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Department of Civil Engineering

Investigation in to some of the engineering properties of soils
found in Debre Birhan town, Ethiopia

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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

e - Void ratio

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

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ABSTRACT

This research deals with the investigation in to some of the engineering and index properties of soils found in Debre Birhan town. Disturbed and undisturbed soil samples were collected from Debre Birhan town from eleven test pits in order to conduct and determine the necessary engineering and index properties.

Insitue soil properties shows that the natural moisture content for the area under study ranges from 20.11% to 58.99 % and the insitue unit weight is in the range of 14.02 kPa to 18.53 kPa. Specific gravity is between 2.62 and 2.81. The specific gravity is above 2.62 indicating that inorganic soils are dominant as most of organic soils contain a value of less than 2.40. The grain size analysis of the area under study shows the soil contains gravel 0-24.63%, Sand 2.37%-38.74%, Silt 27.28%-55.9% and clay in between 8.77% to 67.5%. This shows that the dominant soil types in the area are Silt and Clay.

The liquid limit of the soils is in the range of 31%-80%. Plastic limit of the soils lies in between 18% to 43%. Plasticity index for the area under study lies between 13%-46%.

Soil classification for the area under study is made by both USCS and AASHTO. Soils classification by USCS shows that the soil contains around 41% CH, 18% CL, 18% MH, 14% ML, 4.5% SM and 4.5% SC and AASTHO classification system shows the soils are classified in either of A-6 or A-7.

The unconfined compressive strength test of soils gave a value of q_u between 75kPa to 233 kPa and the amount of cohesion lies in between 37.5 kPa to 116.5 kPa. Consistency is also determined based on the UCS result showing that the soil is medium, stiff or very stiff.

Consolidation test was conducted on three different types of soils which are taken based on the classification result. The range of compression index is in between 0.20-0.38 and the preconsolidation pressure values lies between 145 kPa to 285 kPa.

Engineering soil map is developed for the area investigated in this research. The area under investigation is grouped in to four soil categories and rock sections at 1.5m depth and six soil categories and rock sections at 3.0m depth.

1. Introduction

1.1 General

Debre Birhan is a town in central Ethiopia, located in North Shewa zone of the Amhara Region, about 120 kilometers north east of Addis Ababa on the paved highway to Dessie. The town is at present undertaking rapid construction for different purposes.

Any engineering structure, whether they built above or below the ground surface use soils and rocks as the basic foundation and construction materials. Unlike manmade materials, the properties of these soils and rocks are highly variable and a function of the complex natural processes that occurred in the geologic past. As a consequence, engineers are faced with the challenge of using soils and rocks available near the project site, whose properties are often unknown and of variable quality [9].

Investigation of the underground conditions at a site is prerequisite to the economical design of the substructured 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].

Debre Birhan town has some industrial facilities like factories (small and large scale), warehouses, resorts and lodges. There is still a great potential for investment expansion in the zone mainly as a result of its proximity to the capital and the main road from Addis Ababa to Dessie.

The soil profile of the town varies from place to place; mainly reddish to white brown; dark to light gray soils and black soils cover different parts of the town. Hence it is necessary to investigate the soils found in the town.

1.2 objective of the study

The general objective of this work is to study some of the engineering properties of Debre Birhan soil and prepare soil map of the city.

The particular objectives of the thesis work are,

- i. to determine the grain size distribution and specific gravity of soils
- ii. to determine Atterberg Limits.
- iii. to determine free swell values.
- iv. to undertake Classification of the soils according to the standard.
- v. to investigate the compressibility and shear strength of the soils.
- vi. to develop soil map of Debre Brhan Town

1.3 Methodology of the study

To investigate the engineering properties of Debre Brhan Town, eleven sampling areas were selected following to reconnaissance survey of the area. Since the central area of the town is mainly covered by rocks at shallow depth most of the sampling test pits are at great distance from central part of the city. In order to recover samples excavation was done to a depth of three meter. Disturbed and undisturbed samples were collected in the field and transported for laboratory testing. Locations of the sampling test pits was determined by hand held GPS.

From the recovered samples the following laboratory tests were done.

- Natural moisture content
- Specific gravity test
- Atterberg limit tests
- Grain size analysis
 - ✓ Sieve analysis (wet method)
 - ✓ Hydrometer
- Free swell test
- Unconfined Compression Test
- One-dimensional consolidation test

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

1.4 Scope of the study

Twenty two samples were collected from eleven test pits. The scope of this study is limited to investigating the index properties, unconfined compression strength and consolidation characteristic. After determining the above engineering and index properties of the soils a geotechnical map was prepared which is helpful for civil engineers and related professionals. Due to the budget constraint, the depth of investigation in this research is limited to the maximum depth of three meters.

1.5 Structure of the thesis

The thesis has been divided in to six Chapters. The first Chapter is the introductory part which includes the general background, objective, methodology and scope of the study.

Chapter two deals with a brief literature review including soil formation and deposit, mineralogy of soils, soil particle size and shape, identification and classification of soils . In the third Chapter, description of the sampling area is covered which includes geology, climate, topography and soil characteristics. The fourth Chapter includes insitu properties, laboratory procedures, tests and results of engineering and index properties of the soil.

Comparison of test results with previous test results conducted by other researchers on different areas and discussions of test results is presented in the fifth chapter. In Chapter six conclusions from test results are drawn and recommendation is presented. Appendices and references are attached at the end of the thesis.

2. Literature review

2.1 General

To a civil engineer, the term ‘soil’ means, the loose unconsolidated inorganic material on the earth’s crust produced by the disintegration of rocks, overlying hard rock with or without organic matter [6]. In engineering, soils are considered to include all organic and inorganic earth materials occurring in the zone overlying the rock crust. They are usually non-homogeneous porous material whose engineering behavior is greatly affected by changes in moisture content and density [19]. In order to determine the complexity behavior of soil a detailed geotechnical investigation is required.

A site investigation in one or another is always required for any engineering or building structure. The investigation may range in scope from a simple examination of the surface soils with or without a few shallow trial pits, to a considerable depth below the surface by means of boreholes and in-situ laboratory tests on the materials encountered. The extent of the work depends on the importance and foundation arrangement of the structure, the complexity of soil conditions, and the information which may be available on the behavior of existing foundations on similar soils [18].

2.2 Soil formation and deposit

Soil is formed by the process of ‘Weathering’ of rocks that is disintegration and decomposition of rocks and minerals at or near the earth’s surface through the actions of natural or mechanical and chemical agents into smaller and smaller grains [6].

The main agents responsible for this process are exfoliation, unloading, erosion, freezing, and thawing. Chemical weathering causes both reductions in size and chemical alteration of the original parent rock. The main agents responsible for chemical weathering are hydration, carbonation, and oxidation. Often, chemical and physical weathering takes place in concrete [6].

The physical process may be erosion by the action of wind, water or glaciers, or disintegration caused by alternate freezing and thawing in cracks in the rock. The resultant soil particles retain the same composition as that of the parent rock. Particles of this type are described as being of ‘bulky’ form and their shape can be indicated by terms such as angular, rounded, flat and elongated. The particles occur in a wide range of sizes, from boulders down to the fine rock flour formed by the grinding action of glaciers [17].

Soils that remain at the site of weathering are called residual soils. These soils retain many of the elements that comprise the parent rock. Alluvial soils, also called fluvial soils, are soils that were transported by river and streams. The composition of these soils depends on the environment under which they were transported and is often different from the parent rock. Glacial soils are soils that were transported and deposited by glaciers. Marine soils deposited in a marine environment [6].

2.3 Mineralogy of soils

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).

Humus or organic matter (decomposed organic materials).

2.3.1 Clay mineralogy

The soil cover of the area under study is mainly covered by clay and silts. Thus it is essential to review and study the mineralogy of those soils.

The coarse-grained soils generally contain the mineral quartz and feldspar. These minerals are strong and electrically inert. The behavior of such soils does not depend upon the nature of the mineral present. The behavior of fine-grained soils, on the other hand, depends to a large extent on the nature and characteristics of the minerals present. The most significant properties of clay depend upon the type of mineral. The crystalline minerals whose surface activity is high are clay minerals. These clay minerals impart cohesion and plasticity [1].

The main groups of clay crystalline materials that make up clays are the minerals kaolinite, illite and montmorillonite.

2.3.1.1 Kaolinite

Kaolinite has a structural unit made up of alumina sheets joined to silica sheet and is symbolized as indicated in Fig (2.1a). Kaolinite consists of many such layers stacked one on top of the other as shown in fig (2.1b).

The bond that exists between layers is tight and hence it is difficult to separate the layers. As a result Kaolinite is relatively stable and water is unable to penetrate between the layers. Consequently Kaolinite shows little swelling on wetting [19].

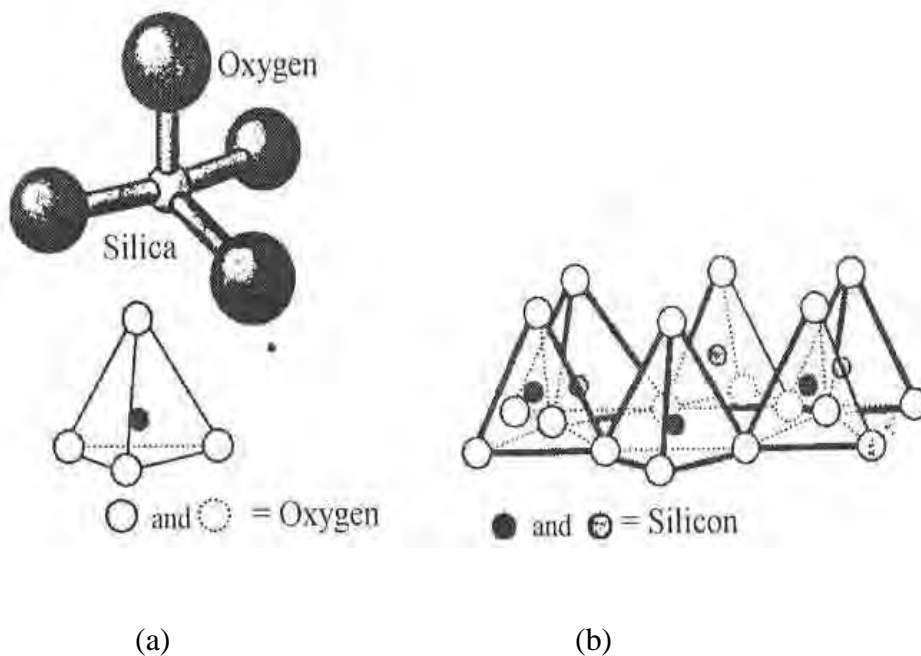
2.3.1.2 Illite

Illite has a basic structure similar to that of montmorillonite. However, the basic illite units are bonded together by potassium ions which are non-exchangeable. Because of this, the illite units are reasonably stable and so that mineral swells much less than montmorillonite.

2.3.1.2 Montmorillonite

These are highly expansive and create major engineering problems. Montmorillonite have a similar structure to illites, however the layers are held together by weak Van der Waals forces and exchangeable ions. Water can easily enter the bond and create swelling.

The three groups are all structured in crystal layers. The physical arrangement of the different layers and the method used to bond individual layers of the structural units produces the distinct mineralogy [22].



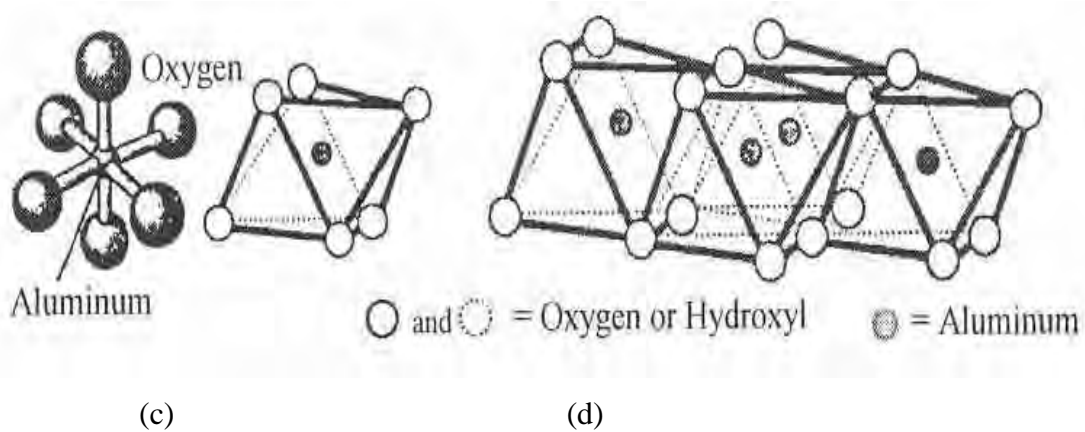


Fig. 2.1 (a) A silica tetrahedron, (b) Silica sheets, (c) An Aluminum octahedron, and (d) aluminum sheets.

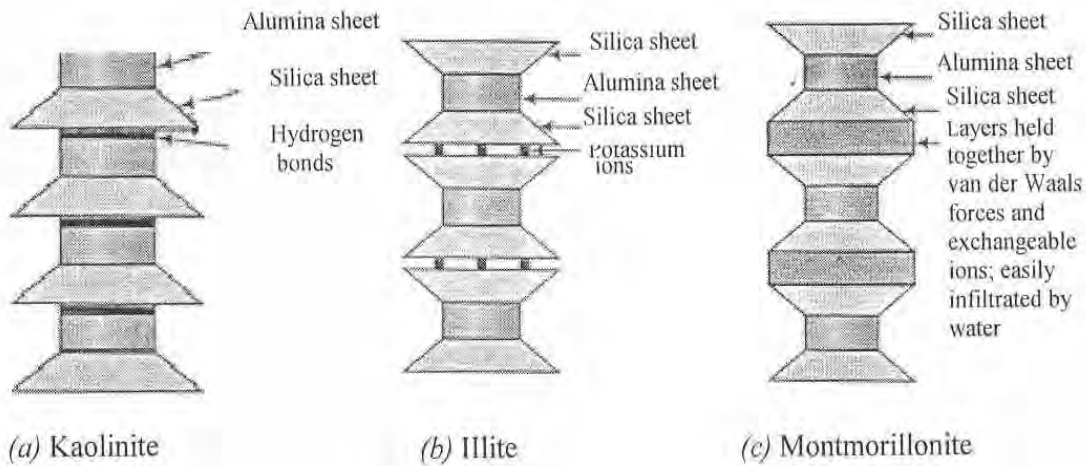


Fig. 2.2 Structure of Kaolinite, illite, and montmorillonite

2.4 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. Grains finer than 0.075 mm constitute the finer fractions of soils. It is possible to distinguish the grains lying between 0.075 mm and 2μ ($1\mu = 1 \text{ micron} = 0.001 \text{ mm}$) under a microscope. Grains having a size between 2μ and 0.1μ

can be observed under a microscope but their shapes cannot be made out. The shape of grains smaller than 1μ can be determined by means of an electron microscope. The molecular structure of particles can be investigated by means of X-ray analysis [14].

2.4.1 Comparison of coarse-grained and fine grained soils for engineering use

Course-grained soils have good load-bearing capacities and good qualities and their strength and volume change characteristics are not significantly affected by change in moisture conditions. They are practically incompressible when dense, but significant volume changes can occur when they are loose. Vibrations accentuate volume changes in loose coarse-grained soils by rearranging the soil fabric into dense configuration.

Fine-grained soils have poor load-bearing capacities compared with coarse grained soils. Fine-grained soils are practically impermeable, change volume and strength with variations in moisture conditions, and are frost susceptible. The engineering properties of coarse-grained soils are controlled mainly by the grain size of the particles and their structural arrangement. The engineering properties of fine-grained soils are controlled by mineralogical factors rather than grain size.

Thin layers of fine-grained soils, even within thick deposits of coarse-grained soils, have been responsible for many geotechnical failures and therefore you need to pay special attention to fine-grained soils [5].

2.5 Identification and classifications of soils

Soil can be described as gravel, sand, silt and clay according to grain size. Most of the natural soils consist of a mixture of organic material in the partly or fully decomposed state. The proportions of the constituents in a mixture vary considerably and there is no generally recognized definition concerning the percentage of, for instance, clay particles that a soil must have to be classified as clay, etc.

Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components. Grouping of soils on the basis of certain definite principles would help the engineer to rate the performance of a given soil either as a sub-base material for roads and airfield pavements, foundations of structures, etc. The classification or grouping of soils is mainly based on one or two index properties of soil which are described in detail in earlier sections. The methods that are used for classifying soils are based on one or the other of the following two broad systems:

1. A textural system which is based only on grain size distribution.
2. The systems that are based on grain size distribution and limits of soil.

Many systems are in use that is based on grain size distribution and limits of soil. The systems that are quite popular amongst engineers are the **AASHTO** Soil Classification System and the **Unified Soil Classification System** [14].

3. Description of the study area

3.1 General

Debre Berhan is a town in central Ethiopia, Located in the North Shewa Zone of the Amhara Region, about 120 kilometers north east of Addis Ababa on the paved highway leading to Dessie, the town has a latitude and longitude of 9°41'N 39°32'E coordinates, the town is divided in to nine kebeles. The town has around 38,717 populations [24].

Debre Birhan town has some industrial facilities like factories (small and large scale), warehouses, resorts and lodges. There is still a great potential for investment expansion in the zone mainly as a result of its location near to the capital and main highway.

3.2 Geology and soil characteristics

Debre Birhan map sheet comprises of two litho-stratigraphic units, thick succession starting from Mesozoic sediments capped with Cenozoic volcanic rocks situated in the plateau and rift valley. The Mesozoic sediments mainly consist of medium-grained sandstone and fine to medium grained mudstone, the mudstone is intercalated with few gypsum lenses [10].

This sedimentation is associated with the two-major transgression and regression cycle or drowning of the craton. Based on lithological similarity, both the sandstone and the mudstone of the study area are correlative to the Amba Aradom Formation, sandstone and shaly sandstone and, upper sandstone and Upper Gypsum. In particular the top most part of Mesozoic sediments of the central part of northwestern Ethiopian plateau (including the NW part of the Debre Birhan map sheet) is classified into two formal litho-stratigraphic sequences: the Muger Mudstone at the base and the Debre Libanos Sandstone at the top. The Sandstone and the Mudstone of the study area are part of this package and are the result of the same environment of deposition, sandy braided stream systems and shallow lagoonal deposits graded into meandering river facies, respectively that marks the start of a major regressive cycle in the Mesozoic [10].

The volcanic rocks of Debre Birhan area is distributed in part of central Ethiopian plateau, rift-margin and central rift-zone, consisting of compositionally wide varieties of volcanic products ranging from Tertiary to Quaternary in age. The NNE-SSW trending boarder faults (e.g., Ankober Boarder Fault) system separates the rift-zone and the plateau. The Tertiary sequence is mostly situated in the plateau and rift margin. The rocks of the Tertiary sequence are the dominant group of volcanic rocks in the study area, which were erupted from fissures, starting in the Oligocene [10].



Figure 3.1: Location of study area [24].

The soil profile of the town varies from place to place mainly black, reddish brown and gray soils covers different parts of the town.

3.3 Topography and drainage conditions

Debre Birhan town is located at higher altitude ranging 2750-2840 above mean sea level. The altitude varies from place to place in which the central part is at higher elevation and the newly constructed places (expansion places) are at relatively lower altitudes. The town consists of a river at the entrance from Addis Ababa.

3.4 Climate

The major factors influencing rainfall in Ethiopia are the Inter Tropical Convergence Zone (ITCZ) and winds blowing from the Atlantic and Indian Oceans. The variation in altitude throughout the country also influences climatic conditions. In addition, the micro-climatic changes over small distances are often created by differences in micro-relief. The traditional classification of climatic zones in Ethiopia is based on altitude and temperature. It divides the country into five climatic zones are shown in Figure 3.1 and summarized in Table 3.1 [9].

Table 3.1 Ethiopian Climatic Zones [9]

Climatic Zone	Elevation (m)	Average Temperature (°C)	Average Annual Rainfall (mm)
Wurch (cold)	> 3 200	< 10	< 800
Dega (cool-cold)	2 300 – 3 200	10 - 16	1 000 - 2000
Weina Dega (warm-cool)	1 500 – 2 300	16 - 20	1 200
Kolla (hot-warm)	500 – 1 500	20 - 28	600 (1 000 in places)
Berha (hot)	< 500	28 - 34	< 400

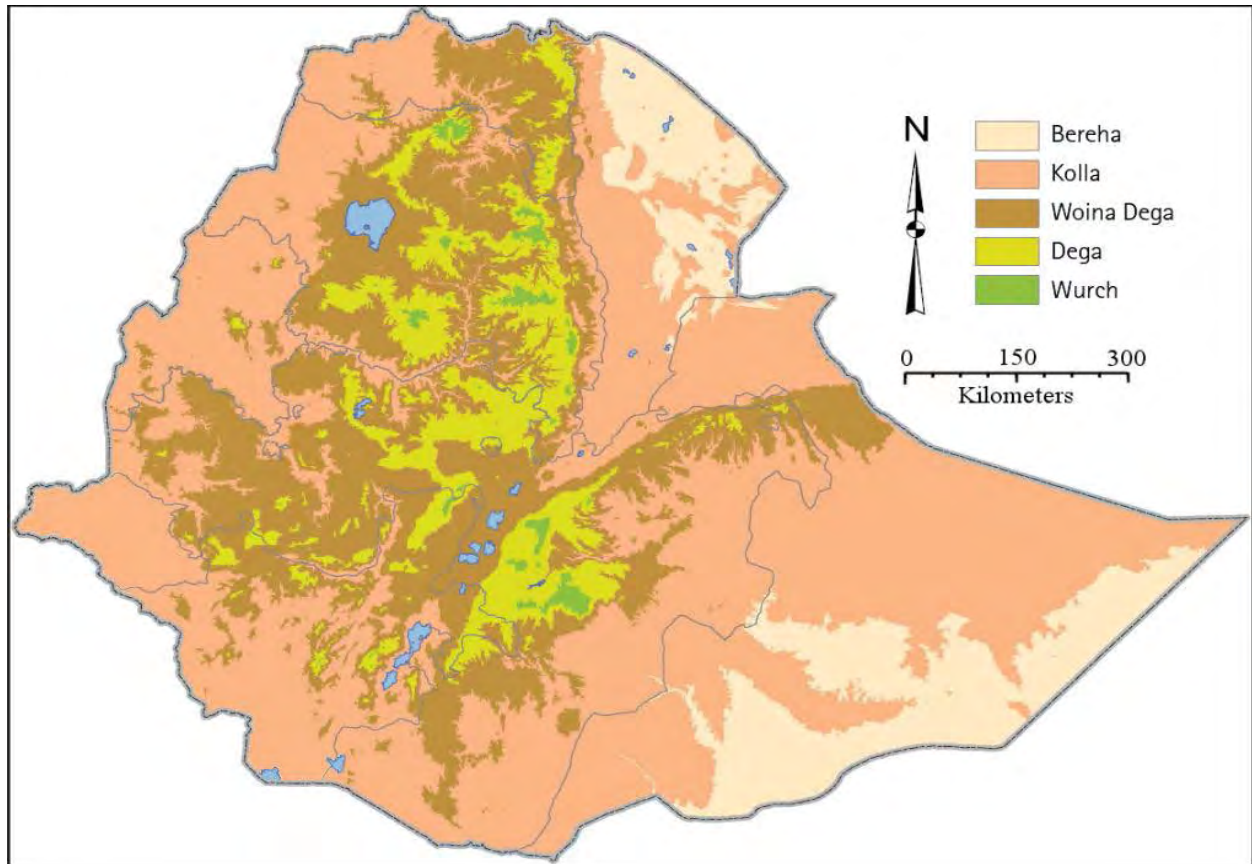


Figure 3.2: Traditional climatic zones in Ethiopia [9].

3.4.1 Rainfall

Rain fall data collected by National Meteorological Service Agency substation on Debre Birhan town located at latitude of 093800, longitude 0393000 and altitude of 2750 for 24 years (1990-2013) shows that the mean annual rain fall is 897.9 mm. Like other major towns in Ethiopia, Debre birhan town received highest rain fall from July to August as shown in Fig 3.2. Since the average altitude of the area under investigation is 2750 m, the climatic zone by traditional classification is Dega (cool-cold).

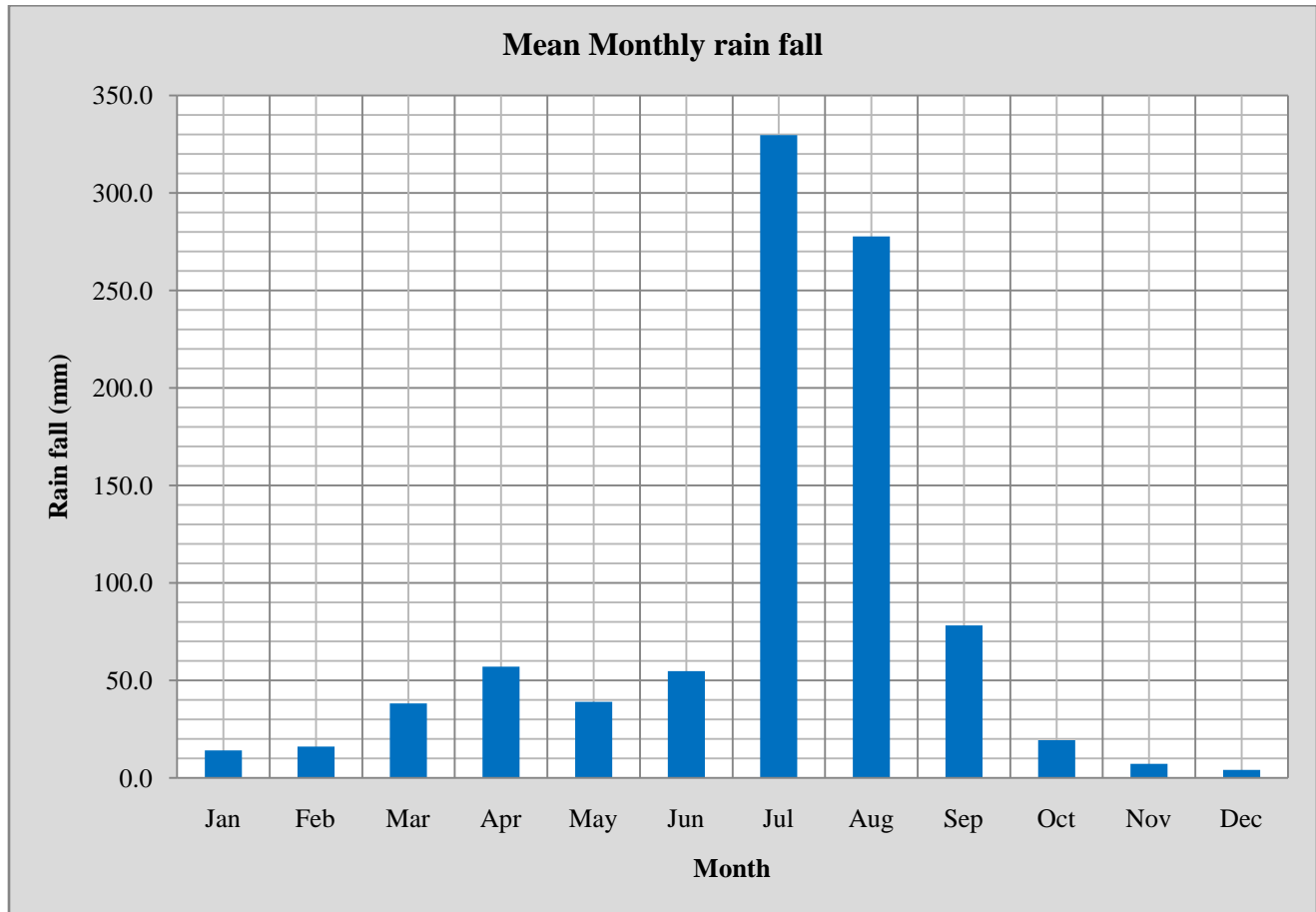


Fig 3.3 Mean monthly rainfall distribution of Debre Birhan town (1990 - 2013 G.C.) [11]

3.4.2 Temperature

In Ethiopia, the mean monthly temperature varies slightly throughout the year, although the difference between the minimum and maximum temperatures is high only in the dry season. According to the National Metrological Agency of Ethiopia, the highest mean maximum temperatures in the country, in the range of 40°C to 45°C, are recorded in the Afar depression. The other hot areas are the north-western lowlands close to the border with Sudan, which experience a mean maximum temperature of 40°C in June, and the western and south-eastern lowlands with mean maximum temperatures of 35°C during April. Most of the Somali, Dire Dawa and Afar regions are also hot for several months in a year. The lowest mean temperatures in the range of 5°C to 15°C or even lower are recorded in the morning or at night between October and January in the highland areas, with an elevation of over 2,000 m above sea level. In these areas, the midday warmth diminishes quickly by late afternoon and nights are usually cold [9].

Data recorded from national metrological service of Ethiopia shows the mean maximum temperature of Debre Birhan town is 19.6°C, mean minimum temperature of 6.2°C and average monthly temperature of 12.9°C. From February to June the town receives highest temperature and from October to December lower temperature is dominant. Figure 3.3 and Figure 3.4 shows the average Monthly Maximum and Minimum temperature distribution and Monthly Average Temperature distribution of Debre Birhan town.

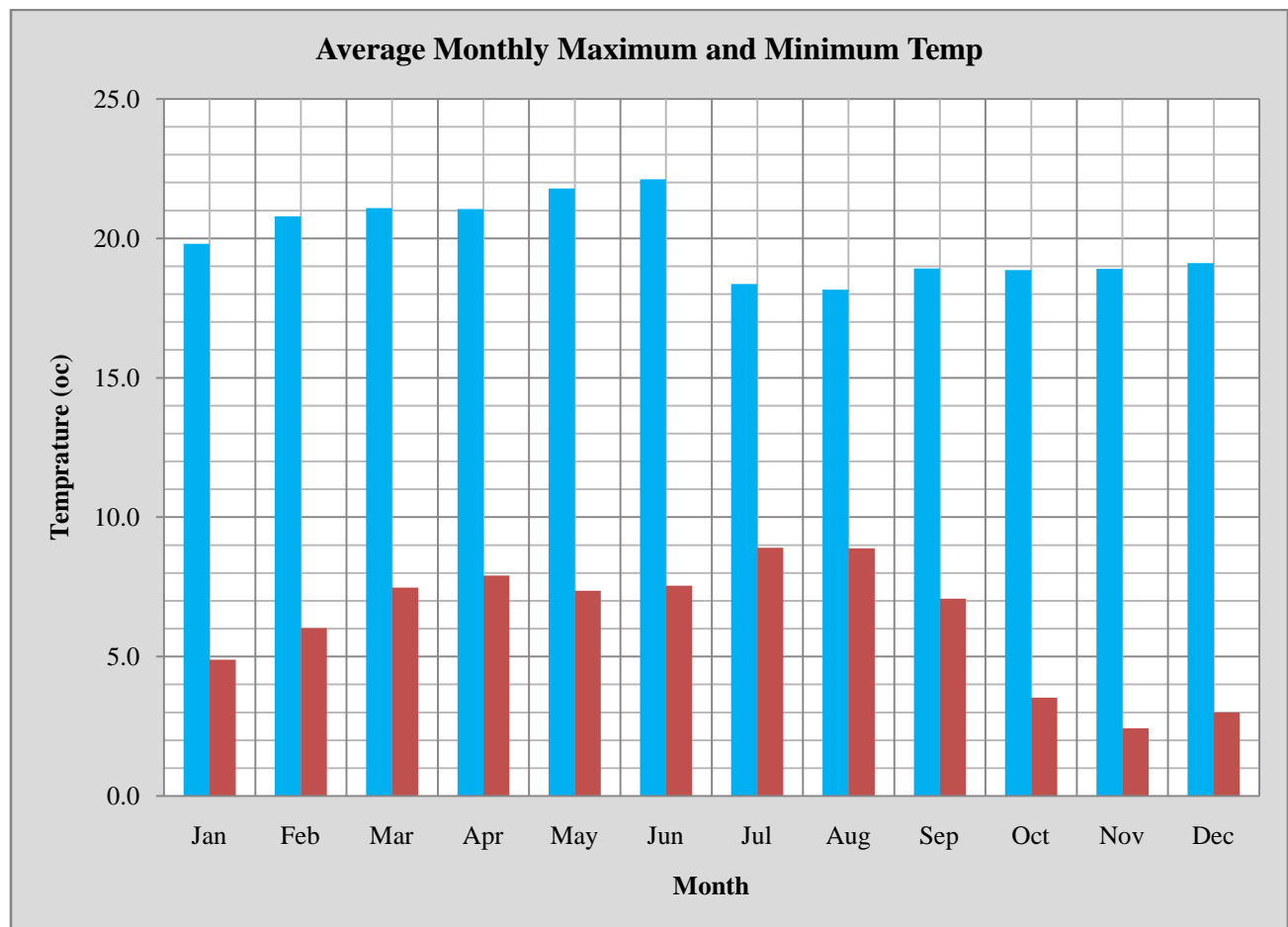


Fig 3.4 Average Monthly Maximum and Minimum temperature distribution of Debre Birhan town (1990 - 2013 G.C) [11]

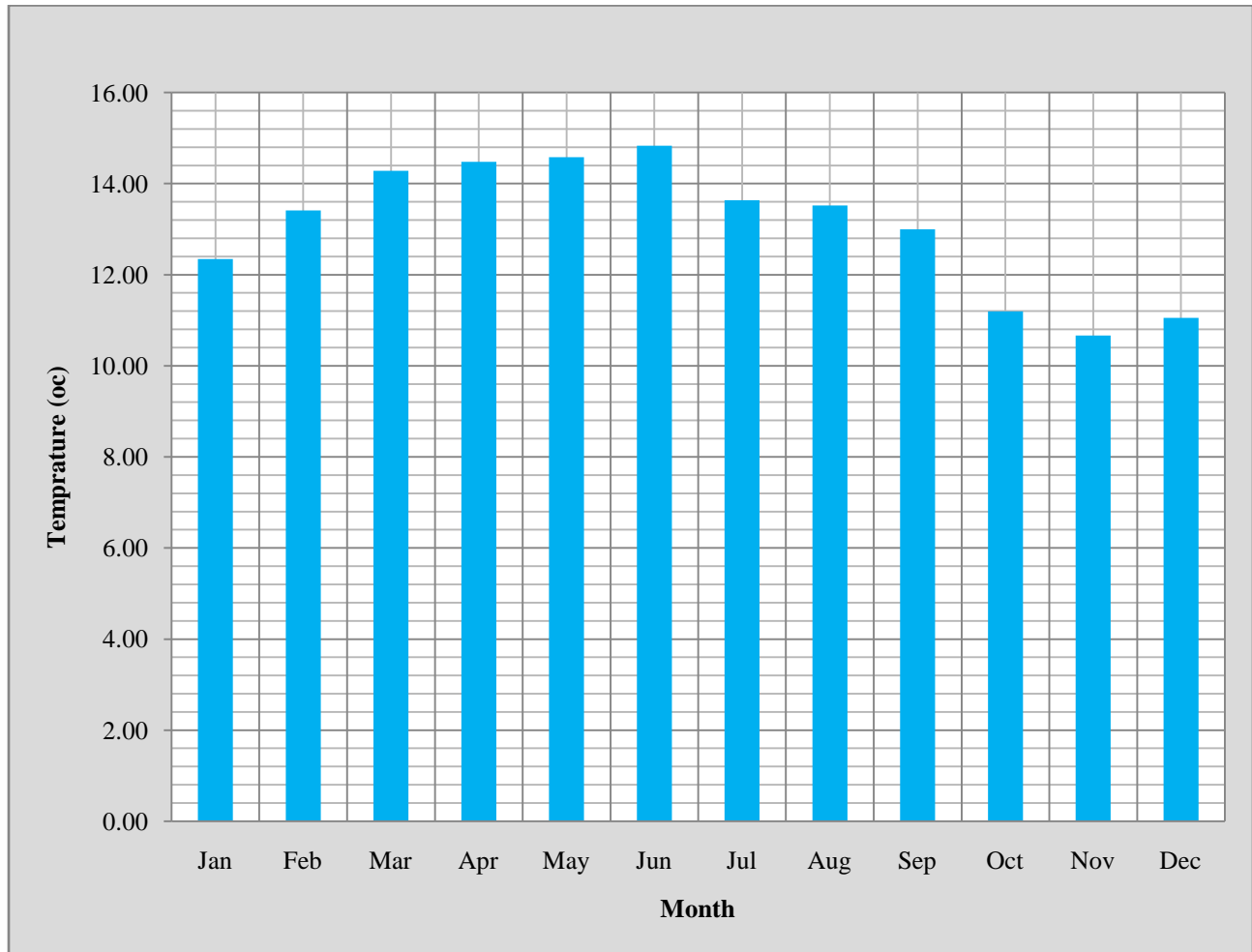


Fig 3.5 Monthly Average Temperature distribution of Debre Birhan town (1990-2013) [11]

4. Insitue properties, Laboratory tests, Results and Discussions

4.1 In situ properties

4.1.1 Sample Description

A reconnaissance survey and gathering of information was done from different residents of Debre Birhan, in order to understand the general soil formation of the area. Accordingly more than twelve sampling areas were selected. From the primary designated locations samples twenty two were recovered from eleven test pits. It was impossible to collect samples from more test pits as some of formations are thin layer of soil rested on solid rock and some of them are deposited by residents and construction companies. The soil cover of the study area varies from place to place especially in the areas between high and low altitudes.

Both disturbed and undisturbed soil samples were collected from the test pits to determine the engineering and index properties of the soils. During recovery of the sample in the field, visual classification was made and location was recorded as described below in the Table 4.1.

Table 4.1 Location of test pits

Sr No.	Kebele of sample recovery	Sample designation	Location			Remark
			Northing	Easting	Elevation	
1	Kebele-01	Tp-01	1070010	559766	2795	
2	Kebele-08	Tp-02	1070762	559922	2809	
3	Kebele-06	Tp-03	1069891	557375	2755	
4	Kebele-08	Tp-04	1070108	558915	2808	
5	Kebele-04	Tp-05	1067935	558756	2765	
6	Kebele-09	Tp-06	1067320	556662	2766	
7	Kebele-01	Tp-07	1071327	560998	2792	
8	Kebele-09	Tp-08	1063926	554930	2830	
9	Kebele-07	Tp-09	1068825	555632	2754	
10	Kebele-09	Tp-10	1067493	555476	2767	
11	Kebele-03	Tp-11	1068900	558893	2764	

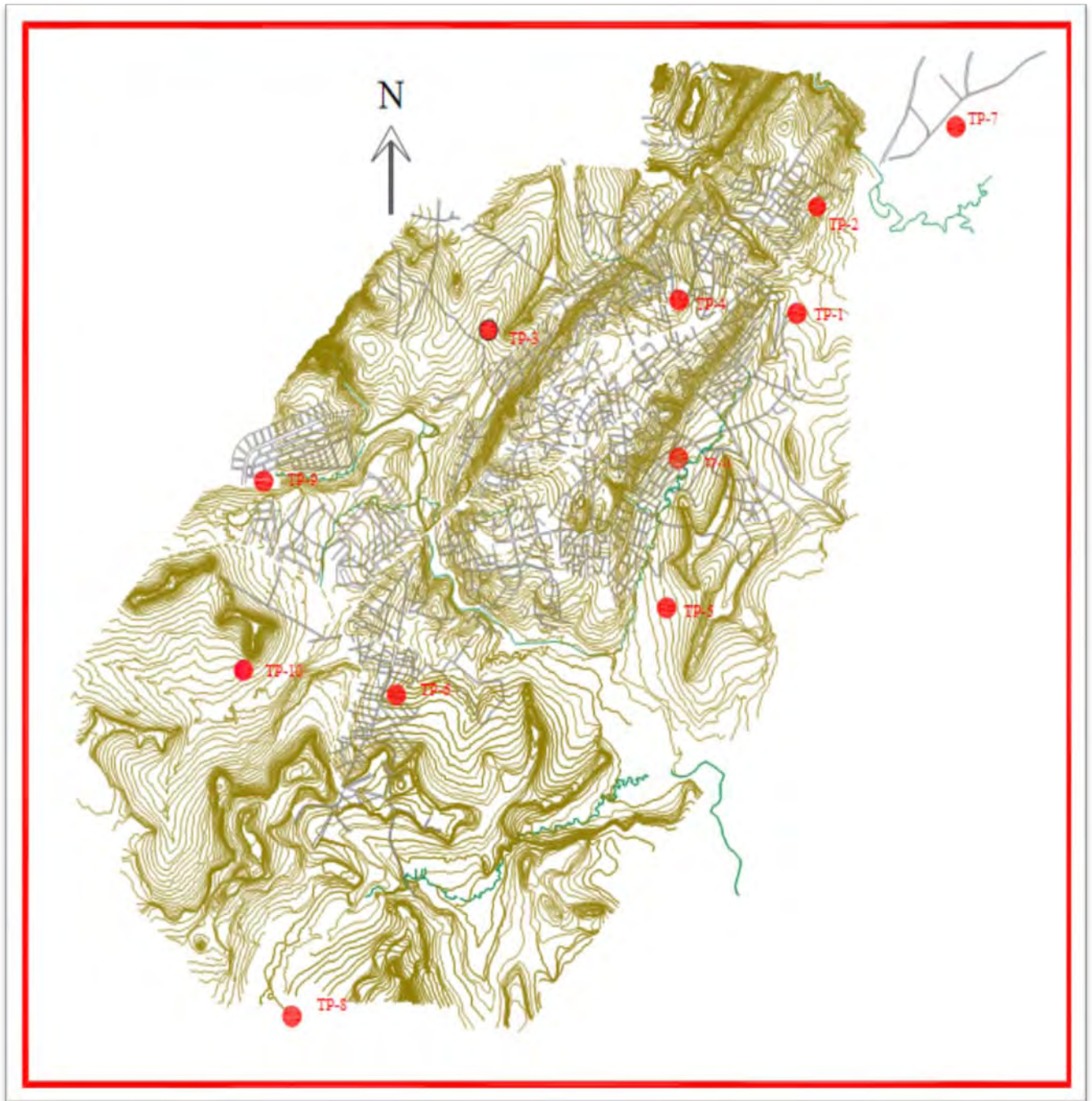


Fig 4.1 Location of test pits on Map (Debre Birhan town)

4.1.2 In situ properties description

In situ properties like in situ density are determined in the field. The dominant types of soils properties in the test pits are black clay in the upper 1.5m and reddish brown to gray silty clay below 1.5m.

4.1.2.1 Natural Moisture content

‘Water content’ or ‘moisture content’ of a soil has a direct bearing on its strength and stability. The water content of a soil in its natural state is termed its ‘Natural moisture content’, which characterizes its performance under the action of load and temperature. The water content may range from a trace quantity to that sufficient to saturate the soil or fill all the voids in it [6].

Moisture content was determined in the laboratory by collecting samples from all test pits and placed in to moisture can and covered properly by plastic. In the site the weight of the moisture can and the weight of can with moist soil was measured. Then the sample was brought to the laboratory and put it in to drying oven at a temperature of $105\pm 5^{\circ}\text{C}$ for 24 hours. Then, the natural moisture content was determined. The test results of all test pits are shown below in Table 4.2 and analysis is attached appendix-A.

4.1.2.2. In situ unit weight

The in-situ unit weight refers to the unit weight of a soil in the undisturbed condition or of a compacted soil in-place [6].

In situ unit weight was determined from the undisturbed samples for most of the test pits. For the samples in which undisturbed sample recovery was difficult, sand replacement method was implemented to determine the in situ unit weight. The test results of all test pits are shown below in Table 4.2.

Table 4.2 Summery natural moisture content and Insitue Unit weight

Sr.No.	Test pit name	Depth of determination	Natural moisture content, %	In situ unit weight, kN/m ³
1	TP-1	1.50m	33.90	16.73
		3.00m	58.99	14.02
2	TP-2	1.50m	22.01	18.10
		3.00m	24.27	17.87
3	TP-3	1.50m	30.02	18.03
		3.00m	31.14	17.79
4	TP-4	1.50m	37.47	17.65
		3.00m	23.62	18.53
5	TP-5	1.50m	32.85	18.24
		3.00m	30.93	16.81
6	TP-6	1.50m	43.04	16.28
		3.00m	46.96	17.09
7	TP-7	1.50m	31.49	18.29
		3.00m	43.64	17.06
8	TP-8	1.50m	43.64	16.48
		3.00m	40.48	16.48
9	TP-9	1.50m	25.55	17.61
		3.00m	28.47	17.92
10	TP-10	1.50m	27.69	16.75
		3.00m	20.11	16.56
11	TP-11	1.50m	33.80	18.24
		3.00m	26.87	18.26

4.2 Index properties

4.2.1 General

The index parameters are a measure of the physical properties and behavior of a soil. They are generally governed to a large extent by its geological history, mineralogical composition, the amount of clay fraction, the structure and distribution of the grains, texture of the grains. Index parameters are mainly used for the purpose of identification, description and classification of soils. Moreover, since their determination in laboratory is relatively simple, and they share the same factors that influence the strength and compression properties, they are usually employed in empirical correlation to predict compression, strength and other parameters. For example, the compression index can be estimated from liquid limit, the undrained shear strength of clay from liquidity index or plasticity index [13].

After collecting samples in the field the index properties of all test pits is determined in the laboratory.

4.2.2 Specific gravity

The specific gravity of most minerals found in soils falls within a range of 2.6 to 2.9. the specific gravity of solids of light-colored sand, which is mostly made of quartzite, may be estimated to be about 2.65;for clayey and silty, it may vary from 2.6 to 2.9 [8]

It is determined that the specific gravity of soils found in Debre Birhan town falls to 2.62-2.81 which is in the range proposed by Bowles and other researchers. The laboratory test results of eleven test pits are summarized below and detail calculation is shown in appendix-A.

Table 4.3 Summery of specific gravity test result

Sr.No.	Test pit name	Depth of determination	Specific gravity	Water used
1	TP-1	1.50m	2.72	Tap water
		3.00m	2.78	>>
2	TP-2	1.50m	2.69	>>
		3.00m	2.70	>>
3	TP-3	1.50m	2.81	>>
		3.00m	2.70	>>
4	TP-4	1.50m	2.65	>>
		3.00m	2.62	>>
5	TP-5	1.50m	2.78	>>
		3.00m	2.72	>>
6	TP-6	1.50m	2.77	>>
		3.00m	2.74	>>
7	TP-7	1.50m	2.73	>>
		3.00m	2.80	>>
8	TP-8	1.50m	2.81	>>
		3.00m	2.77	>>
9	TP-9	1.50m	2.78	>>
		3.00m	2.72	>>
10	TP-10	1.50m	2.79	>>
		3.00m	2.81	>>
11	TP-11	1.50m	2.71	>>
		3.00m	2.76	>>

4.2.3 Grain Size Analysis

4.2.3.1 General

Soils are usually classified into various types. In many cases these various types also have different mechanical properties. A simple subdivision of soils is on the basis of the grain size of the particles that constitute the soil. The classification according to size divides the soils broadly into two distinctive groups, namely, coarse grained and fine grained. Since the properties of coarse grained soils are, to a considerable extent, based on grain size distribution, classification of coarse grained soils according to size would therefore be helpful. Fine grained soils are so much affected by structure, shape of grain, geological origin, and other factors that their grain size distribution alone tells little about their physical properties. However, one can assess the nature of a mixed soil on the basis of the percentage of fine grained soil present in it. It is, therefore, essential to classify the soil according to grain size [14].

Soil particles which are coarser than 0.075 mm are generally termed as coarse grained and the finer ones as silt, clay and peat (organic soil) are considered fine grained. From an engineering point of view, these two types of soils have distinctive characteristics. In coarse grained soils, gravitational forces determine the engineering characteristics. Interparticle forces are predominant in fine grained soils [14].

The mechanical analysis is done in two stages: i) sieve analysis, 2) Sedimentation analysis. The first analysis is meant for coarse-grained soils (particle size greater than 75 micron) which can easily pass through a set of sieves. The second analysis is used for fine grained soils (size smaller than 75 microns). As a soil mass may contain the particles of both types of soils, a combined analysis comprising both sieve analysis and sedimentation analysis may be required for such soils [1].

In this research both types of mechanical analysis was implemented to determine the grain size distribution of soils recovered from eleven test pits. Sieve analysis was conducted in wet type because the soil samples contain large percentage of clay and silts.

A series of sieves in which the sequence is described below, was prepared according to ASTM D422-63 and placed on mechanical shaker. The oven dried sample was placed on series of sieves and shacked for about 10 minutes. The mass of retained soil on each sieve was recorded and plotted as in figure below.

Table 4.4 Series of sieves

Series No.	Sieve designation	Series No.	Sieve designation
1	3-in. (75-mm)	8	No. 10 (2.00-mm)
2	2-in. (50-mm)	9	No. 20 (850- μ m)
3	1 1/2-in. (37.5-mm)	10	No. 40 (425- μ m)
4	1-in. (25.0-mm)	11	No. 60 (250- μ m)
5	3/4-in. (19.0-mm)	12	No. 140 (106- μ m)
6	3/8-in. (9.5-mm)	13	No. 200 (75- μ m)
7	No. 4 (4.75-mm)		

According to ASTM D422-63, a set of sieves giving uniform spacing of points for the graph, other alternative meshes was used. This set consists of the following sieves.

Table 4.5 Series of sieves for plotting

Series No.	Sieve designation	Series No.	Sieve designation
1	3-in. (75-mm))	7	No. 16 (1.18-mm)
2	1 1/2-in. (37.5-mm)	8	No. 30 (600- μ m)
3	3/4-in. (19.0-mm)	9	No. 50 (300- μ m)
4	3/8-in. (9.5-mm)	10	No. 100 (150- μ m)
5	No. 4 (4.75-mm)	11	No. 200 (75- μ m)
6	No. 8 (2.36-mm)		

Particle size distribution-Hydrometer analysis

Hydrometer method combined with wet or dry sieving enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarser particles down to clay sizes. This test method of grain size determination is used for soils finer than 75 microns.

Both methods of grain size analysis were conducted for all soils recovered from eleven test pits. The above procedures were implemented and a combined grain size distribution is plotted. From the grain size analysis obtained from laboratory the soils contain 8.77-67.50% clay, 27.28-55.90% silt, 2.37-38.74% sand and 0-24.63% gravel. Summary of the test result and graph of combined analysis is shown below on Table 4.6 and Fig 4.2, Fig 4.3 and Fig 4.4 detail analysis is attached in appendix-A.

Table 4.6 Percentage of grain size distribution

Sr.No.	Test pit name	Depth of determination	Percent amount of particle size			
			Gravel	Sand	Silt	Clay
1	TP-1	1.50m	0.35	2.84	29.31	67.50
		3.00m	0.00	2.37	47.92	49.71
2	TP-2	1.50m	4.04	23.44	48.74	23.78
		3.00m	1.68	34.11	55.44	8.77
3	TP-3	1.50m	0.11	14.03	42.41	43.45
		3.00m	17.88	38.74	27.81	15.57
4	TP-4	1.50m	2.42	15.39	47.08	35.11
		3.00m	0.43	33.23	48.53	17.81
5	TP-5	1.50m	1.31	7.91	41.72	49.06
		3.00m	0.11	8.74	47.04	44.11
6	TP-6	1.50m	0.17	4.84	46.53	48.46
		3.00m	1.45	7.39	47.23	43.93
7	TP-7	1.50m	0.03	7.26	36.24	56.47
		3.00m	2.11	28.36	55.90	13.63
8	TP-8	1.50m	0.01	2.44	45.15	52.40
		3.00m	0.05	17.27	35.08	47.60
9	TP-9	1.50m	1.46	20.70	43.07	34.77
		3.00m	1.91	34.07	30.00	34.02
10	TP-10	1.50m	0.00	6.86	42.91	50.23
		3.00m	24.63	37.02	27.28	11.07
11	TP-11	1.50m	0.00	15.40	39.55	45.05
		3.00m	0.82	36.32	32.70	30.16

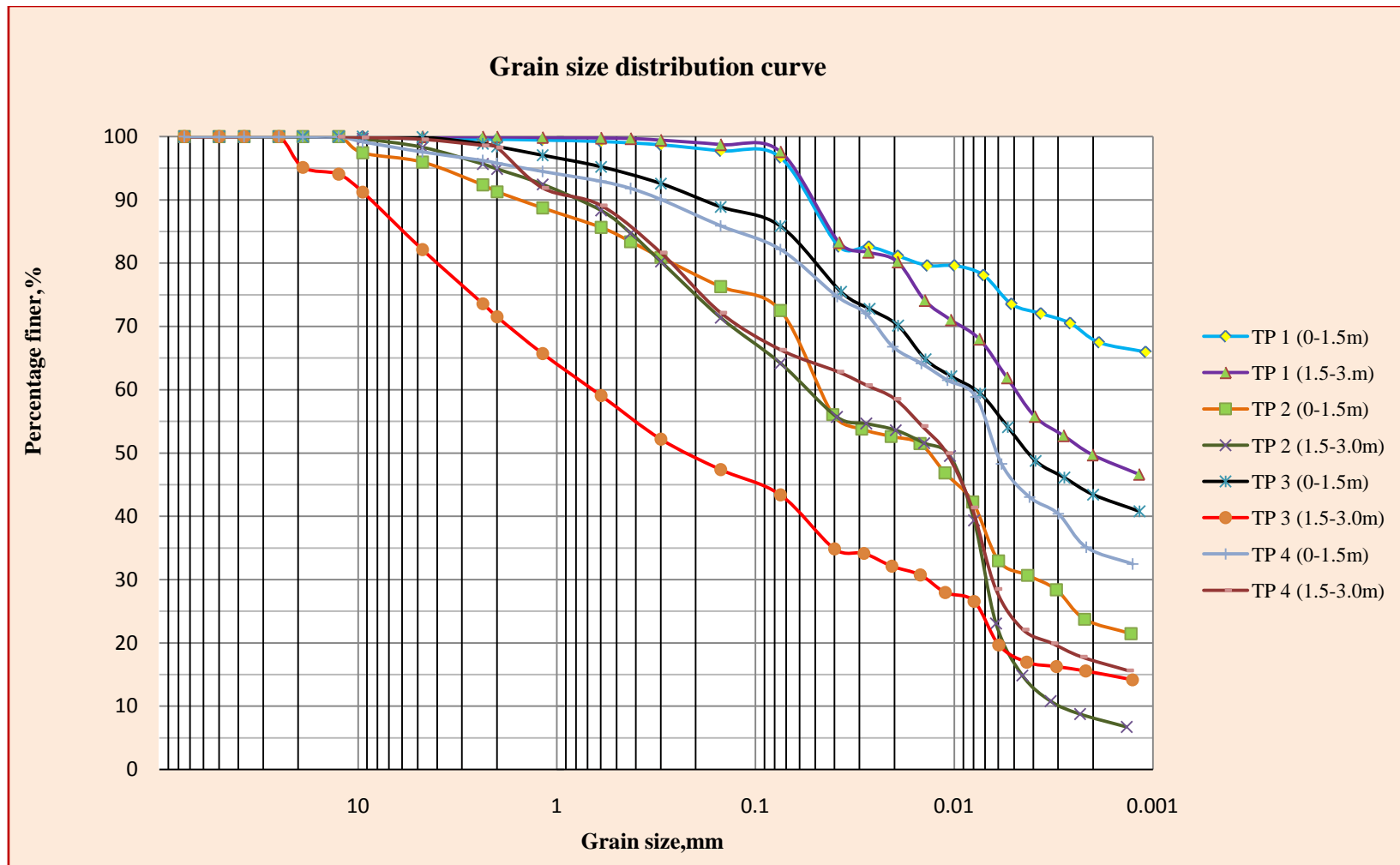


Fig 4.2 Grain size distribution curve of TP 01-TP 04

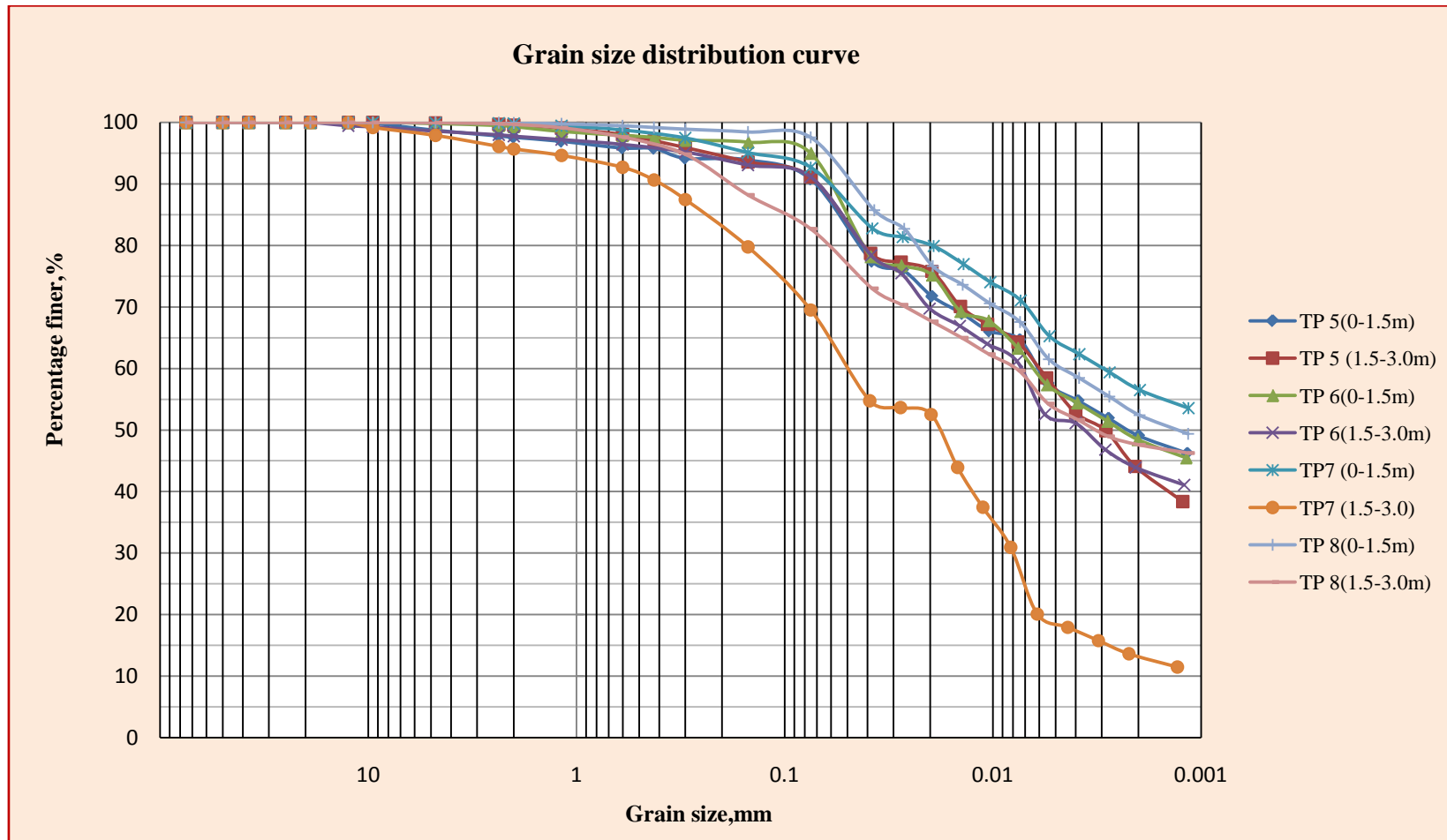


Fig 4.3 Grain size distribution curve of TP 05-TP 08

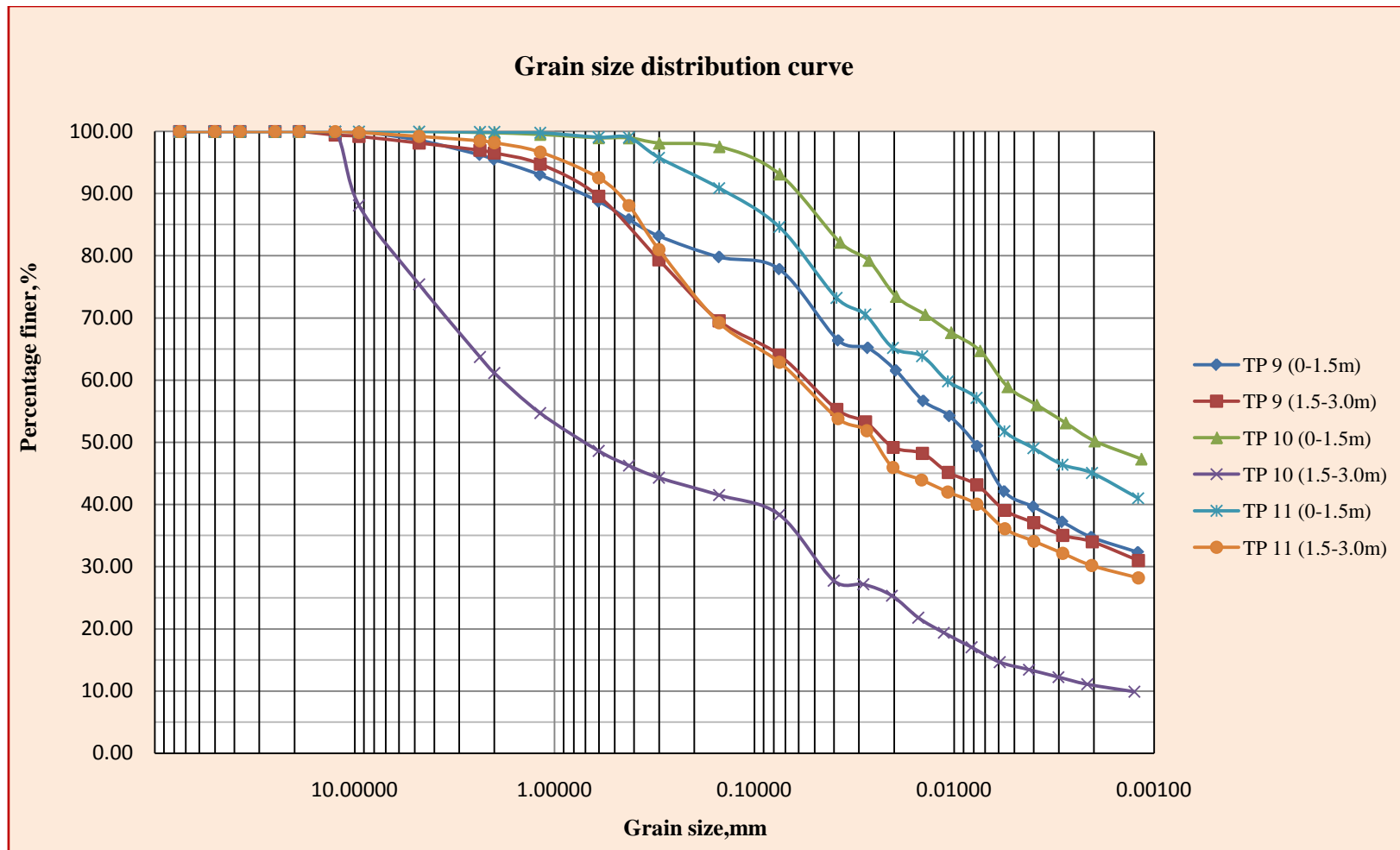


Fig 4.4 Grain size distribution curve of TP 09-TP 11

4.2.4. Atterberg limits

4.2.4.1 General

The presence of water in the voids of a soil can especially affect the engineering behavior of fine-grained soils. Not only is important to know how much water is present in, but also to compare or scale this water content against some standard of engineering behavior. This is what the Atterberg limits do-they are important limits of engineering behavior. Atterberge limits are water contents at certain limiting or critical stages in soil behavior. They, along with the natural water content, are the most important items in the description of fine-grained soils. They are useful in the classification of such soils, and they are useful because they correlate with the engineering properties and engineering behavior of fine-grained soils [Holtz & Kovacs]. Hence depending on moisture content, the behavior of soil can be divided in to four basic states-solid, semisolid, plastic and liquid as shown in Figure 4.5 [8].

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

Table 4.7 Plasticity characteristic according to Burmister (1947)

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

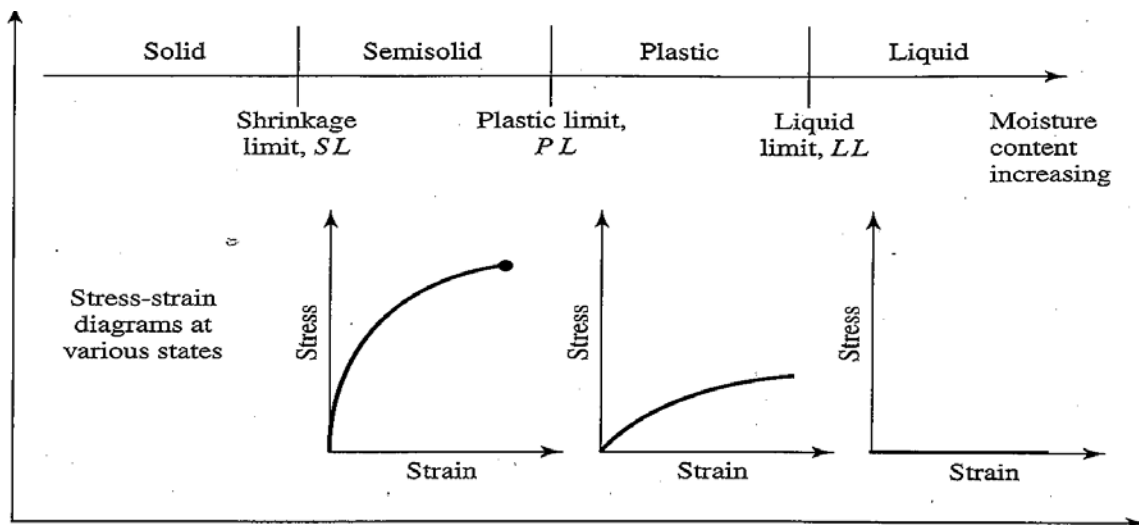


Fig 4.5 Atterberg limits according to Das (2002)

4.2.4.2 Test results

The laboratory test results of both liquid limit and plastic limit is shown below on table 4.6 and detail analysis is attached in appendix-A. From the test result it is observed that liquid limit of Debre Birhan town falls in the range of 32-80% and plastic limit is in the range of 17-43%. The plasticity index range of the soils is from 11% to 46%. According to Burmister (1947) the plasticity of the soils are Medium to high plasticity.

Table 4.8 Atterberg limit test results

Sr.No.	Test pit name	Depth of determination	Liquid limit	Plastic limit	Plasticity index
1	TP-1	1.50m	73	33	40
		3.00m	80	34	46
2	TP-2	1.50m	47	30	17
		3.00m	43	29	14
3	TP-3	1.50m	66	28	38
		3.00m	32	17	15
4	TP-4	1.50m	56	31	25
		3.00m	44	29	15
5	TP-5	1.50m	77	34	43
		3.00m	64	34	30
6	TP-6	1.50m	73	43	30
		3.00m	60	28	32
7	TP-7	1.50m	70	32	38
		3.00m	56	39	17
8	TP-8	1.50m	72	32	40
		3.00m	48	22	26
9	TP-9	1.50m	47	25	22
		3.00m	45	20	25
10	TP-10	1.50m	62	29	33
		3.00m	41	30	11
11	TP-11	1.50m	58	29	29
		3.00m	41	19	22

4.3 Classification of Soils

4.3.1 General

Soil classification systems divide soils and sub groups based on common engineering properties such as the grain size distribution, liquid limit and plastic limit [8]. Soil classification is used to specify a certain soil type that is best suitable for a given application. From engineering point of view, classification may be made based on the suitability of a soil for use as a foundation material or as a construction material. There are several classification schemes available. Each was devised for a specific purpose [5].

4.3.2 Unified Soil Classification System (USCS)

This system employs visual inspection; grain-size analysis and Atterberg limit tests in classifying soils. The coarse soils are classified by their grain size and fine grained soils are classified with the aid of plasticity chart.

Soil classification based o USCS for all test pits of the area under study is made and is shown below on Table 4.9.

The classification of soils according to USCS scheme shows most of the soil of the study area falls in ML, MH, CL and CH region. From the plot of plasticity chart in Figure 4.6 and the classification soils on Table 4.9 the soils found in Debre Birhan town are Silty and clayey of low and higher plasticity.

4.3.2.1 Activity of Clays

The presence of even small amounts of certain clay minerals can have significant effect on the properties of the soil. The identification of clay minerals requires special techniques and equipment. The techniques include microscopic examination, X-ray diffraction, differential thermal analysis, optical property determination and electron micrography. Even qualitative identification of the various clay minerals is adequate for many engineering purposes [6].

An indirect method of obtaining information on the type and effect of clay mineral in a soil is to relate plasticity to the quantity of clay-size particles. It is known that for a given amount of clay mineral the plasticity resulting in a soil will vary for the different types of clays.

‘Activity (A)’ is defined as the ratio of plasticity index to the percentage of clay-sizes:

$$A = \frac{PI}{C} \text{-----} (4.1)$$

Where, C is the percentage of clay sizes, i.e., of particles of size less than 0.002 mm [6].

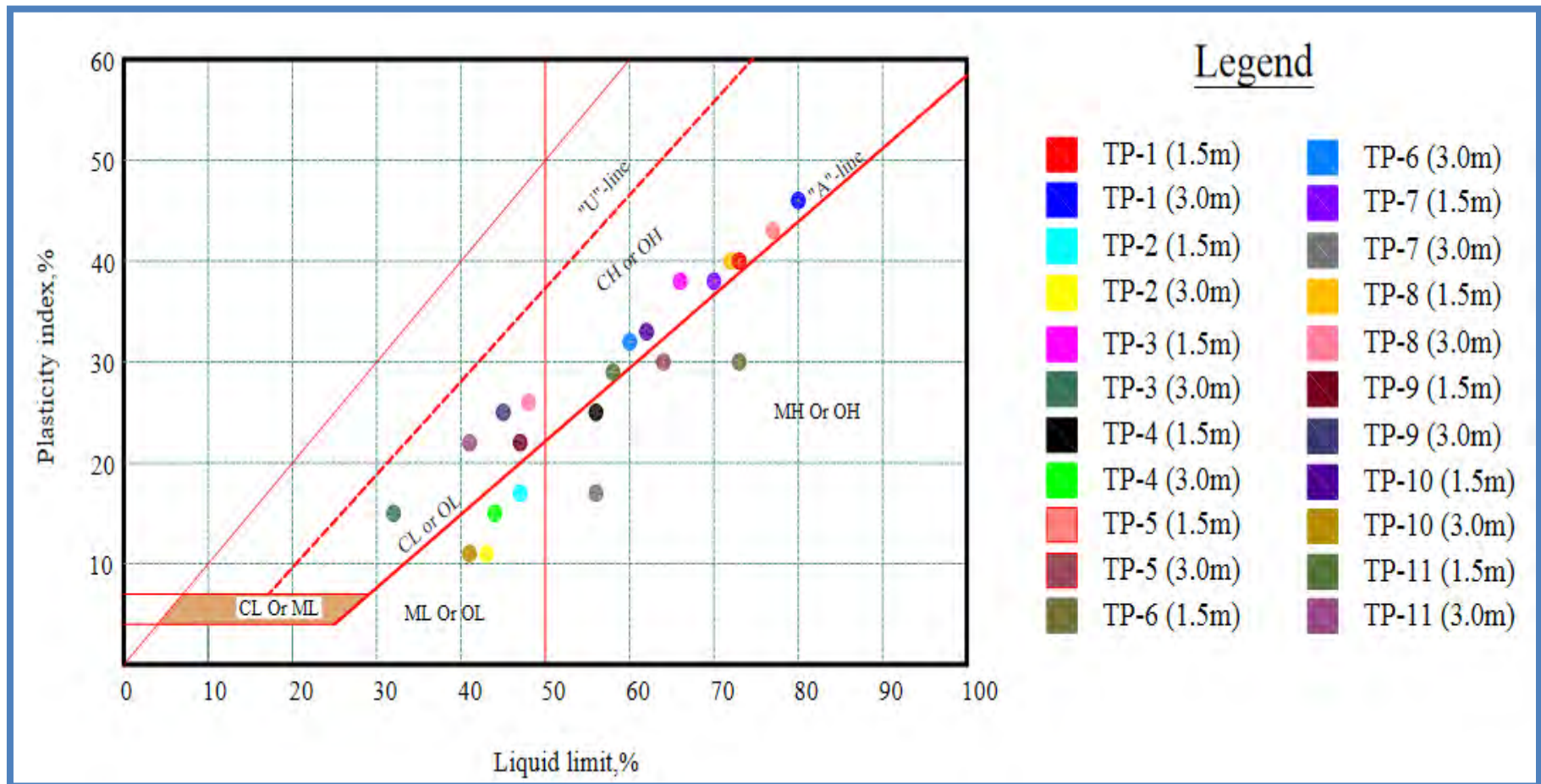


Fig 4.6 plasticity chart

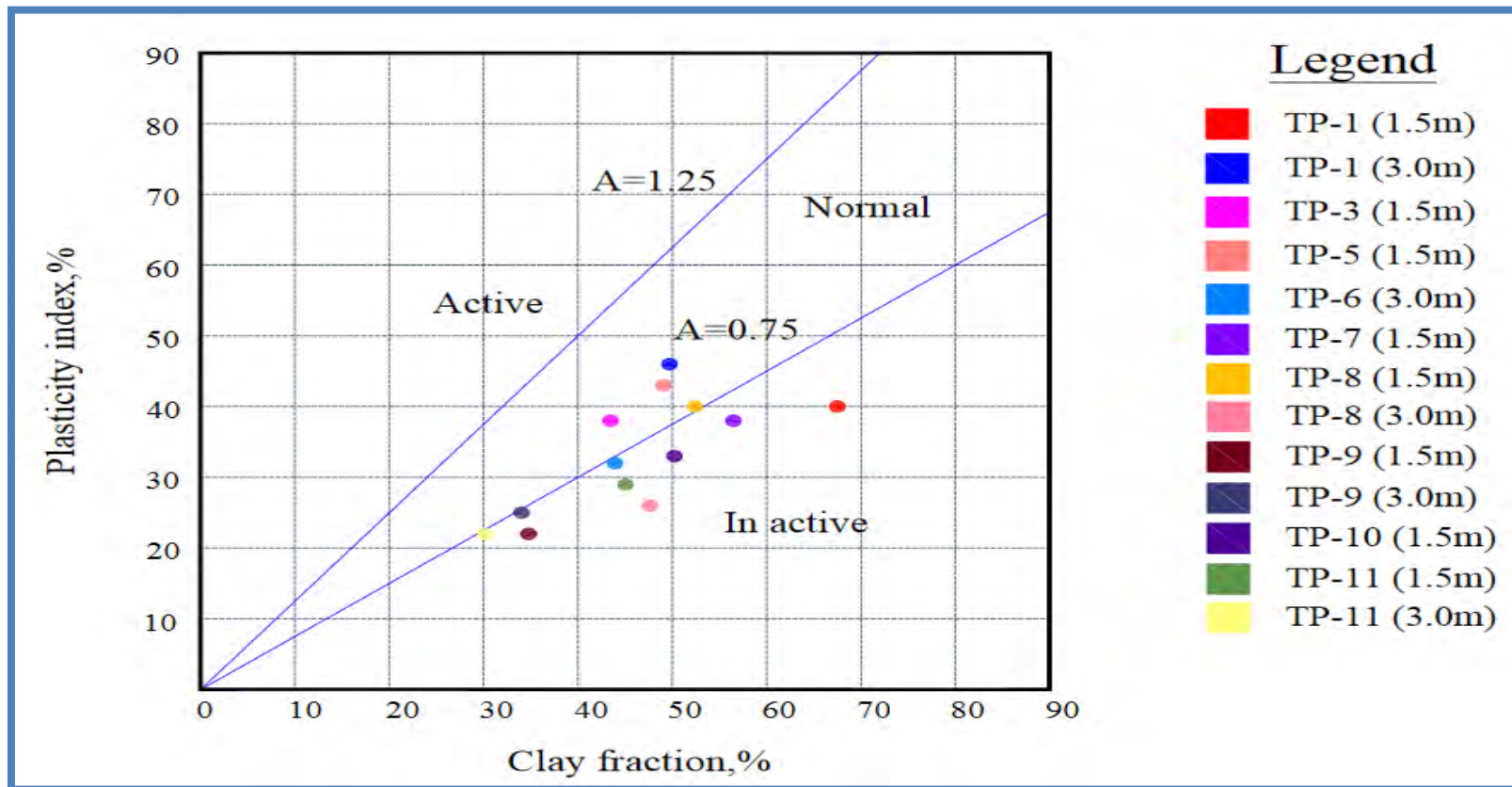


Fig 4.7 Activity chart

Table 4.9 Soil Classification based on USCS

Sr.No.	Test pit name	Depth of determination	Percent amount of particle size				Liquid limit	Plasticity index	Activity	Soil classification USCS
			Gravel	Sand	Silt	Clay				
1	TP-1	1.50m	0.35	2.84	29.21	67.50	73	40	0.59	CH
		3.00m	0.00	2.37	47.92	49.71	80	46	0.93	CH
2	TP-2	1.50m	4.04	23.44	48.74	23.78	47	17		ML
		3.00m	1.68	34.11	55.44	8.77	43	11		ML
3	TP-3	1.50m	0.11	14.03	42.41	43.45	66	38	0.87	CH
		3.00m	17.88	38.74	27.81	15.57	32	15		SC
4	TP-4	1.50m	2.42	15.39	47.08	35.11	56	25		MH
		3.00m	0.43	33.23	48.53	17.81	44	15		ML
5	TP-5	1.50m	1.31	7.91	41.72	49.06	77	43	0.88	CH
		3.00m	0.11	8.74	47.04	44.11	64	30		MH
6	TP-6	1.50m	0.17	4.84	46.53	48.46	73	30		MH
		3.00m	1.45	7.39	47.23	43.93	60	32	0.73	CH
7	TP-7	1.50m	0.03	7.26	36.24	56.47	70	38	0.67	CH
		3.00m	2.11	28.36	55.90	13.63	56	17		MH
8	TP-8	1.50m	0.01	2.44	45.15	52.40	72	40	0.76	CH
		3.00m	0.05	17.27	35.08	47.60	48	26	0.55	CL
9	TP-9	1.50m	1.46	20.70	43.07	34.77	47	22	0.63	CL
		3.00m	1.91	34.07	30.00	34.02	45	25	0.73	CL
10	TP-10	1.50m	0.00	6.86	42.91	50.23	62	33	0.66	CH
		3.00m	24.63	37.02	27.28	11.07	41	11		SM
11	TP-11	1.50m	0.00	15.40	39.55	45.05	58	29	0.64	CH
		3.00m	0.82	36.32	32.70	30.16	41	22	0.73	CL

4.3.3 AASHTO Soil Classification System

This system was originally proposed in 1928 by the U.S. Bureau of Public Roads for use by highway engineers. A Committee of highway engineers for the Highway Research Board, met in 1945 and made an extensive revision of the PRA System. This system is known as the AASHTO (American Association of State Highway and Transportation Officials) System (ASTM D-3242, AASHTO Method M 145). The revised system comprises seven groups of inorganic soils, A-1 to A-7 with 12 subgroups in all. The system is based on the following three soil properties:

1. Particle-size distribution
2. Liquid Limit
3. Plasticity Index [14].

This classification uses similar techniques as that of USC but the dividing line has an equation of the form $PI = LL - 30$.

Classification of soils for the area under study is made by AASHTO method and all soils falls in between A-6 and A-7. The general rating as subgrade material for all soils is poor.

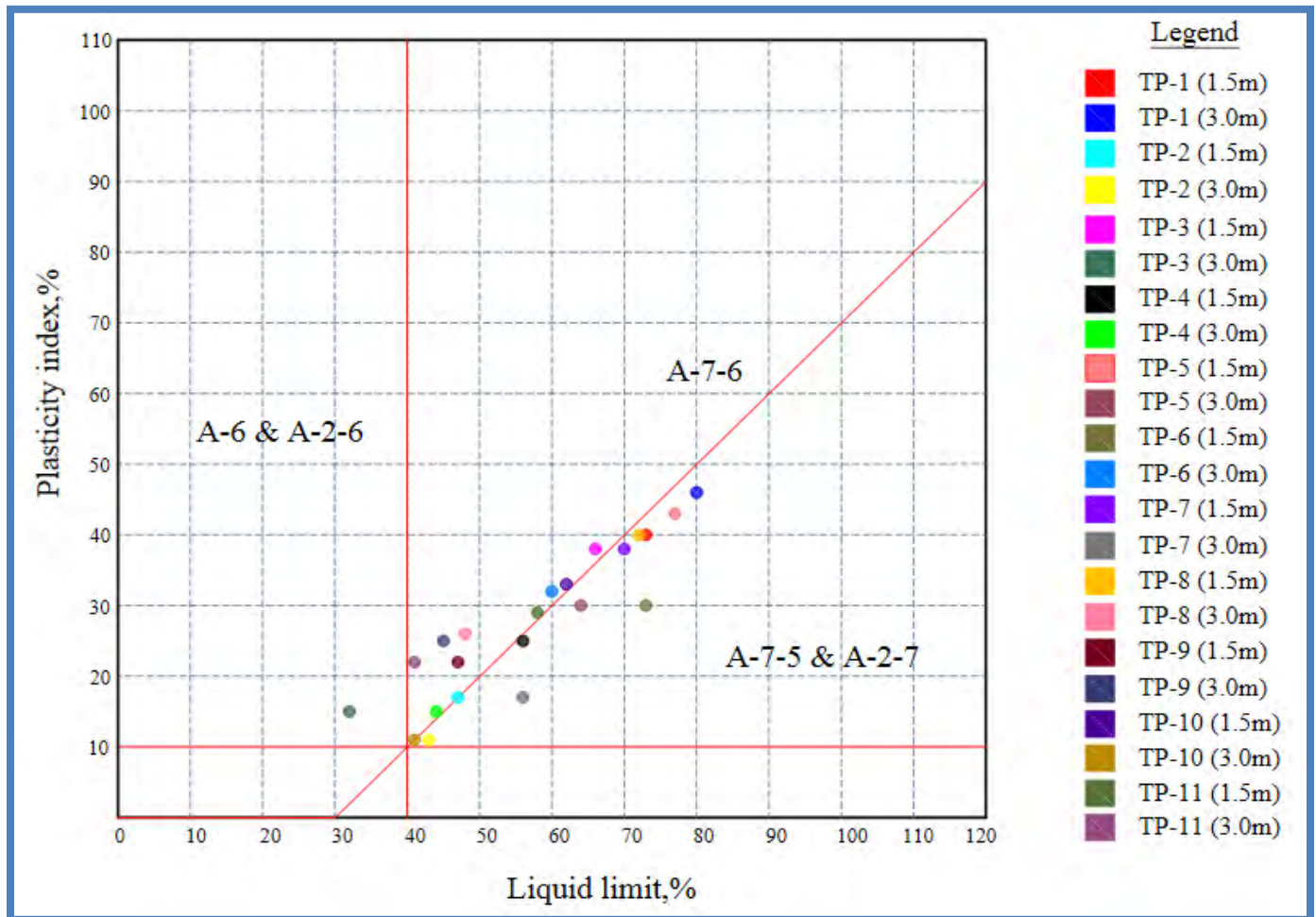


Fig 4.8 AASHTO classification chart

Table 4.10 Soil Classification based on AASHTO

Sr.No.	Test pit name	Depth of determination	Percent amount of particle size			Liquid limit	Plastic limit	Plasticity index	Soil classification ASSTHO	Usual types of significant constituent materials	General rating as subgrade
			No.10 (2mm)	No.40 (425 μ m)	No.200 (75 μ m)						
1	TP-1	1.50m	99.55	99.05	96.71	73	33	40	A-7-5	Clay Soils	Poor!
		3.00m	99.94	99.68	97.63	80	34	46	A-7-6	Clay Soils	Poor!
2	TP-2	1.50m	91.29	83.41	72.52	47	30	17	A-7-5	Clay Soils	Poor!
		3.00m	94.86	84.76	64.21	43	32	11	A-7-6	Clay Soils	Poor!
3	TP-3	1.50m	98.42	94.15	85.86	66	28	38	A-7-6	Clay Soils	Poor!
		3.00m	71.50	56.1	43.38	32	17	15	A-6	Clay Soils	Poor!
4	TP-4	1.50m	95.81	91.79	82.19	56	31	25	A-7-5	Clay Soils	Poor!
		3.00m	98.27	86.2	66.34	44	29	15	A-7-5	Clay Soils	Poor!
5	TP-5	1.50m	97.56	95.75	90.78	77	34	43	A-7-5	Clay Soils	Poor!
		3.00m	99.52	97.03	91.15	64	34	30	A-7-5	Clay Soils	Poor!
6	TP-6	1.50m	99.32	97.54	94.99	73	43	30	A-7-5	Clay Soils	Poor!
		3.00m	97.75	96	96	60	28	32	A-7-6	Clay Soils	Poor!
7	TP-7	1.50m	99.79	98.3	92.71	70	32	38	A-7-6	Clay Soils	Poor!
		3.00m	95.69	90.62	69.53	56	39	17	A-7-5	Clay Soils	Poor!
8	TP-8	1.50m	99.90	99.17	97.55	72	32	40	A-7-5	Clay Soils	Poor!
		3.00m	99.67	96.3	82.68	48	22	26	A-7-6	Clay Soils	Poor!
9	TP-9	1.50m	95.46	85.82	77.84	47	25	22	A-7-6	Clay Soils	Poor!
		3.00m	96.53	85.8	64.02	45	20	25	A-7-6	Clay Soils	Poor!
10	TP-10	1.50m	99.76	98.95	93.14	62	29	33	A-7-6	Clay Soils	Poor!
		3.00m	61.13	46.27	38.35	41	30	11	A-7-5	Clay Soils	Poor!
11	TP-11	1.50m	99.87	98.95	84.60	58	29	29	A-7-5	Clay Soils	Poor!
		3.00m	98.15	88.09	62.86	41	19	22	A-7-6	Clay Soils	Poor!

4. 4. Free Swell of Soils

The swelling (and shrinking) characteristics of expansive clay vary with the type of clay mineral present in the soil, the percentage of that clay mineral, and the change in water content. The active clay minerals include montmorillonite, mixed-layer combinations of montmorillonite and other clay minerals, and under some conditions chlorites and vermiculites [20].

To study the swelling property of the soils, the simplest test conducted is free swell test. This test is performed by slowly pouring 10 ml of oven dry soil which has passed the No. 40(0.425mm) sieve in to 100 ml graduated cylinder filled with distilled (tap) water. After 24 hours, final volume of the suspension being read. Hence, free swell is defined as [7]:

$$\text{Free swell} = \frac{\text{Final volume} - \text{Initial volume of the soil}}{\text{Initial volume}} \times 100 \% \text{-----(4.2)}$$

Holtz and Gibbs suggested that soils having a free-swell value as low as 100 percent can cause considerable damage to lightly loaded structures and soils having a free swell value below 50 percent seldom exhibit appreciable volume change even under light loadings [14].

A laboratory test was conducted for all soil samples of the study area and is listed below in Table 4.11 and detail analysis is attached in appendix-A. From the test result the free swell falls in the range of 35 to 100. This shows most of the soil of Debre Birhan town is marginal in swelling potential property.

Table 4.11 Summery Free swell test results

Sr.No.	Test pit name	Depth of determination	Free Swell	Test condition
1	TP-1	1.50m	80	Oven dry
		3.00m	100	Oven dry
2	TP-2	1.50m	50	Oven dry
		3.00m	55	Oven dry
3	TP-3	1.50m	70	Oven dry
		3.00m	60	Oven dry
4	TP-4	1.50m	50	Oven dry
		3.00m	50	Oven dry
5	TP-5	1.50m	95	Oven dry
		3.00m	85	Oven dry
6	TP-6	1.50m	90	Oven dry
		3.00m	85	Oven dry
7	TP-7	1.50m	80	Oven dry
		3.00m	50	Oven dry
8	TP-8	1.50m	85	Oven dry
		3.00m	70	Oven dry
9	TP-9	1.50m	45	Oven dry
		3.00m	35	Oven dry
10	TP-10	1.50m	95	Oven dry
		3.00m	50	Oven dry
11	TP-11	1.50m	75	Oven dry
		3.00m	50	Oven dry

4.5 Unconfined compression strength (UCS) test

4.5.1 General

The unconfined compression test is a special case of a triaxial compression test in which the all-round pressure $\sigma_3=0$ (minor stress). The tests are carried out only on saturated samples which can stand without any lateral support. The test is, therefore, applicable to cohesive soils only. The test is an undrained test and is based on the assumption that there is no moisture loss during the test. The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils. These tests can also be performed in the field by making use of simple loading equipment [14].

An axial load is rapidly applied to the specimen to cause failure. At failure, the total minor principal stress is zero and the total major principal stress is σ_1 (Figure 4.8) [8].

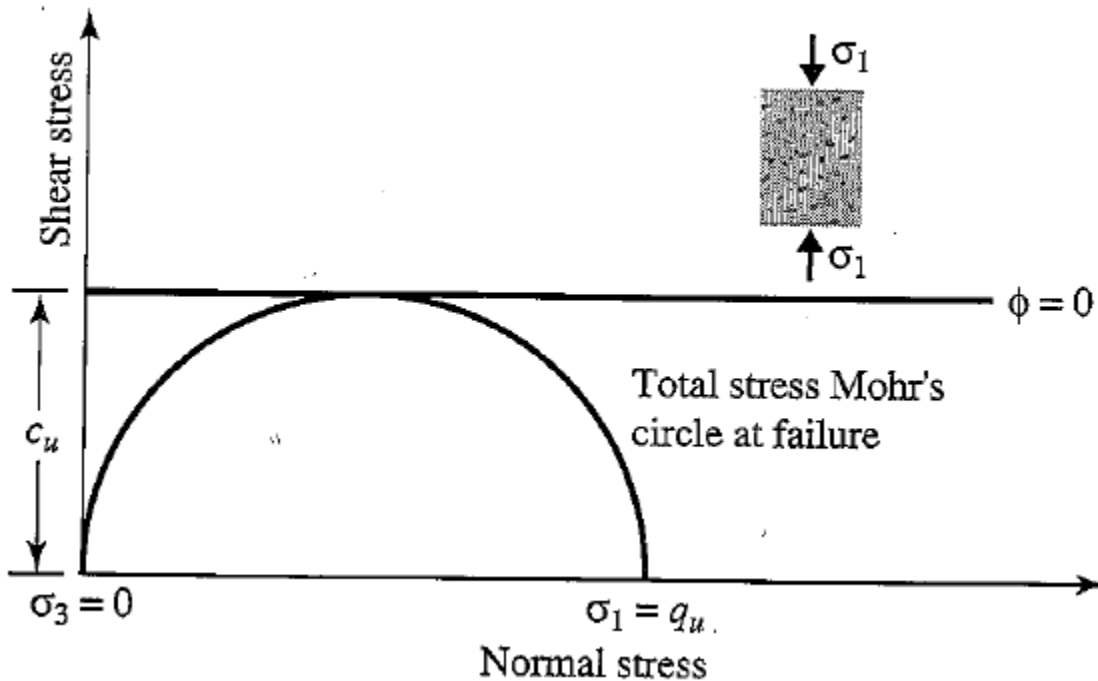


Figure 4.9 Unconfined compression test [8]

Because undrained shear strength is independent of the confining pressure as long as the soil is fully saturated and fully undrained, we have Eqn 4.3 [8];

$$\tau_f = \frac{\sigma_1}{2} = \frac{q_u}{2} = c_u \text{-----} (4.3)$$

Where, q_u is the unconfined compression strength.

In the unconfined compression test the internal angle of friction is negligible and the soil assumed to have only cohesion.

The general relation between consistency and unconfined compression strength of clays is given in Table 4.12.

Table 4.12.General Relationship of consistency and Unconfined Compression strength of clays after Das

Consistency	q_u , KN/m ²
Very soft	0-25
Soft	25-50
Medium	50-100
Stiff	100-200
Very Stiff	200-400
Hard	>400

4. 5.2 Test results

Table 4.13 shows the summery of the unconfined compressive strength and cohesion result of soils for the area under study. Detail analysis for the corresponding test pits is attached in appendix-A. Figures, Figure 4.9 and Figure 4.10 indicate the graph of unconfined compressive strength of Debre Birhan town area. It is observed that the consistency of Debre Birhan soil is either stiff or very stiff.

Table 4.13. Summery of unconfined compressive strength and cohesion

Sr No.	Test pit name	Unconfined strength , q_u (kPa)	Cohesion, C (kPa)	Consistency
1	TP1-1.50m	176.00	88.00	Stiff
2	TP1-3.00m	83.00	41.50	Medium
3	TP3-3.00m	75.00	37.50	Medium
4	TP4-1.50m	134.00	67.00	Stiff
5	TP4-3.00m	203.00	101.50	Very Stiff
6	TP5-1.50m	233.00	116.50	Very Stiff
7	TP5-3.00m	120.00	60.00	Stiff
8	TP6-1.50m	114.00	57.00	Stiff
9	TP7-3.00m	194.00	97.00	Stiff
10	TP11-1.50m	141.00	70.50	Stiff
11	TP11-3.00m	186.00	93.00	Stiff

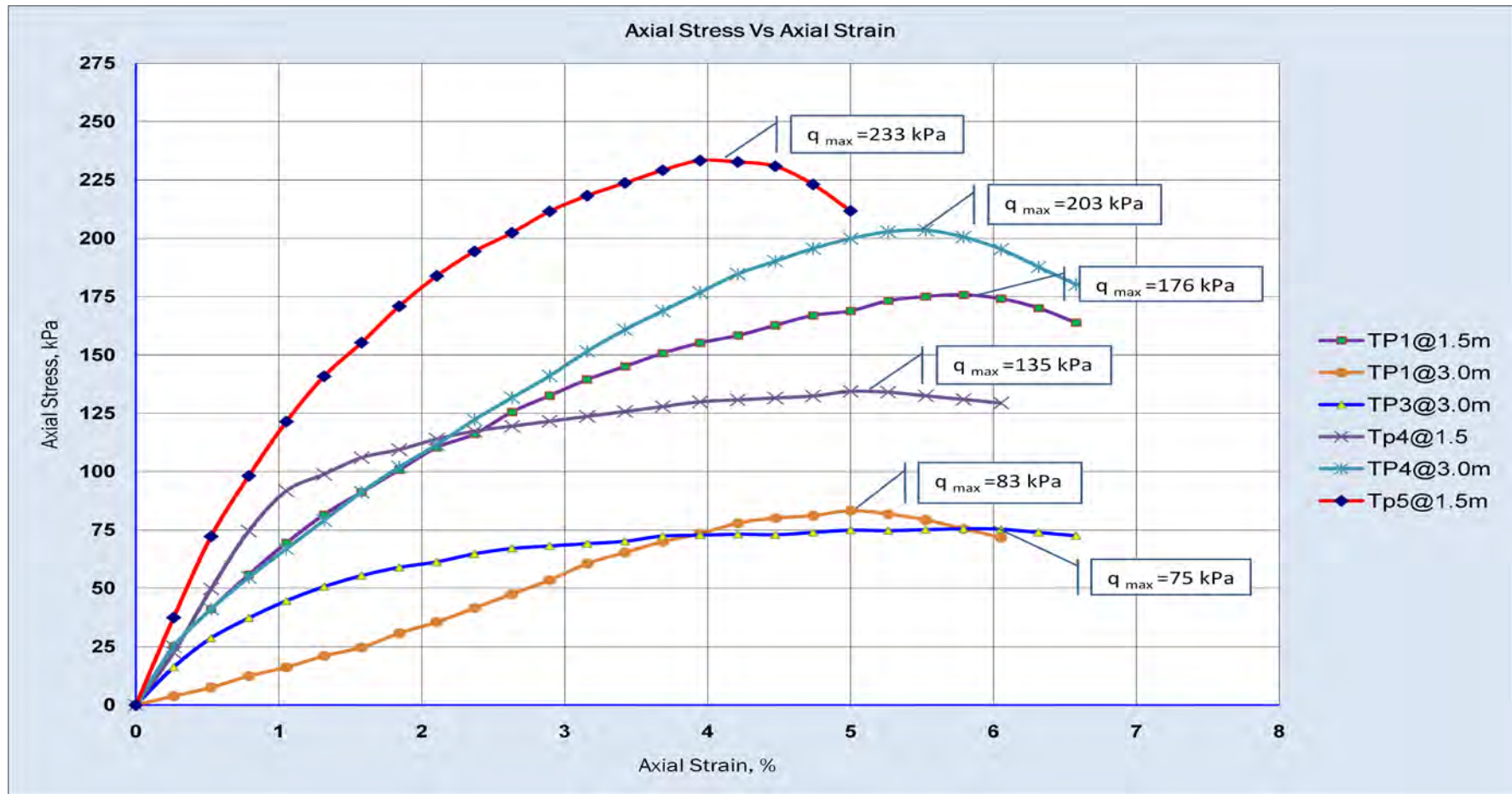


Figure 4.10 Unconfined compressive strength (TP1-TP5)

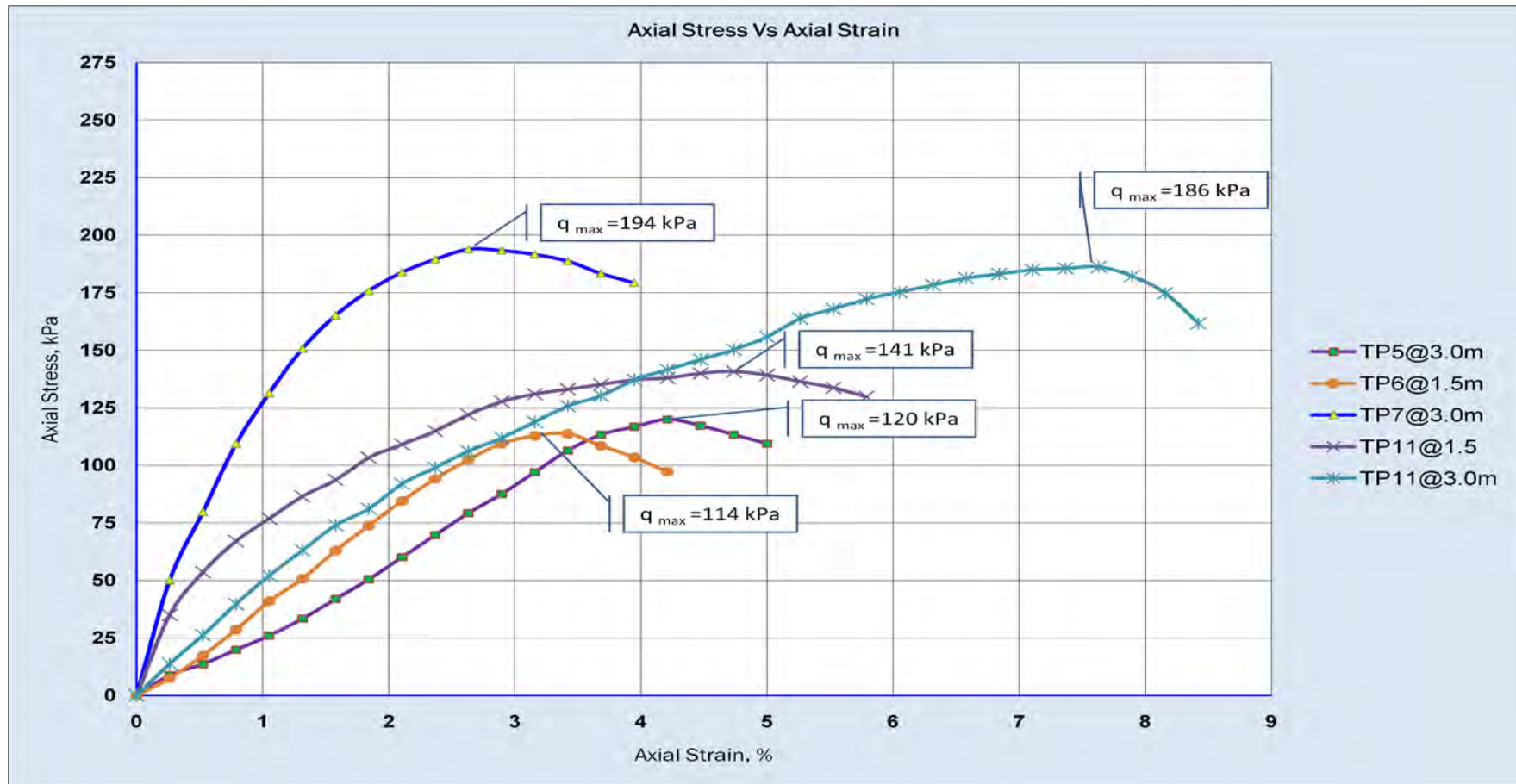


Figure 4.11. Unconfined compressive strength (TP5-TP11)

4.6. Consolidation Test

4.6.1 Test results

One dimensional consolidation test was carried out according to ASTM, D2435-96 test method. Undisturbed sample was recovered from three different test pits (TP6, TP7 and TP8) of Debre Birhan town area after classification was done and properly waxed until it was transported to laboratory.

The final void ratios corresponding to each pressure increment have been calculated and a graph is plotted between pressure as abscissa on a log scale and void ratio as ordinate on arithmetic scale (Fig 4.11 and 4.12).

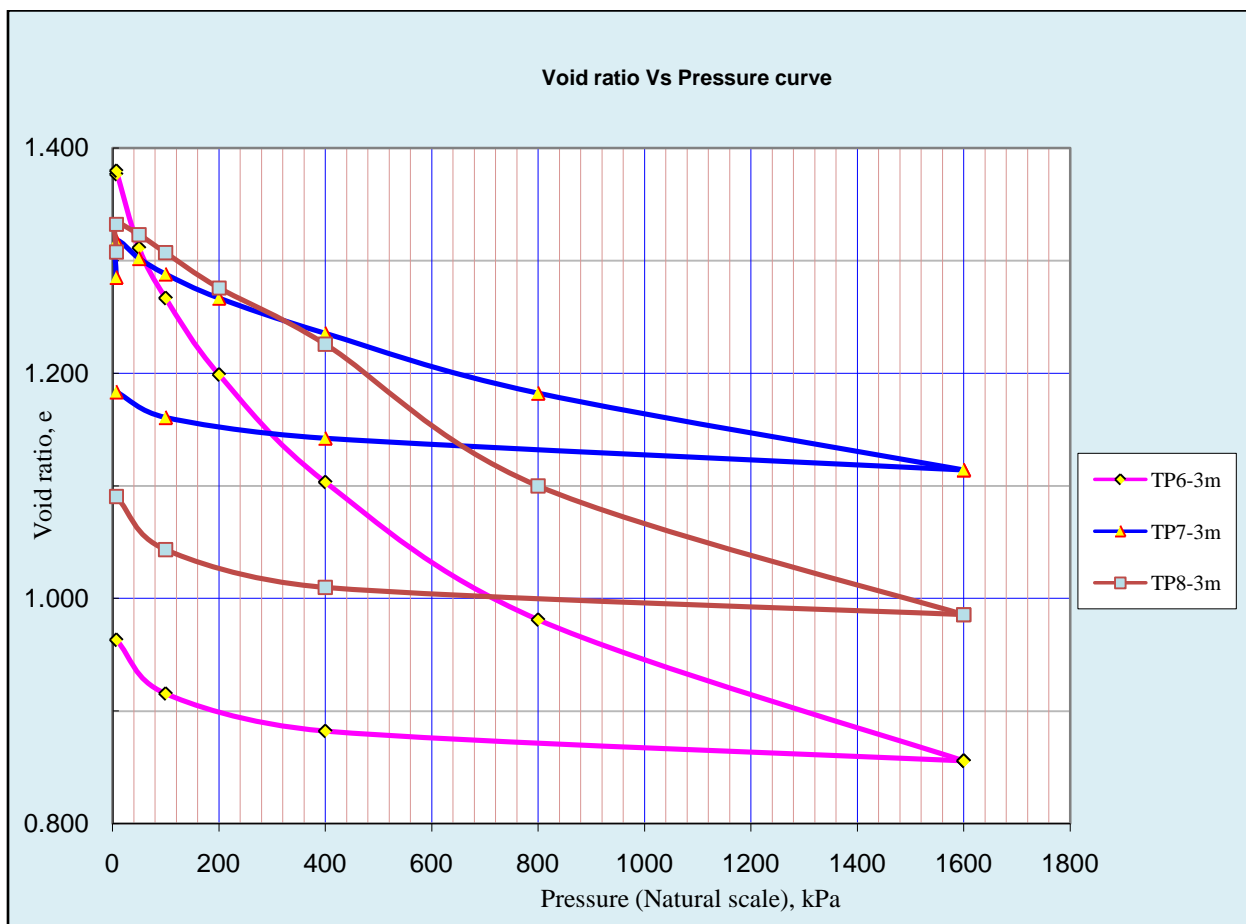


Fig 4.12 Plot of vertical effective stress Vs void ratio on linear scale

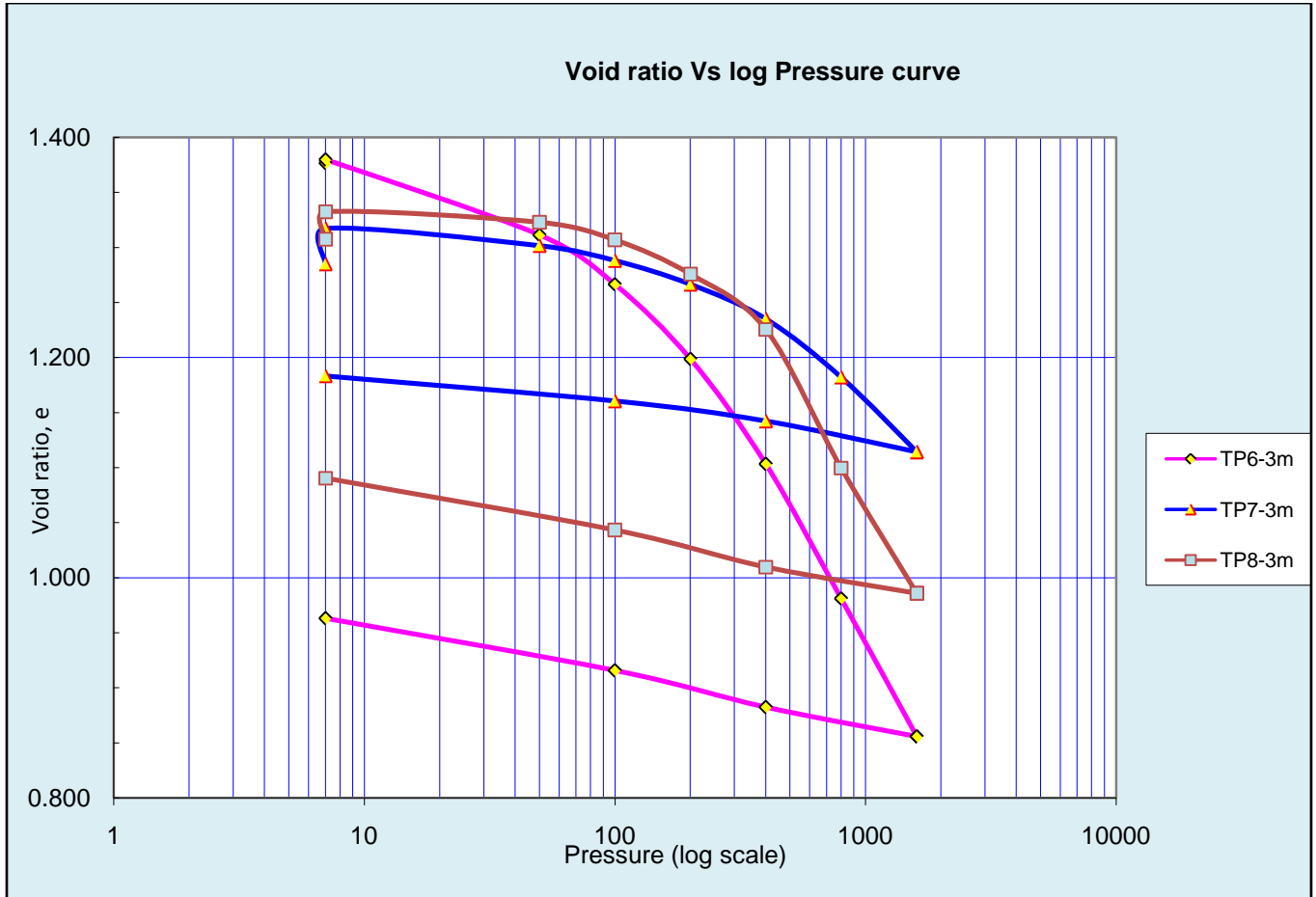


Fig 4.13 Plot of vertical effective stress Vs void ratio on semi-log scale

4.6.1.1 Compression index

Compression index, C_c , is numerically equal to the slope of the straight portion of the e - $\log P$ curve. Its value is constant beyond the range of the re-compration, since beyond this point the plot of e against $\log P$ is straight line. Nothing that,

$$C_c = \frac{e_1 - e_2}{\log \sigma'_2 - \log \sigma'_1} = \frac{\Delta e}{\log(\sigma'_2/\sigma'_1)} \text{----- (4.4)}$$

There après to be an approximate relationship between the liquid limit of a clay soil and the compression index. Skempton (1944) have demonstrated that this relationship can be expressed by the following formula.

$$C_c = 0.009(\omega_l - 10\%)$$

Where ω_l is liquid limit expressed in percent [19].

Fig 4.13 shows a typical schematic diagram how to determine the compression index from the void ratio versus applied effective pressure. The compression index of the area under study is summarized in Table 4.14.

From the one dimensional consolidation test result of soil found at Debre Birhan town, the compression index is in the range of 0.20-0.38.

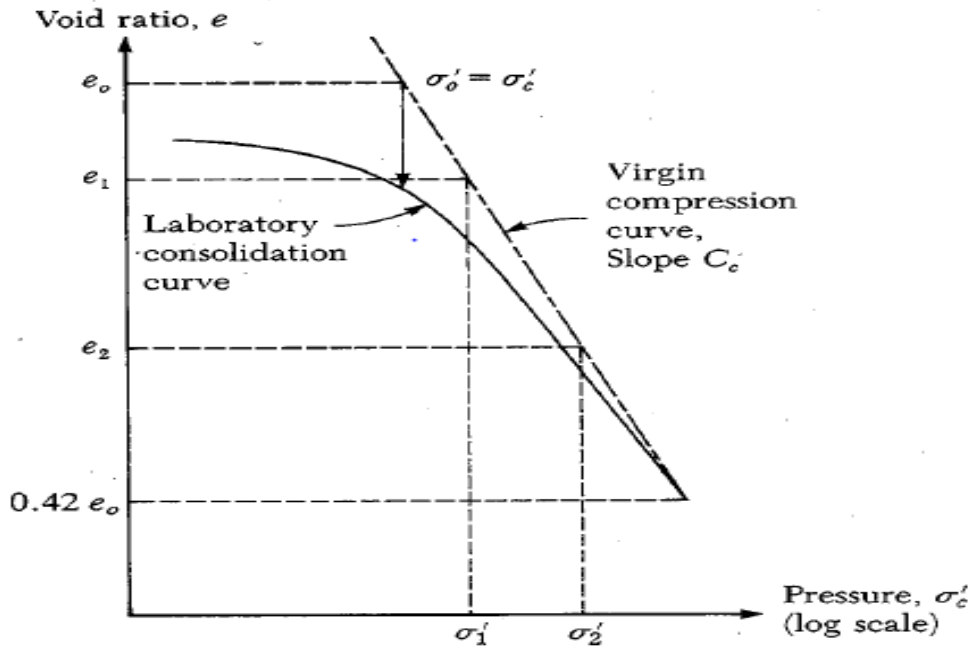


Fig 4.14 determination of Compression index, C_c [8]

4.6.1.2 Coefficient of consolidation

The coefficient of consolidation C_v can be evaluated by means of laboratory tests by fitting the experimental curve with the theoretical. There are two laboratory methods that are in common use for the determination of c_v . They are

1. Casagrande Logarithm of Time Fitting Method.
2. Taylor Square Root of Time Fitting Method [14].

i) Taylor Square Root of Time Fitting Method

This method has been devised by D.W. Taylor (1948). The coefficient of consolidation is the soil property that controls the time-rate or speed of consolidation under a load-increment [6].

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 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 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 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 preconsolidation pressure (or maximum past pressure) of the soil. In addition, the data 50 obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil.

Because of the fact that during the process of consolidation k and m_v are assumed to be constant, the coefficient of consolidation C_v during the process of consolidation of the clay is constant.

The coefficient of consolidation C_v by Taylor Square Root of Time Method is given by;

$$c_v = 0.848 \frac{H_{dr}^2}{t_{90}} \text{----- (4.6)}$$

Where H_{dr} - drainage path (average)

The square time method is used to determine the coefficient of consolidation and plot is shown below in Fig 4.14.

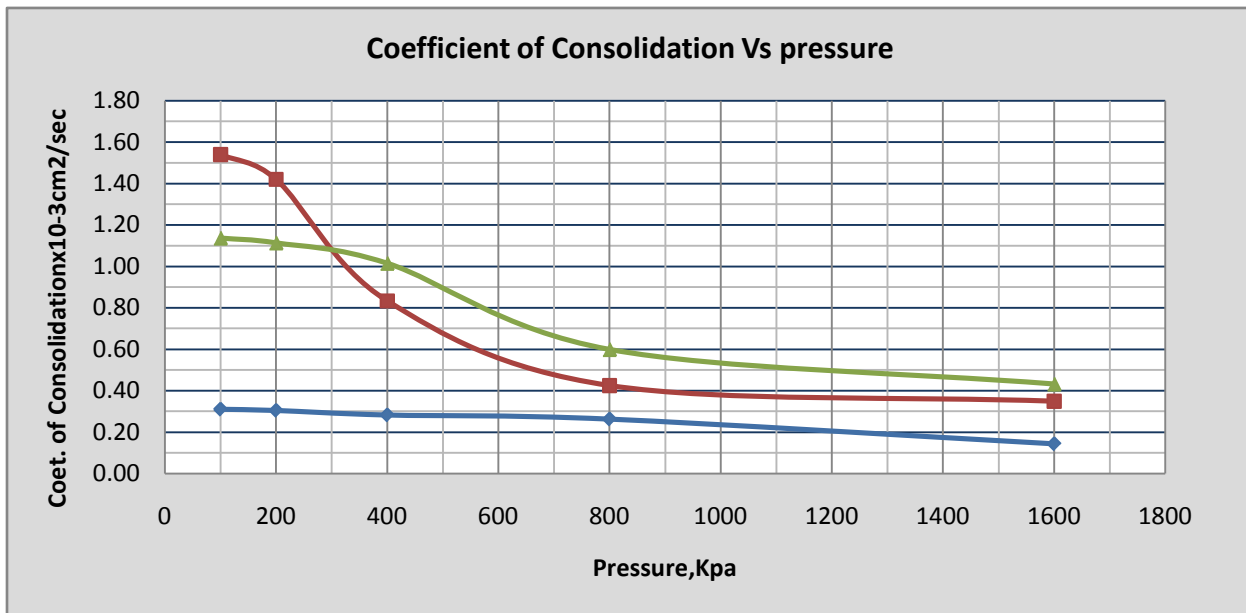


Fig 4.15 Coefficient of Consolidation Vs Pressure

Table 4.14 Summery of consolidation parameters

Sr.No.	Test pit name	Depth (m)	Natural Moisture content (%)	Total unit weight (γ),KPa	Pressure,P, KPa	Void ratio, e_f	Coefficient of consolidation, $C_v, 10^{-3} \text{ cm}^2/\text{sec}$	Coefficient of Compression, $a_v, 10^{-5} \text{ m}^2/\text{sec}$	Compression index, C_c
1	TP6	3	46.96	17.39	7	1.38			0.38
					50	1.31			
					100	1.27	0.31	95.00	
					200	1.20	0.30	65.00	
					400	1.10	0.28	48.00	
					800	0.98	0.26	31.00	
					1600	0.86	0.14	16.00	
2	TP7	3	43.64	17.42	7	1.32			0.20
					50	1.30			
					100	1.29	1.54	27.00	
					200	1.27	1.42	20.00	
					400	1.24	0.83	15.00	
					800	1.18	0.42	13.00	
					1600	1.11	0.35	8.50	
3	TP8	3	40.48	16.36	7	1.33			0.32
					50	1.32			
					100	1.31	1.14	40.00	
					200	1.28	1.11	29.50	
					400	1.23	1.01	25.00	
					800	1.10	0.60	31.50	
					1600	0.99	0.43	14.25	

4.6.1.3 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 [12];

$$K = \frac{c_v a_v \gamma_w}{1+e} \dots\dots\dots (4.7)$$

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 Table 4.15. From the table it is shown that the coefficient of permeability of the area under study ranges from 1.24×10^{-9} to 2.22×10^{-8} cm²/sec.

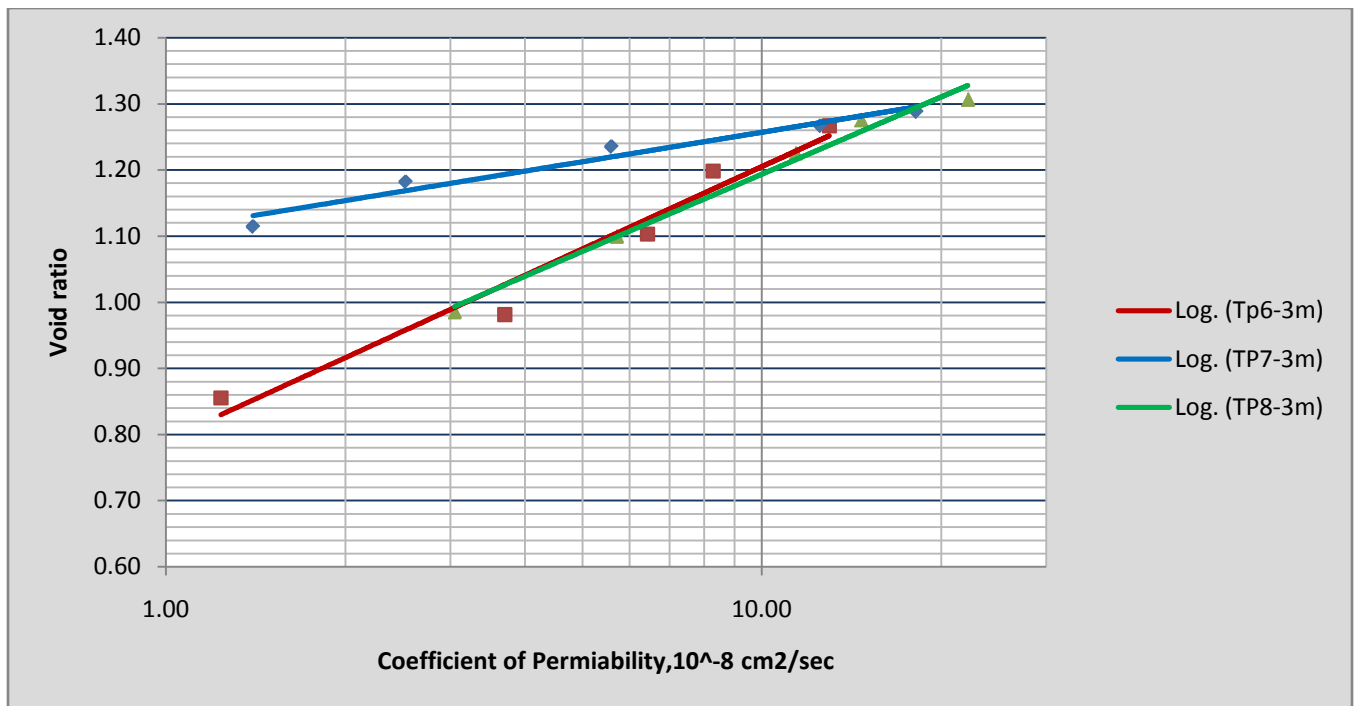


Fig 4.16 Void ratio Vs Log Coefficient of Permeability

Table 4.15 Relationship between Void ratio and coefficient of permeability

Sr.No.	Test pit name	Depth (m)	Pressure,P, Kpa	Void ratio, e_f	Coefficient of consolidation, $C_v, 10^{-3}$ cm ² /sec	Coefficient of Compression, $a_v, 10^{-5}$ m ² /sec	Coefficient of Permiability,K, 10^{-9} cm ² /sec
1	TP6	3	7	1.38			
			50	1.31			
			100	1.27	0.31	95.00	12.97
			200	1.20	0.41	60.00	11.22
			400	1.10	0.32	48.00	7.32
			800	0.98	0.26	28.00	3.70
			1600	0.86	0.14	16.00	1.24
2	TP7	3	7	1.32			
			50	1.30			
			100	1.29	1.54	27.00	18.17
			200	1.27	2.18	20.00	19.26
			400	1.24	0.83	15.00	5.59
			800	1.18	0.42	13.00	2.53
			1600	1.11	0.48	8.50	1.95
3	TP8	3	7	1.33			
			50	1.32			
			100	1.31	1.14	45.00	22.17
			200	1.28	1.52	30.00	19.97
			400	1.23	1.07	25.00	12.06
			800	1.10	0.60	20.00	5.71
			1600	0.99	0.43	14.00	3.05

4.6.1.4 Pre-consolidation pressure

Another very important characteristic of clays is the pre-consolidation pressure σ_p . It is the vertical effective stress beyond which large strains occur and controls the overall behavior of clays, particularly the sensitive clays. Previously, it was believed that the pre-consolidation pressure estimated with Casagrande method was primarily due to previous loading, usually of geologic nature. However, it has become evident in recent years that the profile of the pre-consolidation stress observed in some deposits is greater than the maximum past pressure that could have existed during its geologic history. This discrepancy was attributed to a number of factors, including desiccation, long term secondary compression, thixotropy, weathering and cementation.

Since the exact origin of the pre-consolidation pressure is difficult to establish, the term has been extended to define the break of the $e - \log \sigma_p$ curve (13).

From practical point of view engineers are interested in this threshold point beyond which important plastic deformation take place, particularly in sensitive clays where the normally consolidated branch of the compression curve is very steep. The pre-consolidation pressure serves as basis for normalizing the strength and stiffness characteristics of cohesive deposits. For young normally consolidated soft clays, the effective pre-consolidation pressure is equal to the effective overburden pressure, where the soil deposit is not subjected to previous external load such as building loads [13].

There are different types of determining the pre-consolidation pressure in the field as well as in the laboratory. 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 $e - \log \sigma_p$ curve of an undisturbed sample as shown in Fig. 4.7. 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 [14].

Overconsolidation Ratio

We will create a demarcation for soils based on their consolidation history. We will label a soil whose current vertical effective stress or overburden effective stress, is less than its past maximum vertical effective stress or pre consolidation stress as an overconsolidated soil. The degree of overconsolidation, called overconsolidation ratio, OCR, is defined as;

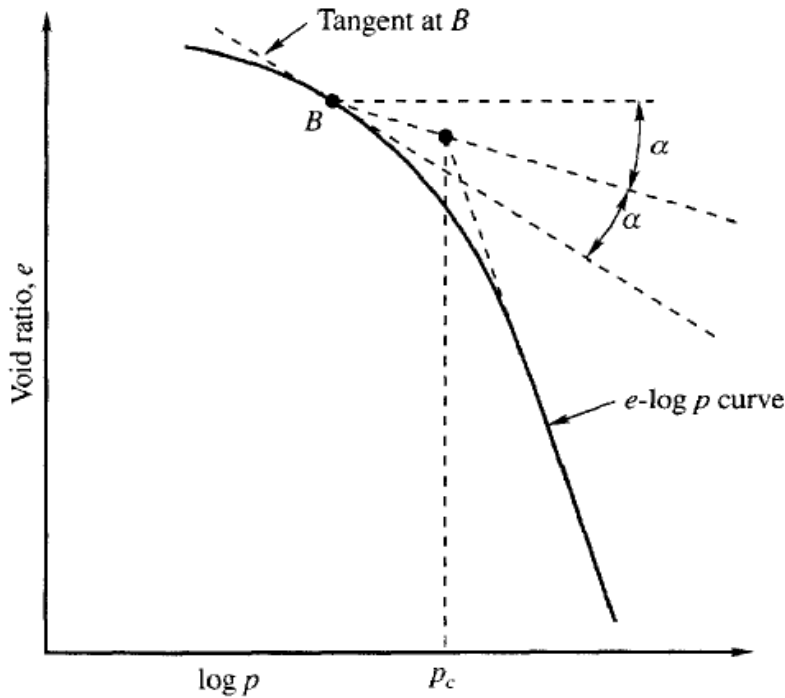


Fig 4.17 Method of determining p_c by Casagrande method [14]

$$\text{OCR} = \frac{P_c}{P_o} \text{-----} (4.8)$$

Where P_c =Pre consolidation pressure

P_o =current vertical effective stress

If $\text{OCR}=1$, the soil is normally consolidated soil [5].

Preconsolidation pressure for three samples is calculated as under listed in Table 4.16. It ranges 145-260 KPa. The OCR ratio for all samples is greater than 1.

Table 4.16 Summery of preconsolidation pressure

Sr.No.	Test pit name	Depth (m)	Natural Moisture content (%)	Total unit weight (γ),Kpa	Pressure,P, Kpa	Void ratio, e_f	Overburden Pressure ,Po, Kpa	Pre consolidation pressure ,Pc,Kpa	Over consolidation ratio (OCR)
1	TP6	3	46.96	17.39	7	1.38	52.17	145	2.78
					50	1.31			
					100	1.27			
					200	1.20			
					400	1.10			
					800	0.98			
					1600	0.86			
2	TP7	3	43.64	17.42	7	1.32	52.25	285	5.45
					50	1.30			
					100	1.29			
					200	1.27			
					400	1.24			
					800	1.18			
					1600	1.11			
3	TP8	3	40.48	16.36	7	1.33	49.07	260	5.30
					50	1.32			
					100	1.31			
					200	1.28			
					400	1.23			
					800	1.10			
					1600	0.99			

5.0 Discussions of the laboratory test results and Comparisons with previously done researches

5.1. Discussions of the laboratory test results of the study area

In situ property test result of soil shows the moisture content of the study area is on the range of 20.11%-58%. The in situ unit weight of the soils is 14.02-18.53 KN/m³ in which the lower value is due to large amount of moisture in the soils.

The specific gravity value varies between 2.62 and 2.81. Since the specific gravity is above 2.62 inorganic soils are dominant, as most of organic soils contain a value of less than 2.40. This range of specific gravity is similar to most of silty and clayey soils as determined in different literatures.

The grain size analysis of the area under study showed the soil contains gravel 0-24.63%, Sand 2.37%-38.74%, Silt 27.28%-55.9% and Clay in between 8.77% to 67.5%. This analysis shows the dominant soil types in the area are Silt and Clay type soils.

From the Atterberg limits and Indices, the liquid limit of the soils is in the range of 32%-80%. Higher value of liquid limit for the soil is at test pit No.1 at 3m. From the laboratory test result the Plastic limit of the soils lies in between 17% to 43%. The difference of liquid limit and plastic limit which is plasticity index (PI) for the area under study lies between 11%-46% as shown in table 4.8.

After conducting the grain size analysis and Atterberg limits, soil classification is made as shown in Table 4.10 by USCS and Table 4.11 by AASTHO classification system. Soils classification by USCS shows the soil contains around 41% CH, 18% CL, 18% MH, 14% ML, 4.5% SM and 4.5% SC. This indicated that a clayey soil in the area under study is about 59% and Silty is around 32% both of which are dominants in the area.

AASTHO classification system showed that the soils are classified in either of A-6 or A-7. By this classification system A-6 is around 4.55%, A-7-5 is around 50% and A-7-6 is about 45.45%. It is clearly indicated that the soil is poor to be used for sub grade material as per the AASTHO recommendation for suitability of soils as sub grade material.

Free swell test results are summarized in Table 4.12. From this table it can be observed that the free swell of soils under investigation lies in between 35% to 100%. This shows that the soil expansiveness property ranges from low to marginal degree of expansiveness.

The UCS test was conducted for undisturbed samples and summery of test results is given on Table 4.14. From UCS test of soils, the value of q_u is in between 75KPa to 233 KPa and the amount of cohesion lies in between 37.5 KPa to 116.5 KPa. Consistency is also determined based on the UCS result and it is found that the soil is medium, stiff or very stiff according to [8].

Consolidation test was conducted on three different types of soils which is taken based on the classification result. The compression index is computed from void ratio versus log of effective stress and it is tabulated on Table 4.15. The range of compression index is in between 0.20-0.38. Higher value of compression index means large settlement may occur under applied effective stress as indicated for soil found at test pit (TP6-3m). Test pit no. 7 shows less value of compression index.

The coefficient of consolidation, C_v , is determined from the compression dial reading versus square root of time for each incremental loading and it is plotted as a function of effective stress in Fig 4.14. The value of C_v as described in the table is in the range of 0.14×10^{-3} to 2.18×10^{-3} cm²/sec. it can be observed that the three curves are almost similar in shape. But for test pit number 7 the value of coefficient of consolidation is smaller than the test pit number 6 and 8. This shows the compressibility of any soil type varies with density, history of previous loading, handling prior to and during compression, and in the magnitude of stress increment relative to the existing loading any point.

The coefficient of permeability can be determined from the value of coefficient of consolidation, compression index and void ratio relations as shown by Equation 4.7. Fig 4.15 shows void ratio versus log of coefficient of permeability. From Table 4.16 one can see that the coefficient of permeability ranges from 1.24×10^{-9} to 22.17×10^{-9} cm²/sec. The value indicates the soil under investigation has low permeability.

Pre consolidation pressure of the soil found in the area under study was calculated from the void ratio versus effective pressure plotted on semi-log scale shown on Fig 4.16. Table 4.17 gives Summery of preconsolidation pressure and the values lies between 145 KPa to 285 KPa. Comparison is made

between the current effective pressure and the preconsolidation pressure and it is found that the over consolidation ratio is greater than one. Hence the soil is over consolidated in its natural state.

Engineering soil map of the area under investigation is prepared and is shown in Figur 5.2. The area is grouped in to four soil categories and rock sections. From this map it is observed that clayey soils with high plasticity are dominant to a depth of 1.50m.

5.2. Comparison of the laboratory test results with other researches

There are numerous researches conducted on expansive and red clay soils found here in Ethiopia and worldwide. Thus comparison of test result conducted in this research is made with other researches to visualize the similarity and difference. Table 6.1 shows the comparison of test result.

Table 5.1 Comparison of test result with other researches

	Researcher Name	Morin and Parry	Dagachew Debebe,2011	Haile Mariam,1992	Fasil Abagena,2003	Current research
	Location	Ethiopia	Adama	Addis Ababa	Bahir Dar	Debre Birhen
Sr.No.	Soil type	Black clay	Silt & silt sand	Red Clay	Red clay	Silt and Clay
1	Specific gravity	2.62-2.94	2.4-2.7	2.61-2.79	2.75-2.83	2.62-2.81
2	Free swell		18-50	10.0-40.0	8.0-13.0	35-100
3	Clay content (%)	13-75	5.4-40.5	48.0-73.0	74-82	8.77-67.50
4	Liquid limit (%)	37-88	29-73	54.0-81.0	61-68	31-80
5	Plasticity index (%)	11-48	5.0-34.0	21.0-30.0	24-31	13-46
6	q _u ,KN/m ²	96.7-267			148-220	75-233
7	Compression index,Cc		0.33-0.40		0.2658-0.4056	0.20-0.38
8	Classification		SM,ML,MH		MH	MH,ML,CH,CL

5.3 Engineering Soil Map

5.3.1 General

It is very important to delineate and categorize soils in a map that consist the same in one or more of the engineering and index property.

These maps show the distribution of soils, and describe their origin, physical characteristics and engineering properties. However, national or regional based soil engineering maps do not exist in Ethiopia. Consequently, maps are often only available in association with specific road construction projects. In the absence of engineering soil maps, it is common practice to use agricultural soil classification systems of the type given in Figure 5.1 [9].

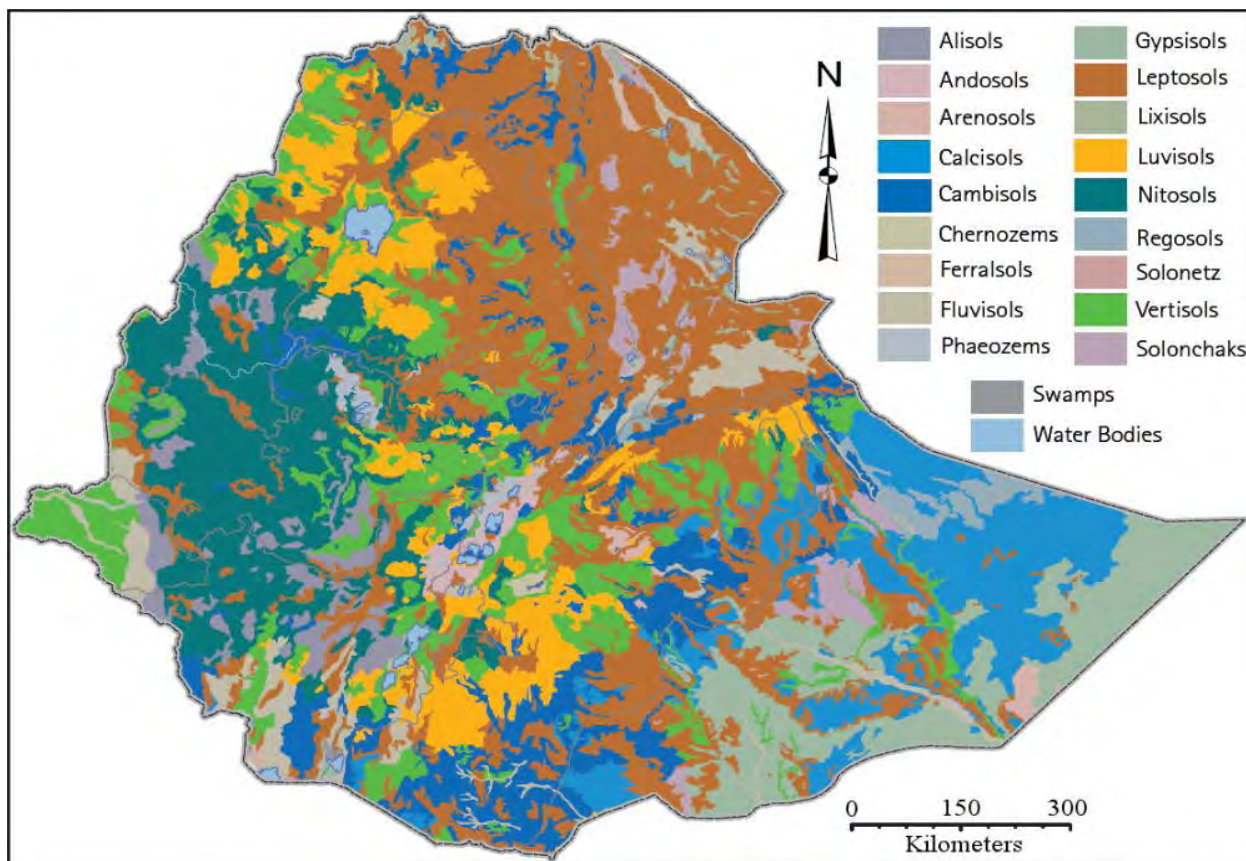


Figure 5.1: Agricultural soil map of Ethiopia [9].

The distribution of soils in Ethiopia is a function of climate, regional landform, local topography and the underlying parent materials. Drainage is also an important factor in the formation of some soils [9].

5.3.2 Soil map

Engineering soil map for the area under investigation is prepared from the classification made by Unified Soil Classification system (USCS). The town is divided in to four groups of soils and rock at 1.50m and six groups of soils and rock section at 3.0m. The dominant type of soil at depth of 1.5m is clay soil with high plasticity. Clay soil having low plasticity and silty soil with high and low plasticity also covered the town in small areas.

The soil map is prepared both at 1.5m and 3.0m as shown below in fig 5.2 and 5.3. Summary of the engineering properties for the corresponding depths is illustrated in table 5.2 and table 5.3.

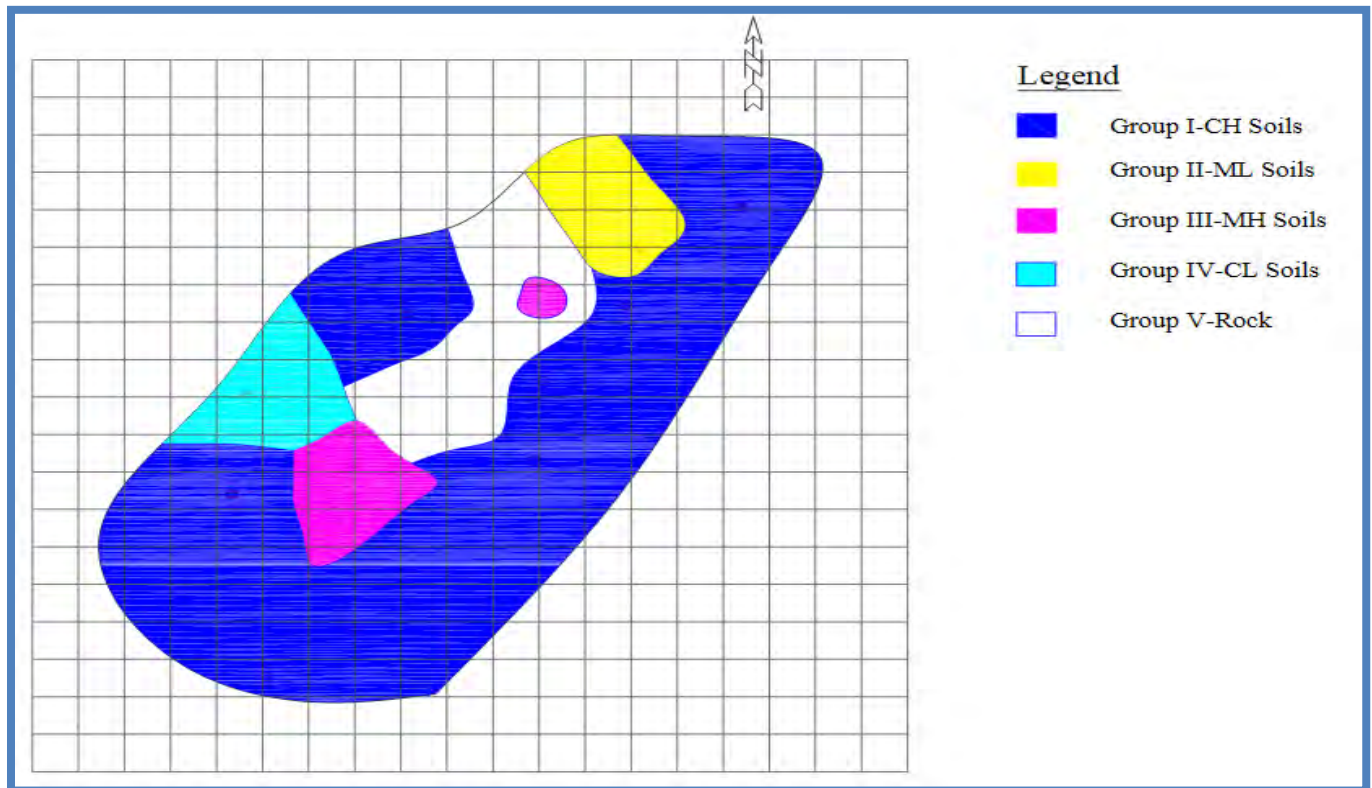


Figure 5.2 Tentative Engineering soil map of Debre Birhan town at 1.50m depth

Table 5.2 Summery of engineering properties of soils at 1.50m

Sr No.	Engineering and index properties	Group of soil				Remark
		CH	ML	MH	CL	
1	Water content (%)	27.69-43.64	22.01	37.4-43.04	30.08	CH-Inorganic clay with high plasticity
2	Specific gravity	2.71-2.81	2.69	2.65-2.77	2.78	ML-Inorganic silt with low plasticity
3	Clay content (%)	43.45-67.5	48.74	46.53-47.08	34.77	MH-Inorganic silt with high plasticity
4	Liquid limit (%)	58-77	47	56-73	47.00	CL-Inorganic clay with low plasticity
5	Plastic limit (%)	28-34	30	31-43	25.00	
6	Plasticity index (%)	29-43	17	25-30	22.00	
7	Free swell (%)	70-95	50	50-90	45.00	
8	Unconfined compressive strength (kPa)	141-233	203	114-134	186	
9	Compression index					

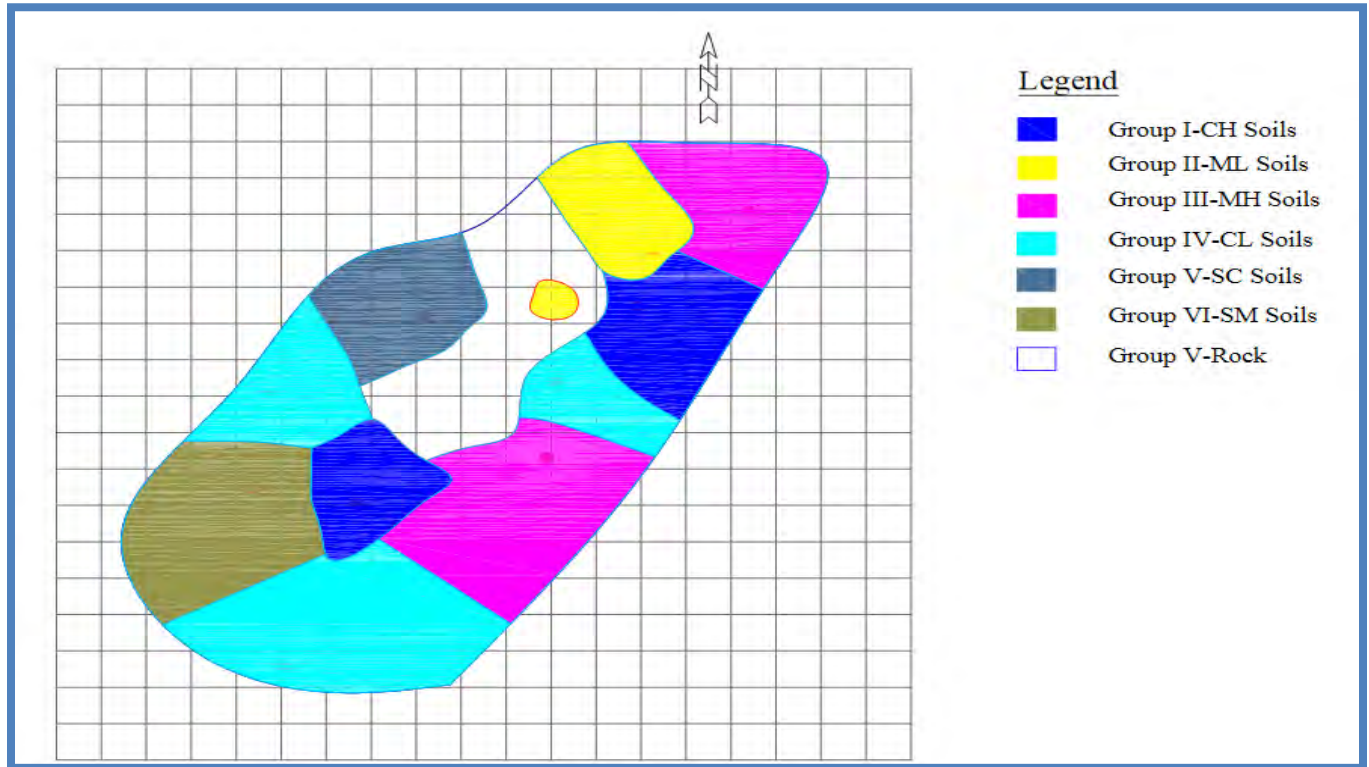


Figure 5.3 Tentative Engineering soil map of Debre Birhan town at 3.0m depth

Table 5.3 Summary of engineering properties of soils at 3.0m

Sr No.	Engineering and index properties	Group of soil						Remark
		CH	ML	MH	CL	SC	SM	
1	Water content (%)	46.96-58.99	23.62-24.27	30.93-43.64	26.87-40.48	31.14	20.11	CH-Inorganic clay with high plasticity
2	Specific gravity	2.74-2.78	2.62-2.70	2.72-2.80	2.72-2.77	2.70	2.81	ML-Inorganic silt with low plasticity
3	Clay content (%)	43.93-49.71	8.77-17.81	13.63-44.11	30.16-47.60	15.57	11.07	MH-Inorganic silt with high plasticity
4	Liquid limit (%)	60-80	43-44	56-64	41-48	32.00	41.00	CL-Inorganic clay with low plasticity
5	Plastic limit (%)	28-34	29	34-39	19-22	17.00	30.00	
6	Plasticity index (%)	32-46	14-15	17-30	22-26	15.00	11.00	
7	Free swell (%)	85-100	50-55	50-85	35-70	60	50.00	
8	Unconfined compressive strength (kPa)	83	203	120-194	186	75		
9	Compression index	0.38		0.2	0.32			

6.0 Conclusion and Recommendation

6.1. Conclusion

1. The moisture content of the soil found in Debre Birhan town range from 20.11%-58%. The in situ unit weight of the soils is 14.02-18.53 KN/m³.
2. The specific gravity of the soil is in between 2.62 and 2.81 which is common for most of soil types.
3. Grain size analysis result shows the soil under investigation is dominantly silt and clay types through which about 32% is silt soil and 59% clay soils.
4. Atterberg limit test shows the liquid limit of the soils is in the range of 31%-80%, Plastic limit falls in between 17% to 43% and plasticity index lies between 11%-46%.
5. Soils classification by USCS shows the soil contains around 41% CH, 18% CL, 18% MH, 14% ML, 4.5% SM and 4.5% SC. This indicated that a the clay content in the area under study is about 59% and silt content is around 32% both of which are dominants in the area. AASTHO classification system shows the soils are classified in either of A-6 or A-7 (A-7-5, A-7-6). The soil is poor to be used for sub grade material as per the AASTHO recommendation for suitability of soils as sub grade material.
6. Free swell test results of soils under investigation lies in between 35% to 100%. This shows that the soil expansiveness property ranges from low to marginal degree of expansiveness.
7. Unconfined Compressive Strength (UCS) test indicates the value of q_u is in between 75KPa to 233 KPa and the amount of cohesion lies in between 37.5 KPa to 116.5 KPa. Based on the UCS result the consistency of soils is medium to very stiff.
8. From consolidation test the amount of compression index, C_c , is in between 0.20-0.38. The value of consolidation coefficient, C_v , is 0.14×10^{-3} to 2.18×10^{-3} cm²/sec. coefficient of permeability from consolidation test gives 1.24×10^{-9} to 22.17×10^{-9} cm²/sec. this shows the soil is almost impermeable.
9. The amount pre consolidation pressure of the soil found in the area under study is determined and it lies between 145 KPa to 285 KPa. Since the over consolidation ratio is greater than one, the soil is over consolidated in its natural state.

6.2 Recommendation

1. Debre Birhan town is growing at faster rate. Hence one can take large number of samples to determine the engineering and index property of the soils of the town.
2. Some part of the town especially areas at higher altitude is covered dominantly by rock. Thus additional detailed geological study on those areas is highly recommended.

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Appendix – A
(Laboratory Test result)

Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
Natural Moisture Content Determination

Test Pit No: TP-01 Sampling depth,m:1.50

Container No.	12	C
mass of container	15.6	14.1
mass of container + wet soil	43.1	41.9
mass of container dry soil	36.2	34.8
Moisture content	33.5	34.3
Aver.	33.90	

Test Pit No: TP-01 Sampling depth,m:3.00

Container No.	50	46
mass of container	15.6	15.7
mass of container + wet soil	74.6	69.6
mass of container dry soil	52.6	49.7
Moisture content	59.5	58.5
Aver.	58.99	

Test Pit No: TP-02 Sampling depth,m:1.50

Container No.	K	G111
mass of container	15.3	15.7
mass of container + wet soil	73.2	73.1
mass of container dry soil	62.9	62.6
Moisture content	21.6	22.4
Aver.	22.01	

Test Pit No: TP-02 Sampling depth,m:3.0

Container No.	D21	TT
mass of container	16	15
mass of container + wet soil	90	88
mass of container dry soil	75.9	73.4
Moisture content	23.5	25.0
Aver.	24.27	

Test Pit No: TP-03

Sampling depth,m:1.50

Container No.	10	B+
mass of container	11.1	11
mass of container + wet soil	41	33.4
mass of container dry soil	34	28.3
Moisture content	30.6	29.5
Aver.	30.02	

Test Pit No: TP-03

Sampling depth,m:3.0

Container No.	16	45
mass of container	15.3	15.4
mass of container + wet soil	82.6	75.8
mass of container dry soil	66.8	61.3
Moisture content	30.7	31.6
Aver.	31.14	

Test Pit No: TP-04

Sampling depth,m:1.50

Container No.	A	J1
mass of container	15.6	15.3
mass of container + wet soil	43.2	62.6
mass of container dry soil	35.8	49.5
Moisture content	36.6	38.3
Aver.	37.47	

Test Pit No: TP-04

Sampling depth,m:3.0

Container No.	12	R59
mass of container	15.4	24.1
mass of container + wet soil	46.6	60.1
mass of container dry soil	40.4	53.5
Moisture content	24.8	22.4
Aver.	23.62	

Test Pit No: TP-05

Sampling depth,m:1.50

Container No.	M4	21A
mass of container	15.7	15.3
mass of container + wet soil	73	75.4
mass of container dry soil	58.4	61
Moisture content	34.2	31.5
Aver.	32.85	

Test Pit No: TP-05

Sampling depth,m:3.0

Container No.	P4	F101
mass of container	15.7	15.6
mass of container + wet soil	48.2	50.1
mass of container dry soil	40.2	42.3
Moisture content	32.7	29.2
Aver.	30.93	

Test Pit No: TP-06

Sampling depth,m:1.50

Container No.	93	52
mass of container	15.7	15
mass of container + wet soil	74.2	62
mass of container dry soil	56.3	48.1
Moisture content	44.1	42.0
Aver.	43.04	

Test Pit No: TP-06

Sampling depth,m:3.0

Container No.	T2	CB
mass of container	15	16
mass of container + wet soil	67	77
mass of container dry soil	51.1	56.7
Moisture content	44.0	49.9
Aver.	46.96	

Test Pit No: TP-07

Sampling depth,m:1.50

Container No.	1	2
mass of container	15.6	15.2
mass of container + wet soil	78	76
mass of container dry soil	63.1	61.4
Moisture content	31.4	31.6
Aver.	31.49	

Test Pit No: TP-07

Sampling depth,m:3.0

Container No.	5	8
mass of container	15	15
mass of container + wet soil	65	68
mass of container dry soil	50	51.7
Moisture content	42.9	44.4
Aver.	43.64	

Test Pit No: TP-08

Sampling depth,m:1.50

Container No.	12	16
mass of container	15	15
mass of container + wet soil	65	68
mass of container dry soil	50	51.7
Moisture content	42.9	44.4
Aver.	43.64	

Test Pit No: TP-08

Sampling depth,m:3.0

Container No.	DYH	J1
mass of container	16	15
mass of container + wet soil	82	76
mass of container dry soil	62.9	58.5
Moisture content	40.7	40.2
Aver.	40.48	

Test Pit No: TP-09

Sampling depth,m:1.50

Container No.	G2	18A
mass of container	16	15
mass of container + wet soil	73	70
mass of container dry soil	61.2	59.0
Moisture content	26.1	25.0
Aver.	25.55	

Test Pit No: TP-09

Sampling depth,m:3.0

Container No.	P33	PS1
mass of container	15.3	15.4
mass of container + wet soil	71.4	68.5
mass of container dry soil	58.9	56.8
Moisture content	28.7	28.3
Aver.	28.5	

Test Pit No: TP-10

Sampling depth,m:1.50

Container No.	19A	A5
mass of container	15	24
mass of container + wet soil	70	78
mass of container dry soil	58.8	65.6
Moisture content	25.6	29.8
Aver.	27.69	

Test Pit No: TP-10

Sampling depth,m:3.0

Container No.	T2	CB
mass of container	15	15
mass of container + wet soil	83	70
mass of container dry soil	71.6	60.8
Moisture content	20.1	20.1
Aver.	20.11	

Test Pit No: TP-11

Sampling depth,m:1.50

Container No.	G2	18A
mass of container	15.4	15.8
mass of container + wet soil	42	52.5
mass of container dry soil	35.3	43.2
Moisture content	33.7	33.9
Aver.	33.80	

Test Pit No: TP-11

Sampling depth,m:3.0

Container No.	P33	PS1
mass of container	15	15.8
mass of container + wet soil	48	50.3
mass of container dry soil	41.1	42.9
Moisture content	26.4	27.3
Aver.	26.87	

Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
Specific Gravity Test

Sample No : TP-01

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i (oc)</i>	22.1	22.1

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.1	164.8
<i>Temperature, T_x (°c)</i>	23.7	23.7
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.38	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9993	0.9993
<i>Specific gravity of soil at 20°c.</i>	2.69	2.85
<i>Average specific gravity of soil .</i>	2.77	

Sample No : TP-01

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i (oc)</i>	22	21.8

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.3	164.7
<i>Temperature, T_x (°c)</i>	22.4	23.3
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.40	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9996	0.9993
<i>Specific gravity of soil at 20°c.</i>	2.75	2.81
<i>Average specific gravity of soil .</i>	2.78	

Specific Gravity Test

Sample No : TP-02

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i (oc)</i>	22.2	22.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160	164.3
<i>Temperature, T_x (°c)</i>	24.9	24.1
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.33	148.55
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9989	0.9991
<i>Specific gravity of soil at 20°c.</i>	2.68	2.70
<i>Average specific gravity of soil .</i>	2.69	

Sample No : TP-02

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i (oc)</i>	22.2	22.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.1	164.3
<i>Temperature, T_x (°c)</i>	24.2	23.4
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.35	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9991	0.9993
<i>Specific gravity of soil at 20°c.</i>	2.70	2.69
<i>Average specific gravity of soil .</i>	2.70	

Specific Gravity Test

Sample No : TP-03

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	23	23.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.5	164.7
<i>Temperature, T_x($^{\circ}$c)</i>	23.7	24.3
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.38	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9991	0.9993
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.81	2.81
<i>Average specific gravity of soil .</i>	2.81	

Sample No : TP-03

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	45.3
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.7	144.7
<i>Observed temperature of water, T_i(oc)</i>	21	2.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.5	160.4
<i>Temperature, T_x($^{\circ}$c)</i>	21.1	21.3
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.70	144.70
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9998	0.9998
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.72	2.69
<i>Average specific gravity of soil .</i>	2.70	

Specific Gravity Test

Sample No : TP-04

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	45.3
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.7	144.7
<i>Observed temperature of water, T_i(oc)</i>	20.8	20.7

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.2	160.3
<i>Temperature, T_x($^{\circ}$c)</i>	21.5	21.2
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.70	144.70
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9998	0.9998
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.63	2.66
<i>Average specific gravity of soil .</i>	2.65	

Sample No : TP-04

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	22.2	22.3

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	159.8	164.1
<i>Temperature, T_x($^{\circ}$c)</i>	23	23
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.40	148.60
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9993	0.9993
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.60	2.63
<i>Average specific gravity of soil .</i>	2.62	

Specific Gravity Test

Sample No : TP-05

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	22	21.7

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.4	164.6
<i>Temperature, T_x($^{\circ}$c)</i>	22.4	22.2
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.40	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9996	0.9996
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.78	2.78
<i>Average specific gravity of soil .</i>	2.78	

Sample No : TP-05

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	22	23.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.1	164.5
<i>Temperature, T_x($^{\circ}$c)</i>	22.1	24
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.40	148.60
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9996	0.9991
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.69	2.74
<i>Average specific gravity of soil .</i>	2.72	

Specific Gravity Test

Sample No : TP-06

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	21.7	21.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.3	164.6
<i>Temperature, T_x($^{\circ}$c)</i>	24	22.7
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.35	148.56
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9991	0.9993
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.76	2.79
<i>Average specific gravity of soil .</i>	2.77	

Sample No : TP-06

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	45.3
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.7	144.7
<i>Observed temperature of water, T_i(oc)</i>	20.2	20.1

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.6	160.5
<i>Temperature, T_x($^{\circ}$c)</i>	21.5	21.2
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.68	144.68
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9998	0.9998
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.75	2.72
<i>Average specific gravity of soil .</i>	2.74	

Specific Gravity Test

Sample No : TP-07

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	45.3
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.7	144.7
<i>Observed temperature of water, T_i(oc)</i>	19.2	19

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.5	160.5
<i>Temperature, T_x(°c)</i>	20.1	20.6
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.68	144.66
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	1	0.9998
<i>Specific gravity of soil at 20°C.</i>	2.72	2.73
<i>Average specific gravity of soil .</i>	2.73	

Sample No : TP-07

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	22.2	22.2

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.4	164.6
<i>Temperature, T_x(°c)</i>	26	25
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.30	148.53
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9986	0.9989
<i>Specific gravity of soil at 20°C.</i>	2.80	2.80
<i>Average specific gravity of soil .</i>	2.80	

Specific Gravity Test

Sample No : TP-08

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	23.3	22.6

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.5	164.6
<i>Temperature, T_x(°c)</i>	26	26.1
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.33	148.53
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9986	0.9986
<i>Specific gravity of soil at 20°C.</i>	2.83	2.80
<i>Average specific gravity of soil .</i>	2.81	

Sample No : TP-08

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	22.8	23.4

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.3	164.6
<i>Temperature, T_x(°c)</i>	23.9	24.1
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.38	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9991	0.9991
<i>Specific gravity of soil at 20°C.</i>	2.75	2.78
<i>Average specific gravity of soil .</i>	2.77	

Specific Gravity Test

Sample No : TP-09

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	20.8	20.8

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.4	164.6
<i>Temperature, T_x($^{\circ}$c)</i>	22.5	22.1
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.40	148.60
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9993	0.9996
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.78	2.78
<i>Average specific gravity of soil .</i>	2.78	

Sample No : TP-09

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	45.3
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.7	144.7
<i>Observed temperature of water, T_i(oc)</i>	19.8	19.8

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.6	160.4
<i>Temperature, T_x($^{\circ}$c)</i>	20.6	21
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.68	144.68
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9998	0.9998
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.75	2.69
<i>Average specific gravity of soil .</i>	2.72	

Specific Gravity Test

Sample No : TP-10

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	21.7	21.5

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.4	164.6
<i>Temperature, T_x(°c)</i>	24.8	24
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.33	148.55
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9989	0.9991
<i>Specific gravity of soil at 20°C.</i>	2.80	2.79
<i>Average specific gravity of soil .</i>	2.79	

Sample No : TP-10

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	23	25.5

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.6	164.7
<i>Temperature, T_x(°c)</i>	22.2	22.2
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.42	148.67
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9996	0.9996
<i>Specific gravity of soil at 20°C.</i>	2.83	2.79
<i>Average specific gravity of soil .</i>	2.81	

Specific Gravity Test

Sample No : TP-11

Sample Depth, m : 1.50

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	23.9	23.9

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.1	164.4
<i>Temperature, T_x($^{\circ}$c)</i>	25.6	25.8
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.35	148.55
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9986	0.9986
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.70	2.73
<i>Average specific gravity of soil .</i>	2.71	

Sample No : TP-11

Sample Depth, m : 3.0

[A] Calibration of pycnometer

<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of dry, clean pycnometer, w_p (g)</i>	45.3	49.7
<i>Weight of pycnometer + water, w_{pw} (g)</i>	144.4	148.6
<i>Observed temperature of water, T_i(oc)</i>	23.2	22

[B] Specific Gravity Determination

<i>Determination No.</i>	<i>1</i>	<i>2</i>
<i>Pycnometer No.</i>	<i>P1</i>	<i>P2</i>
<i>Weight of pycnometer + soil + water, W_{pws} (g)</i>	160.3	164.5
<i>Temperature, T_x($^{\circ}$c)</i>	24.8	22.9
<i>Weight of pycnometer + water at T_x, $W_{pw}(atT_x)$ (g)</i>	144.35	148.58
<i>Weight of dry soil, w_s (gm)</i>	25	25
<i>Conversion factor, K</i>	0.9989	0.9993
<i>Specific gravity of soil at 20$^{\circ}$c.</i>	2.76	2.75
<i>Average specific gravity of soil .</i>	2.76	

Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
Grain Size Analysis

Sample No : TP-01 Sample Depth, m : 1.50

Sieve Analysis Total mass of sample, g 1000

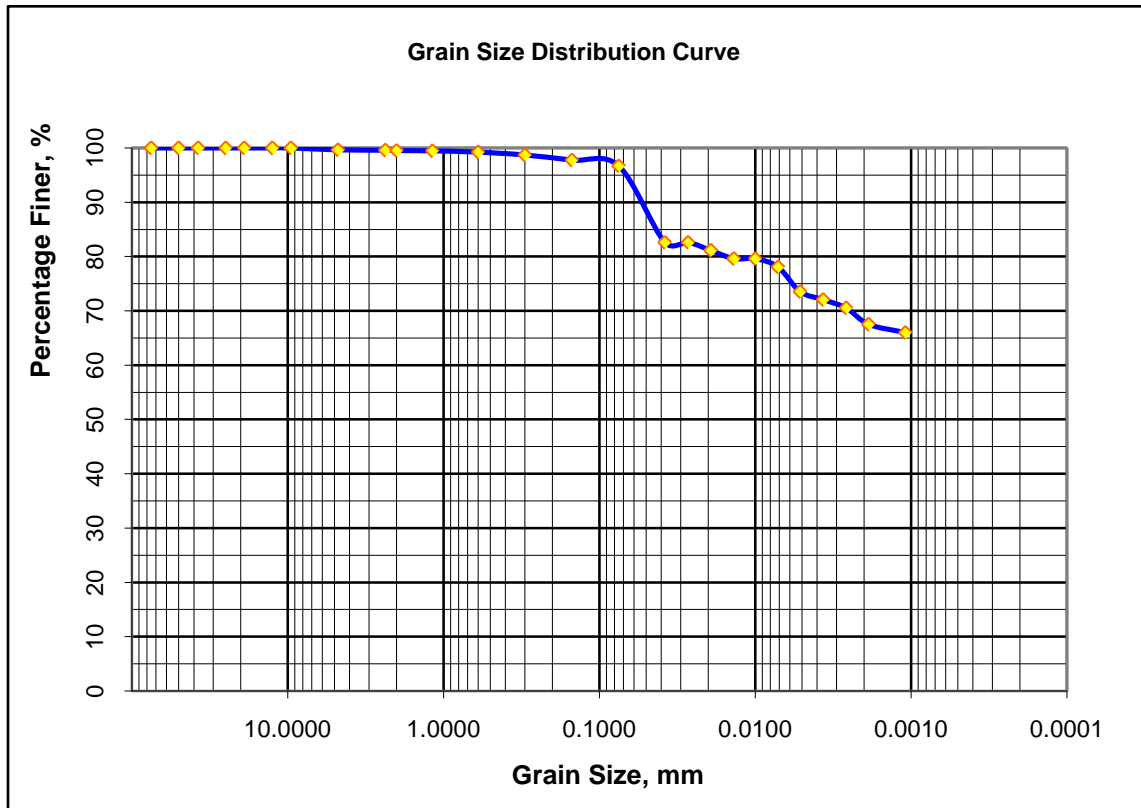
Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passin g (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	1164.6	1164.6	0.0	0.0	0.0	100.0
No 4	4.75	1262.7	1266.2	3.5	0.4	0.4	99.7
No 8	2.36	990.3	991.0	0.7	0.1	0.4	99.6
No 10	2	944.1	944.4	0.3	0.0	0.5	99.6
No 16	1.18	894.3	895.3	1.0	0.1	0.6	99.5
No 30	0.6	833.8	836.1	2.3	0.2	0.8	99.2
No 50	0.3	750.1	755.3	5.2	0.5	1.3	98.7
No 100	0.15	782.4	791.8	9.4	0.9	2.2	97.8
No 200	0.075	764.4	774.9	10.5	1.1	3.3	96.7
pan	-----	736.0	736.0	0.0	0.0	3.3	-----

Hydrometer Analysis

Specific Gravity of soil=2.77 Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combine d (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.01318	0.0381	85.45	82.64
1	1.0300	-0.0027	1.0273	8.36	0.01318	0.0270	85.45	82.64
2	1.0295	-0.0027	1.0268	8.50	0.01318	0.0192	83.88	81.12
4	1.0290	-0.0027	1.0263	8.63	0.01318	0.0137	82.32	79.61
8	1.0290	-0.0027	1.0263	8.63	0.01318	0.0100	82.32	79.61
15	1.0285	-0.0027	1.0258	8.76	0.01318	0.0071	80.75	78.10
30	1.0280	-0.0027	1.0253	8.89	0.01318	0.0051	79.19	76.58
60	1.0270	-0.0027	1.0243	9.16	0.01318	0.0051	76.06	73.56
120	1.0265	-0.0027	1.0238	9.29	0.01318	0.0037	74.49	72.04
240	1.0260	-0.0027	1.0233	9.42	0.01318	0.0026	72.93	70.53
480	1.0250	-0.0027	1.0223	9.69	0.01318	0.0019	69.80	67.50
1440	1.0245	-0.0027	1.0218	9.82	0.01318	0.0011	68.23	65.99

Grain size distribution curve for TP-01 at 1.50m



Grain Size Analysis

Sample No : TP-01 Sample Depth, m : 3.00
 Sieve Analysis Total mass of sample, g 1000

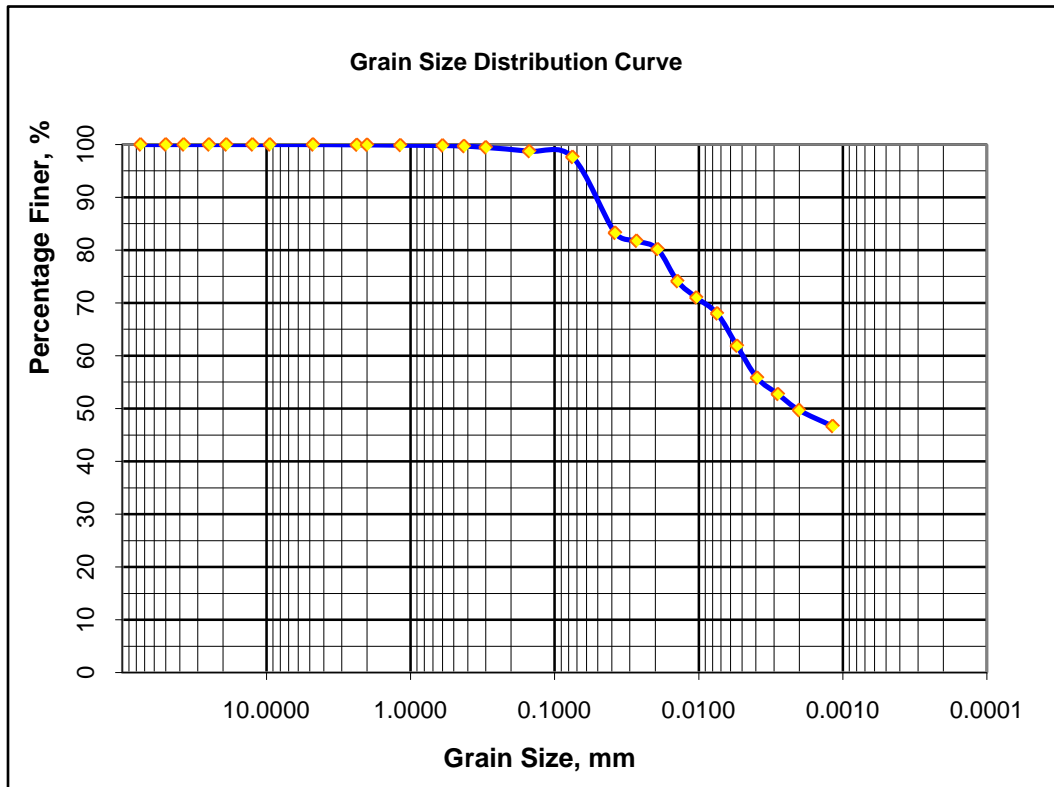
Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	427.9	0.0	0.0	0.0	100.0
No 8	2.36	387.7	388.2	0.5	0.1	0.1	100.0
No 10	2	390.2	390.3	0.1	0.0	0.1	99.9
No 16	1.18	372.6	373.2	0.6	0.1	0.1	99.9
No 30	0.6	325.6	326.6	1.0	0.1	0.2	99.8
No40	0.425	291.7	292.7	1.0	0.1	0.3	99.7
No 50	0.3	301.5	304.0	2.5	0.3	0.6	99.4
No 100	0.15	271.4	278.4	7.0	0.7	1.3	98.7
No 200	0.075	273.8	284.8	11.0	1.1	2.4	97.6
pan	-----	736.0	736.0	0.0	0.0	2.4	-----

Hydrometer Analysis

Specific Gravity of soil=2.78 Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.01314	0.0380	85.27	83.25
1	1.0295	-0.0027	1.0268	8.50	0.01314	0.0271	83.71	81.73
2	1.0290	-0.0027	1.0263	8.63	0.01314	0.0193	82.15	80.20
4	1.0270	-0.0027	1.0243	9.16	0.01314	0.0141	75.90	74.10
8	1.0260	-0.0027	1.0233	9.42	0.01314	0.0104	72.78	71.05
15	1.0250	-0.0027	1.0223	9.69	0.01314	0.0075	69.66	68.01
30	1.0240	-0.0027	1.0213	9.95	0.01314	0.0054	66.53	64.96
60	1.0230	-0.0027	1.0203	10.22	0.01314	0.0054	63.41	61.91
120	1.0210	-0.0027	1.0183	10.75	0.01314	0.0039	57.16	55.81
240	1.0200	-0.0027	1.0173	11.01	0.01314	0.0028	54.04	52.76
480	1.0190	-0.0027	1.0163	11.27	0.01314	0.0020	50.91	49.71
1440	1.0180	-0.0027	1.0153	11.54	0.01314	0.0012	47.79	46.66

Grain size distribution curve for TP-01 at 3.00m



Grain Size Analysis

Sample No : TP-02

Sample Depth, m : 1.50

Total mass of sample,

Sieve Analysis

g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	454.8	480.6	25.8	2.6	2.6	97.4
No 4	4.75	427.8	442.4	14.6	1.5	4.0	96.0
No 8	2.36	387.7	423.7	36.0	3.6	7.6	92.4
No 10	2	377.9	388.6	10.7	1.1	8.7	91.3
No 16	1.18	372.6	398.3	25.7	2.6	11.3	88.7
No 30	0.6	323.3	354.0	30.7	3.1	14.4	85.7
No 40	0.425	292.1	314.5	22.4	2.2	16.6	83.4
No 50	0.3	301.6	326.3	24.7	2.5	19.1	80.9
No 100	0.15	276.0	322.6	46.6	4.7	23.7	76.3
No 200	0.075	258.6	296.2	37.6	3.8	27.5	72.5
pan	-----	736.0	736.0	0.0	0.0	27.5	-----

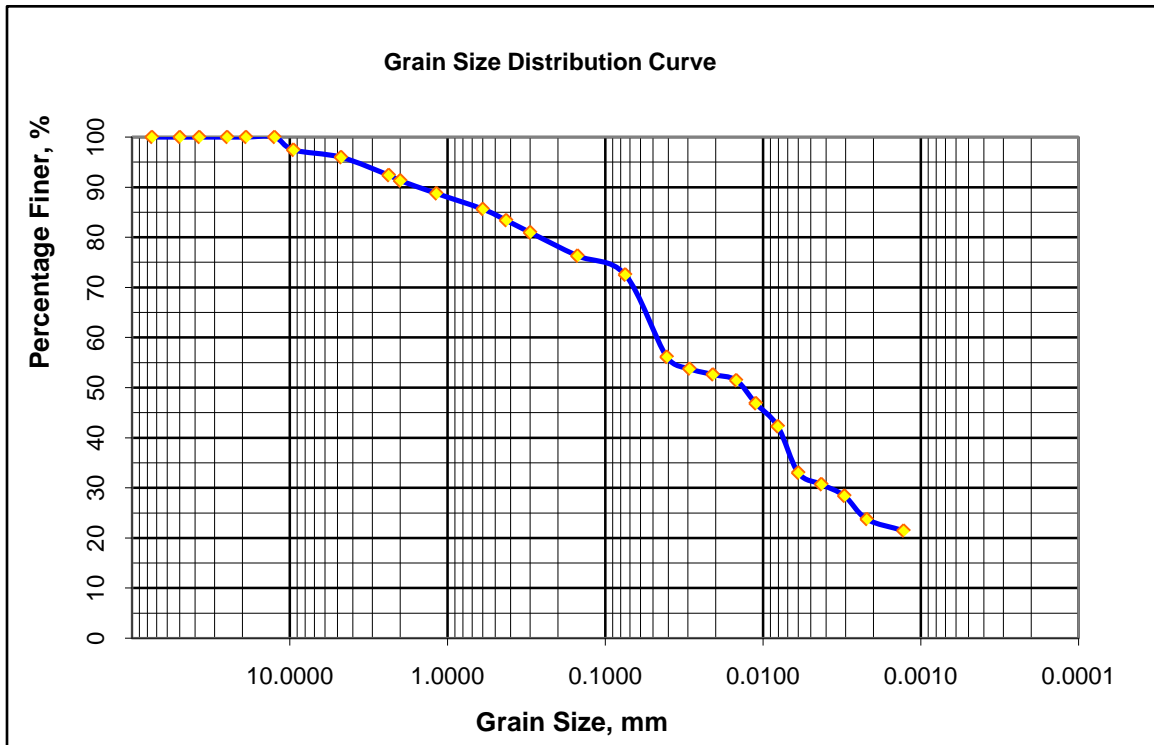
Hydrometer Analysis

Specific Gravity of soil=2.69

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0270	-0.0027	1.0243	9.16	0.013482	0.0408	77.36	56.10
1	1.0260	-0.0027	1.0233	9.42	0.013482	0.0293	74.17	53.79
2	1.0255	-0.0027	1.0228	9.55	0.013482	0.0208	72.58	52.64
4	1.0250	-0.0027	1.0223	9.69	0.013482	0.0148	70.99	51.48
8	1.0230	-0.0027	1.0203	10.22	0.013482	0.0111	64.62	46.87
15	1.0210	-0.0027	1.0183	10.75	0.013482	0.0081	58.26	42.25
30	1.0190	-0.0027	1.0163	11.27	0.013482	0.0058	51.89	37.63
60	1.0170	-0.0027	1.0143	11.80	0.013482	0.0060	45.52	33.01
120	1.0160	-0.0027	1.0133	12.07	0.013482	0.0043	42.34	30.70
240	1.0150	-0.0027	1.0123	12.33	0.013482	0.0031	39.16	28.40
480	1.0130	-0.0027	1.0103	12.86	0.013482	0.0022	32.79	23.78
1440	1.0120	-0.0027	1.0093	13.13	0.013482	0.0013	29.61	21.47

Grain size distribution curve for TP-02 at 1.50m



Grain Size Analysis

Sample No : TP-02

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	454.8	458.4	3.6	0.4	0.4	99.6
No 4	4.75	427.8	441.0	13.2	1.3	1.7	98.3
No 8	2.36	387.7	414.3	26.6	2.7	4.3	95.7
No 10	2	377.9	385.9	8.0	0.8	5.1	94.9
No 16	1.18	372.6	396.6	24.0	2.4	7.5	92.5
No 30	0.6	323.3	364.5	41.2	4.1	11.7	88.3
No 40	0.425	292.1	327.9	35.8	3.6	15.2	84.8
No 50	0.3	301.6	346.3	44.7	4.5	19.7	80.3
No 100	0.15	276.0	364.8	88.8	8.9	28.6	71.4
No 200	0.075	258.6	330.6	72.0	7.2	35.8	64.2
pan	-----	736.0	736.0	0.0	0.0	35.8	-----

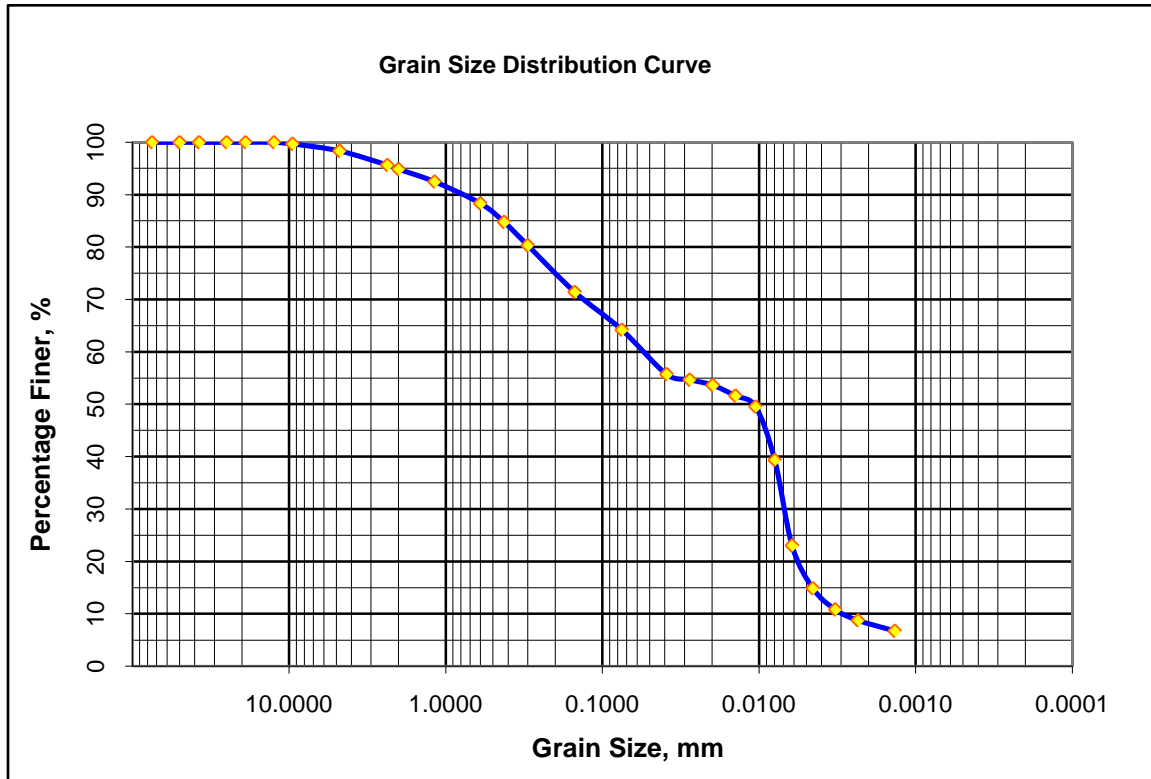
Hydrometer Analysis

Specific Gravity of soil 2.70

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.01344	0.0389	86.72	55.68
1	1.0295	-0.0027	1.0268	8.50	0.01344	0.0277	85.13	54.66
2	1.0290	-0.0027	1.0263	8.63	0.01344	0.0197	83.54	53.64
4	1.0280	-0.0027	1.0253	8.89	0.01344	0.0142	80.36	51.60
8	1.0270	-0.0027	1.0243	9.16	0.01344	0.0105	77.19	49.56
15	1.0220	-0.0027	1.0193	10.48	0.01344	0.0079	61.31	39.36
30	1.0190	-0.0027	1.0163	11.27	0.01344	0.0058	51.78	33.25
60	1.0140	-0.0027	1.0113	12.60	0.01344	0.0062	35.89	23.05
120	1.0100	-0.0027	1.0073	13.65	0.01344	0.0045	23.19	14.89
240	1.0080	-0.0027	1.0053	14.18	0.01344	0.0033	16.84	10.81
480	1.0070	-0.0027	1.0043	14.45	0.01344	0.0023	13.66	8.77
1440	1.0060	-0.0027	1.0033	14.71	0.01344	0.0014	10.48	6.73

Grain size distribution curve for TP-02 at 3.00m



Grain Size Analysis

Sample No : TP-03

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	1164.6	1164.6	0.0	0.0	0.0	100.0
No 4	4.75	1262.7	1263.8	1.1	0.1	0.1	99.9
No 8	2.36	990.2	1000.5	10.3	1.0	1.1	98.9
No 10	2	944.1	948.5	4.4	0.4	1.6	98.4
No 16	1.18	894.5	908.2	13.7	1.4	2.9	97.1
No 30	0.6	833.7	851.8	18.1	1.8	4.8	95.2
No 50	0.3	750.3	776.8	26.5	2.7	7.4	92.6
No 100	0.15	782.7	819.5	36.8	3.7	11.1	88.9
No 200	0.075	765.1	795.6	30.5	3.1	14.1	85.9
pan	-----	736.0	736.0	0.0	0.0	14.1	-----

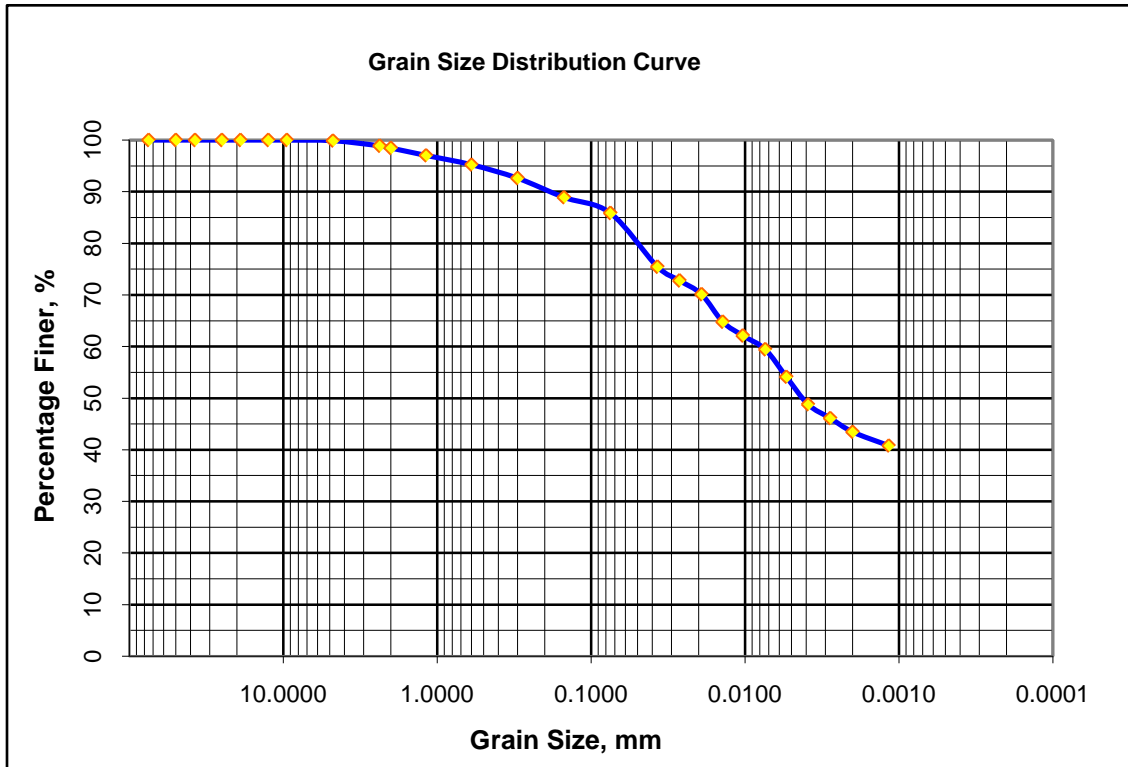
Hydrometer Analysis

Specific Gravity of soil 2.81

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0310	-0.0027	1.0283	8.10	0.013034	0.0371	87.87	75.45
1	1.0300	-0.0027	1.0273	8.36	0.013034	0.0267	84.77	72.78
2	1.0290	-0.0027	1.0263	8.63	0.013034	0.0191	81.66	70.11
4	1.0270	-0.0027	1.0243	9.16	0.013034	0.0139	75.45	64.78
8	1.0260	-0.0027	1.0233	9.42	0.013034	0.0103	72.35	62.12
15	1.0250	-0.0027	1.0223	9.69	0.013034	0.0074	69.24	59.45
30	1.0240	-0.0027	1.0213	9.95	0.013034	0.0053	66.14	56.78
60	1.0230	-0.0027	1.0203	10.22	0.013034	0.0054	63.03	54.12
120	1.0210	-0.0027	1.0183	10.75	0.013034	0.0039	56.82	48.79
240	1.0200	-0.0027	1.0173	11.01	0.013034	0.0028	53.72	46.12
480	1.0190	-0.0027	1.0163	11.27	0.013034	0.0020	50.61	43.45
1440	1.0180	-0.0027	1.0153	11.54	0.013034	0.0012	47.51	40.79

Grain size distribution curve for TP-03 at 1.50m



Grain Size Analysis

Sample No : TP-03

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1226.9	48.5	4.9	4.9	95.2
1/2"	12.5	1216.7	1227.8	11.1	1.1	6.0	94.0
3.8"	9.5	1164.6	1192.5	27.9	2.8	8.8	91.3
No 4	4.75	1262.7	1354.0	91.3	9.1	17.9	82.1
No 8	2.36	990.3	1075.4	85.1	8.5	26.4	73.6
No 10	2	944.1	965.2	21.1	2.1	28.5	71.5
No 16	1.18	894.3	952.3	58.0	5.8	34.3	65.7
No 30	0.6	833.8	900.1	66.3	6.6	40.9	59.1
No 50	0.3	750.1	818.9	68.8	6.9	47.8	52.2
No 100	0.15	782.4	830.6	48.2	4.8	52.6	47.4
No 200	0.075	764.4	804.3	39.9	4.0	56.6	43.4
pan	-----	736.0	736.0	0.0	0.0	56.6	-----

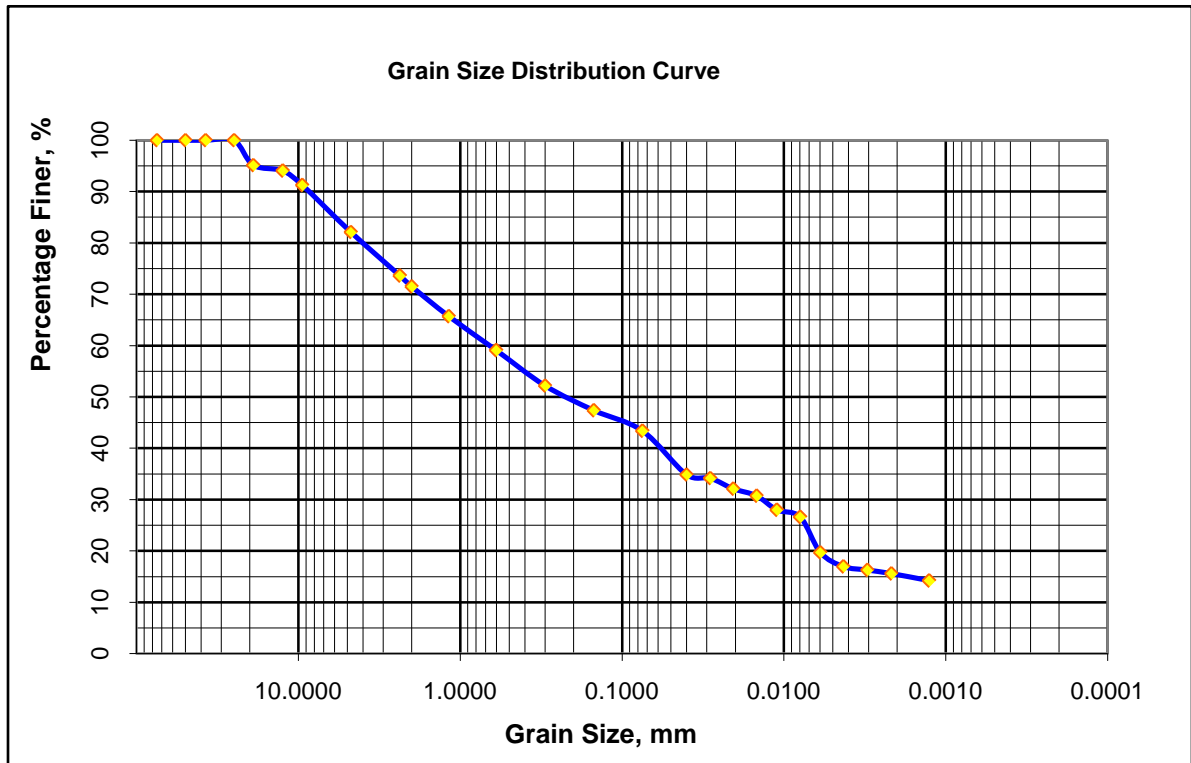
Hydrometer Analysis

Specific Gravity of soil=2.70

Test Temperature, deg.c 20

Elapse Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0280	-0.0027	1.0253	8.89	0.01344	0.0401	80.36	34.86
1	1.0275	-0.0027	1.0248	9.03	0.01344	0.0286	78.78	34.17
2	1.0260	-0.0027	1.0233	9.42	0.01344	0.0206	74.01	32.11
4	1.0250	-0.0027	1.0223	9.69	0.01344	0.0148	70.84	30.73
8	1.0230	-0.0027	1.0203	10.22	0.01344	0.0111	64.48	27.97
15	1.0220	-0.0027	1.0193	10.48	0.01344	0.0079	61.31	26.59
30	1.0190	-0.0027	1.0163	11.27	0.01344	0.0058	51.78	22.46
60	1.0170	-0.0027	1.0143	11.80	0.01344	0.0060	45.42	19.70
120	1.0150	-0.0027	1.0123	12.33	0.01344	0.0043	39.07	16.95
240	1.0145	-0.0027	1.0118	12.46	0.01344	0.0031	37.48	16.26
480	1.0140	-0.0027	1.0113	12.60	0.01344	0.0022	35.89	15.57
1440	1.0130	-0.0027	1.0103	12.86	0.01344	0.0013	32.72	14.19

Grain size distribution curve for TP-03 at 3.00m



Grain Size Analysis

Sample No : TP-04

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	468.7	8.1	0.8	0.8	99.2
No 4	4.75	427.9	444.0	16.1	1.6	2.4	97.6
No 8	2.36	387.7	401.3	13.6	1.4	3.8	96.2
No 10	2	390.2	394.3	4.1	0.4	4.2	95.8
No 16	1.18	372.6	385.8	13.2	1.3	5.5	94.5
No 30	0.6	325.6	341.0	15.4	1.5	7.1	93.0
No 40	0.425	291.7	303.3	11.6	1.2	8.2	91.8
No 50	0.3	301.5	318.5	17.0	1.7	9.9	90.1
No 100	0.15	271.4	313.1	41.7	4.2	14.1	85.9
No 200	0.075	273.8	311.1	37.3	3.7	17.8	82.2
pan	-----	254.1	254.1	0.0	0.0	17.8	-----

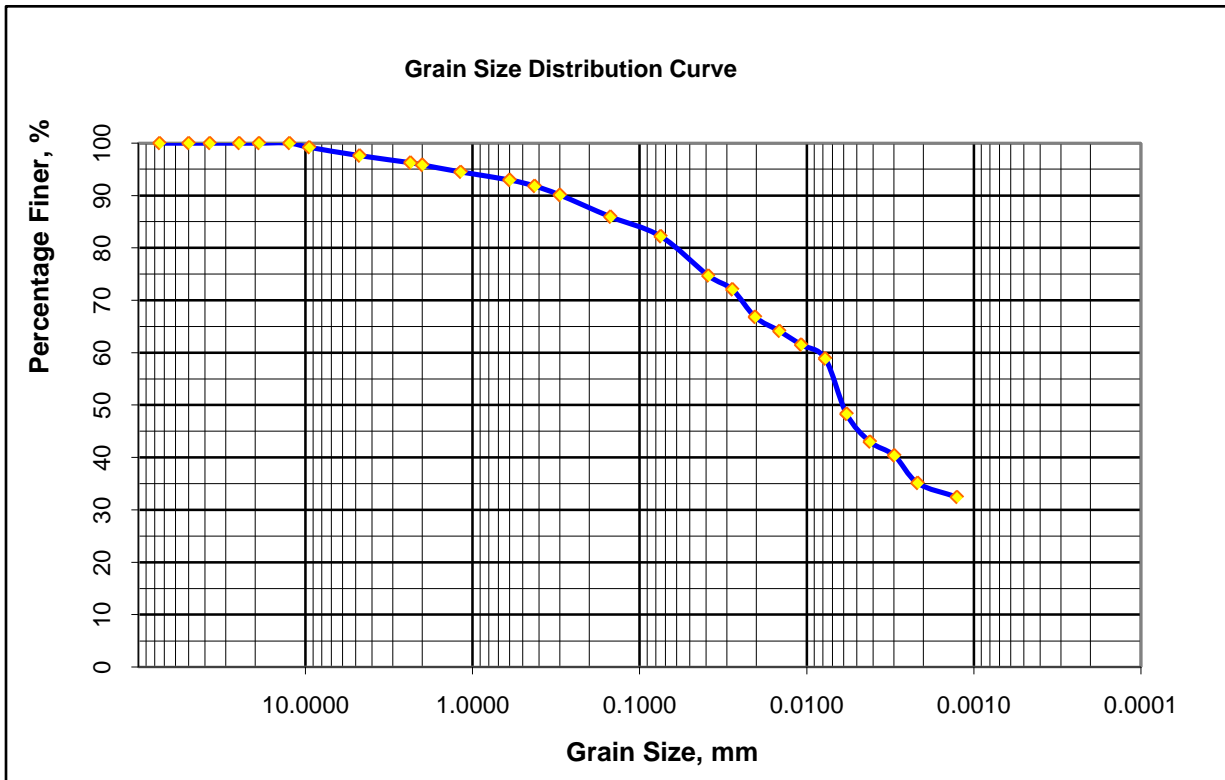
Hydrometer Analysis

Specific Gravity of soil=2.65

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0310	-0.0027	1.0283	8.10	0.01365	0.0388	90.90	74.71
1	1.0300	-0.0027	1.0273	8.36	0.01365	0.0279	87.69	72.07
2	1.0280	-0.0027	1.0253	8.89	0.01365	0.0204	81.27	66.79
4	1.0270	-0.0027	1.0243	9.16	0.01365	0.0146	78.05	64.15
8	1.0260	-0.0027	1.0233	9.42	0.01365	0.0108	74.84	61.51
15	1.0250	-0.0027	1.0223	9.69	0.01365	0.0078	71.63	58.87
30	1.0240	-0.0027	1.0213	9.95	0.01365	0.0056	68.42	56.23
60	1.0210	-0.0027	1.0183	10.75	0.01365	0.0058	58.78	48.31
120	1.0190	-0.0027	1.0163	11.27	0.01365	0.0042	52.36	43.03
240	1.0180	-0.0027	1.0153	11.54	0.01365	0.0030	49.15	40.39
480	1.0160	-0.0027	1.0133	12.07	0.01365	0.0022	42.72	35.11
1440	1.0150	-0.0027	1.0123	12.33	0.01365	0.0013	39.51	32.47

Grain size distribution curve for TP-04 at 1.50m



Grain Size Analysis

Sample No : TP-04

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	1164.6	1166.4	1.8	0.1	0.1	99.9
No 4	4.75	1262.7	1267.3	4.6	0.3	0.4	99.6
No 8	2.36	990.2	1004.8	14.6	1.0	1.4	98.6
No 10	2	944.1	949.0	4.9	0.3	1.7	98.3
No 16	1.18	894.5	990.3	95.8	6.4	8.1	91.9
No 30	0.6	833.7	875.1	41.4	2.8	10.9	89.1
No 50	0.3	750.3	862.3	112.0	7.5	18.3	81.7
No 100	0.15	782.7	924.8	142.1	9.5	27.8	72.2
No 200	0.075	765.1	852.8	87.7	5.8	33.7	66.3
pan	-----	736.0	736.0	0.0	0.0	33.7	-----

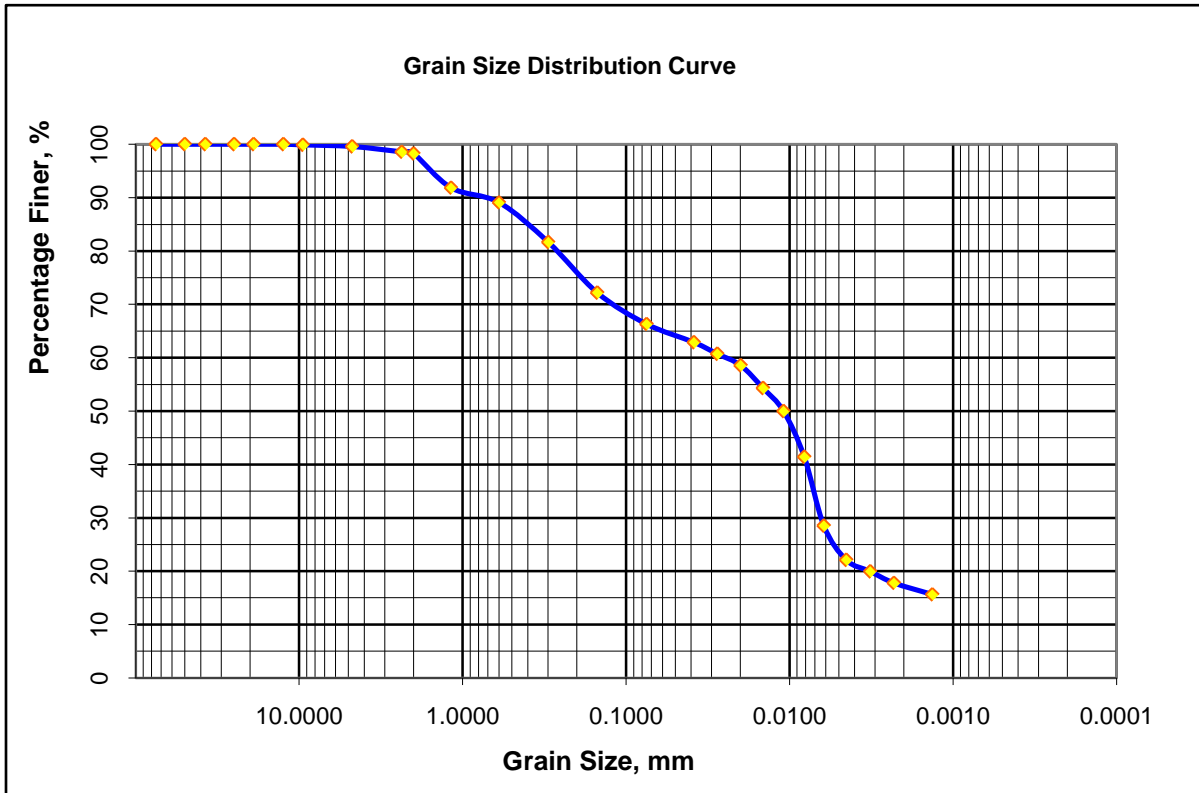
Hydrometer Analysis

Specific Gravity of soil=2.62

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0320	-0.0027	1.0293	7.84	0.013776	0.0386	94.77	62.87
1	1.0310	-0.0027	1.0283	8.10	0.013776	0.0277	91.54	60.73
2	1.0300	-0.0027	1.0273	8.36	0.013776	0.0199	88.30	58.58
4	1.0280	-0.0027	1.0253	8.89	0.013776	0.0145	81.83	54.29
8	1.0260	-0.0027	1.0233	9.42	0.013776	0.0109	75.37	50.00
15	1.0220	-0.0027	1.0193	10.48	0.013776	0.0081	62.43	41.41
30	1.0190	-0.0027	1.0163	11.27	0.013776	0.0060	52.72	34.98
60	1.0160	-0.0027	1.0133	12.07	0.013776	0.0062	43.02	28.54
120	1.0130	-0.0027	1.0103	12.86	0.013776	0.0045	33.32	22.10
240	1.0120	-0.0027	1.0093	13.13	0.013776	0.0032	30.08	19.96
480	1.0110	-0.0027	1.0083	13.39	0.013776	0.0023	26.85	17.81
1440	1.0100	-0.0027	1.0073	13.65	0.013776	0.0013	23.61	15.66

Grain size distribution curve for TP-04 at 3.00m



Grain Size Analysis

Sample No : TP-05

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	462.1	1.5	0.2	0.2	99.9
No 4	4.75	427.9	439.5	11.6	1.2	1.3	98.7
No 8	2.36	387.7	396.9	9.2	0.9	2.2	97.8
No 10	2	390.2	392.3	2.1	0.2	2.4	97.6
No 16	1.18	372.6	379.0	6.4	0.6	3.1	96.9
No 30	0.6	325.6	336.4	10.8	1.1	4.2	95.8
No 40	0.425	291.7	292.6	0.9	0.1	4.3	95.8
No 50	0.3	301.5	317.3	15.8	1.6	5.8	94.2
No 100	0.15	271.4	274.0	2.6	0.3	6.1	93.9
No 200	0.075	273.8	305.1	31.3	3.1	9.2	90.8
pan	-----	254.1	254.1	0.0	0.0	9.2	-----

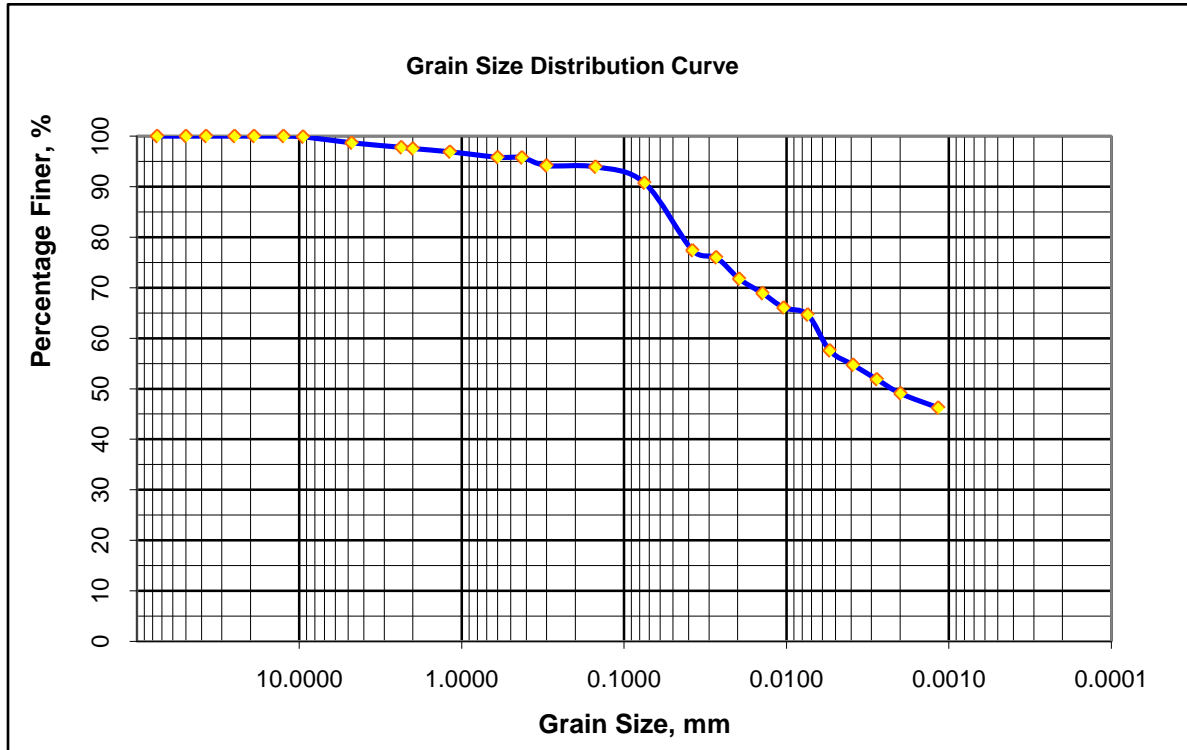
Hydrometer Analysis

Specific Gravity of soil=2.78

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013142	0.0380	85.27	77.41
1	1.0295	-0.0027	1.0268	8.50	0.013142	0.0271	83.71	75.99
2	1.0280	-0.0027	1.0253	8.89	0.013142	0.0196	79.03	71.74
4	1.0270	-0.0027	1.0243	9.16	0.013142	0.0141	75.90	68.91
8	1.0260	-0.0027	1.0233	9.42	0.013142	0.0104	72.78	66.07
15	1.0255	-0.0027	1.0228	9.55	0.013142	0.0074	71.22	64.65
30	1.0240	-0.0027	1.0213	9.95	0.013142	0.0054	66.53	60.40
60	1.0230	-0.0027	1.0203	10.22	0.013142	0.0054	63.41	57.56
120	1.0220	-0.0027	1.0193	10.48	0.013142	0.0039	60.29	54.73
240	1.0210	-0.0027	1.0183	10.75	0.013142	0.0028	57.16	51.89
480	1.0200	-0.0027	1.0173	11.01	0.013142	0.0020	54.04	49.06
1440	1.0190	-0.0027	1.0163	11.27	0.013142	0.0012	50.91	46.22

Grain size distribution curve for TP-05 at 1.50m



Grain Size Analysis

Sample No : TP-05

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	429.0	1.1	0.1	0.1	99.9
No 8	2.36	387.7	390.0	2.3	0.2	0.3	99.7
No 10	2	390.2	391.6	1.4	0.1	0.5	99.5
No 16	1.18	372.6	377.0	4.4	0.4	0.9	99.1
No 30	0.6	325.6	336.4	10.8	1.1	2.0	98.0
No 40	0.425	291.7	301.4	9.7	1.0	3.0	97.0
No 50	0.3	301.5	312.9	11.4	1.1	4.1	95.9
No 100	0.15	271.4	294.5	23.1	2.3	6.4	93.6
No 200	0.075	273.8	298.1	24.3	2.4	8.9	91.2
pan	-----	254.1	254.1	0.0	0.0	8.9	-----

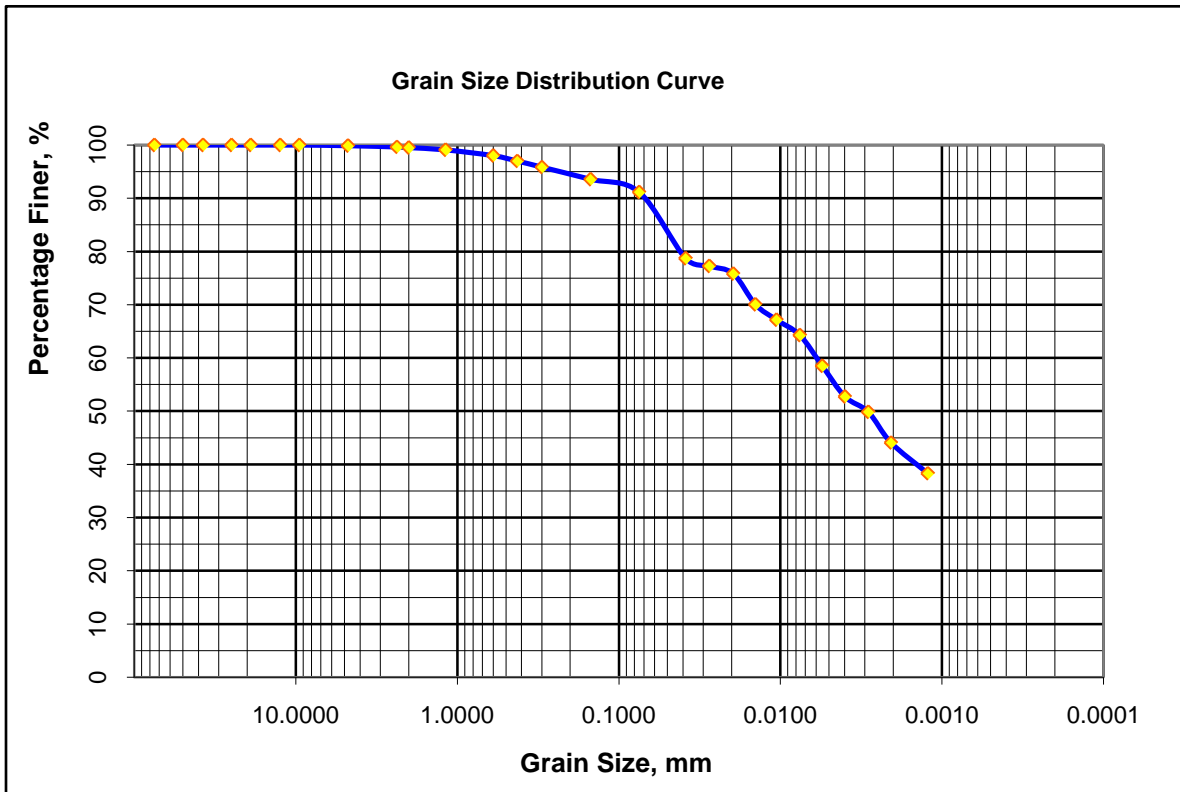
Hydrometer Analysis

Specific Gravity of soil=2.72

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013364	0.0387	86.34	78.70
1	1.0295	-0.0027	1.0268	8.50	0.013364	0.0275	84.76	77.26
2	1.0290	-0.0027	1.0263	8.63	0.013364	0.0196	83.18	75.82
4	1.0270	-0.0027	1.0243	9.16	0.013364	0.0143	76.86	70.05
8	1.0260	-0.0027	1.0233	9.42	0.013364	0.0106	73.69	67.17
15	1.0250	-0.0027	1.0223	9.69	0.013364	0.0076	70.53	64.29
30	1.0240	-0.0027	1.0213	9.95	0.013364	0.0054	67.37	61.41
60	1.0230	-0.0027	1.0203	10.22	0.013364	0.0055	64.20	58.52
120	1.0210	-0.0027	1.0183	10.75	0.013364	0.0040	57.88	52.76
240	1.0200	-0.0027	1.0173	11.01	0.013364	0.0029	54.72	49.87
480	1.0180	-0.0027	1.0153	11.54	0.013364	0.0021	48.39	44.11
1440	1.0160	-0.0027	1.0133	12.07	0.013364	0.0012	42.07	38.34

Grain size distribution curve for TP-05 at 3.00m



Grain Size Analysis

Sample No : TP-06

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	429.6	1.7	0.2	0.2	99.8
No 8	2.36	387.7	390.9	3.2	0.3	0.5	99.5
No 10	2	390.2	392.1	1.9	0.2	0.7	99.3
No 16	1.18	372.6	380.7	8.1	0.8	1.5	98.5
No 30	0.6	325.6	331.9	6.3	0.6	2.1	97.9
No 40	0.425	291.7	295.1	3.4	0.3	2.5	97.5
No 50	0.3	301.5	305.8	4.3	0.4	2.9	97.1
No 100	0.15	271.4	274.6	3.2	0.3	3.2	96.8
No 200	0.075	273.8	291.8	18.0	1.8	5.0	95.0
pan	-----	254.1	254.1	0.0	0.0	5.0	-----

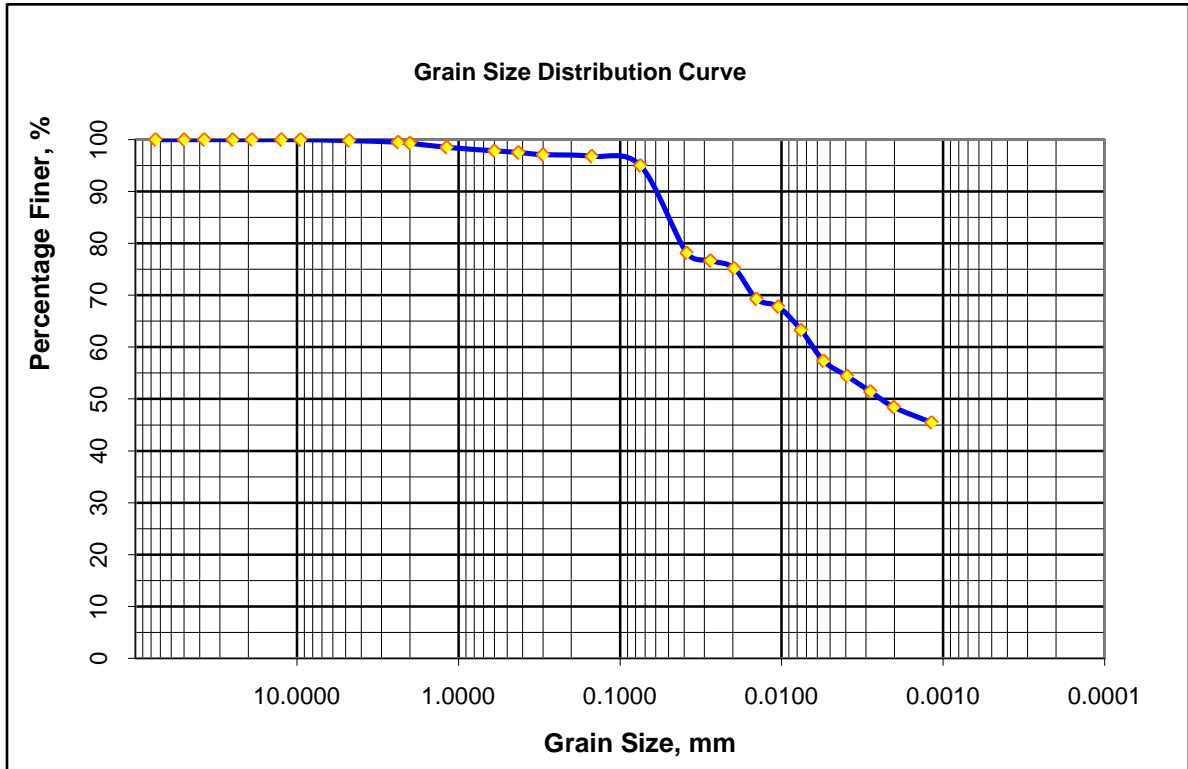
Hydrometer Analysis

Specific Gravity of soil=2.77

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0290	-0.0027	1.0263	8.63	0.013178	0.0387	82.32	78.19
1	1.0285	-0.0027	1.0258	8.76	0.013178	0.0276	80.75	76.71
2	1.0280	-0.0027	1.0253	8.89	0.013178	0.0196	79.19	75.22
4	1.0260	-0.0027	1.0233	9.42	0.013178	0.0143	72.93	69.27
8	1.0255	-0.0027	1.0228	9.55	0.013178	0.0105	71.36	67.79
15	1.0240	-0.0027	1.0213	9.95	0.013178	0.0076	66.67	63.33
30	1.0230	-0.0027	1.0203	10.22	0.013178	0.0054	63.54	60.35
60	1.0220	-0.0027	1.0193	10.48	0.013178	0.0055	60.41	57.38
120	1.0210	-0.0027	1.0183	10.75	0.013178	0.0039	57.28	54.41
240	1.0200	-0.0027	1.0173	11.01	0.013178	0.0028	54.15	51.44
480	1.0190	-0.0027	1.0163	11.27	0.013178	0.0020	51.02	48.46
1440	1.0180	-0.0027	1.0153	11.54	0.013178	0.0012	47.89	45.49

Grain size distribution curve for TP-06 at 1.50m



Grain Size Analysis

Sample No : TP-06

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	1216.8	1222.4	5.6	0.6	0.6	99.4
3.8"	9.5	1164.6	1166.5	1.9	0.2	0.8	99.3
No 4	4.75	1262.7	1269.7	7.0	0.7	1.5	98.6
No 8	2.36	990.2	996.1	5.9	0.6	2.0	98.0
No 10	2	944.1	946.2	2.1	0.2	2.3	97.8
No 16	1.18	894.5	900.1	5.6	0.6	2.8	97.2
No 30	0.6	833.7	841.4	7.7	0.8	3.6	96.4
No 50	0.3	750.3	762.6	12.3	1.2	4.8	95.2
No 100	0.15	782.7	804.0	21.3	2.1	6.9	93.1
No 200	0.075	765.1	784.1	19.0	1.9	8.8	91.2
pan	-----	736.0	736.0	0.0	0.0	8.8	-----

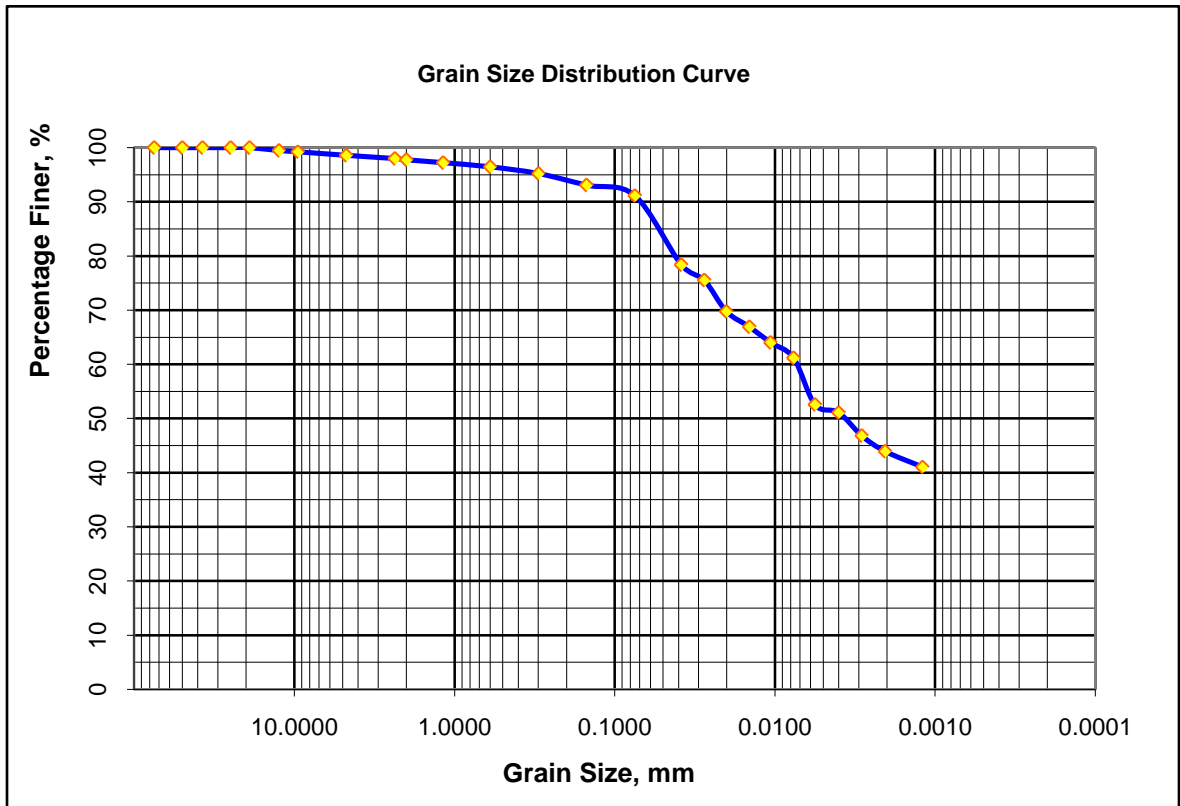
Hydrometer Analysis

Specific Gravity of soil=2.74

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013288	0.0384	85.98	78.38
1	1.0290	-0.0027	1.0263	8.63	0.013288	0.0276	82.83	75.51
2	1.0270	-0.0027	1.0243	9.16	0.013288	0.0201	76.53	69.77
4	1.0260	-0.0027	1.0233	9.42	0.013288	0.0144	73.38	66.89
8	1.0250	-0.0027	1.0223	9.69	0.013288	0.0107	70.23	64.02
15	1.0240	-0.0027	1.0213	9.95	0.013288	0.0077	67.08	61.15
30	1.0230	-0.0027	1.0203	10.22	0.013288	0.0055	63.93	58.28
60	1.0210	-0.0027	1.0183	10.75	0.013288	0.0056	57.63	52.54
120	1.0205	-0.0027	1.0178	10.88	0.013288	0.0040	56.06	51.10
240	1.0190	-0.0027	1.0163	11.27	0.013288	0.0029	51.34	46.80
480	1.0180	-0.0027	1.0153	11.54	0.013288	0.0021	48.19	43.93
1440	1.0170	-0.0027	1.0143	11.80	0.013288	0.0012	45.04	41.06

Grain size distribution curve for TP-06 at 3.00m



Grain Size Analysis

Sample No : TP-07

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1300

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	0.0	0.0	0.0	0.0	0.0	100.0
No 4	4.75	1262.7	1263.1	0.4	0.0	0.0	100.0
No 8	2.36	990.3	991.9	1.6	0.1	0.2	99.8
No 10	2	944.1	944.8	0.7	0.1	0.2	99.8
No 16	1.18	894.3	899.0	4.7	0.4	0.6	99.4
No 30	0.6	833.8	842.3	8.5	0.7	1.2	98.8
No 50	0.3	750.1	767.3	17.2	1.3	2.5	97.5
No 100	0.15	782.4	813.1	30.7	2.4	4.9	95.1
No 200	0.075	764.4	795.4	31.0	2.4	7.3	92.7
pan	-----	736.0	736.0	0.0	0.0	7.3	-----

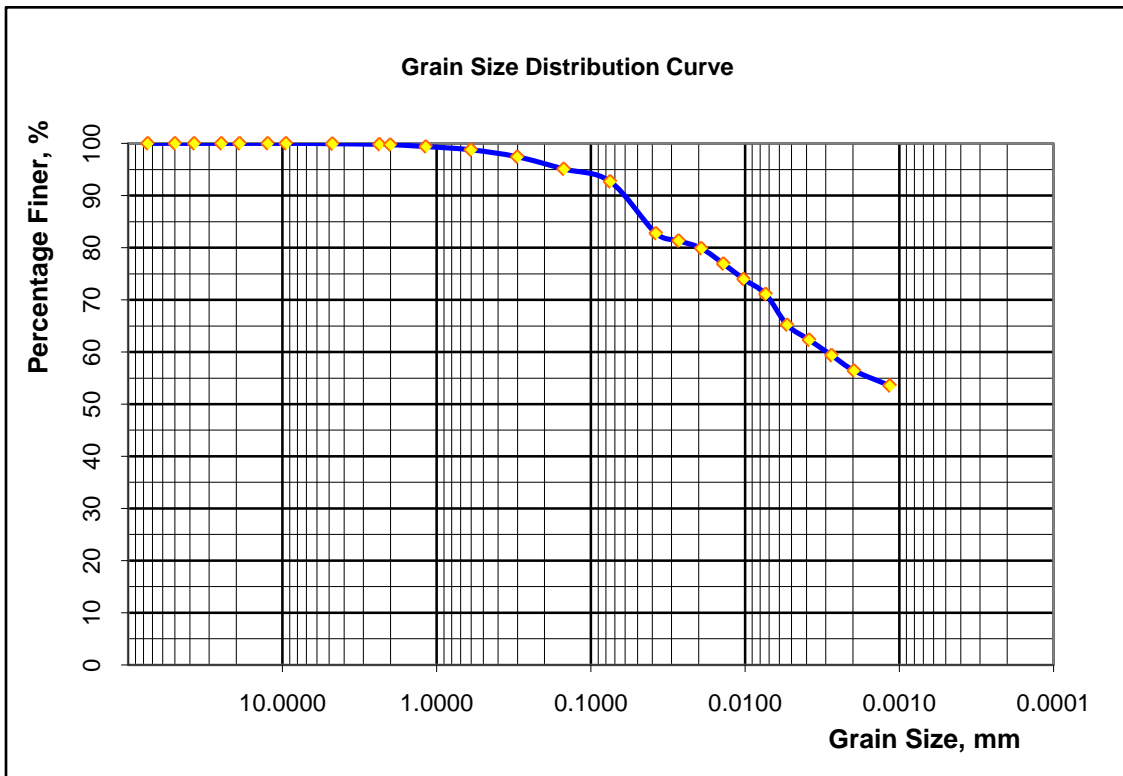
Hydrometer Analysis

Specific Gravity of soil 2.73

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0310	-0.0027	1.0283	8.10	0.013326	0.0379	89.32	82.80
1	1.0305	-0.0027	1.0278	8.23	0.013326	0.0270	87.74	81.34
2	1.0300	-0.0027	1.0273	8.36	0.013326	0.0193	86.16	79.88
4	1.0290	-0.0027	1.0263	8.63	0.013326	0.0138	83.00	76.95
8	1.0280	-0.0027	1.0253	8.89	0.013326	0.0103	79.85	74.03
15	1.0270	-0.0027	1.0243	9.16	0.013326	0.0074	76.69	71.10
30	1.0260	-0.0027	1.0233	9.42	0.013326	0.0053	73.54	68.17
60	1.0250	-0.0027	1.0223	9.69	0.013326	0.0054	70.38	65.25
120	1.0240	-0.0027	1.0213	9.95	0.013326	0.0038	67.22	62.32
240	1.0230	-0.0027	1.0203	10.22	0.013326	0.0027	64.07	59.40
480	1.0220	-0.0027	1.0193	10.48	0.013326	0.0020	60.91	56.47
1440	1.0210	-0.0027	1.0183	10.75	0.013326	0.0012	57.76	53.54

Grain size distribution curve for TP-07 at 1.50m



Grain Size Analysis

Sample No : TP-07

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	454.8	462.9	8.1	0.8	0.8	99.2
No 4	4.75	427.8	440.8	13.0	1.3	2.1	97.9
No 8	2.36	387.7	405.7	18.0	1.8	3.9	96.1
No 10	2	377.9	381.9	4.0	0.4	4.3	95.7
No 16	1.18	372.6	383.2	10.6	1.1	5.4	94.6
No 30	0.6	323.3	342.6	19.3	1.9	7.3	92.7
No 40	0.425	292.1	312.9	20.8	2.1	9.4	90.6
No 50	0.3	301.6	333.0	31.4	3.1	12.5	87.5
No 100	0.15	276.0	353.4	77.4	7.7	20.3	79.7
No 200	0.075	258.6	360.7	102.1	10.2	30.5	69.5
pan	-----	255.6	255.6	0.0	0.0	30.5	-----

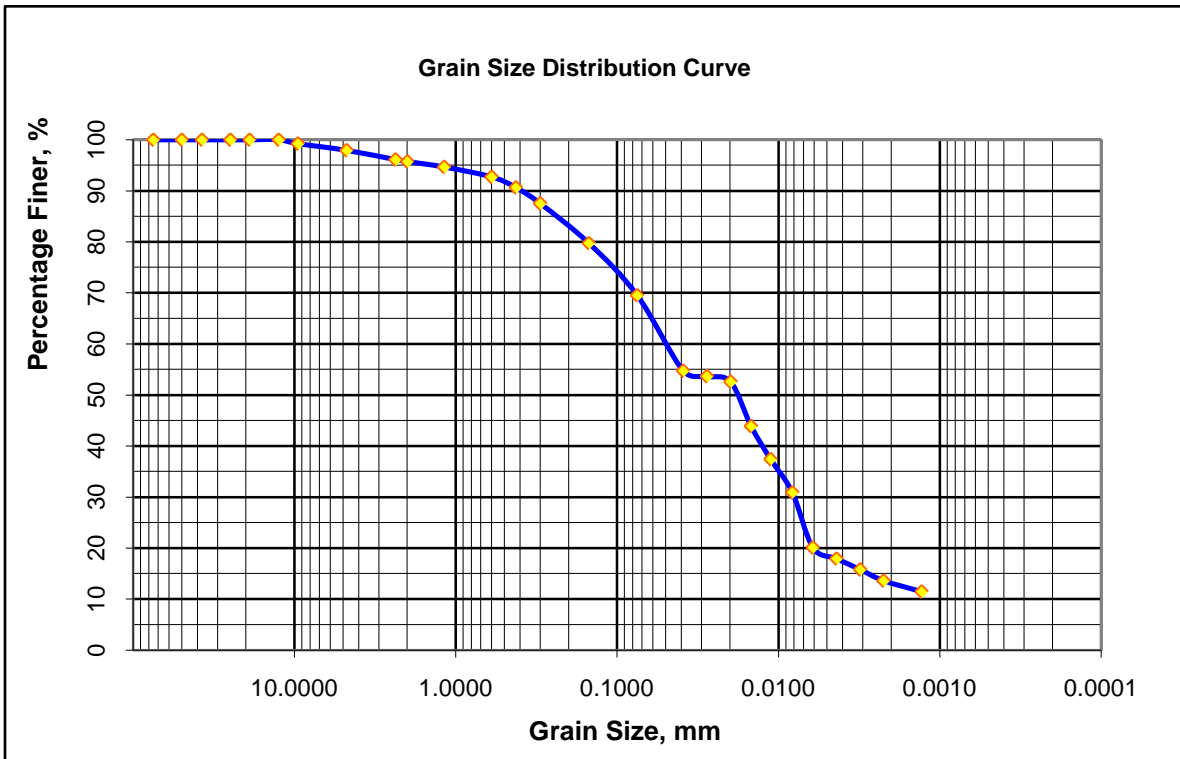
Hydrometer Analysis

Specific Gravity of soil=2.80

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0280	-0.0027	1.0253	8.89	0.01307	0.0390	78.71	54.73
1	1.0275	-0.0027	1.0248	9.03	0.01307	0.0278	77.16	53.65
2	1.0270	-0.0027	1.0243	9.16	0.01307	0.0198	75.60	52.56
4	1.0230	-0.0027	1.0203	10.22	0.01307	0.0148	63.16	43.91
8	1.0200	-0.0027	1.0173	11.01	0.01307	0.0112	53.82	37.42
15	1.0170	-0.0027	1.0143	11.80	0.01307	0.0082	44.49	30.93
30	1.0140	-0.0027	1.0113	12.60	0.01307	0.0060	35.16	24.44
60	1.0120	-0.0027	1.0093	13.13	0.01307	0.0061	28.93	20.12
120	1.0110	-0.0027	1.0083	13.39	0.01307	0.0044	25.82	17.95
240	1.0100	-0.0027	1.0073	13.65	0.01307	0.0031	22.71	15.79
480	1.0090	-0.0027	1.0063	13.92	0.01307	0.0022	19.60	13.63
1440	1.0080	-0.0027	1.0053	14.18	0.01307	0.0013	16.49	11.46

Grain size distribution curve for TP-07 at 3.00m



Grain Size Analysis

Sample No : TP-08

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	428.0	0.1	0.0	0.0	100.0
No 8	2.36	387.7	388.7	1.0	0.1	0.1	99.9
No 10	2	390.2	390.6	0.4	0.0	0.1	99.9
No 16	1.18	372.6	374.6	2.0	0.1	0.2	99.8
No 30	0.6	325.6	330.7	5.1	0.3	0.6	99.4
No 40	0.425	291.7	295.5	3.8	0.3	0.8	99.2
No 50	0.3	301.5	305.8	4.3	0.3	1.1	98.9
No 100	0.15	271.4	278.2	6.8	0.5	1.6	98.4
No 200	0.075	273.8	287.0	13.2	0.9	2.4	97.6
pan	-----	255.6	255.6	0.0	0.0	2.4	-----

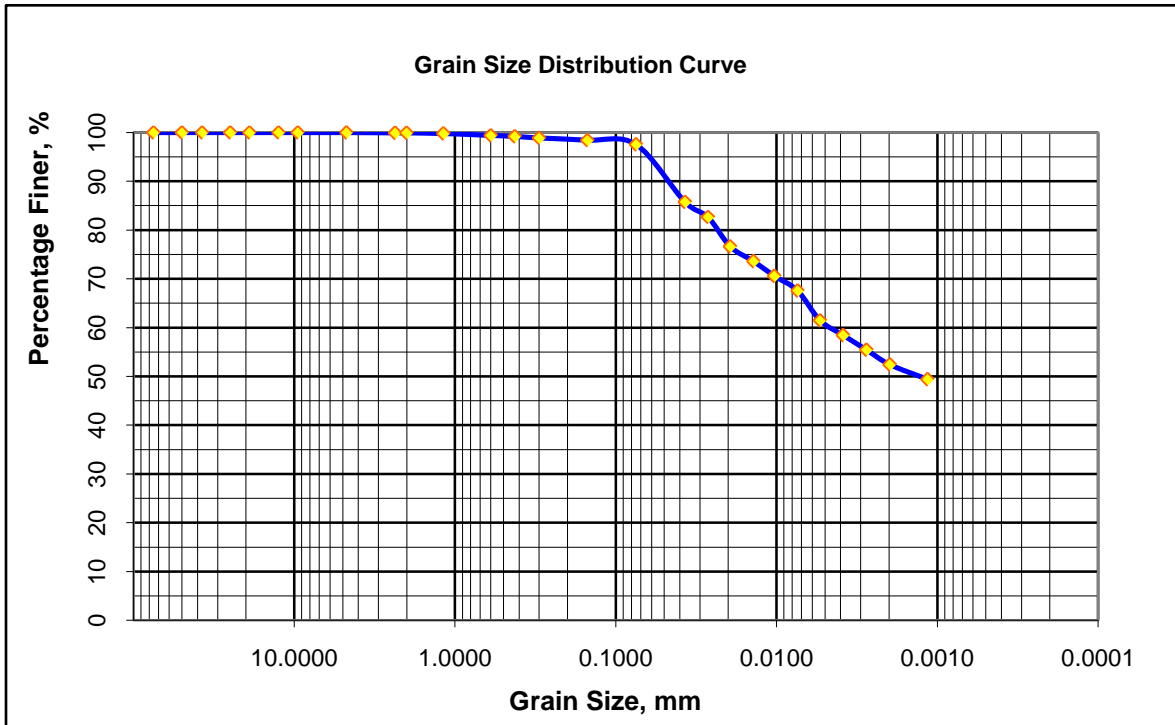
Hydrometer Analysis

Specific Gravity of soil=2.81

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0310	-0.0027	1.0283	8.10	0.013034	0.0371	87.87	85.72
1	1.0300	-0.0027	1.0273	8.36	0.013034	0.0267	84.77	82.69
2	1.0280	-0.0027	1.0253	8.89	0.013034	0.0194	78.56	76.63
4	1.0270	-0.0027	1.0243	9.16	0.013034	0.0139	75.45	73.60
8	1.0260	-0.0027	1.0233	9.42	0.013034	0.0103	72.35	70.58
15	1.0250	-0.0027	1.0223	9.69	0.013034	0.0074	69.24	67.55
30	1.0240	-0.0027	1.0213	9.95	0.013034	0.0053	66.14	64.52
60	1.0230	-0.0027	1.0203	10.22	0.013034	0.0054	63.03	61.49
120	1.0220	-0.0027	1.0193	10.48	0.013034	0.0039	59.93	58.46
240	1.0210	-0.0027	1.0183	10.75	0.013034	0.0028	56.82	55.43
480	1.0200	-0.0027	1.0173	11.01	0.013034	0.0020	53.72	52.40
1440	1.0190	-0.0027	1.0163	11.27	0.013034	0.0012	50.61	49.37

Grain size distribution curve for TP-08 at 1.50m



Grain Size Analysis

Sample No : TP-08

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1187.0	1187.0	0.0	0.0	0.0	100.0
3/4"	19.0	1178.4	1178.4	0.0	0.0	0.0	100.0
1/2"	12.5	1216.7	1216.7	0.0	0.0	0.0	100.0
3.8"	9.5	1164.6	1164.6	0.0	0.0	0.0	100.0
No 4	4.75	1262.7	1263.5	0.8	0.1	0.1	99.9
No 8	2.36	990.2	992.7	2.5	0.2	0.2	99.8
No 10	2	944.1	945.7	1.6	0.1	0.3	99.7
No 16	1.18	894.5	903.0	8.5	0.6	0.9	99.1
No 30	0.6	833.7	856.1	22.4	1.5	2.4	97.6
No 50	0.3	750.3	792.2	41.9	2.8	5.2	94.8
No 100	0.15	782.7	882.2	99.5	6.6	11.8	88.2
No 200	0.075	765.1	847.7	82.6	5.5	17.3	82.7
pan	-----	736.0	736.0	0.0	0.0	17.3	-----

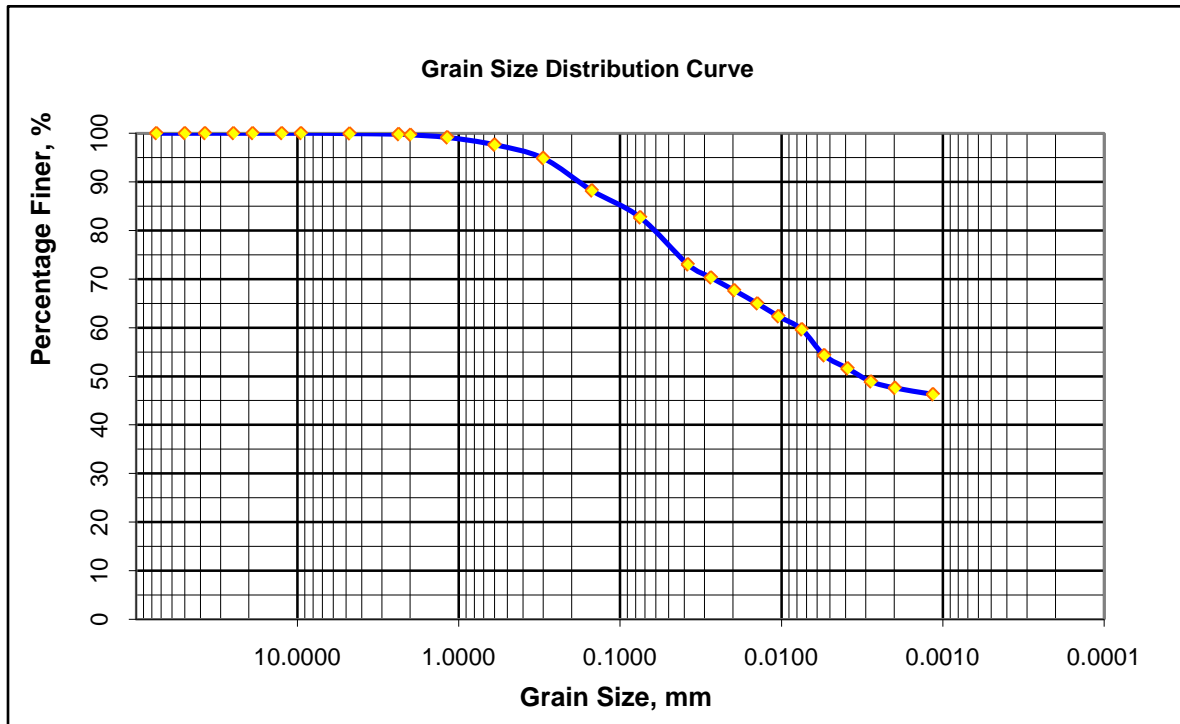
Hydrometer Analysis

Specific Gravity of soil=2.62

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013178	0.0381	88.30	73.01
1	1.0290	-0.0027	1.0263	8.63	0.013178	0.0274	85.07	70.34
2	1.0280	-0.0027	1.0253	8.89	0.013178	0.0196	81.83	67.66
4	1.0270	-0.0027	1.0243	9.16	0.013178	0.0141	78.60	64.99
8	1.0260	-0.0027	1.0233	9.42	0.013178	0.0104	75.37	62.31
15	1.0250	-0.0027	1.0223	9.69	0.013178	0.0075	72.13	59.64
30	1.0240	-0.0027	1.0213	9.95	0.013178	0.0054	68.90	56.96
60	1.0230	-0.0027	1.0203	10.22	0.013178	0.0054	65.66	54.29
120	1.0220	-0.0027	1.0193	10.48	0.013178	0.0039	62.43	51.61
240	1.0210	-0.0027	1.0183	10.75	0.013178	0.0028	59.19	48.94
480	1.0205	-0.0027	1.0178	10.88	0.013178	0.0020	57.58	47.60
1440	1.0200	-0.0027	1.0173	11.01	0.013178	0.0012	55.96	46.27

Grain size distribution curve for TP-08 at 3.00m



Investigation in to some of the engineering properties of soils found in Debre Birhan town

Grain Size Analysis

Sample No : TP-09

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	449.8	21.9	1.5	1.5	98.5
No 8	2.36	387.7	422.5	34.8	2.3	3.8	96.2
No 10	2	390.2	401.6	11.4	0.8	4.5	95.5
No 16	1.18	372.6	409.9	37.3	2.5	7.0	93.0
No 30	0.6	325.6	389.6	64.0	4.3	11.3	88.7
No 40	0.425	291.7	335.0	43.3	2.9	14.2	85.8
No 50	0.3	301.5	341.5	40.0	2.7	16.8	83.2
No 100	0.15	271.4	322.1	50.7	3.4	20.2	79.8
No 200	0.075	273.8	302.8	29.0	1.9	22.2	77.8
pan	-----	255.6	255.6	0.0	0.0	22.2	-----

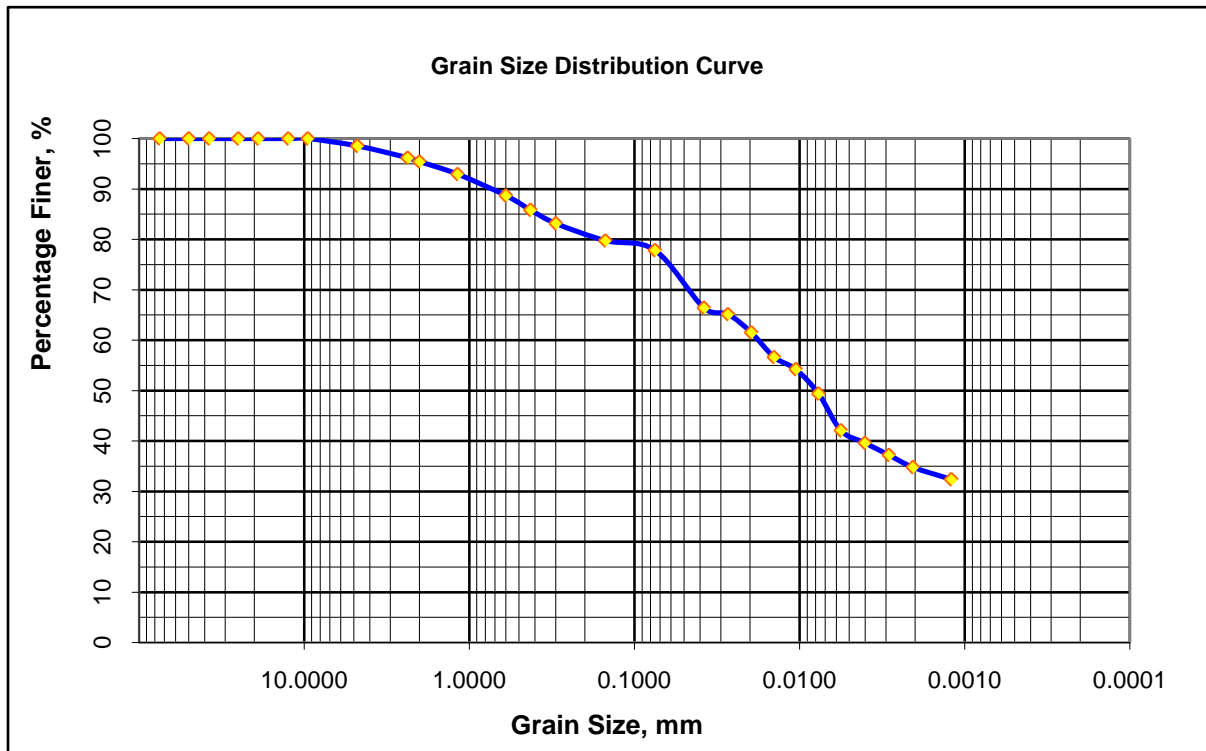
Hydrometer Analysis

Specific Gravity of soil=2.78

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013142	0.0380	85.27	66.38
1	1.0295	-0.0027	1.0268	8.50	0.013142	0.0271	83.71	65.16
2	1.0280	-0.0027	1.0253	8.89	0.013142	0.0196	79.03	61.51
4	1.0260	-0.0027	1.0233	9.42	0.013142	0.0143	72.78	56.65
8	1.0250	-0.0027	1.0223	9.69	0.013142	0.0106	69.66	54.22
15	1.0230	-0.0027	1.0203	10.22	0.013142	0.0077	63.41	49.36
30	1.0210	-0.0027	1.0183	10.75	0.013142	0.0056	57.16	44.49
60	1.0200	-0.0027	1.0173	11.01	0.013142	0.0056	54.04	42.06
120	1.0190	-0.0027	1.0163	11.27	0.013142	0.0040	50.91	39.63
240	1.0180	-0.0027	1.0153	11.54	0.013142	0.0029	47.79	37.20
480	1.0170	-0.0027	1.0143	11.80	0.013142	0.0021	44.67	34.77
1440	1.0160	-0.0027	1.0133	12.07	0.013142	0.0012	41.54	32.34

Grain size distribution curve for TP-09 at 1.50m



Grain Size Analysis

Sample No : TP-09

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1500

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	1216.8	1225.8	9.0	0.6	0.6	99.4
3.8"	9.5	1164.6	1167.7	3.1	0.2	0.8	99.2
No 4	4.75	1262.7	1279.2	16.5	1.1	1.9	98.1
No 8	2.36	990.2	1007.1	16.9	1.1	3.0	97.0
No 10	2	944.1	950.7	6.6	0.4	3.5	96.5
No 16	1.18	894.5	921.4	26.9	1.8	5.3	94.7
No 30	0.6	833.7	911.5	77.8	5.2	10.5	89.5
No 50	0.3	750.3	903.3	153.0	10.2	20.7	79.3
No 100	0.15	782.7	930.2	147.5	9.8	30.5	69.5
No 200	0.075	765.1	847.5	82.4	5.5	36.0	64.0
pan	-----	736.0	736.0	0.0	0.0	36.0	-----

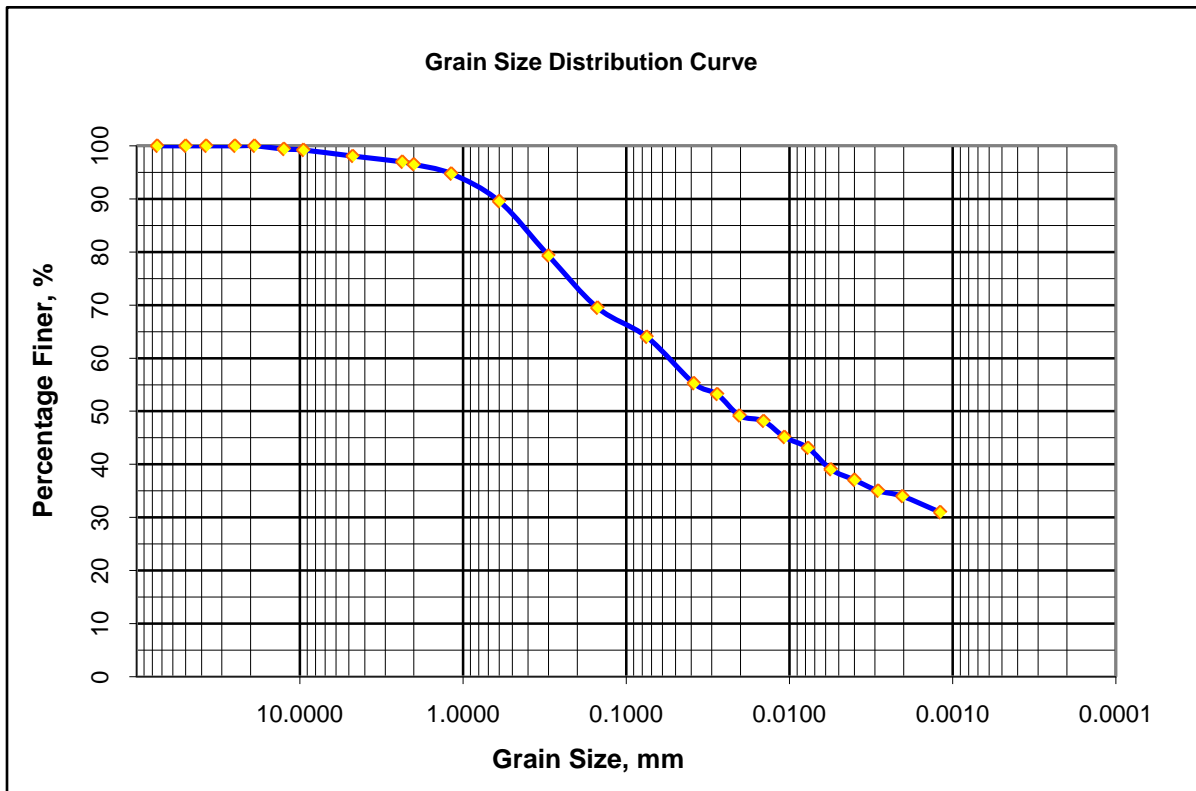
Hydrometer Analysis

Specific Gravity of soil=2.72

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013364	0.0387	86.34	55.28
1	1.0290	-0.0027	1.0263	8.63	0.013364	0.0278	83.18	53.25
2	1.0270	-0.0027	1.0243	9.16	0.013364	0.0202	76.86	49.20
4	1.0265	-0.0027	1.0238	9.29	0.013364	0.0144	75.27	48.19
8	1.0250	-0.0027	1.0223	9.69	0.013364	0.0107	70.53	45.15
15	1.0240	-0.0027	1.0213	9.95	0.013364	0.0077	67.37	43.13
30	1.0230	-0.0027	1.0203	10.22	0.013364	0.0055	64.20	41.10
60	1.0220	-0.0027	1.0193	10.48	0.013364	0.0056	61.04	39.08
120	1.0210	-0.0027	1.0183	10.75	0.013364	0.0040	57.88	37.05
240	1.0200	-0.0027	1.0173	11.01	0.013364	0.0029	54.72	35.03
480	1.0195	-0.0027	1.0168	11.14	0.013364	0.0020	53.13	34.02
1440	1.0180	-0.0027	1.0153	11.54	0.013364	0.0012	48.39	30.98

Grain size distribution curve for TP-09 at 3.00m



Grain Size Analysis

Sample No : TP-10

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	427.9	0.0	0.0	0.0	100.0
No 8	2.36	387.7	389.6	1.9	0.2	0.2	99.8
No 10	2	390.2	390.7	0.5	0.1	0.2	99.8
No 16	1.18	372.6	375.1	2.5	0.3	0.5	99.5
No 30	0.6	325.6	331.0	5.4	0.5	1.0	99.0
No 40	0.425	291.7	291.9	0.2	0.0	1.1	99.0
No 50	0.3	301.5	310.0	8.5	0.9	1.9	98.1
No 100	0.15	271.4	277.0	5.6	0.6	2.5	97.5
No 200	0.075	273.8	317.8	44.0	4.4	6.9	93.1
pan	-----	254.1	254.1	0.0	0.0	6.9	-----

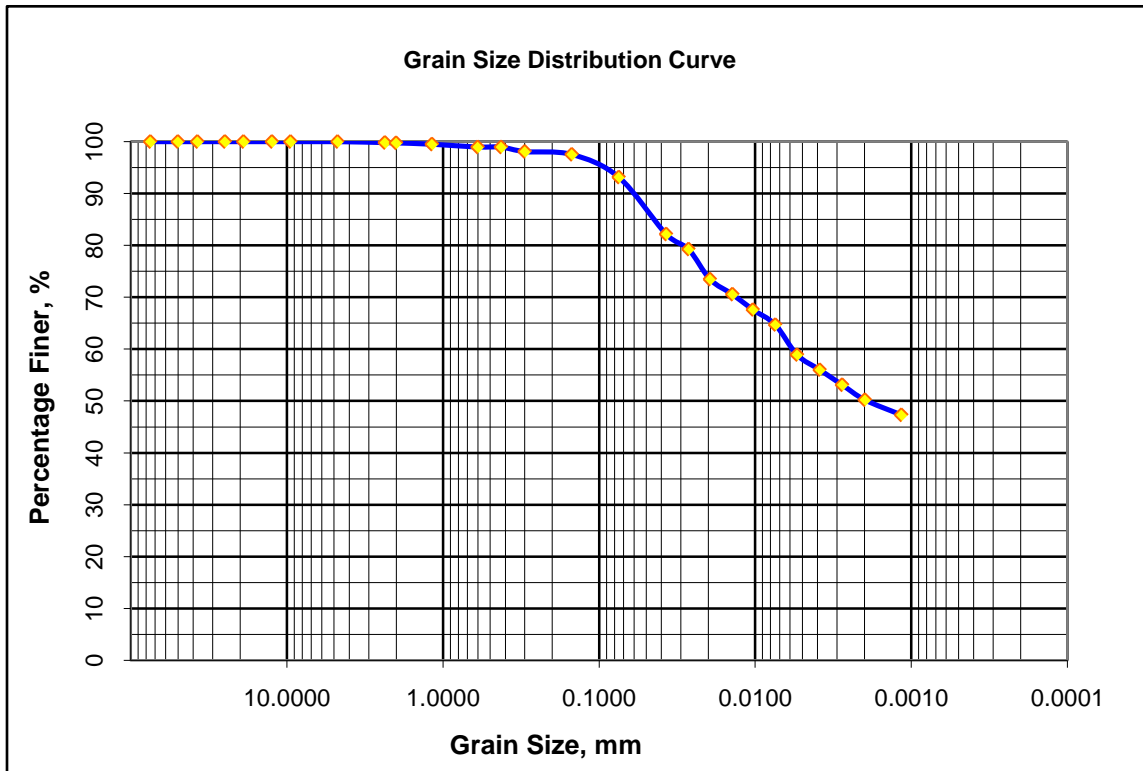
Hydrometer Analysis

Specific Gravity of soil=2.79

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0310	-0.0027	1.0283	8.10	0.013106	0.0373	88.22	82.17
1	1.0300	-0.0027	1.0273	8.36	0.013106	0.0268	85.10	79.26
2	1.0280	-0.0027	1.0253	8.89	0.013106	0.0195	78.87	73.46
4	1.0270	-0.0027	1.0243	9.16	0.013106	0.0140	75.75	70.55
8	1.0260	-0.0027	1.0233	9.42	0.013106	0.0104	72.63	67.65
15	1.0250	-0.0027	1.0223	9.69	0.013106	0.0074	69.52	64.75
30	1.0240	-0.0027	1.0213	9.95	0.013106	0.0053	66.40	61.84
60	1.0230	-0.0027	1.0203	10.22	0.013106	0.0054	63.28	58.94
120	1.0220	-0.0027	1.0193	10.48	0.013106	0.0039	60.16	56.04
240	1.0210	-0.0027	1.0183	10.75	0.013106	0.0028	57.05	53.13
480	1.0200	-0.0027	1.0173	11.01	0.013106	0.0020	53.93	50.23
1440	1.0190	-0.0027	1.0163	11.27	0.013106	0.0012	50.81	47.33

Grain size distribution curve for TP-10 at 1.50m



Grain Size Analysis

Sample No : TP-10

Sample Depth, m : 3.00

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	454.8	574.0	119.2	11.9	11.9	88.1
No 4	4.75	427.8	554.9	127.1	12.7	24.6	75.4
No 8	2.36	387.7	504.3	116.6	11.7	36.3	63.7
No 10	2	377.9	403.7	25.8	2.6	38.9	61.1
No 16	1.18	372.6	436.9	64.3	6.4	45.3	54.7
No 30	0.6	323.3	384.3	61.0	6.1	51.4	48.6
No 40	0.425	292.1	315.4	23.3	2.3	53.7	46.3
No 50	0.3	301.6	321.2	19.6	2.0	55.7	44.3
No 100	0.15	276.0	304.0	28.0	2.8	58.5	41.5
No 200	0.075	258.6	290.2	31.6	3.2	61.7	38.4
pan	-----	255.6	254.1	-1.5	-0.2	61.5	-----

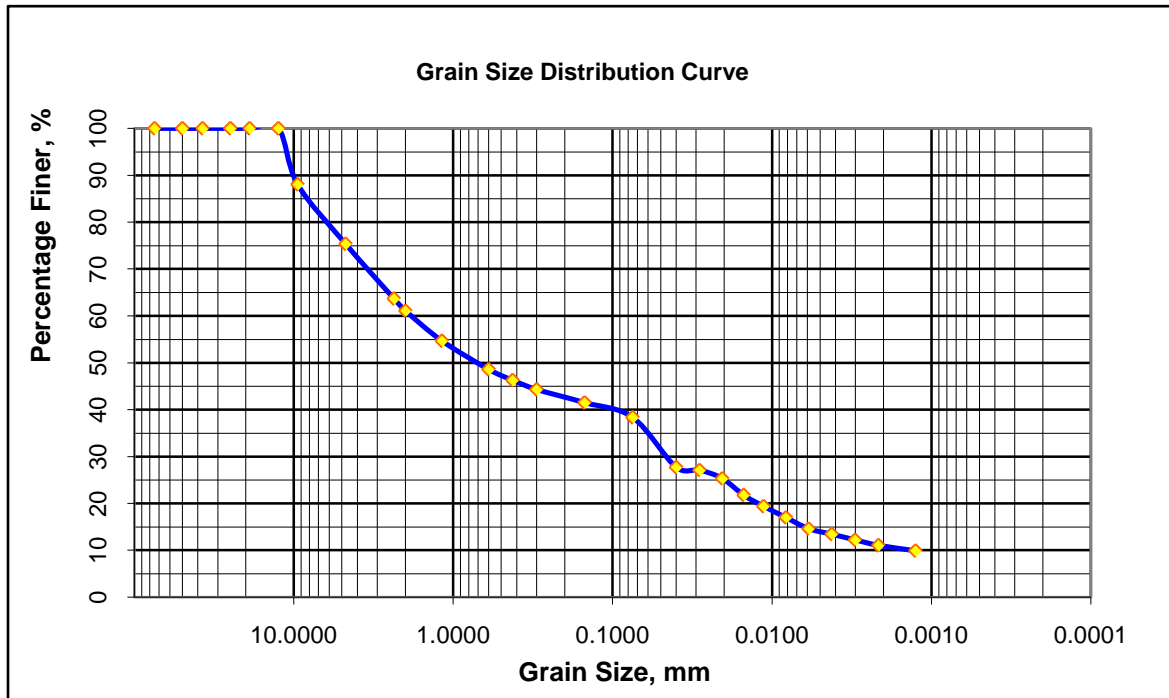
Hydrometer Analysis

Specific Gravity of soil=2.81

Test Temperature, deg.c 20

Elapse d Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0260	-0.0027	1.0233	9.42	0.013034	0.0400	72.35	27.74
1	1.0255	-0.0027	1.0228	9.55	0.013034	0.0285	70.79	27.15
2	1.0240	-0.0027	1.0213	9.95	0.013034	0.0206	66.14	25.36
4	1.0210	-0.0027	1.0183	10.75	0.013034	0.0151	56.82	21.79
8	1.0190	-0.0027	1.0163	11.27	0.013034	0.0113	50.61	19.41
15	1.0170	-0.0027	1.0143	11.80	0.013034	0.0082	44.40	17.03
30	1.0160	-0.0027	1.0133	12.07	0.013034	0.0058	41.30	15.84
60	1.0150	-0.0027	1.0123	12.33	0.013034	0.0059	38.19	14.65
120	1.0140	-0.0027	1.0113	12.60	0.013034	0.0042	35.09	13.46
240	1.0130	-0.0027	1.0103	12.86	0.013034	0.0030	31.98	12.26
480	1.0120	-0.0027	1.0093	13.13	0.013034	0.0022	28.88	11.07
1440	1.0110	-0.0027	1.0083	13.39	0.013034	0.0013	25.77	9.88

Grain size distribution curve for TP-10 at 3.00m



Grain Size Analysis

Sample No : TP-11

Sample Depth, m : 1.50

Sieve Analysis

Total mass of sample, g 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	460.6	0.0	0.0	0.0	100.0
No 4	4.75	427.9	427.9	0.0	0.0	0.0	100.0
No 8	2.36	387.7	388.9	1.2	0.1	0.1	99.9
No 10	2	390.2	390.3	0.1	0.0	0.1	99.9
No 16	1.18	372.6	373.7	1.1	0.1	0.2	99.8
No 30	0.6	325.6	332.7	7.1	0.7	0.9	99.1
No 40	0.425	291.7	292.2	0.5	0.1	1.0	99.0
No 50	0.3	301.5	333.8	32.3	3.2	4.2	95.8
No 100	0.15	271.4	320.2	48.8	4.9	9.1	90.9
No 200	0.075	273.8	336.7	62.9	6.3	15.4	84.6
pan	-----	254.1	254.1	0.0	0.0	15.4	-----

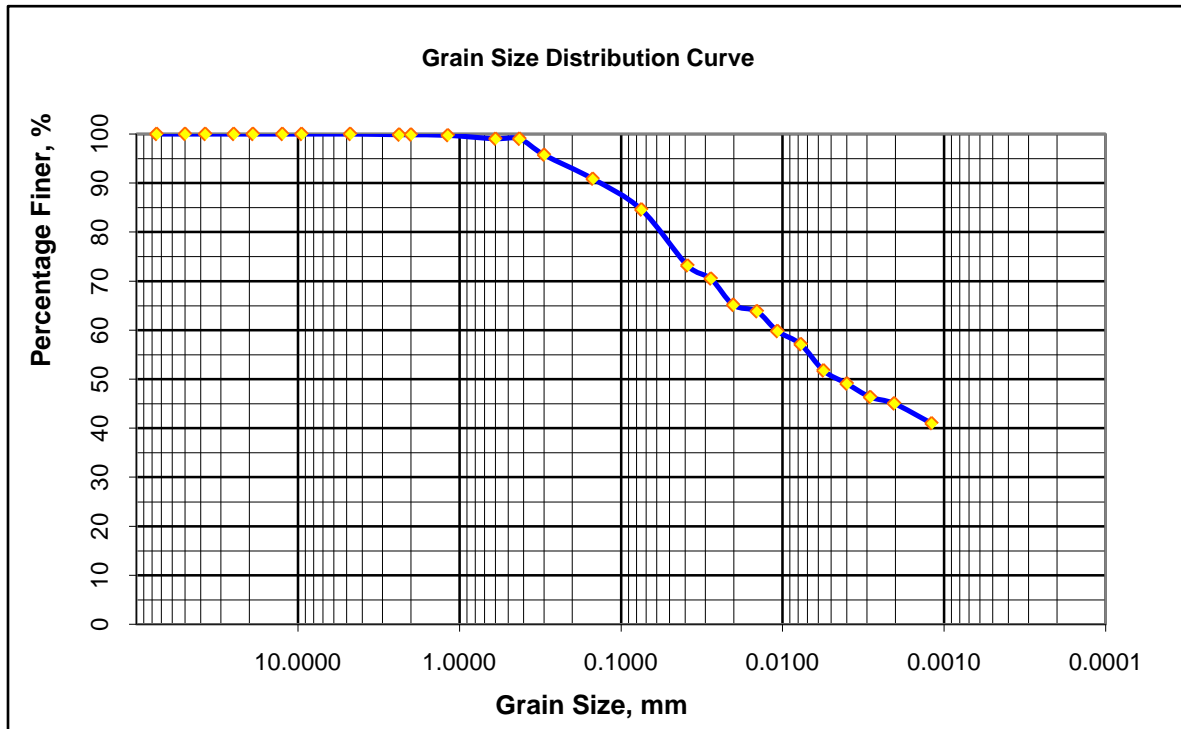
Hydrometer Analysis

Specific Gravity of soil=2.71

Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013402	0.0388	86.53	73.20
1	1.0290	-0.0027	1.0263	8.63	0.013402	0.0278	83.36	70.52
2	1.0270	-0.0027	1.0243	9.16	0.013402	0.0203	77.02	65.16
4	1.0265	-0.0027	1.0238	9.29	0.013402	0.0144	75.44	63.82
8	1.0250	-0.0027	1.0223	9.69	0.013402	0.0108	70.68	59.80
15	1.0240	-0.0027	1.0213	9.95	0.013402	0.0077	67.51	57.12
30	1.0230	-0.0027	1.0203	10.22	0.013402	0.0055	64.34	54.43
60	1.0220	-0.0027	1.0193	10.48	0.013402	0.0056	61.17	51.75
120	1.0210	-0.0027	1.0183	10.75	0.013402	0.0040	58.00	49.07
240	1.0200	-0.0027	1.0173	11.01	0.013402	0.0029	54.83	46.39
480	1.0195	-0.0027	1.0168	11.14	0.013402	0.0020	53.25	45.05
1440	1.0180	-0.0027	1.0153	11.54	0.013402	0.0012	48.49	41.03

Grain size distribution curve for TP-11 at 1.50m



Grain Size Analysis

Sample No : TP-11 Sample Depth, m : 3.00
 Sieve Analysis Total mass of sample, g 1000

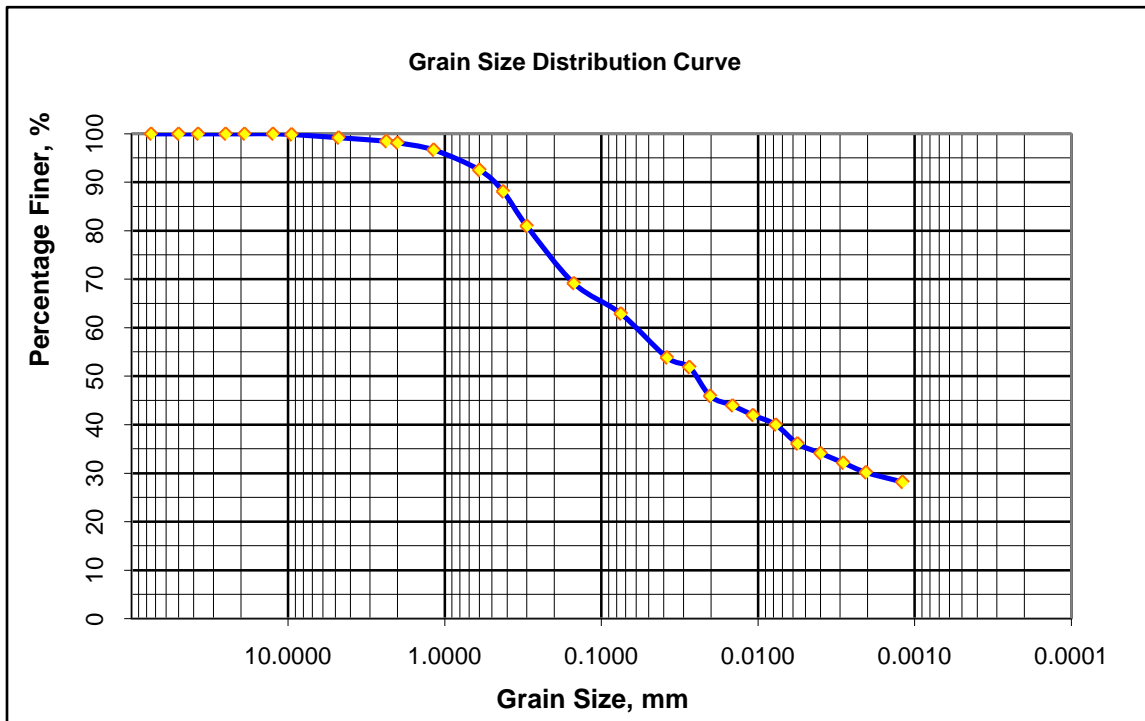
Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing g (%)
3"	75.0	0.0	0.0	0.0	0.0	0.0	100.0
2"	50.0	0.0	0.0	0.0	0.0	0.0	100.0
1.5"	37.5	0.0	0.0	0.0	0.0	0.0	100.0
1"	25.0	0.0	0.0	0.0	0.0	0.0	100.0
3/4"	19.0	0.0	0.0	0.0	0.0	0.0	100.0
1/2"	12.5	0.0	0.0	0.0	0.0	0.0	100.0
3.8"	9.5	460.6	462.4	1.8	0.2	0.2	99.8
No 4	4.75	427.9	434.3	6.4	0.6	0.8	99.2
No 8	2.36	387.7	394.9	7.2	0.7	1.5	98.5
No 10	2	390.2	393.3	3.1	0.3	1.9	98.2
No 16	1.18	372.6	387.6	15.0	1.5	3.4	96.7
No 30	0.6	325.6	366.9	41.3	4.1	7.5	92.5
No 40	0.425	291.7	336.0	44.3	4.4	11.9	88.1
No 50	0.3	301.5	372.6	71.1	7.1	19.0	81.0
No 100	0.15	271.4	389.3	117.9	11.8	30.8	69.2
No 200	0.075	273.8	337.1	63.3	6.3	37.1	62.9
pan	-----	254.1	254.1	0.0	0.0	37.1	-----

Hydrometer Analysis

Specific Gravity of soil 2.76 Test Temperature, deg.c 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
3/4	1.0300	-0.0027	1.0273	8.36	0.013214	0.0382	85.62	53.82
1	1.0290	-0.0027	1.0263	8.63	0.013214	0.0274	82.49	51.85
2	1.0260	-0.0027	1.0233	9.42	0.013214	0.0203	73.08	45.94
4	1.0250	-0.0027	1.0223	9.69	0.013214	0.0145	69.94	43.96
8	1.0240	-0.0027	1.0213	9.95	0.013214	0.0108	66.80	41.99
15	1.0230	-0.0027	1.0203	10.22	0.013214	0.0077	63.67	40.02
30	1.0220	-0.0027	1.0193	10.48	0.013214	0.0055	60.53	38.05
60	1.0210	-0.0027	1.0183	10.75	0.013214	0.0056	57.40	36.08
120	1.0200	-0.0027	1.0173	11.01	0.013214	0.0040	54.26	34.11
240	1.0190	-0.0027	1.0163	11.27	0.013214	0.0029	51.12	32.14
480	1.0180	-0.0027	1.0153	11.54	0.013214	0.0020	47.99	30.16
1440	1.0170	-0.0027	1.0143	11.80	0.013214	0.0012	44.85	28.19

Grain size distribution curve for TP-11 at 3.00m



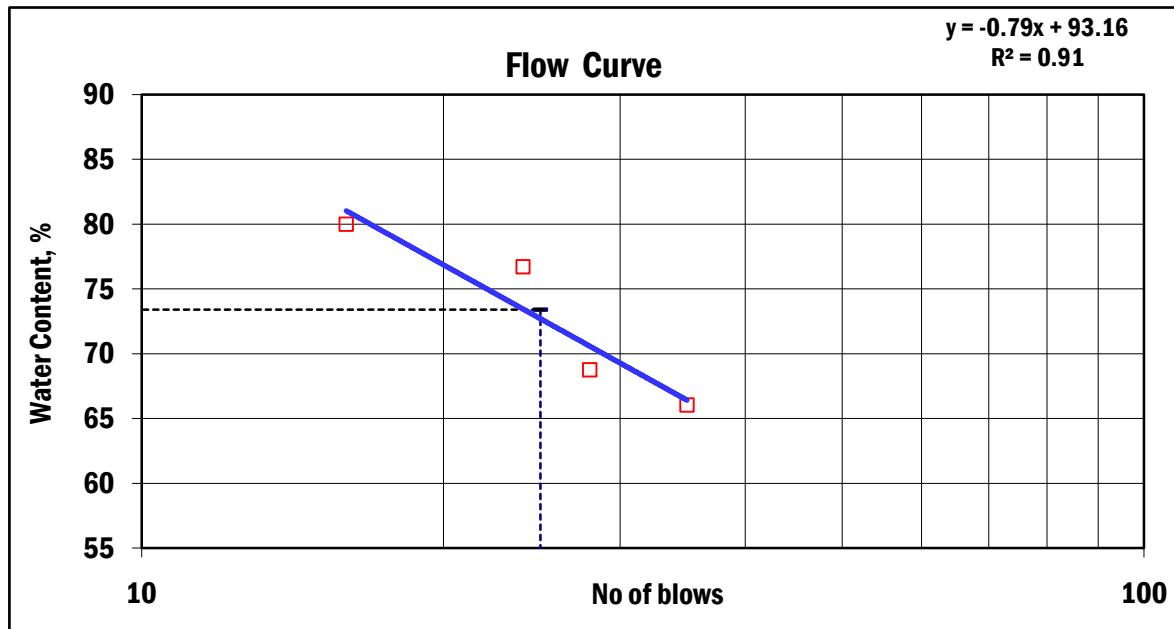
Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
Liquid Limit and Plastic Limit Test

Sample No : TP-01

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	10	B	CB	CN50	57	G111
Mass of container, g	15.60	15.50	30.80	15.60	15.80	15.60
Mass of container + Wet soil, g	24.40	23.60	43.70	30.00	23.70	25.90
Mass of container + Dry soil, g	20.90	20.30	38.10	23.60	21.80	23.30
Mass of water, g	3.50	3.30	5.60	6.40	1.90	2.60
Mass of dry soil, g	5.30	4.80	7.30	8.00	6.00	7.70
Water content, %	66.04	68.75	76.71	80.00	31.67	33.77
No of blows	35	28	24	16	-----	-----

Liquid Limit, % = 73 Plastic Limit, % = 33 PI, % = 40



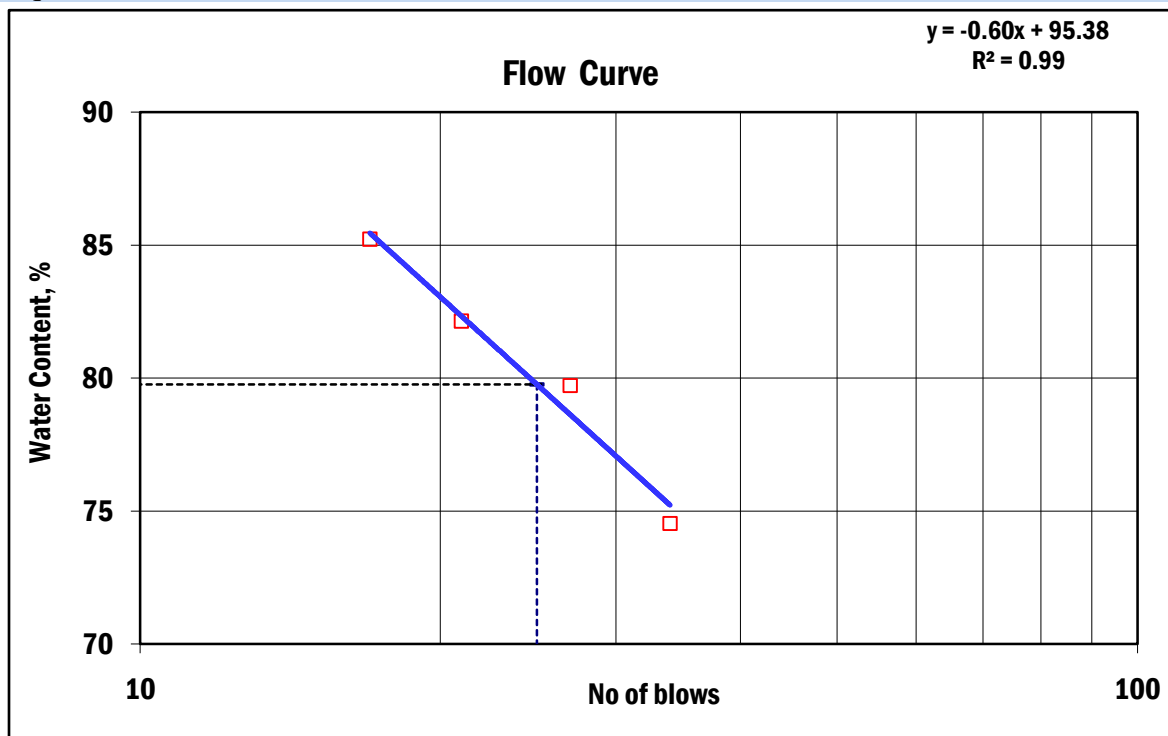
Liquid Limit and Plastic Limit Test

Sample No : TP-01

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	MS	D25	CN50	J3	A63	D34
Mass of container, g	15.70	15.90	15.60	15.30	15.70	15.50
Mass of container + Wet soil, g	25.30	29.20	30.90	31.60	22.10	22.50
Mass of container + Dry soil, g	21.20	23.30	24.00	24.10	20.50	20.70
Mass of water, g	4.10	5.90	6.90	7.50	1.60	1.80
Mass of dry soil, g	5.50	7.40	8.40	8.80	4.80	5.20
Water content, %	74.55	79.73	82.14	85.23	33.33	34.62
No of blows	34	27	21	17	-----	-----

Liquid Limit, % = 80 Plastic Limit, % = 34 PI, %= 46

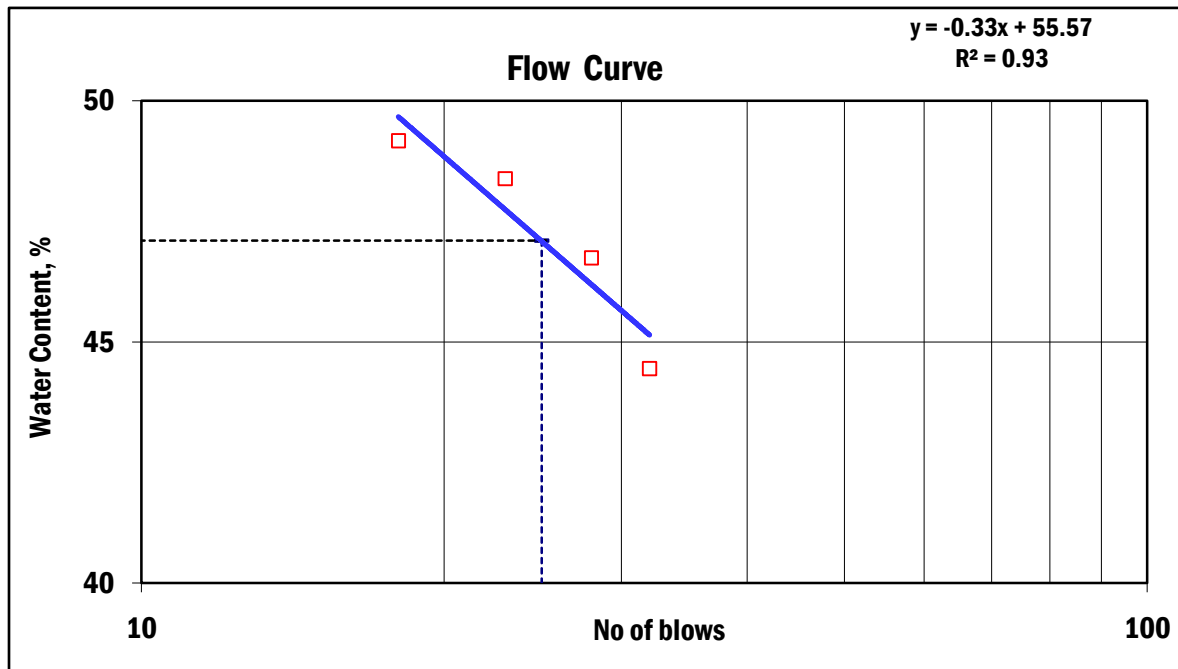


Liquid Limit and Plastic Limit Test

Sample No : TP-02 Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	H44	R10	J43	12	A114	J7
Mass of container, g	14.20	15.50	15.80	15.70	15.90	15.80
Mass of container + Wet soil, g	29.80	29.00	34.20	33.60	22.00	22.20
Mass of container + Dry soil, g	25.00	24.70	28.20	27.70	20.60	20.70
Mass of water, g	4.80	4.30	6.00	5.90	1.40	1.50
Mass of dry soil, g	10.80	9.20	12.40	12.00	4.70	4.90
Water content, %	44.44	46.74	48.39	49.17	29.79	30.61
No of blows	32	28	23	18	-----	-----

Liquid Limit, % = 47 Plastic Limit, % = 30 PI, % = 17

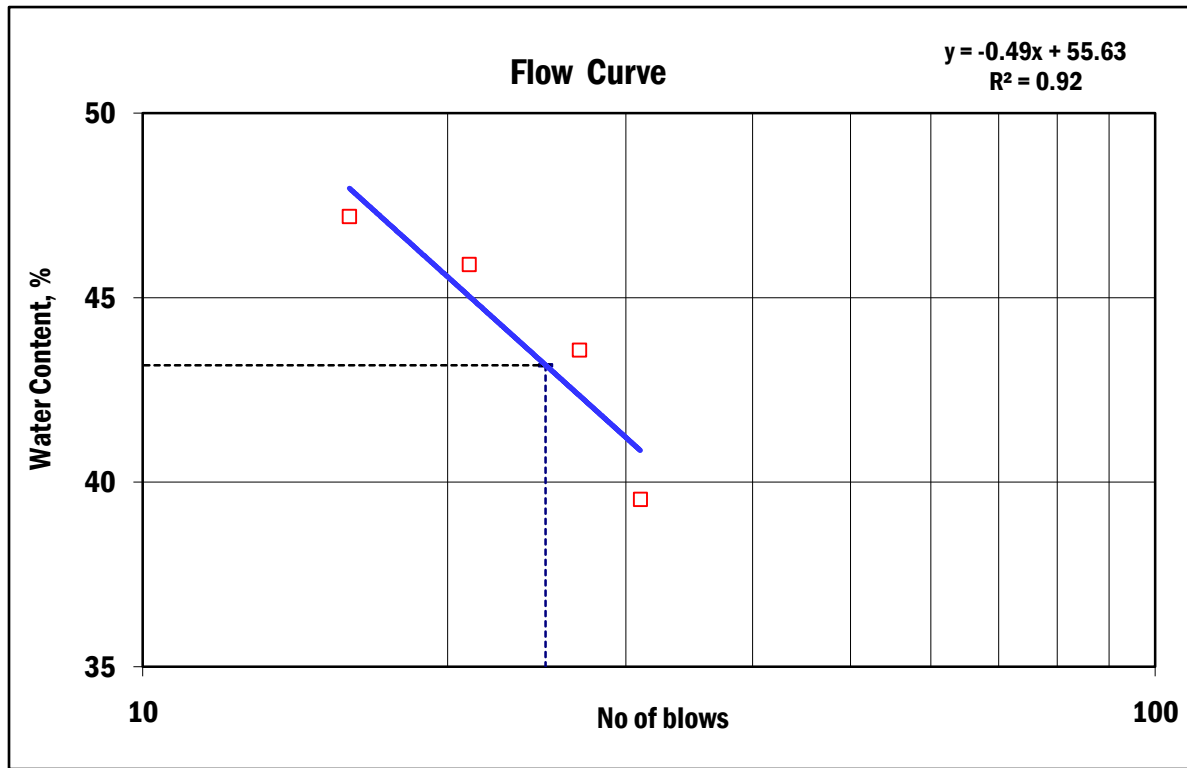


Liquid Limit and Plastic Limit Test

Sample No : TP-02 Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	M4	R59	21A	p4	F101	93
Mass of container, g	15.70	15.40	15.40	16.00	15.50	15.70
Mass of container + Wet soil, g	33.70	26.60	33.20	34.40	21.90	22.10
Mass of container + Dry soil, g	28.60	23.20	27.60	28.50	20.30	20.60
Mass of water, g	5.10	3.40	5.60	5.90	1.60	1.50
Mass of dry soil, g	12.90	7.80	12.20	12.50	4.80	4.90
Water content, %	39.53	43.59	45.90	47.20	33.33	30.61
No of blows	31	27	21	16	-----	-----

Liquid Limit, % = 43 Plastic Limit, % = 32 PI, %= 11



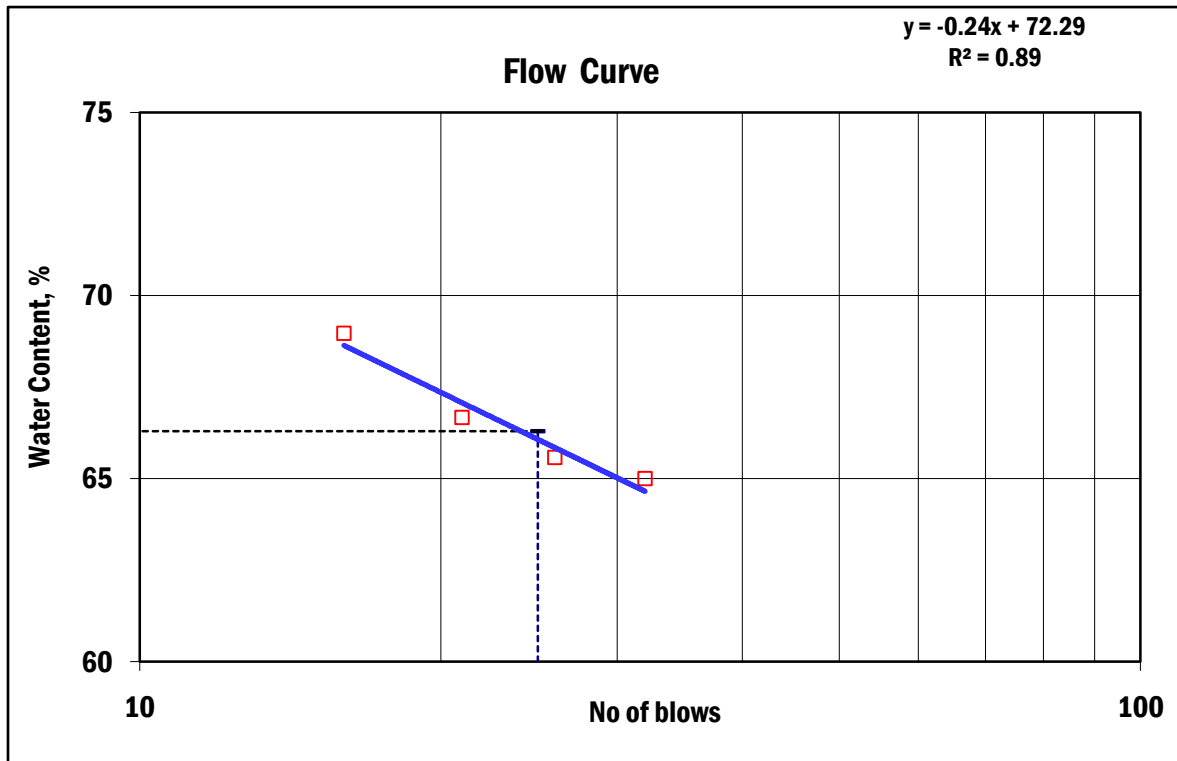
Liquid Limit and Plastic Limit Test

Sample No : TP-03

Sample Depth, m : 1.50

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	R4	C52	A3	T2	CB	A28
Mass of container, g	15.60	15.80	15.90	15.50	30.70	15.60
Mass of container + Wet soil, g	28.80	25.90	29.40	30.20	37.70	23.60
Mass of container + Dry soil, g	23.60	21.90	24.00	24.20	36.10	21.90
Mass of water, g	5.20	4.00	5.40	6.00	1.60	1.70
Mass of dry soil, g	8.00	6.10	8.10	8.70	5.40	6.30
Water content, %	65.00	65.57	66.67	68.97	29.63	26.98
No of blows	32	26	21	16	-----	-----

Liquid Limit, % = 66 Plastic Limit, % = 28 PI, % = 38



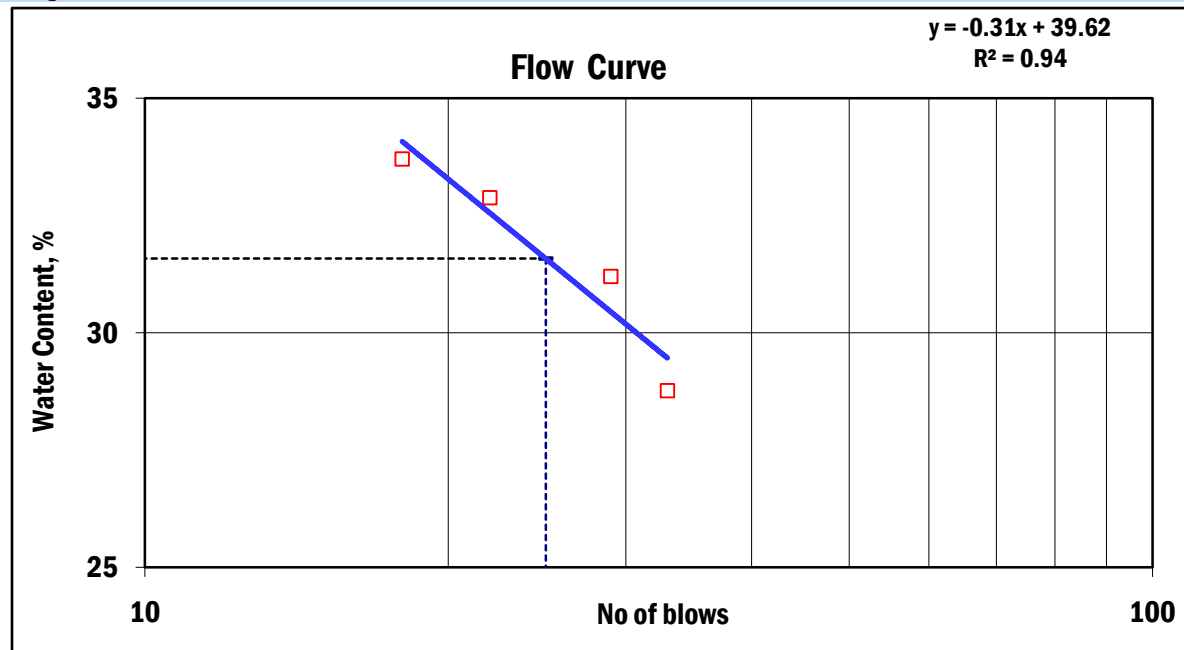
Liquid Limit and Plastic Limit Test

Sample No : TP-03

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A307	23A	A300	HY	X	MZ
Mass of container, g	15.40	15.60	15.60	29.10	15.50	15.80
Mass of container + Wet soil, g	34.20	32.00	35.00	53.30	21.90	22.50
Mass of container + Dry soil, g	30.00	28.10	30.20	47.20	21.00	21.50
Mass of water, g	4.20	3.90	4.80	6.10	0.90	1.00
Mass of dry soil, g	14.60	12.50	14.60	18.10	5.50	5.70
Water content, %	28.77	31.20	32.88	33.70	16.36	17.54
No of blows	33	29	22	18	-----	-----

Liquid Limit, % = 32 Plastic Limit, % = 17 PI, % = 15



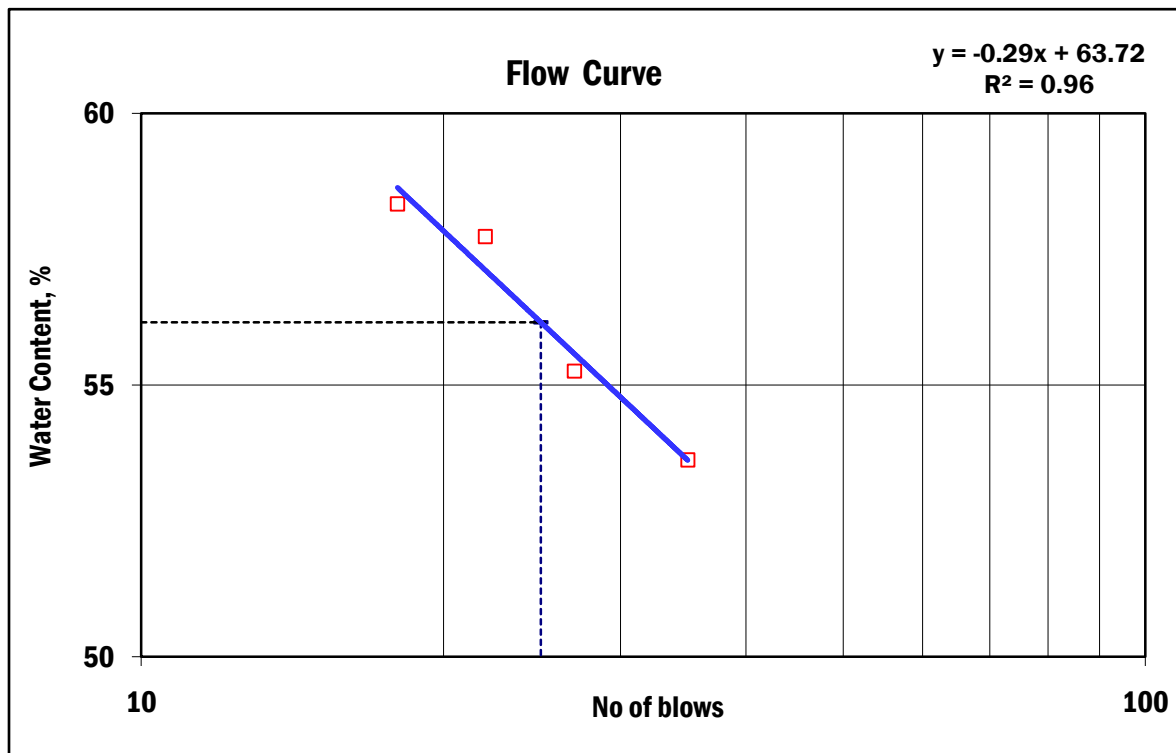
Liquid Limit and Plastic Limit Test

Sample No : TP-04

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	F3	G3	TA2	C290	C36	A27
Mass of container, g	15.70	13.80	15.30	14.20	14.00	15.60
Mass of container + Wet soil, g	26.30	31.50	30.60	27.50	22.20	22.90
Mass of container + Dry soil, g	22.60	25.20	25.00	22.60	20.20	21.20
Mass of water, g	3.70	6.30	5.60	4.90	2.00	1.70
Mass of dry soil, g	6.90	11.40	9.70	8.40	6.20	5.60
Water content, %	53.62	55.26	57.73	58.33	32.26	30.36
No of blows	35	27	22	18	-----	-----

Liquid Limit, % = 56 Plastic Limit, % = 31 PI, %= 25



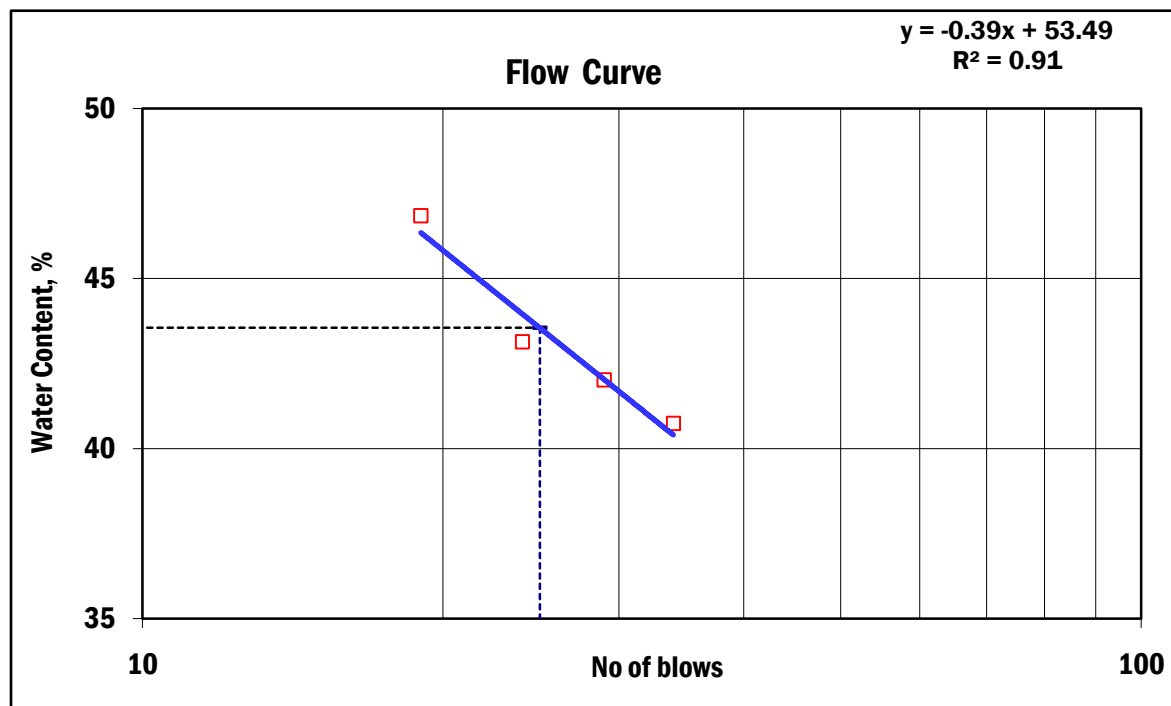
Liquid Limit and Plastic Limit Test

Sample No : TP-04

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	G2	18A	P33	A303	PS1	A28
Mass of container, g	15.60	15.50	15.70	15.40	15.20	15.60
Mass of container + Wet soil, g	34.60	32.40	37.60	31.70	21.60	22.60
Mass of container + Dry soil, g	29.10	27.40	31.00	26.50	20.10	21.10
Mass of water, g	5.50	5.00	6.60	5.20	1.50	1.50
Mass of dry soil, g	13.50	11.90	15.30	11.10	4.90	5.50
Water content, %	40.74	42.02	43.14	46.85	30.61	27.27
No of blows	34	29	24	19	-----	-----

Liquid Limit, % = 44 Plastic Limit, % = 29 PI, % = 15



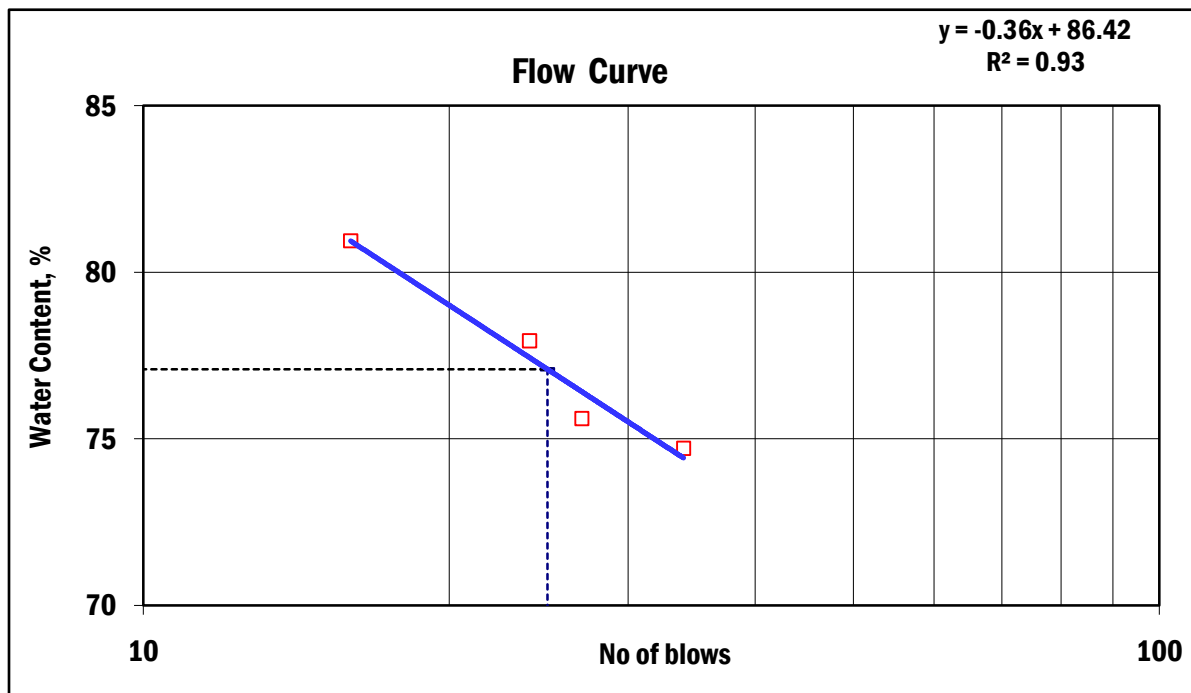
Liquid Limit and Plastic Limit Test

Sample No : TP-05

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	19A	TA3	C21	H5	A5	A301
Mass of container, g	15.60	15.80	15.40	15.50	15.50	15.40
Mass of container + Wet soil, g	30.80	30.20	27.50	30.70	21.90	21.50
Mass of container + Dry soil, g	24.30	24.00	22.20	23.90	20.20	20.00
Mass of water, g	6.50	6.20	5.30	6.80	1.70	1.50
Mass of dry soil, g	8.70	8.20	6.80	8.40	4.70	4.60
Water content, %	74.71	75.61	77.94	80.95	36.17	32.61
No of blows	34	27	24	16	-----	-----

Liquid Limit, % = 77 Plastic Limit, % = 34 PI, % = 43



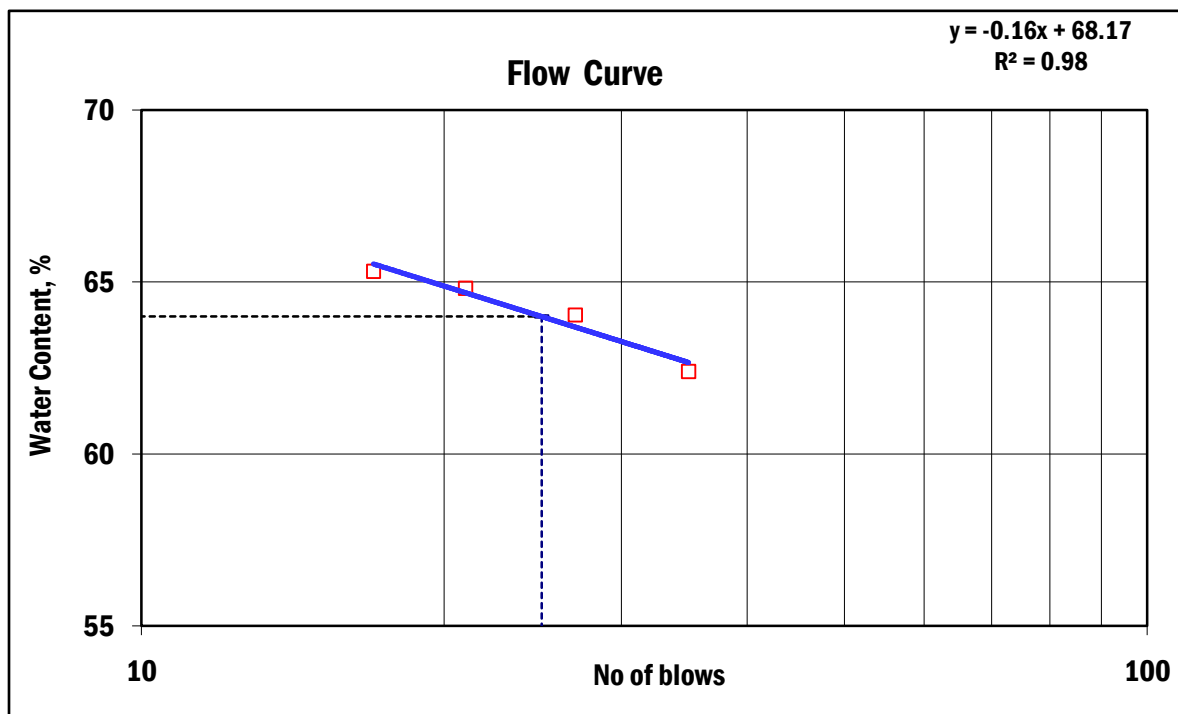
Liquid Limit and Plastic Limit Test

Sample No : TP-05

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C52	A2	J6	T2	CN50	MS
Mass of container, g	15.80	15.50	15.60	15.50	15.50	15.40
Mass of container + Wet soil, g	34.80	30.10	33.40	31.70	21.90	21.50
Mass of container + Dry soil, g	27.50	24.40	26.40	25.30	20.20	20.00
Mass of water, g	7.30	5.70	7.00	6.40	1.70	1.50
Mass of dry soil, g	11.70	8.90	10.80	9.80	4.70	4.60
Water content, %	62.39	64.04	64.81	65.31	36.17	32.61
No of blows	35	27	21	17	-----	-----

Liquid Limit, % = 64 Plastic Limit, % = 34 PI, % = 30



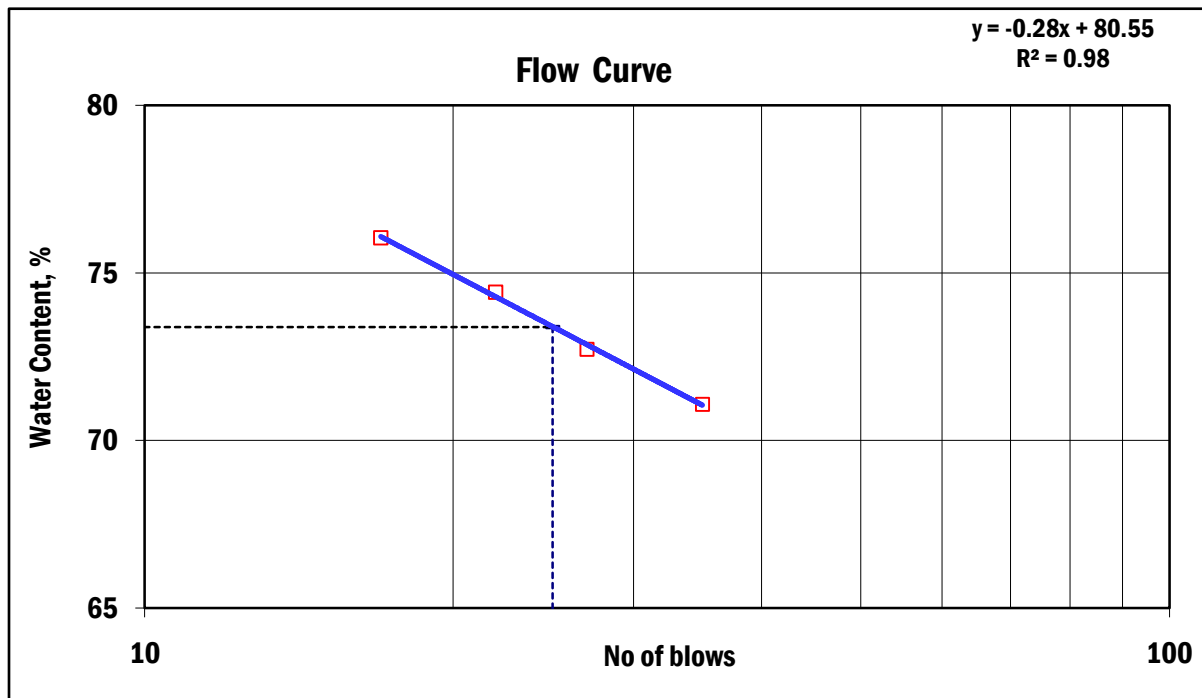
Liquid Limit and Plastic Limit Test

Sample No : TP-06

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	M1	H100	A34	G11	Q25	G45
Mass of container, g	14.90	15.70	15.70	15.80	15.70	15.70
Mass of container + Wet soil, g	29.10	29.00	38.20	32.70	24.70	25.90
Mass of container + Dry soil, g	23.20	23.40	28.60	25.40	22.00	22.80
Mass of water, g	5.90	5.60	9.60	7.30	2.70	3.10
Mass of dry soil, g	8.30	7.70	12.90	9.60	6.30	7.10
Water content, %	71.08	72.73	74.42	76.04	42.86	43.66
No of blows	35	27	22	17	-----	-----

Liquid Limit, % = 73 Plastic Limit, % = 43 PI, % = 30



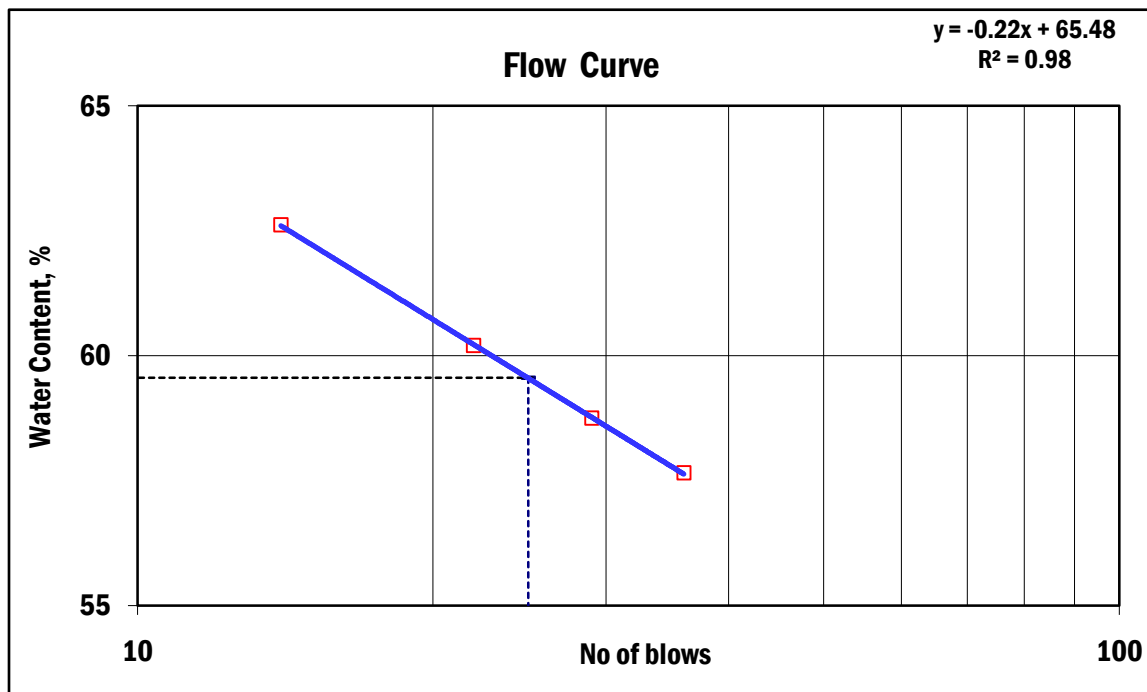
Liquid Limit and Plastic Limit Test

Sample No : TP-06

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	DYH	109	A508	55	J1	24
Mass of container, g	15.60	15.60	15.60	15.80	15.30	15.70
Mass of container + Wet soil, g	33.10	28.30	31.30	33.20	21.30	22.40
Mass of container + Dry soil, g	26.70	23.60	25.40	26.50	20.00	20.90
Mass of water, g	6.40	4.70	5.90	6.70	1.30	1.50
Mass of dry soil, g	11.10	8.00	9.80	10.70	4.70	5.20
Water content, %	57.66	58.75	60.20	62.62	27.66	28.85
No of blows	36	29	22	14	-----	-----

Liquid Limit, % = 60 Plastic Limit, % = 28 PI, % = 32



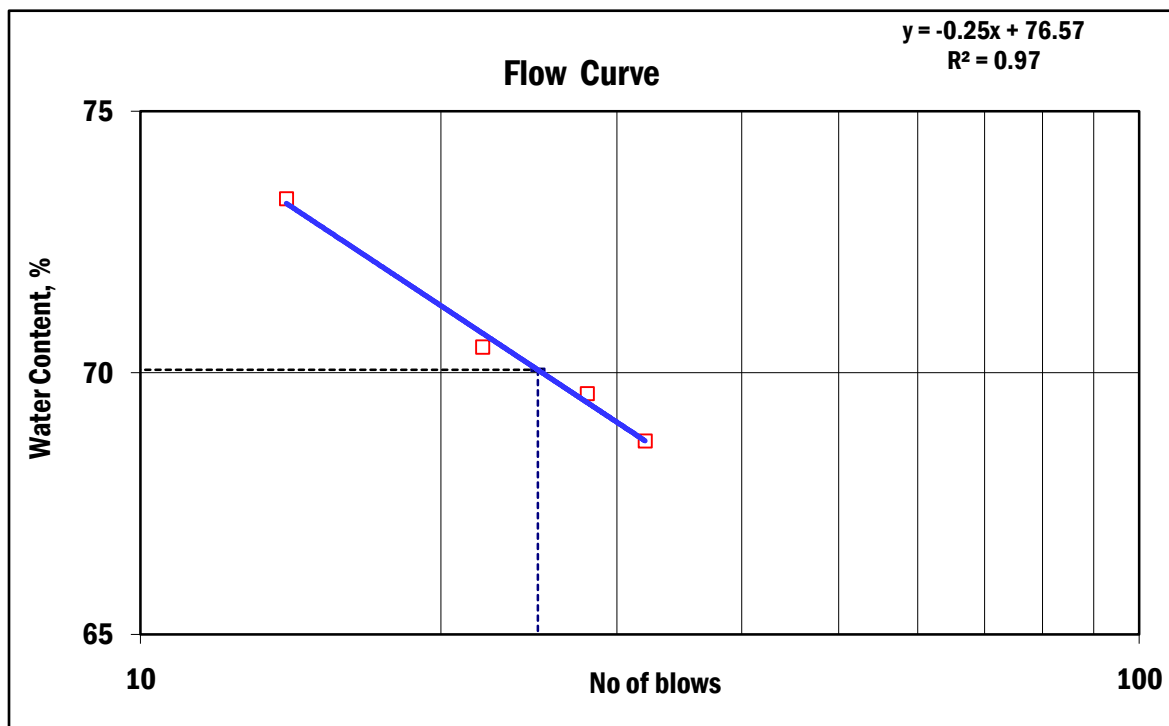
Liquid Limit and Plastic Limit Test

Sample No : TP-07

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	GA	D25	J3	19	D34	A3
Mass of container, g	15.60	15.90	15.40	15.50	15.60	15.90
Mass of container + Wet soil, g	37.70	33.20	36.20	36.30	22.50	25.90
Mass of container + Dry soil, g	28.70	26.10	27.60	27.50	20.90	23.40
Mass of water, g	9.00	7.10	8.60	8.80	1.60	2.50
Mass of dry soil, g	13.10	10.20	12.20	12.00	5.30	7.50
Water content, %	68.70	69.61	70.49	73.33	30.19	33.33
No of blows	32	28	22	14	-----	-----

Liquid Limit, % = 70 Plastic Limit, % = 32 PI, %= 38



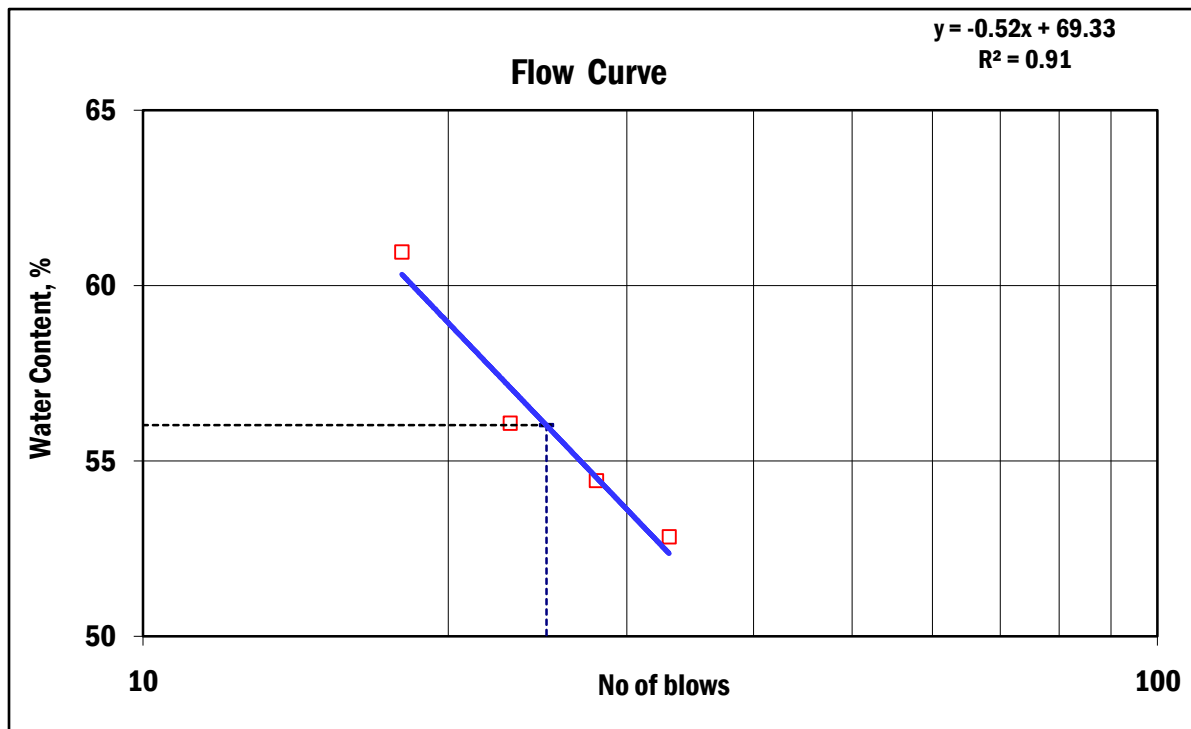
Liquid Limit and Plastic Limit Test

Sample No : TP-07

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	55	A500	24	109	D21	140
Mass of container, g	15.70	15.60	15.70	15.70	13.90	15.50
Mass of container + Wet soil, g	31.90	29.50	32.40	32.60	20.40	22.30
Mass of container + Dry soil, g	26.30	24.60	26.40	26.20	18.60	20.40
Mass of water, g	5.60	4.90	6.00	6.40	1.80	1.90
Mass of dry soil, g	10.60	9.00	10.70	10.50	4.70	4.90
Water content, %	52.83	54.44	56.07	60.95	38.30	38.78
No of blows	33	28	23	18	-----	-----

Liquid Limit, % = 56 Plastic Limit, % = 39 PI, % = 17



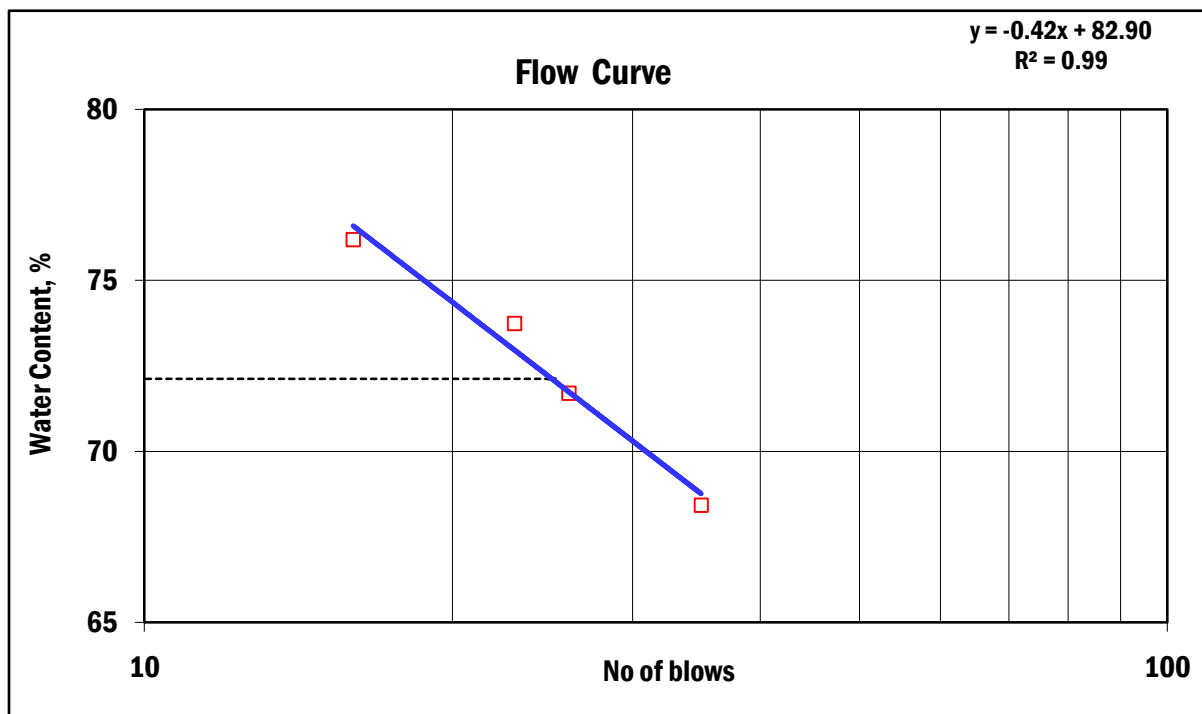
Liquid Limit and Plastic Limit Test

Sample No : TP-08

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	M5	A6	GP	CS2	A28	E10
Mass of container, g	15.70	15.40	15.60	15.80	15.70	15.90
Mass of container + Wet soil, g	31.70	33.60	32.80	34.30	22.20	22.10
Mass of container + Dry soil, g	25.20	26.00	25.50	26.30	20.60	20.60
Mass of water, g	6.50	7.60	7.30	8.00	1.60	1.50
Mass of dry soil, g	9.50	10.60	9.90	10.50	4.90	4.70
Water content, %	68.42	71.70	73.74	76.19	32.65	31.91
No of blows	35	26	23	16	-----	-----

Liquid Limit, % = 72 Plastic Limit, % = 32 PI, % = 40



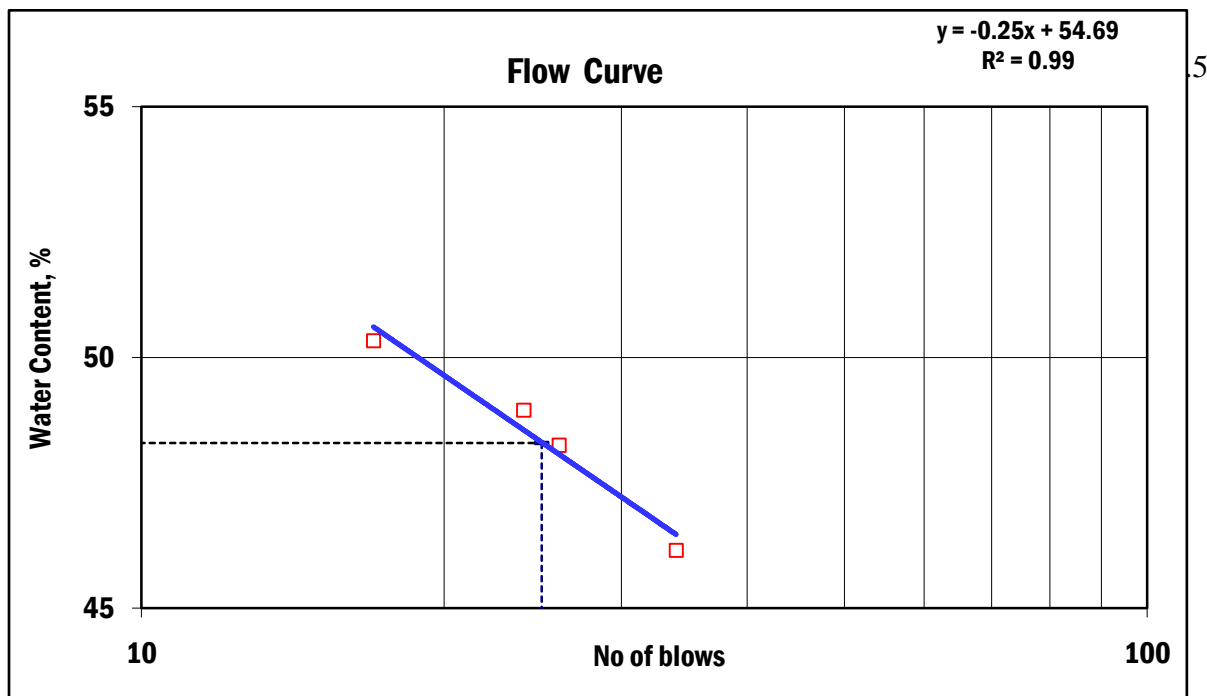
Liquid Limit and Plastic Limit Test

Sample No : TP-08

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	TT	A63	T2	Z8	80	G34
Mass of container, g	15.60	15.70	15.50	15.80	15.60	15.60
Mass of container + Wet soil, g	34.60	32.60	36.80	38.20	22.80	23.20
Mass of container + Dry soil, g	28.60	27.10	29.80	30.70	21.60	21.70
Mass of water, g	6.00	5.50	7.00	7.50	1.20	1.50
Mass of dry soil, g	13.00	11.40	14.30	14.90	6.00	6.10
Water content, %	46.15	48.25	48.95	50.34	20.00	24.59
No of blows	34	26	24	17	-----	-----

Liquid Limit, % = 48 Plastic Limit, % = 22 PI, %= 26



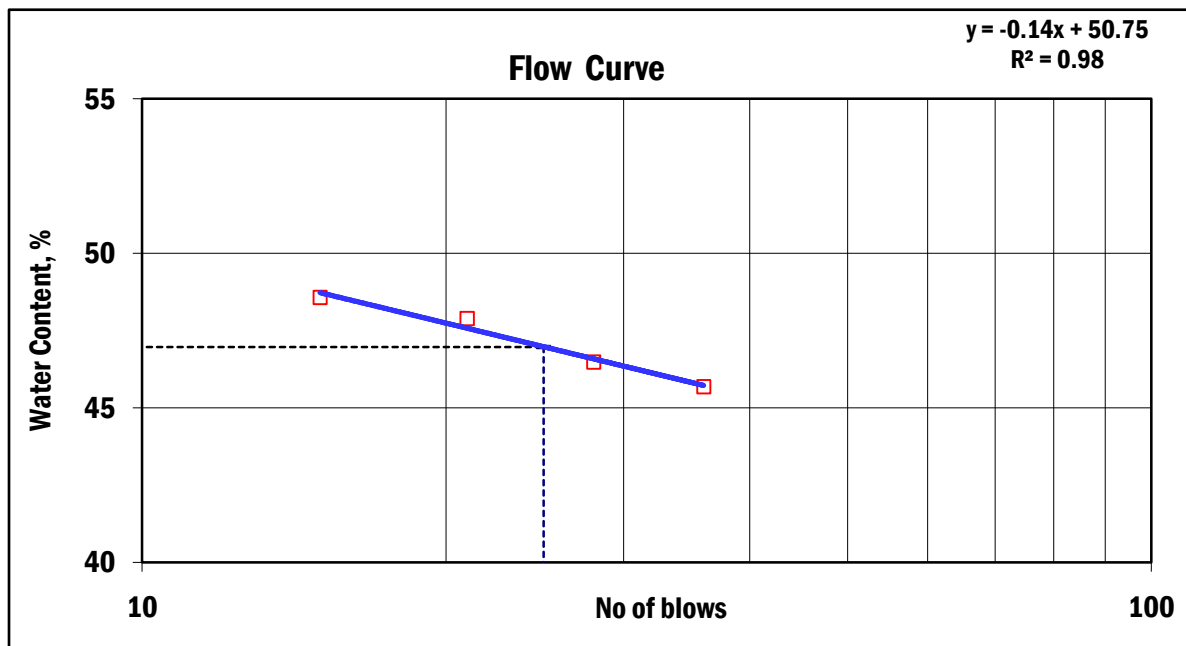
Liquid Limit and Plastic Limit Test

Sample No : TP-09

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	R10	GA	H44	A114	Z8	A34
Mass of container, g	15.50	15.60	14.20	15.90	15.80	15.70
Mass of container + Wet soil, g	39.10	36.40	35.20	36.70	22.40	27.80
Mass of container + Dry soil, g	31.70	29.80	28.40	29.90	21.10	25.40
Mass of water, g	7.40	6.60	6.80	6.80	1.30	2.40
Mass of dry soil, g	16.20	14.20	14.20	14.00	5.30	9.70
Water content, %	45.68	46.48	47.89	48.57	24.53	24.74
No of blows	36	28	21	15	-----	-----

Liquid Limit, % = 47 Plastic Limit, % = 25 PI, %= 22



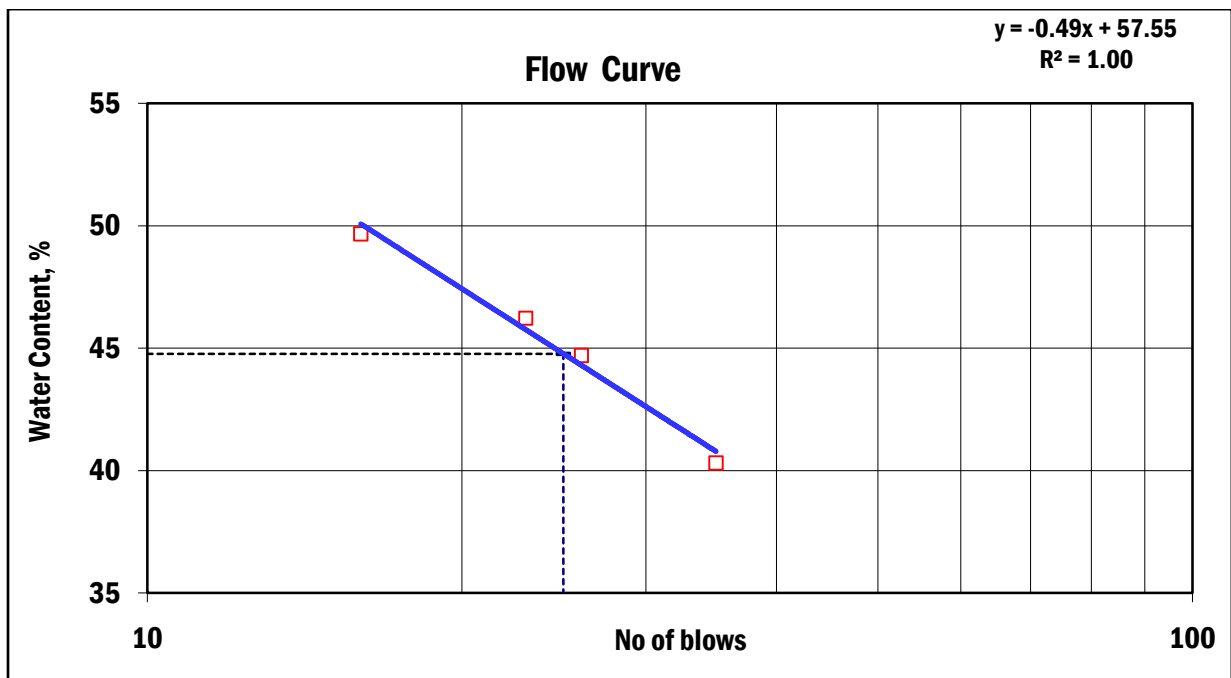
Liquid Limit and Plastic Limit Test

Sample No : TP-09

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	DYH	J1	Zb	+	TS	A9
Mass of container, g	15.50	15.20	15.60	15.00	15.60	15.40
Mass of container + Wet soil, g	33.60	34.30	29.20	37.60	21.70	22.10
Mass of container + Dry soil, g	28.4	28.40	24.90	30.10	20.70	21.00
Mass of water, g	5.20	5.90	4.30	7.50	1.00	1.10
Mass of dry soil, g	12.90	13.20	9.30	15.10	5.10	5.60
Water content, %	40.31	44.70	46.24	49.67	19.61	19.64
No of blows	35	26	23	16	-----	-----

Liquid Limit, % = 45 Plastic Limit, % = 20 PI, % = 25



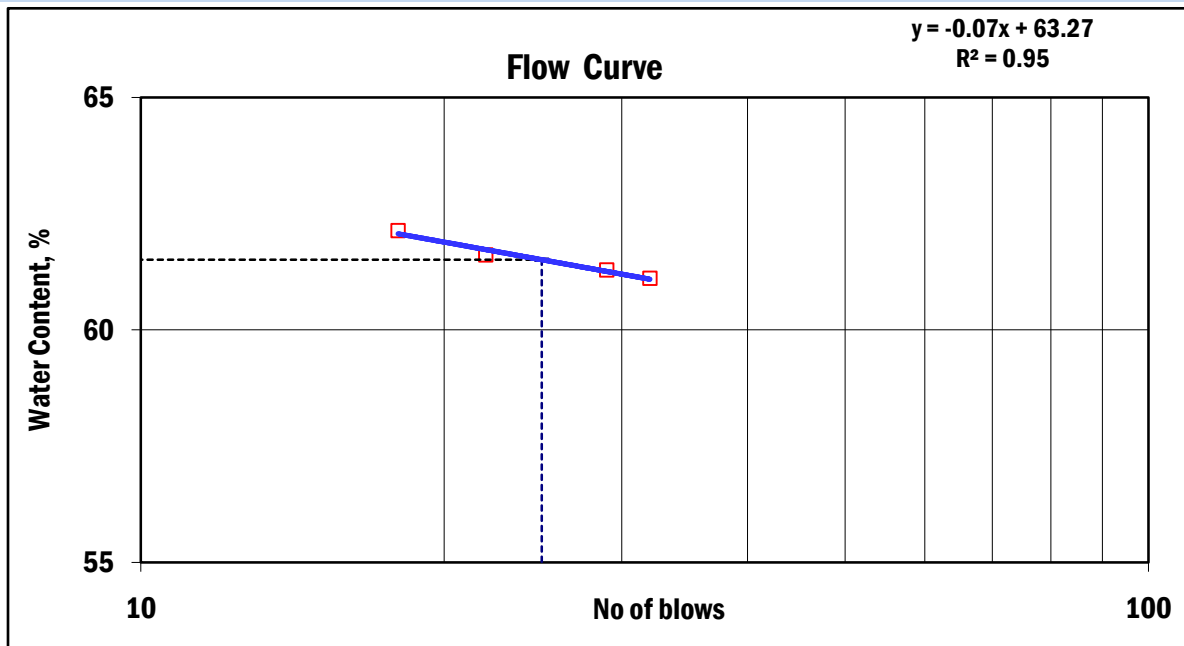
Liquid Limit and Plastic Limit Test

Sample No : TP-10

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	J3	A24	D34	10	B	E10
Mass of container, g	15.30	15.60	15.40	15.60	15.50	15.90
Mass of container + Wet soil, g	26.90	35.60	31.40	32.30	21.80	24.20
Mass of container + Dry soil, g	22.50	28.00	25.30	25.90	20.40	22.30
Mass of water, g	4.40	7.60	6.10	6.40	1.40	1.90
Mass of dry soil, g	7.20	12.40	9.90	10.30	4.90	6.40
Water content, %	61.11	61.29	61.62	62.14	28.57	29.69
No of blows	32	29	22	18	-----	-----

Liquid Limit, % = 62 Plastic Limit, % = 29 PI, % = 33



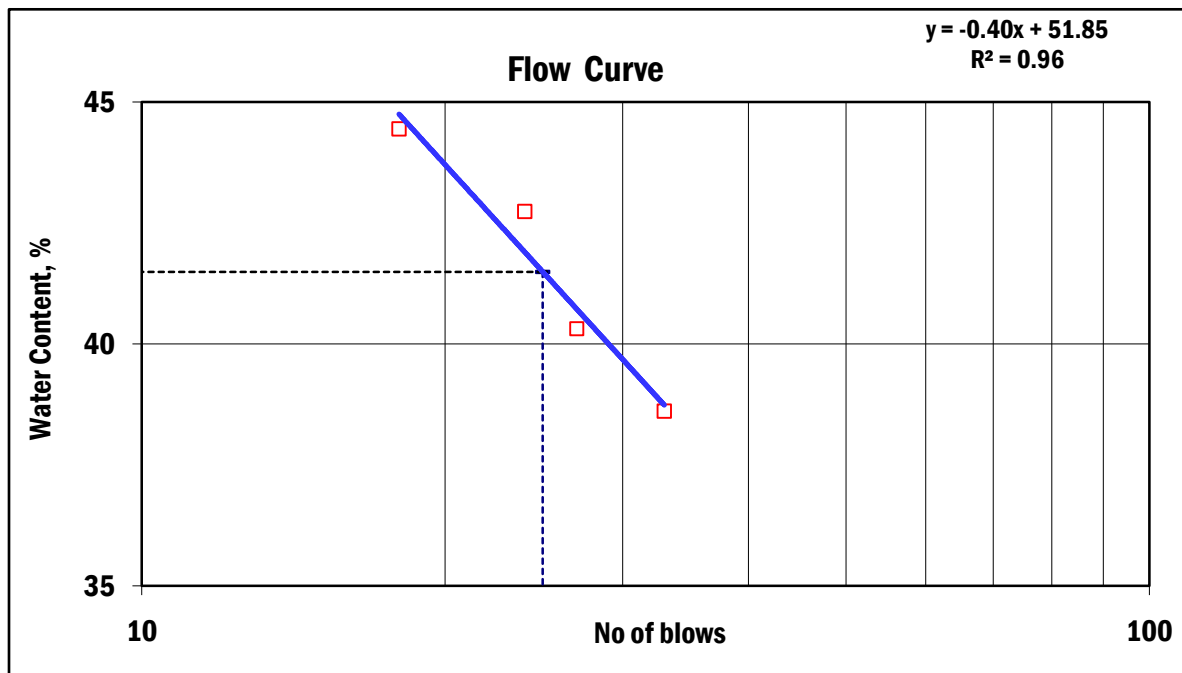
Liquid Limit and Plastic Limit Test

Sample No : TP-10

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	10	TT	B	E10	A24	19
Mass of container, g	15.60	15.60	15.50	15.80	15.70	15.50
Mass of container + Wet soil, g	29.60	33.00	33.20	32.70	22.10	21.90
Mass of container + Dry soil, g	25.70	28.00	27.90	27.50	20.65	20.40
Mass of water, g	3.90	5.00	5.30	5.20	1.45	1.50
Mass of dry soil, g	10.10	12.40	12.40	11.70	4.95	4.90
Water content, %	38.61	40.32	42.74	44.44	29.29	30.61
No of blows	33	27	24	18	-----	-----

Liquid Limit, % = 41 Plastic Limit, % = 30 PI, % = 11



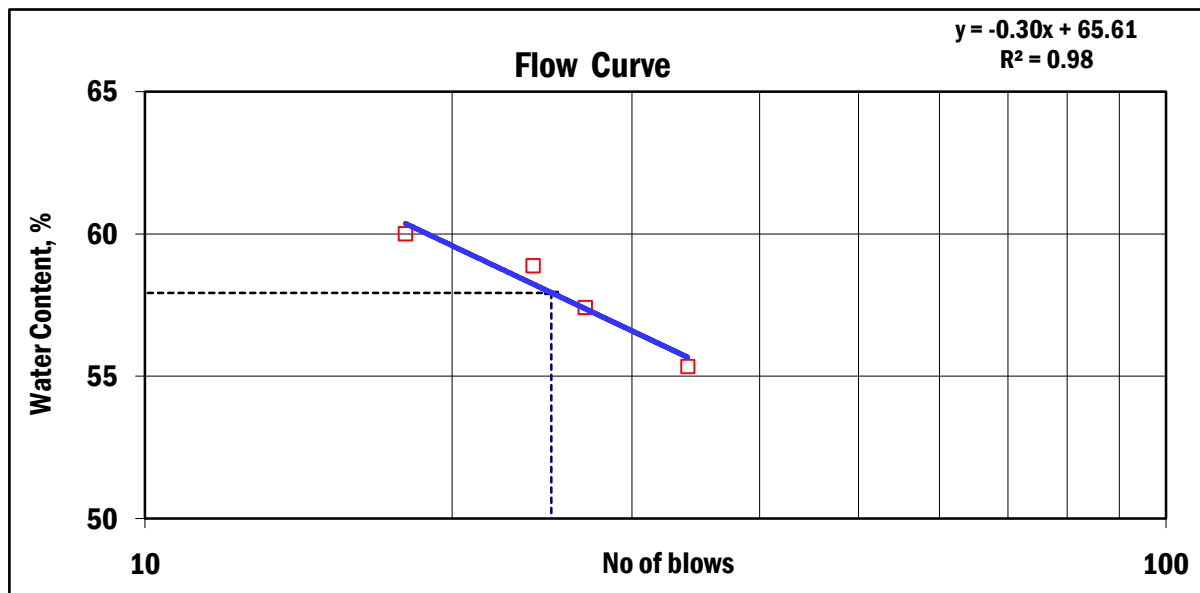
Liquid Limit and Plastic Limit Test

Sample No : TP-11

Sample Depth, m : 1.5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	TS	140	A9	+	D21	ZB
Mass of container, g	15.60	15.50	15.40	14.90	13.90	15.60
Mass of container + Wet soil, g	31.60	31.40	32.40	33.30	22.30	22.00
Mass of container + Dry soil, g	25.90	25.60	26.10	26.40	20.40	20.60
Mass of water, g	5.70	5.80	6.30	6.90	1.90	1.40
Mass of dry soil, g	10.30	10.10	10.70	11.50	6.50	5.00
Water content, %	55.34	57.43	58.88	60.00	29.23	28.00
No of blows	34	27	24	18	-----	-----

Liquid Limit, % = 58 Plastic Limit, % = 29 PI, % = 29



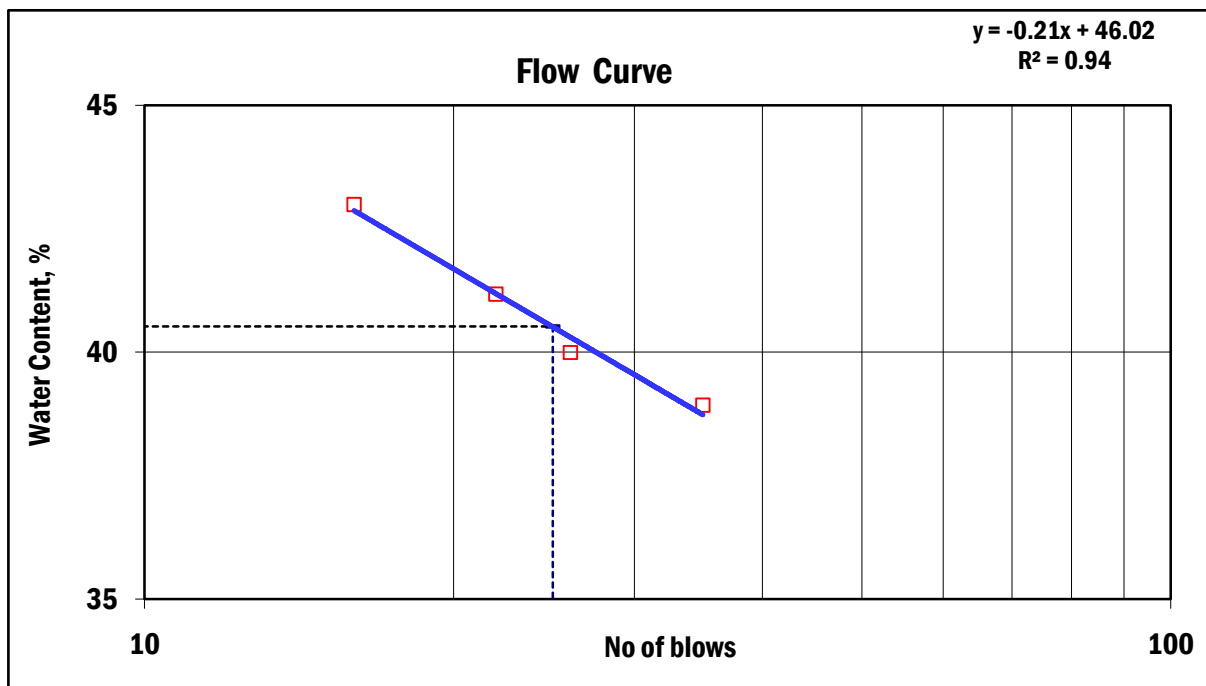
Liquid Limit and Plastic Limit Test

Sample No : TP-11

Sample Depth, m : 3.0

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	19	A63	A3	x	A6	A07
Mass of container, g	15.50	15.70	15.90	15.50	15.40	15.50
Mass of container + Wet soil, g	36.20	29.70	37.50	30.80	22.20	32.60
Mass of container + Dry soil, g	30.40	25.70	31.20	26.20	21.10	29.80
Mass of water, g	5.80	4.00	6.30	4.60	1.10	2.80
Mass of dry soil, g	14.90	10.00	15.30	10.70	5.70	14.30
Water content, %	38.93	40.00	41.18	42.99	19.30	19.58
No of blows	35	26	22	16	-----	-----

Liquid Limit, % = 41 Plastic Limit, % = 19 PI, % = 22



Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
Free swell test

Sample No : TP-01

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	18.0	18.0	80

Sample No : TP-01

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	20.0	20.0	100

Sample No : TP-02

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

Sample No : TP-02

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.0	15.0	15.5	55

Free swell test

Sample No : TP-03

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	17.0	17.0	17.0	70

Sample No : TP-03

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.0	16.0	16.0	60

Sample No : TP-04

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

Sample No : TP-04

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

Free swell test

Sample No : TP-05

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	19.0	19.5	95

Sample No : TP-05

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	19.0	18.5	85

Sample No : TP-06

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	19.0	19.0	19.0	90

Sample No : TP-06

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	19.0	18.5	85

Free swell test

Sample No : TP-07

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	18.0	18.0	80

Sample No : TP-07

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

Sample No : TP-08

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	19.0	18.5	85

Sample No : TP-08

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	16.0	17.0	70

Free swell test

Sample No : TP09

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	14.0	14.5	45

Sample No : Tp-09

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	13.0	14.0	13.5	35

Sample No : TP-10

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	19.0	19.5	95

Sample No : TP-10

Sample Depth, m : 3.0

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

Free swell test

Sample No : TP-11

Sample Depth, m : 1.5

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	17.0	18.0	17.5	75

Sample No : TP-11

Sample Depth, m : 3.0

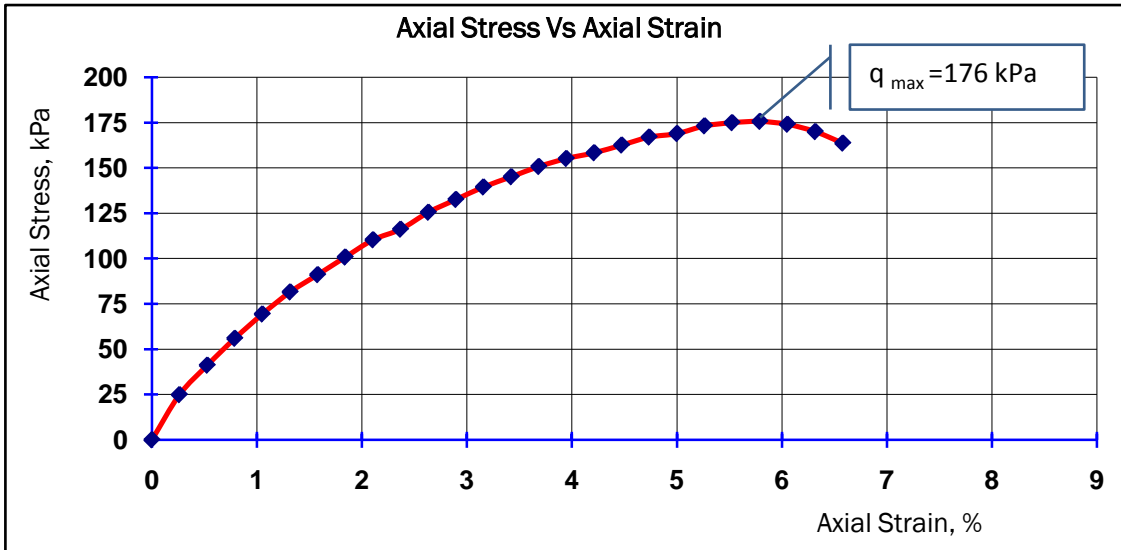
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

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Geotechnical Engineering Laboratory
Unconfined Compressive Strength Test

Test Pit No:	TP-01	Cross- Sectional Area , m ²	0.001134
Depth, m :	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Moisture content, %	33.90
Diameter of sample , mm	38	Wet unit weight, kN/m ³	16.73
Length of sample , mm	76	Dry Unit Weight, kN/m ³	12.50
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	20	0.0284	0.001137	24.98
0.40	0.53	33	0.0469	0.001140	41.10
0.60	0.79	45	0.0639	0.001143	55.90
0.80	1.05	56	0.0795	0.001146	69.38
1.00	1.32	66	0.0937	0.001149	81.55
1.20	1.58	74	0.1051	0.001152	91.19
1.40	1.84	82	0.1164	0.001155	100.78
1.60	2.11	90	0.1278	0.001159	110.31
1.80	2.37	95	0.1349	0.001162	116.13
2.00	2.63	103	0.1463	0.001165	125.57
2.20	2.89	109	0.1548	0.001168	132.53
2.40	3.16	115	0.1633	0.001171	139.44
2.60	3.42	120	0.1704	0.001174	145.11
2.80	3.68	125	0.1775	0.001177	150.74
3.00	3.95	129	0.1832	0.001181	155.14
3.20	4.21	132	0.1874	0.001184	158.32
3.40	4.47	136	0.1931	0.001187	162.66
3.60	4.74	140	0.1988	0.001191	166.99
3.80	5.00	142	0.2016	0.001194	168.91
4.00	5.26	146	0.2073	0.001197	173.18
4.20	5.53	148	0.2102	0.001200	175.07
4.40	5.79	149	0.2116	0.001204	175.76
4.60	6.05	148	0.2102	0.001207	174.09
4.80	6.32	145	0.2059	0.001211	170.08
5.00	6.58	140	0.1988	0.001214	163.76
5.20					

Unconfined Compressive Strength , kPa = 176

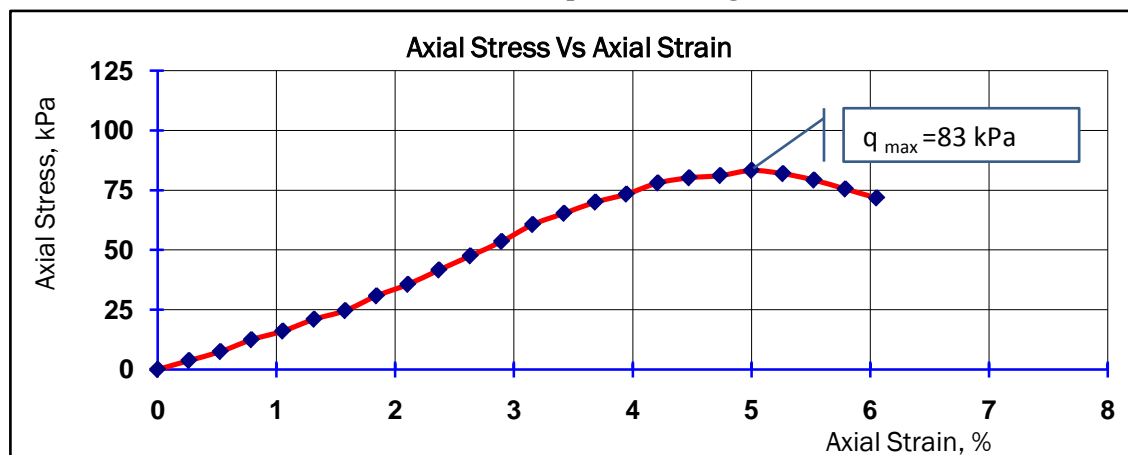


Unconfined Compressive Strength Test

Test Pit No:	TP-01	Cross- Sectional Area , m ²	0.001134
Depth, m :	3.00	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	58.99
Diameter of sample , mm	38	Moisture content, %	14.02
Length of sample , mm	76	Wet unit weight, kN/m ³	8.82
		Dry Unit Weight, kN/m ³	1.70
		Rate of Strain, mm/min	

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	3	0.0043	0.001137	3.75
0.40	0.53	6	0.0085	0.001140	7.47
0.60	0.79	10	0.0142	0.001143	12.42
0.80	1.05	13	0.0185	0.001146	16.11
1.00	1.32	17	0.0241	0.001149	21.01
1.20	1.58	20	0.0284	0.001152	24.65
1.40	1.84	25	0.0355	0.001155	30.73
1.60	2.11	29	0.0412	0.001159	35.55
1.80	2.37	34	0.0483	0.001162	41.56
2.00	2.63	39	0.0554	0.001165	47.55
2.20	2.89	44	0.0625	0.001168	53.50
2.40	3.16	50	0.0710	0.001171	60.63
2.60	3.42	54	0.0767	0.001174	65.30
2.80	3.68	58	0.0824	0.001177	69.95
3.00	3.95	61	0.0866	0.001181	73.36
3.20	4.21	65	0.0923	0.001184	77.96
3.40	4.47	67	0.0951	0.001187	80.14
3.60	4.74	68	0.0966	0.001191	81.11
3.80	5.00	70	0.0994	0.001194	83.26
4.00	5.26	69	0.0980	0.001197	81.85
4.20	5.53	67	0.0951	0.001200	79.25
4.40	5.79	64	0.0909	0.001204	75.49
4.60	6.05	61	0.0866	0.001207	71.75

Unconfined Compressive Strength , kPa = 83

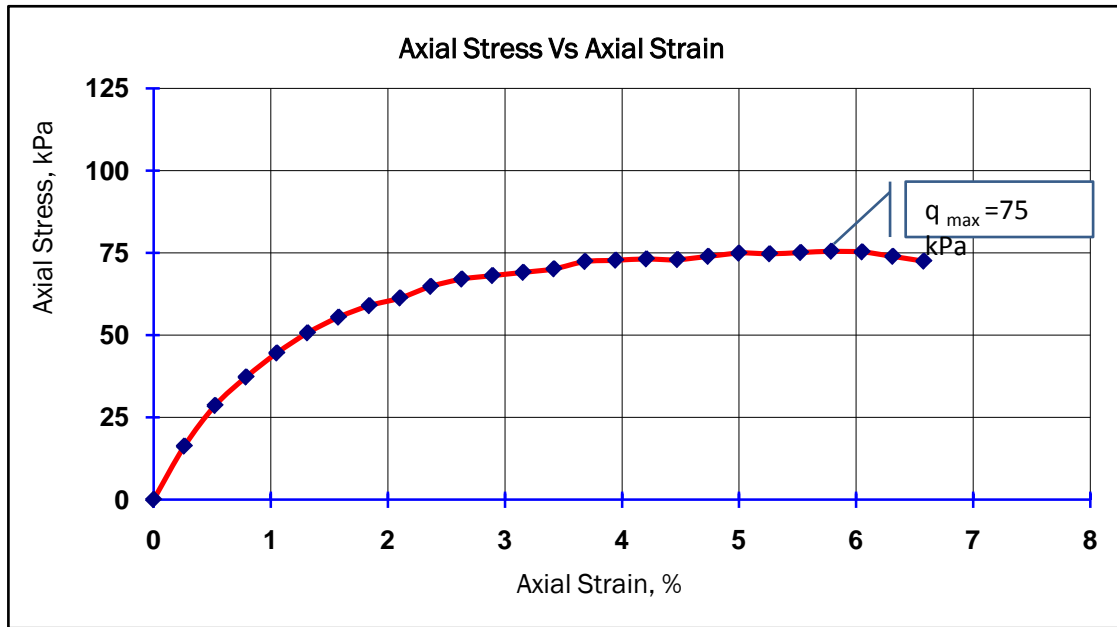


Unconfined Compressive Strength Test

Test Pit No:	TP-03	Cross- Sectional Area , m ²	0.001134
Depth, m :	3.00	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	31.14
Diameter of sample , mm	38	Moisture content, %	17.79
Length of sample , mm	76	Wet unit weight, kN/m ³	13.57
		Dry Unit Weight, kN/m ³	1.70
		Rate of Strain, mm/min	

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	13	0.0185	0.001137	16.23
0.40	0.53	23	0.0327	0.001140	28.65
0.60	0.79	30	0.0426	0.001143	37.27
0.80	1.05	36	0.0511	0.001146	44.60
1.00	1.32	41	0.0582	0.001149	50.66
1.20	1.58	45	0.0639	0.001152	55.45
1.40	1.84	48	0.0682	0.001155	58.99
1.60	2.11	50	0.0710	0.001159	61.29
1.80	2.37	53	0.0753	0.001162	64.79
2.00	2.63	55	0.0781	0.001165	67.05
2.20	2.89	56	0.0795	0.001168	68.09
2.40	3.16	57	0.0809	0.001171	69.11
2.60	3.42	58	0.0824	0.001174	70.14
2.80	3.68	60	0.0852	0.001177	72.36
3.00	3.95	60.5	0.0859	0.001181	72.76
3.20	4.21	61	0.0866	0.001184	73.16
3.40	4.47	61	0.0866	0.001187	72.96
3.60	4.74	62	0.0880	0.001191	73.95
3.80	5.00	63	0.0895	0.001194	74.94
4.00	5.26	63	0.0895	0.001197	74.73
4.20	5.53	63.5	0.0902	0.001200	75.11
4.40	5.79	64	0.0909	0.001204	75.49
4.60	6.05	64	0.0909	0.001207	75.28
4.80	6.32	63	0.0895	0.001211	73.90
5.00	6.58	62	0.0880	0.001214	72.52

Unconfined Compressive Strength , kPa =75

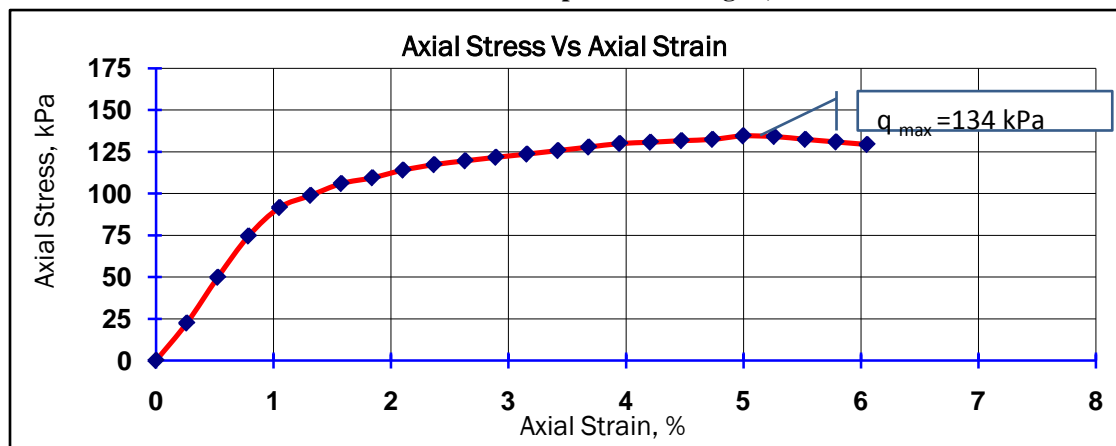


Unconfined Compressive Strength Test

Test Pit No:	TP-04	Cross- Sectional Area , m ²	0.001134
Depth, m :	1.50	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	37.47
Diameter of sample , mm	38	Moisture content, %	37.47
Length of sample , mm	76	Wet unit weight, kN/m ³	17.65
		Dry Unit Weight, kN/m ³	12.84
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	18	0.0256	0.001137	22.48
0.40	0.53	40	0.0568	0.001140	49.82
0.60	0.79	60	0.0852	0.001143	74.53
0.80	1.05	74	0.1051	0.001146	91.68
1.00	1.32	80	0.1136	0.001149	98.85
1.20	1.58	86	0.1221	0.001152	105.98
1.40	1.84	89	0.1264	0.001155	109.38
1.60	2.11	93	0.1321	0.001159	113.99
1.80	2.37	96	0.1363	0.001162	117.35
2.00	2.63	98	0.1392	0.001165	119.47
2.20	2.89	100	0.1420	0.001168	121.58
2.40	3.16	102	0.1448	0.001171	123.68
2.60	3.42	104	0.1477	0.001174	125.76
2.80	3.68	106	0.1505	0.001177	127.83
3.00	3.95	108	0.1534	0.001181	129.89
3.20	4.21	109	0.1548	0.001184	130.73
3.40	4.47	110	0.1562	0.001187	131.57
3.60	4.74	111	0.1576	0.001191	132.40
3.80	5.00	113	0.1605	0.001194	134.41
4.00	5.26	113	0.1605	0.001197	134.04
4.20	5.53	112	0.1590	0.001200	132.48
4.40	5.79	111	0.1576	0.001204	130.93
4.60	6.05	110	0.1562	0.001207	129.39

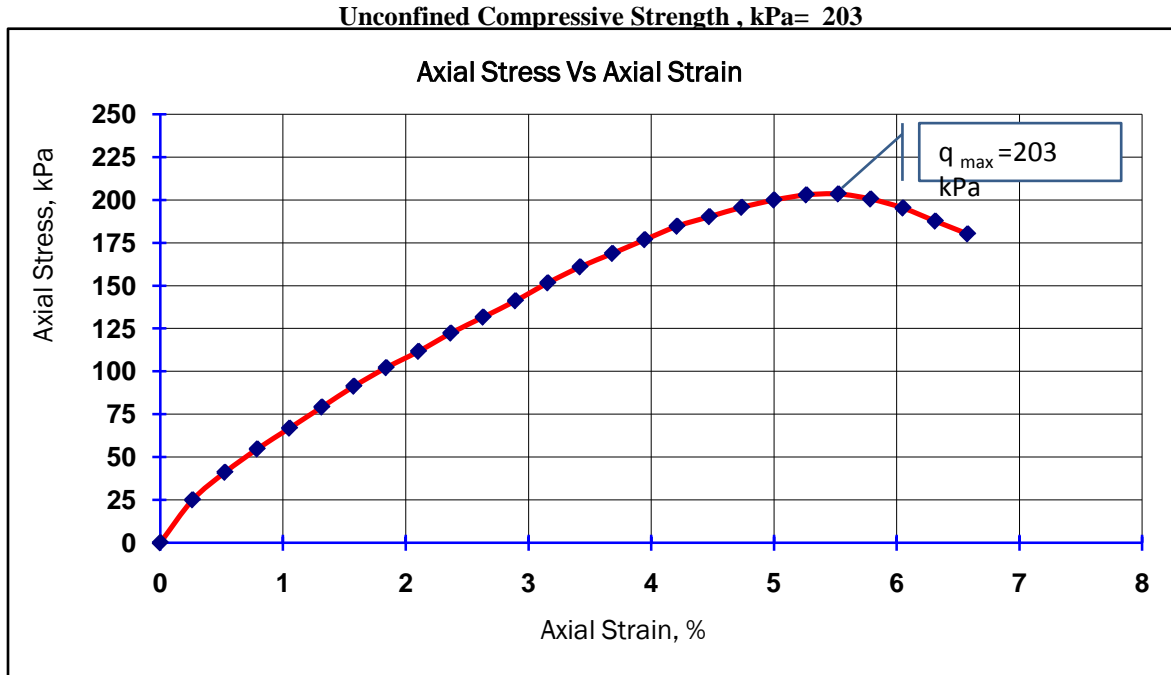
Unconfined Compressive Strength , kPa = **134**



Unconfined Compressive Strength Test

Test Pit No:	TP-04	Cross- Sectional Area , m ²	0.001134
Depth, m :	3.00	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	23.62
Diameter of sample , mm	38	Moisture content, %	23.62
Length of sample , mm	76	Wet unit weight, kN/m ³	18.87
		Dry Unit Weight, kN/m ³	15.26
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	20	0.0284	0.001137	24.98
0.40	0.53	33	0.0469	0.001140	41.10
0.60	0.79	44	0.0625	0.001143	54.66
0.80	1.05	54	0.0767	0.001146	66.90
1.00	1.32	64	0.0909	0.001149	79.08
1.20	1.58	74	0.1051	0.001152	91.19
1.40	1.84	83	0.1179	0.001155	102.01
1.60	2.11	91	0.1292	0.001159	111.54
1.80	2.37	100	0.1420	0.001162	122.24
2.00	2.63	108	0.1534	0.001165	131.67
2.20	2.89	116	0.1647	0.001168	141.04
2.40	3.16	125	0.1775	0.001171	151.57
2.60	3.42	133	0.1889	0.001174	160.83
2.80	3.68	140	0.1988	0.001177	168.83
3.00	3.95	147	0.2087	0.001181	176.79
3.20	4.21	154	0.2187	0.001184	184.70
3.40	4.47	159	0.2258	0.001187	190.17
3.60	4.74	164	0.2329	0.001191	195.61
3.80	5.00	168	0.2386	0.001194	199.83
4.00	5.26	171	0.2428	0.001197	202.84
4.20	5.53	172	0.2442	0.001200	203.46
4.40	5.79	170	0.2414	0.001204	200.53
4.60	6.05	166	0.2357	0.001207	195.26
4.80	6.32	160	0.2272	0.001211	187.68
5.00	6.58	154	0.2187	0.001214	180.13

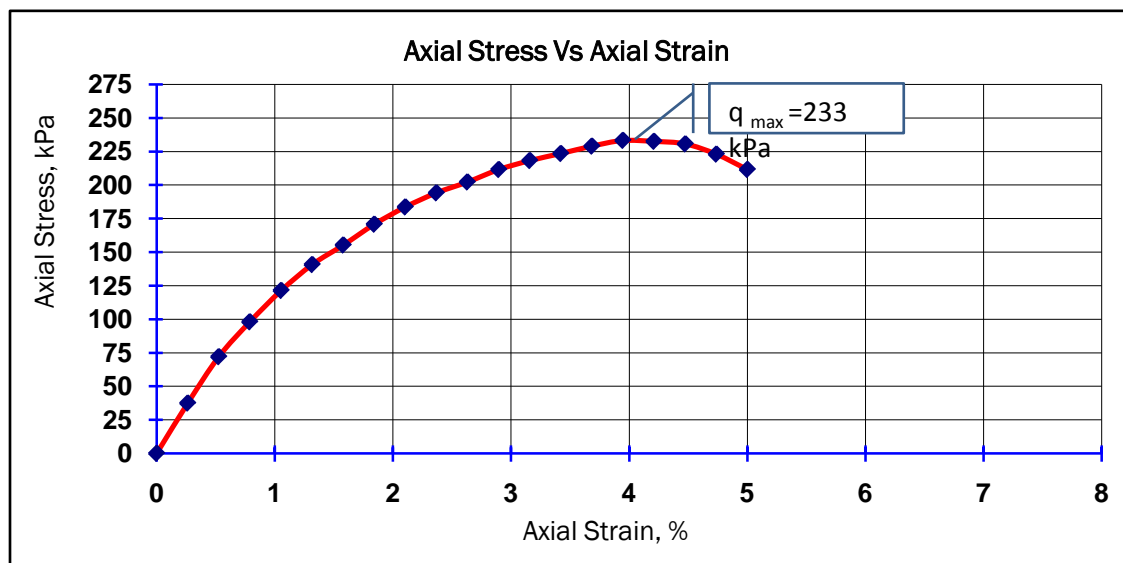


Unconfined Compressive Strength Test

Test Pit No:	TP-05	Cross- Sectional Area , m ²	0.001134
Depth, m :	1.50	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	32.85
Diameter of sample , mm	38	Moisture content, %	18.24
Length of sample , mm	76	Wet unit weight, kN/m ³	13.73
		Dry Unit Weight, kN/m ³	1.70
		Rate of Strain, mm/min	

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	30	0.0426	0.001137	37.46
0.40	0.53	58	0.0824	0.001140	72.24
0.60	0.79	79	0.1122	0.001143	98.13
0.80	1.05	98	0.1392	0.001146	121.41
1.00	1.32	114	0.1619	0.001149	140.86
1.20	1.58	126	0.1789	0.001152	155.27
1.40	1.84	139	0.1974	0.001155	170.83
1.60	2.11	150	0.2130	0.001159	183.86
1.80	2.37	159	0.2258	0.001162	194.37
2.00	2.63	166	0.2357	0.001165	202.38
2.20	2.89	174	0.2471	0.001168	211.55
2.40	3.16	180	0.2556	0.001171	218.26
2.60	3.42	185	0.2627	0.001174	223.71
2.80	3.68	190	0.2698	0.001177	229.13
3.00	3.95	194	0.2755	0.001181	233.31
3.20	4.21	194	0.2755	0.001184	232.68
3.40	4.47	193	0.2741	0.001187	230.84
3.60	4.74	187	0.2655	0.001191	223.05
3.80	5.00	178	0.2528	0.001194	211.73

Unconfined Compressive Strength , kPa = 233

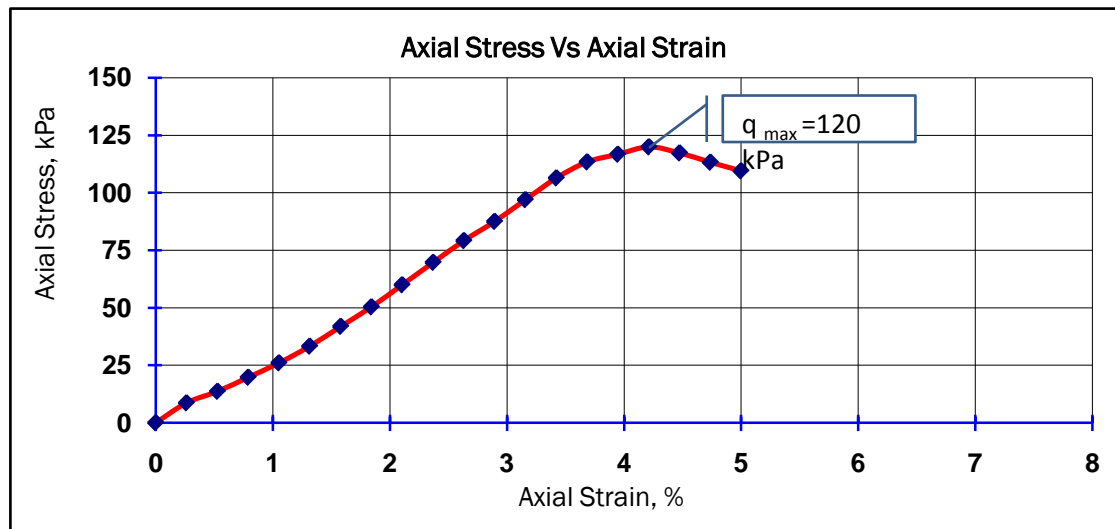


Unconfined Compressive Strength Test

Test Pit No:	TP-05	Cross- Sectional Area , m ²	0.001134
Depth, m :	3.00	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	30.93
Diameter of sample , mm	38	Moisture content, %	30.93
Length of sample , mm	76	Wet unit weight, kN/m ³	16.81
		Dry Unit Weight, kN/m ³	12.84
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	7	0.0099	0.001137	8.74
0.40	0.53	11	0.0156	0.001140	13.70
0.60	0.79	16	0.0227	0.001143	19.88
0.80	1.05	21	0.0298	0.001146	26.02
1.00	1.32	27	0.0383	0.001149	33.36
1.20	1.58	34	0.0483	0.001152	41.90
1.40	1.84	41	0.0582	0.001155	50.39
1.60	2.11	49	0.0696	0.001159	60.06
1.80	2.37	57	0.0809	0.001162	69.68
2.00	2.63	65	0.0923	0.001165	79.24
2.20	2.89	72	0.1022	0.001168	87.54
2.40	3.16	80	0.1136	0.001171	97.00
2.60	3.42	88	0.1250	0.001174	106.41
2.80	3.68	94	0.1335	0.001177	113.36
3.00	3.95	97	0.1377	0.001181	116.66
3.20	4.21	100	0.1420	0.001184	119.94
3.40	4.47	98	0.1392	0.001187	117.21
3.60	4.74	95	0.1349	0.001191	113.31
3.80	5.00	92	0.1306	0.001194	109.43

Unconfined Compressive Strength , kPa = **120**

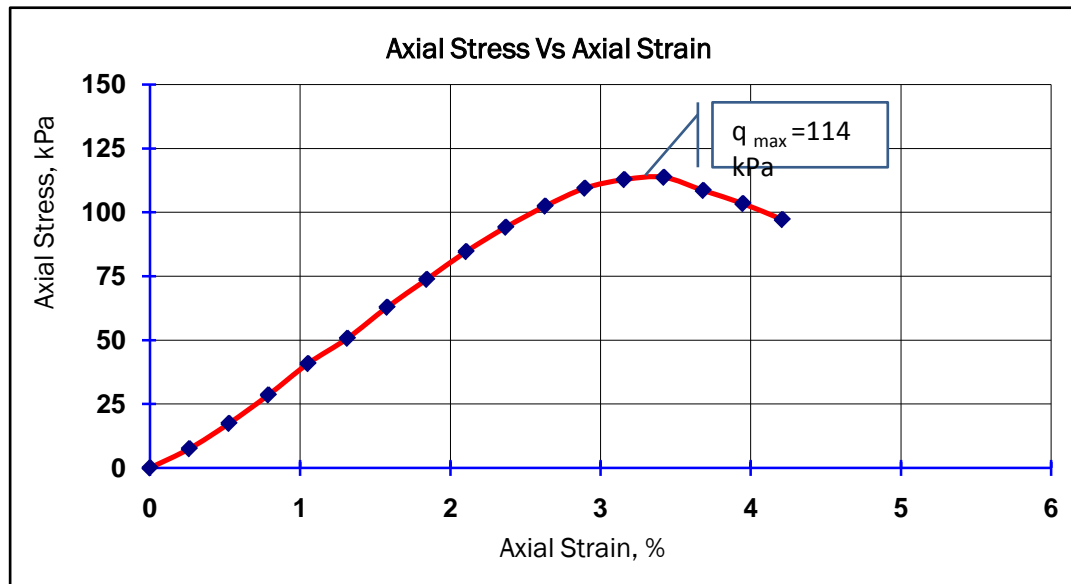


Unconfined Compressive Strength Test

Test Pit No:	TP-06	Cross- Sectional Area , m ²	0.001134
Depth, m :	1.50	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	43.04
Diameter of sample , mm	38	Moisture content, %	43.04
Length of sample , mm	76	Wet unit weight, kN/m ³	16.28
		Dry Unit Weight, kN/m ³	11.38
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	6	0.0085	0.001137	7.49
0.40	0.53	14	0.0199	0.001140	17.44
0.60	0.79	23	0.0327	0.001143	28.57
0.80	1.05	33	0.0469	0.001146	40.88
1.00	1.32	41	0.0582	0.001149	50.66
1.20	1.58	51	0.0724	0.001152	62.85
1.40	1.84	60	0.0852	0.001155	73.74
1.60	2.11	69	0.0980	0.001159	84.57
1.80	2.37	77	0.1093	0.001162	94.13
2.00	2.63	84	0.1193	0.001165	102.41
2.20	2.89	90	0.1278	0.001168	109.42
2.40	3.16	93	0.1321	0.001171	112.77
2.60	3.42	94	0.1335	0.001174	113.67
2.80	3.68	90	0.1278	0.001177	108.54
3.00	3.95	86	0.1221	0.001181	103.43
3.20	4.21	81	0.1150	0.001184	97.15

Unconfined Compressive Strength , kPa = **114**

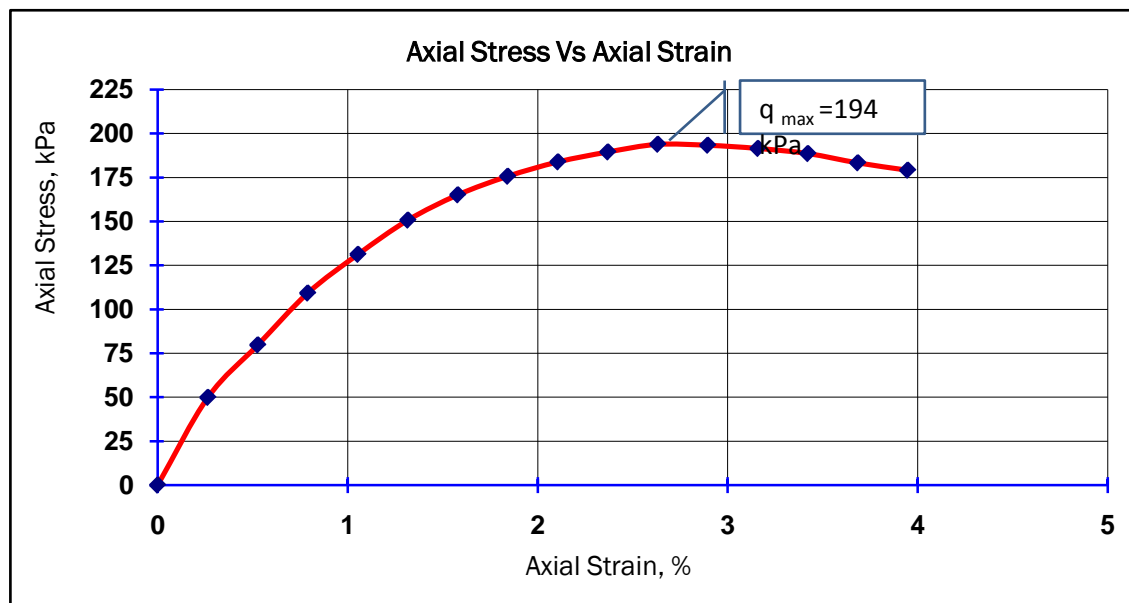


Unconfined Compressive Strength Test

Test Pit No:	TP-07	Cross- Sectional Area , m ²	0.001134
Depth, m :	3.00	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	43.64
Diameter of sample , mm	38	Moisture content, %	43.64
Length of sample , mm	76	Wet unit weight, kN/m ³	17.06
		Dry Unit Weight, kN/m ³	11.88
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	40	0.0568	0.001137	49.95
0.40	0.53	64	0.0909	0.001140	79.71
0.60	0.79	88	0.1250	0.001143	109.31
0.80	1.05	106	0.1505	0.001146	131.32
1.00	1.32	122	0.1732	0.001149	150.74
1.20	1.58	134	0.1903	0.001152	165.13
1.40	1.84	143	0.2031	0.001155	175.75
1.60	2.11	150	0.2130	0.001159	183.86
1.80	2.37	155	0.2201	0.001162	189.48
2.00	2.63	159	0.2258	0.001165	193.84
2.20	2.89	159	0.2258	0.001168	193.32
2.40	3.16	158	0.2244	0.001171	191.58
2.60	3.42	156	0.2215	0.001174	188.64
2.80	3.68	152	0.2158	0.001177	183.30
3.00	3.95	149	0.2116	0.001181	179.20

Unconfined Compressive Strength , kPa = **194**

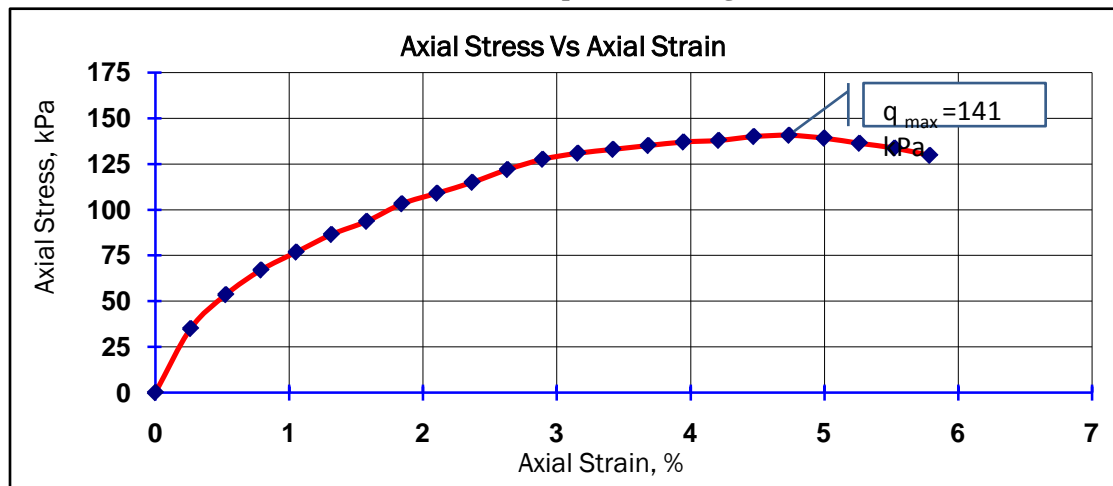


Unconfined Compressive Strength Test

Test Pit No:	TP-11	Cross- Sectional Area , m ²	0.001134
Depth, m :	1.50	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	33.80
Diameter of sample , mm	38	Moisture content, %	18.24
Length of sample , mm	76	Wet unit weight, kN/m ³	13.64
		Dry Unit Weight, kN/m ³	1.70
		Rate of Strain, mm/min	

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	28	0.0398	0.001137	34.97
0.40	0.53	43	0.0611	0.001140	53.56
0.60	0.79	54	0.0767	0.001143	67.08
0.80	1.05	62	0.0880	0.001146	76.81
1.00	1.32	70	0.0994	0.001149	86.49
1.20	1.58	76	0.1079	0.001152	93.66
1.40	1.84	84	0.1193	0.001155	103.24
1.60	2.11	89	0.1264	0.001159	109.09
1.80	2.37	94	0.1335	0.001162	114.91
2.00	2.63	100	0.1420	0.001165	121.91
2.20	2.89	105	0.1491	0.001168	127.66
2.40	3.16	108	0.1534	0.001171	130.95
2.60	3.42	110	0.1562	0.001174	133.02
2.80	3.68	112	0.1590	0.001177	135.07
3.00	3.95	114	0.1619	0.001181	137.10
3.20	4.21	115	0.1633	0.001184	137.93
3.40	4.47	117	0.1661	0.001187	139.94
3.60	4.74	118	0.1676	0.001191	140.75
3.80	5.00	117	0.1661	0.001194	139.17
4.00	5.26	115	0.1633	0.001197	136.41
4.20	5.53	113	0.1605	0.001200	133.67
4.40	5.79	110	0.1562	0.001204	129.75

Unconfined Compressive Strength , kPa = 141

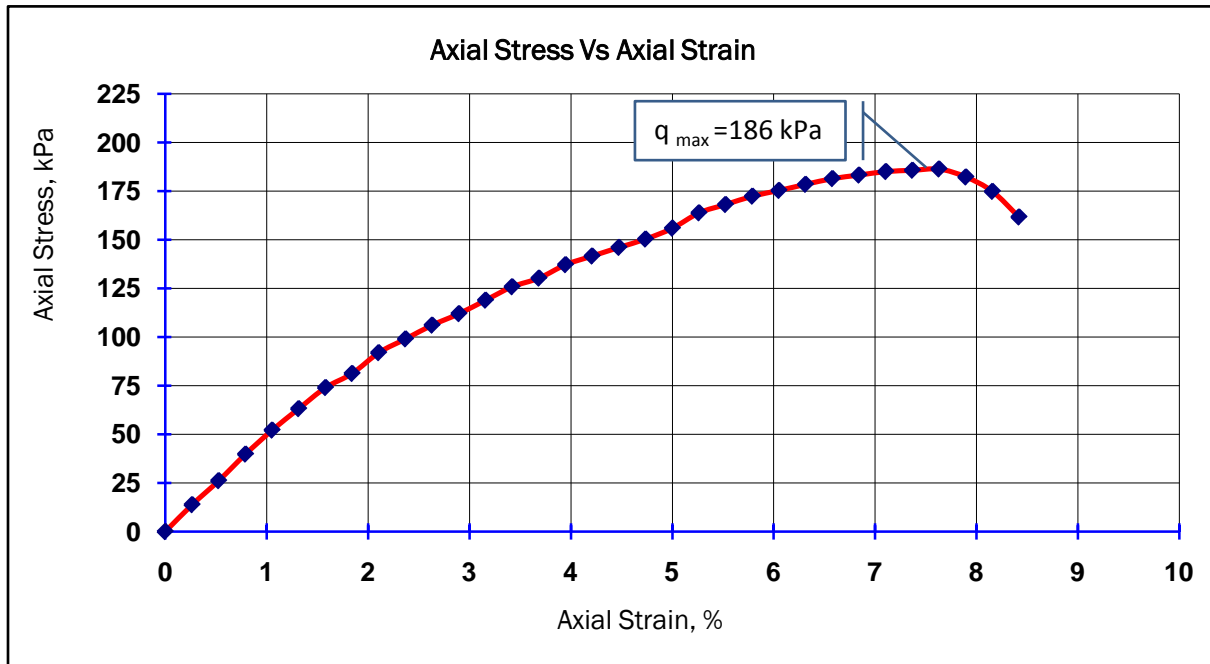


Unconfined Compressive Strength Test

Test Pit No:	TP-11	Cross- Sectional Area , m ²	0.001134
		Ring Calibration Factor,	
Depth, m :	3.00	kN/div	0.00142
Sampling	Undisturbed	Moisture content, %	26.87
Diameter of sample , mm	38	Wet unit weight, kN/m ³	18.26
Length of sample , mm	76	Dry Unit Weight, kN/m ³	14.39
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	11	0.0156	0.001137	13.74
0.40	0.53	21	0.0298	0.001140	26.16
0.60	0.79	32	0.0454	0.001143	39.75
0.80	1.05	42	0.0596	0.001146	52.03
1.00	1.32	51	0.0724	0.001149	63.02
1.20	1.58	60	0.0852	0.001152	73.94
1.40	1.84	66	0.0937	0.001155	81.11
1.60	2.11	75	0.1065	0.001159	91.93
1.80	2.37	81	0.1150	0.001162	99.02
2.00	2.63	87	0.1235	0.001165	106.06
2.20	2.89	92	0.1306	0.001168	111.86
2.40	3.16	98	0.1392	0.001171	118.83
2.60	3.42	104	0.1477	0.001174	125.76
2.80	3.68	108	0.1534	0.001177	130.24
3.00	3.95	114	0.1619	0.001181	137.10
3.20	4.21	118	0.1676	0.001184	141.52
3.40	4.47	122	0.1732	0.001187	145.92
3.60	4.74	126	0.1789	0.001191	150.29
3.80	5.00	131	0.1860	0.001194	155.82
4.00	5.26	138	0.1960	0.001197	163.69
4.20	5.53	142	0.2016	0.001200	167.97
4.40	5.79	146	0.2073	0.001204	172.22
4.60	6.05	149	0.2116	0.001207	175.27
4.80	6.32	152	0.2158	0.001211	178.30
5.00	6.58	155	0.2201	0.001214	181.30
5.20	6.84	157	0.2229	0.001217	183.13
5.40	7.11	159	0.2258	0.001221	184.94
5.60	7.37	160	0.2272	0.001224	185.57
5.80	7.63	161	0.2286	0.001228	186.20
6.00	7.89	158	0.22436	0.001231	182.21
6.20	8.16	152	0.21584	0.001235	174.79
6.40	8.42	141	0.20022	0.001238	161.68

Unconfined Compressive Strength , kPa =186



Addis Ababa University
Faculty of Technology
Civil Engineering Department
Geotechnical Engineering Laboratory
One Dimension Consolidation Test

Test Pit No **TP06**
Depth, m **3.00**

Time(min.)	Ötime	Dial Guage Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	7.000	7.026	6.450	6.074	5.502	4.700	3.672
0.1	0.32	-	6.868	6.398	6.002	5.420	4.632	3.612
0.25	0.50	-	6.852	6.390	5.992	5.404	4.618	3.596
0.50	0.71	-	6.840	6.382	5.980	5.392	4.602	3.572
1	1.00	-	6.818	6.372	5.968	5.370	4.576	3.540
2	1.41	-	6.790	6.354	5.938	5.336	4.534	3.488
4	2.00	-	6.746	6.324	5.898	5.280	4.464	3.420
8	2.83	-	6.682	6.284	5.840	5.200	4.456	3.326
15	3.87	-	6.614	6.242	5.770	5.106	4.448	3.212
30	5.48	-	6.552	6.194	5.694	4.992	4.304	3.084
60	7.75	-	6.514	6.160	5.616	4.900	4.178	2.954
120	10.95	-	6.490	6.136	5.596	4.836	4.082	2.826
240	15.49	-	6.472	6.110	5.564	4.790	3.822	2.744
480	21.91	-	6.460	6.096	5.534	4.748	3.772	2.680
1440	37.95	7.026	6.450	6.074	5.502	4.700	3.672	2.616

Cummulative Dial Guage Reading At The End Of Each Cosecutive Unloading

Dial Guage Reading, mm						
1600 [kPa]	800 [kPa]	400 [kPa]	200 [kPa]	100 [kPa]	50 [kPa]	7 [kPa]
2.616		2.840		3.120		3.520

One Dimension Consolidation Test

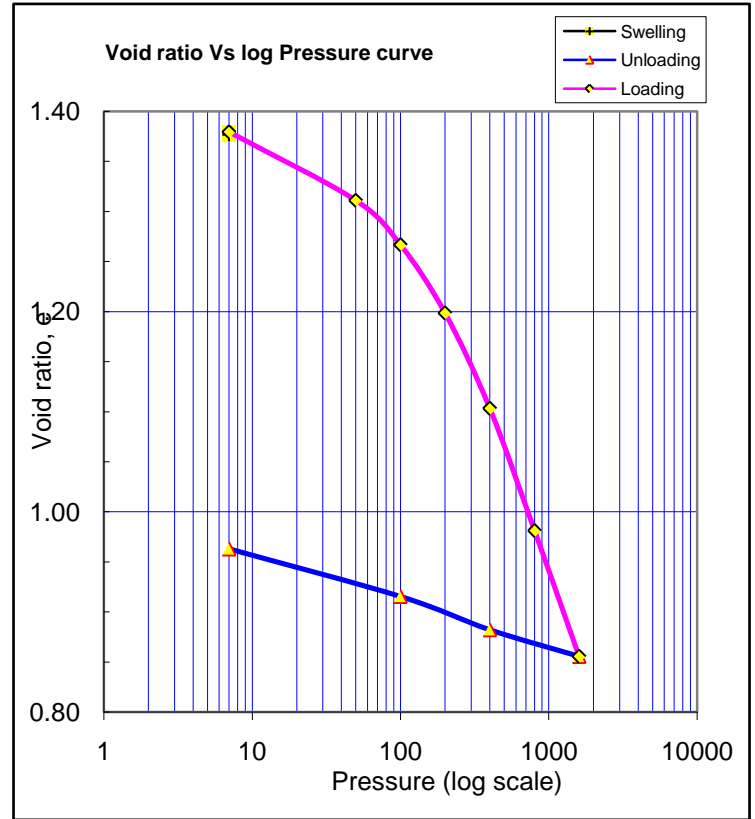
Test Pit No TP06
Depth, m 3.00

[A] In the beginning of the test

Sample type : Un disturbed
 Ring Area,cm²: 20.27
 Height of sample,mm: 20.00
 Seating Load,Kpa 7.00
 Initial Void Ratio, e₀: 1.38
 Initial moisture content,% 40.48
 Specific Gravity: 2.77
 Wet density,g/cm³ 1.74

[B] In the end of the test

Final Moisture Content,% 32.72
 Dry specimen wt (m_s), gm: 47.24
 Dry density,g/cm³ 1.17
 Height of Solids(H_s), mm 8.42
 Final Void Ratio, e_f: 0.96



[C] Calculation table:

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, H _v (mm)	Void Ratio, E
Loading					
7	7.000	0.00	20.00	11.58	1.38
7	7.026	0.03	20.03	11.61	1.38
50	6.450	-0.55	19.45	11.03	1.31
100	6.074	-0.93	19.07	10.66	1.27
200	5.502	-1.50	18.50	10.09	1.20
400	4.700	-2.30	17.70	9.28	1.10
800	3.672	-3.33	16.67	8.26	0.98
1600	2.616	-4.38	15.62	7.20	0.86
Unloading					
1600	2.616	-4.38	15.62	7.20	0.86
400	2.840	-4.16	15.84	7.42	0.88
100	3.120	-3.88	16.12	7.70	0.92
7	3.520	-3.48	16.52	8.10	0.96

One Dimension Consolidation Test

Test Pit No TP-07
Depth, m 3.00

Time(min.)	Ötime	Dial Guage Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	8.000	8.282	8.146	8.026	7.838	7.564	7.100
0.1	0.32	-	8.214	8.124	7.950	7.824	7.390	6.916
0.25	0.50	-	8.206	8.108	7.936	7.688	7.384	6.908
0.50	0.71	-	8.202	8.100	7.926	7.682	7.382	6.878
1	1.00	-	8.196	8.094	7.920	7.674	7.334	6.856
2	1.41	-	8.190	8.088	7.914	7.670	7.328	6.830
4	2.00	-	8.186	8.080	7.910	7.652	7.322	6.800
8	2.83	-	8.178	8.072	7.894	7.632	7.276	6.700
15	3.87	-	8.176	8.068	7.872	7.620	7.270	6.658
30	5.48	-	8.172	8.050	7.864	7.612	7.222	6.632
60	7.75	-	8.170	8.060	7.858	7.590	7.194	6.610
120	10.95	-	8.168	8.044	7.852	7.582	7.184	6.600
240	15.49	-	8.164	8.030	7.844	7.574	7.180	6.582
480	21.91	-	8.154	8.030	7.842	7.570	7.164	6.554
1440	37.95	8.282	8.146	8.026	7.838	7.564	7.100	6.504

Cummulative Dial Guage Reading At The End Of Each Cosecutive Unloading

Dial Guage Reading, mm						
1600 [kPa]	800 [kPa]	400 [kPa]	200 [kPa]	100 [kPa]	50 [kPa]	7 [kPa]
6.504		6.710		6.910		7.110

One Dimension Consolidation Test

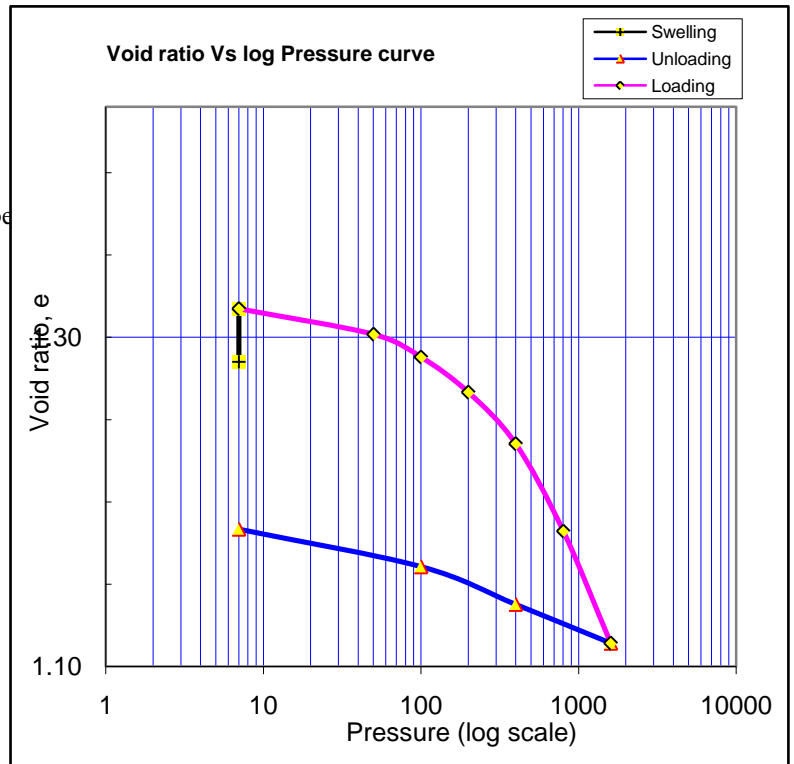
Test Pit No TP07
Depth, m 3.00

[A] In the beginning of the test

Sample type : Un disturbe
 Ring Area,cm²: 20.27
 Height of sample,mm: 20.00
 Seating Load,Kpa 7.00
 Initial Void Ratio, e₀: 1.32
 Initial moisture content,% 40.48
 Specific Gravity: 2.77
 Wet density,g/cm3 1.74

[B] In the end of the test

Final Moisture Content,% 26.79
 Dry specimen wt (m_s), gm: 49.14
 Dry density,g/cm3 1.21
 Height of Solids(H_s), mm 8.75
 Final Void Ratio, e_f: 1.18



[C] Calculation table:

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, H _v (mm)	Void Ratio, E
Loading					
7	8.000	0.00	20.00	11.25	1.29
7	8.282	0.28	20.28	11.53	1.32
50	8.146	0.15	20.15	11.39	1.30
100	8.026	0.03	20.03	11.27	1.29
200	7.838	-0.16	19.84	11.09	1.27
400	7.564	-0.44	19.56	10.81	1.24
800	7.100	-0.90	19.10	10.35	1.18
1600	6.504	-1.50	18.50	9.75	1.11
Unloading					
1600	6.504	-1.50	18.50	9.75	1.11
400	6.710	-1.29	18.71	9.96	1.14
100	6.910	-1.09	18.91	10.16	1.16
7	7.110	-0.89	19.11	10.36	1.18

One Dimension Consolidation Test

Test Pit No TP-08
Depth, m 3.00

Time(min.)	Ötime	Dial Guage Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	6.000	6.216	6.134	5.996	5.726	5.292	4.200
0.1	0.32	-	6.188	6.052	5.840	5.510	5.200	4.176
0.25	0.50	-	6.178	6.044	5.830	5.490	5.166	4.054
0.50	0.71	-	6.172	6.038	5.820	5.480	5.138	4.036
1	1.00	-	6.166	6.034	5.810	5.460	4.880	3.984
2	1.41	-	6.160	6.028	5.798	5.446	4.814	3.916
4	2.00	-	6.156	6.020	5.788	5.428	4.800	3.824
8	2.83	-	6.152	6.016	5.778	5.408	4.762	3.706
15	3.87	-	6.150	6.010	5.770	5.388	4.656	3.588
30	5.48	-	6.148	6.006	5.762	5.370	4.612	3.472
60	7.75	-	6.134	6.002	5.752	5.354	4.564	3.384
120	10.95	-	6.134	5.996	5.748	5.338	4.480	3.322
240	15.49	-	6.134	5.996	5.742	5.324	4.376	3.280
480	21.91	-	6.134	5.996	5.734	5.312	4.232	3.248
1440	37.95	6.216	6.134	5.996	5.726	5.292	4.200	3.212

Cummulative Dial Guage Reading At The End Of Each Cosecutive Unloading

Dial Guage Reading, mm						
1600 [kPa]	800 [kPa]	400 [kPa]	200 [kPa]	100 [kPa]	50 [kPa]	7 [kPa]
3.212		3.420		3.710		4.120

One Dimension Consolidation Test

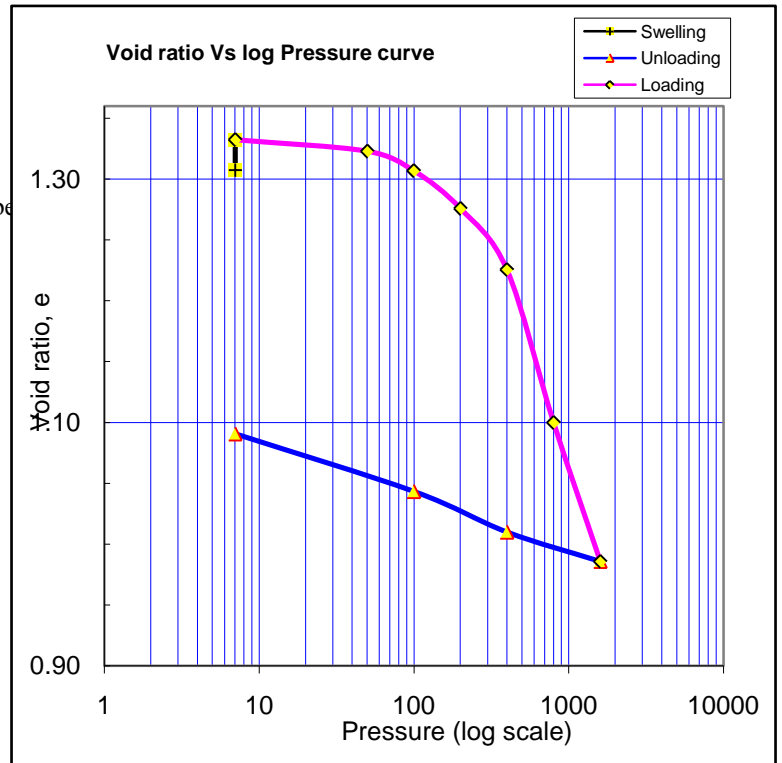
Test Pit No TP08
Depth, m 3.00

[A] In the beginning of the test

Sample type : Un Disturbed
 Ring Area, cm²: 20.27
 Height of sample, mm: 20.00
 Seating Load, Kpa: 7.00
 Initial Void Ratio, e₀: 1.33
 Initial moisture content, %: 40.48
 Specific Gravity: 2.77
 Wet density, g/cm³: 1.64

[B] In the end of the test

Final Moisture Content, %: 33.99
 Dry specimen wt (m_s), gm: 48.66
 Dry density, g/cm³: 1.20
 Height of Solids (H_s), mm: 8.67
 Final Void Ratio, e_f:



[C] Calculation table:

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, H _v (mm)	Void Ratio, E
Loading					
7	6.000	0.00	20.00	11.33	1.31
7	6.216	0.22	20.22	11.55	1.33
50	6.134	0.13	20.13	11.47	1.32
100	5.996	0.00	20.00	11.33	1.31
200	5.726	-0.27	19.73	11.06	1.28
400	5.292	-0.71	19.29	10.62	1.23
800	4.200	-1.80	18.20	9.53	1.10
1600	3.212	-2.79	17.21	8.54	0.99
Unloading					
1600	3.212	-2.79	17.21	8.54	0.99
400	3.420	-2.58	17.42	8.75	1.01
100	3.710	-2.29	17.71	9.04	1.04
7	4.120	-1.88	18.12	9.45	1.09

Appendix – B
(Meteorological data)

Investigation in to some of the engineering properties of soils found in Debre Birhan town

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.0	62.2	20.7	59.5	0.9	1.6	321.0	217.2	168.7	0.6	0.0	0.0
1991	4.8	8.3	64.6	21.0		63.7	215.6	387.5	86.6	6.4	0.0	6.4
1992	30.3	26.7	19.4	80.2	19.3	13.3	307.6	267.6	92.9	41.9	0.5	1.8
1993	x	43.2	0.0	116.9	60.5	9.1	x	168.4	x	43.2	0.0	1.1
1994	0.0	0.0	95.6	0.0	23.2	92.7	281.7	222.9	101.7	x	36.5	0.0
1995	0.0	28.5	19.1	68.4	26.3	23.3	x	233.8	60.4	5.1	0.0	1.7
1996	20.7	2.8	75.4	9.7	129.2	138.0	328.4	252.5	24.3	0.0	3.0	0.0
1997	29.5	4.0	41.2	82.4	25.9	96.9	272.1	200.6	34.8	89.7	x	x
1998	23.1	13.2	14.9	49.3	43.0	13.5	337.3	289.0	70.6	5.2	0.0	0.0
1999	6.9	0.0	26.5	2.8	11.0	48.9	362.4	365.1	52.4	59.6	1.4	0.0
2000	0.0	0.0	25.9	47.3	37.1	45.8	352.4	317.5	105.2	28.5	18.8	6.8
2001	0.0	33.8	71.2		64.6	34.9	406.7	260.4	32.2	4.1	0.0	3.4
2002	18.1	28.0	60.6	46.1	18.4	29.1	214.4	294.8	109.1	3.1	0.0	8.4
2003	15.6	36.3	60.2	85.7	3.8	99.5	334.1	288.7	74.2	x	0.0	7.4
2004	24.4	9.7	29.7	113.3	5.6	99.7	334.7	301.3	78.9	14.1	11.8	0.0
2005	34.3	4.5	28.6	49.5	76.4	91.1	310.7	228.3	106.8	0.7	1.5	0.0
2006	17.3	24.4	61.0	38.3	19.8	35.2	432.6	224.2	59.8	8.6	x	26.3
2007	2.0	30.4	8.9	71.8	13.6	93.2	309.9	414.6	128.5	4.9	5.7	0.0
2008	0.3	1.7	0.0	34.6	68.9	66.4	397.7	234.8	76.6	9.9	54.6	1.2
2009	47.2	0.0	8.1	31.4	14.9	13.7	423.4	273.1	31.4	36.6	1.2	25.3
2010	47.2	21.6	55.7	119.3	42.2	35.4	242.3	312.2	53.8	0.3	8.5	3.9
2011	0.3	7.0	76.8	38.6	111.2	73.4	357.4	312.3	79.0	0.0	4.3	0.0
2012	0.0	0.0	5.2	93.3	57.9	56.0	351.6	394.5	92.4	0.0	0.0	0.0
2013	0.8	0.0	48.8	54.2	23.9	40.1	358.5	204.4	79.6	63.1	11.5	0.0

Monthly rain fall data from national metrological agency

Investigation in to some of the engineering properties of soils found in Debre Birhan town

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	19.0	18.5	19.9	20.1	22.6	23.0	18.6	18.9	18.4	18.2	18.5	18.8
1991	23.3	22.7	22.7	22.1	x	22.5	18.0	17.8	19.0	18.2	18.6	18.3
1992	18.1	18.9	21.7	21.5	21.6	22.6	18.3	16.6	17.5	17.3	17.3	18.7
1993	18.9	18.7	20.6	19.4	19.9	21.9	18.5	18.9	18.4	18.0	18.2	18.9
1994	19.7	20.9	20.4	21.5	22.0	21.4	17.4	17.6	18.1	x	19.3	19.8
1995	20.2	20.8	21.3	20.8	22.1	23.4	x	18.7	19.4	19.2	19.8	19.7
1996	19.1	21.8	20.7	21.2	20.1	19.2	18.5	18.6	19.6	18.9	18.7	18.4
1997	19.2	20.1	21.2	19.9	21.4	21.1	18.0	18.3	19.3	18.3	18.8	19.8
1998	19.8	21.0	20.9	22.2	22.4	23.3	17.8	17.7	18.7	18.6	18.4	18.4
1999	19.3	21.5	20.5	21.8	22.6	22.4	17.1	18.1	18.6	17.9	17.8	18.6
2000	19.7	20.5	21.5	20.8	21.8	22.7	18.3	17.7	18.5	18.4	18.5	19.4
2001	19.9	20.8	19.2	21.2	22.2	21.5	17.9	17.6	19.6	19.9	19.6	19.3
2002	19.5	21.2	20.7	21.4	23.0	22.8	21.5	17.5	18.6	19.6	19.8	19.3
2003	20.3	21.4	21.2	20.8	21.8	22.5	18.0	18.3	19.0	19.4	18.5	19.4
2004	20.7	20.4	21.0	20.4	23.1	21.2	18.7	18.7	19.1	18.6	19.5	19.6
2005	20.1	22.1	22.0	21.3	20.4	21.6	18.3	18.9	19.3	19.0	18.8	18.9
2006	20.0	21.0	20.5	20.0	21.9	22.6	19.0	18.0	18.6	19.6	x	19.1
2007	19.9	20.6	21.8	20.8	22.7	21.2	18.0	18.2	18.7	19.0	18.6	18.7
2008	19.4	20.2	22.0	20.8	21.3	21.2	18.9	19.0	19.4	19.2	18.4	19.1
2009	19.3	20.3	21.5	21.7	22.4	23.6	17.9	18.7	19.9	18.8	19.7	18.5
2010	19.3	20.9	20.4	20.8	21.3	22.7	18.7	18.1	19.0	19.8	19.2	19.2
2011	19.5	21.6	20.1	21.9	21.2	22.2	19.1	18.2	18.8	19.4	19.4	19.4
2012	20.3	21.3	22.1	20.6	21.4	22.3	18.4	18.3	19.4	19.8	20.5	20.2
2013	20.8	21.9	22.1	22.2	22.0	22.0	17.6	17.4	19.1	18.8	19.0	19.1

Monthly Maximum Temperature data from national metrological agency

Investigation in to some of the engineering properties of soils found in Debre Birhan town

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	3.1	9.2	7.1	6.8	5.5	5.9	8.6	8.9	7.3	2.0	2.1	0.2
1991	5.3	6.1	8.4	7.7	x	7.4	9.0	8.8	7.1	1.6	1.7	0.8
1992	6.8	7.9	8.5	7.3	6.5	6.9	7.9	9.0	7.0	3.6	3.9	4.2
1993	5.8	6.9	5.8	8.2	6.8	6.5	8.8	8.6	7.8	4.5	1.5	2.5
1994	3.6	5.1	8.7	8.0	7.1	7.1	8.6	7.8	6.7	x	0.8	2.5
1995	2.8	7.5	6.7	8.7	6.4	6.7	x	9.2	7.0	2.7	1.2	5.8
1996	6.3	4.6	7.4	7.1	8.0	7.9	8.2	8.5	6.4	1.4	2.1	3.2
1997	6.1	2.2	8.2	7.0	6.7	8.5	8.6	8.1	7.1	6.1	4.3	2.3
1998	7.7	8.4	9.3	9.6	7.7	7.2	9.3	9.5	7.3	3.7	-1.0	-2.1
1999	2.2	3.1	5.9	5.2	5.8	6.3	8.6	8.6	6.2	4.6	-1.2	1.8
2000	1.0	3.4	4.8	7.0	7.1	5.7	8.6	8.1	6.8	3.3	1.7	1.0
2001	1.5	4.5	8.3	6.0	8.2	8.0	9.2	9.2	6.4	3.3	2.9	4.6
2002	5.0	6.3	8.4	7.6	7.7	7.6	9.1	9.1	7.5	3.1	2.8	7.2
2003	5.3	6.9	7.9	9.5	7.0	8.0	9.4	9.6	8.1	3.0	2.7	1.6
2004	5.0	4.4	5.6	8.9	6.7	8.1	9.2	9.0	7.0	3.3	2.7	5.2
2005	5.3	7.3	8.3	9.2	9.2	7.8	9.2	9.2	8.3	3.9	2.0	1.7
2006	5.9	8.0	7.5	8.5	7.4	8.2	9.8	9.8	7.4	5.4	x	4.7
2007	6.6	7.5	7.7	8.5	8.1	9.0	9.6	9.2	7.5	3.4	3.9	1.0
2008	5.4	5.0	5.5	7.7	8.6	8.5	8.6	9.2	7.0	4.2	4.0	4.6
2009	6.3	7.6	8.1	7.4	7.0	8.4	9.3	9.3	6.5	4.9	3.1	7.3
2010	6.3	9.3	9.2	9.2	9.2	8.1	9.1	9.3	7.2	3.7	4.1	4.8
2011	6.5	4.6	7.4	8.8	7.9	7.6	8.7	8.7	7.5	3.4	4.8	2.0
2012	3.8	3.5	6.0	8.4	7.5	7.6	8.7	7.9	6.5	1.8	1.9	3.7
2013	3.6	5.2	8.6	7.5	7.2	7.9	8.7	8.5	6.3	4.2	3.7	1.3

Monthly Minimum Temperature data from national metrological agency

DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Messele Haile and has not been presented as a thesis for a degree in any other university, and that all sources of materials used for this thesis have also been duly acknowledged.

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Addis Ababa.

Date of submission: October, 2015