

# ADDIS ABABA UNIVERSITY



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

### *Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project*

A thesis submitted to the school of Graduate Studies of Addis Ababa University in Partial fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (**Geotechnical Engineering**)

**By**

**Endalk Fentie Teshome**

**Advisor: Dr.Ing. Samuel Tadesse**

**November, 2019**



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SCHOOL OF CIVIL AND ENVIRONMENTAL  
ENGINEERING**

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## Abstract

Collapsible soils present significant geotechnical and structural engineering challenges for different types of constructions. These soils suffer volume changes and collapse deformation upon wetting. Situations in arid and semi-arid climates favor the formation of the most problematic collapsible soils. Almost all naturally occurring collapsible soil deposits are debris flows, rapid alluvial depositions, and wind-blown deposits (loess). If unrecognized, it may cause pumps or deep sinkholes, which leads to traffic accidents and loss of lives. Hence, this research was conducted to investigate the physical properties and the severity of collapse of the soils found in the road project of Turmi - Omo.

To achieve the objective of this research, papers, journals, actual design reports, contract document of the project and different books have been scrutinized under literature review, samples from the research area were collected from different test pits below the natural ground level, and then laboratory tests for index properties and oedometer tests have been carried out using disturbed and remolded samples.

From the test results the subgrade soil classes fall in A-4, A-6 and A-7-6 according to AASHTO classification. In addition, according to USCS the soils under investigation are classified as ML (group of inorganic silt of medium compressibility). The evaluation of susceptibility of soil to collapse was measured by performing single oedometer tests on samples remolded at their in-situ densities and at maximum dry densities.

The oedometer test results at the investigated depth of soil showed that, the collapse potential of samples remolded at their in-situ densities and natural moisture contents is within the range of 1.49 % to 5.93 % and that indicates that the severity of collapse is slight to moderate. And also, the collapse potential of samples remolded at their maximum dry densities and optimum moisture contents is within the range of 0.19 % to 0.495 % and thus the severity of collapse is very slight. Though the results indicated that the severity to collapse is very slight, the soil in the investigated section is collapsible and the collapse potential could be significantly reduced by compaction during construction.

## Table of Contents

<b>Acknowledgements.....</b>	<b>I</b>
<b>Abstract.....</b>	<b>II</b>
<b>List of Tables .....</b>	<b>VI</b>
<b>List of Figures.....</b>	<b>VII</b>
<b>List of abbreviations and symbols.....</b>	<b>VIII</b>
<b>Chapter One .....</b>	<b>1</b>
1. Introduction.....	1
1.1. General.....	1
1.2. Statement of the Problem .....	2
1.3. Objectives .....	2
1.3.1. General Objective.....	2
1.3.2. Specific objectives: .....	2
1.4. Research Methodology.....	3
1.5. Limitation of Study.....	5
<b>Chapter Two.....</b>	<b>6</b>
2. Literature review .....	6
2.1. General.....	6
2.2. Origin and Occurrence of Collapsible Soil.....	7
2.2.1. Residual Soils.....	7
2.2.2. Aeolian Soils .....	8
2.2.3. Alluvial and Colluvial Soils .....	8
2.3. Properties of Collapsible Soils .....	9
2.3.1. Relationship between Collapse Potential with other Parameters .....	11
2.4. Identification of Collapsible Soil.....	11
2.4.1. Direct Methods.....	12
2.4.1.1. Single Oedometer Test.....	12
2.4.1.2. Using Trial Pit and Observation of Existing Structure .....	13
2.4.2. Indirect Method to Evaluate the Collapse Potential.....	14
2.5. Review of Laboratory Index and Collapse Potential Tests .....	16
2.6. Previous Researches .....	20
2.7. Improvement Method of Collapsible Soil .....	21
2.7.1. Dynamic Compaction.....	22
2.7.2. Impact Roller Compaction .....	23
2.7.3. Pre-Wetting .....	24

2.7.4.	Chemical Stabilization or Grouting.....	24
2.7.5.	Treatment using Cement Material.....	25
2.7.6.	Excavate and Re-compact .....	25
<b>Chapter Three</b>	<b>.....</b>	<b>26</b>
3.	Materials and Methods.....	26
3.1.	Materials .....	26
3.1.1.	Soil Sample .....	26
3.1.2.	Project location.....	26
3.1.3.	Topography .....	28
3.1.4.	Climate .....	28
3.1.5.	Geology .....	29
	Pit Location.....	29
3.2.	Methods .....	30
3.2.1.	Sample Preparation .....	30
3.2.2.	Field and Laboratory Tests.....	30
<b>Chapter Four</b>	<b>.....</b>	<b>31</b>
4.	Laboratory Test Results and Discussion.....	31
4.1.	General.....	31
4.2.	Index Property Laboratory Tests .....	33
4.2.1.	Natural Moisture Content.....	33
4.2.2.	Specific Gravity Test.....	33
4.2.3.	Grain-Size Distribution of Soil .....	35
4.2.3.1.	General .....	35
4.2.4.	Atterberg Limits .....	37
4.2.5.	In-situ Field Density.....	39
4.2.6.	Laboratory Compaction Test.....	40
4.2.7.	Laboratory Oedometer Test .....	43
4.2.7.1.	Actual Stress Analysis for the Designed Layers of the Road Section .....	43
4.2.7.1.1.	Loading.....	43
4.2.7.1.2.	Load analysis.....	45
4.3.	Discussion of Laboratory Tests .....	50
4.3.1.	General .....	50
4.3.1.1.	Field Density and Laboratory Compaction Test .....	50
4.3.1.2.	Specific Gravity Test and Natural Moisture Content.....	51
4.3.1.3.	Grain size analysis.....	51
4.3.1.4.	Atterberg Limit Test.....	51

4.3.1.5.	Discussion on Single Oedometer Test and Collapse Potential .....	52
4.3.1.5.1.	Evaluation by using Indirect Method .....	52
4.3.1.5.2.	Evaluation by using Direct Method .....	53
4.3.1.6.	Comparison of Index Property Test Results of Collapsible Soil with other Researches.....	54
4.4.	Recommended remedial measures for the studied road section.....	57
<b>Chapter Five</b>	.....	<b>62</b>
5.	Conclusions and Recommendations .....	62
5.1.	Conclusions .....	62
5.2.	Recommendations .....	63
<b>References</b>	.....	<b>64</b>
<b>Appendices</b>	.....	<b>66</b>
Appendix-A:	Each Test Pits at Depth the Depth of Investigation.....	66
Appendix-B:	Test Result of In-situ Density (FDT).....	69
Appendix-C:	Test Result of Natural Moisture Content.....	70
Appendix-D:	Test Result of Specific Gravity .....	70
Appendix-E:	Test result of Grain Size Distribution .....	74
Appendix-F:	Test Result of Modified Compaction.....	86
Appendix-G:	Test Result of Atterberg Limit Test with its Graph.....	92
Appendix-H:	Test result of Oedometer with different Loading Conditions and Densities...	98

## List of Tables

Table 2-1 Degree of collapse based on collapse potential value ( $I_e$ ), ASTM D5333 .....	13
Table 2-2 Properties of tested soils (after Basama and Tuncer, 1992) .....	21
Table 2-3 Different method for improving performance of collapsible soils (U.S Army 1990)..	22
Table 3-1 Monthly Rainfall and Average Temperature at project corridor (NMSA), 2009.....	28
Table 3-2 Coordinate of the pit location .....	29
Table 4-1 Result of moisture content at the investigated depth.....	33
Table 4-2 Typical test detail description of the specific gravity for station 47+500 .....	34
Table 4-3 Results of the specific gravity test for each sampling station .....	34
Table 4-4 Typical sample grain size classification results from sieve analysis and hydrometer analysis (combined) for station 49+560.....	35
Table 4-5 Proportion of sand, silt and clay for each test pit .....	36
Table 4-6 Classification result by using AASHTO and USCS method.....	37
Table 4-7 Typical detail Atterberg limits test result calculation for Station 60+030 .....	38
Table 4-8 Summarized Atterberg limits test results for all soil samples .....	39
Table 4-9 Result of natural moisture content and In situ density .....	40
Table 4-10 Sample test result of modified proctor test for Pit#3.....	41
Table 4-11 Summarized test result of modified proctor test.....	42
Table 4-12 Maximum and minimum fill heights (m) .....	45
Table 4-13 Summarized oedometer test results of collapse potential for each test pits at different loading condition .....	47
Table 4-14 Collapsible soil properties comparison (Compiled by Yideneke M., 2015) .....	55
Table 4-15 Summarized field and laboratory test results and classification .....	56
Table 4-16 : Comparison between different mechanisms of treating collapsible soils .....	60

## List of Figures

Figure 2-1 Structure of collapsible soils (Houston, et al.,1988) .....	6
Figure 2-2 Formation of collapsible soils .....	8
Figure 2-3 Family of collapsible soils (Rogers 1994) .....	9
Figure 2-4 Schematic view of key characteristics of collapsible soils (Alain El Howayek) .....	10
Figure 2-5 Single oedometre test result (Houston, et al., 1988) .....	12
Figure 2-6 Liquid limit vs Dry unit weight to evaluate the susceptibility of collapse after Holtz and Hilf (1961).....	15
Figure 2-7 Typical collapse potential test results .....	19
Figure 2-8 Dynamic compaction dropping weight mechanism (Aileen Yenco, 2013) .....	23
Figure 3-1 Location map of the project location .....	27
Figure 4-1 Typical test pits photograph .....	32
Figure 4-2 Typical sample grain size distribution curve for station 60+030 .....	36
Figure 4-3 Combined grain size distribution curves for all sampling stations .....	37
Figure 4-4 Typical graph of moisture content vs number of blows for station 60+030 .....	39
Figure 4-5 Typical plots of dry density vs moisture content for test pit#3 .....	41
Figure 4-6 Modified Proctor compaction test results for all test pits .....	42
Figure 4-7 Traffic standard loading of design truck, design tandem and design lane load .....	44
Figure 4-8 Distribution of load for approximate increase in vertical stress under a rectangle .....	44
Figure 4-9 Typical deformation vs stress plot of oedometer test result for sample remolded at the maximum dry density and optimum moisture content and at a standard load of 200kPa .....	47
Figure 4-10 Combined plot of deformation vs stress for station 49+560 at different loading conditions and densities .....	48
Figure 4-11 Combined plot of deformation vs stress for station 53+550 at different loading conditions and densities .....	48
Figure 4-12 Combined plot of strain vs deformation for station 60+030 of sample 1 at different loading conditions and densities .....	49
Figure 4-13 Combined plot of strain vs deformation for station 60+030 of sample 2 at different loading conditions and densities .....	49

## List of abbreviations and symbols

AAiT	Addis Ababa Institute of technology
AASHTO	American Association of State Highway and Transport Officials
ASTM	American Society of Testing and Materials
ERA	Ethiopian Roads Authority
LL	Liquid Limit
MDD	Maximum Dry Density
NMC	Natural Moisture Content
NMSA	National Meteorological Services Agency
PI	Plasticity Index
PL	Plastic Limit
USCS	Unified Soil Classification System
B	Width
C <sub>p</sub>	Collapse potential
D <sub>f</sub>	Dial reading after wetting
D <sub>i</sub>	Dial reading before wetting
D <sub>o</sub>	Dial reading of oedometer test at seating load
e <sub>1</sub>	Final void ratio
e <sub>o</sub>	Initial void ratio
F	Volume change factor
gr	Gram
H <sub>o</sub>	Initial specimen height
I <sub>e</sub>	Collapse index
L	Length
S <sub>f</sub>	Final degree of saturation
S <sub>o</sub>	Initial degree of saturation
V <sub>s</sub>	Volume of solid
V <sub>vf</sub>	Final void ratio
V <sub>vi</sub>	Initial void ratio
Z	Depth of fill
Δe	Void ratio
ΔH	Cumulative compression
Δσ <sub>z</sub>	Vertical load increase at a specific depth

## **Chapter One**

### **1. Introduction**

#### **1.1. General**

The Turmi – Omo project is located in the Southern Nations and Nationalities Peoples Regional State, South Omo zone; in the south part of Ethiopia and crosses two Woredas namely Hamer and Kangatom. The climate in this area is classified as hot semi- arid with mean annual temperature of 25°C to 30°C and low annual rainfall of 200mm to 400 mm.

Many researches investigate the main reasons for foundation failure problems. They found that there are mainly two often cited unsaturated soil problems confronting the geotechnical and foundation engineers. These are collapsible and expansive soil behavior, and they are associated with wetting-induced volume change, many soils can prove problematic in geotechnical engineering because they expand, collapse, disperse, and undergo excessive settlement with a distinct lack of strength. Some characteristics may be attributable to their composition, the nature of their pore fluids, their mineralogy or their fabric [1].

A collapsible soil is one in which the constituent parts have an open packing and which forms a metastable state that can collapse to form a closely packed, more stable structure with significantly reduced volume. The most important property that a collapsible soil possesses is that of low interparticle bond strength. It is when these bonds are destroyed (through either soil loading, soil saturation or a combination of both) that the collapse of the soil occurs [2]. Foundations on collapsible soils suffer from sudden settlement, which may contribute to serious damage or catastrophic failure due to inundation. In general, a partial or full wetting of the moisture-sensitive unsaturated soil deposit causes either collapsing in most gypseous and loess soil or swelling in many types of clay soils. Therefore, a major consideration for a technical professional dealing with unsaturated soils is related to the effect of wetting on engineering performance. This soil behavior leads to great challenges in foundations design during and after the construction of engineering structures [3].

## **1.2. Statement of the Problem**

One of the transport systems in the world is highway. It's very important for moving from country to country and place to place, totally it can play significant role for development of one country. But most of the time roads are damaged before the design life due to poor sub base and subgrade soils such as expansive and collapsible soils. The collapsible soil has significant impact in road construction due to its behavior of a sudden volume change and collapse deformation upon wetting.

The major effect of road failure leads to accident and generates additional cost for maintenance. In order to provide maximum structural support, a subgrade soil must be compacted to an adequate density. But collapsible soil is unsaturated soil that undergoes a large volume change upon saturation due to loading or unloading after being compacted. The sudden and usually large volume change could cause considerable structural damage. In Ethiopia, collapsible soil is present in the southern part of Omo River, in the central and southern part of the rift valley, around Ziway, Shashemene, Awassa and Afar region. This soil, if properly treated, will prevent series damage for ongoing and future different projects.

Hence, to reduce failures of structures and the resulting economic damages, it is in need to know the behavior of such soils for further recommendation and alternative remedial measures during and after construction period.

## **1.3. Objectives**

### **1.3.1. General Objective**

The general objective of this research is to study the physical characteristics and severity of collapse of collapsible soils found in Turmi – Omo Road project.

### **1.3.2. Specific objectives:**

- To study the actual physical properties of collapsible soils in the studied area.
- To evaluate the collapse potential based on the physical properties and oedometer test results
- To study the severity of the material to collapse

- Compare the collapse potential of soil found around the studied area to previously made researches.

#### **1.4. Research Methodology**

To achieve the objectives mentioned, different data collection procedures and analysis techniques have been used:

- **Site reconnaissance:** the researcher has used surface conditions such as topography, geology, and surface and sub-surface water for selecting sampling pit location. In the study area, especially in the selected road section; the depth of ground water table is far from the original ground level and this shows that the road subgrade is not be affected by the rise of the ground water in all seasons. Thus, surface water has been considered during the study.
- **Pit excavation:** It is the method used to take sample soils for the study. A total number of six test pits were excavated after the test pit locations are decided based on the project's contract data, routine laboratory tests and consultant's design document. The data were used in order to know the exact location of collapsible soils from the road stretch. Based on the review of the said documents and site reconnaissance; the studied road section doesn't show a significant variety from station to station in its property and visual description, thus six test pits have taken for the field and laboratory tests.
- **Sampling procedures:** following the decision of pit locations, disturbed samples from six locations were collected and for each test pit the sample is taken at 1.2 meter depth. The reason why the sample is disturbed, the material is sandy or silty soil with small clay content and hence it is difficult to recover undisturbed samples. Generally, the soil under investigation has cohesionless property and difficult to get undisturbed sample. And also, the project area is far from Addis Ababa, thus during transportation the undisturbed samples will be affected. This is, therefore; disturbed samples were collected and prepared for the laboratory tests. Moreover, the reasons why the samples from each test pits is taken at 1.2 meter depth is that:
  - The study for the selected road section is limited for subgrade investigation

- During site reconnaissance, a representative pit excavation has been carried out and thus from visual description the material in the test pits has similar and continuous soil layers.
  
- **Laboratory and field tests:** The procedures were used in order to perform the laboratory and field tests based on AASHTO and ASTM standards. The tests made are:
  - Natural moisture content determination
  - Grain size analysis (Sieve and Hydrometer)
  - Atterberg Limit Test
  - Field density test
  - Compaction test
  - Determination of specific gravity
  - Single oedometer tests
  
- **Soil classification and evaluation of test results:** Analyses were made after the test results were collected and then the soils were classified based on both USCS and AASHTO classification systems. And also, the results of the soil under investigation are evaluated based on the previous researches.

### **1.5. Limitation of Study**

Six samples were collected from test pits. The study is limited to index properties and oedometer tests. The study for the selected road section is limited for subgrade investigation. Due to the materials cohesionless property and difficult to get undisturbed sample, the single oedometer tests were done on samples remolded at their in-situ densities and at maximum dry density. In addition, reference materials on collapsible soils that are found in Ethiopian are scarce or easy to say none. So, most of the referenced materials are from the researches done in other countries and also due to unavailability of the equipment at the project site and limitation of cost, in-situ plate loading test (in order to know the actual settlement after loading and inundation) are not performed.

## Chapter Two

### 2. Literature review

#### 2.1. General

In this chapter the researcher tries to provide the behavior of collapsible soils and focuses on topics such as formation, types and distribution, physical characteristics, structure and collapse mechanisms of the said soil. In connection to the above, this chapter also outlines the method of testing of collapsible soils and its general field identification procedures.

Mainly collapsible soils are soils that are liable to large volumetric strains when they become wet and this soils are associated with an open structure formed by sharp grains, low initial in-situ density, low natural water content, low plasticity, relatively high stiffness and strength in the dry state, and often by particle size in the silt to fine sand variety [4].

The main geotechnical problem associated with these soils is the significant loss of shear strength and volume reduction occurring when they are exposed to the additional water. Generally, collapsible soils are under unsaturated condition. Moreover, when there is additional water on these soils, the additional water can cause to dissolve or soften the bonds between the particles and allow them to take a denser packing. This mechanism, referred to as wetting-induced collapse, or hydro collapse, can take place with or without extra loading. The amount of collapse usually increases with initial applied pressure and decreases with initially water content and dry unit weight [5].

As long as the soil remains dry, these cementing agents produce a strong soil that is able to carry loads. However, if the soil becomes wet, the cementing agents soften and the honeycomb structure collapse as shown in Figure 2-1 [6].



**Figure 2-1** Structure of collapsible soils (Houston, et al.,1988)

Rogers (1994) provided a compilation of the major definitions of collapsible soils from different literatures and that:

- “A soil that undergoes an appreciable amount of volume changes upon wetting, load application, or a combination of both.” (Sultan 1969)
- “Any unsaturated soil that goes through radical rearrangement of particles and great loss of volume upon wetting with or without additional loading.” (Dudley 1970)
- “Additional settlement due to the wetting of a partially saturated soil, normally without any increase in applied pressure.” (Jennings and knight 1975)
- “A state of under consolidation related to apparent cohesive strength of unsaturated soil.”(Booth 1977)

## **2.2. Origin and Occurrence of Collapsible Soil**

The most extensive collapsible soil deposits are wind-deposited sands and silts. Alluvial flood plains, mud flows, colluvial deposits, residual soils that can be collapsible.

According to Rogers (1994), collapsible soil could occur distributed in the world especially North and South USA, China, South Africa, Eastern Europe, Central Asia, Japan, New Zealand, Australia and Nigeria. Collapsible soil classification with respective location:-

### **Sand deposit such as:**

- Granitic sands of South Africa
- The collapsible Aeolian sands of the fringes
- Kalahari sands of South Africa

### **Silt deposit:**

- Loess and volcanic dust of South America
- China loess
- Eastern European and central Asian loess
- North America loess and others

### **2.2.1. Residual Soils**

These types of soils are formed in-place by weathering of rock. Sometimes this process involves decomposition of rock minerals into clay minerals that may be removed by leaching, leaving a honeycomb structure and a high void ratio. When this structure develops, the soil is prone to

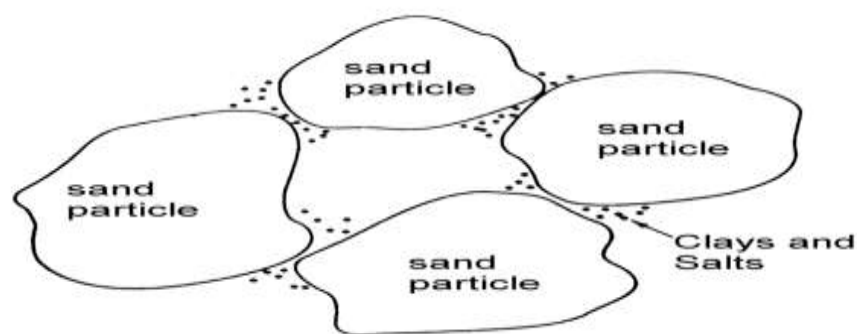
collapse. Residual soils are likely to have greatest amount of spatial variation, thus making it more difficult to predict the collapse potential [6].

### **2.2.2. Aeolian Soils**

Soils deposited by wind are known as aeolian soils. This category includes windblown sand dunes, loess, volcanic dust deposits, etc. Loess i.e. aeolian silt or sandy silt is the most common aeolian soil which covers much of the earth's surface. It is found in the United States, central Europe, China, Africa, Australia, the former Soviet Union, India, Argentina, and elsewhere [7].

### **2.2.3. Alluvial and Colluvial Soils**

Alluvial soils that are transported by water and some other colluvial soils transported by gravity can be highly collapsible. These collapsible soils are frequently found in the southwestern United States as well as other regions of the world with similar climates. In this type of climate, when there is a short bursts of intense precipitation often induce rapid down-slope movements of soil known as flows. While moving, the soil is nearly saturated state and those have a high void ratio. Upon reaching the last stop, the soil dries quickly by evaporation, and capillary tension draws the pore water toward the particle contact points, bringing clay and silt particles and soluble salts with it, as shown in the Figure 2-2. Once the soil becomes dry, these materials bond the particles together, thus forming the honeycomb structure.



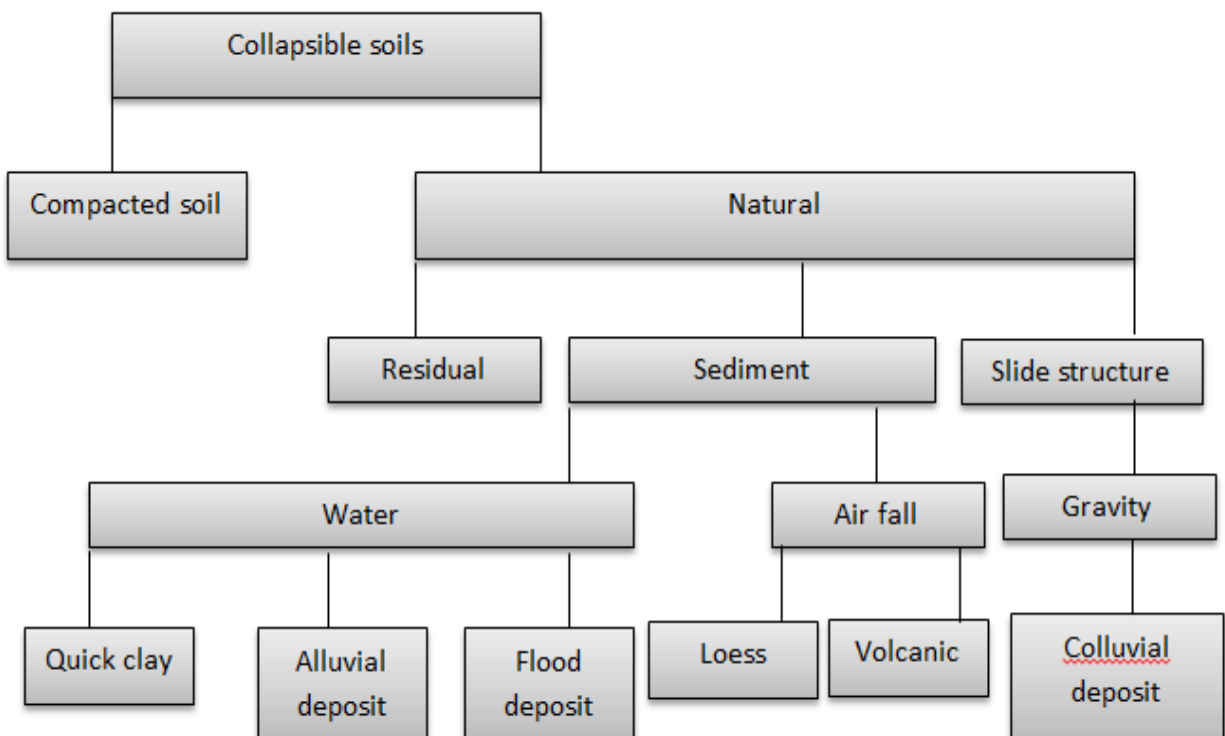
**Figure 2-2** Formation of collapsible soils

After the next flow, more honeycomb structured soil forms. The new flowed layer dries rapidly by evaporation, too, so the previous deposited soil remains dry. Thus, deep deposits of collapsible soil can form. These deposits are often very erratic, and may include inter-bedded

strata of both collapsible and non-collapsible soils. Family of collapsible soils, is shown in the Figure 2-3 [6].

### 2.3. Properties of Collapsible Soils

Collapsible soils are soils which remain at a stable state in unsaturated conditions but are susceptible to appreciable volume change induced by water infiltration alone or water infiltration in combination with external loading (including self-weight) and dynamic force at full saturation or near saturation. However, in general, the study of collapsible soils is limited to collapse produced by static external loading, while the collapse due by dynamic forces is usually studied in the context of liquefaction phenomena. Collapsible soils have typical features that contribute to collapse including: an open (metastable) structure which results in low bulk density, high void ratio and high porosity, geologically young deposit, lately altered deposit, significant sensitivity, and weak inter-particle bonding [2].

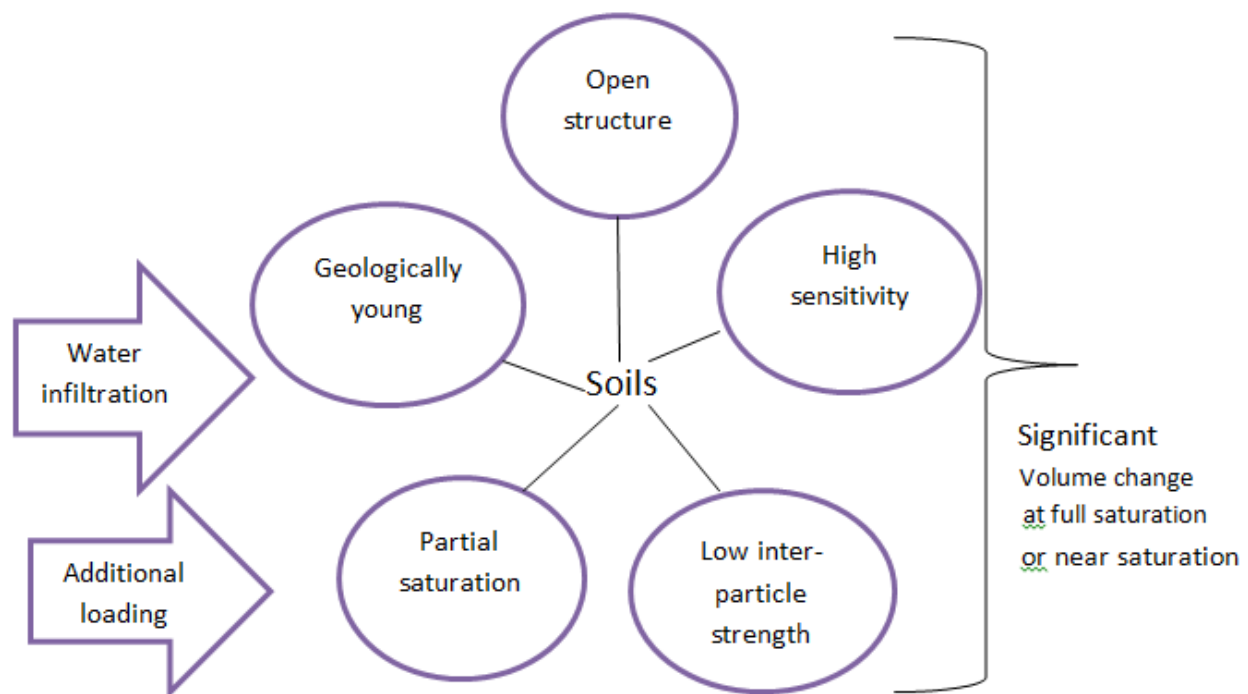


**Figure 2-3** Family of collapsible soils (Rogers 1994)

According to Rogers (1994), the most collapsible soils have the following main properties:-

- An open structure
- High void ratio
- Low dry density
- High porosity
- Geologically young or recently altered deposit
- High sensitivity
- Low inter particle bond strength

Schematic view of key characteristics of collapsible soils is shown in the Figure 2-4.



**Figure 2-4** Schematic view of key characteristics of collapsible soils (Alain El Howayek)

Any type of soil compacted at dry of optimum condition and at low dry density may develop a collapsible fabric or metastable structure. A compacted and metastable soil structure is supported by microforces of shear strength, which are bonds that are highly dependent upon capillary action. The bonds start losing strength with the increasing of the water content and at a critical degree of saturation; the soil structure collapses [8 &9].

According to Rogers (1994), the collapse trigger is typically defined as being an increase in load or wetting or a combination of the two. The increase in load, or more properly stress, will

typically derive from an accumulation of deposits over a long period of time, although dynamic stresses from an event such as an earthquake would provide an obvious trigger mechanism as would stress increases caused by construction operations. Wetting usually refers to an increase in saturation ratio, often approaching full saturation from a partially saturated state.

### **2.3.1. Relationship between Collapse Potential with other Parameters**

Studies on collapsible soils indicates the different relationship between the potential of collapse and some other parameters like initial dry unit weight, initial water content and pressure at wetting [5].

- The denser the soils, the lower the initial void ratios, thus, resulting in less collapse upon wetting. Furthermore, a dense state of soil would reduce the relative contribution of the metastable forces in supporting the soil structure.
- Higher initial water content reduces the metastable forces, and what remains from these forces to be reduced completely by wetting is less; as a result, less collapse would occur.
- According to Booth (1977) and Cox (1978), for any soil there are combinations of initial dry density, molding water content, and over burden pressure at which no volume change will occur when this soil is inundated.
- For a given soil there appears to be a critical molding water content at soaking above which no collapse will occur. For some soils the critical water content is above standard proctor optimum water content [9].
- For any given set of conditions, the amount of collapse generally decreases with increasing precollapse moisture content, increasing pre-collapse dry density, and decreasing overburden pressure [10].

### **2.4. Identification of Collapsible Soil**

In order to identify soil properties adapting different mechanisms are a vital procedure for engineers. Engineers have used many different techniques to identify and evaluate collapsible soils. They may be divided into two categories of indirect and direct methods.

### 2.4.1. Direct Methods

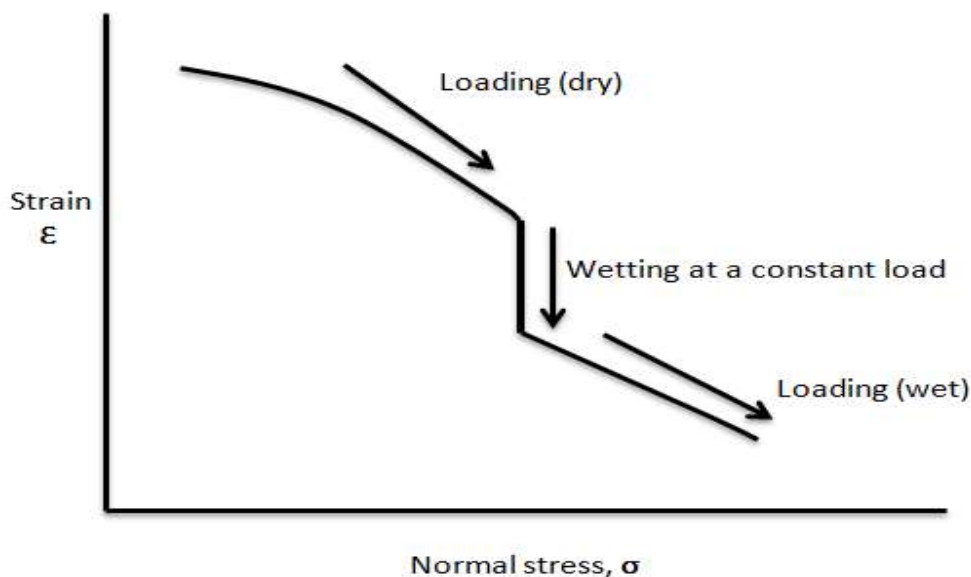
This method involves actual measuring of values, either in laboratory or in-situ, and measuring the corresponding strain. The results of such tests can be extrapolated to the entire soil deposit and potential settlements can be predicted and for other further action.

#### 2.4.1.1. Single Oedometer Test

Single oedometre test method is generally used for assessing collapse potential. The detail procedures to conduct one dimensional oedometer laboratory tests are shown below:

- Disturbed or undisturbed soil sample in an oedometer with in-situ moisture content or at the laboratory maximum dry density is consolidated with stress increments (5kPa,12kPa,25kPa,50kPa,100kPa and 200kPa)
- When the applied vertical stress based on the given standard applied load, the load on the soil sample in the test equipment becomes equal or slightly higher than the overburden pressure, the sample is then inundated for 24hours.
- Following the inundation, the strain observed after inundation is called hydrocollapse strain (collapse due to water).
- After hydroconsolidation, additional stresses increments are applied to allow the soil to consolidate.

Sample hydrocollapse single oedometer test is shown in the Figure 2-5.



**Figure 2-5** Single oedometre test result (Houston, et al., 1988)

According to ASTM D 5333 method the collapse potential in the laboratory can be done. This test method used to determine the magnitude of collapse potential that may occur for a given vertical (axial) stress and an index for rating the potential for collapse and the procedure in this method is valid for both undisturbed and remolded sample [11]. Degree of collapse based on collapse potential value ( $I_e$ ), ASTM D5333 is shown in the Table 2-1.

**Table 2-1** Degree of collapse based on collapse potential value ( $I_e$ ), ASTM D5333

Degree of Collapse	Collapse Index $I_{e,\%}$
None	0
Slight	0.1 to 2.0
Moderate	2.1 to 6.0
Moderately Severe	6.1 to 10.0
Severe	>10

The single oedometer test is faster and more closely simulates the actual loading and wetting sequence that occurs in the field. However, this method provides less information, since it only gives the hydrocollapse potential at one normal stress. Therefore, the soil should be at a normal stress as close as possible to that which will be present in the field. <sup>[6]</sup>

#### **2.4.1.2. Using Trial Pit and Observation of Existing Structure**

The potential for collapse at a specific location is initially evaluated based on the geological and environmental setting. Soils with a collapsible fabric can be identified in the field and/or by laboratory tests. <sup>[12]</sup>

- **Trial pit**

A reduction in volume may be observed by proper backfilling a pit or a trial hole. If the soil has a collapsible grain structure, the excavated material will fail to fill the pit completely.

- **Observation of existing structure**

In areas where development has already taken place the most significant field evidence is the presence of cracking distortion of existing buildings. An evaluation of the crack pattern and history must undertake in association with knowledge of the soil profile.

- **In situ testing (plate loading test)**

The vertical plate bearing test may be used to obtain a comparison between the stress-deformation curves or modulus of compressibility of a soil at natural in situ moisture content and in a saturated condition. Some method of saturating the soil during the test is therefore required.

#### **2.4.2. Indirect Method to Evaluate the Collapse Potential**

Generally different researchers propose different methods to evaluate the susceptibility of collapse potential of the soil and presented here under that are compiled by (Das, 2007 after modified by Lutenegro) [20].

- ✚ Based on the void ratio at liquid limit to natural void ratio by Denisov (1951)

Coefficient of subsidence  $K = \text{void ratio at liquid limit} / \text{natural void ratio}$

If,  $K = 0.5 - 0.75$ : highly collapsible soil;

If,  $K = 1.0$ : non collapsible loam;

If,  $K = 1.5 - 2.0$ : non collapsible soil

- ✚ Based on KD value the collapsible soil can be known according to Priklonski (1952)

$$KD = \frac{(\text{Natural moisture content} - \text{Plastic limit})}{\text{Plasticity index}} \quad \text{or:}$$

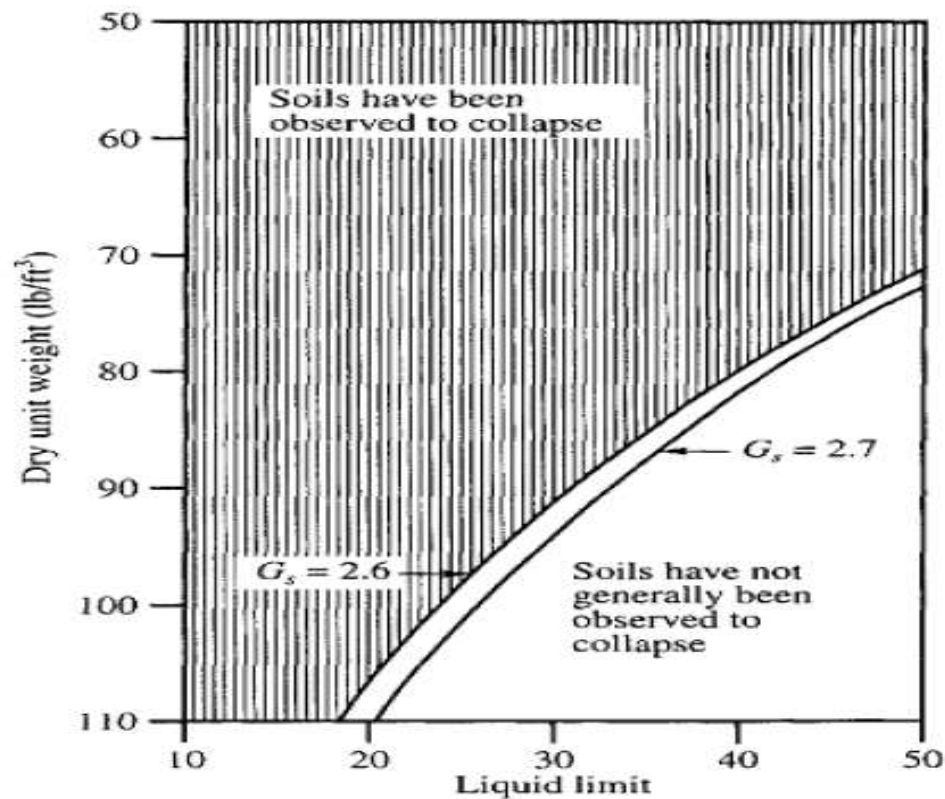
$$KD = \frac{W_n - PL}{PI}$$

If,  $KD < 0$ : highly collapsible soils

If,  $KD > 0.5$ : non collapsible soils

If,  $KD > 1.0$ : swelling soils

- ✚ By using natural dry density and liquid limit as criteria for predicting collapse. A plot giving the relationship between liquid limit and dry unit weight of soil, such that soils that plot above the line shown in the Figure 2-6 are susceptible to collapse upon wetting [10].



**Figure 2-6** Liquid limit vs Dry unit weight to evaluate the susceptibility of collapse after Holtz and Hilf (1961)

- ✚ Clevenger (1958), suggested a criterion for collapsibility based on dry density, that is, if the dry density is less than  $12.6 \text{ kN/m}^3$ , then the soil is liable to undergo significant settlement. On the other hand, if the dry density is greater than  $14.1 \text{ kN/m}^3$ , then the amount of collapse should be small, while at intermediate densities the settlements are transitional [13].
- ✚ Handy (1995), suggested that collapsibility could be determined either by the percentage clay content or from the ratio of liquid limit to saturation moisture content. He maintained that soils with clay fraction contents [14]:
  - Clay content of less than 16 percent had a high probability for collapse;
  - Clay content of between 16 and 24 percent were probably collapsible;
  - Clay content between 25 and 32 percent had a probability of collapse of less than 50 percent;
  - Clay content which exceeded 32 percent was non-collapsible.

## **2.5. Review of Laboratory Index and Collapse Potential Tests**

### **➤ Grain Size Analysis**

In this system soils are divided into coarse grained and fine grained. The soil grain size analysis carried out in two stages (sieve analysis for coarse grained soils and hydrometer analysis for fine grained soils). The physical properties of fine -grained soils are dictated to a great extent by the amounts and types of clay minerals present in them. Hence, for proper interpretation of soil characteristics and detail classification, the plasticity that is the result of the presence of clay minerals needs to be considered. Two commonly used systems for classifying soils based on particle distribution and Atterberg limits are AASHTO System (American Association of State Highway and Transportation Officials) and USCS System (Unified Soil Classification System) [20].

- **Using AASHTO Soil Classification System**

In this soil classification system, soils are generally placed in seven major groups: A-1, A-2, A-3, A-4, A-5, A-6 and A-7. Group A-1 is divided into two subgroups: A-1-a and A-1-b. Group A-2 is divided into four subgroups: A-2-4, A-2-5, A-2-6 and A-2-7. Soils under group A-7 are also divided into two subgroups: A-7-5 and A-7-6. It generally classifies a soil broadly into granular material and silt-clay material. The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7 [21].

- **Using USCS Classification System**

This system describes a system for classifying minerals and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required. The Unified system uses symbols to represent the soil types and the index properties of the soil. [21]

### **➤ Atterberg Limit Tests**

When a cohesive soil is mixed with an excessive amount of water, it will be in a somewhat liquid state and flow like a viscous liquid. However, when this viscous liquid is gradually dried, with the loss of moisture it will pass into a plastic state. With further reduction of moisture, the soil will pass into a semisolid and then into a solid state. Atterberg limits depend on the clay and/or

organic contamination, the physical properties of most fine grain soils, and particularly clayey soils, are greatly affected by moisture content. The moisture content (in percent) at which the cohesive soil will pass from a liquid state to a plastic state is called the liquid limit of the soil. Similarly, the moisture contents (in percent) at which the soil changes from a plastic to a semisolid state and from a semisolid state to a solid state are referred to as the plastic limit and the shrinkage limit, respectively. These limits are referred to as the Atterberg limit.

- **Liquid Limit:**

The liquid limit is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow on the application of a very small shearing force. When a soil becomes a viscous fluid, the soil will begin to flow under its own weight and very small amount of energy input. The liquid limit is primarily used by civil and geotechnical engineers as a physical property of a soil.

- **Plastic Limit:**

Plastic limit is defined as the moisture content, in percent, at which a cohesive soil will change from a plastic state to a semisolid state. In the laboratory, the plastic limit is defined as the moisture content (%) at which a thread of soil will just crumble when rolled to a diameter of 3.00 mm.

- **Specific Gravity Test**

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil.

The specific gravity of a soil is used in calculating the phase relationships of soils water, and solids in a given volume of the soil. Also specific gravity of soils is an important engineering index, which is frequently used in determination of different properties of soils in laboratory as well as in real practice.

The specific gravity is given by:

$$GS = \frac{\gamma_s}{\gamma_w} \quad (2-1)$$

Where:  $G_s$  = Specific gravity of the soil

$\gamma_s$  = Unit weight of soil particle

$\gamma_w$  = Unit weight of water

### ➤ **Compaction Test**

This test is performed to determine the relationship between the moisture content and dry density of soil for a specified compaction effort. This compaction effort is the amount of mechanical energy applied to the soil mass. The main purpose of compaction test is that to decrease settlement, to decrease permeability and finally to increase shearing and compressive strength of soil sample.

For compaction process water plays an important role. Up to certain water content the presence of water helps the compaction process as a lubricant for the grains rearrangement that is it plays a positive roll, after that when we keep on increasing the water content in the soil sample to be compacted, compaction process will be very difficult, here presence of water prevents further compaction and adding water at this stage will make the process more difficult.

The dry density which can be achieved for a soil depends on the degree of compaction applied and the moisture content. The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction.

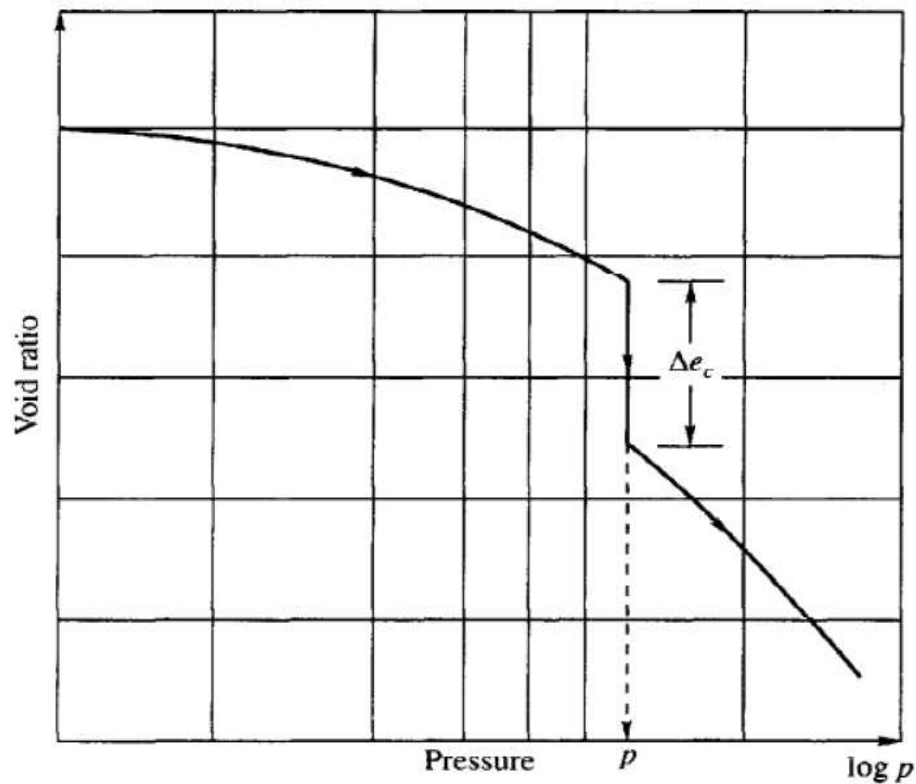
The purpose of this laboratory test is to determine the maximum dry density and optimum moisture content. There are two types of compaction tests are routinely performed;

- The standard Procter test, and
- The modified Procter test.

### ➤ **Collapse Potential Test**

Jennings and Knight (1975), suggested the procedure to determining the collapse potential of collapsible soil. The procedure is as follow;

A sample of undisturbed or remolded soil is cut and fit into a consolidometer ring and loads are applied progressively until about 200 kPa is reached. At this pressure the specimen is flooded with water for saturation and left for 24 hours and typical collapse potential test is shown in the Figure 2-7.



**Figure 2-7** Typical collapse potential test results

It follows from the above graphical presentation that a reduction void ratio ( $e_c$ ) upon inundation without a change in applied load.

The collapse potential is then defined as:

$$Cp(\%) = \frac{e_c}{(1+e_o)} \quad (2-2)$$

Where  $e_c$ = change in void ratio at 200kPa, upon wetting and  $e_o$ = initial void ratio

Since the test is conducted as one dimensional test the collapse potential can also be expressed as:

$$Cp(\%) = \left(\frac{h}{h_o}\right) * 100 \quad (2-3)$$

Where  $h$ =change in height up on wetting and  $h_o$ = initial height of the specimen.

This test is guide or indicator test only to determine the potential for collapse settlement to occur and is merely a qualitative indication of the severity of the problem.

## **2.6. Previous Researches**

- ❖ The researcher, Mekonnen Yidenek (2015); has studied on review of collapsible soils in case of Omo-F6 road project which is around the studied area and concluded the following:
  - Consideration of collapsible soils is vital in designing and constructing civil engineering infrastructures and a lot has to be done to characterize the geotechnical properties.
  - The study area is covered with loose deposits of clayey/sandy Silts with small in-situ dry densities, low moisture content, high void ratios and porosity. Besides moderate to severe collapse potential is obtained. The result of most of the geotechnical properties indicates that significant portion of the soils in the study area exhibit a potential for collapse upon wetting.
  - From the Atterberg limit test results, LL and PI values ranging from 22-51% and 2-21% respectively were found.
  - The classification of the soils based on AASHTO classification indicate that the project subgrade comprises of soils groups A-6, A-4, A-2-4, A-7-5 and A-7-6
  - The initial void ratio for the soils in the study area ranges from 0.5 to 1.4.
  - From the collapse potential test results, about 83% of the samples show moderate to severe collapse potential, in accordance with ASTM D5333 testing procedure. Hence considerable portion of the study area is covered with collapsible subgrade soils which need proper treatment prior to any construction activity.
- ❖ According to Basama and Tuncer, 1992 had studied the evaluation and control of the collapsible soils and the study indicates and concluded here under:
  - Collapse potential decrease with an increase in the difference between clay and sand percentage, compaction water, initial dry unit weight, while it increases with pressure at wetting.
  - Some of the properties of the soils laboratory test results are presented in Table 2-2:

**Table 2-2** Properties of tested soils (after Basama and Tuncer, 1992)

Properties							
Soils Series	Grain size characteristics			Consistency Limit		Compaction Characteristics	
	Sand	Silt	Clay	Liquid limit LL (%)`	Plasticity index PI (%)	Maximum dry unit weight (KN/m3)	Optimum water content (%)
S1	40.6	50.5	8.9	36.6	12.7	18.7	14.5
S2	47.8	47.2	5.0	29.1	11.2	19.3	13.5
S3	13.3	73.5	13.2	57.2	28.9	17.0	19.3
S4	19.6	70.4	10.0	28.0	7.0	17.2	14.3
S5	24.4	49.6	26.0	36.0	11.1	16.3	21.0
S6	42.1	42.9	15.0	28.2	10.6	18.3	13.5
S7	84.0	7.0	9.0	30.0	3.0	-	-
S8	92.2	5.8	2.0	25.0	5.0	-	-

## 2.7. Improvement Method of Collapsible Soil

Relatively, collapsible soil is not difficult as black cotton soil i.e. collapsible soil only shrink when getting wet and strong at dry state while black cotton soil shrink when dry and swell when getting wet. The choice of the appropriate method depends on the depth of the collapsing soil, type of structure to be constructed, and the cost and practicality of the method. Improvement method of collapsible soil can be corresponding to its severity, based on collapse potential value. According to U.S. Army in 1990 improving method of collapsible soil it classify and shown in Table 2-3.

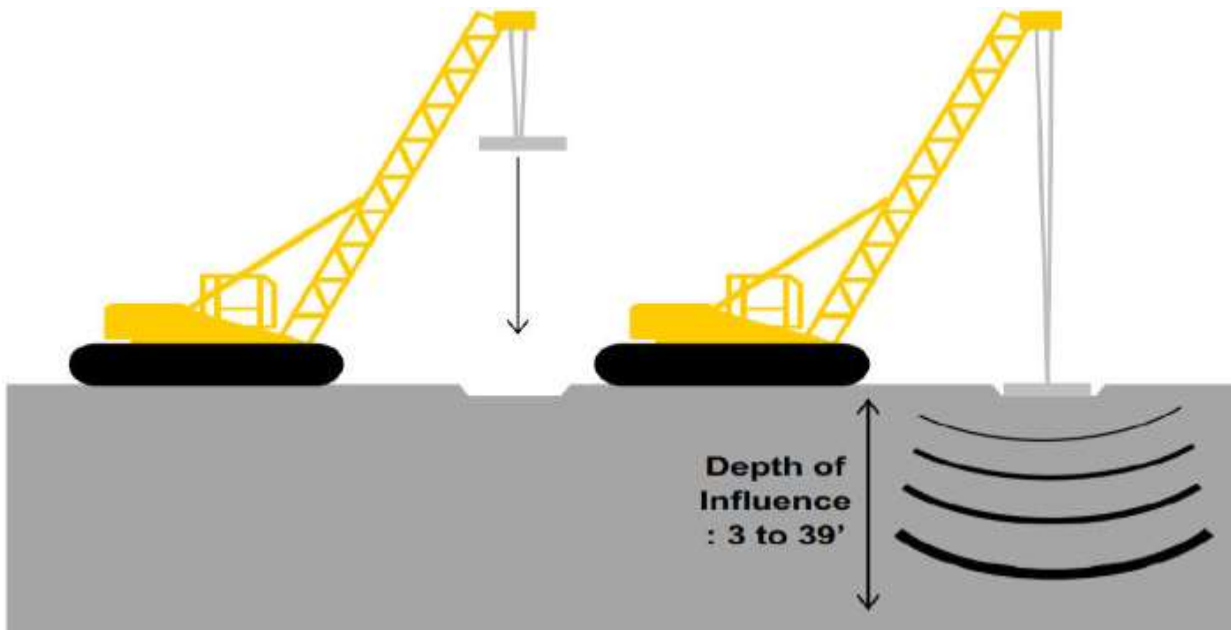
**Table 2-3** Different method for improving performance of collapsible soils (U.S Army 1990)

depth of soil (m)	description
0-5	Wetting, mixing, and compaction
	Over excavation and re-compaction with or without chemical
	Additives such as Lime or cement
	Hydro-compaction
	Vibroflotation
>5	Lime pressure injection
	Sodium silicate injection
	Pre-wetting by pounding: vertical sand drains
	promote wetting of subsurface soil

### 2.7.1. Dynamic Compaction

Dynamic compaction is one type of improving mechanism for collapsible soils; a large weight is dropped, or tamped, multiple times through patterns by a crane onto the ground, which compresses the soil structure (Yencon, 2013). This type of compaction create a dense mass of soil immediately below the area of impact and also a high energy compression, wave like tree roots downwards and outwards (Pan & Selby, 2002). This process increases the soil bearing capacity and reduces after construction settlement. Another name of dynamic compaction is called dynamic consolidation, not only for collapsible soil but also several types of problematic soil in order to perform permanent and temporary works. Before used the equipment, may fulfill some parameters among this, existing soil characteristics, weight, size, drop height number of optimal blows, grid spacing applied energy, depth of improvement and calibration testing on the entire project (Ali et al., 1997).

As shown in Figure 2-8, compacting process is repeated for a set number of blows on one spot before presiding to the next point.



**Figure 2-8** Dynamic compaction dropping weight mechanism (Aileen Yenco, 2013)

Any equipment has its own advantages and disadvantages but we can use as their function and requirement for civil engineering project. Dynamic compaction is more preferable for new constructions that are away from urban areas.

### **2.7.2. Impact Roller Compaction**

According to Paige Green, 2008, a collapsible soil by its nature needs to be wetted up and heavily compacted in order to disrupt the collapsible fabric. The most obvious remedial measure is to preclude the presence of water – this is however, generally impracticable. Conventional compaction plant has been shown to be only moderately effective in removing the collapse potential to any significant depth, even after the addition of compaction water. However, modern high energy impact compaction techniques using large impact rollers (25 kJ), with or without the addition of water, have proved most effective in reducing the collapse potential to a significant depth. If this work is done in the wet season, a more economical and effective result is obtained as a result of the improved lubrication offered by the water.

An effective but more expensive method is to excavate the material, break down the collapsible structure and any lumps (using a grid roller where necessary) and then to compact the layer back into the excavation using conventional rollers with the appropriate quantity of water in lifts not exceeding about 250 mm.

### **2.7.3. Pre-Wetting**

Pre-wetting means flooding or wetting of the soil which is expected to exhibit collapse upon saturation before the structure is built, so that the soil collapse will be minimized after the structure is built (Houston 1997; Gibbs & Bara 1967; & Hasen et al., 1989 in Amer Ali 2000).

Pre-wetting is useful for canals and roadways where the induced loads are small, pre-wetting without preloading is not sufficient to prevent future foundation settlement. Pre-wetting causes the soil to collapse under its existing overburden pressure. Therefore additional loads imposed by the foundation are not compensated for and will result in additional settlement (Rollins and Rogers 1994 in Amer Ali 2000). This type of treatment is the easiest, but it proved to be completely ineffective in reducing collapse potential for shallow foundation.

### **2.7.4. Chemical Stabilization or Grouting**

Chemical stabilization by additives such as sodium silicate and calcium chloride, develop cementation within the soil structure and thus it resists collapse when wetted. Penetration of chemical solutions into the desired depth is essential for the success of the operation. The method is most applicable to fine sand deposits. The advantage of grouting is that it can be used after a structure is already in place. According to Houston 1997 pointed out that grouting provides soil improvement by one or more of the following mechanisms;

- If the grout viscosity is low enough and the soil permeability is high enough, the grout simply permeates into the soil and greatly strengthens and stiffens it.
- If the grout viscosity is high and the soil permeability is low, the grout bulb compresses and densifies the surrounding soil. This process is called compaction grouting.
- The third mechanism can be called soil reinforcement. If enough grout is put into the ground at enough locations depths, then the stiff grouted zones will tend to carry the overburden and structural loads while loose zones will be unloaded to some extent.

Prewetting with a 2 percent solution of sodium silicate provides cementation that reduces the potential for settlement. For depths of collapsible soils greater than 1.5 m, lime pressure and sodium silicate injections could also be helpful, though expensive [22].

### **2.7.5. Treatment using Cement Material**

By using cement, treatment of collapsible soils has been used around the world. Jefferson et al., 2008 reviewed different researches made on cement treatment methods.

- The use of fly ash to treat loess in the USA (Zia and Fox,2000)
- Treatment of loess with waste cement kiln dust (Sreekrishnavilasam et al., 2007)
- The use of fly ash and rice husk ash in Thailand (Gasaluck and nantasarn 2002).
- Soil cement cushions (mixed with 3 to 7% portland cement by weight) (Jefferson et al.,2005)

### **2.7.6. Excavate and Re-compact**

According to Paige and Green, an effective but more expensive method is to excavate the material, break down the collapsible structure and any lumps (using a grid roller where necessary) and then to compact the layer back into the excavation using conventional rollers with the appropriate quantity of water in lifts not exceeding about 250 mm [4].

## **Chapter Three**

### **3. Materials and Methods**

#### **3.1. Materials**

##### **3.1.1. Soil Sample**

The soil sample used is obtained at a depth of 1.2 meter by a method of disturbed sampling from the selected road sections. Test pits were dug at different six stations by using back loader following the test sampling stations decided based on the methodology stated in Chapter one to a maximum depth of 1.2 meter. The soil horizon within the pits was thoroughly observed to identify and distinguish uniform strata. The test pits were then logged by measuring the thickness of each stratum and properly describing materials of the stratum. Finally, disturbed samples were collected from each test pits. The disturbed samples from each station were collected in order to carry out different laboratory tests.

##### **3.1.2. Project location**

Environmental information on the climate, topography and geological aspects of the project area is an essential requirement to the understanding of the engineering characteristics of the area and is a pre-requisite for the planning, design and constructions of roads. The project road is located in the Southern part of Ethiopia, in Southern Nations Nationalities and people of Ethiopia in South Omo Zone, Hamer & Nangatom Wereda and connects the village of Turmi and Omo River Bridge (Gnangatome). The project starts at the junction point before Turmi Junction on Keyafer-Turmi road & ends at points where 1km before Omo River Bridge. The location map and general layout of the project road is shown in Figure 3-1.

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*



**Figure 3-1** Location map of the project location

### **3.1.3. Topography**

Morphological set up of the project route corridor can be categorized generally into three major physiographic subdivisions; i.e., flat, rolling and mountainous terrain. The project route has maximum elevation of 1035m above sea level & the minimum elevation of 380m above sea level.

### **3.1.4. Climate**

The route traverses an area which lies within the equatorial type of climate modified by location and altitude conditions. The climate in this area is classified as hot semi-arid with mean annual temperature 25 to 30°C and low annual rainfall in average of 200mm to 400mm. Hot and uniform average temperatures ranging mainly between 25°C and 30°C and modified to some extent by location and altitude are experienced throughout the year. The month of April receives the highest mean temperature greater than 30°C. Monthly Rainfall and Average Temperature at project corridor presented in Table 3-1.

**Table 3-1** Monthly Rainfall and Average Temperature at project corridor (NMSA), 2009

Item	October - January	February – May	June - September
Rainfall (mm)	100-199	100-199	200-400
Average Temperature (°c)	25-30	>30	25-30

Based on Temperature/Altitude Relationships, the climatic condition of Ethiopia is classified into five temperature zones; As per ERA Site Investigation Manual, 2013

- “Wirch”; 3300 masl and above.
- “Dega”; 2300 – 3300masl.
- “Weina-Dega”; 1500 – 2300masl.
- “Kola”; 500 – 1500masl.
- “Berha”; below 500masl.

Accordingly, the project area is classified as Kola to Berha.

### **3.1.5. Geology**

According to the Geological Map of Ethiopia, the major geological formations along the project area are:

- Q; Alluvial & Lacustrine deposits; sand, silt, clay, diatomite, limestone and beach sand.
- Nb; Mursi and Bofa Basalts; Alkaline basalts
- Pjr; Jimma Volcanic (Upper part) Rhyolite & Trachyte flows and tuff with minor basalts

### **Pit Location**

A total number of six test pits were excavated after the test pit locations are decided based on the project's contract data, routine laboratory tests and consultant's design document. All pit locations from the stretch of the road section are on the stretch that has a tendency to collapse and its location is presented in the table 3-2.

**Table 3-2** Coordinate of the pit location

<b>Sample Description</b>	<b>Station</b>	<b>Northing</b>	<b>Easting</b>	<b>Elevation</b>
Pit#1	47+500	564782.09	188257.96	400.115
Pit#2	49+560	565300.39	186264.39	389.064
Pit#3	53+550	567567	182490	383.83
Pit#4	55+500	567720.43	180995.663	385.539
Pit#5	58+840	569991.3	178775.8	387.30
Pit#6	60+030	570682.9	177748.5	385.615

## **3.2. Methods**

### **3.2.1. Sample Preparation**

Following the decision of pit locations, disturbed samples from six locations were collected and for each test pit the sample is taken at 1.2 meter depth. After the collection of disturbed soil samples, moist sample was transported to the laboratory in plastic bags. Sample preparation was done in accordance with the method stated in AASHTO T87-86.

### **3.2.2. Field and Laboratory Tests**

The procedures were used in order to perform the laboratory and field tests based on AASHTO and ASTM standards. The tests made are:

No.	Test type	Method used
1	Natural moisture content determination	ASTM D 2216
2	Grain size analysis (Sieve and Hydrometer)	ASTM D 422
3	Atterberg Limit Test	AASHTO T89 and T90
4	Field density test	AASHTO T-191
5	Compaction test	AASHTO T-180 method D
6	Determination of specific gravity	ASTM D 854
7	Single oedometer tests	ASTM D 5333

## **Chapter Four**

### **4. Laboratory Test Results and Discussion**

#### **4.1. General**

The laboratory testing activities are started by preparing the samples for testing to find out the properties of the soil. The tests include particle size distribution tests to obtain the amount and distribution of different particles sizes, compaction test to find out the laboratory maximum dry density and optimum moisture content, Atterberg limits to find the liquid limit and plasticity index, specific gravity, and finally the oedometer test at different densities to measure out the collapse potential and to recommend remedial measure specific to the selected road project. Soil samples for various laboratory tests were collected from Turmi - Omo road project. Generally, before excavation of test pits and collection of representative soil samples, a site visit, and reviewing of contract document of the project and design consultant's information are made to get the sections whereby collapsible soils found. Most of the laboratory tests were carried out based on the AASHTO manual for soil testing, and some of the laboratory tests were done by using ASTM manual.



**Figure 4-1** Typical test pits photograph

## **4.2. Index Property Laboratory Tests**

The physical property tests serve mainly for identification and classification are commonly known as index properties of the soil. The index laboratory test methods and results are shown below.

### **4.2.1. Natural Moisture Content**

The natural moisture content test is an indicator of the amount of water present in the soil at the time of sampling. Natural water content of soil (w %) is expressed as the ratio of mass of water in a given soil to the mass of solid particles in percentage. This laboratory determination of moisture content is on the basis of mass of soil but not on the basis of volume. The test for natural moisture content was conducted directly during in-situ density test and the result of the moisture content value for each test pits samples are presented hereunder the table 4-1.

**Table 4-1** Result of moisture content at the investigated depth

<b>Sample Description</b>	<b>Station</b>	<b>Natural moisture content (%)</b>
Pit#1	47+500	11.80
Pit#2	49+560	11.26
Pit#3	53+550	14.30
Pit#4	55+500	14.10
Pit#5	58+840	13.50
Pit#6	60+030	10.30

### **4.2.2. Specific Gravity Test**

This laboratory test is performed to determine the specific gravity of soil by using a pycnometer according to the test methods of ASTM D 854 and it is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature.

For the study area, the specific gravity test was done in the laboratory according to the aforesaid test method and the specific gravity is found within the range of 2.61 and 2.66. The results are presented in Table 4.3.

**Table 4-2** Typical test detail description of the specific gravity for station 47+500

<b>Specific Gravity Test Data For Station 47+500</b>		
<b>Trial</b>	<b>1</b>	<b>2</b>
Pycnometer #	A	B
A. Mass of Pycnometer (empty, clean)	49.48	44.65
B. Mass of empty pycno +Water	151.99	147.25
C. Temperature of Water at Measured	23.6	23.6
D. Density of Water	0.9974	0.9974
E. Mass of pycno + Soil +full of water (boiled)	158.5	153.34
F. Temperature at Measured	24.1	24.1
G. Density of water	0.99727	0.99727
H. Mass of pycnometre+ full Water	152.19	147.16
I. Mass of Dry sample	10.01	10.02
J. Specific Gravity at specific Temperature	2.698	2.602
K. Correction factor K	0.99919	0.99919
L. Specific gravity at Temperature=20°C	2.69583	2.60014
Average Specific Gravity at 20°C	2.65	

**Table 4-3** Results of the specific gravity test for each sampling station

<b>Sample Description</b>	<b>Station</b>	<b>Specific gravity</b>
Pit#1	47+500	2.65
Pit#2	49+560	2.64
Pit#3	53+550	2.61
Pit#4	55+500	2.62
Pit#5	58+840	2.63
Pit#6	60+030	2.66

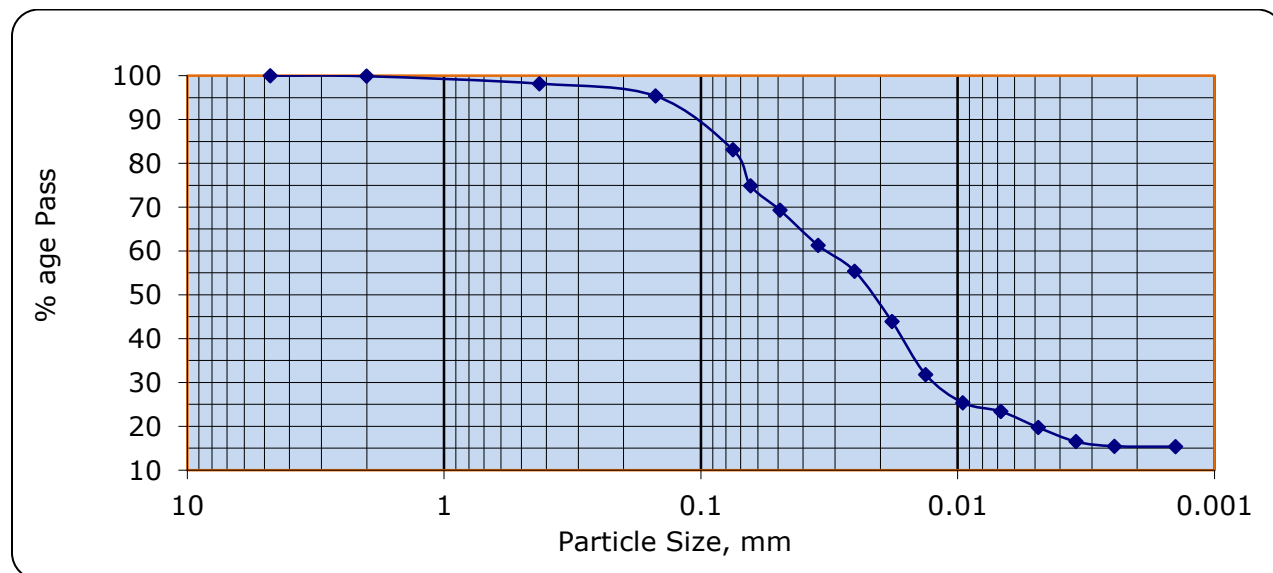
### 4.2.3. Grain-Size Distribution of Soil

#### 4.2.3.1. General

This type of test is important in order to categorize the soil in to separate sizes and so determines the relative proportions of each size accordingly. From the grain size analysis result of each test pit in percent, the sand content ranges from 5-18%, silt content ranges from 58-74.5% and clay content ranges from 15.5-27.7%. And also one can see from the results, the portion of the silt content is high relative to the others. Typical grain size classification results from sieve analysis and hydrometer analysis (combined), proportion of sand, silt and clay content, and classification results by using AASHTO and USCS method are shown in Tables 4.4, 4.5 and 4.6 respectively. Figure 4.2 shows typical sample grain size distribution curve for station 60+030.

**Table 4-4** Typical sample grain size classification results from sieve analysis and hydrometer analysis (combined) for station 49+560

	Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative mass retained in (%)	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	1.3	0.13	0.13	99.87
	0.425	16.9	1.69	1.82	98.18
	0.15	28.4	2.84	4.66	95.34
	0.075	122.6	12.26	16.92	83.08
Hydrometer Analysis	0.064		8.21	25.13	74.87
	0.049108		5.59	30.72	69.28
	0.034899		8.02	38.75	61.25
	0.025166		5.88	44.63	55.37
	0.018016		11.50	56.13	43.87
	0.013328		12.06	68.20	31.80
	0.009536		6.45	74.64	25.36
	0.006785		1.98	76.62	23.38
	0.004848		3.66	80.29	19.71
	0.00346		3.21	83.50	16.50
	0.002451		1.04	84.54	15.46
0.001417		0.11	84.65	15.35	



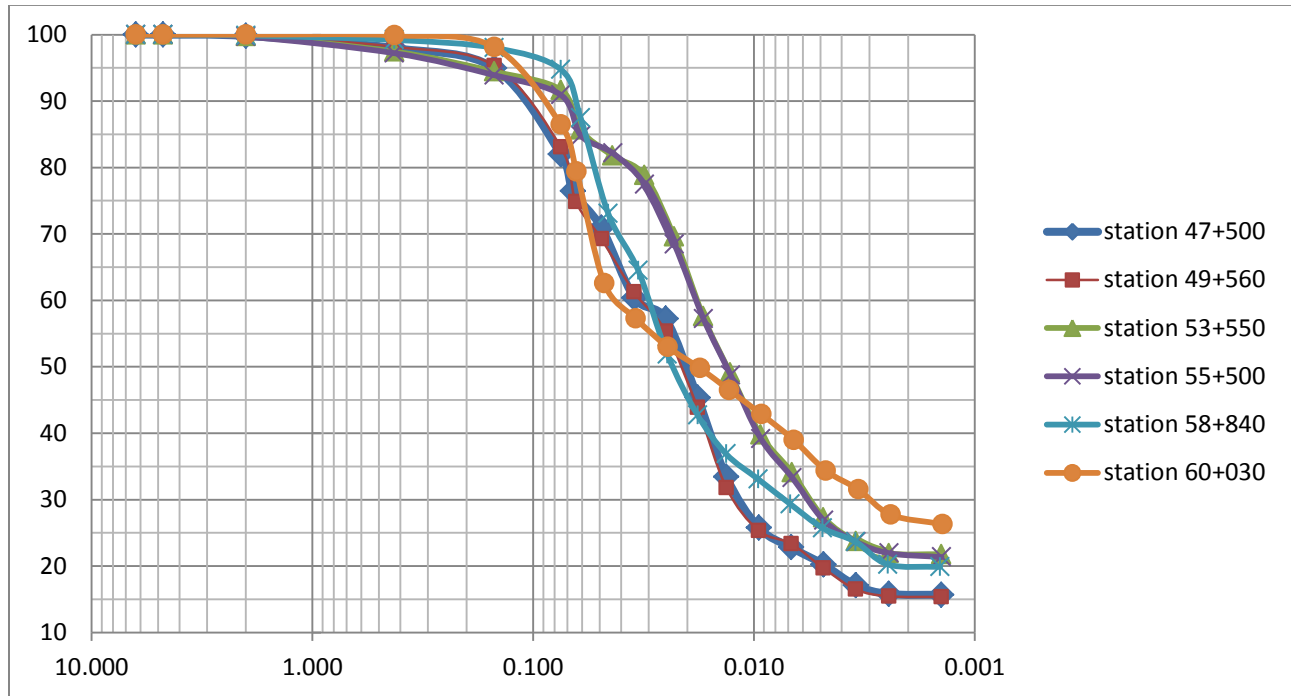
**Figure 4-2** Typical sample grain size distribution curve for station 60+030

**Table 4-5** Proportion of sand, silt and clay for each test pit

Designation	Station	Depth	Percent amount of particle size		
			Sand %	Silt %	Clay %
Pit#1	47+500	1.2	17.8	66.2	15.8
Pit#2	49+560	1.2	16.8	67.6	15.5
Pit#3	53+550	1.2	8.09	70.0	21.7
Pit#4	55+500	1.2	8.77	68.9	23.2
Pit#5	58+840	1.2	5.11	74.5	20.2
Pit#6	60+030	1.2	13.5	58.7	27.7

**Table 4-6** Classification result by using AASHTO and USCS method

At test pits of 1.2 meter depth	Percent passing on sieve			LL (%)	PI (%)	Group Index	Group Classification	Sub grade rating	USCS
	No.10	No.40	No.200						
Pit#1	100	99.81	82.00	38.7	9.7	8	A-4	Fair to Poor	ML
Pit#2	100	99.87	83.08	39.4	10.1	8	A-4	Fair to Poor	ML
Pit#3	100	99.78	91.69	49.2	21.1	14	A-7-6	Fair to Poor	ML
Pit#4	100	99.71	90.94	46.3	19.3	13	A-7-6	Fair to Poor	ML
Pit#5	100	99.88	94.77	46.5	19.8	13	A-7-6	Fair to Poor	ML
Pit#6	100	100.0	86.46	40.1	15.5	8	A-6	Fair to Poor	ML



**Figure 4-3** Combined grain size distribution curves for all sampling stations

#### 4.2.4. Atterberg Limits

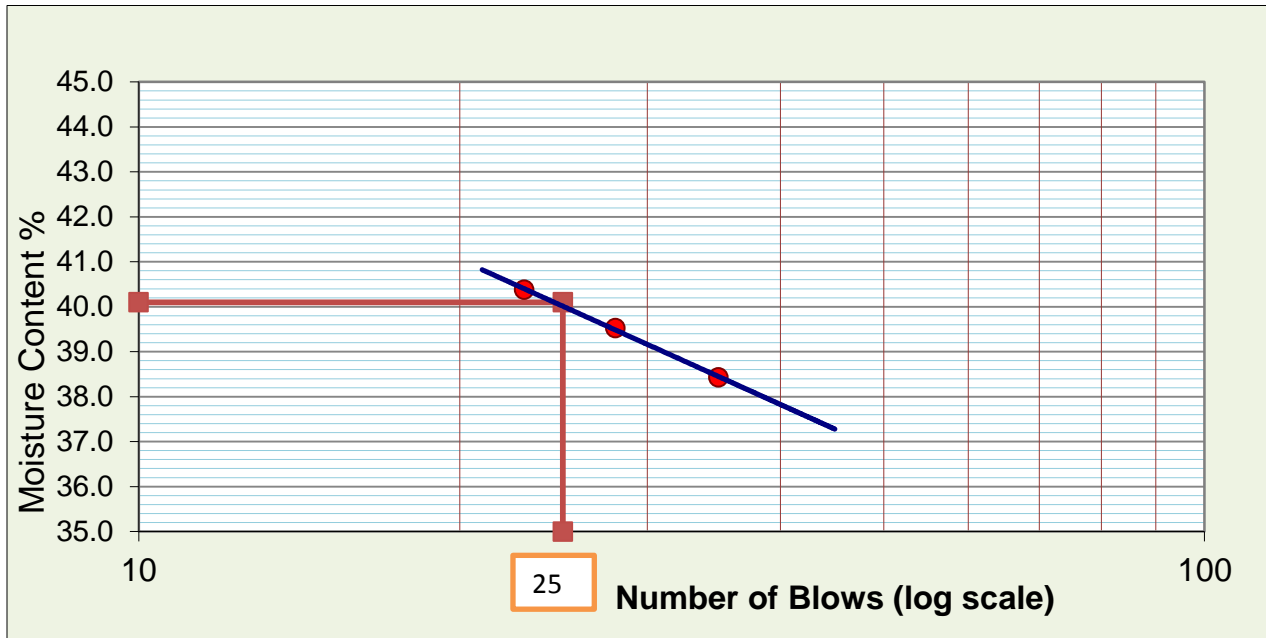
The Atterberg limits define the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. These tests were done according to the test method of AASHTO T89 and T90, from the test

result one can observe that the value of liquid limit ranges from 38 - 49.28%, plastic limits ranges from 23 – 29.3% and the plasticity index ranges from 9.7 – 21.1%.

Typical detail Atterberg limits test result calculation and the summarized Atterberg limits test results for all soil samples are shown in Tables 4.7 and 4.8 respectively. Figure 4.4 shows typical moisture content vs. number of blows plot for the determination of liquid limit.

**Table 4-7** Typical detail Atterberg limits test result calculation for Station 60+030

	Liquid Limit			Plastic Limit	
No. of Blows	35	28	23		
Container Number	A-1	D-5	B-3	C-3	D-4
Wt. of Container + Wet Soil (g) = (W <sub>1</sub> )	43.85	40.39	43.80	27.77	26.27
Wt. of Container + Dry Soil (g) = (W <sub>2</sub> )	38.42	35.75	37.84	26.81	25.56
Weight of Moisture (g) = (W <sub>1</sub> - W <sub>2</sub> ) = A	5.43	4.64	5.96	0.96	0.71
Wt. of Container (g) = (W <sub>3</sub> )	24.29	24.01	23.08	22.94	22.64
Weight of Dry Soil (g) = (W <sub>2</sub> - W <sub>3</sub> ) = B	14.13	11.74	14.76	3.87	2.92
Moisture Content (%) = (A / B) x 100	38.43	39.52	40.38	24.81	25.32
<b>Liquid Limit</b>	<b>40.10</b>			<b>25.0</b>	
Plasticity Index PI = LL-PL	<b>15.1</b>				



**Figure 4-4** Typical graph of moisture content vs number of blows for station 60+030

**Table 4-8** Summarized Atterberg limits test results for all soil samples

Designation	Station	Depth	Atterberg limits value		
			Liquid Limit	Plastic Limit	Plasticity Index
Pit#1	47+500	1.2	38.70	29.0	9.70
Pit#2	49+560	1.2	39.40	29.3	10.10
Pit#3	53+550	1.2	49.26	28.2	21.1
Pit#4	55+500	1.2	46.3	27.0	19.3
Pit#5	58+840	1.2	46.58	26.8	19.8
Pit#6	60+030	1.2	40.1	25.0	15.1

#### 4.2.5. In-situ Field Density

The test was conducted based on the testing procedures for density of soil in-place by the Sand-Cone Method (AASHTO T-191). The field density test was conducted on each test pits at a depth of 1.2 meter in the center of each test pit following the preparation of the excavated bottom area in order to find out the natural dry density and moisture content.

The in-place wet density of the soil is determined by dividing the wet mass of the excavated material by the volume of the hole. Following the determination of the wet sample of the excavated material in the hole, to find out the natural moisture content; the sample were transported into the laboratory of the project site. Finally, the water content of the material from the hole is determined and the dry mass of the material from the hole and the in-place dry density are calculated using the wet mass of the soil, the water content, and the volume of the hole. Test results are shown in Table 4.9. From the test results one can observe that the values of the in-situ density within the range of 1.2 to 1.5gr/cc and which shows the soil under investigation is loose in its natural state.

**Table 4-9** Result of natural moisture content and In situ density

<b>Designation</b>	<b>Station</b>	<b>Bulk Dnsity (gr/cc)</b>	<b>Dry Density (gr/cc)</b>	<b>Natural Moisture Content (%)</b>
Pit#1	47+500	1.377	1.231	11.8
Pit#2	49+560	1.379	1.239	11.26
Pit#3	53+550	1.524	1.334	14.3
Pit#4	55+500	1.525	1.337	14.1
Pit#5	58+840	1.403	1.237	13.5
Pit#6	60+030	1.278	1.159	10.3

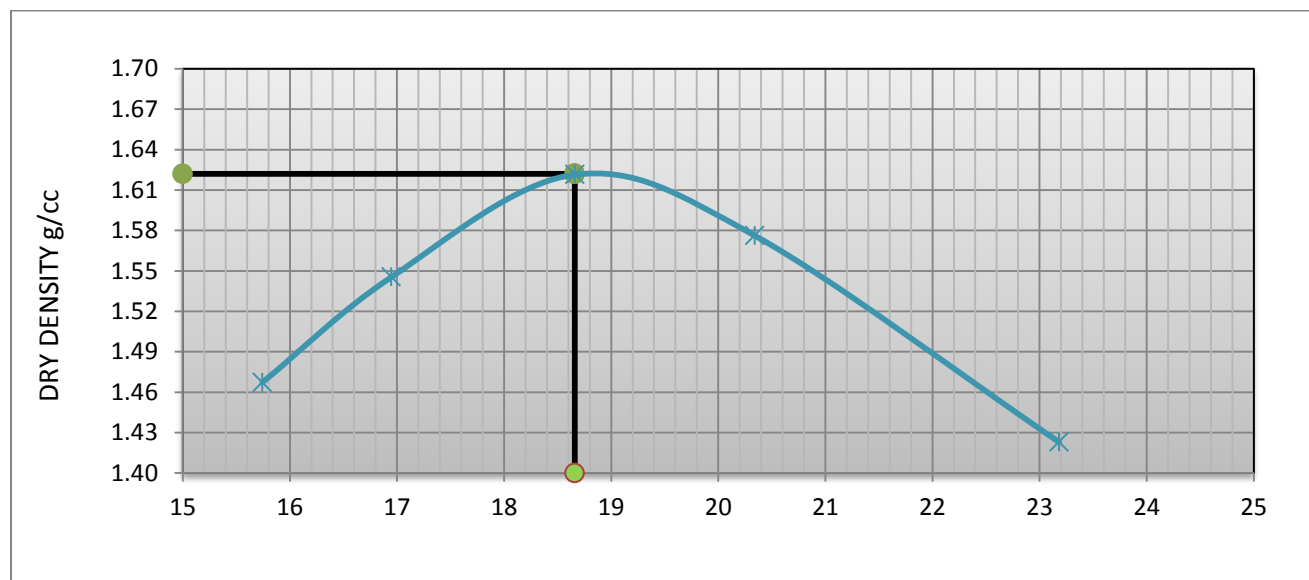
#### **4.2.6. Laboratory Compaction Test**

The modified Proctor compaction tests were conducted in order to find out the laboratory maximum dry density and optimum moisture content. The tests were carried out according to AASHTO T-180 method D.

Typical detail calculation for the determination of maximum dry density and optimum moisture content from modified Proctor tests is presented in Table 4.10. The summarized test results of modified proctor tests are shown in Table 4.11. Figure 4.5 shows, typical plot of dry density Vs. moisture content.

**Table 4-10** Sample test result of modified proctor test for Pit#3

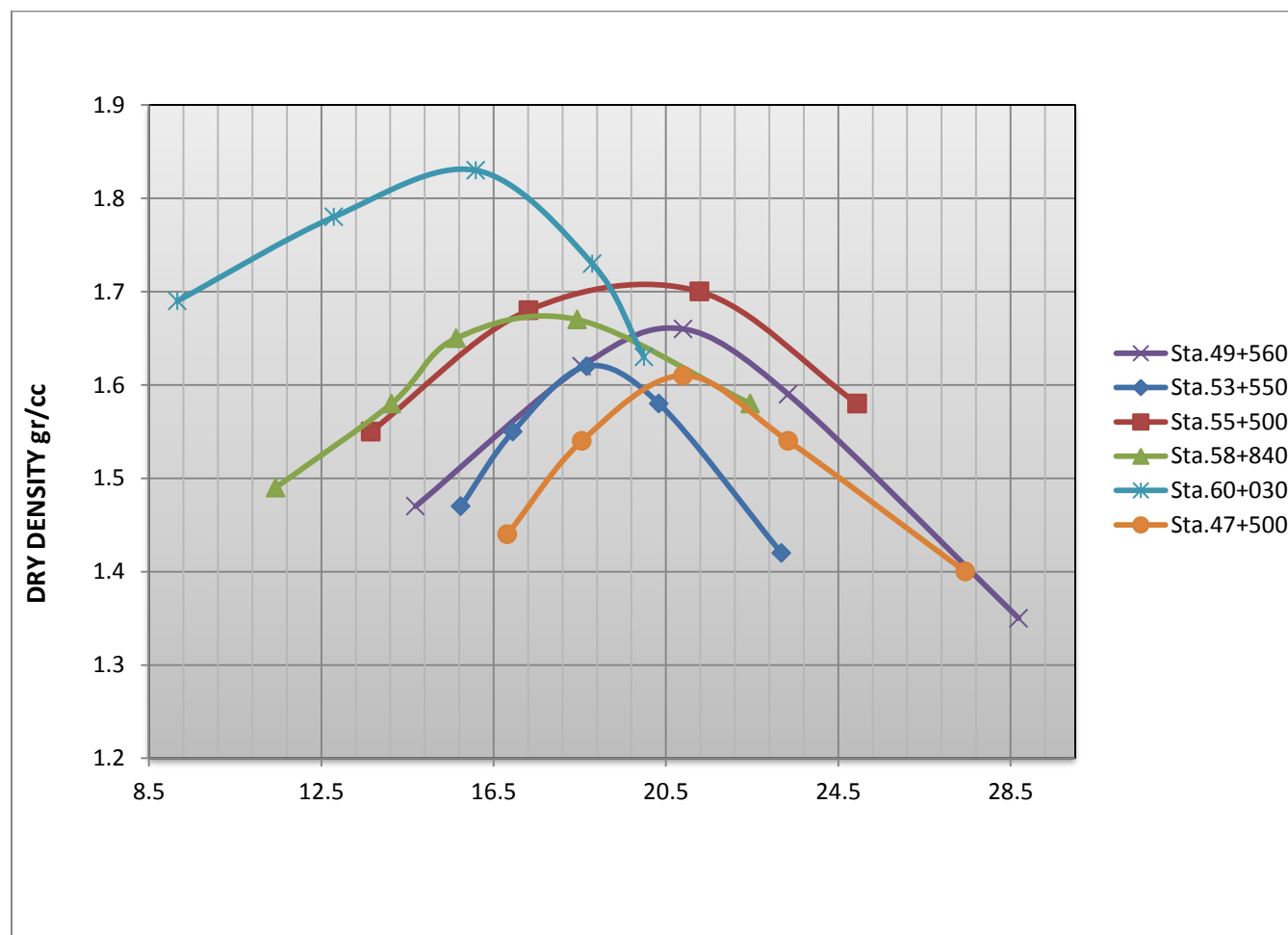
Density	TRIAL NUMBER	1	2	3	4	5	
	WEIGHT OF SOIL + MOLD	gr	8700	8920	9155	9100	8810
	WEIGHT OF MOLD	gr	5280	5280	5280	5280	5280
	WEIGHT OF SOIL	gr	3420	3640	3875	3820	3530
	VOLUME OF MOLD	cc	2014	2014	2014	2014	2014
	WET DENSITY OF SOIL	gr/cc	1.70	1.81	1.92	1.90	1.75
Moisture	CONTAINER NUMBER	T-5	T-2	T-7	H-4	H-3	
	WET SOIL + CONTAINER	gr	223.5	225.5	218.3	219.0	223.5
	DRY SOIL + CONTAINER	gr	197.4	197.4	188.7	186.8	186.8
	WEIGHT OF WATER	gr	26.1	28.1	29.6	32.2	36.7
	WEIGHT OF CONTAINER	gr	31.6	31.6	30.1	28.5	28.5
	WEIGHT OF DRY SOIL	gr	165.8	165.8	158.6	158.3	158.3
	MOISTURE CONTENT	%	15.74	16.95	18.66	20.34	23.18
<b>DRY DENSITY OF SOIL</b>	<b>gr/cc</b>	<b>1.47</b>	<b>1.55</b>	<b>1.62</b>	<b>1.58</b>	<b>1.42</b>	



**Figure 4-5** Typical plots of dry density vs moisture content for test pit#3

**Table 4-11** Summarized test result of modified proctor test

Designation	Station	Bulk Dnsity (gr/cc)	Dry Density (gr/cc)	Optimum Moisture Content (%)
Pit#1	47+500	1.917	1.59	20.6
Pit#2	49+560	2.02	1.67	20.7
Pit#3	53+550	1.92	1.62	18.6
Pit#4	55+500	2.05	1.71	20.4
Pit#5	58+840	1.97	1.68	17.5
Pit#6	60+030	2.12	1.83	15.8



**Figure 4-6** Modified Proctor compaction test results for all test pits

#### 4.2.7. Laboratory Oedometer Test

The oedometer is laboratory equipment used to study the settlement behavior of soils. The one dimensional single oedometer tests were performed on remolded disturbed soil samples collected from test pits No.2, 3, 6(1) and 6(2). The reason why four samples have taken is that, the materials test result of the six test pits from soil classification shows a similarity in its property and hence four samples has been taken for oedometer test. The laboratory tests were carried out in accordance with testing procedures described in ASTM D 5333.

Due to the cohesionless nature of the samples, it was difficult to collect undisturbed samples. However, the tests were done on samples remolded at different moisture contents and densities.

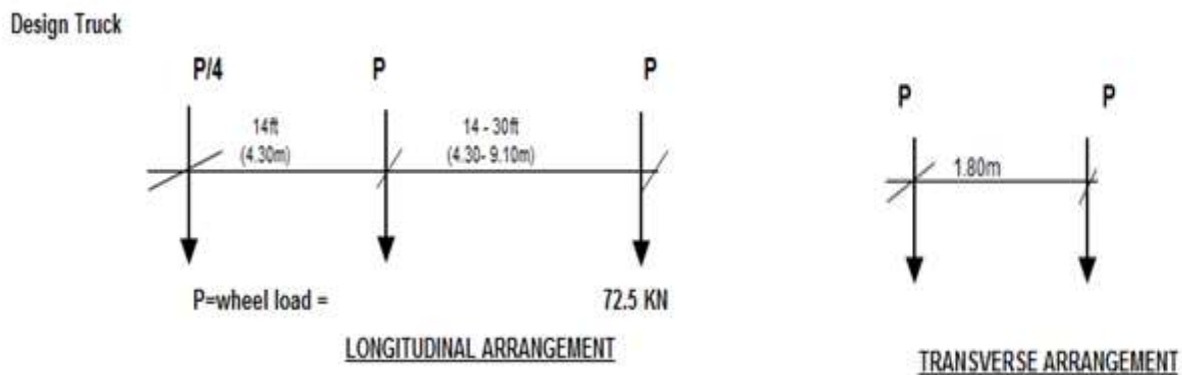
In addition to the loading procedures stated in ASTM D 5333, additional tests were carried on remolded samples inundated at the actual loading conditions of the project after the final design. The test results of collapse potential is presented as applied stress versus deformation curve and the results for some of the samples is depicted below.

##### 4.2.7.1. Actual Stress Analysis for the Designed Layers of the Road Section

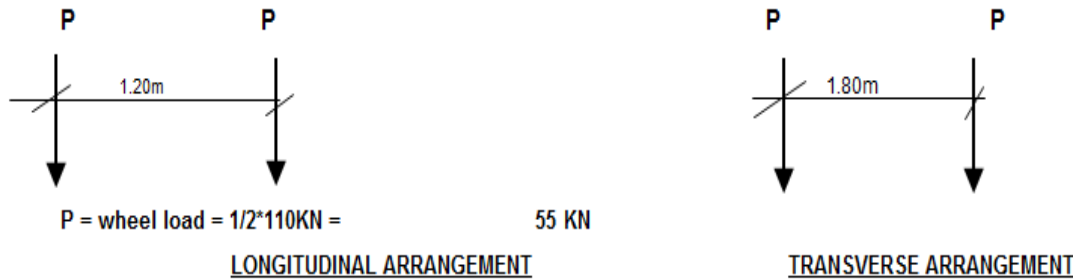
###### 4.2.7.1.1. Loading

Actual load in the designed road section were calculated based on different loading that consists of a combination of: Design truck or Design Tandem, Design lane loading, and embankments (surcharge load) to be applied simultaneously. Accordingly, the loadings are presented below:

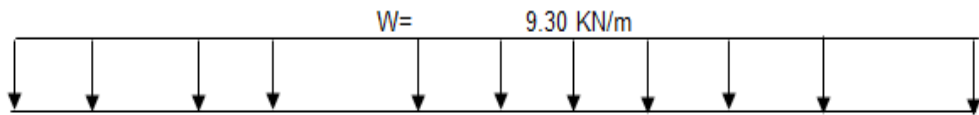
###### ¶ Traffic load:



Design Tandem



Design Lane Loading



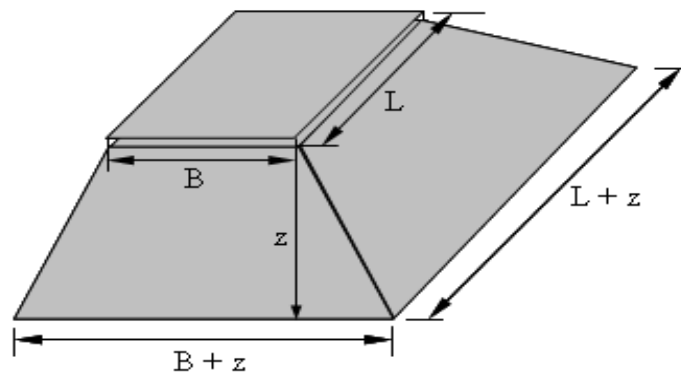
**Note:** Lane loading is uniformly distributed over a width of 3.00m.  
Dynamic Load Allowance is not applied for lane loading

**Figure 4-7** Traffic standard loading of design truck, design tandem and design lane load

**Vertical Stress Distribution of Rectangular Loads**

Though there are different methods of stress analysis, for this study the analysis is performed based on approximate method (sometimes called the 2:1 method). The surface load on an area,  $B \times L$ , is dispersed at a depth  $z$  over an area  $(B+z) \times (L+z)$  as illustrated in Figure 4-8 and the vertical load increase under the center of the rectangle is:

$$\Delta\sigma_z = \frac{q_s BL}{(B+z)(L+z)} \tag{4.1}$$



**Figure 4-8** Distribution of load for approximate increase in vertical stress under a rectangle

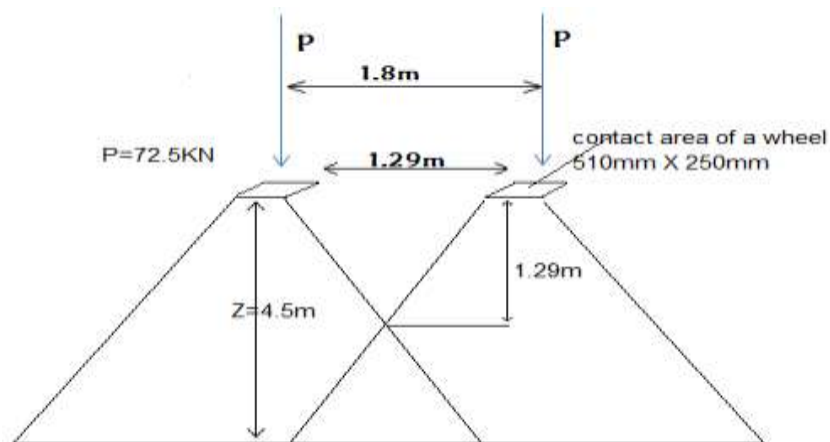
**4.2.7.1.2. Load analysis**

Based on the typical sections proposed in the design of the road section the maximum and minimum fill heights are presented in Table 4-12.

**Table 4-12** Maximum and minimum fill heights (m)

Station from	minimum fill height (m)	maximum fill height (m)	average fill height (m)
47+000 to 53+000	1.2	4.5	2.8
53+000 to 55+000	2	2.9	2.34
55+000 to 58+000	1	4.33	2.21
58+000 to 60+000, and	1.3	2.73	2.03
60+000 to the end	2.587	4.57	3.6

For the above loading arrangement using vertical stress distribution of rectangular loads and adding the surcharge load from embankment and pavement structure at the maximum fill height is computed and for design truck the transverse direction is critical.



**Vehicle load:**

$$\Delta\sigma_z = \frac{q_s BL}{(B+z)(L+z)}$$

Equation 4.1

$$q_s BL = 72.5 \text{ kN}$$

$$B = 0.51 \text{ m}, L = 0.25 \text{ m}, z = 4.5 \text{ m}$$

$$\Delta\sigma_z = \frac{72.5\text{KN}}{(0.51+4.5)*(0.25+4.5)} = 3.05\text{kN/m}^2$$

However for fill depth of greater than 1.29m there will be overlap of wheel loads, hence the total vehicle load will be twice the above calculated load.

$$\Delta\sigma_z = 6.1\text{kN/m}^2$$

**Lane load:**

The design lane load shall consist of a load of 9.3N/mm uniformly distributed in the longitudinal direction. Transversely, the design lane load shall be assumed to be uniformly distributed over a 3m width.

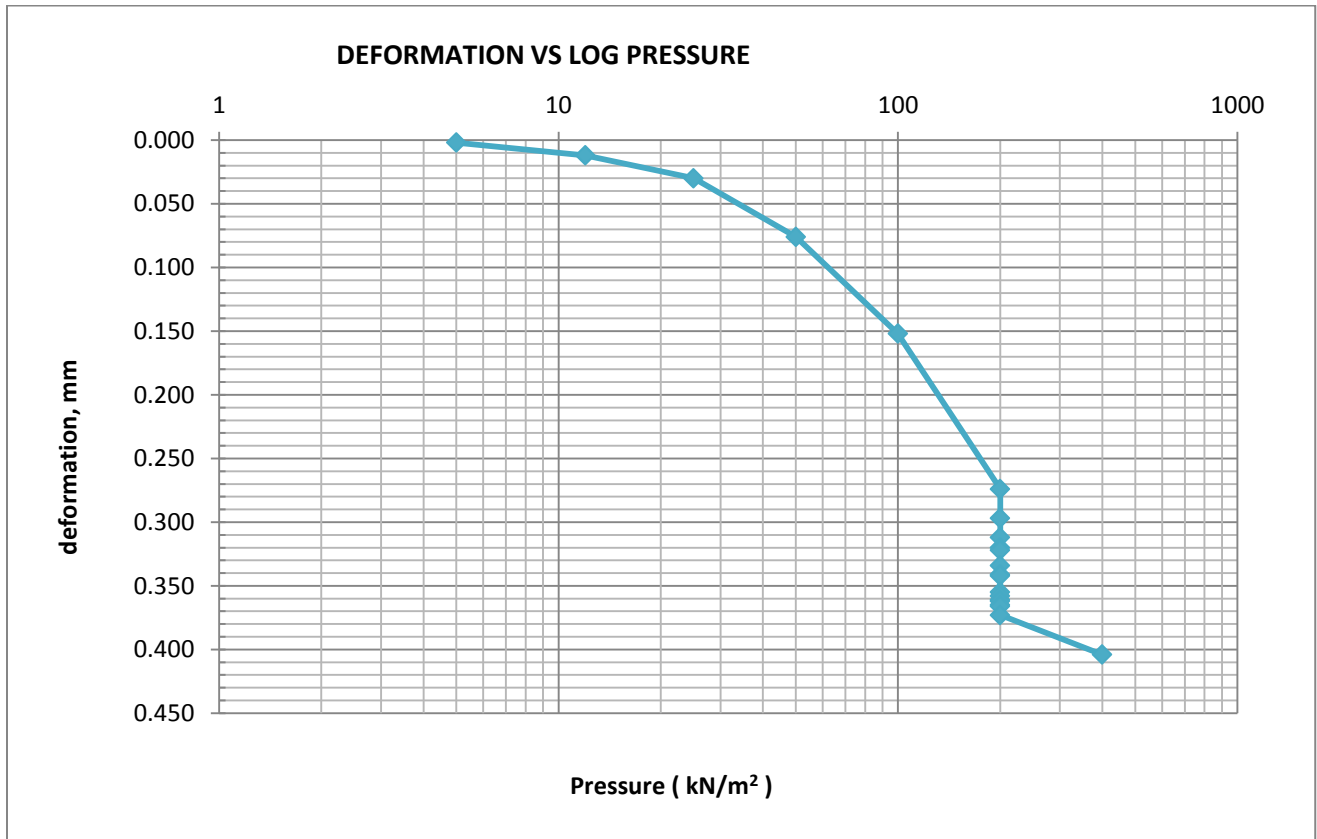
**Dead load:**

For fill height of 4.5m, we have surcharge loading from Asphalt concrete, base course, sub-base and embankment material. The following unit weight values have been taken: hot mix asphalt concrete = 23kN/m<sup>3</sup>, crushed base course = 22kN/m<sup>3</sup>, sub-base and embankment material =21kN/m<sup>3</sup> and compacted soil =19.25kN/m<sup>3</sup>.

$$\text{Stress from dead load} = (4.5-0.5)*19.25+0.25*21+0.2*22+0.05*23=87.80\text{KN/m}^2$$

Total stress at the maximum fill height of 4.5m depth will be the combination of vehicle load, lane load and dead load. Total stress on collapsible soil at the subgrade level (kN/m<sup>2</sup>) = (6.09+2.07+87.80)= 95.93 kN/m<sup>2</sup> and hence the total stress at the depth of 4.5m is 104.28 kN/m<sup>2</sup>.

As we see from the above the maximum stress in the road section is 104.28Kpa. Hence, during the loading condition of the laboratory oedometer test, in order to check the actual collapse potential the maximum applied load was 105kPa. The sample oedometer test results and typical deformation vs stress plot of oedometer test are shown in Figure 4-9 and Table 4-14 respectively.



**Figure 4-9** Typical deformation vs stress plot of oedometer test result for sample remolded at the maximum dry density and optimum moisture content and at a standard load of 200kPa

**Table 4-13** Summarized oedometer test results of collapse potential for each test pits at different loading condition

Designation	Collapse Potential (Cp %)			
	At MDD and Loading of 200kPa	At MDD and Loading of 105kPa	At In-situ density and Loading of 200kPa	At In-situ density and Loading of 105kPa
Pit#2 sample 1	0.23	0.19	1.89	1.49
Pit#3 sample 1	0.29	0.21	3.46	1.95
Pit#6 sample 1	0.495	0.29	5.93	4.47
Pit#6 sample 2	0.45	0.34	5.76	5.015

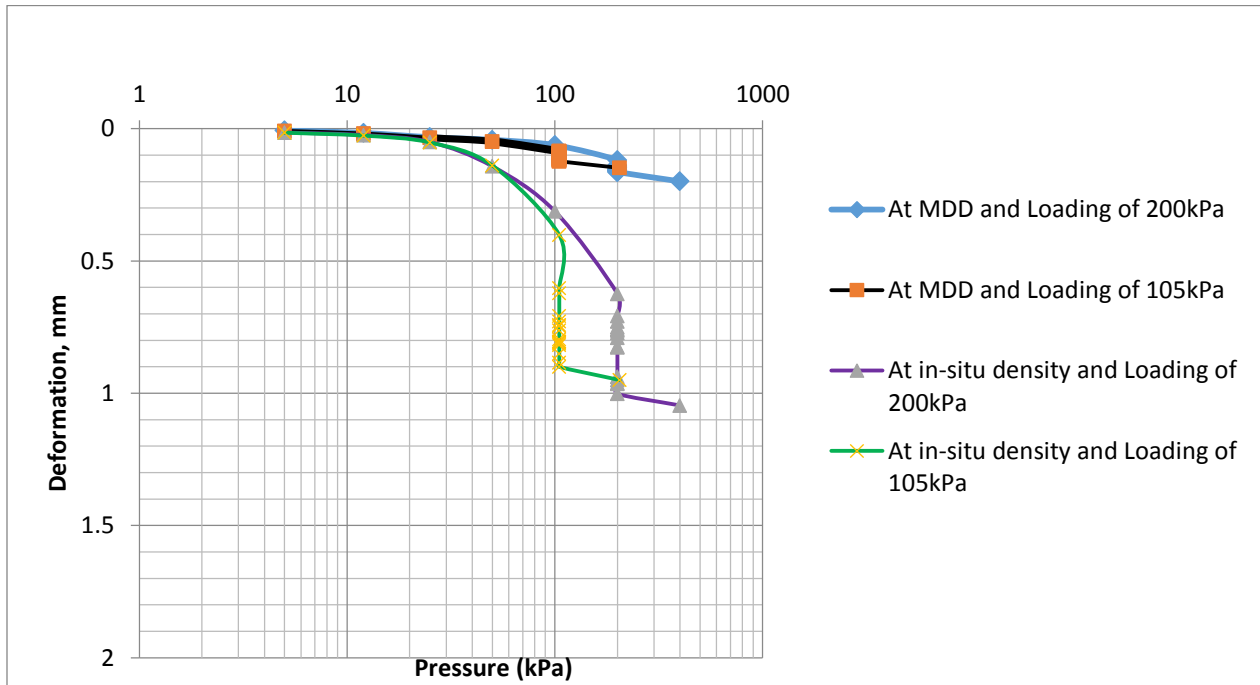


Figure 4-10 Combined plot of deformation vs stress for station 49+560 at different loading conditions and densities

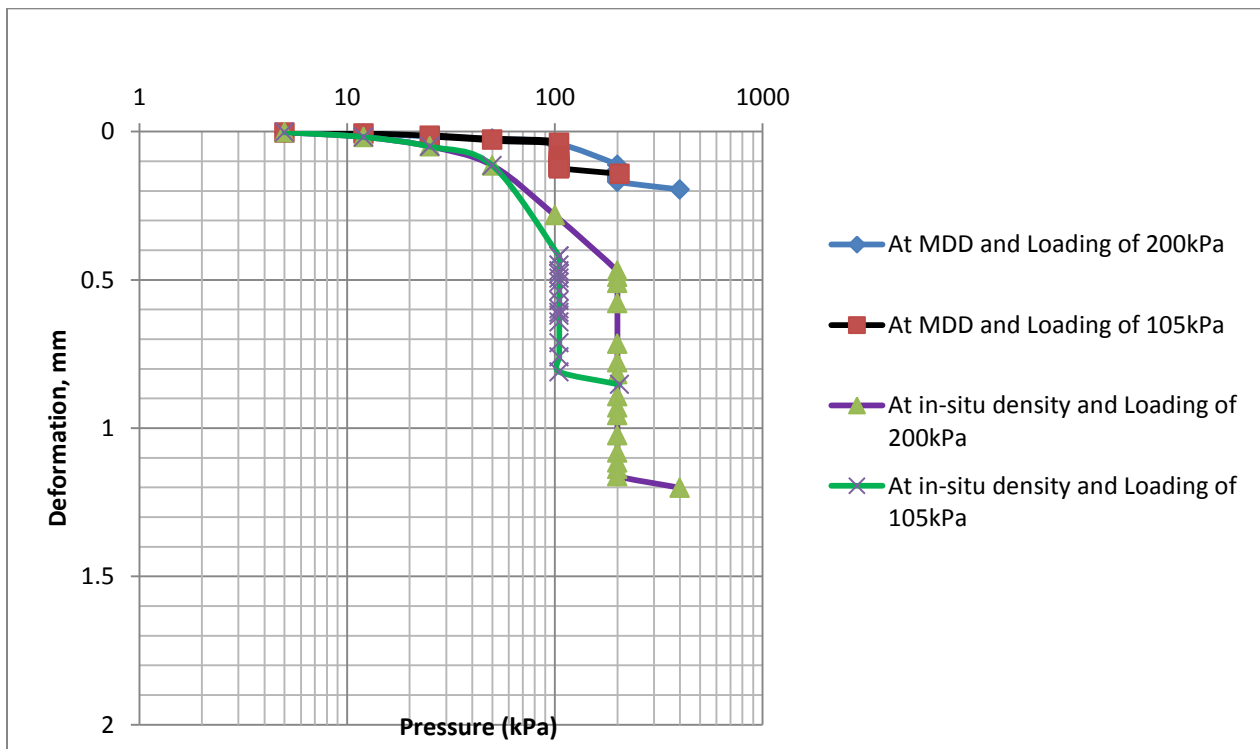
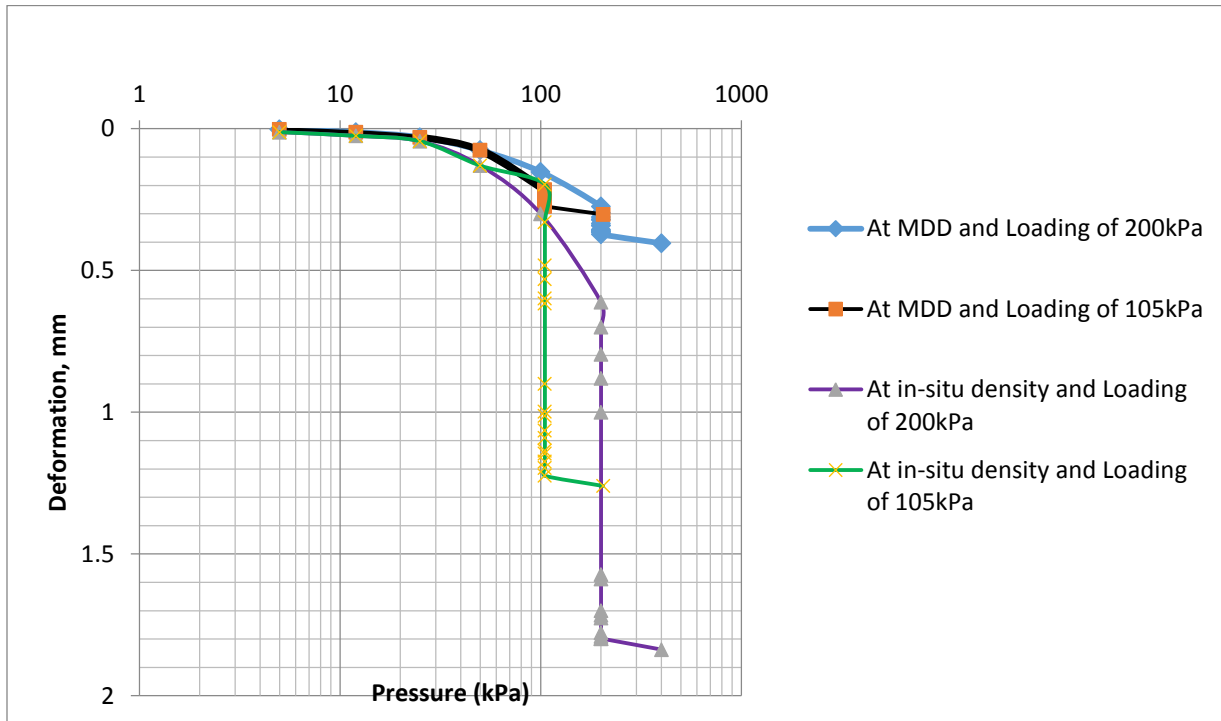
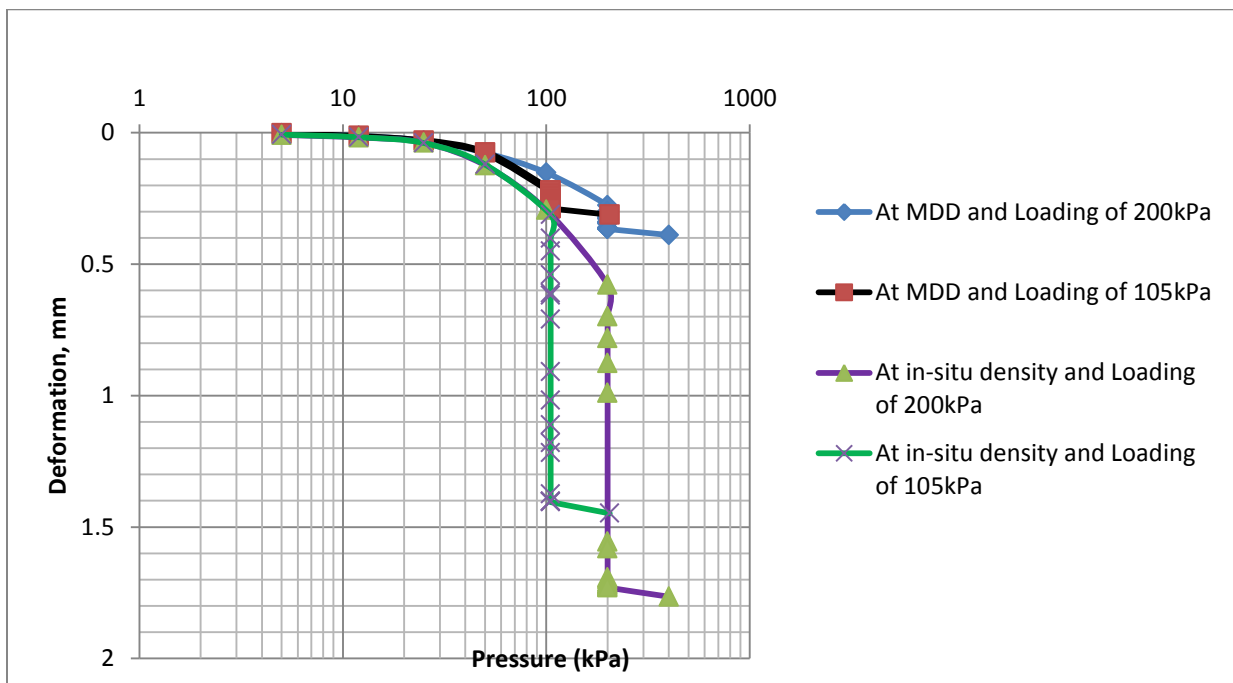


Figure 4-11 Combined plot of deformation vs stress for station 53+550 at different loading conditions and densities



**Figure 4-12** Combined plot of strain vs deformation for station 60+030 of sample 1 at different loading conditions and densities



**Figure 4-13** Combined plot of strain vs deformation for station 60+030 of sample 2 at different loading conditions and densities

### **4.3. Discussion of Laboratory Tests**

#### **4.3.1. General**

Generally in this part which is the discussion, intended to present the origin of studied soils and their classification according to AASHTO and USCS Soil Classification System. It also presents the use of physical properties of soils samples to evaluate the collapse potential, as indirect method for collapse potential evaluation and discussion of the results. Moreover, it presents the analysis of the one dimensional single oedometer test results as direct method for collapse potential evaluation on remolded soil specimens at their in-situ densities and laboratory maximum dry densities of soil specimens with the applied standard load of testing and actual stress on the selected road section. Hence, from the laboratory tests the physical properties of soil in the study area of selected road section are determined and the results of these tests are discussed here under.

##### **4.3.1.1. Field Density and Laboratory Compaction Test**

The nature of compaction state (looseness or denseness) of the subgrade soils and the natural moisture content were determined from the results of field density tests. The test was conducted based on the testing procedures for density of soil in-place by the Sand-Cone Method (AASHTO T-191). The in-situ bulk density of soils at the depth of investigation in the study area ranges from 1.27 to 1.52 gr/cm<sup>3</sup> and the in-situ dry density is within the range of 1.16 to 1.34gr/cm<sup>3</sup>. As one can see that the in-situ density is low and indicates that the soil has a potential to collapse. Generally from the results of the in-situ density one can observe that the in-situ density is low and the stretch of the road section is naturally at loose state and hence a special attention should be given during the design of sub grade of the road section this may cause easily settlement of the road section during a new construction.

The modified Proctor compaction tests were conducted in order to find out the laboratory maximum dry density and optimum moisture content and the tests were carried out according to AASHTO T-180 method D. The laboratory modified compaction test values of the studied area ranges from 1.59 to 1.83 gr/cm<sup>3</sup>.

#### **4.3.1.2. Specific Gravity Test and Natural Moisture Content**

For the study area the specific gravity test were done in the laboratory according to the test methods ASTM D 854 and the specific gravity is found within the range of 2.61 and 2.66.

The test for natural moisture content was conducted directly during in-situ density test and the result is found within the range of 10.3 and 14.3%.

#### **4.3.1.3. Grain size analysis**

The grain size distribution analysis results at the depth of investigation indicate that the dominant proportion of soil particle in the research area is silt. The clay content ranging from 15.5 – 27.7%, silt fraction 58.7 – 74%, sand fraction 5 – 17.8% and gravel content from 0.1 – 0.29%.

Classifications of soils in the study area based on AASHTO Classification system is shown in Table 4.15. Classifications of soils in the study area based on AASHTO classification system is classified in group of A-4, A-6 and A-7-6, which are silty and clayey soils with group index ranging from 8 to 14. The group index result indicates that generally the soil of the study area for the use of highway subgrade is fair to poor. The smaller the value of the group index, the better is the soil for highway subgrade material. A group index of zero indicates a good subgrade, whereas group index of 20 or greater shows a very poor highway subgrade material. And also, according to USCS; the soil under investigation is classified as inorganic silts of medium compressibility (ML).

#### **4.3.1.4. Atterberg Limit Test**

Atterberg limits test results revealed that the liquid limit of the soil in the research area ranges from 38.7 to 49.26%, plastic limit ranges from 23.8 to 29.3% and plasticity index ranges from 9.7 to 21.1%. As one can see in the literature review, one can observe that the result of Atterberg limit test values of the soil under investigation shows the susceptibility of the soil to collapse. Even if the portion of the clay content is small in the study area of the road section, it has been found that both liquid limit and plastic limits depend upon the type and amount of clay in the soil. Hence, based on AASHTO and USCS classification; the soil under investigation is classified as A-4, A-6 and A-7-6 and inorganic silts of medium compressibility (ML) respectively.

#### **4.3.1.5. Discussion on Single Oedometer Test and Collapse Potential**

Due to the cohesionless nature of the samples, it was difficult to collect undisturbed samples. Hence, one dimensional single oedometer tests were carried out on samples remolded at field densities and maximum dry densities in accordance with testing procedures described in ASTM D 5333. In addition to the loading conditions stated in ASTM D 5333, additional oedometer tests were carried out on remolded samples inundated at the actual loading conditions of the project after final design of the road pavements.

The oedometer test results showed that, the collapse potential of the samples remolded at their in-situ densities is within the range of 1.49 % to 5.93 % and indicates that the severity of collapse is slight to moderate. And also, the collapse potential of the samples prepared at their maximum dry densities is within the range of 0.19 % to 0.495 % and thus the severity of collapse is very slight. Generally, the results indicated that the soil is collapsible and collapse potential could be significantly reduced by compaction during construction.

Generally, based on the field and laboratory test results; one can evaluate the collapse potential according to different evaluation criteria. The evaluation of collapse potential or susceptibility of soil to collapse using the physical properties of soils was reported in the literature as an indirect method and the susceptibility of collapse can be evaluated by using the collapse potential values as direct method and presented here under.

##### **4.3.1.5.1. Evaluation by using Indirect Method**

Several collapse criteria have been proposed for predicting whether a soil is liable to collapse upon inundation and hence the evaluation are made here under.

- **Prikloński's** criterion, this criterion is by using the liquidity index to expect the collapse of soil. The criterion is if the liquidity index is less than zero, the soil is considered as collapsible and the liquidity index is defined as the different between natural moisture content and plastic limit divided by plasticity index ( $LI = (N.M.C-PL)/PI$ ). From the above presented test results, the plastic limits of all soil samples greater than its natural moisture content, and in this case the liquidity index is less than zero. Hence, by using Prikloński's criterion the soil under investigation is collapsible.

- **Clevenger (1958)** criterion, this method stated by using the natural dry density. If the natural dry density is less than  $12.6 \text{ kN/m}^3$ , significant settlement will be occur while if the natural dry density is greater than  $14.1 \text{ kN/m}^3$  small settlement will be occur. Hence, from the test results of the in-situ densities of the soils under investigation have natural dry density of less than  $12.6$  for test pit# 1, 2, 5, and 6 and this indicates significant settlement will be occur in the road section and also for sample pit#3 and 4 the natural dry density is greater than  $12.6 \text{ kN/m}^3$ , thus at transitional settlement.
- The third criterion was proposed by **Handy (1973)**. This criterion by using clay content and if the clay content between  $16.0\%$  to  $24.0\%$  the soil is collapsible while if the clay content is less than  $16.0\%$  the soil is highly collapsible. As one can see from the test results the value of the clay content proportion from all of the test pits is in the range of  $15.5$  to  $21.1\%$  and shows the soil has a potential to collapse.
- Even if there are different criteria of evaluation of the collapse of soils by indirect method that are proposed by different researchers, in this research the researcher evaluate by the above three criterion and the last one of for this study after **Holtz and Hilf (1961)**. This criterion is based on the liquid limit and dry density of the soil with its specific gravity of the material. Hence, based on this evaluation criterion; the direct reading from the graph; the point is above the specific gravity line and indicates the soil has a potential to collapse.

#### **4.3.1.5.2. Evaluation by using Direct Method**

For this research the direct method used to evaluate the susceptibility of collapse potential is from a single Oedometer test results at different densities and loading conditions.

As it was stated in the literature review Chapter under Table 2.1 of degree of collapse based on collapse potential value ( $I_e$ ), one can evaluate the degree of collapse as direct method. Hence, from the oedometer test results and according to the criteria stated by ASTM D 5333; the collapse potential for the case at in-situ densities is within the range of  $1.49\%$  to  $5.93\%$  and indicates that the severity of collapse is slight to moderate.

And also, the collapse potential for the maximum laboratory dry density value; in the range from  $0.19\%$  to  $0.495\%$  and thus the severity of collapse is very slight. Therefore, the results indicated that the soil in its natural state is collapsible and collapse potential could be significantly reduced

by compaction during construction. In addition to that, prevention of the subgrade material from wetting has a vital role to minimize the collapse potential of the soil.

#### **4.3.1.6. Comparison of Index Property Test Results of Collapsible Soil with other Researches**

A comparison between collapsible soils in the study area and those in other parts of the world is made based on the geotechnical properties. The geotechnical properties used for comparison include NMC, dry density, LL, PI, specific gravity, and collapse potential. From the test results, it can be inferred that the soils under investigation are found in dry state with low dry density. The LL and PI are also similar with collapsible soils in other parts of the world. The collapse potential results indicate all soil samples show slight to moderate collapse.

Generally the soils in the study area show some similarities with collapsible soils found in other parts of the world. The differences of some properties may be owing to the different geological and environmental conditions. Table 4-15 shows, comparison of the properties of collapsible soils of the study area with those found in other parts of the world.

**Table 4-14** Collapsible soil properties comparison (Compiled by Yideneke M., 2015)

Properties Country	NMC (%)	Dry density (g/cm <sup>3</sup> )	LL (%)	PI (%)	Specific gravity (Gs )	Collapse potential ,Cp % at in-situ density and 200kPa	Reference
Study area (South Ethiopia Turmi-Omo road project)	10.3-14.3	1.16-1.34	38.7-49.3	9.7-21.1	2.61-2.66	1.89-5.93	This study (Turmi-Omo road project), 2019
South Ethiopia (around the study area Omo-F6 road project)	1.9-10.4	0.96-1.44	22-51	2-21	2.5-2.79	1.25-15.1	Omo-F6 road project (CCCC, 2015)
Nigeria (South west)	17.5	-	43	10	2.67	3.7-11.5	Owolabi, Titilayo. A, EJGE, 2014
Collapsible Criteria		1.0 to 1.585 (Paige- Green 2008)	25-55 (Bowels)	-	2.6-2.8 (Bowels)	Stated in Table 2.1	-

**Table 4-15** Summarized field and laboratory test results and classification

Test pit	Grain size distribution proportion in %				Atterberg limit value			Laboratory and in-situ dry density with its moisture content and Specific gravity					AASHTO and USCS classification	
	Gravel	Sand	Silt	Clay	LL	PL	PI	Dry density	Optimum moisture content	In-situ dry density	Natural moisture content	Specific gravity	AASHTO	USCS
47+500	0.19	17.8	66.2	15.8	38.7	29.0	9.7	1.593	20.6	1.231	11.8	2.65	A-4(8)	ML
49+560	0.13	16.8	67.6	15.5	39.4	29.3	10.1	1.638	17.5	1.239	11.26	2.64	A-4(8)	ML
53+550	0.22	8.09	70.0	21.7	49.3	28.2	21.1	1.62	18.6	1.334	14.3	2.61	A-7-6(14)	ML
55+500	0.295	8.77	68.9	23.2	46.3	27.0	19.3	1.716	20.0	1.337	14.1	2.62	A-7-6(13)	ML
58+840	0.12	5.11	74.5	20.2	46.6	26.8	19.8	1.684	17.5	1.237	13.5	2.63	A-7-6(13)	ML
60+030	0.1	13.5	58.7	27.7	40.1	25.0	15.1	1.828	15.8	1.159	10.3	2.66	A-6(10)	ML

#### **4.4. Recommended remedial measures for the studied road section**

The subgrade is the supporting ground beneath of a pavement structure and it is located below the base and sub-base courses. Investigation to such depth is important to any structural design and pavement life, and it may consist of materials forming the natural ground surface or exposed in excavations. The strength, stiffness, and moisture characteristics of materials forming the subgrade can have a significant influence on pavement performance. The subgrade and base layers must be strong enough to resist shear failure and should have adequate stiffness to minimize vertical deflection. A critical component of pavement design is, therefore, the investigation and testing of the subgrade upon which the pavement structure will be constructed. In cases where the subgrade is of inadequate strength, methods of improvement must be considered [18].

As it was stated in the literature review Chapter, one can use different mechanisms of stabilizing the collapsible potential of soils like using dynamic compaction, compaction using impact rollers, treatment using cement materials, prewetting, removal and re-compaction and chemical grouting. These mechanisms have their own advantages and disadvantages and also depend on the condition of the site and the severity of the collapse potential with different specific sites.

Hence, among the different adopted treatment mechanisms of the collapsible soils fabric; selection of the most effective remedial measures which suit to the particular site condition, environmental impact practicality and economic conditions is vigorous. This is, therefore; in order to treat collapsible soils different parameters shall be considered as criteria for choice of appropriate remedial measures. Based on the aforementioned treatment methods and laboratory test results, for reasonable comparison the selected criteria are:

- Practicality
- Availability of material for treatment
- Impact of treatment on environment
- Cost of treatment
- Treatment depth
- Treatment period

Generally, the different treatment methods are qualitatively compared with the above mentioned criteria in order to select the best improvement mechanism of collapsible soils.

✓ **Dynamic Compaction**

As one can see in the literature review, this method of treating collapsible soils is that; the in-situ subgrade will be compacted to a treatment depth of 10 meters with a rate which is very slow to compact road subgrades and thus takes time. It is apparent that the contract period for road projects is limited that the items of works in the road section such as earthwork and pavement layer construction shall be fast and preparation of subgrade soils is a pre-request for the other subsequent actions. Moreover, this method is not practical and applied in Ethiopian road construction projects. Hence, the dynamic compaction has considerable impact on the project vicinity and it is not recommended as remedial measure for the project road.

✓ **Impact Roller Compaction**

In this method, ground improvement is typically measured to effective depths of 1 to 3 meters using eccentrically shaped large impact rollers (25 kJ). It is relatively fast and has no significant environmental impact. This method is known, practical and applied for most of completed and under road construction projects that are held in Ethiopia and impact roller compaction has been used effectively in different countries such as China and South Africa to treat collapsible soils.

✓ **Cement Materials Treatment**

The study area is found 900 km from Addis Ababa where transporting cost of cement is expensive. In addition to that, some section of the road is covered with collapsible soils and treatment cost will be significant. Moreover, treatment of soils by this method is not practical for most of constructed and under progress road projects. In this regard this remedial measure is not considered as reasonable option.

✓ **Prewetting and Surcharging**

This method involves inundation of the collapsible soil and then surcharging with sufficient load to make precollapse before actual construction. The prevailing temperature in the project area is hot with semi-arid climatic condition where evaporation is very high and prewetting is not feasible. Besides, surcharging involves the placement and removal of a fill similar to or greater than the permanent load which is not feasible as the area is found in flat terrain with scarcity of surcharging material. This method is relatively practical in Ethiopian road construction projects.

✓ **Removal and Replacement**

The study area is generally flat and rolling where borrow material for replacement is scarce and the available materials are found at a far distance for the said road section whereby the collapsible soils fund. The treatment method involves material production, hauling, excavation of the natural subgrade and layer by layer compaction by a thickness of 25 cm. This treatment method needs borrow material source and spoil area which will degrade the natural environment and this affects the environment. This method is relatively practical in road construction projects.

✓ **Chemical Grouting**

The treatment method will be effective if sodium silicate is available however the chemical shall be imported and the grouting the considerable portion of the project is costly. Generally, the comparisons are tabulated in the table 4-17:

**Table 4-16 :** Comparison between different mechanisms of treating collapsible soils

Criteria Treatment method by:	Treatment Depth (m)	Treatment Period	Environmental Impact	Availability of the material	Practicability in Ethiopian road constructions projects	Suitability rank
Impact roller compaction	1-3	Fast	No/significant	In-situ subgrade	Practical	(1)
Dynamic compaction	10	Slow	Yes/vibration	In-situ subgrade	Not practical	NO
Prewetting and surcharging	-	Slow	No	It needs surcharge material (fill) material	Practical	(4)
Cement	-		No	Transportation of cement	Not practical	No
Removal and replacement	Removal of the sensitive subgrade soils	Slow	Yes	Shortage/Scarcity of Borrow Material for replacement	Practical	(3)
Chemical grouting	-		Yes	Importation of sodium silicate	Not practical	No
Removal and re-compaction	Removal up to depth of influence and Compaction to a lift thickness of 0.25 meter	Slow	Environmental friendly	In-situ subgrade	Relatively Practical	(2)

Hence, for the study area; it has been found that the collapse potentials of the soil at its in-situ density is slight to moderate, and at maximum dry density is very low and slight. Hence, from these results one can deduce that; the collapse potential can be minimized by effective compaction method in the site using appropriate compaction machinery.

Hence, from the above general over view and from the results of the oedometer tests; the following remedial measures may be used to minimize the degree of collapsibility of the subgrade soli of the road section.

- ✚ Due to the susceptibility of the material in the study area to collapse, irrespective of the degree of collapsibility of the subgrade soils, moisture control and compaction control of the subgrade soil are the two best treatment methodologies.
- ✚ As one can see from the laboratory oedometer test results, the values of the collapse potentials decrease by greater than 80% when the samples are compacted at their maximum dry densities. Hence, appropriate compaction during construction is the best mechanism to treat collapsibility of the material (compaction using impact rollers).
- ✚ In connection to the above, even if the ground water table is far from the original ground level; surface water percolation into the subgrade can wet the material and cause hydrocollapse. Hence, prevention of the contamination of the surface water to the subgrade is the best mechanism to minimize collapsibility of the material. In this regard, the material shall be treating as expansive soil and hence during construction the remedial measures for expansive soils should be applied.

## **Chapter Five**

### **5. Conclusions and Recommendations**

#### **5.1. Conclusions**

This part summarized the conclusions reached in this research. The main objective of this research is to investigate the physical properties and the severity of collapse of the soils in the studies area. Based on field and laboratory test results at the investigated depth of the material, the following conclusions are drawn.

- At the investigated depth the subgrade soil classes fall in A-4, A-6 and A-7-6 according to AASHTO classification and according to USCS the subgrade soils classified as ML group of inorganic silt of medium plasticity.
- The laboratory test results of the soils showed that the specific gravity, liquid limit and plasticity index are ranging from 2.61-2.66, 38-49.28% and 9.7-21.1% respectively.
- The collapse potential values computed from the results of oedometer tests conducted on samples remolded at in-situ densities and natural moisture contents and at dry densities and optimum moisture contents fall within the ranges of 1.49-5.93 % and 0.19-0.495% respectively. From the test results, it has been observed that the collapse potential value can be reduced by compaction.
- The collapse potential value reduced from the range 1.89-5.76% to 1.49-5.02% in case of in-situ densities and from the range 0.23-0.493% to 0.19-0.34% in case of maximum dry densities when the final load during oedometer test changes from the standard load of 200kPa to 105kPa and hence the collapse value can be reduced by minimizing the stress.
- From the test result, the severity of collapse by the in-situ density and the laboratory maximum density changes from slight to moderate to very slight and this shows the material can be treat by the combination of preventing water contamination with subgrade and compaction technique to be used in the field to reduce the collapse potential of soil. And also physical and engineering properties shall be made with comparisons.

## **5.2. Recommendations**

The work presented in this thesis was concerned with study of the physical properties of the studied area and propose remedial measures. The study was carried out and the collapse potential of these soils evaluated. Additional work is required to better identify the collapsible soils and reducing the collapse potential of the studied area and hence this can be summarized as follows:

- Moisture control and compaction of the subgrade soils are the two best recommended methodologies to treat the subgrade soil in the project site.
- In-situ plate loading test (in order to know the actual subgrade settlement) shall be carried out in detail during design stage for such problematic collapsible subgrade soil.
- Appropriate and detail researches shall be conducted in all areas whereby collapsible soils found in the future in order to prepare appropriate treatment mechanisms (dynamic compaction, impact roller compaction, prewetting, soil replacement and others) for the said soils.
- Treatment of studied soils by compaction, wetting or combination of them could be tried in the field to analyze the effects of using these treatments in reducing of collapse potential and for all treatment methods of the collapse potential, economical analysis shall be made in detail.



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## Appendices



### Appendix-A: Each Test Pits at Depth the Depth of Investigation

No	Test pits	Station	Visual Description	Location
1		47+500	Light Brown to Gray Silty sandy clay soil	E=188257.96 N=564782.09 Elevation=400.115
2		49+560	Light grayish silty soil	E=186264.39 N=565300.39 Elevation=389.064

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

3		53+500	Grayish silty clay soil	E=182490 N=567567 Elevation=383.83
4		55+500	Brownish Silty Clay Soil	E=180995.663 N=567720.43 Elevation=385.539

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

5		58+840	Grayish Silty Clay Soil	E=178775.8 N=569991.3 Elevation=387.3
6		60+030	Light Brown Silty clay	E=177748.5 N=570682.9 Elevation=385.615

**Appendix-B: Test Result of In-situ Density (FDT)**

Project Name: Turmi-Omo Design and Build Road Proect								
DENSITY OF SOIL IN-PLACE BY SAND - CONE METHOD								
TEST METHOD : AASHTO T – 191								
Representing Station		From 47+000-60+500						
Date of Testing		From 19/3/2019 up to 21/3/19						
Test Reference	Test Ref.	No.	47+500	49+560	53+550	55+500	58+840	60+030
	Density of Sand Ds	gr/cc	1.34	1.34	1.34	1.34	1.34	1.34
	Depth of Hole	cm	15.0	15.0	15.0	15.0	15	15
Bulk Density of Determination	Wt. Of Weight Soil Wws	gr	4250	4249.0	3200	3210	3915.0	3690
	Initial Wt. Sand in Jar Wsb1	gr	8615	8625.0	7985	7985	8685.0	8180
	Final Wt. Sand in Jar Wsb2	gr	2955	2970.0	3635	3635	3410.0	2775
	Wt. Sand in Cone Wsb3	gr	1525.0	1525.0	1537.0	1525.0	1537.0	1537.0
	Wt. Sand in Hole, Wsh=Wsb1- Ws2-Wsb3	gr	4135	4130	2813	2825	3738	3868
	Volume of Sand in Hole, Vsh=Wsh/Ds	cc	3086	3082	2099	2108	2790	2887
	Bulk Density of Wet Soil WD=Wws/Vsh	gr/cc	1.377	1.379	1.524	1.523	1.403	1.278
Container No.	No.	A	C	G	E	F	G	
Wt. Of Dry Soil B	gr	3800.0	3819.0	2800.0	2813.0	3450.0	3345.0	
Wt. of Water Ww= Wws-B	gr	450.0	430.0	400.0	397.0	465.0	345.0	
Moisture Content Mc=(Ww/B)*100	%	11.8	11.26	14.3	14.1	13.5	10.3	
Density of Dry Soil DD=WD*100/(Mc+100)	gr/cc	<b>1.231</b>	<b>1.239</b>	<b>1.334</b>	<b>1.334</b>	<b>1.237</b>	<b>1.159</b>	

### **Appendix-C: Test Result of Natural Moisture Content**

Station	47+500	49+560	53+550	55+500	58+840	60+030
Natural Moisture Content	11.8	11.26	14.3	14.1	13.5	10.3

Remark: The natural moisture content is determined during field density test and the value for each station is easily taken from the field density test.

### **Appendix-D: Test Result of Specific Gravity**

#### **For Station 47+500**

<b>Specific Gravity Test Data For Station 47+500</b>			
Trial	1	2	
Pycnometer #	A	B	
A. Mass of Pycnometer (empty, clean)	49.48	44.65	
B. Mass of empty pycno +Water	151.97	147.21	
C. Temperature of Water at Measured	23.4	23.4	
D. Density of Water	0.99745	0.99745	
E. Mass of pycno + Soil +full of water (boiled)	158.45	153.39	
F. Temperature at Measured	23.9	23.9	
G. Density of water	0.99732	0.99732	
H. Mass of pycnometre+ full Water	152.19	147.16	
I. Mass of Dry sample	10.01	10.02	
J. Specific Gravity at specific Temperature	2.698	2.602	
K. Correction factor K	0.9991	0.9991	
L. Specific gravity at Temperature=20°C	2.659	2.634	
Average Specific Gravity at 20°C	2.65		

**For Station 49+560**

<b>Specific Gravity Test Data For Station 49+560</b>			
Trial	1	2	
Pycnometer #	A	B	
A. Mass of Pycnometer (empty, clean)	49.7	44.78	
B. Mass of empty pycno +Water	152.2	147.18	
C. Temperature of Water at Measured	23.4	23.2	
D. Density of Water	0.99746	0.99755	
E. Mass of pycno + Soil +full of water (boiled)	158.42	153.42	
F. Temperature at Measured	24.0	24.0	
G. Density of water	0.99732	0.99732	
H. Mass of pycnometre+ full Water	152.20	147.15	
I. Mass of Dry sample	10.02	10.04	
J. Specific Gravity at specific Temperature	2.609	2.670	
K. Correction factor K	0.9991	0.9991	
L. Specific gravity at Temperature=20 °c	2.627	2.653	
Average Specific Gravity at 20 °c	2.64		

**For Station 53+550**

<b>Specific Gravity Test Data For Station 53+550</b>			
Trial	1	2	
Pynometer #	A	B	
A. Mass of Pycnometer (empty, clean)	49.7	51.5	
B. Mass of empty pycno +Water	152.17	153.63	
C. Temperature of Water at Measured	24.3	24.5	
D. Density of Water	0.99723	0.99717	
E. Mass of pycno + Soil +full of water (boiled)	158.39	159.79	
F. Temperature at Measured	24.4	24.4	
G. Density of water	0.9972	0.9972	
H. Mass of pycnometre+ full Water	152.17	153.63	
I. Mass of Dry sample	10.01	10.01	
J. Specific Gravity at specific Temperature	2.634	2.593	
K. Correction factor K	0.99902	0.99897	
L. Specific gravity at Temperature=20 °c	2.631	2.590	
Average Specific Gravity at 20 °c	2.61		

**For Station 55+500**

<b>Specific Gravity Test Data For Station 55+500</b>			
Trial	<b>1</b>	<b>2</b>	
Pyknometer #	A	B	
A. Mass of Pycnometer (empty, clean)	49.59	51.38	
B. Mass of empty pycno +Water	151.27	153.44	
C. Temprature of Water at Measured	23	23	
D. Density of Water	0.99757	0.99757	
E. Mass of pycno + Soil +full of water (boiled)	157.99	159.69	
F.Temprature at Measured	24	24	
G. Density of water	0.99732	0.99732	
H. Mass of pycnometre+ full Water	151.87	153.33	
I. Mass of Dry sample	10.01	10.03	
J. Specific Gravity at specific Temprature	2.547	2.726	
K. Correction factor K	0.9991	0.9991	
L. Specific gravity at Temperature=20 °c	2.631	2.6369	
Average Specific Gravity at 20 °c	2.63		

**For Station 58+840**

<b>Specific Gravity Test Data For Station 58+840</b>			
Trial	<b>1</b>	<b>2</b>	<b>3</b>
Pycnometer #	A	B	C
A. Mass of Pycnometer (empty, clean)	49.71	51.5	44.78
B. Mass of empty pycno +Water	152.23	153.7	146.75
C. Temperature of Water at Measured	23.4	23	22.9
D. Density of Water	0.99745	0.99754	0.99756
E. Mass of pycno + Soil +full of water (boiled)	158.55	159.89	152.79
F.Temperature at Measured	24.5	24	24.3
G. Density of water	0.99717	0.9973	0.99723
H. Mass of pycnometre+ full Water	152.2	153.68	146.72
I. Mass of Dry sample	10.01	10.03	10.03
J. Specific Gravity at specific Temperature	2.727	2.619	2.526
K. Correction factor K	0.99924	0.99933	0.99936
L. Specific gravity at Temperature=20 °c	2.72516	2.61681	2.52420
Average Specific Gravity at 20 °c	2.62		

**For Station 60+030**

<b>Specific Gravity Test Data For Station 60+030</b>			
Trial	1	2	
Pycnometer #	A	B	
A. Mass of Pycnometer (empty, clean)	51.5	44.78	
B. Mass of empty pycno +Water	152.23	153.7	
C. Temperature of Water at Measured	23.2	23.3	
D. Density of Water	0.99749	0.99747	
E. Mass of pycno + Soil +full of water (boiled)	159.98	152.99	
F. Temperature at Measured	24	24	
G. Density of water	0.9973	0.9973	
H. Mass of pycnometre+ full Water	153.66	146.75	
I. Mass of Dry sample	10.04	10.04	
J. Specific Gravity at specific Temperature	2.692	2.635	
K. Correction factor K	0.99929	0.99926	
L. Specific gravity at Temperature=20 °c	2.69	2.63	
Average Specific Gravity at 20 °c	2.66		

**Appendix-E: Test result of Grain Size Distribution**

**For Station 47+500**

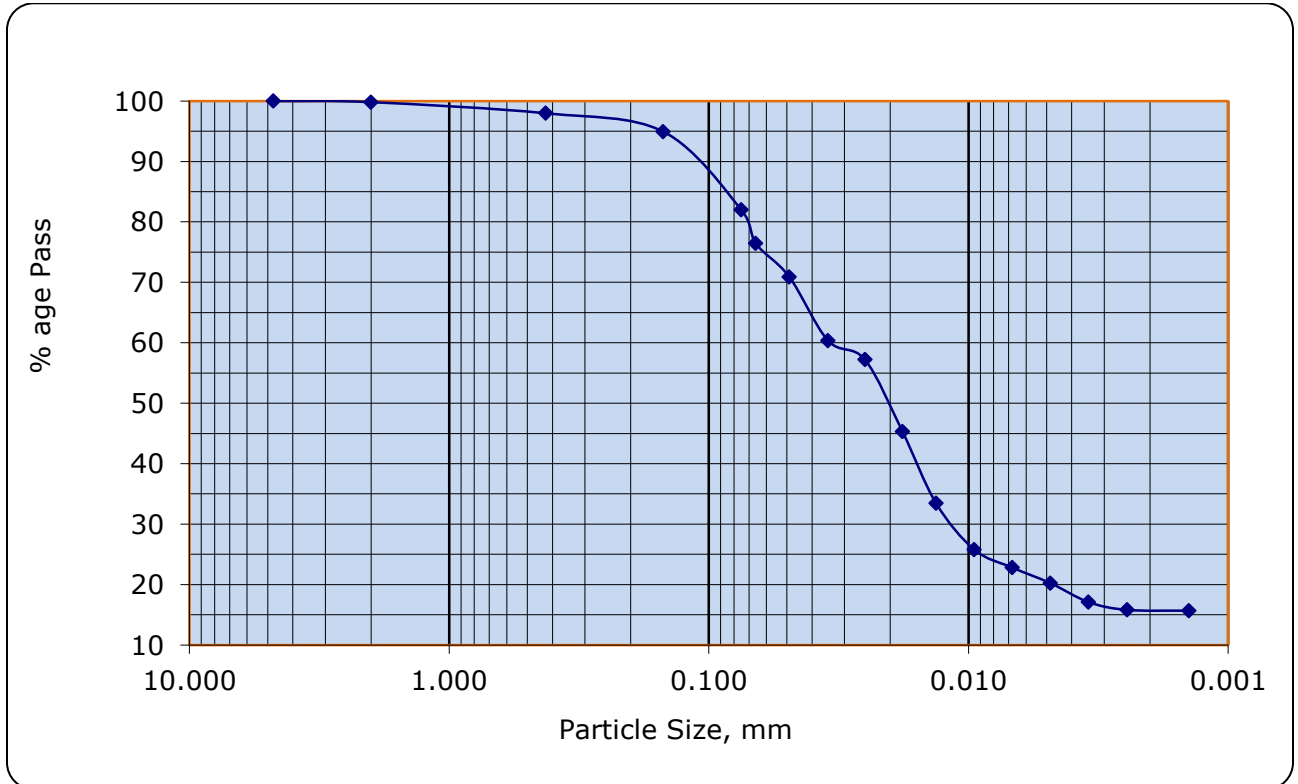
**Combined test result of Sieve and Hydrometer analysis**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Cumulative mass retained in %	% Passing,
Sieve Analysis	6.300	0	0	0.00	100
	4.750	0	0	0.00	100
	2.000	1.9	0.19	0.19	99.81
	0.425	18.3	1.83	2.02	97.98
	0.150	30.3	3.03	5.05	94.95
	0.075	129.5	12.95	18.00	82.00
Hydrometer Analysis	0.0660		5.56	23.56	76.44
	0.0490		5.53	29.09	70.91
	0.0348		10.54	39.63	60.37
	0.0250		3.16	42.79	57.21
	0.0179		11.91	54.70	45.30
	0.0133		11.85	66.55	33.45
	0.0095		7.66	74.21	25.79
	0.0068		2.98	77.19	22.81
	0.0048		2.58	79.77	20.23
	0.0034		3.13	82.91	17.09
	0.0024		1.29	84.20	15.80
	0.0014		0.13	84.33	15.67

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy.reading	Composite correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm) table(7-4)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:00:30 . AM	0.5	1.0250	0.00402	1.0290	20.8	9.7	0.01354	0.060	76.44
3:01:15 . AM	1	1.0229	0.00402	1.0269	20.8	10.2	0.01354	0.043	70.91
3:02:15 . AM	2	1.0189	0.00402	1.0229	20.8	11.3	0.01354	0.032	60.37
3:04:15 . AM	4	1.0177	0.00402	1.0217	20.8	11.6	0.01354	0.023	57.21
3:08:15 . AM	8	1.0132	0.00400	1.0172	21.0	12.8	0.01351	0.017	45.30
3:15:15 . AM	15	1.0087	0.00400	1.0127	21.0	14.0	0.01351	0.013	33.45
3:30:15 . AM	30	1.0058	0.00399	1.0098	21.1	14.8	0.01350	0.010	25.79
4:00:15. AM	60	1.0047	0.00396	1.0087	21.4	15.1	0.01345	0.007	22.81
5:00:15 . AM	120	1.0039	0.00378	1.0077	23.2	15.3	0.01317	0.005	20.23
7:00:15 . AM	240	1.0028	0.00369	1.0065	24.1	15.6	0.01303	0.003	17.09
11:00:15 . AM	480	1.0025	0.0035	1.0060	26.0	15.6	0.01274	0.002	15.80
3:00:15. AM	1440	1.0019	0.00405	1.0060	20.5	15.8	0.01359	0.001	15.67

**Graph of percentage pass and size**



**For Station 49+560**

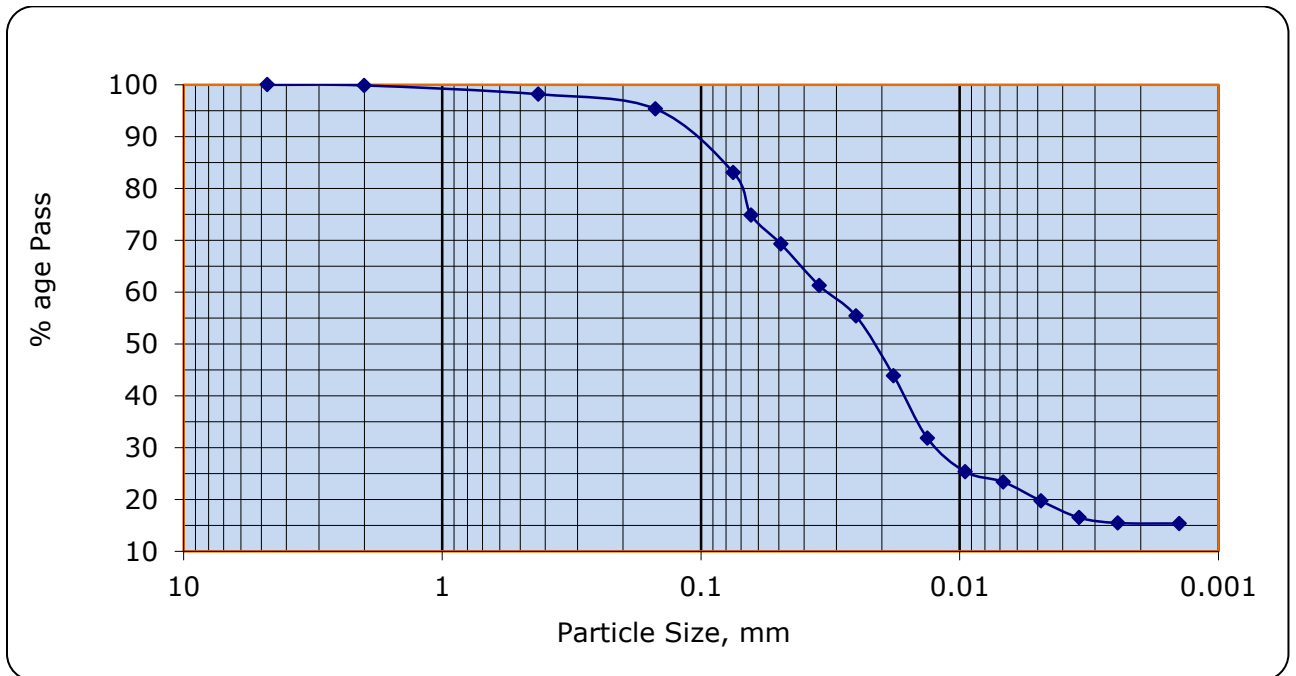
**Result of Sieve and hydrometer analysis (combined)**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Comulative mass retained in %	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	1.3	0.13	0.13	99.87
	0.425	16.9	1.69	1.82	98.18
	0.15	28.4	2.84	4.66	95.34
	0.075	122.6	12.26	16.92	83.08
Hydrometre Analysis	0.064		8.21	25.13	74.87
	0.049108		5.59	30.72	69.28
	0.034899		8.02	38.75	61.25
	0.025166		5.88	44.63	55.37
	0.018016		11.50	56.13	43.87
	0.013328		12.06	68.20	31.80
	0.009536		6.45	74.64	25.36
	0.006785		1.98	76.62	23.38
	0.004848		3.66	80.29	19.71
	0.00346		3.21	83.50	16.50
	0.002451		1.04	84.54	15.46
	0.001417		0.11	84.65	15.35

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy.reading	Composit correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:00:30 . AM	0.5	1.0240	0.004	1.0280	21.0	9.95	0.013556	0.060	74.87
3:01:15 . AM	1	1.0219	0.004	1.0259	21.0	10.50	0.013556	0.044	69.28
3:02:15 . AM	2	1.0189	0.004	1.0229	21.0	11.30	0.013556	0.032	61.25
3:04:15 . AM	4	1.0167	0.004	1.0207	21.0	11.88	0.013556	0.023	55.37
3:08:15 . AM	8	1.0124	0.00399	1.0164	21.1	13.02	0.013540	0.017	43.87
3:15:15 . AM	15	1.0079	0.00399	1.0119	21.1	14.21	0.013540	0.013	31.80
3:30:15 . AM	30	1.0055	0.00398	1.0095	21.2	14.85	0.013525	0.010	25.36
4:00:15. AM	60	1.0048	0.00394	1.0087	21.6	15.03	0.013463	0.007	23.38
5:00:15 . AM	120	1.0036	0.00377	1.0074	23.3	15.35	0.013199	0.005	19.71
7:00:15 . AM	240	1.0025	0.00367	1.0062	24.3	15.64	0.013044	0.003	16.50
11:00:15 . AM	480	1.0023	0.00348	1.0058	26.2	15.69	0.012749	0.002	15.46
3:00:15. AM	1440	1.0017	0.00404	1.0057	20.6	15.85	0.013618	0.001	15.35

**Graph of percentage pass vs size of particle**



**For Station 53+500**

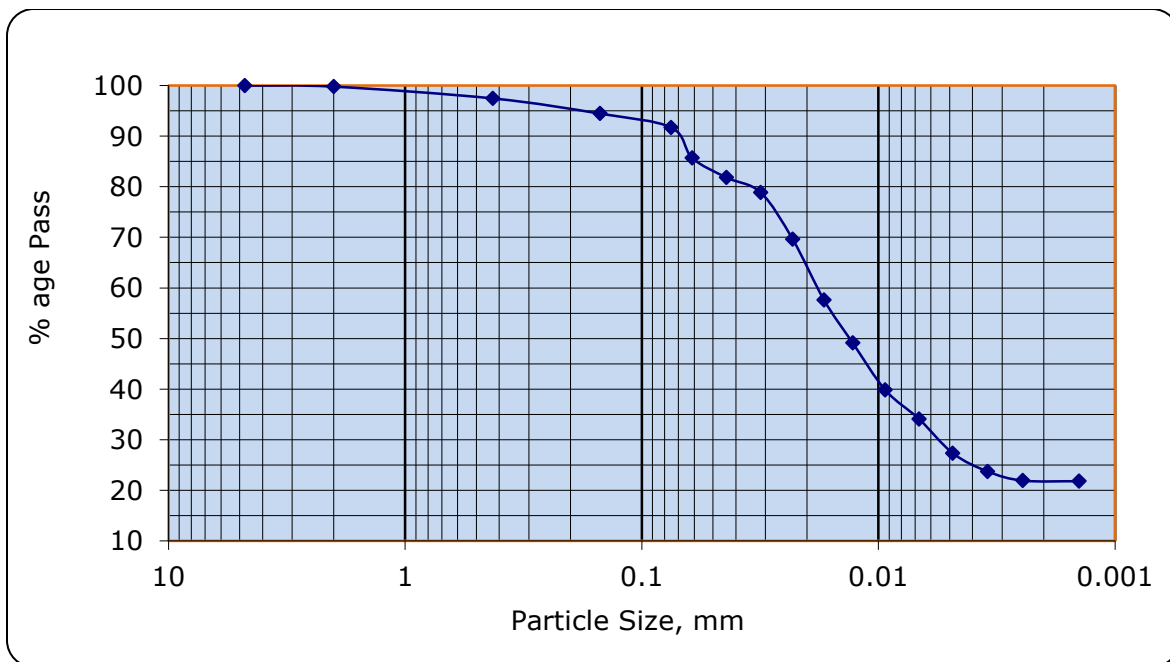
**Result of Sieve and hydrometer analysis (combined)**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Comulative mass retained in %	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	2.2	0.22	0.22	99.78
	0.425	23.3	2.33	2.55	97.45
	0.15	30.1	3.01	5.56	94.44
	0.075	27.5	2.75	8.31	91.69
Hydrometer Analysis	0.0612		6.01	14.32	85.68
	0.0438		3.86	18.19	81.81
	0.0314		2.97	21.16	78.84
	0.0230		9.22	30.38	69.62
	0.0170		12.01	42.39	57.61
	0.0128		8.50	50.89	49.11
	0.0093		9.30	60.19	39.81
	0.0067		5.71	65.90	34.10
	0.0048		6.78	72.68	27.32
	0.0035		3.60	76.28	23.72
	0.0025		1.81	78.09	21.91
	0.0014		0.12	78.21	21.79

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy.reading	Composite correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm) table(7-4)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:09:30 . AM	0.5	1.0248	0.00402	1.0288	20.8	9.7	0.013714	0.061	85.68
3:10:00 . AM	1	1.0235	0.00402	1.0275	20.8	10.1	0.013714	0.044	81.81
3:01:00 . AM	2	1.0225	0.00402	1.0265	20.8	10.3	0.013714	0.031	78.84
3:03:00 . AM	4	1.0194	0.00402	1.0234	20.8	11.2	0.013714	0.023	69.62
3:17:00 . AM	8	1.0154	0.00402	1.0194	20.8	12.2	0.013714	0.017	57.61
3:24:15 . AM	15	1.0125	0.00402	1.0165	20.8	13.0	0.013714	0.013	49.11
3:39:15 . AM	30	1.0094	0.00399	1.0134	21.1	13.8	0.013668	0.009	39.81
4:09:00. AM	60	1.0075	0.00397	1.0115	21.3	14.3	0.013638	0.007	34.10
5:09:00 . AM	120	1.0053	0.00389	1.0092	22.1	14.9	0.013514	0.005	27.32
7:09:00 . AM	240	1.0043	0.00369	1.0080	24.1	15.2	0.013207	0.003	23.72
11:09:00 .AM	480	1.0038	0.00359	1.0074	25.1	15.3	0.013053	0.002	21.91
3:09:00. AM	1440	1.0034	0.00396	1.0073	21.4	15.4	0.013040	0.001	21.79

**Graph of percentage pass vs size of particle**



**For Station 55+500**

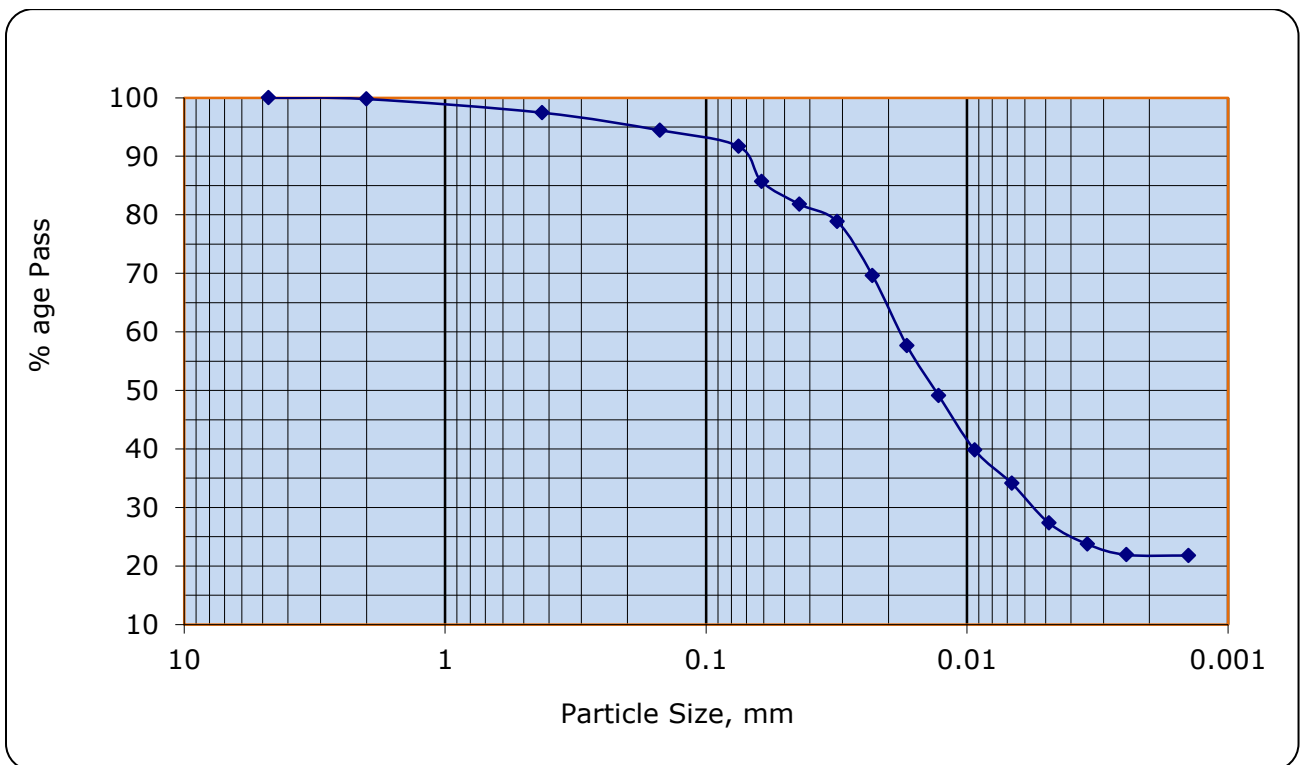
**Result of Sieve and hydrometer analysis (combined)**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Cumulative mass retained in %	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	2.2	0.22	0.22	99.78
	0.425	23.3	2.33	2.55	97.45
	0.15	30.1	3.01	5.56	94.44
	0.075	27.5	2.75	8.31	91.69
Hydrometer Analysis	0.0612		6.01	14.32	85.68
	0.0438		3.86	18.19	81.81
	0.0314		2.97	21.16	78.84
	0.0230		9.22	30.38	69.62
	0.0170		12.01	42.39	57.61
	0.0128		8.50	50.89	49.11
	0.0093		9.30	60.19	39.81
	0.0067		5.71	65.90	34.10
	0.0048		6.78	72.68	27.32
	0.0035		3.60	76.28	23.72
	0.0025		1.81	78.09	21.91
	0.0014		0.12	78.21	21.79

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy.reading	Composit correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm) table(7-4)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:09:30 . AM	0.5	1.0248	0.00403	1.0288	20.7	9.8	0.013687	0.061	84.77
3:10:00 . AM	1	1.0239	0.00403	1.0279	20.7	10.1	0.013687	0.044	82.16
3:01:00 . AM	2	1.0223	0.00403	1.0263	20.7	10.4	0.013687	0.031	77.45
3:03:00 . AM	4	1.0192	0.00403	1.0233	20.7	11.2	0.013687	0.023	68.45
3:17:00 . AM	8	1.0154	0.00403	1.0195	20.7	12.2	0.013687	0.017	57.24
3:24:15 . AM	15	1.0125	0.00403	1.0166	20.7	13.0	0.013687	0.013	48.74
3:39:15 . AM	30	1.0094	0.00397	1.0133	21.3	13.8	0.013595	0.009	39.18
4:09:00 . AM	60	1.0074	0.00397	1.0113	21.3	14.4	0.013595	0.007	33.30
5:09:00 . AM	120	1.0053	0.00388	1.0091	22.2	14.9	0.013456	0.005	26.89
7:09:00 . AM	240	1.0044	0.00367	1.0080	24.3	15.2	0.013132	0.003	23.65
11:09:00 . AM	480	1.0039	0.00358	1.0075	25.2	15.3	0.012993	0.002	21.94
3:09:00 . AM	1440	1.0033	0.00397	1.0073	21.3	15.3	0.013595	0.001	21.36

**Graph of percentage pass vs size of particle**



**For Station 58+840**

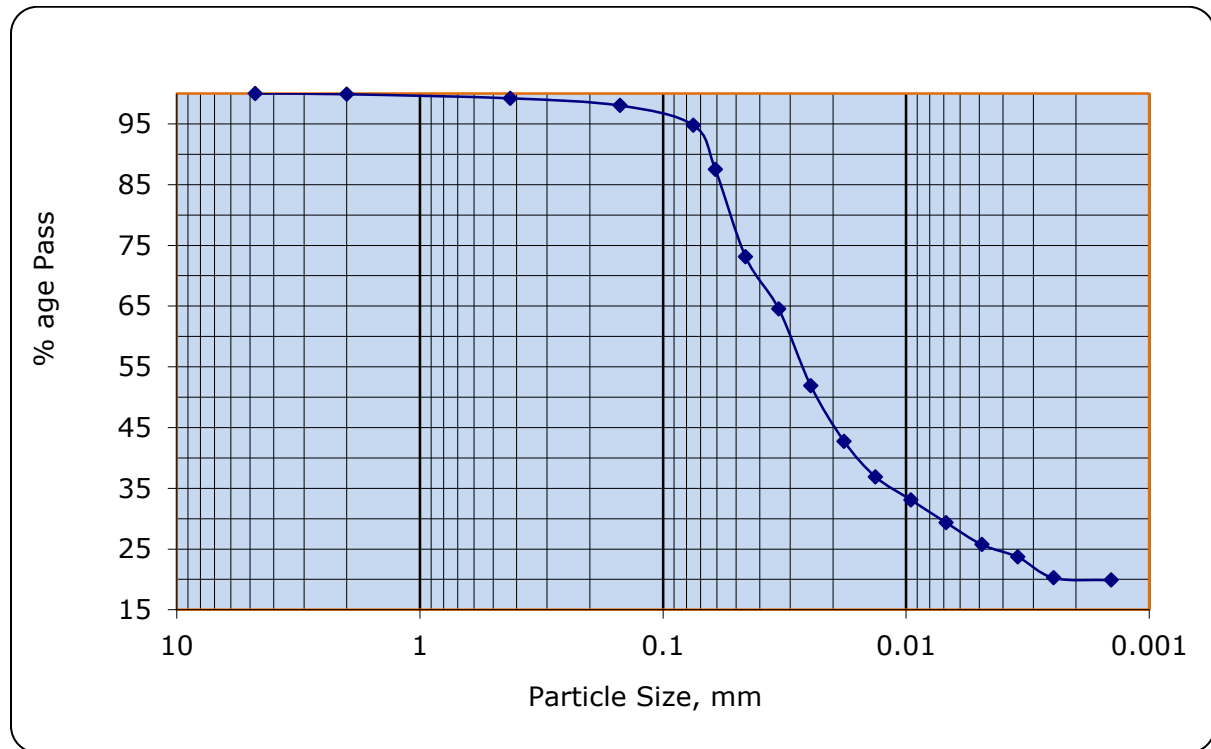
**Result of Sieve and hydrometer analysis (combined)**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Cumulative mass retained in %	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	1.2	0.12	0.12	99.88
	0.425	6.7	0.67	0.79	99.21
	0.15	12	1.2	1.99	98.01
	0.075	32.4	3.24	5.23	94.77
Hydrometre Analysis	0.061		7.30	12.53	87.47
	0.046		14.37	26.91	73.09
	0.033		8.59	35.50	64.50
	0.025		12.60	48.10	51.90
	0.018		9.17	57.28	42.72
	0.013		5.84	63.12	36.88
	0.010		3.79	66.91	33.09
	0.007		3.76	70.67	29.33
	0.005		3.61	74.28	25.72
	0.003		2.05	76.33	23.67
	0.002		3.43	79.75	20.25
	0.001		0.37	80.12	19.88

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy. reading	Composite correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm) table(7-4)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:08:30 . AM	0.5	1.025	0.0041	1.0286	20.0	9.81	0.01375	0.061	87.47
3:09:15 . AM	1	1.0198	0.0041	1.0239	20.0	11.06	0.01375	0.046	73.09
3:10:15 . AM	2	1.0170	0.00409	1.0211	20.1	11.80	0.01374	0.033	64.50
3:12:15 . AM	4	1.0129	0.00407	1.0170	20.3	12.89	0.01371	0.025	51.90
3:16:15 . AM	8	1.0099	0.00407	1.0140	20.3	13.68	0.01371	0.018	42.72
3:23:15 . AM	15	1.0081	0.00396	1.0121	21.4	14.16	0.01354	0.013	36.88
3:38:15 . AM	30	1.0068	0.00402	1.0108	20.8	14.50	0.01363	0.010	33.09
4:08:15 . AM	60	1.0056	0.00399	1.0096	21.1	14.82	0.01358	0.007	29.33
5:08:15 . AM	120	1.0045	0.00391	1.0084	21.9	15.11	0.01346	0.005	25.72
7:08:15 . AM	240	1.0040	0.00374	1.0077	23.6	15.24	0.01320	0.003	23.67
11:08:15 AM	480	1.0030	0.00362	1.0066	24.8	15.51	0.01301	0.002	20.25
3:08:15. Pm	1440	1.0025	0.004	1.0065	21.0	15.64	0.01386	0.001	19.88

**Graph of percentage pass vs size of particle**



**For Station 60+030**

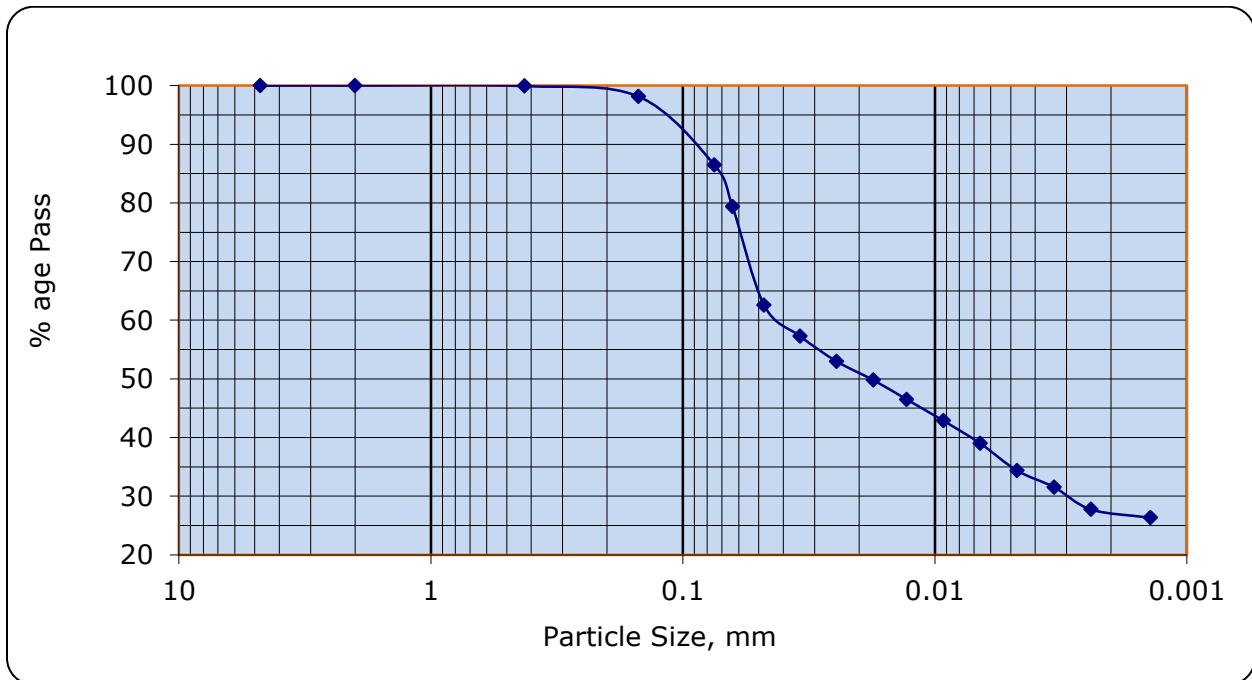
**Result of Sieve and hydrometer analysis (combined)**

	Sieve Size, mm	Mass Retained (gm)	% Retained	Cumulative mass retained in %	% Passing,
Sieve Analysis	6.3	0	0	0.00	100
	4.75	0	0	0.00	100
	2	0	0	0.00	100.00
	0.425	0.9	0.09	0.09	99.91
	0.15	17.8	1.78	1.87	98.13
	0.075	116.7	11.67	13.54	86.46
Hydrometer Analysis	0.064		7.07	20.61	79.39
	0.048		16.84	37.44	62.56
	0.034		5.28	42.72	57.28
	0.025		4.29	47.02	52.98
	0.018		3.20	50.22	49.78
	0.013		3.30	53.52	46.48
	0.009		3.63	57.15	42.85
	0.007		3.86	61.01	38.99
	0.005		4.62	65.63	34.37
	0.003		2.84	68.47	31.53
	0.002		3.80	72.27	27.73
	0.001		1.42	73.69	26.31

**Hydrometer Analysis**

Time	Elapsed Time T(min)	Actual Hy. reading	Composite correction	(R) Hydro. Reading with com. Correction	Temperature (°C)	Effective depth Of Hyd. L (cm) table(7-4)	Value of K	Diameter of soil particle D(mm)	Soil in suspension, P(%of soil finer)
3:00:45 . AM	0.5	1.0200	0.00405	1.0241	20.5	11.01	0.01355	0.064	79.39
3:01:15 . AM	1	1.0149	0.00405	1.0190	20.5	12.36	0.01355	0.048	62.56
3:02:15 . AM	2	1.0133	0.00405	1.0174	20.5	12.78	0.01355	0.034	57.28
3:04:15 . AM	4	1.0120	0.00405	1.0161	20.5	13.12	0.01355	0.025	52.98
3:08:15 . AM	8	1.0110	0.00408	1.0151	20.2	13.39	0.01360	0.018	49.78
3:15:15 . AM	15	1.0100	0.00408	1.0141	20.2	13.65	0.01360	0.013	46.48
3:30:15 . AM	30	1.0089	0.00408	1.0130	20.2	13.94	0.01360	0.009	42.85
4:00:15 . AM	60	1.0078	0.00401	1.0118	20.9	14.24	0.01349	0.007	38.99
5:00:15 . AM	120	1.0065	0.00391	1.0104	21.9	14.58	0.01334	0.005	34.37
7:00:15 . AM	240	1.0058	0.00375	1.0096	23.5	14.77	0.01309	0.003	31.53
11:00:15 . AM	480	1.0048	0.0036	1.0084	25.0	15.03	0.01286	0.002	27.73
3:00:15. AM	1440	1.0039	0.00407	1.0080	20.3	15.27	0.01358	0.001	26.31

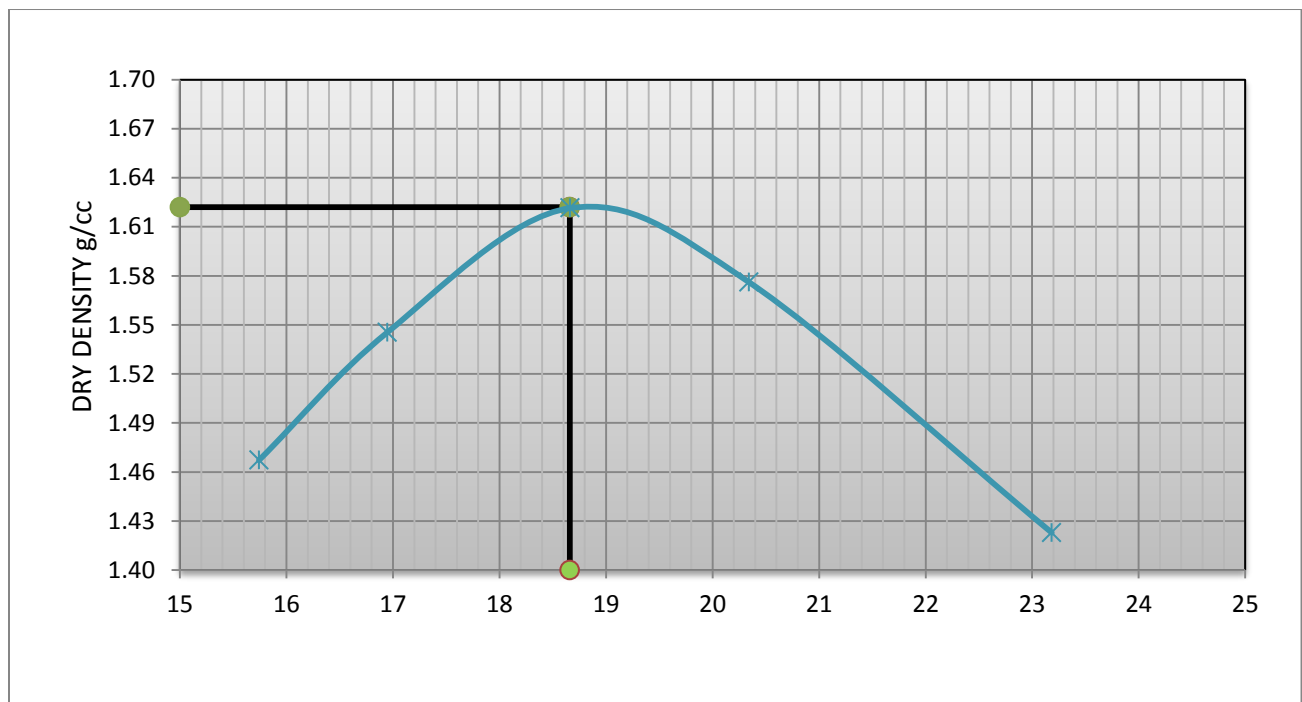
**Graph of percentage pass vs size of particle**



**Appendix-F: Test Result of Modified Compaction**

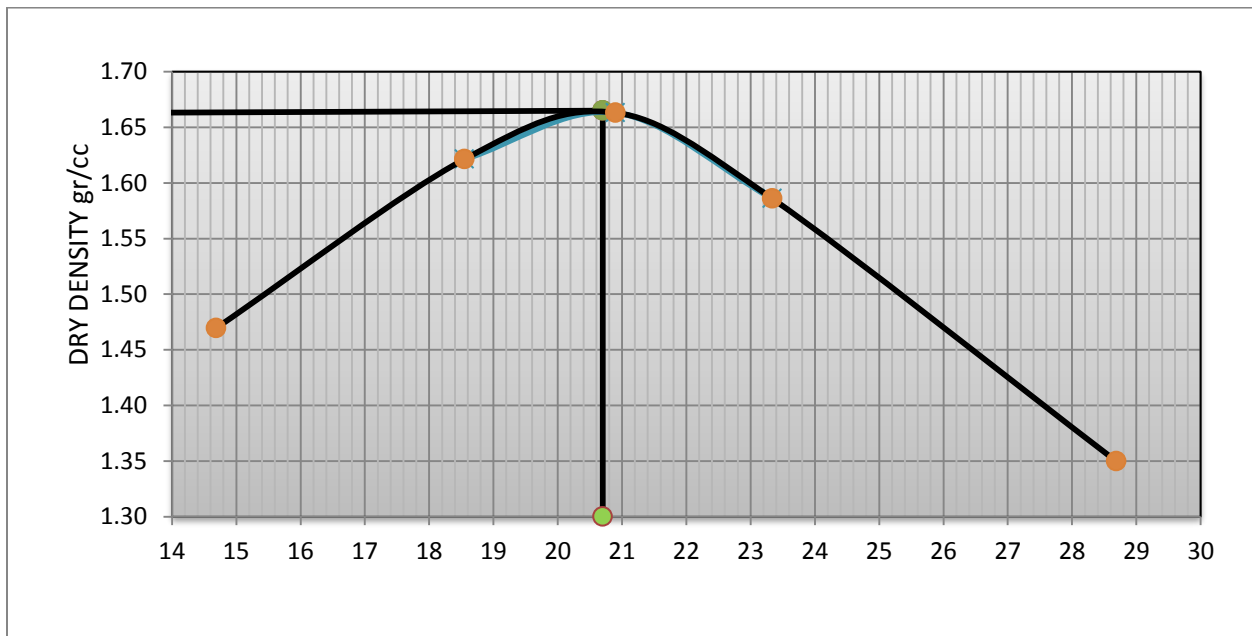
**For Station 47+500**

DENSITY	TRIAL NUMBER		1	2	3	4	5
	WEIGHT OF SOIL + MOLD	gr	8700	8920	9155	9100	8810
	WEIGHT OF MOLD	gr	5280	5280	5280	5280	5280
	WEIGHT OF SOIL	gr	3420	3640	3875	3820	3530
	VOLUME OF MOLD	cc	2014	2014	2014	2014	2014
	WET DENSITY OF SOIL	gr/cc	1.70	1.81	1.92	1.90	1.75
MOISTURE	CONTAINER NUMBER		T-5	T-2	T-7	H-4	H-3
	WET SOIL + CONTAINER	gr	223.5	225.5	218.3	219.0	223.5
	DRY SOIL + CONTAINER	gr	197.4	197.4	188.7	186.8	186.8
	WEIGHT OF WATER	gr	26.1	28.1	29.6	32.2	36.7
	WEIGHT OF CONTAINER	gr	31.6	31.6	30.1	28.5	28.5
	WEIGHT OF DRY SOIL	gr	165.8	165.8	158.6	158.3	158.3
	MOISTURE CONTENT	%	15.74	16.95	18.66	20.34	23.18
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.47	1.55	1.62	1.58	1.42



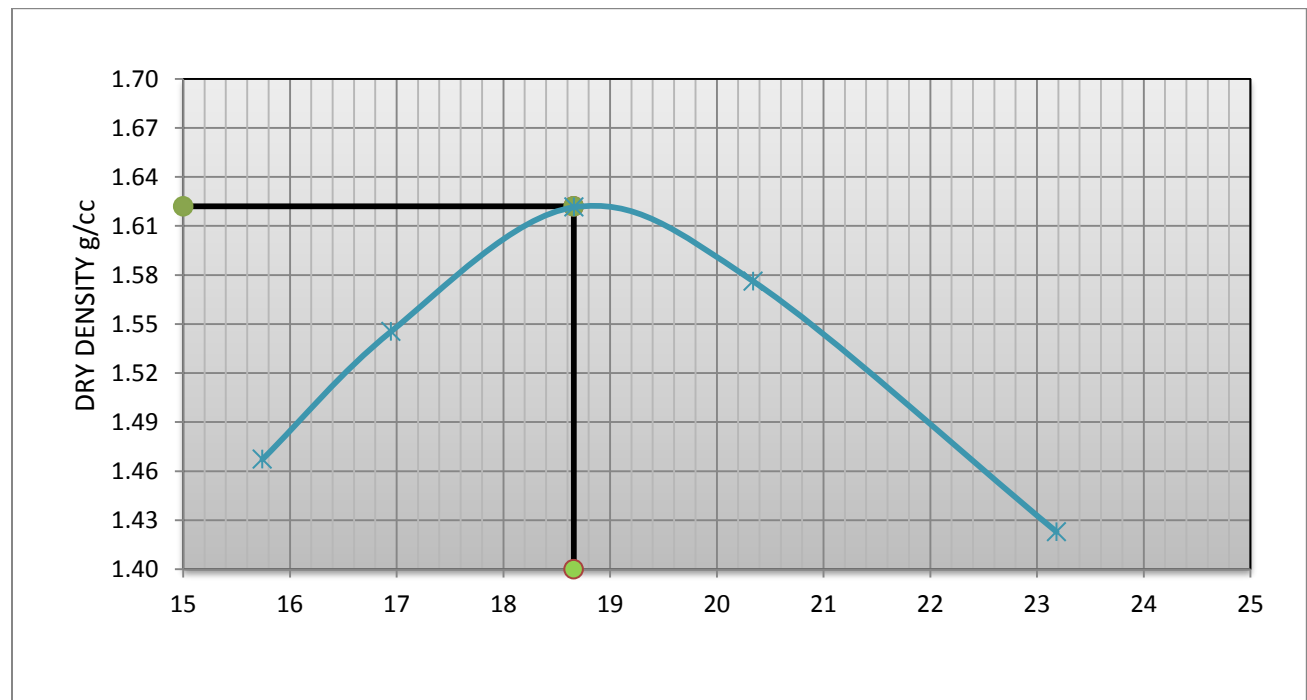
**For Station 49+560**

DENSITY	TRIAL NUMBER		1	2	3	4	5
	WEIGHT OF SOIL + MOLD	gr	8665	9150	9332	9220	8741
	WEIGHT OF MOLD	gr	5210	5210	5210	5210	5180
	WEIGHT OF SOIL	gr	3455	3940	4122	4010	3561.00
	VOLUME OF MOLD	cc	2050	2050	2050	2050	2050
	WET DENSITY OF SOIL	gr/cc	1.7	1.92	2.01	1.96	1.7
MOISTURE	CONTAINER NUMBER		T-3	T-4	T-1	T-5	T-2
	WET SOIL + CONTAINER	gr	218	224.0	215.0	209.0	216.8
	DRY SOIL + CONTAINER	gr	193.9	193.9	183.4	175	175
	WEIGHT OF WATER	gr	24.1	30.1	31.6	34	41.8
	WEIGHT OF CONTAINER	gr	29.8	31.6	32.2	29.3	29.3
	WEIGHT OF DRY SOIL	gr	164.10	162.3	151.2	145.7	145.70
	MOISTURE CONTENT	%	14.69	18.55	20.90	23.34	28.69
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.47	1.62	1.66	1.59	1.35



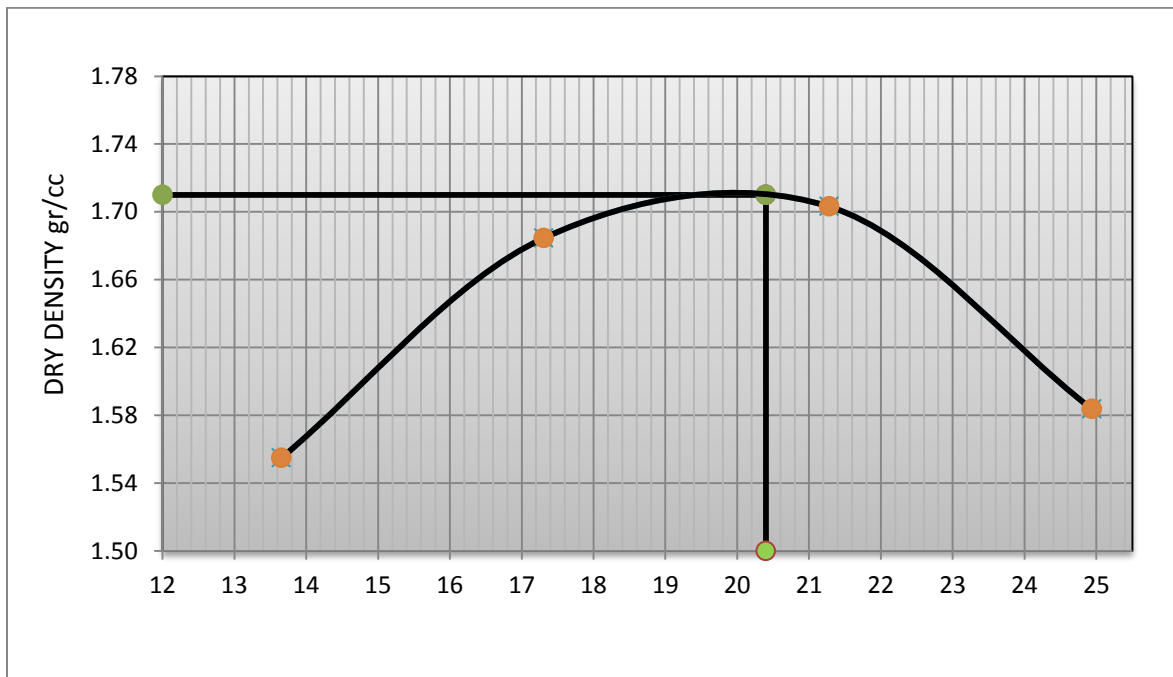
**For Station 53+550**

<b>DENSITY</b>	TRIAL NUMBER		1	2	3	4	5
	WEIGHT OF SOIL + MOLD	gr	8700	8920	9155	9100	8810
	WEIGHT OF MOLD	gr	5280	5280	5280	5280	5280
	WEIGHT OF SOIL	gr	3420	3640	3875	3820	3530
	VOLUME OF MOLD	cc	2014	2014	2014	2014	2014
	WET DENSITY OF SOIL	gr/cc	1.70	1.81	1.92	1.90	1.75
<b>MOISTURE</b>	CONTAINER NUMBER		T-5	T-2	T-7	H-4	H-3
	WET SOIL + CONTAINER	gr	223.5	225.5	218.3	219.0	223.5
	DRY SOIL + CONTAINER	gr	197.4	197.4	188.7	186.8	186.8
	WEIGHT OF WATER	gr	26.1	28.1	29.6	32.2	36.7
	WEIGHT OF CONTAINER	gr	31.6	31.6	30.1	28.5	28.5
	WEIGHT OF DRY SOIL	gr	165.8	165.8	158.6	158.3	158.3
	MOISTURE CONTENT	%	15.74	16.95	18.66	20.34	23.18
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.47	1.55	1.62	1.58	1.42



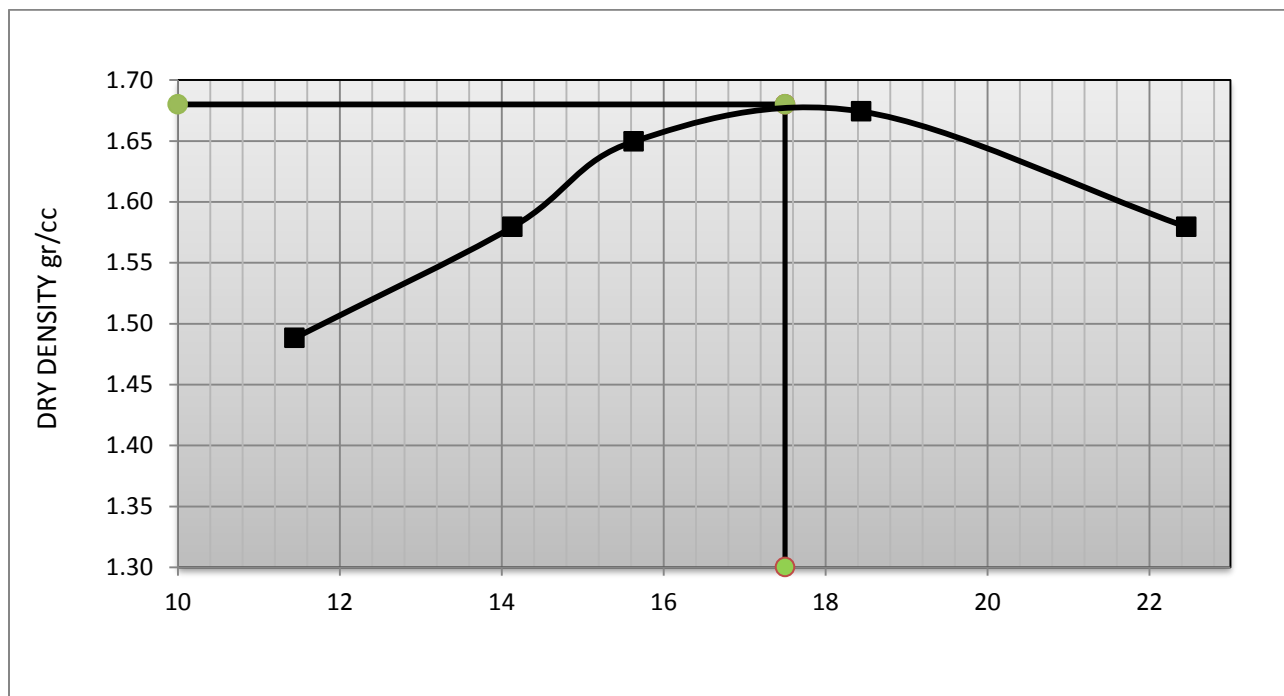
**For Station 55+500**

DENSITY	TRIAL NUMBER		1	2	3	4
	WEIGHT OF SOIL + MOLD	gr	8789	9210	9390	9215
	WEIGHT OF MOLD	gr	5230	5230	5230	5230
	WEIGHT OF SOIL	gr	3559	3980	4160	3985
	VOLUME OF MOLD	cc	2014	2014	2014	2014
	WET DENSITY OF SOIL	gr/cc	1.77	1.98	2.07	1.98
MOISTURE	CONTAINER NUMBER		F-7	H-2	H-8	H-3
	WET SOIL + CONTAINER	gr	242.0	232.0	211.8	230.0
	DRY SOIL + CONTAINER	gr	216.4	201.9	180.2	190.1
	WEIGHT OF WATER	gr	25.6	30.1	31.6	39.9
	WEIGHT OF CONTAINER	gr	28.9	28	31.7	30.1
	WEIGHT OF DRY SOIL	gr	187.5	173.9	148.5	160
	MOISTURE CONTENT	%	13.65	17.31	21.28	24.94
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.55	1.68	1.70	1.58



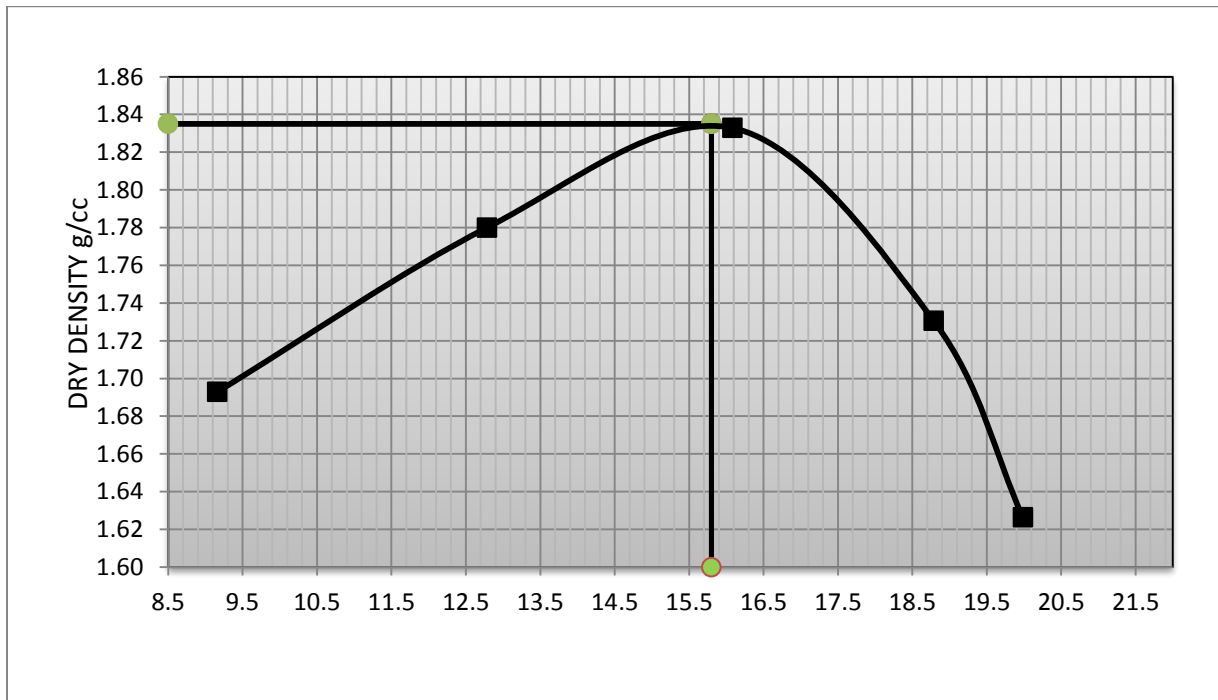
**For Station 58+840**

DENSITY	TRIAL NUMBER		1	2	3	4	5
	WEIGHT OF SOIL + MOLD	gr	8610	8905	9120	9275	9175
	WEIGHT OF MOLD	gr	5210	5210	5210	5210	5210
	WEIGHT OF SOIL	gr	3400	3695	3910	4065	3965
	VOLUME OF MOLD	cc	2050	2050	2050	2050	2050
	WET DENSITY OF SOIL	gr/cc	1.66	1.80	1.91	1.98	1.93
MOISTURE	CONTAINER NUMBER		H-4	H-1	T-6	H-3	H-5
	WET SOIL + CONTAINER	gr	242.9	219.0	241.7	229.1	214.3
	DRY SOIL + CONTAINER	gr	221.4	195.4	213.3	198.1	180.3
	WEIGHT OF WATER	gr	21.5	23.6	28.4	31	34
	WEIGHT OF CONTAINER	gr	33.5	28.4	31.6	30.0	28.9
	WEIGHT OF DRY SOIL	gr	187.9	167	181.7	168.1	151.4
	MOISTURE CONTENT	%	11.44	14.13	15.63	18.44	22.46
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.49	1.58	1.65	1.67	1.58



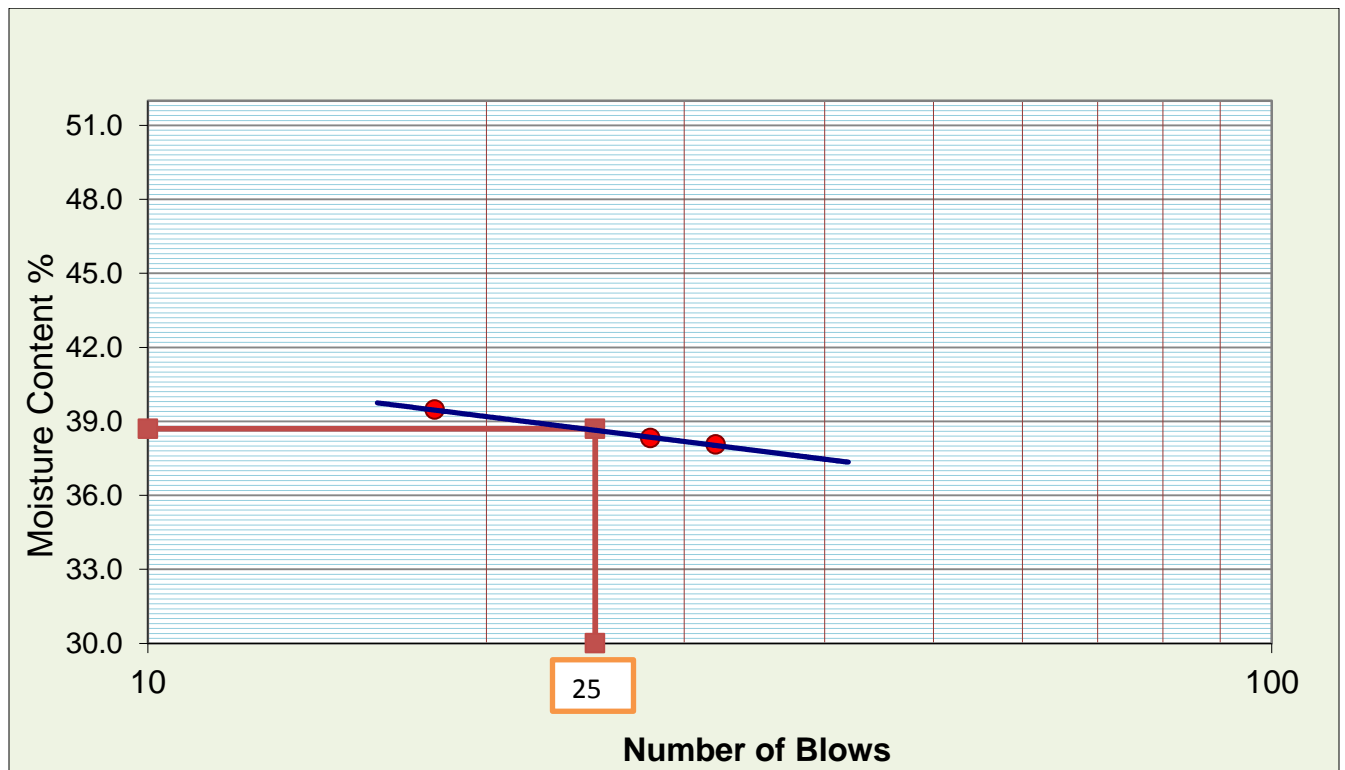
**For Station 60+030**

DENSITY	TRIAL NUMBER		1	2	3	4	5
	WEIGHT OF SOIL + MOLD	gr	8942	9385	9505	9360	9150
	WEIGHT OF MOLD	gr	5220	5220	5220	5220	5220
	WEIGHT OF SOIL	gr	3722	4165	4285	4140	3930
	VOLUME OF MOLD	cc	2014	2014	2014	2014	2014
	WET DENSITY OF SOIL	gr/cc	1.85	2.07	2.13	2.06	1.95
MOISTURE	CONTAINER NUMBER		H-4	H-1	T-6	H-3	H-6
	WET SOIL + CONTAINER	gr	240.5	217.0	219.8	208.2	208.2
	DRY SOIL + CONTAINER	gr	222.7	195.7	193.5	180	178.5
	WEIGHT OF WATER	gr	17.8	21.3	26.3	28.2	29.7
	WEIGHT OF CONTAINER	gr	28.4	29.1	30.0	29.9	29.9
	WEIGHT OF DRY SOIL	gr	194.3	166.6	163.5	150.1	148.6
	MOISTURE CONTENT	%	9.16	12.79	16.09	18.79	19.99
<b>DRY DENSITY OF SOIL</b>		<b>gr/cc</b>	1.69	1.78	1.83	1.73	1.63



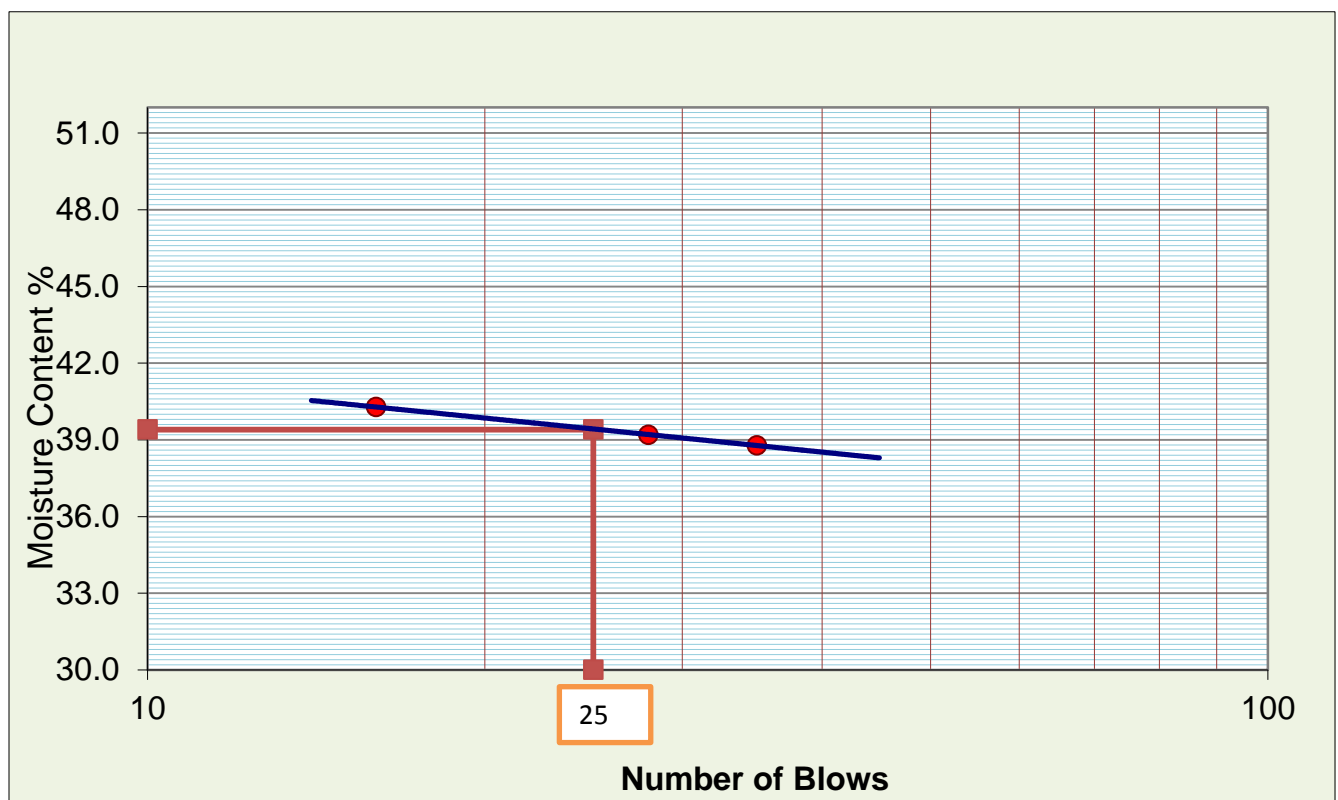
**Appendix-G: Test Result of Atterberg Limit Test with its Graph**

Station 47+500	Liquid Limit				Plastic Limit	
No. of Blows	32	28	18	19		
Container Number	A-1	B-4	C-1		C-3	C-4
Wt. of Container + Wet Soil (g) = (W <sub>1</sub> )	45.89	37.12	42.54		27.70	27.73
Wt. of Container + Dry Soil (g) = (W <sub>2</sub> )	39.95	33.25	37.22		26.90	26.70
Weight of Moisture (g) = (W <sub>1</sub> - W <sub>2</sub> ) = A	5.94	3.87	5.32		0.80	1.03
Wt. of Container (g) = (W <sub>3</sub> )	24.34	23.15	23.74		24.21	23.06
Weight of Dry Soil (g) = (W <sub>2</sub> - W <sub>3</sub> ) = B	15.61	10.10	13.48		2.69	3.64
Moisture Content (%) = (A / B) x 100	38.05	38.32	39.47		29.74	28.30
<b>Liquid Limit</b>	<b>38.7</b>			AV. Plas. Lim.	<b>29.0</b>	
Plasticity Index PI = LL-PL	<b>9.7</b>					

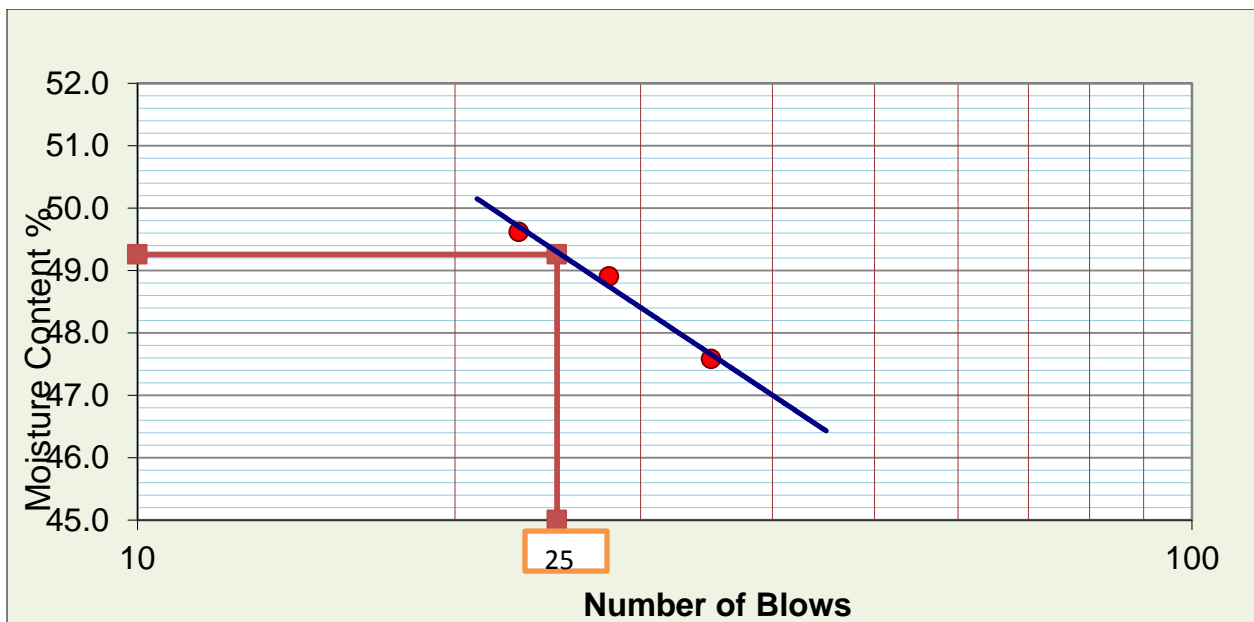


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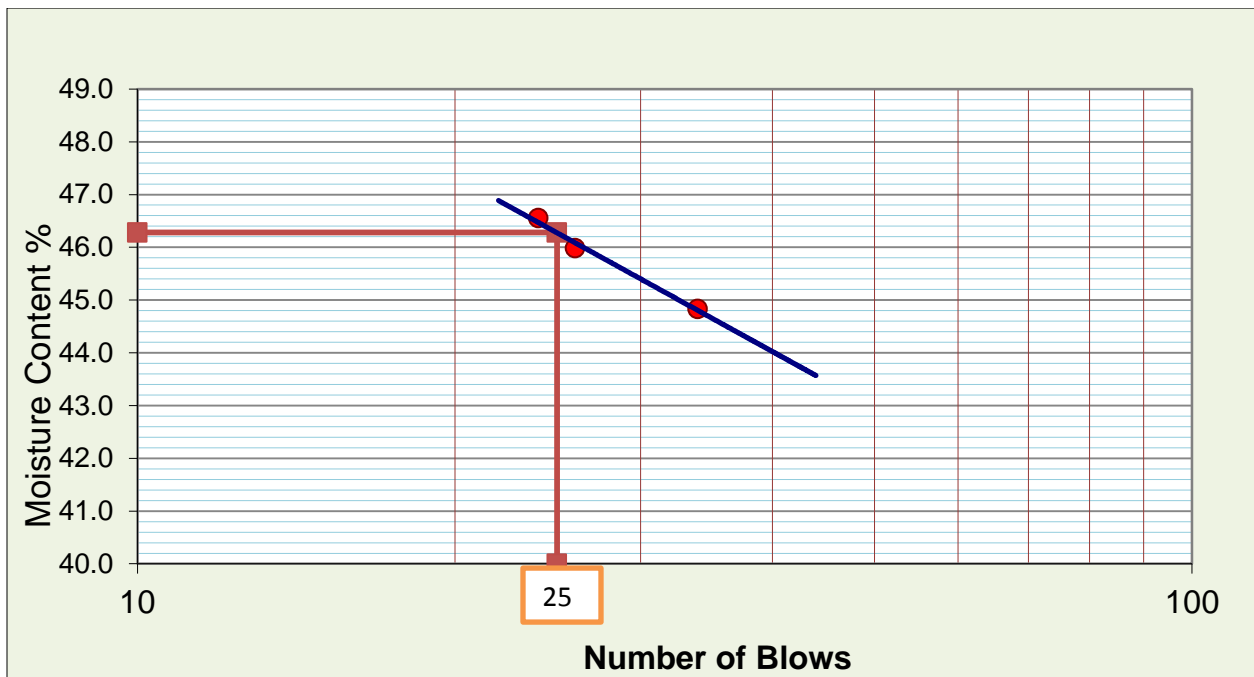
Station 49+560	Liquid Limit				Plastic Limit	
No. of Blows	35	28	16	19		
Container Number	A-1	B-4	C-5		D-5	D-2
Wt. of Container + Wet Soil (g) = (W <sub>1</sub> )	37.76	38.12	39.72		25.85	25.00
Wt. of Container + Dry Soil (g) = (W <sub>2</sub> )	33.99	33.93	35.22		25.43	24.59
Weight of Moisture (g) = (W <sub>1</sub> - W <sub>2</sub> ) = A	3.77	4.19	4.50		0.42	0.41
Wt. of Container (g) = (W <sub>3</sub> )	24.27	23.24	24.05		24.02	23.17
Weight of Dry Soil (g) = (W <sub>2</sub> - W <sub>3</sub> ) = B	9.72	10.69	11.17		1.41	1.42
Moisture Content (%) = (A / B) x 100	38.79	39.20	40.29		29.79	28.87
<b>Liquid Limit</b>	<b>39</b>			AV. Plas. Lim.	<b>29.3</b>	
Plasticity Index PI = LL-PL	<b>10.1</b>					



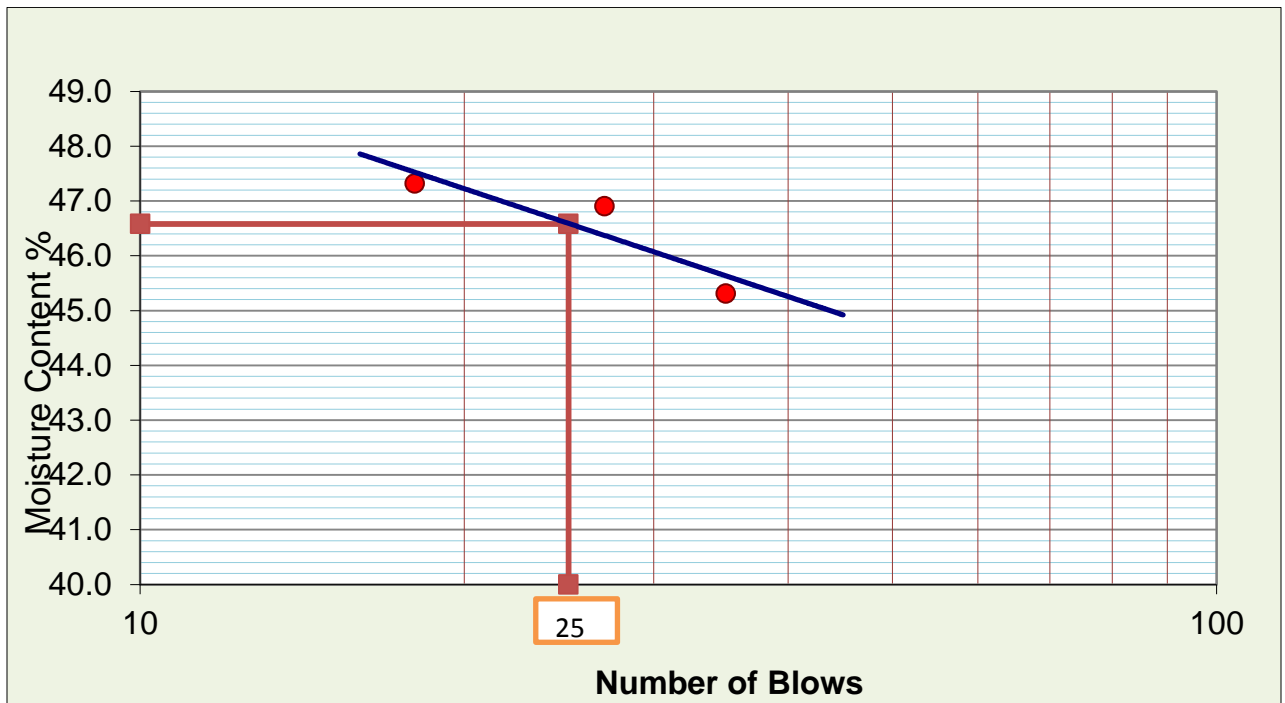
Station 53+560	Liquid Limit				Plastic Limit	
No. of Blows	35	28	23	19		
Container Number	B-4	A-1	D-5		B-1	D-3
Wt. of Container + Wet Soil (g) = ( $W_1$ )	26.88	26.55	26.14		16.68	17.06
Wt. of Container + Dry Soil (g) = ( $W_2$ )	22.75	22.52	22.22		16.05	16.46
Weight of Moisture (g) = ( $W_1 - W_2$ ) = A	4.13	4.03	3.92		0.63	0.60
Wt. of Container (g) = ( $W_3$ )	14.07	14.28	14.32		13.84	14.32
Weight of Dry Soil (g) = ( $W_2 - W_3$ ) = B	8.68	8.24	7.90		2.21	2.14
Moisture Content (%) = ( $A / B$ )x 100	47.58	48.91	49.62		28.51	28.04
<b>Liquid Limit</b>	<b>49.26</b>			AV. Plas. Lim.	<b>28.3</b>	
Plasticity Index PI = LL-PL	<b>21.0</b>					



Station 55+500	Liquid Limit				Plastic Limit	
No. of Blows	34	26	24	19		
Container Number	A-3	B-2	D-4		B-1	D-5
Wt. of Container + Wet Soil (g) = ( $W_1$ )	28.20	27.65	25.40		17.60	18.90
Wt. of Container + Dry Soil (g) = ( $W_2$ )	24.30	23.76	21.89		16.82	18.06
Weight of Moisture (g) = ( $W_1 - W_2$ ) = A	3.90	3.89	3.51		0.78	0.84
Wt. of Container (g) = ( $W_3$ )	15.60	15.30	14.35		13.87	15.01
Weight of Dry Soil (g) = ( $W_2 - W_3$ ) = B	8.70	8.46	7.54		2.95	3.05
Moisture Content (%) = ( $A / B$ )x 100	44.83	45.98	46.55		26.44	27.54
<b>Liquid Limit</b>	<b>46.30</b>			AV. Plas. Lim.	<b>26.99</b>	
Plasticity Index PI = LL-PL	<b>19.3</b>					

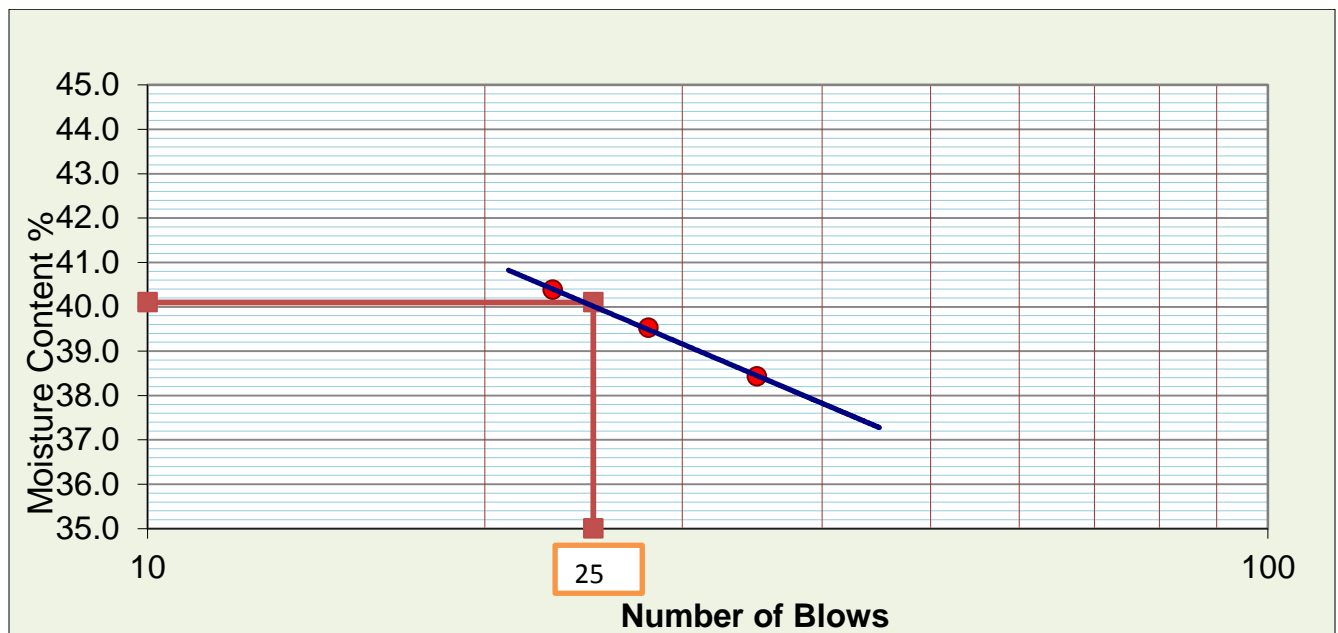


Station 58+840	Liquid Limit				Plastic Limit	
No. of Blows	35	27	18	19		
Container Number	B-1	D-3	B-4		A-1	B-3
Wt. of Container + Wet Soil (g) = (W <sub>1</sub> )	30.10	29.04	28.89		17.06	16.00
Wt. of Container + Dry Soil (g) = (W <sub>2</sub> )	25.03	24.34	24.13		16.48	15.64
Weight of Moisture (g) = (W <sub>1</sub> - W <sub>2</sub> ) = A	5.07	4.70	4.76		0.58	0.36
Wt. of Container (g) = (W <sub>3</sub> )	13.84	14.32	14.07		14.28	14.32
Weight of Dry Soil (g) = (W <sub>2</sub> - W <sub>3</sub> ) = B	11.19	10.02	10.06		2.20	1.32
Moisture Content (%) = (A / B) x 100	45.31	46.91	47.32		26.36	27.27
<b>Liquid Limit</b>	<b>46.58</b>			AV. Plas. Lim.	<b>26.82</b>	
Plasticity Index PI = LL-PL	<b>19.8</b>					



*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

For station 60+030	Liquid Limit				Plastic Limit	
No. of Blows	35	28	23	19		
Container Number	A-1	D-5	B-3		C-3	D-4
Wt. of Container + Wet Soil (g) = (W <sub>1</sub> )	43.85	40.39	43.80		27.77	26.27
Wt. of Container + Dry Soil (g) = (W <sub>2</sub> )	38.42	35.75	37.84		26.81	25.56
Weight of Moisture (g) = (W <sub>1</sub> - W <sub>2</sub> ) = A	5.43	4.64	5.96		0.96	0.71
Wt. of Container (g) = (W <sub>3</sub> )	24.29	24.01	23.08		22.94	22.64
Weight of Dry Soil (g) = (W <sub>2</sub> - W <sub>3</sub> ) = B	14.13	11.74	14.76		3.87	2.92
Moisture Content (%) = (A / B) x 100	38.43	39.52	40.38		24.81	24.32
<b>Liquid Limit</b>	<b>40.10</b>			AV. Plas. Lim.	<b>24.56</b>	
Plasticity Index PI = LL-PL	<b>15.5</b>					



**Appendix-H: Test result of Oedometer with different Loading Conditions and Densities**

**For station 49+560**

**Oedometer test result at the maximum standard load of 200kp and at its in situ density**

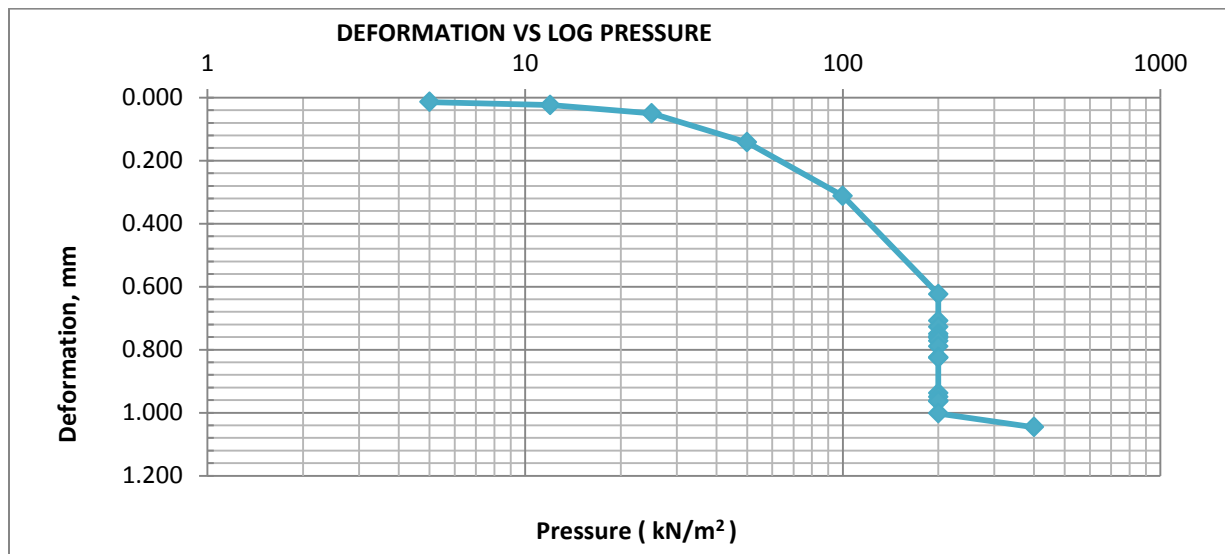
Specific Gravity	2.64	Overall settlement	1.002	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	18.436	Volume Change	1.99	Thickness of sample	20
$V_{vi} = V_t - V_s$	20.83	Final volume	37.28	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.1301	Final bulk density	1.694	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	26.304	Final Dry Density	1.25		
Volume change factor=F	0.1075	Final void ratio	1.02		
		$V_{vf} = V_{tf} - V_s$	18.85		
		Final saturation $S_f$ , %	87.85		

<b>Before Inundation</b>	
Moisture Content (%)	11.26
Mass of Ring+Wet. Soil(g)	123.32
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	132.33
Wet. Of wet Soil	63.16
<b>Moisture Content After inundation</b>	
Mass of Can	30.55
Mass of can+Wet Soil	91.24
Mass of can+Dry Soil	75.33
Moisture Content After inundation	35.53
Bulk Density	1.38
In-situ Dry density	1.24

<b>Collapse Index, I<sub>c</sub> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.014
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 200KPa after wetting ,mm	1.002
$d_i$ , dial reading at 200KPa before wetting, mm	0.624
collapse Index $I_c = ((d_f - d_i)/h_o) \cdot 100$	1.89

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	7.0	0.014	0.002	1.130
1hr	12	12.0	0.024	0.003	1.128
2hr	25	25.0	0.050	0.005	1.125
3hr	50	71.0	0.142	0.015	1.115
4hr	100	156.0	0.312	0.034	1.097
5hr	200	312.0	0.624	0.067	1.063
0.1min	200	354.0	0.708	0.076	1.054
0.25min	200	364.0	0.728	0.078	1.052
0.5min	200	375.0	0.750	0.081	1.049
1min	200	379.0	0.758	0.082	1.049
2min	200	381.0	0.762	0.082	1.048
4min	200	386.0	0.772	0.083	1.047
8min	200	395.0	0.790	0.085	1.045
15min	200	412.0	0.824	0.089	1.042
30min	200	413.0	0.826	0.089	1.041
1hr	200	469.0	0.938	0.101	1.029
2hr	200	475.0	0.950	0.102	1.028
4hr	200	481.0	0.962	0.103	1.027
8hr	200	482.0	0.964	0.104	1.026
24hr	200	501.0	1.002	0.108	1.022
48hr	400	523.0	1.046	0.112	1.018



**Stress vs strain result at the maximum standard load of 200kp and at it's in - situ density**

**Oedometer test result at the actual load of 105kp and at it's in - situ density**

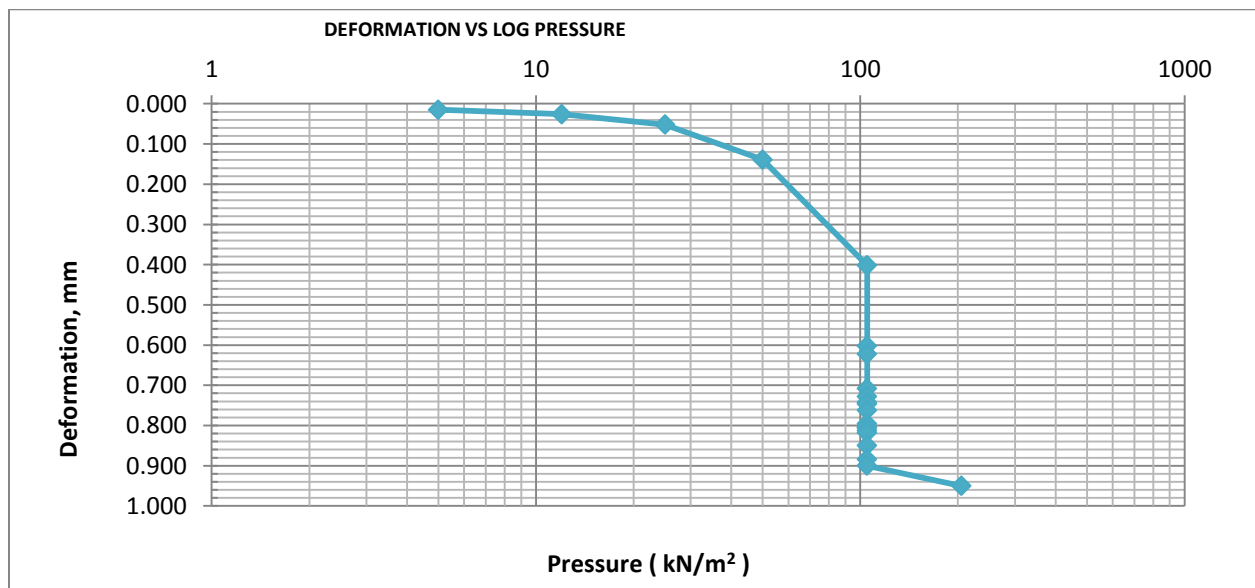
Specific Gravity	2.64	Overall settlement	0.900	Diameter of sample	50
$V_s = DD/G_s * V_t (cm^3)$	18.43552	Volume Change	1.79	Thickness of sample	20
$V_{vi} = V_t - V_s$	20.83	Final volume	37.48	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.130127	Final bulk density	1.685	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	26.3036	Final Dry Density	1.25		
Volume change factor=F	0.107657	Final void ratio	1.03		
		$V_{vf} = V_{tf} - V_s$	19.05		
		Final saturation $S_f$ , %	86.29		

<b>Before Inundation</b>	
Moisture Content (%)	11.26
Mass of Ring+Wet. Soil(g)	123.32
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	132.33
Wet. Of wet Soil	63.16
<b>Moisture Content After inundation</b>	
Mass of Can	30.33
Mass of can+Wet Soil	91.66
Mass of can+Dry Soil	75.70
Moisture Content After inundation	35.18
Bulk Density	1.38
In-situ Dry density	1.24

<b>Collapse Index, I<sub>c</sub> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.015
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 200KPa after wetting ,mm	0.900
$d_i$ , dial reading at 200KPa before wetting, mm	0.602
collapse Index $I_c = ((d_f - d_i)/h_o) * 100$	1.49

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi - Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	7.5	0.015	0.002	1.130
1hr	12	13.0	0.026	0.003	1.127
2hr	25	26.0	0.052	0.006	1.125
3hr	50	69.5	0.139	0.015	1.115
4hr	105	201.0	0.402	0.043	1.087
5hr	105	301.0	0.602	0.065	1.065
0.1min	105	311.0	0.622	0.067	1.063
0.25min	105	354.0	0.708	0.076	1.054
0.5min	105	364.0	0.728	0.078	1.052
1min	105	371.0	0.742	0.080	1.050
2min	105	373.0	0.746	0.080	1.050
4min	105	381.0	0.762	0.082	1.048
8min	105	398.0	0.796	0.086	1.044
15min	105	402.0	0.804	0.087	1.044
30min	105	403.0	0.806	0.087	1.043
1hr	105	406.0	0.812	0.087	1.043
2hr	105	409.0	0.818	0.088	1.042
4hr	105	425.0	0.850	0.092	1.039
8hr	105	442.0	0.884	0.095	1.035
24hr	105	450.0	0.900	0.097	1.033
48hr	205	475.0	0.950	0.102	1.028



**Stress vs strain result at the maximum actual load of 105kPa and at it's in - situ density**

**Oedometer test result at the maximum standard load of 200kp and at maximum dry density**

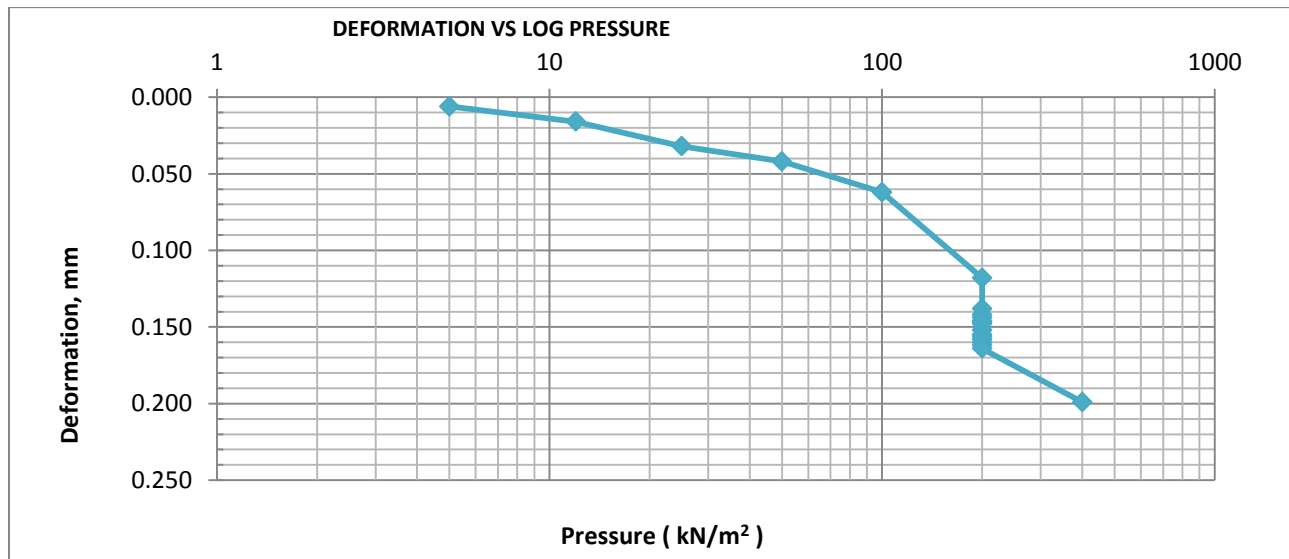
Specific Gravity	2.64	Overall settlement	0.164	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	24.352	Volume Change	0.34	Thickness of sample	20
$V_{vi} = V_t - V_s$	14.92	Final volume	38.93	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.6126	Final bulk density	2.061	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	75.4167	Final Dry Density	1.70		
Volume change factor=F	0.0856	Final void ratio	0.60		
		$V_{vf} = V_{tf} - V_s$	14.58		
		Final saturation $S_f$ , %	97.09		

<b>Before Inundation</b>	
Moisture Content (%)	17.50
Mass of Ring+Wet. Soil(g)	144.21
Mass of Ring(g)	68.67
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	148.89
Wet. Of wet Soil	80.22
<b>Moisture Content After inundation</b>	
Mass of Can	79.13
Mass of can+Wet Soil	159.11
Mass of can+Dry Soil	145.00
Moisture Content After inundation	21.42
Bulk Density	1.92
AT MDD (Max. Dry Density) gr/cc	<b>1.64</b>

<b>Collapse Index, I<sub>c</sub> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.006
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 200KPa after wetting ,mm	0.164
$d_i$ , dial reading at 200KPa before wetting, mm	0.118
collapse Index $I_c = ((d_f - d_i)/h_o) \cdot 100$	0.23

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_l = e_o - \Delta e$
5min	5	3.0	0.006	0.001	0.613
1hr	12	8.0	0.016	0.001	0.611
2hr	25	16.0	0.032	0.003	0.610
3hr	50	21.0	0.042	0.004	0.609
4hr	100	31.0	0.062	0.005	0.607
5hr	200	59.0	0.118	0.010	0.602
0.1min	200	69.0	0.138	0.012	0.601
0.25min	200	71.0	0.142	0.012	0.600
0.5min	200	72.0	0.144	0.012	0.600
1min	200	73.0	0.146	0.012	0.600
2min	200	73.5	0.147	0.013	0.600
4min	200	74.0	0.148	0.013	0.600
8min	200	76.0	0.152	0.013	0.600
15min	200	77.5	0.155	0.013	0.599
30min	200	78.0	0.156	0.013	0.599
1hr	200	79.0	0.158	0.014	0.599
2hr	200	79.0	0.158	0.014	0.599
4hr	200	80.0	0.160	0.014	0.599
8hr	200	81.0	0.162	0.014	0.599
24hr	200	82.0	0.164	0.014	0.599
48hr	400	99.5	0.199	0.017	0.596



**Stress vs strain result at the maximum standard load of 200kPa and at maximum dry density**

**Oedometer test result at the actual load of 105kPa and at its maximum dry density**

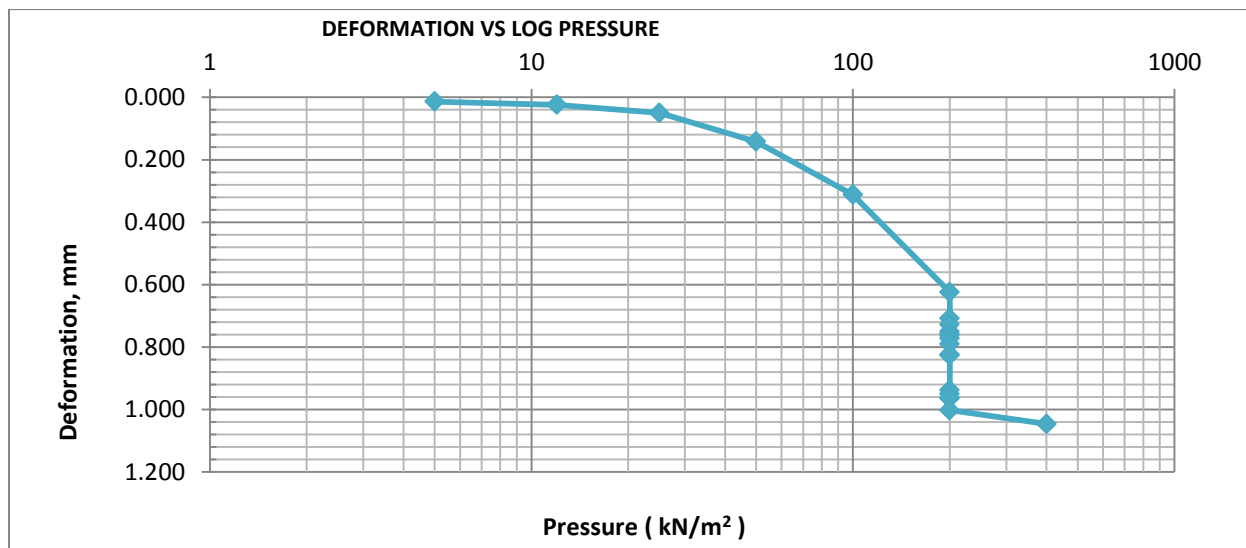
Specific Gravity	2.64	Overall settlement	0.123	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	24.3005	Volume Change	0.26	Thickness of sample	20
$V_{vi} = V_t - V_s$	14.97	Final volume	39.01	Area of sample	1962.50
Initial Void ratio $e_0 = V_v/V_s$	0.61602	Final bulk density	2.049	Volume of Sample	39.27
Initial $S_o = V_w/V_{vi}$	74.9976	Final Dry Density	1.69		
Volume change factor = F	0.08745	Final void ratio	0.61		
		$V_{vf} = V_{tf} - V_s$	14.71		
		Final saturation $S_f$ , %	94.33		

<b>Before Inundation</b>	
Moisture Content (%)	17.50
Mass of Ring+Wet. Soil(g)	144.05
Mass of Ring(g)	68.67
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	148.58
Wet. Of wet Soil	79.91
<b>Moisture Content After inundation</b>	
Mass of Can	78.90
Mass of can+Wet Soil	158.21
Mass of can+Dry Soil	144.44
Moisture Content After inundation	21.01
Bulk Density	1.9
AT MDD (Max. Dry Density) gr/cc	<b>1.63</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.008
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 105KPa after wetting ,mm	0.123
$d_i$ , dial reading at 105KPa before wetting, mm	0.085
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	0.19

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	4.0	0.008	0.001	0.616
1hr	12	9.0	0.018	0.002	0.614
2hr	25	17.0	0.034	0.003	0.613
3hr	50	24.0	0.048	0.004	0.612
4hr	105	42.5	0.085	0.007	0.609
5hr	105	42.5	0.085	0.007	0.609
0.1min	105	43.5	0.087	0.008	0.608
0.25min	105	44.0	0.088	0.008	0.608
0.5min	105	45.0	0.090	0.008	0.608
1min	105	48.0	0.096	0.008	0.608
2min	105	48.5	0.097	0.008	0.608
4min	105	51.0	0.102	0.009	0.607
8min	105	53.0	0.106	0.009	0.607
15min	105	56.0	0.112	0.010	0.606
30min	105	57.0	0.114	0.010	0.606
1hr	105	58.0	0.116	0.010	0.606
2hr	105	58.5	0.117	0.010	0.606
4hr	105	59.0	0.118	0.010	0.606
8hr	105	60.5	0.121	0.011	0.605
24hr	105	61.5	0.123	0.011	0.605
48hr	205	74.0	0.148	0.013	0.603



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**

**For station 53+550**

**Oedometer test result at the maximum standard load of 200kp and at its in situ density**

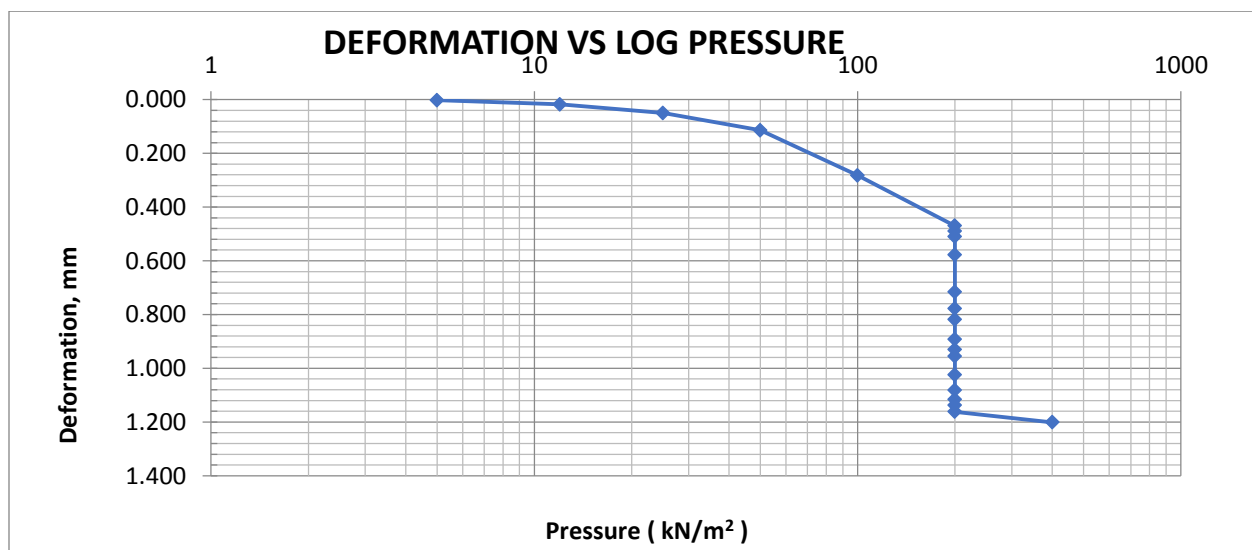
Specific Gravity	2.61	Overall settlement	1.162	Diameter of sample	50
$V_s = DD/G_s \cdot V_t (\text{cm}^3)$	20.0487	Volume Change	2.30	Thickness of sample	20
$V_{vi} = V_t - V_s$	19.22	Final volume	36.97	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.95873	Final bulk density	1.812	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	38.9298	Final Dry Density	1.45		
Volume change factor = F	0.09874	Final void ratio	0.84		
		$V_{vf} = V_{tf} - V_s$	16.92		
		Final saturation $S_f$ , %	79.80		

<b>Before Inundation</b>	
Moisture Content (%)	14.30
Mass of Ring+Wet. Soil(g)	129.01
Mass of Ring(g)	69.20
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	136.2
Wet. Of wet Soil	67
<b>Moisture Content After inundation</b>	
Mass of Can	78.48
Mass of can+Wet Soil	141.10
Mass of can+Dry Soil	128.48
Moisture Content After inundation	25.24
Bulk Density	1.52
In-situ Dry density	1.33

<b>Collapse Index, <math>I_e</math> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.002
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 200KPa after wetting ,mm	1.162
$d_i$ , dial reading at 200KPa before wetting, mm	0.470
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	3.46

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	1.0	0.002	0.000	0.959
1hr	12	9.0	0.018	0.002	0.957
2hr	25	25.0	0.050	0.005	0.954
3hr	50	57.0	0.114	0.011	0.947
4hr	100	141.0	0.282	0.028	0.931
5hr	200	235.0	0.470	0.046	0.912
0.1min	200	245.0	0.490	0.048	0.910
0.25min	200	255.0	0.510	0.050	0.908
0.5min	200	289.0	0.578	0.057	0.902
1min	200	358.0	0.716	0.071	0.888
2min	200	389.0	0.778	0.077	0.882
4min	200	409.0	0.818	0.081	0.878
8min	200	446.0	0.892	0.088	0.871
15min	200	465.0	0.930	0.092	0.867
30min	200	478.0	0.956	0.094	0.864
1hr	200	512.0	1.024	0.101	0.858
2hr	200	541.0	1.082	0.107	0.852
4hr	200	558.0	1.116	0.110	0.849
8hr	200	569.0	1.138	0.112	0.846
24hr	200	581.0	1.162	0.115	0.844
48hr	400	600.5	1.201	0.119	0.840



**Stress vs strain result at the maximum standard load of 200kp and at it's in - situ density**

**Oedometer test result at the actual load of 105kPa and at it's at it's in - situ density**

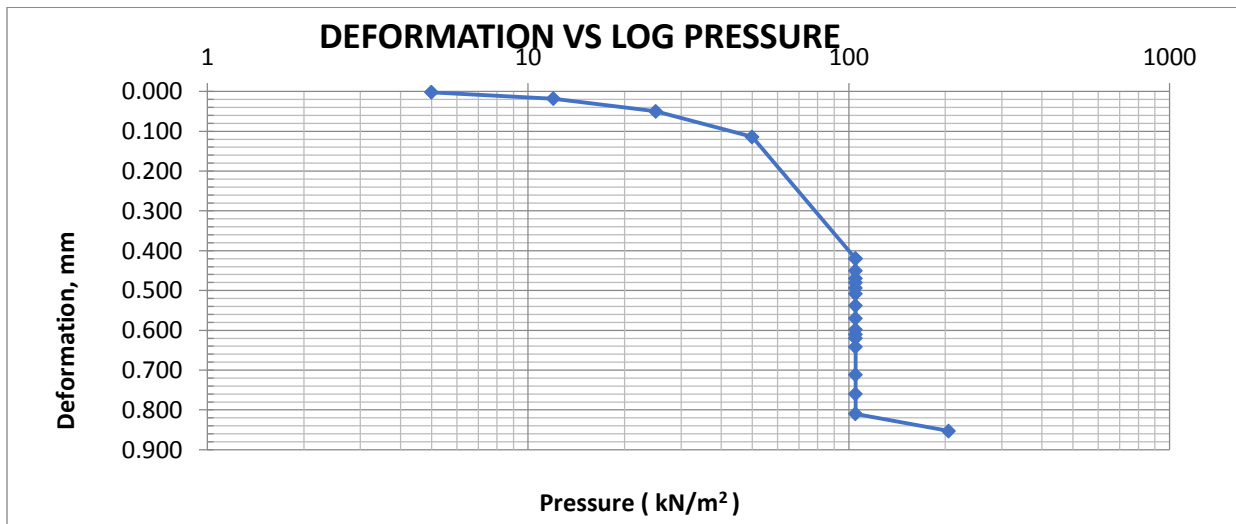
Specific Gravity	2.66	Overall settlement	0.810	Diameter of sample	50
$V_s = DD/G_s * V_t (cm^3)$	19.5041	Volume Change	1.61	Thickness of sample	20
$V_{vi} = V_t - V_s$	19.77	Final volume	37.66	Area of sample	1962.50
initial Void ratio $e_0 = V_v / V_s$	1.01342	Final bulk density	1.779	Volume of Sample	39.27
initial $S_o = V_w / V_{vi}$	37.5343	Final Dry Density	1.43		
Volume change factor = F	0.10189	Final void ratio	0.93		
		$V_{vf} = V_{tf} - V_s$	18.16		
		Final saturation $S_f$ , %	71.53		

<b>Before Inundation</b>	
Moisture Content (%)	14.30
Mass of Ring+Wet. Soil(g)	128.50
Mass of Ring(g)	69.20
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	136.2
Wet. Of wet Soil	67
<b>Moisture Content After inundation</b>	
Mass of Can	75.99
Mass of can+Wet Soil	141.10
Mass of can+Dry Soil	128.48
Moisture Content After innudation	24.04
Bulk Density	1.51
In-situ Dry density	1.32

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.002
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 105KPa after wetting ,mm	0.810
d <sub>i</sub> , dial reading at 105KPa before wetting, mm	0.420
Collapse Index $I_e = ((d_f - d_i) / h_o) * 100$	1.95

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
0sec	5	1.0	0.002	0.000	1.013
5sec	12	9.0	0.018	0.002	1.012
1hr	25	25.0	0.050	0.005	1.008
2hr	50	57.0	0.114	0.012	1.002
3hr	105	210.0	0.420	0.043	0.971
4hr	105	210.0	0.420	0.043	0.971
0.1min	105	225.0	0.450	0.046	0.968
0.25min	105	235.0	0.470	0.048	0.966
0.5min	105	240.0	0.480	0.049	0.965
1min	105	247.0	0.494	0.050	0.963
2min	105	254.0	0.508	0.052	0.962
4min	105	269.0	0.538	0.055	0.959
8min	105	285.0	0.570	0.058	0.955
15min	105	299.0	0.598	0.061	0.952
30min	105	305.0	0.610	0.062	0.951
1hr	105	310.0	0.620	0.063	0.950
2hr	105	321.0	0.642	0.065	0.948
4hr	105	356.0	0.712	0.073	0.941
8hr	105	380.0	0.760	0.077	0.936
24hr	105	405.0	0.810	0.083	0.931
48hr	205	426.5	0.853	0.087	0.927



**Stress vs strain result at the maximum actual load of 105kPa and at it's in - situ density**

**Oedometer test result at the maximum standard load of 200kp and at maximum dry density**

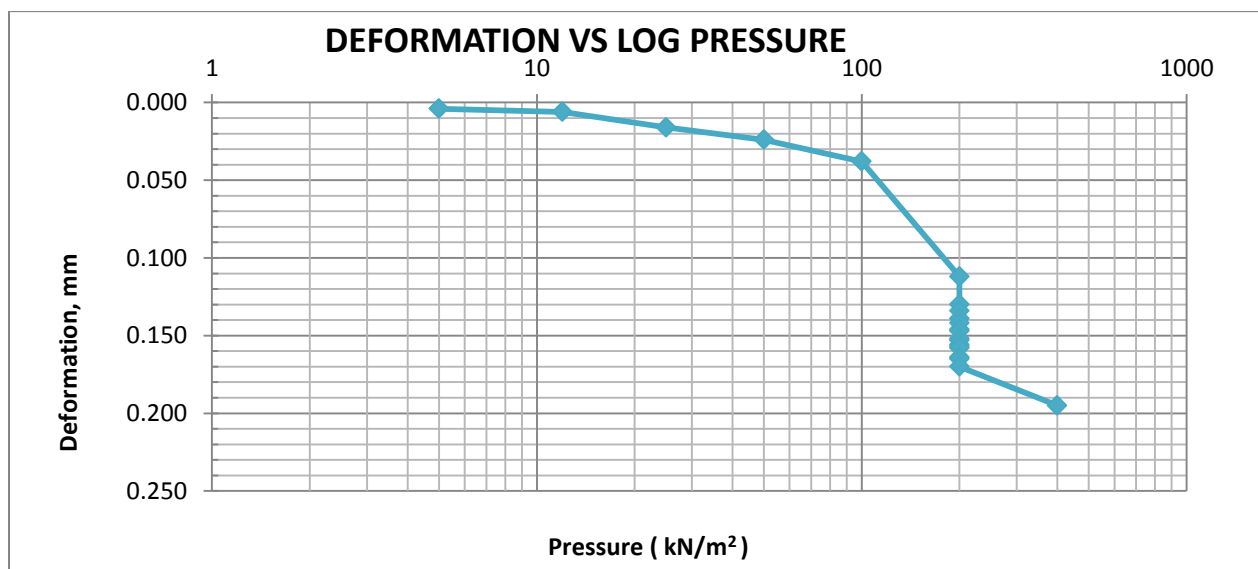
Specific Gravity	2.61	Overall settlement	0.170	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	24.3712	Volume Change	0.35	Thickness of sample	20
$V_{vi} = V_t - V_s$	14.90	Final volume	38.92	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.61133	Final bulk density	2.060	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	79.4105	Final Dry Density	1.70		
Volume change factor=F	0.08535	Final void ratio	0.60		
		$V_{vf} = V_{tf} - V_s$	14.55		
		Final saturation $S_f$ , %	97.19		

<b>Before Inundation</b>	
Moisture Content (%)	18.60
Mass of Ring+Wet. Soil(g)	144.11
Mass of Ring(g)	68.67
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	148.85
Wet. Of wet Soil	80.18
<b>Moisture Content After inundation</b>	
Mass of Can	78.23
Mass of can+Wet Soil	158.20
Mass of can+Dry Soil	144.10
Moisture Content After inundation	21.41
Bulk Density	1.92
AT MDD (Max. Dry Density) gr/cc	<b>1.62</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.004
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 200KPa after wetting ,mm	0.170
d <sub>i</sub> , dial reading at 200KPa before wetting, mm	0.112
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	0.29

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	2.0	0.004	0.000	0.611
1hr	12	3.0	0.006	0.001	0.611
2hr	25	8.0	0.016	0.001	0.610
3hr	50	12.0	0.024	0.002	0.609
4hr	100	19.0	0.038	0.003	0.608
5hr	200	56.0	0.112	0.010	0.602
0.1min	200	65.0	0.130	0.011	0.600
0.25min	200	67.0	0.134	0.011	0.600
0.5min	200	69.5	0.139	0.012	0.599
1min	200	71.0	0.142	0.012	0.599
2min	200	73.0	0.146	0.012	0.599
4min	200	73.5	0.147	0.013	0.599
8min	200	76.0	0.152	0.013	0.598
15min	200	76.5	0.153	0.013	0.598
30min	200	78.0	0.156	0.013	0.598
1hr	200	78.5	0.157	0.013	0.598
2hr	200	79.0	0.158	0.013	0.598
4hr	200	82.0	0.164	0.014	0.597
8hr	200	82.5	0.165	0.014	0.597
24hr	200	85.0	0.170	0.015	0.597
48hr	400	97.5	0.195	0.017	0.595



**Stress vs strain result at the maximum standard load of 200kPa and at maximum dry density**

**Oedometer test result at the actual load of 105kPa and at its maximum dry density**

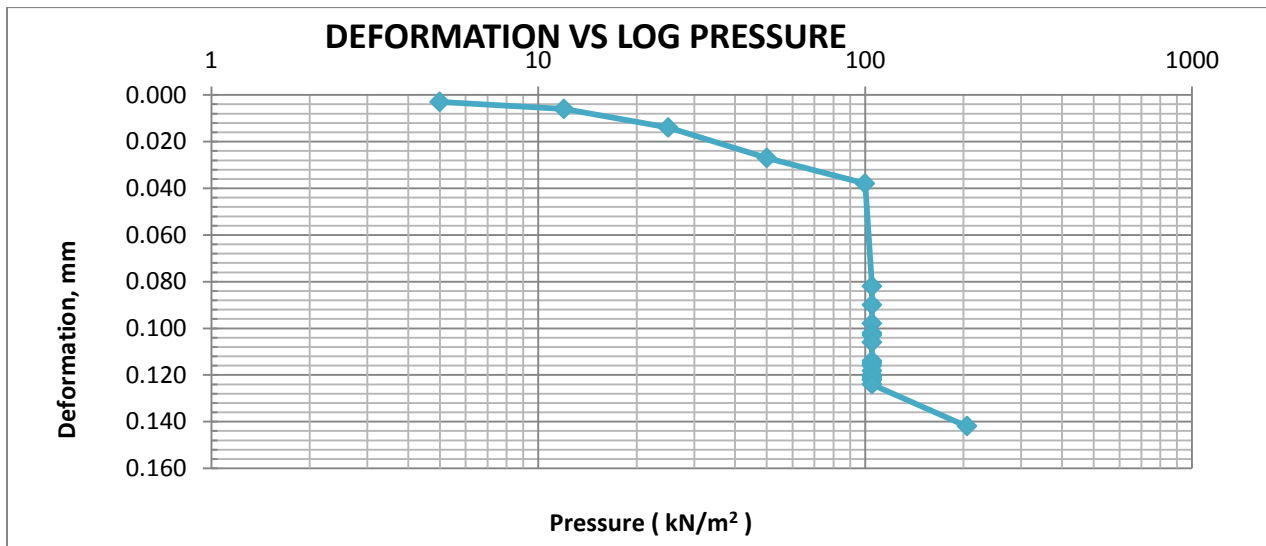
Specific Gravity	2.61	Overall settlement	0.124	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	24.0126	Volume Change	0.26	Thickness of sample	20
$V_{vi} = V_t - V_s$	15.26	Final volume	39.01	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.63539	Final bulk density	2.048	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	76.4032	Final Dry Density	1.69		
Volume change factor=F	0.08844	Final void ratio	0.62		
		$V_{vf} = V_{tf} - V_s$	14.99		
		Final saturation $S_f$ , %	93.11		

<b>Before Inundation</b>	
Moisture Content (%)	18.60
Mass of Ring+Wet. Soil(g)	143.00
Mass of Ring(g)	68.67
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	148.56
Wet. Of wet Soil	79.89
<b>Moisture Content After inundation</b>	
Mass of Can	77.88
Mass of can+Wet Soil	157.99
Mass of can+Dry Soil	143.99
Moisture Content After inundation	21.18
Bulk Density	1.9
AT MDD (Max. Dry Density) gr/cc	<b>1.60</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.003
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 105KPa after wetting ,mm	0.124
d <sub>i</sub> , dial reading at 105KPa before wetting, mm	0.082
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	0.21

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	1.5	0.003	0.000	0.635
1hr	12	3.0	0.006	0.001	0.635
2hr	25	7.0	0.014	0.001	0.634
3hr	50	13.5	0.027	0.002	0.633
4hr	100	19.0	0.038	0.003	0.632
5hr	105	41.0	0.082	0.007	0.628
0.1min	105	45.0	0.090	0.008	0.627
0.25min	105	49.0	0.098	0.009	0.627
0.5min	105	51.0	0.102	0.009	0.626
1min	105	51.5	0.103	0.009	0.626
2min	105	53.0	0.106	0.009	0.626
4min	105	57.0	0.114	0.010	0.625
8min	105	57.5	0.115	0.010	0.625
15min	105	58.0	0.116	0.010	0.625
30min	105	59.1	0.118	0.010	0.625
1hr	105	60.0	0.120	0.011	0.625
2hr	105	60.5	0.121	0.011	0.625
4hr	105	61.0	0.122	0.011	0.625
8hr	105	61.0	0.122	0.011	0.625
24hr	105	62.0	0.124	0.011	0.624
48hr	205	71.0	0.142	0.013	0.623



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**

**Station: 60+030 (sample one)**

**Oedometer test result at the maximum standard load of 200kp and at its in-situ density**

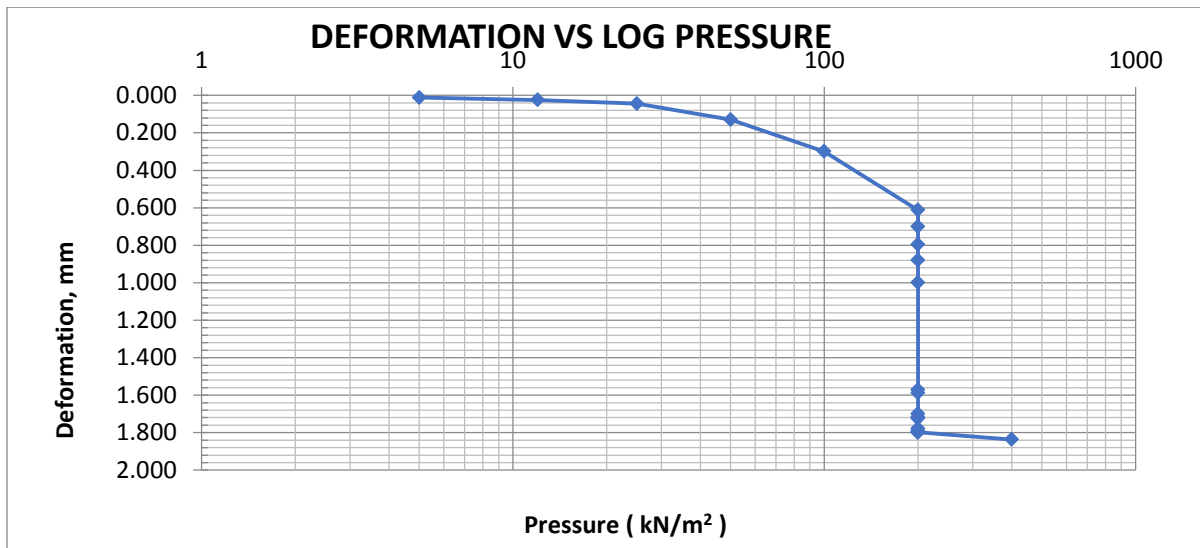
Specific Gravity	2.66	Overall settlement	1.798	Diameter of sample	50
$V_s = DD/G_s * V_t (cm^3)$	17.1201	Volume Change	3.55	Thickness of sample	20
$V_{vi} = V_t - V_s$	22.15	Final volume	35.72	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.2938	Final bulk density	1.656	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	21.1764	Final Dry Density	1.25		
Volume change factor = F	0.11528	Final void ratio	1.09		
		$V_{vf} = V_{tf} - V_s$	18.60		
		Final saturation $S_f, \%$	77.85		

<b>Before Inundation</b>	
Moisture Content (%)	10.30
Mass of Ring+Wet. Soil(g)	119.40
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	128.33
Wet. Of wet Soil	59.16
<b>Moisture Content After inundation</b>	
Mass of Can	30.16
Mass of can+Wet Soil	89.40
Mass of can+Dry Soil	74.90
Moisture Content After inundation	32.41
Bulk Density	1.28
In-situ Dry density	1.16

<b>Collapse Index, <math>I_e</math> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.012
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 200KPa after wetting ,mm	1.798
$d_i$ , dial reading at 200KPa before wetting, mm	0.612
collapse Index $I_e = ((d_f - d_i)/h_o) * 100$	5.93

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_l = e_o - \Delta e$
5min	5	6.0	0.012	0.001	1.294
1hr	12	12.5	0.025	0.003	1.291
2hr	25	22.0	0.044	0.005	1.289
3hr	50	65.0	0.130	0.015	1.279
4hr	100	150.0	0.300	0.035	1.259
5hr	200	306.0	0.612	0.071	1.223
0.1min	200	350.0	0.700	0.081	1.213
0.25min	200	398.0	0.796	0.092	1.202
0.5min	200	440.0	0.880	0.101	1.192
1min	200	500.0	1.000	0.115	1.179
2min	200	786.0	1.572	0.181	1.113
4min	200	794.0	1.588	0.183	1.111
8min	200	850.0	1.700	0.196	1.098
15min	200	858.0	1.716	0.198	1.096
30min	200	863.0	1.726	0.199	1.095
1hr	200	889.0	1.778	0.205	1.089
2hr	200	895.0	1.790	0.206	1.087
4hr	200	899.0	1.798	0.207	1.087
8hr	200	899.5	1.799	0.207	1.086
24hr	200	899.0	1.798	0.207	1.087
48hr	400	918.5	1.837	0.212	1.082



**Stress vs strain result at the maximum standard load of 200kPa and at its in-situ density**

**Oedometer test result at the actual load of 105kp and at its in-situ density**

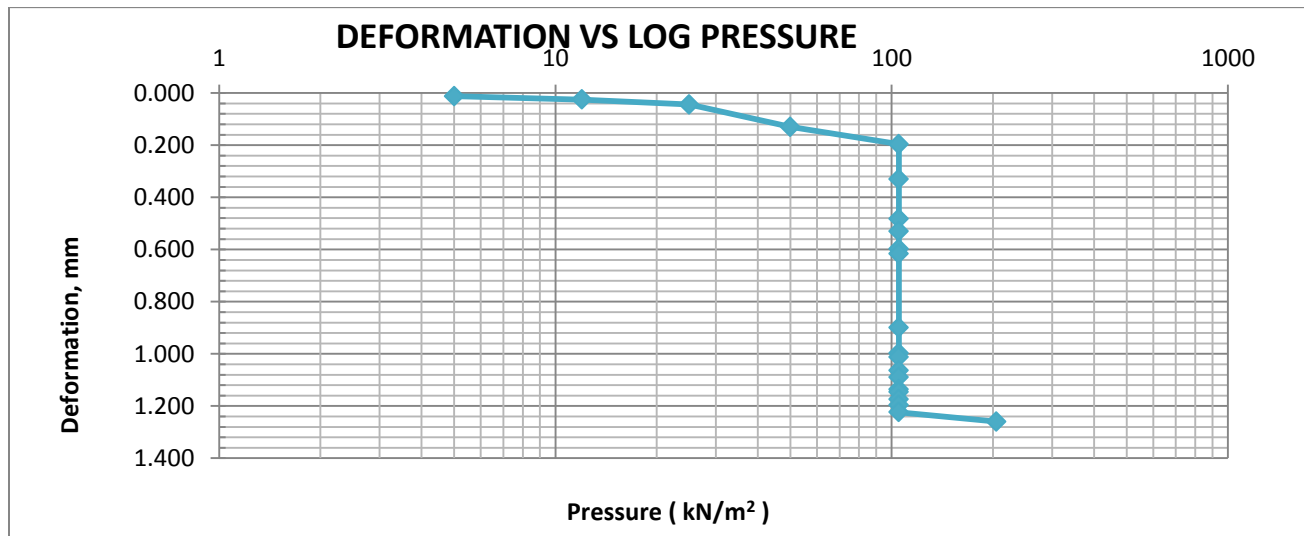
Specific Gravity	2.66	Overall settlement	1.224	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	17.1542	Volume Change	2.42	Thickness of sample	20
$V_{vi} = V_t - V_s$	22.12	Final volume	36.85	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.28924	Final bulk density	1.615	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	21.2513	Final Dry Density	1.22		
Volume change factor=F	0.11536	Final void ratio	1.15		
		$V_{vf} = V_{tf} - V_s$	19.69		
		Final saturation $S_f$ , %	73.96		

<b>Before Inundation</b>	
Moisture Content (%)	10.30
Mass of Ring+Wet. Soil(g)	119.50
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	128.68
Wet. Of wet Soil	59.51
<b>Moisture Content After inundation</b>	
Mass of Can	30.16
Mass of can+Wet Soil	89.40
Mass of can+Dry Soil	74.90
Moisture Content After inundation	32.41
Bulk Density	1.28
In-situ Dry density	1.16

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.012
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 105KPa after wetting ,mm	1.224
d <sub>i</sub> , dial reading at 105KPa before wetting, mm	0.330
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	4.47

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
0sec	5	6.0	0.012	0.001	1.289
5sec	12	12.5	0.025	0.003	1.286
1hr	25	22.0	0.044	0.005	1.284
2hr	50	65.0	0.130	0.015	1.274
3hr	105	98.0	0.196	0.023	1.267
4hr	105	165.0	0.330	0.038	1.251
0.1min	105	241.0	0.482	0.056	1.234
0.25min	105	265.0	0.530	0.061	1.228
0.5min	105	299.0	0.598	0.069	1.220
1min	105	308.0	0.616	0.071	1.218
2min	105	450.0	0.900	0.104	1.185
4min	105	499.0	0.998	0.115	1.174
8min	105	506.0	1.012	0.117	1.172
15min	105	532.0	1.064	0.123	1.166
30min	105	545.0	1.090	0.126	1.164
1hr	105	568.0	1.136	0.131	1.158
2hr	105	573.0	1.146	0.132	1.157
4hr	105	587.0	1.174	0.135	1.154
8hr	105	598.0	1.196	0.138	1.151
24hr	105	612.0	1.224	0.141	1.148
48hr	205	630.0	1.260	0.145	1.144



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**

**Oedometer test result at the maximum standard load of 200kp and at maximum dry density**

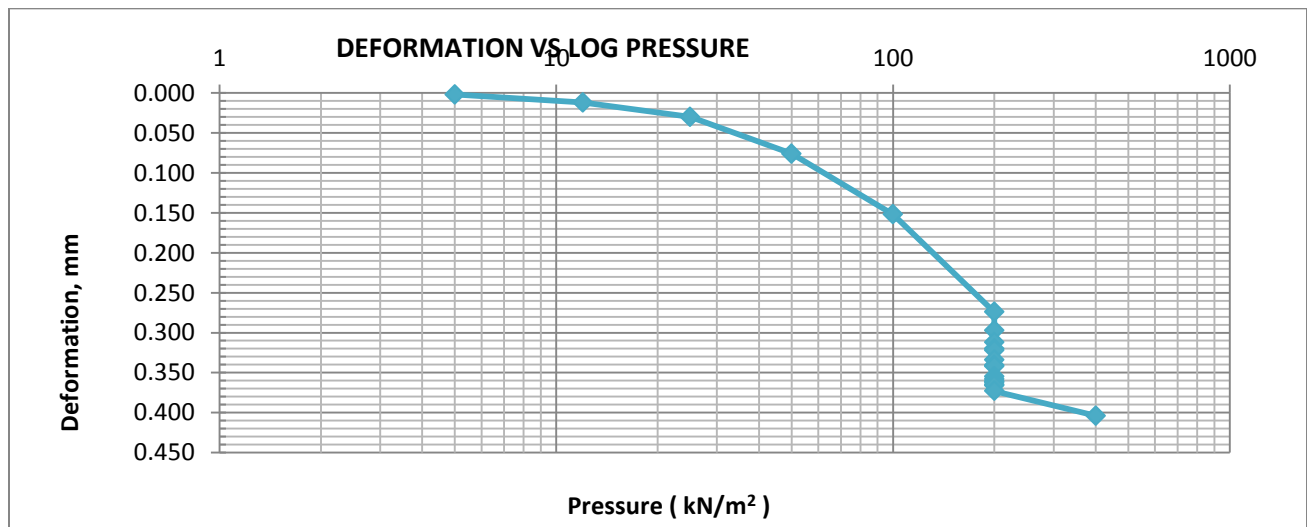
Specific Gravity	2.66	Overall settlement	0.373	Diameter of sample	50
$V_s = DD/G_s * V_t (\text{cm}^3)$	25.8321	Volume Change	0.75	Thickness of sample	20
$V_{vi} = V_t - V_s$	13.44	Final volume	38.52	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.5202	Final bulk density	2.190	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	80.7915	Final Dry Density	1.86		
Volume change factor=F	0.07805	Final void ratio	0.49		
		$V_{vf} = V_{tf} - V_s$	12.69		
		Final saturation $S_f$ , %	99.05		

<b>Before Inundation</b>	
Moisture Content (%)	15.80
Mass of Ring+Wet. Soil(g)	148.20
Mass of Ring(g)	68.63
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	153
Wet. Of wet Soil	84.37
<b>Moisture Content After inundation</b>	
Mass of Can	29.50
Mass of can+Wet Soil	107.03
Mass of can+Dry Soil	93.10
Moisture Content After inundation	17.50
Bulk Density	2.03
AT MDD (Max. Dry Density) gr/cc	<b>1.75</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.002
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 200KPa after wetting ,mm	0.373
d <sub>i</sub> , dial reading at 200KPa before wetting, mm	0.274
collapse Index $I_e = ((d_f - d_i)/h_o) * 100$	0.495

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	1.0	0.002	0.000	0.520
1hr	12	6.0	0.012	0.001	0.519
2hr	25	15.0	0.030	0.002	0.518
3hr	50	38.0	0.076	0.006	0.514
4hr	100	76.0	0.152	0.012	0.508
5hr	200	137.0	0.274	0.021	0.499
0.1min	200	148.5	0.297	0.023	0.497
0.25min	200	156.0	0.312	0.024	0.496
0.5min	200	160.0	0.320	0.025	0.495
1min	200	161.0	0.322	0.025	0.495
2min	200	167.0	0.334	0.026	0.494
4min	200	170.5	0.341	0.027	0.494
8min	200	171.0	0.342	0.027	0.494
15min	200	177.5	0.355	0.028	0.492
30min	200	179.0	0.358	0.028	0.492
1hr	200	180.5	0.361	0.028	0.492
2hr	200	181.0	0.362	0.028	0.492
4hr	200	182.5	0.365	0.028	0.492
8hr	200	183.0	0.366	0.029	0.492
24hr	200	186.5	0.373	0.029	0.491
48hr	400	202.0	0.404	0.032	0.489



**Stress vs strain result at the maximum standard load of 200kPa and at maximum dry density**

**Oedometer test result at the actual load of 105kPa and at its maximum dry density**

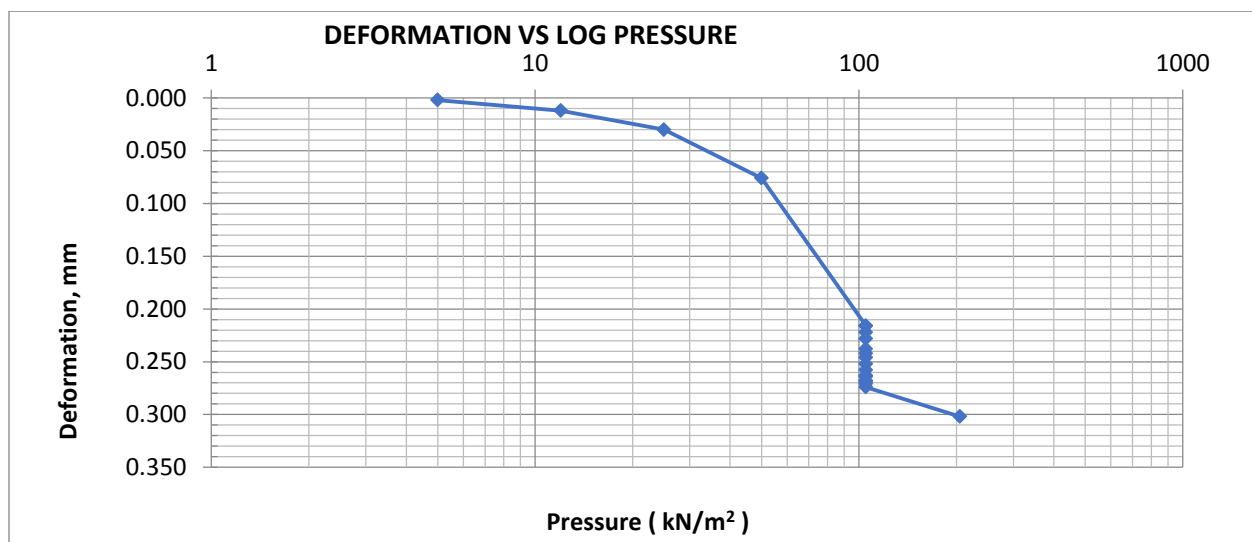
Specific Gravity	2.66	Overall settlement	0.274	Diameter of sample	50
$V_s = DD/G_s \cdot V_t (\text{cm}^3)$	26.0561	Volume Change	0.56	Thickness of sample	20
$V_{vi} = V_t - V_s$	13.21	Final volume	38.71	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.50713	Final bulk density	2.202	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	82.8735	Final Dry Density	1.88		
Volume change factor=F	0.07812	Final void ratio	0.49		
		$V_{vf} = V_{tf} - V_s$	12.66		
		Final saturation $S_f$ , %	98.97		

<b>Before Inundation</b>	
Moisture Content (%)	15.80
Mass of Ring+Wet. Soil(g)	148.10
Mass of Ring(g)	67.84
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	153.1
Wet. Of wet Soil	85.26
<b>Moisture Content After inundation</b>	
Mass of Can	42.96
Mass of can+Wet Soil	118.65
Mass of can+Dry Soil	107.53
Moisture Content After inundation	17.22
Bulk Density	2.04
AT MDD (Max. Dry Density) gr/cc	<b>1.76</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
do, dial reading at seating stress, mm	0.002
ho, initial specimen height, mm	20
df, dial reading at 105KPa after wetting ,mm	0.274
di, dial reading at 105KPa before wetting, mm	0.216
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	0.29

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	1.0	0.002	0.000	0.507
1hr	12	6.0	0.012	0.001	0.506
2hr	25	15.0	0.030	0.002	0.505
3hr	50	38.0	0.076	0.006	0.501
4hr	105	108.0	0.216	0.017	0.490
5hr	105	108.0	0.216	0.017	0.490
0.1min	105	111.0	0.222	0.017	0.490
0.25min	105	114.0	0.228	0.018	0.489
0.5min	105	119.0	0.238	0.019	0.489
1min	105	121.0	0.242	0.019	0.488
2min	105	123.0	0.246	0.019	0.488
4min	105	126.0	0.252	0.020	0.487
8min	105	129.0	0.258	0.020	0.487
15min	105	131.5	0.263	0.021	0.487
30min	105	132.0	0.264	0.021	0.487
1hr	105	132.0	0.264	0.021	0.487
2hr	105	134.0	0.268	0.021	0.486
4hr	105	134.5	0.269	0.021	0.486
8hr	105	135.5	0.271	0.021	0.486
24hr	105	137.0	0.274	0.021	0.486
48hr	205	151.0	0.302	0.024	0.484



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**

**For station 60+030 sample 2**

**Oedometer test result at the maximum standard load of 200kp and at its in-situ density**

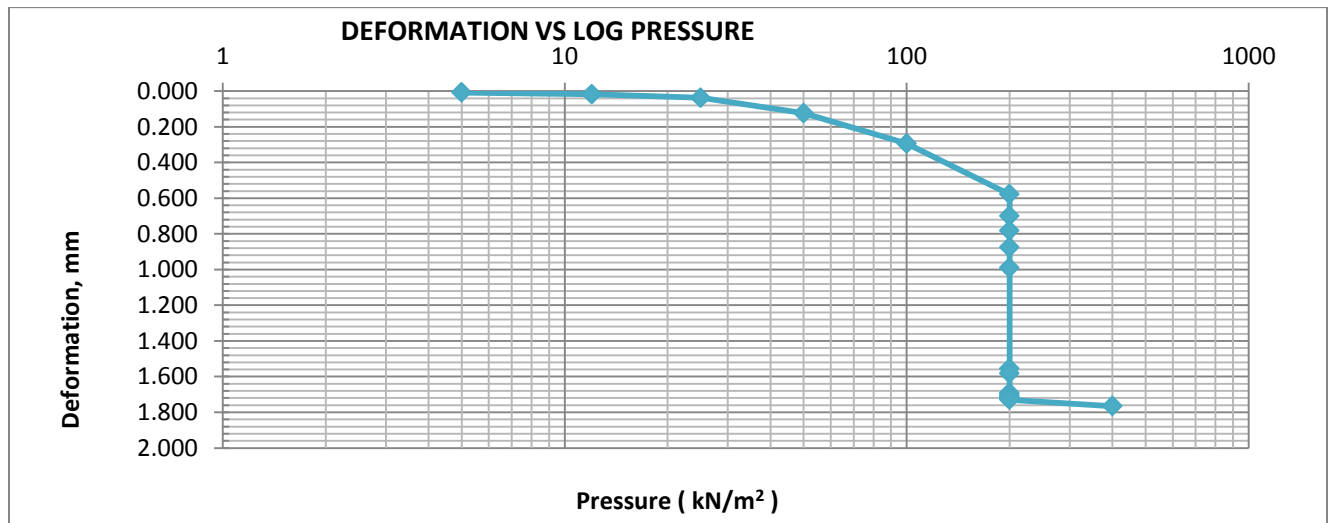
Specific Gravity	2.66	Overall settlement	1.730	Diameter of sample	50
$V_s = DD/G_s \cdot V_t (\text{cm}^3)$	17.8358	Volume Change	3.42	Thickness of sample	20
$V_{vi} = V_t - V_s$	21.43	Final volume	35.85	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.20175	Final bulk density	1.671	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	22.7985	Final Dry Density	1.26		
Volume change factor=F	0.11068	Final void ratio	1.01		
		$V_{vf} = V_{tf} - V_s$	18.02		
		Final saturation $S_f$ , %	81.58		

<b>Before Inundation</b>	
Moisture Content (%)	10.30
Mass of Ring+Wet. Soil(g)	121.50
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	129.1
Wet. Of wet Soil	59.93
<b>Moisture Content After inundation</b>	
Mass of Can	30.16
Mass of can+Wet Soil	90.50
Mass of can+Dry Soil	75.70
Moisture Content After inundation	32.50
Bulk Density	1.33
In-situ Dry density	1.21

<b>Collapse Index, I<sub>e</sub> Computation</b>	
do, dial reading at seating stress, mm	0.008
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 200KPa after wetting ,mm	1.730
d <sub>i</sub> , dial reading at 200KPa before wetting, mm	0.578
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	5.76

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F * \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	4.0	0.008	0.001	1.202
1hr	12	9.0	0.018	0.002	1.200
2hr	25	19.0	0.038	0.004	1.198
3hr	50	62.0	0.124	0.014	1.188
4hr	100	147.0	0.294	0.033	1.169
5hr	200	289.0	0.578	0.064	1.138
0.1min	200	349.5	0.699	0.077	1.124
0.25min	200	391.0	0.782	0.087	1.115
0.5min	200	438.0	0.876	0.097	1.105
1min	200	495.0	0.990	0.110	1.092
2min	200	778.0	1.556	0.172	1.030
4min	200	791.0	1.582	0.175	1.027
8min	200	846.0	1.692	0.187	1.014
15min	200	849.0	1.698	0.188	1.014
30min	200	854.0	1.708	0.189	1.013
1hr	200	857.0	1.714	0.190	1.012
2hr	200	859.0	1.718	0.190	1.012
4hr	200	860.5	1.721	0.190	1.011
8hr	200	863.0	1.726	0.191	1.011
24hr	200	865.0	1.730	0.191	1.010
48hr	400	882.5	1.765	0.195	1.006



**Stress vs strain result at the maximum standard load of 200kPa and at its in-situ density**

**Oedometer test result at the actual load of 105kPa and at its in-situ density**

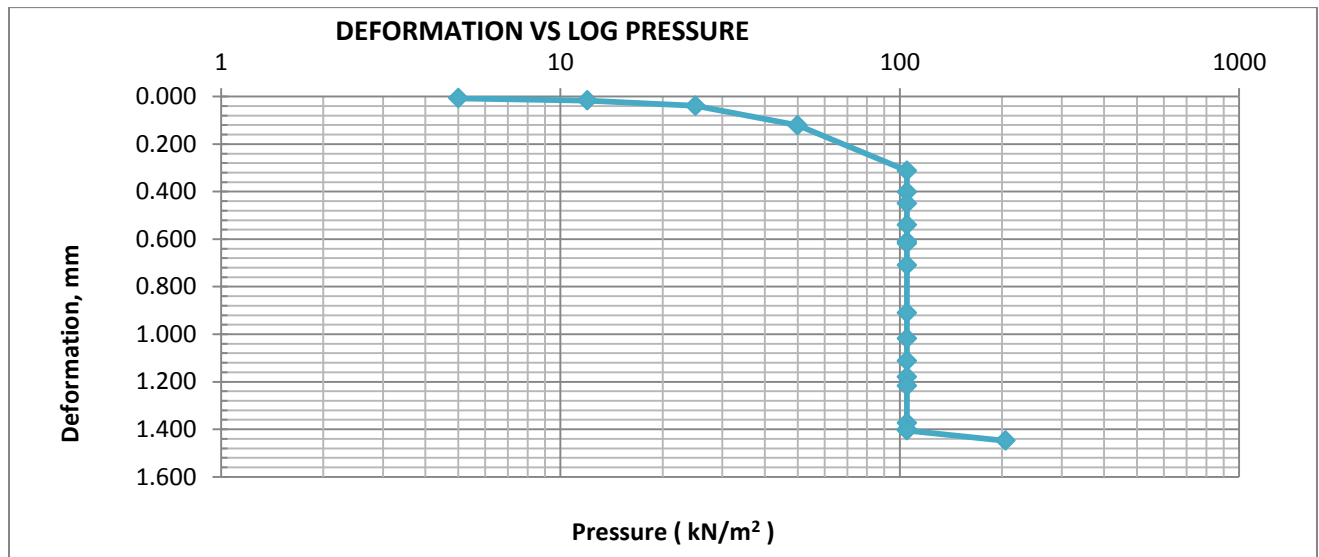
Specific Gravity	2.66	Overall settlement	1.405	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	17.8358	Volume Change	2.78	Thickness of sample	20
$V_{vi} = V_t - V_s$	21.43	Final volume	36.49	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	1.20175	Final bulk density	1.643	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	22.7985	Final Dry Density	1.24		
Volume change factor=F	0.11083	Final void ratio	1.05		
		$V_{vf} = V_{tf} - V_s$	18.66		
		Final saturation $S_f$ , %	78.83		

<b>Before Inundation</b>	
Moisture Content (%)	10.30
Mass of Ring+Wet. Soil(g)	121.50
Mass of Ring(g)	69.17
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	129.13
Wet. Of wet Soil	59.96
<b>Moisture Content After inundation</b>	
Mass of Can	30.16
Mass of can+Wet Soil	90.50
Mass of can+Dry Soil	75.70
Moisture Content After inundation	32.50
Bulk Density	1.33
In-situ Dry density	1.21

<b>Collapse Index, I<sub>e</sub> Computation</b>	
$d_o$ , dial reading at seating stress, mm	0.007
$h_o$ , initial specimen height, mm	20
$d_f$ , dial reading at 105KPa after wetting ,mm	1.405
$d_i$ , dial reading at 105KPa before wetting, mm	0.402
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	5.015

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, KPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
0sec	5	3.5	0.007	0.001	1.202
5sec	12	8.5	0.017	0.002	1.200
1hr	25	19.5	0.039	0.004	1.197
2hr	50	60.5	0.121	0.013	1.188
3hr	105	156.0	0.312	0.035	1.167
4hr	105	201.0	0.402	0.045	1.157
0.1min	105	225.0	0.450	0.050	1.152
0.25min	105	270.0	0.540	0.060	1.142
0.5min	105	305.0	0.610	0.068	1.134
1min	105	309.0	0.618	0.068	1.133
2min	105	355.0	0.710	0.079	1.123
4min	105	455.0	0.910	0.101	1.101
8min	105	509.0	1.018	0.113	1.089
15min	105	556.0	1.112	0.123	1.079
30min	105	590.0	1.180	0.131	1.071
1hr	105	609.0	1.218	0.135	1.067
2hr	105	687.0	1.374	0.152	1.049
4hr	105	701.0	1.402	0.155	1.046
8hr	105	701.5	1.403	0.155	1.046
24hr	105	702.5	1.405	0.156	1.046
48hr	205	724.0	1.448	0.160	1.041



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**

**Oedometer test result at the maximum standard load of 200kp and at maximum dry density**

Specific Gravity	2.66	Overall settlement	0.366	Diameter of sample	50
$V_s = DD/G_s \cdot V_t$ (cm <sup>3</sup> )	25.9295	Volume Change	0.74	Thickness of sample	20
$V_{vi} = V_t - V_s$	13.34	Final volume	38.53	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.51449	Final bulk density	2.195	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	81.6881	Final Dry Density	1.87		
Volume change factor=F	0.07779	Final void ratio	0.49		
		$V_{vf} = V_{tf} - V_s$	12.60		
		Final saturation $S_f$ , %	99.95		

<b>Before Inundation</b>	
Moisture Content(%)	15.80
Mass of Ring+Wet. Soil(g)	148.50
Mass of Ring(g)	68.63
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	153.2
Wet. Of wet Soil	84.57
<b>Moisture Content After inundation</b>	
Mass of Can	29.50
Mass of can+Wet Soil	107.03
Mass of can+Dry Soil	93.10
Moisture Content After inundation	17.50
Bulk Density	2.0
AT MDD (Max. Dry Density) gr/cc	<b>1.8</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
d <sub>o</sub> , dial reading at seating stress, mm	0.002
h <sub>o</sub> , initial specimen height, mm	20
d <sub>f</sub> , dial reading at 200KPa after wetting ,mm	0.366
d <sub>i</sub> , dial reading at 200KPa before wetting, mm	0.276
collapse Index $I_e = ((d_f - d_i)/h_o) \cdot 100$	0.45



**Oedometer test result at the actual load of 105kPa and at its maximum dry density**

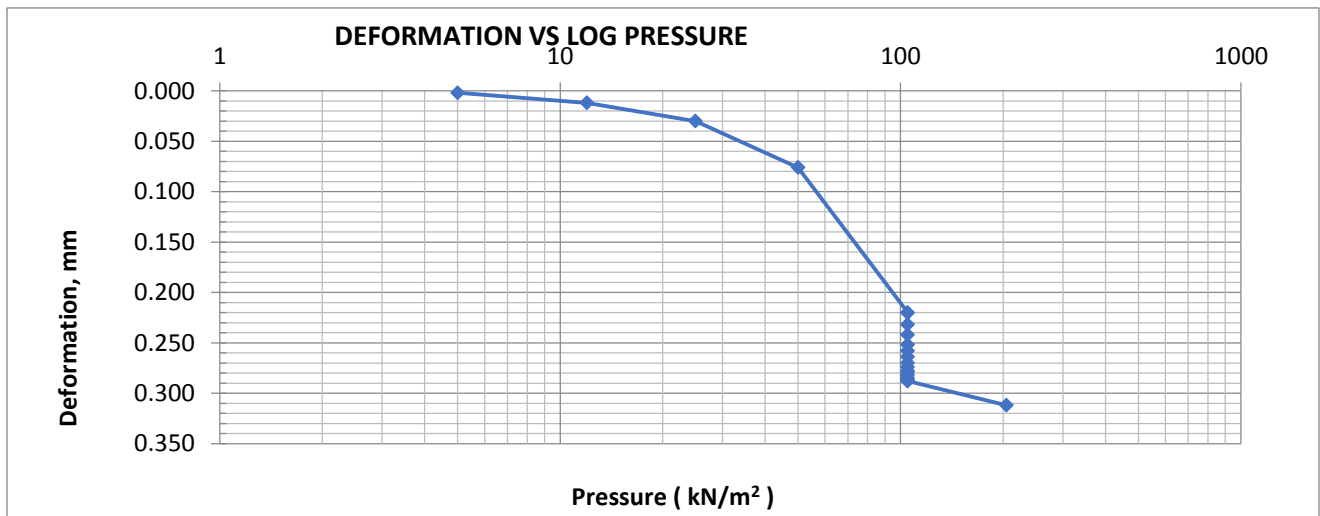
Specific Gravity	2.66	Overall settlement	0.288	Diameter of sample	50
$V_s = DD/G_s * V_t (cm^3)$	26.0236	Volume Change	0.59	Thickness of sample	20
$V_{vi} = V_t - V_s$	13.25	Final volume	38.68	Area of sample	1962.50
initial Void ratio $e_0 = V_v/V_s$	0.50901	Final bulk density	2.186	Volume of Sample	39.27
initial $S_o = V_w/V_{vi}$	82.5674	Final Dry Density	1.86		
Volume change factor= $F$	0.07808	Final void ratio	0.49		
		$V_{vf} = V_{tf} - V_s$	12.66		
		Final saturation $S_f, \%$	98.87		

<b>Before Inundation</b>	
Moisture Content (%)	15.80
Mass of Ring+Wet. Soil(g)	148.00
Mass of Ring(g)	67.84
<b>After Inundation</b>	
Mass of Ring+Wet. Soil(g)	152.4
Wet. Of wet Soil	84.56
<b>Moisture Content After inundation</b>	
Mass of Can	42.96
Mass of can+Wet Soil	118.75
Mass of can+Dry Soil	107.53
Moisture Content After inundation	17.38
Bulk Density	2.0
AT MDD (Max. Dry Density) gr/cc	<b>1.8</b>

<b>Collapse Index, I<sub>e</sub> Computation</b>	
do, dial reading at seating stress, mm	0.002
ho, initial specimen height, mm	20
d <sub>f</sub> , dial reading at 105KPa after wetting ,mm	0.288
d <sub>i</sub> , dial reading at 105KPa before wetting, mm	0.220
collapse Index $I_e = ((d_f - d_i)/h_o) * 100$	0.34

*Study the Physical Characteristics and Severity to Collapse of Collapsible Soils: A Case of Turmi – Omo Road Project)*

Elapsed Time in (Sec,Min,Hr)	Applied Stress, kPa	Dial Reading, mm	Cumulative Compression, mm	Void Ratio $\Delta e = F \cdot \Delta H$	$e_1 = e_0 - \Delta e$
5min	5	1.0	0.002	0.000	0.509
1hr	12	6.0	0.012	0.001	0.508
2hr	25	15.0	0.030	0.002	0.507
3hr	50	38.0	0.076	0.006	0.503
4hr	105	110.0	0.220	0.017	0.492
5hr	105	110.0	0.220	0.017	0.492
0.1min	105	116.0	0.232	0.018	0.491
0.25min	105	121.0	0.242	0.019	0.490
0.5min	105	126.0	0.252	0.020	0.489
1min	105	129.0	0.258	0.020	0.489
2min	105	132.0	0.264	0.021	0.488
4min	105	135.0	0.270	0.021	0.488
8min	105	137.0	0.274	0.021	0.488
15min	105	139.0	0.278	0.022	0.487
30min	105	139.5	0.279	0.022	0.487
1hr	105	141.0	0.282	0.022	0.487
2hr	105	142.5	0.285	0.022	0.487
4hr	105	143.5	0.287	0.022	0.487
8hr	105	143.5	0.287	0.022	0.487
24hr	105	144.0	0.288	0.022	0.487
48hr	205	156.0	0.312	0.024	0.485



**Stress vs strain result at the actual load of 105kPa and at its maximum dry density**