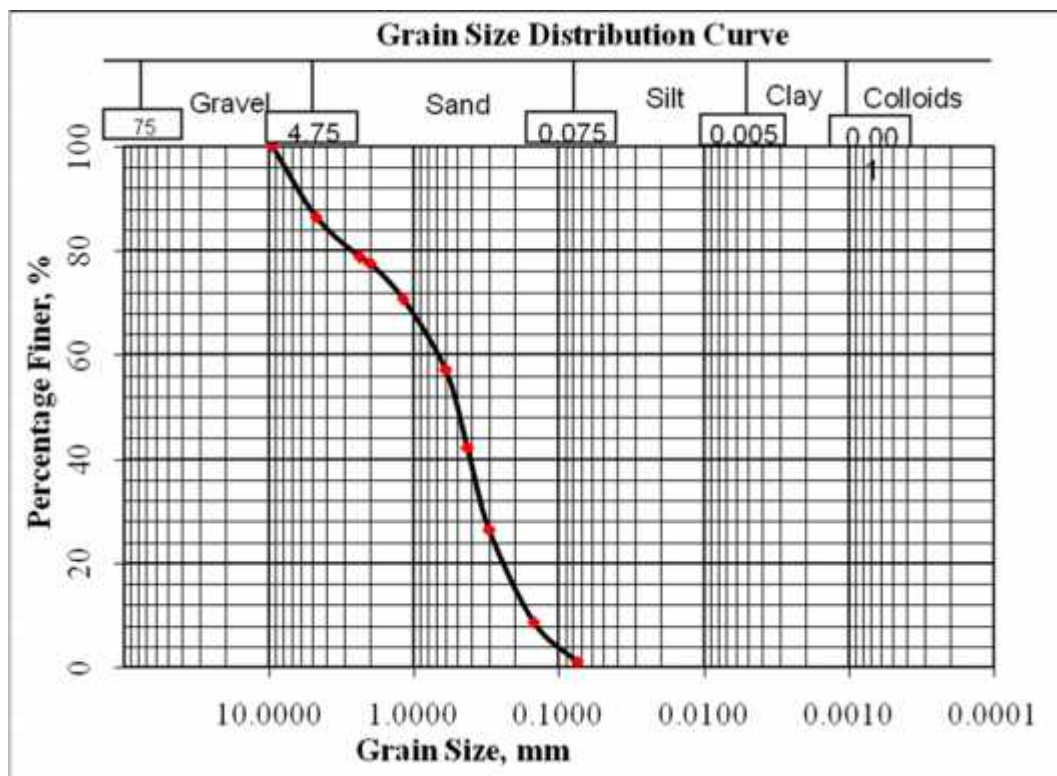
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APPENDIX-A

Particle Size Analysis

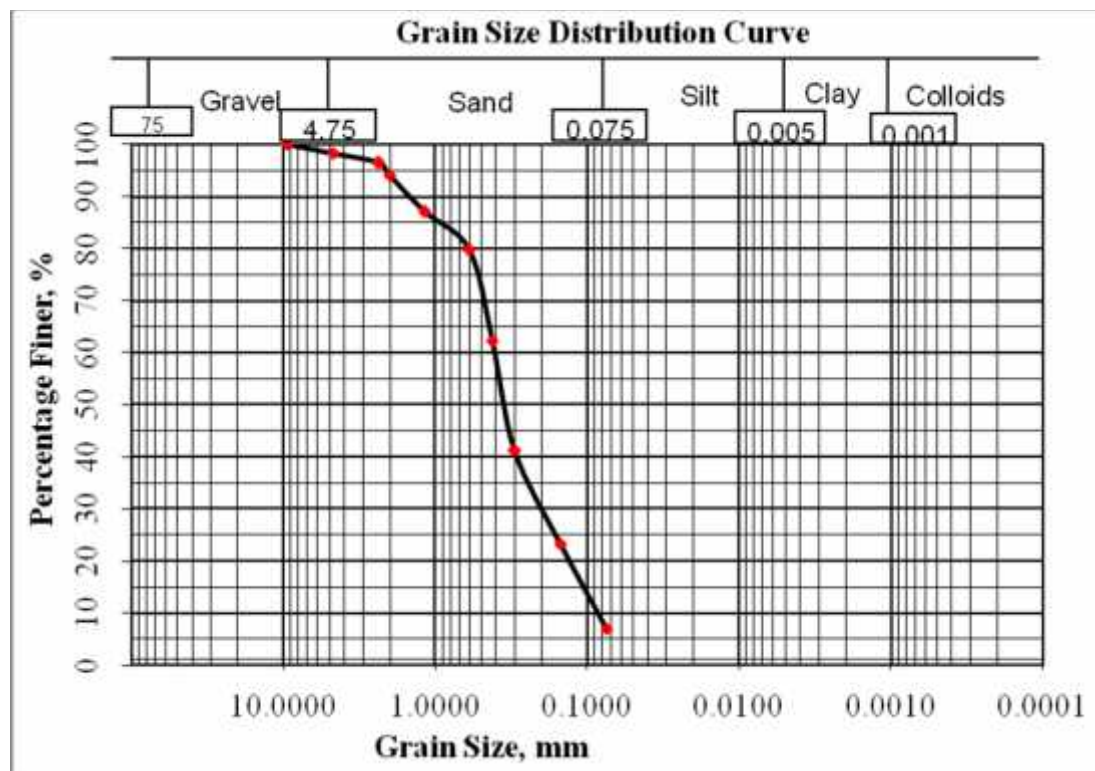
Sieve size test for pit no.1

Location: <i>Around adama University</i>				Job ref.	<i>Thesis research</i>	
				Pit no.	#1	
Soil Description: <i>Inorganic silts</i>				Sample no.	#1	
				Depth	3m	
Test method: <i>ASTM D 422-63</i>				Date	20/09/2007E.C	
.....Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0.0	0	100.0
4.75	431	498	67	13.4	13.4	86.6
2.36	389	428	39	7.8	21.2	78.8
2	377	383	6	1.2	22.4	77.6
1.18	354	388	34	6.8	29.2	70.8
0.6	312	380	68	13.6	42.8	57.2
0.425	291	366	75	15.0	57.8	42.2
0.3	287	366	79	15.8	73.6	26.4
0.15	268	356	88	17.6	91.2	8.8
0.075	272	310	38	7.6	98.8	1.2
Pan	254	260	6	1.2	100.0	0.0



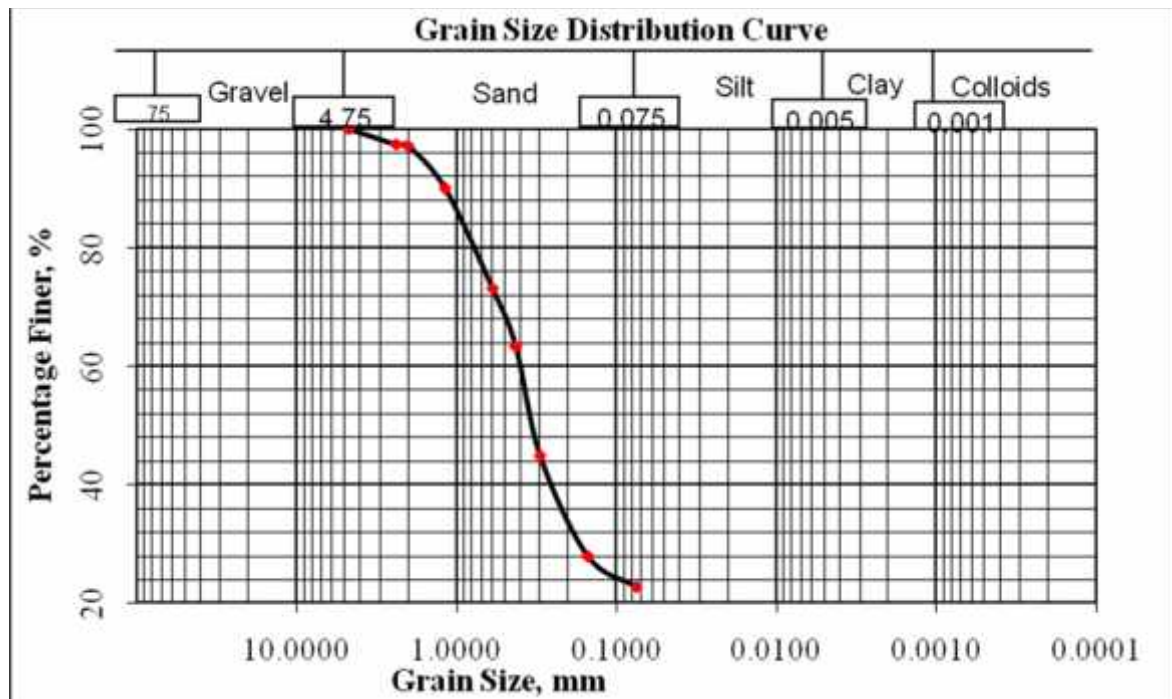
Sieve size test for pit no.2

Location: <i>Kechema</i>				Job ref.	<i>Thesis research</i>	
				Pit no.	#2	
Soil Description: <i>Inorganic silts</i>				Sample no.	#1	
				Depth	2.5m	
Test method: <i>ASTM D 422-63</i>				Date	20/09/2007 E.C	
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0.0	0.0	100.0
4.75	431	440	9	1.8	1.8	98.2
2.36	389	398	9	1.8	3.6	96.4
2	378	390	12	2.4	6.0	94.0
1.18	355	390	35	7.0	13.0	87.0
0.6	313	350	37	7.4	20.4	79.6
0.425	291	378	87	17.4	37.8	62.2
0.3	287	392	105	21.0	58.8	41.2
0.15	268	358	90	18.0	76.8	23.2
0.075	259	340	81	16.2	93.0	7.0
pan	240	275	35	7	100	0



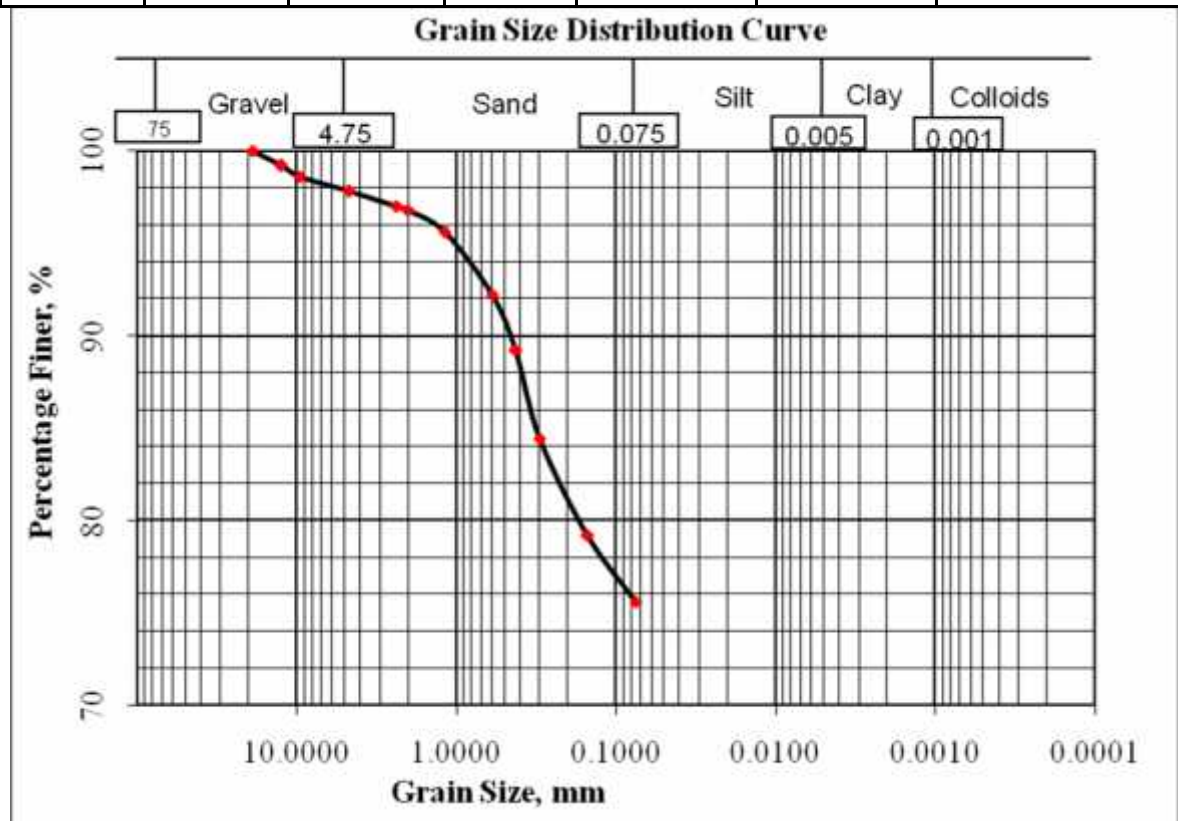
Sieve size test for pit no.3

Location: <i>Migira</i>					Job ref.	<i>Thesis research</i>
					Pit no.	<i>#1</i>
Soil Description: <i>Inorganic silts</i>					Sample no.	<i>#3</i>
					Depth	<i>3m</i>
Test method: <i>ASTM D 422-63</i>					Date	<i>20/09/2007E.C</i>
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
4.75	431	431	0	0.0	0.0	100.0
2.36	389	402	13	2.6	2.6	97.4
2	377	378	1	0.2	2.8	97.2
1.18	354	390	36	7.2	10.0	90.0
0.6	312	396	84	16.8	26.8	73.2
0.425	291	340	49	9.8	36.6	63.4
0.3	287	380	93	18.6	55.2	44.8
0.15	268	352	84	16.8	72.0	28.0
0.075	272	298	26	5.2	77.2	22.8
Pan	254	368	114	22.8	100.0	0.0



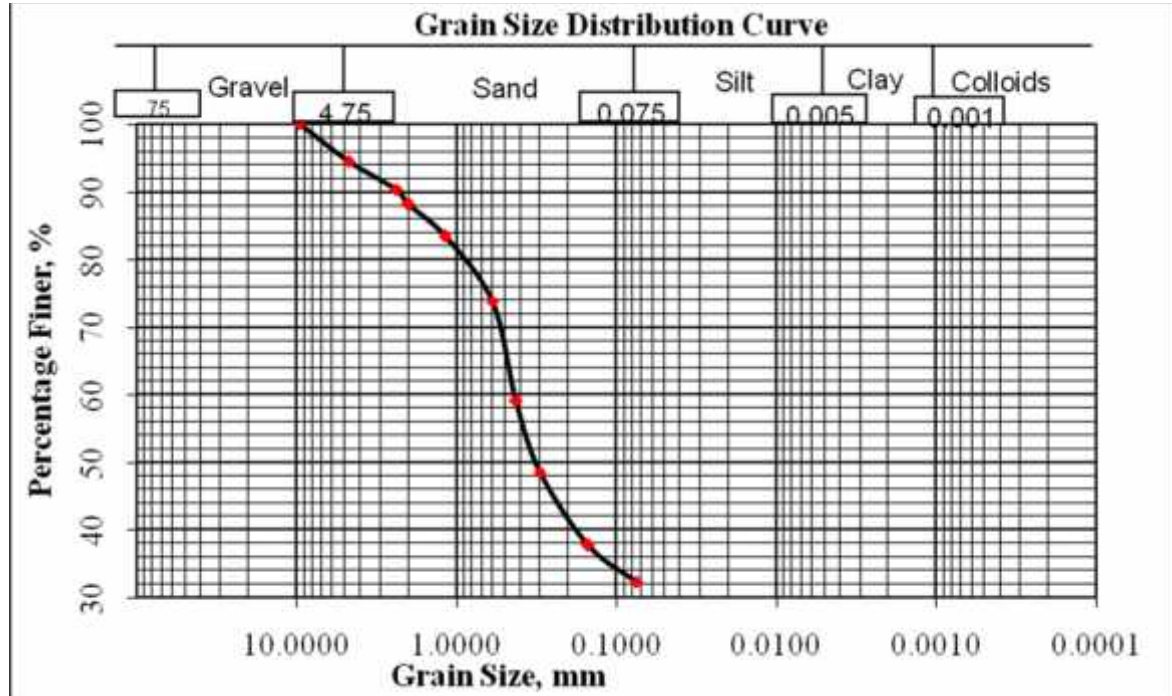
Sieve size test for pit no.4

Location: <i>Boku</i>					Job ref.	<i>Thesis research</i>
					Pit no.	<i>#1</i>
Soil Description: <i>Inorganic silts</i>					Sample no.	<i>#4</i>
					Depth	<i>3 m</i>
Test method: <i>ASTM D 422-63</i>					Date	<i>20/09/2007E.C</i>
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
19	438	438	0	0.0	0.0	100.0
12.5	448	452	4	0.8	0.8	99.2
9.5	446	449	3	0.6	1.4	98.6
4.75	431	435	4	0.8	2.2	97.8
2.36	389	393	4	0.8	3.0	97.0
2	377	378	1	0.2	3.2	96.8
1.18	354	360	6	1.2	4.4	95.6
0.6	312	329	17	3.4	7.8	92.2
0.425	291	306	15	3.0	10.8	89.2
0.3	287	311	24	4.8	15.6	84.4
0.15	266	292	26	5.2	20.8	79.2
0.075	259	277	18	3.6	24.4	75.6
Pan	240	618	378	75.6	100.0	0.0



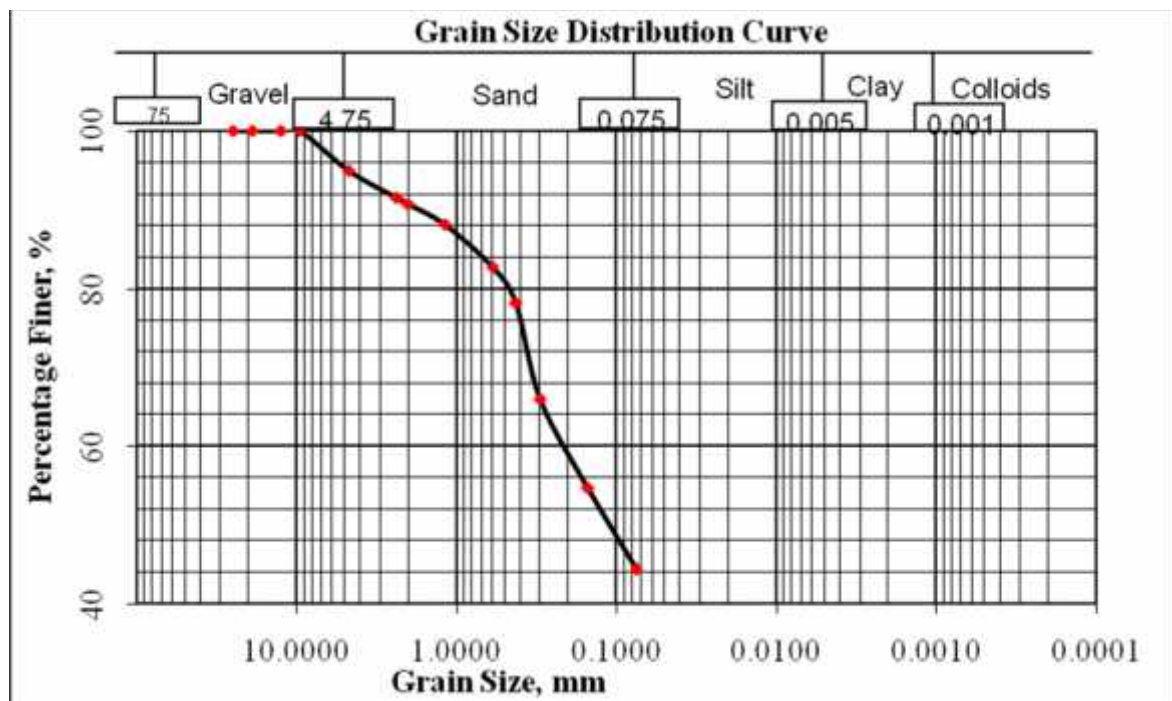
Sieve size test for pit no.5

Location: <i>Bole</i>					Job ref.	<i>Thesis research</i>
					Pit no.	<i>#1</i>
Soil Description: <i>Inorganic silts</i>					Sample no.	<i>#5</i>
					Depth	<i>3</i>
Test method: <i>ASTM D 422-63</i>					Date	<i>20/09/2007E.C</i>
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0	0	100
4.75	431	458	27	5	5	95
2.36	389	410	21	4	10	90
2	377	388	11	2	12	88
1.18	354	378	24	5	17	83
0.6	312	360	48	10	26	74
0.425	291	364	73	15	41	59
0.3	287	340	53	11	51	49
0.15	266	320	54	11	62	38
0.075	259	286	27	5	68	32
Pan	240	402	162	32	100	0



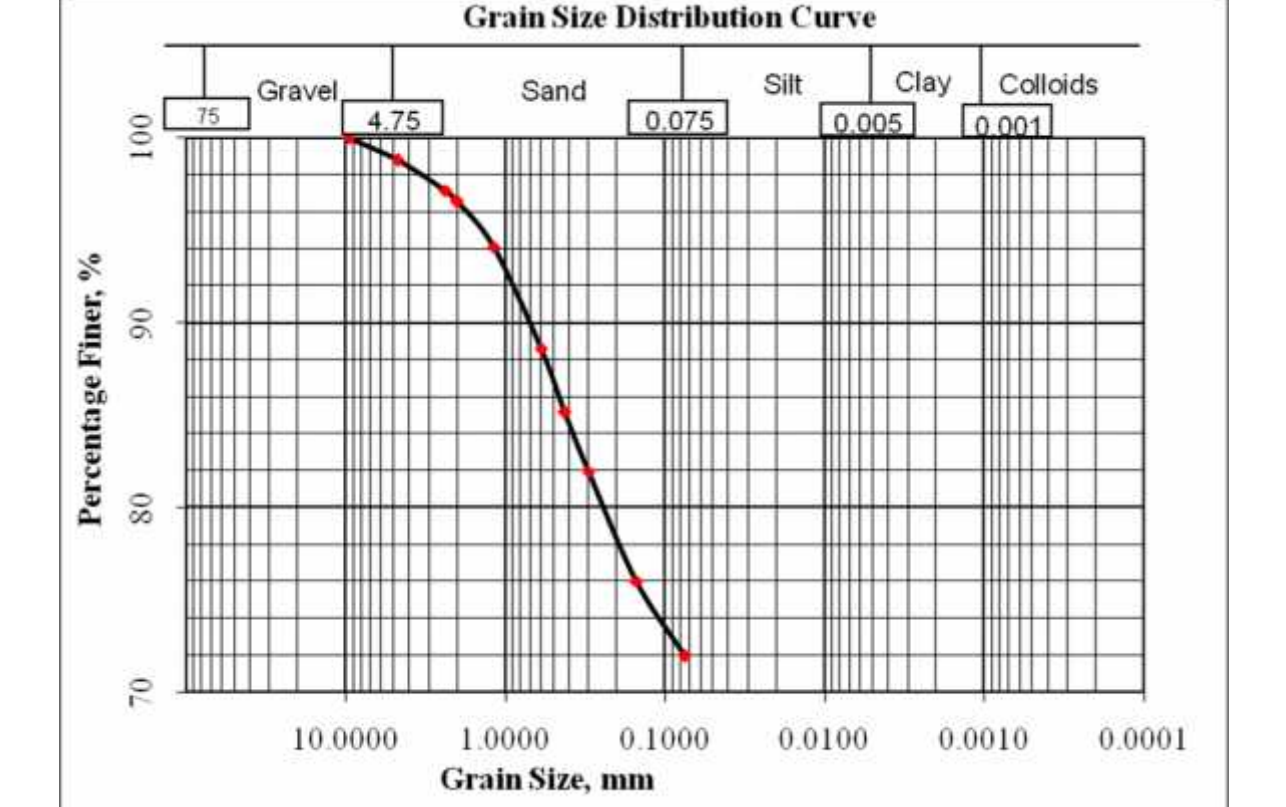
Sieve size test for pit no.6

Location: <i>Wonji Mazoria</i>					Job ref.	<i>Thesis research</i>
					Pit no.	#1
Soil Description: <i>Inorganic silts</i>					Sample no.	#6
					Depth	3m
Test method: <i>ASTM D 422-63</i>					Date	20/09/2007E.C
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
25	446	446	0	0	0	100
19	438	448	10	2	2	98
12.5	448	464	16	3.2	5.2	94.8
9.5	446	453	7	1.4	6.6	93.4
4.75	431	456	25	5	11.6	88.4
2.36	389	406	17	3.4	15	85
2	377	381	4	0.8	15.8	84.2
1.18	354	367	13	2.6	18.4	81.6
0.6	312	339	27	5.4	23.8	76.2
0.425	291	314	23	4.6	28.4	71.6
0.3	287	315	28	5.6	34	66
0.15	268	324	56	11.2	45.2	54.8
0.075	272	324	52	10.4	55.6	44.4
Pan	254	476	222	44.4	100	0



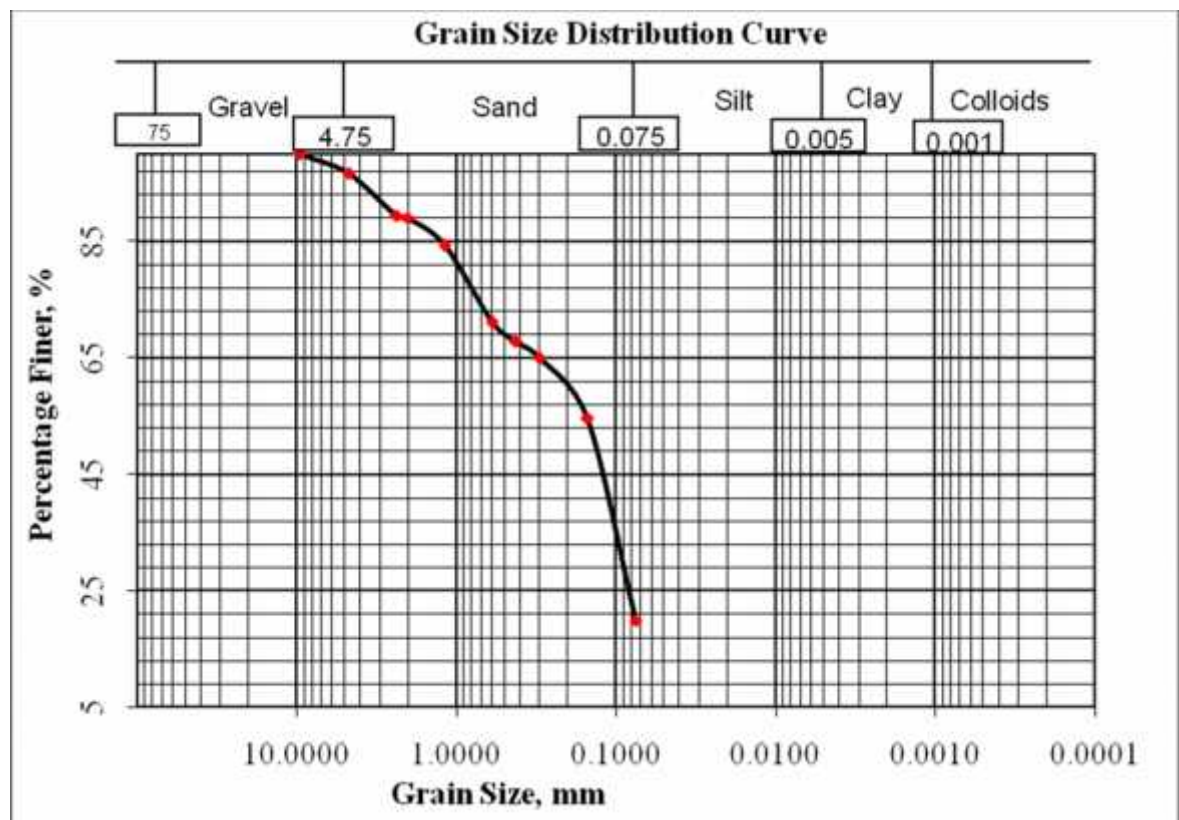
Location: <i>Pekok</i>	Job ref.	<i>Thesis research</i>
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					Pit no.	#1
Soil Description: <i>Inorganic silts</i>					Sample no.	#7
					Depth	3m
Test method: <i>ASTM D 422-63</i>					Date	20/09/2007E.C
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0	0	100
4.75	431	437	6	1.2	1.2	98.8
2.36	389	397	8	1.6	2.8	97.2
2	377	386	9	1.8	4.6	95.4
1.18	354	398	44	8.8	13.4	86.6
0.6	312	356	44	8.8	22.2	77.8
0.425	291	334	43	8.6	30.8	69.2
0.3	287	303	16	3.2	34	66
0.15	266	358	92	18.4	52.4	47.6
0.075	272	385	113	22.6	75	25
Pan	240	365	125	25	100	0



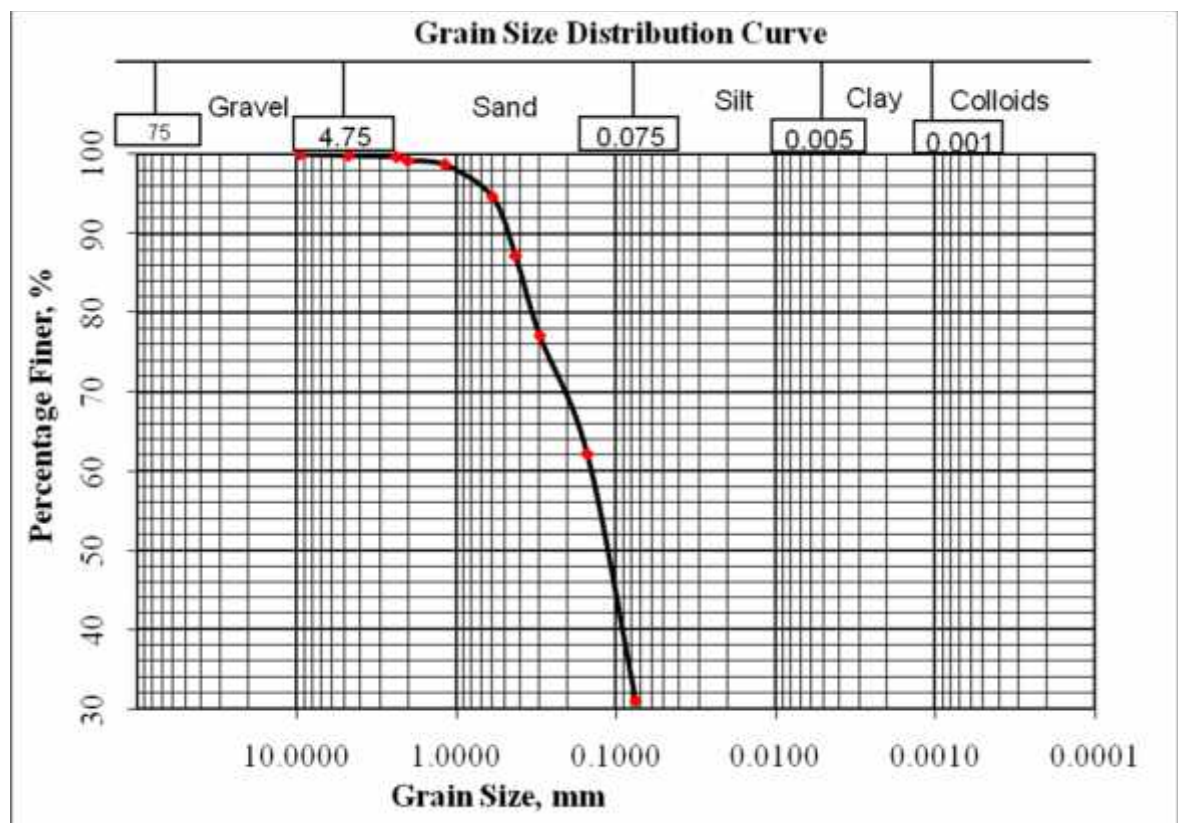
Sieve size test for pit no.8

Location: <i>Muger</i>					Job ref.	<i>Thesis research</i>
					Pit no.	<i>#1</i>
Soil Description: <i>Inorganic silts</i>					Sample no.	<i>#8</i>
					Depth	<i>3m</i>
Test method: <i>ASTM D 422-63</i>					Date	<i>20/09/2007E.C</i>
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0	0	100
4.75	431	448	17	3	3	97
2.36	389	425	36	7	11	89
2	377	379	2	0	11	89
1.18	354	378	24	5	16	84
0.6	312	378	66	13	29	71
0.425	291	307	16	3	32	68
0.3	287	301	14	3	35	65
0.15	266	318	52	10	45	55
0.075	272	446	174	35	80	20
Pan	240	339	99	20	100	0



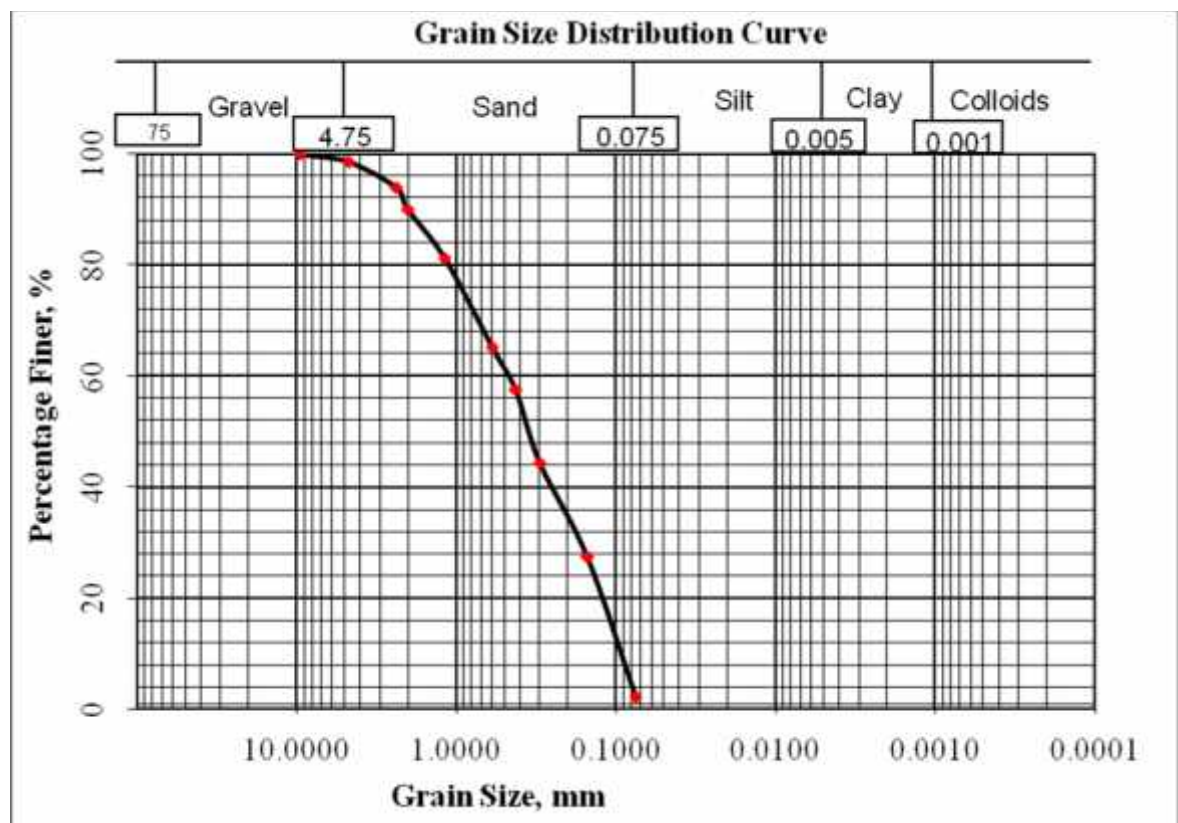
Sieve size test for pit no.9

Location: <i>Municipality</i>				Job ref.	<i>Thesis research</i>	
				Pit no.	#1	
Soil Description: <i>Inorganic silts</i>				Sample no.	#9	
				Depth	3m	
Test method: <i>ASTM D 422-63</i>				Date	20/09/2007E.C	
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0	0	100
4.75	431	432	1	0.2	0.2	99.8
2.36	389	390	1	0.2	0.4	99.6
2	377	379	2	0.4	0.8	99.2
1.18	354	357	3	0.6	1.4	98.6
0.6	312	332	20	4	5.4	94.6
0.425	291	328	37	7.4	12.8	87.2
0.3	287	338	51	10.2	23	77
0.15	266	340	74	14.8	37.8	62.2
0.075	272	428	156	31.2	69	31
Pan	240	395	155	31	100	0



Sieve size test for pit no.10

Location: <i>Aba Geda</i>				Job ref.	<i>Thesis research</i>	
				Pit no.	#1	
Soil Description: <i>Inorganic silts</i>				Sample no.	#10	
				Depth	3m	
Test method: <i>ASTM D 422-63</i>				Date	20/09/2007E.C	
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.5	446	446	0	0	0	100
4.75	431	438	7	1.4	1.4	98.6
2.36	389	412	23	4.6	6	94
2	377	397	20	4	10	90
1.18	354	398	44	8.8	18.8	81.2
0.6	312	392	80	16	34.8	65.2
0.425	291	329	38	7.6	42.4	57.6
0.3	287	353	66	13.2	55.6	44.4
0.15	266	351	85	17	72.6	27.4
0.075	272	398	126	25.2	97.8	2.2
Pan	240	251	11	2.2	100	0



APPENDIX-B

Standard compaction test for pit no.1

Location: <i>Around Adama University</i>			Job		<i>Thesis research</i>
			Pit no.		<i>1</i>
Soil Description: <i>Inorganic silts</i>			Sample no.		<i>1</i>
			Depth		<i>1.5m</i>
Test method: <i>ASTM D 698-91</i>			Date		<i>25/09/2007E.C</i>
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5
Mold diameter, cm	10	Mold Height, cm	12	Volume, CC	944
Water Content Determination					
Determination No			2	3	4
Container No			27	44	8
Mass of Container, M ₁ ,g			5.34	5.39	5.22
Mass of Container + Wet Soil, M ₂ ,g			162.	177.	176.6
Mass of Container + Dry Soil, M ₃ ,g			136.	145.	142.3
Mass of Water, M ₂ -M ₃ ,g			25.6	31.5	34.35
Mass of Dry Soil, M ₃ -M ₁ ,g			131.3	140.2	137
Moisture Content, $W=(M_2-M_3)/(M_3-M_1)*100$, %			19.5	22.5	25.07
Density Determination					
Water content. W _o , %			19.5	22.5	25.07
Wt of soil + mold, g			718	729	7353
Wt of mold, g			562	562	5627
Wt of soil in mold, g			156	166	1726
Wet density, g/cc			1.65	1.76	1.828
Dry density, g/cc			1.38	1.43	1.462
			13.8	14.3	14.62
Soil Density-Moisture Curve					
Optimum moisture Content (%)		25	Maximum Dry Density (kg/cm ³)		14.62

Standard compaction test for pit no.3

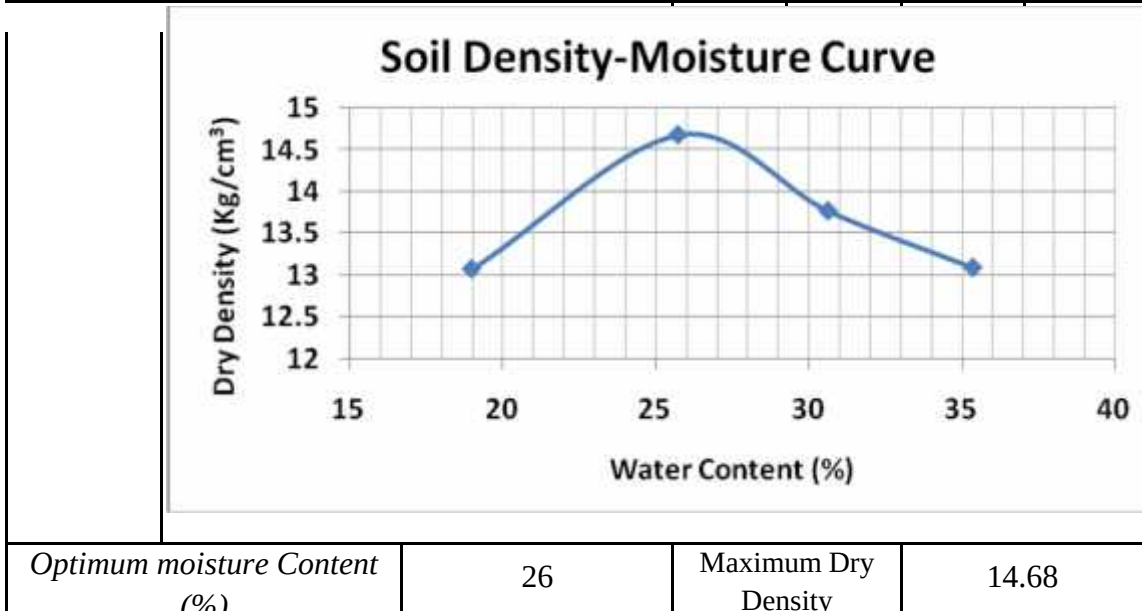
Location: <i>Around Adama University</i>			Job ref.		<i>Thesis research</i>
			Pit no.		5
Soil Description: <i>Inorganic silts</i>			Sample no.		5
			Depth		2.5m
Test method: <i>ASTM D 698-91</i>			Date		15/11/2007E.C
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5
Mold diameter, cm	10	Mold Height,	12	Volume, CC	944
Water Content Determination					
Determination No			2	3	4
Container No			73	46	66
Mass of Container, M ₁ ,g			14.81	17.18	15.64
Mass of Container + Wet Soil, M ₂ ,g			50.16	56.49	53.75
Mass of Container + Dry Soil, M ₃ ,g			44	48.18	44.73
Mass of Water, M ₂ -M ₃ ,g			6.16	8.31	9.02
Mass of Dry Soil, M ₃ -M ₁ ,g			29.19	31	29.09
Moisture Content, $W=(M_2-M_3)/(M_3-M_1)*100, \%$			21.08	26.79	30.98
Density Determination					
Water content. W _o , %			21.08	26.79	30.98
Wt of soil + mold, g			7019	7161	7258
Wt of mold, g			5615	5615	5615
Wt of soil in mold, g			1404	1546	1643
Wet density, g/cc			1.49	1.641	1.744
Dry density, g/cc			1.23	1.294	1.331
Dry density, Kg/cm ³			12.3	12.94	13.31
Soil Density-Moisture Curve 					
Optimum moisture Content (%)		31	Maximum Dry Density (kg/cm ³)		13.31

Standard compaction test for pit no.5

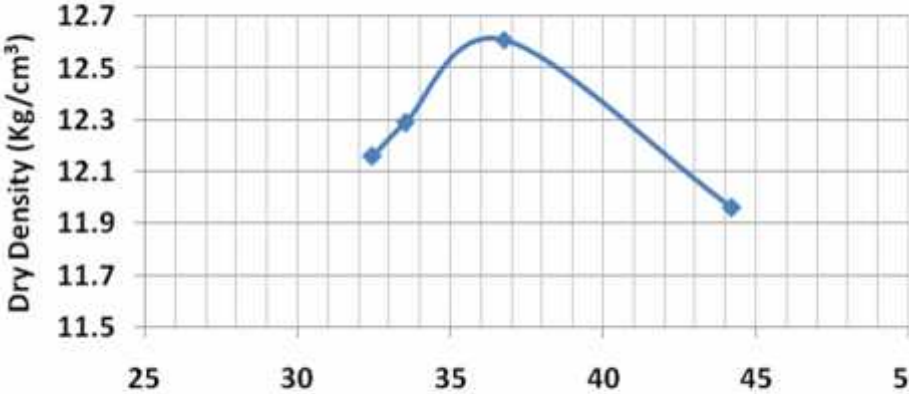
Location: <i>Around Adama University</i>			Job ref.		<i>Thesis research</i>
			Pit no.		5
Soil Description: <i>Inorganic silts</i>			Sample no.		5
			Depth		2.5m
Test method: <i>ASTM D 698-91</i>			Date		15/11/2007E.C
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5
Mold diameter, cm	10	Mold Height.	12	Volume, CC	944
Water Content Determination					
Determination No		2	3	4	5
Container No		73	46	66	8
Mass of Container, M1 ,g		14.81	17.18	15.64	15.49
Mass of Container + Wet Soil, M2 ,g		50.16	56.49	53.75	63.11
Mass of Container + Dry Soil, M3 ,g		44	48.18	44.73	50.21
Mass of Water, M2-M3 ,g		6.16	8.31	9.02	12.9
Mass of Dry Soil, M3-M1 ,g		29.19	31	29.09	34.72
Moisture Content, $W=(M2-M3)/(M3-$		21.08	26.79	30.98	37.21
Density Determination					
Water content. W_o , %		21.08	26.79	30.98	37.21
Wt of soil + mold, g		7019	7161	7258	7254
Wt of mold, g		5615	5615	5615	5615
Wt of soil in mold, g		1404	1546	1643	1639
Wet density, g/cc		1.49	1.641	1.744	1.739
Dry density, g/cc		1.23	1.294	1.331	1.268
Dry density, Kg/cm^3		12.3	12.94	13.31	12.68
Soil Density-Moisture Curve					
Optimum moisture Content (%)		31	Maximum Dry Density (kg/cm^3)		13.31

Standard compaction test for pit no.7

Location: <i>Around Adama University</i>			Job ref.		<i>Thesis research</i>
			Pit no.		7
Soil Description: <i>Inorganic silts</i>			Sample no.		7
			Depth		2.6m
Test method: <i>ASTM D 698-91</i>			Date		15/11/2007E.C
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5
Mold diameter, cm	10	Mold Height,	12	Volume, CC	944
<i>Water Content Determination</i>					
Determination No			2	3	4
Container No			30	47	41
Mass of Container, M ₁ ,g			5	5	5
Mass of Container + Wet Soil, M ₂ ,g			174	176	231
Mass of Container + Dry Soil, M ₃ ,g			147	141	178
Mass of Water, M ₂ -M ₃ ,g			27	35	53
Mass of Dry Soil, M ₃ -M ₁ ,g			142	136	173
Moisture Content, $W=(M_2-M_3)/(M_3-M_1)*100$, %			19.01	25.7	30.6
<i>Density Determination</i>					
Water content. W _o , %			19.01	25.7	30.6
Wt of soil + mold, g			7099	737	7329
Wt of mold, g			5630	563	5630
Wt of soil in mold, g			1469	174	1699
Wet density, g/cc			1.556	1.84	1.79
Dry density, g/cc			1.307	1.46	1.37



Standard compaction test for pit no.9

Location: <i>Around Adama University</i>			Job ref.		<i>Thesis research</i>	
			Pit no.		9	
Soil Description: <i>Inorganic silts</i>			Sample no.		9	
			Depth		3.0m	
Test method: <i>ASTM D 698-91</i>			Date		15/11/2007E.C	
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5	
Mold diameter, cm	10	Mold Height, cm	12	Volume, CC	944	
<i>Water Content Determination</i>						
Determination No			2	3	4	5
Container No			36	16	98	59
Mass of Container, M ₁ ,g			14.86	15.69	14.8	15.55
Mass of Container + Wet Soil, M ₂ ,g			37.8	50.52	43.82	58.63
Mass of Container + Dry Soil, M ₃ ,g			32.17	41.77	36.02	45.43
Mass of Water, M ₂ -M ₃ ,g			5.63	8.75	7.8	13.2
Mass of Dry Soil, M ₃ -M ₁ .g			17.31	26.08	21.22	29.88
Moisture Content, $W=(M_2-M_3)/(M_3-M_1)*100, \%$			32.46	33.53	36.76	44.2
<i>Density Determination</i>						
Water content. W _o , %			32.46	33.53	36.76	44.2
Wt of soil + mold, g			7136	7177	7243	7244
Wt of mold, g			5615	5615	5615	5615
Wt of soil in mold, g			1521	1562	1628	1629
Wet density, g/cc			1.611	1.654	1.724	1.725
Dry density, g/cc			1.216	1.229	1.261	1.196
Dry density, Kg/cm ³			12.16	12.29	12.61	11.96
	Soil Density-Moisture Curve 					
Optimum moisture Content (%)		37	Maximum Dry Density (kg/cm ³)		12.61	

DECLARATION

I, the undersigned, declare that this thesis is the result of my own work performed under the supervision of my research advisor Dr Argaw Asha. Except where specific reference is made to the works of others, the contents of this thesis are original and have never been submitted, in part or as a whole, to any other university for any degree or other qualifications. All sources of materials used for this thesis have also been duly acknowledged.

Name Senait G/silasee

Signature _____

Place School of Civil Engineering and Architecture,

Adama Science and Technology University,

Adama.

Date JUNE 2016

