ADDISS ABEBA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Relationships between Plastic Index with Linear, Volumetric Shrinkage for Tendaho Road Project

A project paper Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters in Geotechnical Engineering

By

Tesfaye Mebratu Belay

March,2019

tmebratu321@gmail.com

APPROVAL SHEET

Addis Ababa Institute of Technology Faculty of
Civil and Environmental Engineering
Department of Civil Engineering

Relationships between plastic index with Linear, volumetric shrinkage for Tendaho road project

By: Tesfaye Mebratu Belay

Dr.Ing. Samuel Tadesse	_______________	___________
Advisor	Signature	Date
Dr.Ing. Henok Fikre	______________	__________
Internal Examiner	Signature	Date

DECLARATION

I, the undersigned, declare that this Project is my own original work. In compliance with internationally accepted practices, I have duly acknowledged and referenced all materials used in this work.

Tesfaye Mebratu Belay

Signature: _________

Date: ___________

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to the Almighty God who is always in favor of me. I would like to thank my advisor Dr. Ing Samuel Tadesse for his guidance and wealth of knowledge, which has contributed immensely towards my research work.

I would also like to express my sincere appreciation to Ethiopian Construction Supervision Works Corporation Geotechnical Department Staffs, who allowed me to use data for this study and for helping me out in every possible manner whenever I needed assistance. Importantly, I am forever indebted to my family and friends for their constant encouragement, endless patience and support throughout my educational life.

Table of Contents

List of Figures

List of Tables

ABBREVIATION

AASHTO	American Association of State Highway and Transportation Officials
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
ASTM	American Society for Testing and Materials
LS	Linear shrinkage
VS	Volumetric shrinkage
Ws	shrinkage limit
W	moisture content
R	Shrinkage ratio
BS	British Standard
CH	Inorganic clays of high plasticity
MH	Inorganic silts of high plasticity
CL	Inorganic clays of low plasticity
ML	Inorganic silts of low plasticity

ABSTRACT:

Currently there is a belief within the geotechnical Engineering Profession that there is not strong form of correlation between plastic index with linear, volumetric shrinkages properties for a soil [16]. This project would concentrate on soils from one particular road project which is known as tendaho access road. The soils in tendaho have been predominately consist of clays, silts, sands and gravels. The analysis to determine if there is a relationship between plastic index with volumetric shrinkage, plastic index with linear shrinkage results was undertaken using a sampling and testing program for 29 soils that had different characteristics. The soils that were tested all originated from Pliocene-Pleistocene volcanic rocks and associated fluvio-lacustrinesediments. this formation and are located in in Afar depression 580 kms North-East of the capital Addis Ababa, within the lower delta of Awash basin. The soils that were tested ranged from silts with sands and extended through to moderatly reactive clays. All these samples were subjected to the same testing program and included atterberg limits, linear shrinkage, volumetric shrinkage, free swell and particle size distribution. Upon completion of the testing program the volumetric and linear shrinkage results were plotted against the plastic index. This data was then graphed and the strongest trendline was fitted to it and the corresponding equation calculated. For a correlation to be considered a useful estimating tool the strength of this relationship must exceed R^2 =0.80[14]. There were three correlations which met the requirement of $R^2 > 0.8$.The equations for these correlations could be used to estimate the plastic index from linear, volumetric shrinkage of a soil.

Key word: volumetric shrinkage , linear shrinkage , plastic index,

1. INTRODUCTION

1.1 GENERAL

Proper Geotechnical investigation is an essential requirement to the design and construction of civil engineering projects. The proper design of civil engineering structures like foundation of buildings, retaining walls, high ways, etc. requires adequate knowledge of sub surface conditions at the sites of the structures. Many damages to buildings, roads and other structures founded on soils are mainly due to the lack of proper investigation of substructure condition.

The soil behavior is very challenging because it is such a unique material that shows different properties even with in short distance. Due to continuous interaction with soil throughout the history, many methods have been developed to comprehend its behavior. However, it still comprises many unknowns so, many people have been researching and analyzing this material continuously to understand. The key tools to predict the behavior of soils can be described as geotechnical parameters which allow the engineers to define the engineering properties of soils have been determined from empirical correlations have been established in order to estimate the geotechnical parameters of soil.

Generally believed that shrinkage correlate with plasticity and, in addition to the soil fabric, they depend on the same soil characteristics, such as mineralogical composition, particle size distribution, and type of adsorbed cations. It is also believed that there is a relationship between shrinkage, which has led to several classifications of clay soils where shrinkage parameters such as shrinkage limit, linear shrinkage and volumetric shrinkage are used as criteria.[1]

1.2 STATEMENT OF THE PROBLEM

Plastic index is determined using casagrande or cone penetrometer apparatus in laboratory and it possible conduct test in field but due to un availability of material including mercury as well as time taken to conduct a test both linear and volumetric shrinkage test need time and also very sensitive test so difficult to conduct test on field correlation of shrinkage limit with plastic index use to minimize cost and time .

1.3. IMPORTANCE

The topographical nature of tendaho road project are subjected to high temperature which affected by shrinkage [12]. Due to the unavailability of equipment and also financial and time limitations in a project, in many cases various types of relationships are important to estimate the geotechnical parameters using the values that are extracted from laboratory testing. These important indicating parameters are natural moisture content and Atterberge limits, grain size analysis with linear and volumetric shrinkage.

1.4 OBJECTIVE

The objectives of this project is to assist in providing an alternative method to calculate numerical value of of linear, volumetric shrinkage value from plastic index value and determine effect of plastic index on shrinkage limit property soil located within the top 3 meters of the surface in tendaho acess road project finally examine the validity of the correlation with previous study and give conclusion.

1.5 SCOPE OF THE PROJECT

The scope of this project is to develop relationship between plastic index test value with linear volumetric test value in laboratory. It is also the attention of this study to see the difference of the newly relation with the existing ones.

2.0 LITERATURE REVIEW

The origin of soils is related to a complex combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, will shrink. The conditions and processes which determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected.[1]

According to Kumar (2008) the major issue in geotechnical practice is to predict after-consolidation shrinkage settlements of expansive soils. The author proposed a general formula to evaluate volumetric shrinkage in relation to field moisture content changes but suggested that the moisture content should be considered jointly with the ‘‘material’’ properties of a soil. It is generally believed that shrinkage correlate with plasticity, they depend on the same soil characteristics.[16]

Relationship between the volumetric Shrinkage and index parameters. With respect to the problem raised by Head 1992, he develop relationship between volumetric shrinkage and plastic index for natural clay soils which commonly form the founding material for construction in Poland were used in this investigation: glacial tills (14 samples), alluvial clay soils (4 samples) and Mio-Pliocene clays (16 samples). Soil Plotted on the plasticity chart shows both glacial tills and alluvial soils proved to be clays of low and medium plasticity (CL, CM). The Mio-Pliocene soils fell into several categories: most of the samples being clays of high to extremely high plasticity with three samples falling below the A-line and classified as silts of high to extremely high plasticity (MH). with R^2=0.899 [16]

$$Vs=0.67PI+3.956. \ldots\ldots\ldots\ldots\text{eq 2.2}$$

As far as correlations with plastic index parameters are concerned, the 1967 edition of BS1377 (BSI, 1967) gave the following relationship between plasticity index (PI) and linear shrinkage (LS) for silt and clays soil [9]

$$.PI=2.13Ls\ldots\ldots\ldots\ldots\text{eq 2.3}$$

2.1 LABORATORY TESTING METHODS

2.1.1 Moisture in Soils

General principles

Naturally occurring soils nearly always contain water as part of their structure. The moisture content of a soil is assumed to be the amount of water within the pore space between the soil grains that is removable by oven drying at 105-l 10°C, expressed as a percentage of the mass of dry soil. By dry is meant the result of oven drying at that temperature to constant mass, usually for a period of about 12-24h. In non-cohesive granular soils this procedure removes all water present. There are several ways in which water is held in cohesive soils, which contain clay minerals existing as plate-like particles of less than 2 µm across. The shape and very small size of these particles, together with their chemical composition, enables them to combine with or hold onto water by several complex means. A simplified illustration of the zones of water surrounding a clay particle is obtained by considering the following five categories of water, indicated diagrammatically in Figure 1.

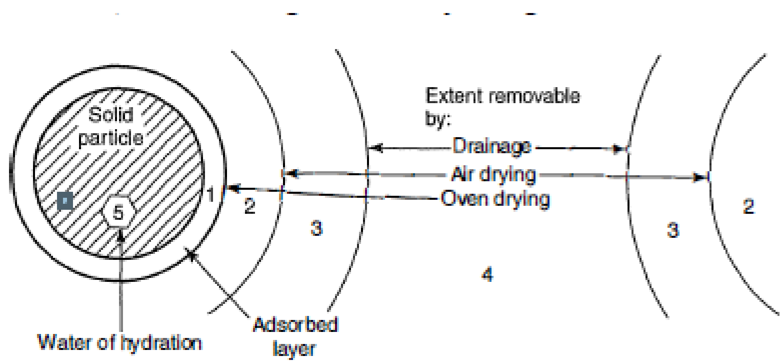


Figure 2. 1 Representation of categories of water surrounding clay particles

1. Adsorbed water held on the surface of the particle by powerful forces of electrical attraction and virtually in a solid state. This layer is of very small thickness, perhaps of the order of 0.005 µm. This water cannot be removed by oven drying at 110°C, and may, therefore, be considered to be part of the solid soil grain.

2. Water which is not so tightly held and can be removed by oven drying, but not by air drying (hygroscopic moisture).
3. Capillary water, held by surface tension, generally removable by air drying.
4. Gravitational water, which can move in the voids between soil grains and is removable by drainage.
5. Chemically combined water, in the form of water of hydration within the crystal structure. Except for gypsum and some tropical clays, this water is not generally removable by oven drying. For the purpose of routine soil testing, moisture content relates only to the water that is removable by oven drying at 105 -110°C. The water of category 1 above is not taken into account in the determination of moisture content and will not be referred to again in that context. The possible presence of water of category 5 is one reason for avoiding oven drying of tropical soils Moisture content is usually expressed as a percentage, always on the basis of the oven-dry mass of soil. If the mass of water removed by drying at 105°C is denoted by mw, and the mass of dried soil by m_0, the moisture content, w, is given by the equation:[2]

$$w(\%) = \frac{m_w}{m_D} \times 100$$

…………….eq 2.4

Laboratory determination of moisture content

Equipment:

- Drying oven
- Balance
- Moisture can
- Gloves
- Spatula.

Test Procedure:

- Record the moisture can and lid number. Determine and record themass ofan empty, clean, and dry moisture can with its lid (MC)
- Place the moist soil in the moisture can and secure the lid.Determine and record the mass of the moisture can (now containing the moist soil) with the lid (MCMS).
- Remove the lid and place the moisture can (containing the moistsoil) in the drying oven that is set at 105 °C. Leave it in the oven overnight.
- Remove the moisture can. Carefully but securely, replace the lid onthe moisture can using gloves, and allow it to cool to room temperature. Determine and record the mass of the moisture can and lid (containing the dry soil) (MCDS).
- Empty the moisture can and clean the can and lid.

Data Analysis:

- Determine the mass of soil solids.
- *MS = MCDS –MSC……….eq 2.5*
- Determine the mass of pore water.
- *MW = MCMS –MCDS……..eq2.6*
- Determine the water content.

$$w = \frac{Mw}{Ms} x100$$

………eq2.7

Test result of project

Due to The climatic condition of tendaho road project is hot so the moisture content was low

2.1.2 The Atterberg Limits

The condition of a clay soil can be altered by changing the moisture content; the softening of clay by the addition of water is a well-known example. For every clay soil there is a range of moisture contents within which the clay is of a plastic consistency, and the Atterberg limits provide a means of measuring and describing the plasticity range in numerical terms. If sufficient water is mixed with a clay it can be made into a slurry, which behaves as a viscous liquid. This is known as the liquid state. If the moisture content is gradually reduced by allowing it to dry out slowly, the clay eventually begins to hold together and to offer some resistance to deformation; this is the plastic state. With further loss of water the clay shrinks and the stiffness increases until there is little plasticity left, and the clay becomes brittle; this is the semi-solid state. As drying continues, the clay continues to shrink in proportion to the amount of water lost, until it reaches the minimum volume attainable by this process. Beyond that point further drying results in no further decrease in volume, and this is called the 'solid' state. The change from one phase to the next is not observable as a precise boundary, but takes place as a gradual transition. Nevertheless three arbitrary but specific boundaries have been established empirically, and are universally recognized. The moisture contents at these boundaries are known collectively as the Atterberg limits or consistency limits.

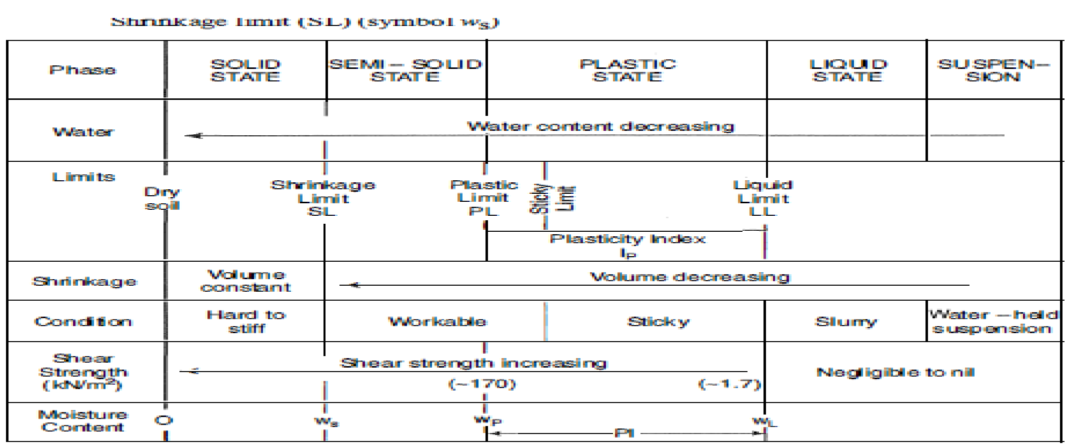


Figure 2. 2 Phases of soil and the Atterberg limits

The moisture content range between the PL and LL is known as the plasticity index (Pl) (symbol Ip), and is a measure of the plasticity of the clay. Cohesion less soils have no plasticity phase, so their PI is zero. The tests to determine the Atterberg limits are carried out only on the fraction of soil that passes a 425 µm sieve. For soils that contain particles coarser than that size, the particles retained on the 425 µm sieve must be removed as part of the sample preparation procedure.

2.1.2.1 Liquid limit - Cone penetrometer method (BS 1377: Part 2: 1990: 4.3)

This is the British Standard definitive method for determining the liquid limit of soils. It is based on the measurement of penetration into the soil of a standardized cone of specified mass. At the liquid limit the cone penetration is 20 mm. The method was Developed at TRL from various cone tests that have been in use in other countries and was adopted by the BSI with a few modifications. It requires the same apparatus as is used for bituminous materials testing, (BS 2000: Part 49), but fitted with a special cone.

Apparatus

- Penetrometer apparatus complying with the requirements of BS 2000: Part 49, and illustrated.
- Cone for the penetrometer the main features being:
  - (a) stainless steel or duralumin
  - (b) smooth, polished surface
  - (c) length approximately 35 mm
  - (d) cone angle 30°
  - (e) sharp point
  - (f) mass of cone and sliding shaft 80 ± 0.1 g
- Sharpness gauge for cone, consisting of a small steel plate 1. 7 5 ± 0 .1 mm thick with a 1.5 mm ± 0.02 mm diameter hole accurately drilled and reamed.
- Flat glass plate, about 500 mm square and 10 mm thick, with bevelled edges and rounded comers.

- Metal cups, of brass or aluminum alloy, 55 m diameter and 40 mm deep. The rim must be parallel to the base, which must be flat.
- Wash bottle containing distilled or de-ionised water.
- Metal straight-edge, about 100 mm long.
- Palette knives or spatulas:
  (a) two 200 mm long x 30 mm
  (b) one 150 mm long x 25 mm
  (c) one 100 mm long x 20 mm
  (d) one square-ended, 150 mm long x 25 mm (preferably of rubber or plastics)
- Moisture content apparatus

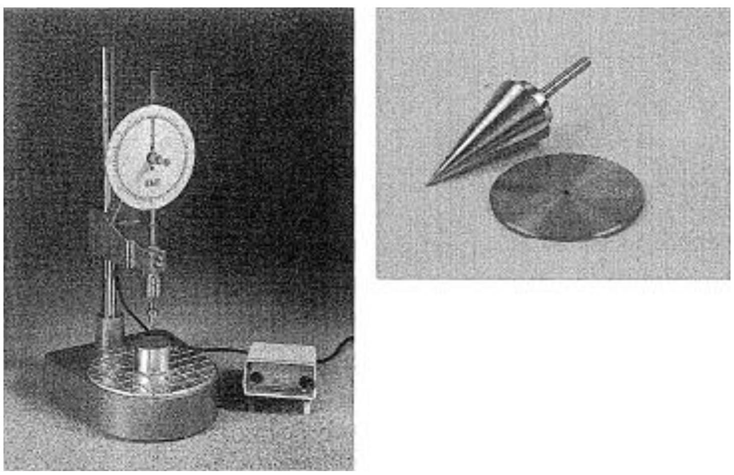


Figure 2. 3 Apparatus for cone penetrometer liquid test:

(a) Cone penetrometer with *automatic timing device, (b) cone and gauge plate*

Test Procedure

- Selection and preparation of sample

  Prepare and mature the test sample.Use the natural material if possible, if not use the wet preparation method. Place about 300 g of the prepared soil paste on the glass plate.If the plastic limit test is also to be done, set aside a small portion in a sealed bag or container before adding too much water while the soil is still firm

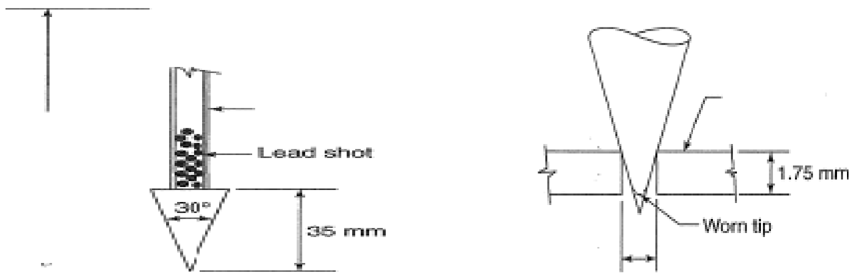


Figure 2. 4 Details of cone for penetrometer

- Checking apparatus

The cone penetrometer apparatus must comply with main points to check are:

(a) The cone designed specially for testing soils must be fitted.

(b) Mass of cone and stem 80 ± 0.1 g. This is most important. The stem is hollow, so that lead-shot can be inserted to bring the cone and stem assembly to the specified mass.

(c) Sharpness of the cone point can be checked by pushing the tip into the hole of the sharpness gauge plate. If the point cannot. be felt when brushed lightly with the tip of the finger, the cone should be replaced.

(d) The cone must fall freely when the release button is pushed, and the sliding shaft must be clean and dry.

(e) The penetration dial indicator should be calibrated by inserting gauge blocks between the stem of the indicator and the top of the sliding shaft to which the cone is fixed. Alternatively, calibrated vernier callipers could be used.

(f) The apparatus must stand on a firm level bench.

(g) If the apparatus is fitted with an automatic timing device, this should automatically lock the cone shaft assembly 5 seconds after pressing the button which releases it. This time interval should be verified against a reference timer.

- Mixing and working

Mix the soil paste on the glass plate with the spatulas for at least 10 min. Some soils, especially heavy clays, may need a longer mixing time to break down the soil structure. If necessary add more distilled or de-ionised water to give a cone penetration of about 15 mm, and mix well. It is essential to obtain a uniform distribution of water throughout the sample.Keep the soil together near the middle of the glass plate to minimise drying out due to exposure to air. Cover with a damp cloth or polythene when not mixing.

Thorough mixing and kneading is hard-work, but it is the most important feature of the Atterberg tests and must never be overlooked.

- Placing in cup
  - (a) Press the soil paste against the side of the cup, to avoid trapping air.
  - (b) Press more paste well into the bottom of the cup, without creating an air-pocket.
  - C) Fill the middle and press well down. The small spatula is convenient for these operations.
  - (d) The top surface is finally smoothed off level with the rim using the straight-edg
- Adjustment of cone

  Lock the cone and shaft unit near the upper end of its travel and lower the supporting assembly carefully.
- Adjustment of dial gauge

  Lower the stem of the dial gauge to make contact with the top of the cone shaft. Record the reading of the dial gauge to the nearest 0.1
- Measuring cone penetration

  Allow the cone to fall by pressing the button, which must be held in the pressed position for 5 s, timed with a second timer or watch. If an auto-timer is used it is necessary only to press the button and release it immediately .Automatic relocking of the stem is indicated by a click. The apparatus must remain steady and must not be jerked. After 5 s release the button so as to lock the cone in place. Lower the dial gauge stem to make contact with the top of the cone shaft, without allowing the pointer sleeve to rotate relative to the stem adjustment knob. Record the dial reading to the nearest 0.1 mm. If the pointer was initially set to read zero, the reading gives the cone penetration directly.

- Repeat penetration

  Lift out the cone and clean it carefully. Avoid touching the sliding stem. Add a little more wet soil to the cup, without entrapping air, smooth off, and repeat stages 5-7. If the second cone penetration differs from the first by not more than 0.5 mm, the average value is recorded, and the moisture content is measured.

- Moisture content measurement

  Take a moisture content sample of about 10 g from the area penetrated by the cone, using the tip of a small spatula..

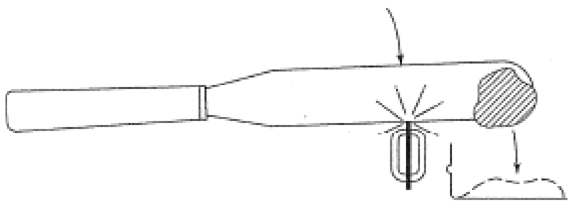


Figure 2. 5 Transferring moisture sample to container

- Remixing

  The soil remaining in the cup is remixed with the rest of the sample on the glass plate together with a little more distilled water, until a uniform softer consistency is obtained. The cup is scraped out with the square-ended spatula, wiped clean and dried, and stages4-9 are repeated at least three more times (making four in all), with further increments of distilled water. A range of penetration values from about 15 mm to 25 mm should be covered, fairly uniformly distributed.

- Calculation and plotting

  The moisture content of the soil from each penetration reading is calculated from the wet and dry weighings as in the moisture content test.

  Each cone penetration (mm) is plotted as ordinate, against the corresponding moisture content(%) as abscissa, both to linear scales, on a graph as shown in Figure 2.14, which also shows typical data. The best straight line fitting these points is drawn.

- Results

  From the graph the moisture content corresponding to a cone penetration of 20 mm is read off to the nearest 0.1 %. The result is reported to the nearest whole number as the liquid limit (cone test).The percentage of material retained on the 425 µm sieve is reported to the nearest 1 %, together with the method of sample preparation.The plastic limit and plasticity index are usually reported with the liquid limit.

2.1.2.2 Liquid limit-Casagrande method (AASHTOT89&90)

Apparatus

- Mechanical device(the Casagrande apparatus)

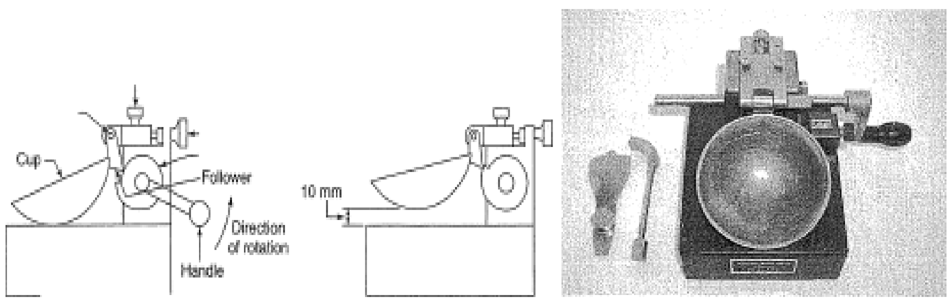


Figure 2. 6 Casagrande liquid limit apparatus and tools and detail

1. Grooving tool. It must be kept clean and dry,
2. Flat glass plate,.

3 Wash bottle containing distilled or de-ionised water.

4. Two palette lmives (spatulas), blades 200 mm long and 30 mm wide.
5. Spatula with blade about 150 mm long and 25 mm wide.
6. Moisture content apparatus

Test Procedure

- *As for the cone penetrometer test*
- *Adjustment of apparatus*

The Casagrande apparatus must be clean, and the bowl must be dry and oil-free. rhythm.

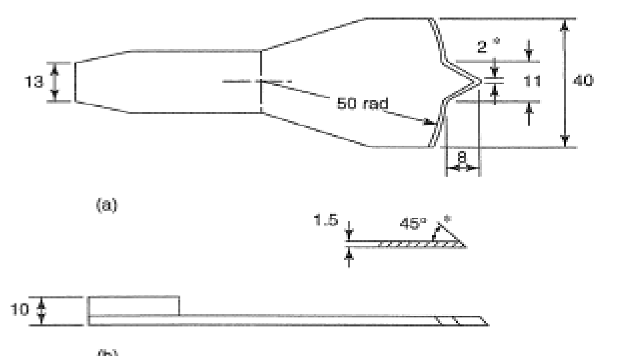


Figure 2. 7 Grooving tool for Casagrande apparatus (dimensions in mm)

- Remixing

As for the cone penetrometer test The same remarks regarding the vital importance of thorough mixing apply to this test.

- Placing in bowl

See that the bowl of the apparatus is resting on the base, and is not supported by the cam. Place a portion of the mixed soil in the cup, pressing it from the middle outwards to prevent trapping any air. The smaller spatula is best for this. The surface of the soil paste should be smoothed off level and parallel to the base, giving a depth at the greatest thickness of 10 mm

- Cutting groove

Cut a groove through the sample from back to front, dividing it into two equal halves. Starting near the hinge, draw the grooving tool from the hinge· towards the front in a continuous movement with a circular motion, keeping the tool normal to the surface of the cup .The chamfered edge of the tool faces the direction of movement. The tip should lightly scrape the inside of the bowl.

It is sometimes difficult to cut a smooth groove in soils of low plasticity without tearing the soil. Procedure recommends cutting the groove with several strokes of the grooving tool, or alternatively forming a groove with a spatula and using the tool to trim to the required dimensions. Sliding of the soil pat on the surface of the cup must be avoided, otherwise the soil will slide back again during the test, instead of flowing as it should. The curved grooving tool If a smooth groove cannot be cut with the standard tool, this fact should be recorded. If a groove is formed by any other means, the method should be reported.

- Application of blows

Tum the crank handle of the machine at a steady rate of two revolutions per second, so that the bowl is lifted and dropped. Use a seconds timer if necessary to obtain the correct speed. If a revolution counter is not fitted, count the number of bumps, counting aloud if necessary. Continue turning until the groove is closed along a distance of 13 mm. The back end of the standard grooving tool serves as a length gauge. The groove is closed when the two parts of the soil come into contact at the bottom of the groove

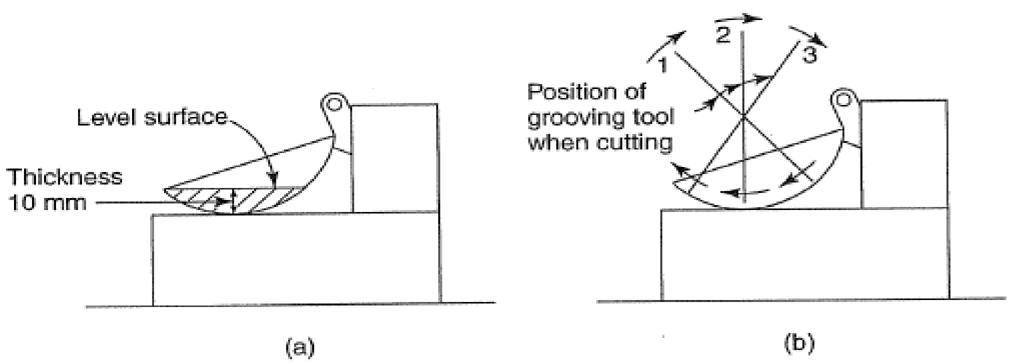


Figure 2. 8 Soil placed in Casagrande bowl, and use of grooving tool

Record the number of blows required to reach this condition.

- Repeat run

Add a little more soil from the mixture on the glass plate, about as much as was removed in forming the groove. Mix with the soil in the cup. Repeat stages 4-6 until two consecutive runs give the same number of blows for closure. Record the number immediately. Ensure that the soil does not dry out between repeat tests, because the number of blows will increase with decreasing moisture content.

- Moisture content measurement

Take a small quantity (about 10 g) of soil from the zone of the groove where the two portions have flowed together, using the small spatula. Place it in a moisture content container, replace the lid and determine the moisture content as in the moisture content test

- Repeat tests

Remove the soil from the bowl and mix it in with the remaining soil paste on the glass plate. Add a little more water, and mix in thoroughly. Clean the bowl of the apparatus and wipe it dry. Reset the revolution counter, if fitted, to zero. Clean and dry the grooving tool and spatula. Repeat stages 4-8 at least three more times (four determinations in all), adding a little more water each time. The moisture contents should be such that the number of blows is roughly evenly spaced over the range from about 50 to 10. There should preferably be at least two blow-counts each side of 25. If necessary, do an additional repeat test. The test must start at the drier condition (about 50 blows) and proceed towards the wetter condition (10 blows).Whenever the soil is left on the glass plate, it should be covered with a damp cloth to prevent drying out. The procedure requires a minimum of 3 determinations covering the range 35 to 15 bumps.

- Calculations

Calculate the moisture content for each blow count, as in the moisture content test. Using a semi-logarithmic chart, plot the moisture content as ordinate (linear scale) against the corresponding number of blows as abscissa (logarithmic scale). Draw the best straight line fitting the plotted points. This is called the flow curve (Figure 2.21). Draw the ordinate representing 25 blows, and where it intersects the flow curve draw the horizontal line to the moisture content axis. Read off this value of moisture content and record it on the horizontal line to the nearest 0.1 %,

.

- Results

The moisture content read off from the flow curve is reported to the nearest whole number as the liquid limit LL of the soil.The method of test (using the Casagrande apparatus) is reported. Also report the percentage of material retained on the 425 µm sieve (if the sample was sieved), and the method of sample preparation. The plastic limit (PL) is usually reported at the same time.

.

2.1.2.3 .Plastic limit (AASHTOT89&90)

This test is to determine the lowest moisture content at which the soil is plastic. It can be carried out only on soils with some cohesion, on the fraction passing a 425 μm sieve. The test may be carried out either on soil in its natural state or on soil prepared by the wet preparation method, both as The test is usually carried out in conjunction with the liquid limit test.

Apparatus

- The most important piece of apparatus for this test is the hand of the operator, which should be clean and free from grease.
- Glass plate and small tools as used for the liquid limit test.
- A separate glass plate reserved for rolling of threads
- Two palette knives or spatulas
- A short length (say 100 mm) of 3 mm diameter metal rod.
- Standard moisture content apparatus -

Test procedure

- Preparation of sample

Prepare and mature the test sample by one of the methods .Take about 20 g of the prepared soil paste and spread it on the glass mixing plate so that it can partially dry. Mix occasionally to avoid local drying· out. It is convenient to set aside this sample just before carrying out the liquid limit test.

- Rolling into a ball

When the soil is plastic enough, it is well kneaded and then.shaped into a ball. Mould the ball between the fingers and roll between the palms of the hands so that the warmth of the hands slowly dries it. When slight cracks begin to appear on the surface, divide the ball into two portions each of about 10 g. Further divide each into four equal parts, but keep each set of four parts together.

- Rolling into threads

One of the parts is kneaded by the fingers to equalize the distribution of moisture, and then formed into a thread about 6 mm diameter using the first finger and thumb of each hand. The thread must be intact and homogeneous. Using a steady pressure, roll the thread between the fingers of one hand and the surface of the glass plate (see Figure 2.22). The pressure should reduce the diameter of the thread from 6 mm to about 3 mm after between five and ten back-and-forth movements of the hand. Some heavy clays may. Need more than this because this type of soil tends to become harder near the plastic limit. It is important to maintain a uniform rolling pressure throughout; do not reduce pressure as the thread approaches 3 mm diameter. Dry the soil further by molding between the fingers again, not by continued rolling which gives a dried crust. Form it into a thread and roll out again as before. Repeat this procedure until the thread crumbles when it has been rolled to 3 mm diameter. The metal rod serves as a reference for gauging this diameter. Crumbling of the thread occurs in different ways with different types of soil. These include: falling apart in small pieces; breaking into a number of short pieces tapered towards the ends; longitudinal splitting from the ends towards the middle. And then falling apart. The essential requirement is to reach the crumbling condition, not to finish with spaghetti-like threads. Crumbling must be the result of the decreasing moisture content only, and not due to mechanical breakdown caused by excessive pressure, or oblique rolling or detachment of an excessive length beyond the width of the hand.

The first crumbling point is the plastic limit. It may be possible to gather the pieces together after crumbling, to reform a thread and to continue rolling under pressure, but this should not be done.

Figure 2. 9 roll plastic limit soil

- Moisture content measurement

As soon as the crumbling stage is reached, gather the crumbled threads and place them into a weighed moisture content container. Replace the lid immediately.

- Repeat tests ·.

Repeat stage 3 for the other three pieces of soil, and place in the same container. Weigh the container and soil as soon as possible, dry in the oven overnight, cool and weigh dry, as in the standard moisture content 'procedure Repeat stages 3-5 on the other set of four portions of the soil using a second moisture content container. Take tests on enough portions, each of 1.5 g to 2.0 g, to give at least 6 g of soil in each container.

- Calculations

Calculate the moisture content of the soil in each of the two containers. If they differ by more than 0.5% moisture content, the test should be repeated.Calculate the average of the two results, which when rounded to the nearest whole number gives the plastic limit of the soil (wp).The difference between the liquid limit and plastic limit is calculated to give the plasticity index (/p) of the soil:

PI=LL-PL…………….eq 2.8

Typical test data are included in Figure 2.14 (which shows three determinations).

- Report results

  The value of the plastic limit PL is reported to the nearest whole number. If it was not possible to perform the plastic limit test, the soil is reported as non-plastic (NP). This also applies if the plastic limit is equal to or greater than the liquid limit; the latter can occur in some soils with a high mica content (Tubey and Webster, 1978).

  The value of the plasticity index PI is also reported to the nearest whole number. The method of preparation of the soil is reported, as is the percentage of material retained on the 425 µm sieve if the soil was sieved. The result is usually reported on the same sheet as the liquid limit test [2]

2.1.2.4 Comparison of methods

Results obtained by the cone method are proven to be more consistent and less liable to experimental and personal errors than those obtained by the Casagrande method (Sherwood and Ryley, 1968). For liquid limit values of up to 100% there is little difference between the results obtained by each method. Above 100%, the cone method tends to give slightly lower values (Littleton and Farmilo, 1977). The relationship between results obtained from the

Casagrande and cone methods, based on evidence available in 1978, is shown graphically

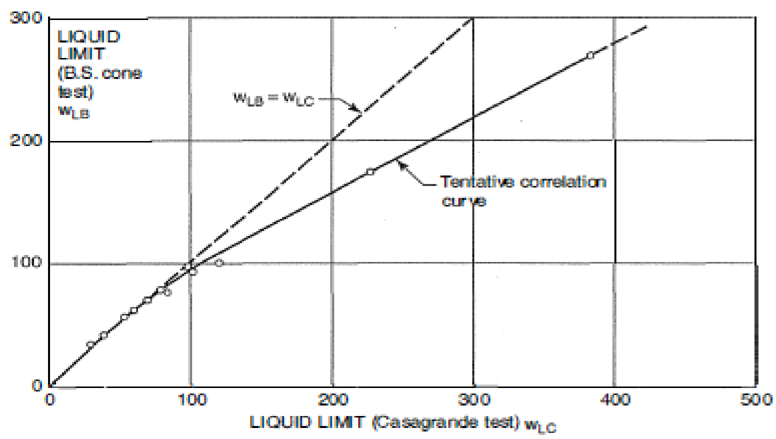


Figure 2. 10 Correlation of liquid limit results from two test methods

Both tests are carried out on remoulded soil, the fraction passing a 425 μm sieve beingused. The cone method may not be any quicker to perform, but it is fundamentally more satisfactory as the mechanics of the test depend directly on the static shear strength of the soil. The Casagrande procedure, on the other hand, introduces a dynamic component not related to shear strength in the same way for all soils. The definition of the liquid limit is dependent on the point at which the soil begins to acquire a recognizable shear strength (about 1. 7 kN/m2) so a test that is based on this property is to be preferred to any other empirical method. The one-point methods are useful as rapid test procedures, when only a very small amount of soil is available, or when a result of lesser accuracy is acceptable [2]

2.1.3 Shrinkage characteristics

Shrinkage limit

When the water content of a fine-grained soil is reduced below the plastic limit, shrinkage of the soil mass cont inues until the shrinkage limit is reached. At that point the solid particles are in close contact and the water contained in the soil is just sufficient to fill the voids between them. Further reduction of water content cannot bring the particles closer together, so there is no further decrease in volume of the soil mass. Air enters the voids and the soil takes on a lighter color. Below the shrinkage limit the soil is considered to be a solid in which the particles remain in contact and in an arrangement that gives a dense state of packing.

Clays are more susceptible to shrinkage than silts and sands. In most cohesive soils the shrinkage limit is appreciably below the plastic limit. In silts the two limits are close together and may be difficult to measure. The shrinkage of a cohesive soil is illustrated graphically in Figure 2.12, in which the change in volume of the soil mass is plotted against its moisture content as the soil is allowed to dry. The portion AB of the curve is linear, and shows that the decrease in volume is directly proportional the loss of water. To the left of point C there is no further decrease in volume as the soil dries. The portion BC represents the transition zone between these two conditions. The point E is found from the intersection of the two straight lines AB and DC, and this enables the shrinkage limit value to be determined as shown. The straight line AB is extrapolated to meet the volume axis at F, which represents the state of the soil if shrinkage could continue without the formation of air voids - that is, by the solid particles merging together to eventually form a single lump. The volume OF therefore represents the volume of the dry solids in the soil mass. If expressed in ml, it is theoretically equal to the mass of dry soil (g) divided by the particle density of the soil grains.[2]

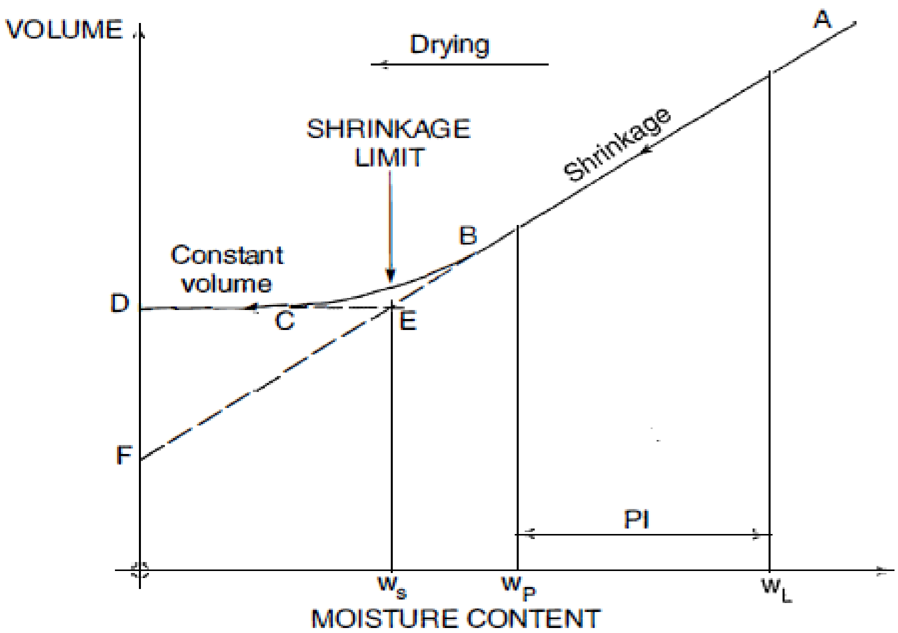


Figure 2. 11 Shrinkage curve for clay soil

2.1.3.1. Type of shrinkage limit

2.1.3.1.1 Volumetric Shrinkage limit method (AASHTO T92)

It requires only one measurement of volume of the soil specimen, which .is done by weighing displaced mercury. Shrinkage limit is calculated directly from initial moisture content, dried mass and volume. In this procedure a shrinkage curve is not produced, but intermediate volume measurements could be made if a curve is required. This would be necessary if the test were used as an alternative method for measuring the shrinkage limit of an undisturbed soil sample.

Apparatus

- Shrinkage dish, porcelain, about 42·mm diameter and 12 mm deep·.but it varies
- Glass cup, about 57 mm diameter and 38 mm deep, with rim ground :flat.
- Prong plate, glass or clear acrylic, fitted with three non-corrodible prongs. Dimensions are not critical but the plate should be large enough to completely cover the glass cup.
- Glass plate, large enough to cover tbe shrinkage dish.
- Two porcelain evaporating dishes 150 mm diameter.
- Measuring cylinder 25 ml.
- Mercury, rather more than will fill the glass cup.
- Straight edge, spatula, small tools.
- Balance, 200 g capacity, reading to 0.01 g.
- Moisture content apparatus (Section 2.5.2).
- Large tray containing a small amount of water, to retain any spilled mercury.
- Petroleum jelly (Vaseline).

Test procedure

- Preparation of specimen

  About 30 g of soil passing the 425 µm sieve prepared from natural soil or by using the wet sieving process is required. Place the soil in an evaporating dish and thoroughly mix with distilled water to make into a readily workable paste. Air bubbles must not be included. The moisture content should be somewhat greater than the liquid limit. The consistency should be such as to require about 10 blows of the Casagrande liquid limit apparatus· to close the groove or to give about 25 -28 mm penetration of the cone penetrometer.
- Preparation of apparatus

  Clean and dry the shrinkage dish, and weigh it to 0.01 g (m2). Its internal volume is determined by measuring the volume of mercury held. Place the dish in an evaporating dish and fill it to overflowing with mercury. The evaporating dish will catch the overflow. Press the small glass plate firmly over the top of the shrinkage dish so that excess mercury is displaced, but avoid trapping any air. Remove the glass plate carefully and transfer the mercury to the 25 ml measuring cylinder. Record the volume of mercury in ml, which is the volume of the shrinkage dish (Vi).

Coat the inside of the shrinkage dish with a thin layer of petroleum jelly. This is to prevent soil sticking to the dish.

- Forming soil pat

  Add the mixed soil paste to the shrinkage dish so as to about one-third fill it. Avoid trapping air. Tap the dish on the bench surface to cause the soil to flow to the edges of the dish. This should also release any small air bubbles present. The bench should be padded with a few layers of blotting paper or similar material.

  Add a second amount of soil, about the same as the first, and repeat the tapping operation until all entrapped air has been released. Add more soil, and continue tapping, so that the dish is completely filled with an excess standing out. Strike off the excess with a straight edge, and clean off adhering soil from the outside

- Weighing

  Immediately after the above, weigh the soil and dish to 0.01 g (m3). Calculate the mass of wet soil (m1) from

  $$\boxed{m_1 = m_3 - m_2} \text{……………………..eq2.9}$$

- Drying

  Leave the soil in the dish to dry in the air for a few hours, or overnight, until its colour changes from dark to light. Place it in the oven at 105 -110°C, and dry to a constant mass. If the shrinkage curve during drying is required, make a series of volume measurements at suitable intervals before drying in the oven. Leave the soil in the shrinkage dish exposed to warm air and when it has shrunk away from the dish and can be safely handled, determine its volume and mass. Place the soil pat on a flat surface to dry further and repeat the measurements until the colour changes from dark to light. Then dry in the oven.

- Weighing dry

  Cool in a desiccator, and weigh the dry soil and container to 0.01 g (m4). Calculate the mass of dry soil md from

- Measurement of volume

  Remove the dried soil pat carefully from the shrinkage dish. It should be intact if it was given long enough to dry in air before transferring to the oven.Place the glass cup in a clean evaporating dish standing on the large tray. Fill the cup to overflowing with mercury and remove the excess by pressing the glass prong plate firmly on top of the cup. Avoid trapping air under the glass plate. Carefully remove the prong plate, and brush off any mercury drops adhering to the glass cup. Place the cupinto another clean evaporating dish without spilling any mercury.Place the soil pat on the surface of the mercury (it will float). Press the three prongs of the prong plate carefully on the sample so as to force it under the mercury (Figure 2.25).Avoid trapping any air. Press the plate firmly onto the dish. Displaced mercury will beheld in the evaporating dish. Brush off any droplets .of mercury adhering to the cup into the dish. Transfer all the displaced mercury to the measuring cylinder and record its volume CVct). This is equal to the volume of the dry soil-pat.

- Calculations

  Calculate the moisture content of the initial wet soil-pat, wi , from the equation

$$\boxed{w_1 = \left(\frac{m_1 - m_d}{m_d}\right)\times 100\%}$$ ……………….eq2.10

The shrinkage limit (w**8)** can then be calculated from the equation

$$\boxed{w_S = w_1 - \left(\frac{V_1 - V_d}{m_d}\right)\times 100\%}$$ ……………eq2.11

where Vi= volume of wet soil pat (ml); Vd= volume of dry soil pat (ml); md = mass of dry soil-pat (g).

The shrinkage ratio, *R8*, can be calculated from

$$\boxed{R_S = \frac{m_d}{V_d}}$$ ………………….eq 2.12

If intermediate measurements of volume and mass were made, corresponding values of U and *w* can be derived and the shrinkage curve plotted, as described in section 2.7.2. An appropriate value of Vs can also be calculated.

- Results

The shrinkage limit is reported to the nearest whole number. The method of test, of preparation and the percentage of material passing the 425 μm sieve should be reported.The shrinkage ratio is reported to two places of decimals.

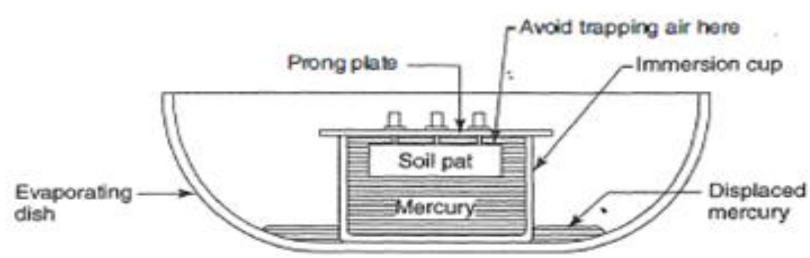


Figure 2. 12 Immersion of sample in shrinkage limit test

2.1.3.1.2 Linear shrinkage (BS1377:Part2:1990:6.5)

This test gives the percentage linear shrinkage of a soil. It can be used for soil of low plasticity, including silts, as well as for clays.

Apparatus

- Mould, of brass or other non-corrodible metal, 140 mm long and 25 mm diameter.
- Flat glass plate (as for the liquid limit test).

- Palette knives.
- Silicone grease or petroleum jelly.
- Vernier callipers measuring up to 150 mm and reading to 0.1 mm, or steel rule graduated to 0.5 mm.
- Moisture content apparatus (Section 2.5.2). Oven drying temperatures of 60-65°C and
- 105 -110°C are required.

Test procedure ,

- Preparation of mould

Clean and dry the mould. Apply a thin film of grease to the inner surfaces to prevent soil from sticking.

- Preparation of sample

About 150 g of soil passing the 425 μm sieve, prepared from natural soil or by using the wet sieving process described in Section 2.6.3, is required. This proportion of the original sample passing the 425 μm sieve is recorded. Place the soil on the glass plate and mix thoroughly with distilled water, as for the liquid limit test. Continue mixing until it becomes a smooth homogeneous paste at about theliquid limit. This is not critical, but it may be checked using the cone penetrometer, which should give a penetration of about 20 mm.

- Placing in mould

Place the paste in the mould, avoiding the trapping of air as far as possible, so that the mould is slightly overfilled. Tap it gently on the bench to remove any air pockets. Level off along the top edge of the mould with a palette knife or straight-edge. Wipe off any soil adhering to the rim of the mould.

- Drying

Leave the mould exposed to the air but in a draught-free position, so that the soil can dry slowly. When the soil has shrunk away from the walls of the mould it can be transferred to an oven set at 60-65°C. When shrinkage has virtually ceased, increase the drying Temperature to 105-ll 0° C to complete the drying.

- Measurement of length

Allow the mould and soil to cool in a desiccator. Measure the length of the bar of soil with the vernier callipers, making two or three readings and taking the average (L0).
If the specimen has curved during drying, remove it carefully from the mould and measure the lengths of the top and bottom surfaces. Take the mean of these two lengths as the dry length *L0.*
If the specimen has fractured in one place, the two portions can be fitted together before measuring the length. If it has cracked badly, and the length is difficult to measure, repeat the test, using a slower drying rate or leaving the mould longer in air before transferring to the oven.

- Calculations

Calculate the linear shrinkage (Ls) as a percentage of the original length of the specimen from the equation

$$\boxed{L_S = \left(1 - \frac{L_D}{L_0}\right) \times 100\%}$$ ………………..eq2.13

where *L0* = original length (140 mm if a standard mould is used); *L0* length of dry specimen.
For some soils the plasticity index, lp, might be found to be proportional to Ls. This can be useful for silty soils for which the plastic limit is difficult to determine

- *Results*

The linear shrinkage of the soil is reported to the nearest whole number. The percentage of soil passing the 425 μm sieve is also reported, together with the method of specimen preparation.

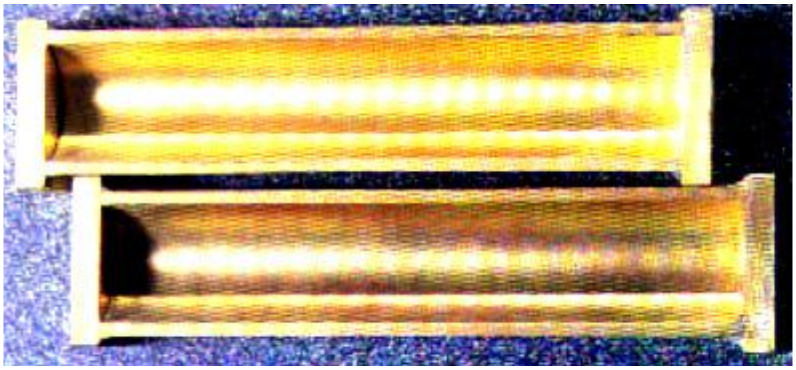


Figure 2. 13 linear shrinkage mold

Shrinkage ratio

The shrinkage ratio is the ratio of the change in volume, expressed as a percentage of the final dry volume, to the change in moisture content, above the shrinkage limit. In Figure 11 the shrinkage ratio is equal to the slope of the line AE. (Points A, E, D, F correspond to those . The heights of the vertical columns represent diagrammatically the total volumes of soil at various points on the graph, and their subdivisions indicate the volumes of solid, water (Vw), and (below SL) air, contained within the soil.

2.1.4 Free swell test (Gibbs and Holtz, 1956)

Characteristics

Free swell is defined as the increase in volume of the soil from a loose dry powder form when it is poured into water, expressed as a percentage of the original volume.

Soils with free swell values less than 50% are not likely to show expansive properties. Values of 100% or more are associated with clays that could swell ·considerably when wetted, especially under light loadings

Preparation of sample

About 10 g of soil is oven dried and passed through a 425 μm sieve. Place the dried soil loosely in a dry 25 ml cylinder up to the 10 ml mark. The powder should not be compacted or shaken down.

Procedure

- Place 50 ml of distilled water in a 50 ml glass measuring cylinder.

- Pour the dry soil powder slowly and steadily into the water. The word used in the original text is drizzle, an apt description.
- Allow the main part of the solid particles to come to rest; this will take from a few
- minutes to half an hour. The finest particles may remain in suspension for much longer
- but these can be ignored.
- Read off and record the volume of settled solids *(V* ml).

Calculation and report

Free swell is defined as the change in volume of the dry soil expressed as a percentage of its original volume. It is calculated from the equation

$$\text{free swell} = \frac{V-10}{10}\times 100\% \quad \text{……………………..eq2.14}$$

if the original dry loose volume was 10 ml.

The result is reported to the nearest whole number

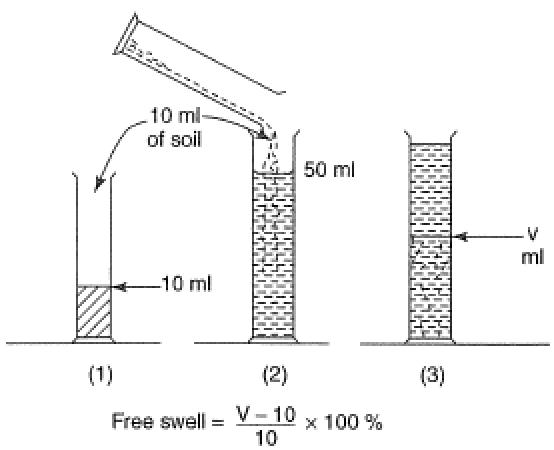


Figure 2. 14 Free swell test

2.1.5 Organic content

Soils high in organic content tend to develop voids by decay which makes them undesirable for engineering use. Even a small amount of organic matter in clay, will result, in an appreciable increase in liquid limit of the material, without increase in plasticity index. Soils containing even moderate amounts of organic matter are significantly more compressible and less stable than inorganic soils.

Organic content in soil is derived from a wide variety of animal and plant remains, so there can be a great variety of organic compounds. They can all have undesirable effects on the engineering behaviour of soils. These can be summarised as follows:

- Reduction of bearing capacity.
- Increase in compressibility.
- Increase in swelling and shrinkage potential due to changes in moisture content.
- The presence of gas in the voids can lead to large immediate settlements, and can affect the derivation of consolidation coefficients from laboratory tests.
- The gas can also give misleading shear strength values derived from total stress tests.
- The presence of organic matter (e.g. in peat) is usually associated with acidity (low pH) and sometimes with the presence of sulphates. Detrimental effects on foundations could result if precautions are not taken.
- Organic matter is detrimental in soils used for stabilization for roads. A measure of the organic content of soils is necessary in order to make allowance forthese effects.[17]

2.1.6 Particle size distribution

The objective of particle size distribution is to determine the percentage of soils passing different sieve opening sizes. In this study, this determination is used for classification purpose and for overall engineering characteristics indication. Wet sieve and dry sieve analysis were conducted on the sample obtained from the site. If percent passing No.200 (75µm) is greater than 35%, then it implies that this soil is categorized as fine grained soil (Silt-Clay material). On the other hand, if percent passing No.200 (75µm) is less than 35%, it implies that the soil is categorized as coarse grained soil (granular material) according to AASHTO M145. Particle size distribution test is not only used to categorize soil as coarse and fine grained but it also helps to determine the soil class together with the Atterberg limits.Accordingly, summary of the grain size distribution for the fine grained soil is taken for analysisas the project objective is to get a correlation equation of fine grained soils.[17]

2.2 Classification

The liquid and plastic limits provide the most useful way of identifying and classifying the fine-grained cohesive soils. Particle size tests provide quantitative data on the range of sizes of particles and the amount of clay present, but say nothing about the type of clay. Clay particles are too small to be examined visually (except under an electron microscope) but the Atterberg limits enable clay soils to be classified physically, and the probable type-of clay minerals to be assessed. Classification is usually accomplished by means of the plasticity chart (also referred to as the A-line chart). This is a graphical plot of the plasticity index (Ip) as ordinate against liquid limit (wd as abscissa. The standard chart is shown in Figure 14. When the values of wL and Ip for inorganic clays are plotted on this chart, most of the points lie just above the line marked 'A-line·, and in a narrow band parallel to it. The A-line is defined by the relationship:-

$$I_P = 0.73\ (w_L - 20) \qquad \text{……………….eq2.15}$$

This line was derived from experimental evidence and does not represent a well-defined boundary between soil types, but it does form a useful reference datum. The dashed line labelled 'B-line' is a tentative upper limit for all soils, which has also been drawn from experimental data. It is defined by the relationship In British practice this chart is divided into five zones, giving the following categories for clays:

.

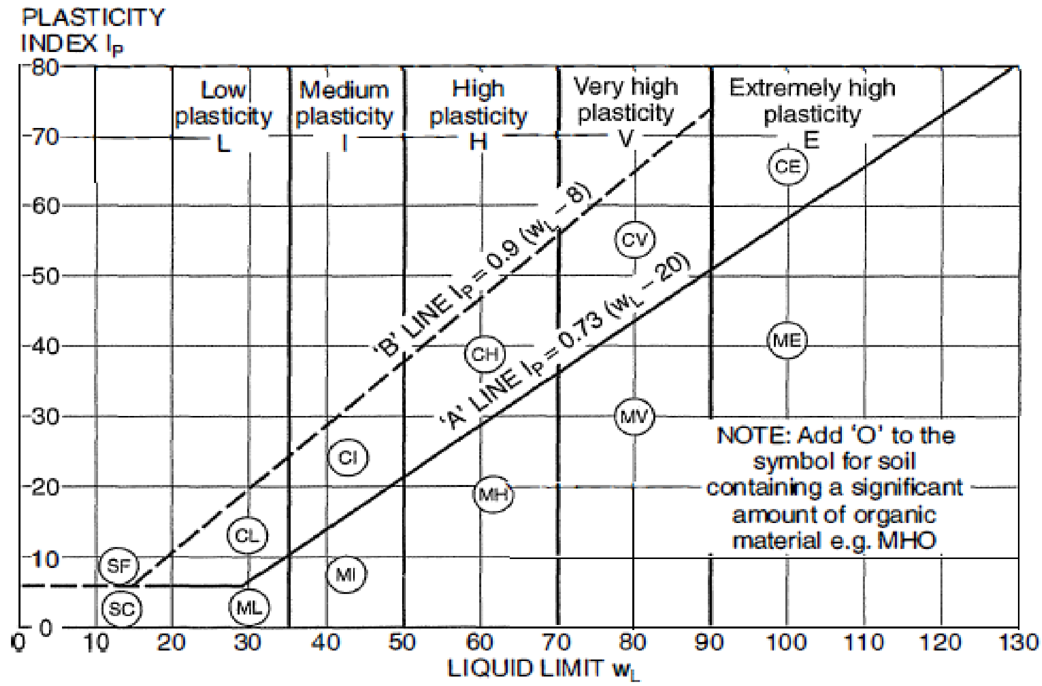


Figure 2. 15 Plasticity chart

- Low plasticity (CL), less than 35 liquid limit.
- 2 .Medium plasticity (CI), liquid limit from 35 to 50.
- High plasticity (CH), liquid limit from 50 to 70.
- Very high plasticity (CV), liquid limit from 70 to 90.
- Extremely high plasticity (CE), liquid limit exceeding 90

The letters in parentheses are the standard symbols by which each group is known. Silts when plotted on this chart generally fall below the A-line. They are divided into five categories similar to those for clays. The group symbols are ML, MI, MH, MV, ME. Clays containing appreciable amounts of organic matter also plot below the A-line. Organic clays and silts include the letter 'O' after the group symbol (for example, CHO, MIO). In the USA, the plasticity chart is divided into three groups:

- .Low plasticity (CL), liquid limit less than 30.
- Intermediate plasticity (CI), liquid limit from 30 to 50.

- .High plasticity (CH), liquid limit exceeding 50.An extended version of the A-line chart, embracing liquid limits up to 500, is given in Figure.2.16[2]

.

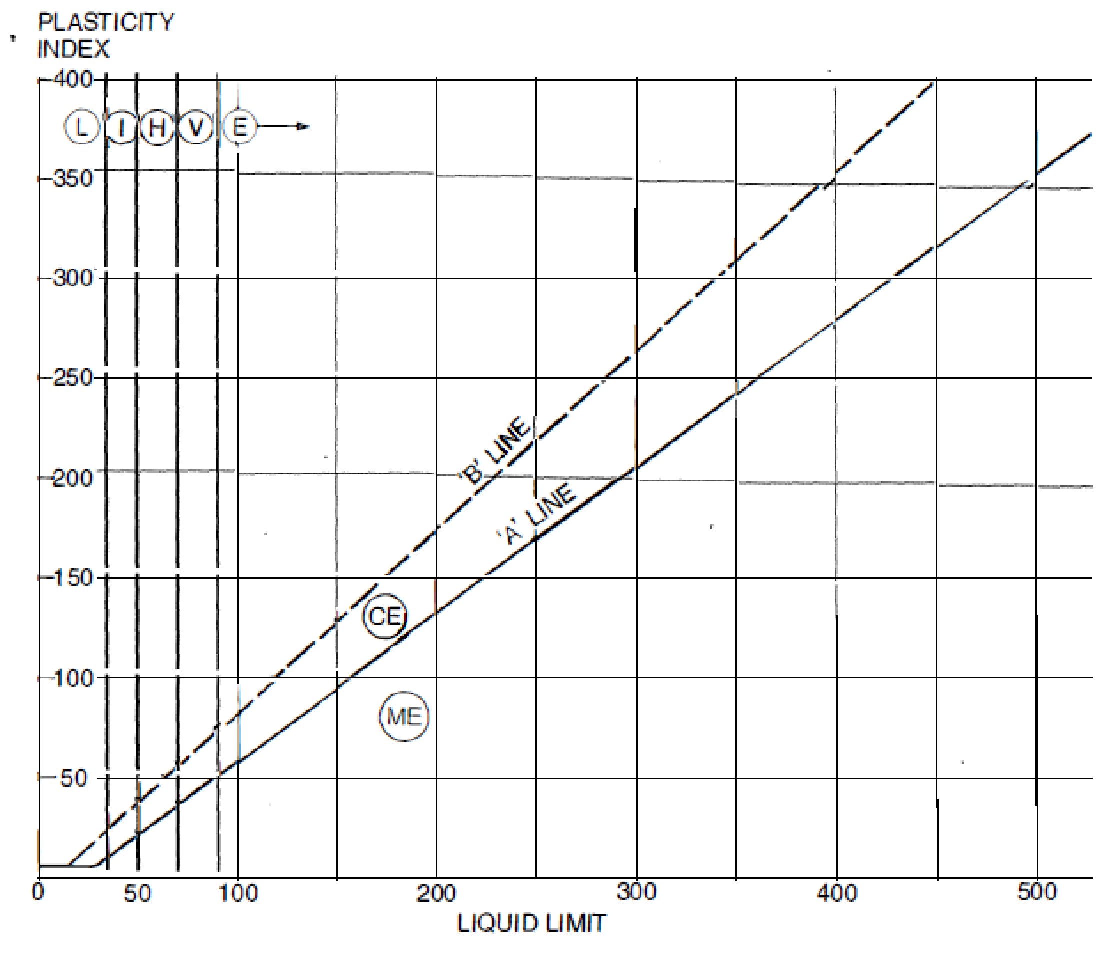


Figure 2. 16 Extended plasticity chart

AASHTO Classification System

- The AASHTO classification system, also called Public Roads Administration (PRA) classification, is based on the following three soil properties:
- Grain-size distribution
- Liquid limit
- Plasticity index

- This system is generally used by highway engineers, for classification of sub-grade soils for the highway pavements. According to this system, soil is classified into seven major groups, A-1 through A-7.
- Soils classified under groups A-1, A-2, and A-3 are granular materials with 35% or less passing through a No. 200 sieve.Soils with more than 35% passing a No. 200 sieve are classified under groups A-4, A-5, A-6 and A-7. These soils are mostly silt and clay-type materials.
- To classify a soil using AASHTO soil classification Table, one must proceed from left to right with required test data available. By the process of elimination, the first group from the left into which the test data will fit gives the correct classification.
- Under this classification system, a characteristic called group index (G.I) is used to describe the performance of a soil when used as a highway sub grade material.

Group index is not used to place the soil in a particular group, but is actually a means of rating the value of a soil as a sub grade material, within its own group.

GI = 0.2a+ 0.005ac + 0.01bd

Where:

a = that portion of percentage of particles passing No.200 sieve greater than 35% and not exceeding 75%, expressed as positive whole number (0 to 40).

b = that portion of percentage of particles passing No.200 sieve greater than 15% and not exceeding 55 %, expressed as positive whole number (0 to 40).

c = that portion of the liquid limit greater than 40 and not exceeding 60 , expressed as positive whole number (0 to 20).

d = that portion of the plasticity index greater than 10 and not exceeding 30, expressed as positive whole number (0 to 20

General Classification	Granular Materials (35 per cent or less passing No. 200)							Silt-clay Materials (More than 35 percent passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis per cent passing											
No. 10	50 max										
No. 40	30 max	50 max	51 min								
No. 200	15 max	10 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 sieve											
Liquid limit				40max	41 min	40max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 (max)		N.P	10max	10max	11 min	11min	10 max	10 max	11 min	11 min
Group index	0		0	0		4 max		8 max	12 max	16max	20 max
Usual types of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as sub-grade	Excellent to good							Fair to poor			

The A-7 group is subdivided into A-7-5 or A-7-6 depending on the plastic limit. For P.L.<30, the classification is A-7-6; for P.L ≥30, it is A-7-5.

It was also observed that based on the test results acquired, the sample is categorized as A-4,A-6,A-7-5,A-7-6 material using AASHTO classification system. It also describes the soil as (MH or OH,MHor OL, MLor OL,CLorOL,CHor OH) using Unified Soil Classification method. This could not be verified due to the fact that secondary data was used for the study.

2.2.1 Activity of Clays

The Atterberg limits are related to the combined effects of two intrinsic properties of a clay, namely particle size and mineral composition. For a particular clay mixed with coarser material, Skempton (1953) showed that the plasticity index depended on the clay fraction (the percentage of particles finer than 2 μm) and that the ratio of plasticity index/clay fraction was constant. For different clays different ratios were obtained, but the ratio was more or less constant for each clay type. The relationship between PI and clay fraction for a particular clay was termed the colloidal activity, or simply activity, where

$$\text{activity} = \frac{I_P}{\text{clay fraction}}$$
…………………eq2.16

To be consistent with the Atterberg limits, the clay fraction used here should be expressed as a percentage of that portion of the soil sample that passes through a 425 µm sieve. On this basis, clays can be classified into four groups as shown in:-

Table 2. 1 Activity of clays

Activity of clays

Description	*Activity*
Inactive clays	<0.75
Normal clays	0.75–1.25
Active clays	1.25–2
Highly active clays	>2
(e.g. bentonite)	(6 or more)

Test result

The soil in tendaho road project type inactive clay to normally clay so soil are less probability for expansion when contact with water

3.0 METHODOLOGY

3.1 DATA SOURCE

For this project Secondary data on tendaho road project was collected. The specific area has been selected for the reason that is on a design stage and suitable to get recent and organized data.

3.2 LOCATION OF STUDY

- Executive areal description Summary

  Tendaho Road Project consists of a network of roads within the command area of Tendaho Irrigation Project with a total production of about more than 500,000 tons of sugar per annum (WWDSE-WPCS (I), 2005).These roads when completed will provide access to every zone within the command area of the irrigation project.[13]

  The field subgrade investigation was started on April 25, 2013 and was completed on June 24, 2013. About 252 test pits were dug with a total depth of 504m to study the surface and subsurface conditions of the road network. A total of 29 samples were collected for subsequent laboratory testing and analysis. [17]

- Location, accessibility, existing facilities

  Tendaho Project is located in Afar region 580 kms North-East of the capital Addis Ababa, within the lower delta of Awash basin. The project is accessible through two asphalt highways; through the asphalt highway connecting Addis Ababa and Samara (Addis Ababa – Dessie – Bati – Semara – Dupti) and through the Addis Ababa – Nazareth – Awash – Logia – Dubti route. Both roads are asphalt roads except the final stretch from Logia to the project site and the section Tendaho Road Project elevation ranges from400 m.a.s.l at Tendaho to 250.00 m.a.s.l. near Assayita.The only Perennial River in the project site is Awash River.

Geotechnical Investigation Subgrade Investigation Report from Kombolcha to Mille on the first route. The project area lies between latitudes 110 30’ to 110 50’ North and longitudes 400 45’ to 410 03’ East. Low land, hot climatic conditions, no vegetation cover, active geological processes and nomad’s life are typical expression of the area.

The existing Tendaho Dam is constructed across the Awash River and the command area stretches from Dubti to Assayita. The project will irrigate more than 60,000 ha of sugarcane plantation, which provides raw material (sugarcane) for a large-scale sugar factory. Owing to the meandering features of river Awash, the command area is split up into several isolated areas concentrated around Dubti, Boyale, Galifage, DitBahari, Bokaitti, Assayita etc, all along the route of river Awash. The project (Tendaho Road Projects) consists of a network of roads within the command area.[13]

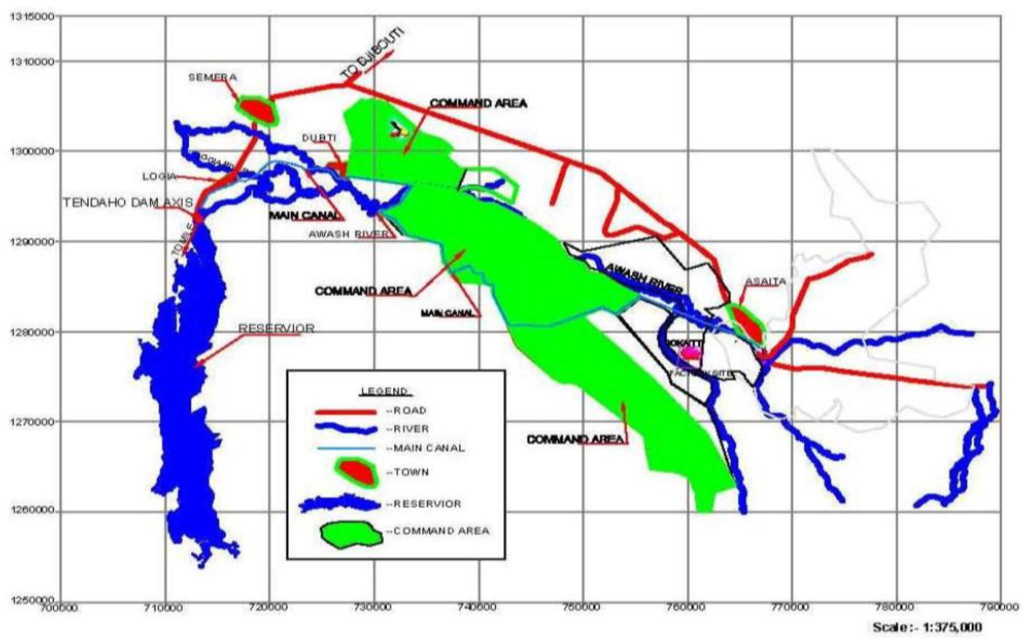


Figure 3. 1 : Location Map of Tendaho Project (From Technical Task Force Report, 2011)

- Climate

The climate of the Tendaho Road Project area is arid, with temperatures varying from 17 to 43 degree Celsius. The mean annual rainfall is 200 mm having two rainy seasons: March to April and July to August. The mean annual sunshine hours is 9.8 hours having small variation through months. The relative humidity varies from 31% in June to 96% in

February. Wind speed is maximum in March reaching 187 km/day and minimum in September reaching 95.4 km/day. [13]

The following table gives monthly climate data at the project area.

Station : Tendaho (1979-2002)
Altitude :350 meter(s) above M.S.L.
Latitude:11.30 Deg. (North) Longitude : 41.00 D eg. (East)

Month	MaxTemp (°C)	MiniTemp (°C)	Humidity (%)	Wind Spd. (km/day)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)	ETo (mm/month)	Rainfall (mm)
Jan	32.3	17.9	66.8	164.7	8.9	20	4.75	147.3	4.4
Feb	33.7	19.3	65.3	176.9	8.4	20.7	5.25	147.0	12.9
Mar	35.7	21.5	62.3	187.1	8.2	21.7	5.99	185.7	22.0
Apr	38.0	22.6	60.7	170.4	9.3	23.9	6.58	197.4	36.8
May	40.2	24.1	55.0	124.6	9.9	24.4	6.47	200.6	9.2
Jun	43.2	26.1	50.5	126.4	8.3	21.6	6.52	195.6	3.2
Jul	41.0	25.6	54.8	137.2	7.3	20.2	6.11	189.4	40.9
Aug	39.3	25.2	58.8	134.3	7.8	21.3	6.04	187.2	49.9
Sep	38.9	24.4	59.4	95.4	8.0	21.5	5.49	164.7	14.5
Oct	36.9	20.8	63.1	102.3	9.5	22.7	5.36	166.2	5.5
Nov	34.5	17.9	62.2	133.2	10.0	21.8	5.04	151.2	1.6
Dec	32.8	17.1	65.5	148.3	9.8	20.7	4.71	146.0	5.4
							Annual	**2078.2**	**206.1**

Table 3.1 monthly climate data at the project area

- Geology and Topography

The project area is located in Afar Depression, where the three rifts namely, Main Ethiopian rift (MER), Red Sea, and Gulf of Aden form a triple junction. The area is known for its seismicity and volcanic activity. The MER and Afar Depression/Triangle are flanked on both sides by escarpments mainly Phanerozoic sedimentary sequences and Tertiary basic and acidic volcanic rock succession. [12]

The rift floors are covered largely by Pliocene-Pleistocene volcanic rocks and associated fluvio-lacustrinesediments.

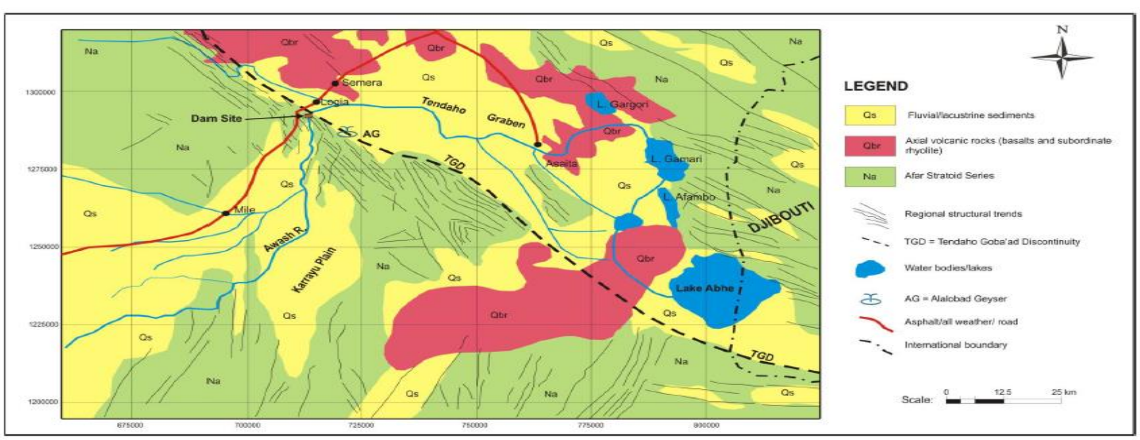


Figure 3. 2: Regional Geologic Map of Tendaho Project ((modified from Aquater, 1996; Tefera et al. 1996; Tesfaye et al. 2003).)

3.3 REVIEW OF LITERATURES

Literatures regarding plastic index and shrinkage limit has been thoroughly studied and reviewed at the early stage of the study. Technical papers, journals and published reports were reviewed to keep up to date on the published correlations that relate the plastic index values with shrinkage limit value(both linear and volumetric). Summary of the literature review is presented in previous chapter.

3.4 DATA COLLECTION AND ANALYSIS

In order to attain the purpose of this research work ethical considerations are concentrating on in the context of quantitative and qualitative research. Before starting any data collection formal letter will be obtained from AAIT department and an official permission will be obtained from laboratory head. To collect the actual secondary data which were done? the following measurements are required:

For the subgrade investigation of Tendaho Road project, test pits were excavated and logged to identify the type of soils available and to classify and characterize the sub-grade soils. In general:

- ✓ Test pits were excavated at 2.5km interval (based on site condition and heterogeneity the spacing of the pits were modified in few locations)
- ✓ Soil sampling at 5km interval from a representative layer based on site condition

Subgrade samples were collected and subsequent tests were carried out to classify the sub grade soil type: grain size analysis (hydrometer), natural moisture content, atterberg limits, free swell and volume shrinkage grain size analysis, linear shrinkage.

On the basis of the origin of their constituents, soils of the study area are classified in to two broad groups; residual soils and transported soils. According to the recent geotechnical investigation, the entire flat area is covered by alluvial and lacustrine deposits. The alluvial deposits are of significant depth and show stratification. The lacustrine deposits are usually fine grained.

Based on the visual inspections and test pit logging during the investigations, the native material is classified as follows. The following soil types are commonly encountered along the road network. For convenience, the command area is subdivided in to seven (7) areas, namely PC1 to PC7; the geotechnical investigation was carried out in all areas except PC-6. This report follows the above mentioned division of the command area throughout the report.

- PC-1 – Silty CLAY (the clay is moist in almost every test pit)
- PC-2 – Silty CLAY and occasionally silty SAND
- PC-3 – Silty CLAY (dry but occasionally moist)
- PC-4 – Clayey SILT
- PC-5 – Silty CLAY
- PC-7 – Silty Clay(dry) and occasionally moist clayey SILT

According to the recent investigation of the native soil, black cotton soils/problematic soils were observed only in certain locations of the road network especially. Very wet areas were observed around the western boundary of PC-2, mid-way between the northern eastern and southern border of PC-3. Geothermal zones prevail around the southern corner of PC-2 [17]

4.0 DATA ANALYSIS AND DISCUSSION

4.1 DATA SELECTION

As previously indicated, source of data for this study is a Secondary data on afar logia town. The test was conducted at the beginning of the dry season. From the tests that were conducted only samples which represent fine grain soil are taken in to consideration for the analysis. Twenty nine points were put under consideration for this study where coupled plastic index and shrinkage limit test in Laboratory were conducted. For each testing location, in addition to the plastic index and shrinkage limit value, particle size distribution (Sieve analysis), plastic limit, liquid limit, and moisture contents were also measured.

4.2 SUMMARY OF TEST RESULTS

The summary of laboratory plastic index data in percent and shrinkage limit (linear and volumetric) data in percent for soil samples is indicated below. From the summary, it can be observed that soil samples which have lesser plastic index value have lesser linear and volumetric shrinkage value in magnitude. This is because soil with a better plastic index value

No	Test pit No	**Soil test Parameter**							**Soil classifcation**	
		Moistue content (%)	Grain Size Analysis	Atteberg limit	Linear Shrinkae (%)	Volumetric Shrinkage (%)	Free swell (%)	Organic content(%)	ASSHTO	UNIFIED
1	TRP-TP-1 0.2-2.00m Lab No: 051/08	3.55	Clay% 22.44 Silt % 75.84 Sand % 1.72	LL % 44.70 PL % 29.88 PI % 14.82	5.89	15.02	35.00	0.22	A-7-5	ML or OL
2	TRP-TP-2 0.2-2.00m Lab No: 052/08	4.22	Clay% 28.07 Silt % 71.42 Sand % 0.51	LL % 42.50 PL % 29.62 PI % 12.88	6.10	15.66	35.00	0.40	A-7-5	ML or OL
3	TRP-TP-3 0.2-2.00m Lab No: 054/08	7.23	Clay% 44.09 Silt % 53.17 Sand % 2.73	LL % 59.85 PL % 33.97 PI % 25.88	12.77	18.88	60.00	0.29	A-7-5	MH or OH
4	TRP-TP-4 0.2-2.00m Lab No: 055/08	4.69	Clay% 36.72 Silt % 62.59 Sand % 0.69	LL % 62.60 PL % 33.91 PI % 28.69	13.60	19.78	46.00	0.52	A-7-6	MH or OH

have lesser magnitude of volume change to penetration

5	TRP-TP-5 1.0-2.00m Lab No: 556/08	8.13	Clay% 58.12 Silt% 40.89 sand % 0.99	LL % 61.87 PL % 33.65 PI % 28.22	13.37	19.22	51.00	0.41	A-7-6	MH or OH
6	TRP-TP-6 0.15-2.00m Lab No: 058/08	5.66	Clay% 15.05 Silt % 67.00 Sand % 17.95	LL % 27.40 PL % 18.13 PI % 9.27	4.29	4.39	12.61	0.16	A-4	MLor OL
7	TRP-TP-7 0.30-2.00m Lab No: 059/08	6.48	Clay% 34.62 Silt % 63.44 Sand % 1.93	LL % 46.70 PL % 26.67 PI % 20.03	18.50	9.49	17.11	0.29	A-7-5	CL or OL
8	TRP-TP-8 0.30-1.80m Lab No: 060/08	7.00	Clay% 35.42 Silt % 54.69 Sand % 9.89	LL % 58.80 PL % 29.03 PI % 29.77	22.50	14.11	20.04	0.16	A-7-5	MH or OH
9	TRP-TP-9 0.20-2.00m Lab No: 061/08	6.25	Clay% 71.13 Silt % 19.25 Sand % 9.62	LL % 90.30 PL % 45.34 PI % 44.96	26.00	21.31	85	0.95	A-7-5	MH or OH
10	TRP-TP-10 0.20-2.00m Lab No: 062/08	4.02	Clay% 66.78 Silt % 31.80 Sand % 1.42	LL % 98.53 PL % 48.00 PI % 50.53	21.82	24.03	68.00	0.83	A-7-5	MH or OH
11	TRP-TP-11 0.20-2.00m Lab No: 063/08	5.23	Clay% 21.27 Silt % 77.83 Sand % 0.90	LL % 46.90 PL % 25.70 PI % 21.20	10.06	17.88	37.5	0.33	A-7-6	CL or OL
12	TRP-TP-12 0.10-2.00m Lab No: 064/08	8.02	Clay% 18.46 Silt % 69.35 Sand % 12.19	LL % 36.50 PL % 26.37 PI % 10.13	4.80	13.72	12.5	0.21	A-5	ML or OL
13	TRP-TP-13 0.20-2.00m Lab No: 065/08	4.89	Clay% 67.92 Silt % 30.77 Sand % 1.31	LL % 85.80 PL % 44.46 PI % 41.34	18.22	21.20	55	0.62	A-7-5	MH or OH
14	TRP-TP-14 0.50-2.00m Lab No: 066/08	9.23	Clay% 6.67 Silt % 69.73 Sand % 23.60	LL % 38.00 PL % 26.98 PI % 11.02	5.22	14.00	27.5	0.28	A-6	ML or OL
15	TRP-TP-4 0.20-1.50m Lab No: 067/09	4.06	Clay% 11.62 Silt % 60.47 Sand % 17.52 Gravel%	LL % 42.13 PL % 30.66 PI % 11.47	5.44	14.88	50	0.62	A-7-5	ML or OL
16	TRP-TP-12 0.30-1.40m Lab No: 068/08	7.38	Clay% 28.13 Silt % 47.58 Sand % 24.29	LL % 47.95 PL % 31.63 PI % 16.32	7.73	16.41	65	0.72	A-7-5	CL or OL
17	TRP-TP-14 0.00-1.30m Lab No: 069/08	2.77	Clay% 5.83 Silt % 58.77 Sand %35.40	LL % 31.00 PL % 25.18 PI % 5.82	2.82	8.28	27.5	0.44	A-4	ML or OL
18	TRP-TP-20 0.00-1.20m Lab No: 070/08	5.97	Clay% 27.43 Silt % 68.36 Sand % 4.21	LL % 46.19 PL % 33.64 PI % 12.55	5.89	15.02	60	0.29	A-7-5	ML or OL
19	TRP-TP-20 0.27-1.40m Lab No: 071/08	4.62	Clay% 10.53 Silt % 71.17 Sand % 18.30	LL % 39.15 PL % 27.85 PI % 11.30	5.36	14.22	27.5	0.55	A-6	ML or OL
20	TRP-TP-29 0.40-1.40m Lab No: 072/08	3.79	Clay% 3.90 Silt % 51.93 Sand % 44.17	LL % 31.80 PL % 25.30 PI % 6.50	3.11	9.04	6.25	0.78	A-4	ML or OL

21	TRP-TP-38 0.25-1.40m Lab No: 073/08	5.41	Clay% 10.02 Silt % 57.19 Sand % 32.79	LL % 31.13 PL % 24.85 PI % 6.28	2.98	8.67	16.25	0.69	A-4	ML or OL
22	TRP-TP-39 0.20-1.40m Lab No: 074/08	3.8	Clay% 3.60 Silt % 65.27 Sand % 31.13	LL % 27.13 PL % 22.77 PI % 4.36	2.07	6.07	2.5	0.54	A-4	ML or OL
23	TRP-TP-40 0.00-1.40m Lab No: 075/08	7.17	Clay% 16.42 Silt % 63.44 Sand % 20.14	LL % 37.75 PL % 28.97 PI % 8.78	4.22	12.13	52.50	0.48	A-4	ML or OL
23	TRP-TP-41 0.00-1.30m Lab No: 076/08	5.32	Clay% 11.03 Silt % 71.49 Sand % 17.48	LL % 33.86 PL % 26.66 PI % 7.20	3.41	9.89	30.00	0.66	A-4	ML or OL
24	TRP-TP-42 0.00-1.20m Lab No: 077/08	5.32	Clay% 8.02 Silt % 77.26 Sand % 14.72	LL % 38.00 PL % 28.39 PI % 9.61	4.55	13.05	21.25	0.58	A-4	ML or OL
25	TRP-TP-43 0.00-1.35m Lab No: 078/08	7.03	Clay% 6.93 Silt % 75.35 Sand % 17.72	LL % 35.48 PL % 25.42 PI % 10.06	4.77	13.63	27.50	0.78	A-4	ML or OL
26	TRP-TP-44 0.00-1.40m Lab No: 079/08	8.23	Clay% 7.02 Silt %68.53 Sand % 24.45	LL % 27.88 PL % 23.16 PI % 4.72	2.24	6.56	28.75	0.52	A-4	ML or OL
27	TRP-TP-48 0.00-1.30m Lab No: 080/08	6.23	Clay% 9.10 Silt %30.29 Sand % 60.61	LL % 32.90 PL % 26.08 PI % 6.82	3.23	9.39	30.00	0.26	A-4	ML or OL
28	TRP-TP-15-1 0.20-0.80m Lab No: 081/08	5.05	Clay% 23.55 Silt %71.88 Sand % 4.57	LL % 56.40 PL % 33.10 PI % 23.30	11.55	18.21	59.00	0.36	A-4	MH or OH
29	TRP-TP-15-2 0.20-0.80m Lab No: 082/08	4.68	Clay% 9.65 Silt %88.95 Sand % 1.40	LL % 34.00 PL % 23.33 PI % 9.67	4.58	13.13	22.50	0.10	A-4	ML or OL

Table 4. 1 summary of test Result and classification

4.2 DATA ANALYSIS

Regression analysis which is a statistical technique for modeling and investigating the relationship between two or more variables is used. Regression analysis may take the form linear, parabolic, logarithmic etc. depending on the trend that may exist between the dependent and independent variables. Regression analysis can be either simple regression or multiple regression analysis, depending on the number of variables involved in the system. If the model contains more than one regression variable, then it is a multiple regression model. Alternatively, a regression model containing one independent variable or regressor is termed as simple regression model. A variable whose value is predicted is called dependent or response variable. A variable used to predict the value of dependent variable is termed independent or regressor variable.

For this study, since the number of variables involved is limited to two in number, linear Regression is assumed with best-fitting line for the bivariate observations in the form of

$y = ax + b$……………..(4.1)

Where

y= the response variable,

x= the predictor variable,

a, and b are coefficients, a stands for the y-intercept and b stands for the slope.

For this study, the shrinkage limit value(both linear and volumetric shrinkage value) is the dependent variable whereas plastic index value is the regressor variable. Scatter plot is used to show the relationship between the response and regressor variables using points of coupled linear, volumetric shrinkage test and plastic index test results as shown below the result were analyzes based on soil type so MLor CL soil type analys individualy but due to limited data availability combined MH or CH with CL or OL soil type for analysis.

Statistical software called XLSTAT is employed to study the relation between the regressor variable and the response variable.

Regression analysis between linear shrinkage with plastic index

For ML or OL soil classification

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ls	19	0	19	2.066	6.480	4.299	1.310
PI	19	0	19	4.360	14.820	9.119	2.903

Correlation matrix:

	PI	Ls
PI	**1**	0.997
Ls	0.997	**1**

Regression of variable Ls:

Goodness of fit statistics (Ls):

Observations	19.000
Sum of weights	19.000
DF	17.000
R^2	0.993
Adjusted R^2	0.993
MSE	0.012
RMSE	0.112
MAPE	1.646
DW	1.338
Cp	2.000
AIC	-81.451
SBC	-79.563

PC	0.008

Analysis of variance (Ls):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	30.683	30.683	2464.960	**< 0.0001**
Error	17	0.212	0.012		
Corrected Total	18	30.895			

Computed against model Y=Mean(Y)

Model parameters (Ls):

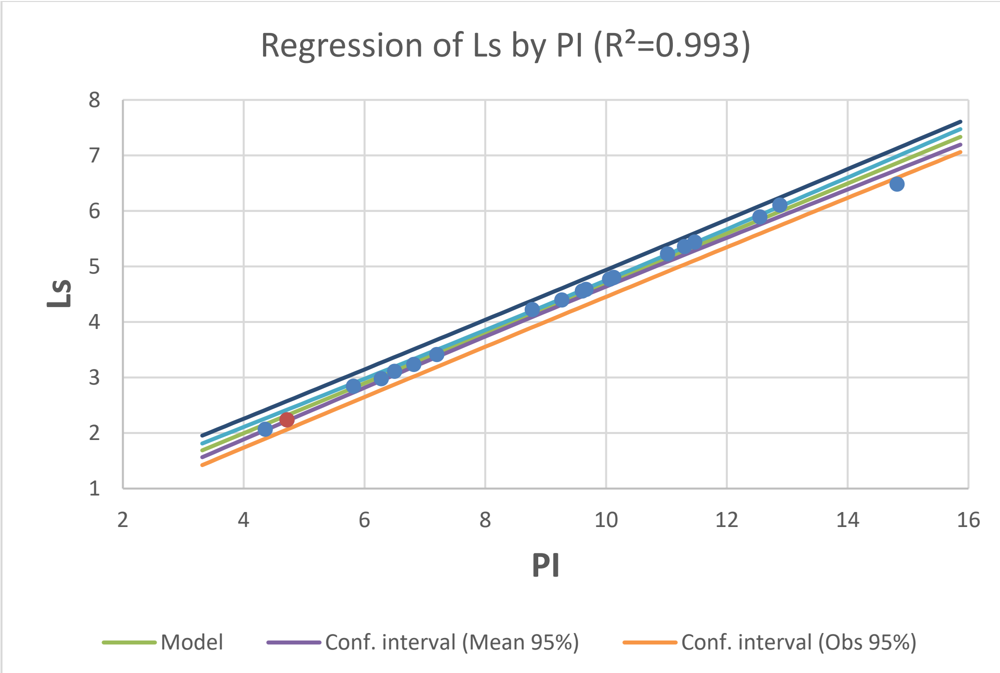
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	0.198	0.086	2.285	**0.035**	0.015	0.380
PI	0.450	0.009	49.648	**< 0.0001**	0.431	0.469

Equation of the model (Ls):

Ls = 0.197+0.449*PI

Standardized coefficients (Ls):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.997	0.020	49.648	**< 0.0001**	0.954	1.039


Regression of Ls by PI (R²=0.993)
8
7
6
5
4
3
2
1
Ls
2
4
6
8
10
12
14
16
PI
Model
Conf. interval (Mean 95%)
Conf. interval (Obs 95%)

Regression analysis between linear shrinkage with plastic index

For combined ML or OL& MH or OH Soil classification

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ls	11	0	11	7.735	21.820	13.956	4.660
PI	11	0	11	16.320	50.530	30.022	10.976

Correlation matrix:

	PI	Ls
PI	**1**	0.994
Ls	0.994	**1**

Regression of variable Ls:

Goodness of fit statistics (Ls):

Observations	11.000
Sum of weights	11.000
DF	9.000
R^2	0.988
Adjusted R^2	0.987
MSE	0.289
RMSE	0.538
MAPE	2.759
DW	2.685
Cp	2.000
AIC	-11.852
SBC	-11.057
PC	0.017

Analysis of variance (Ls):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	214.513	214.513	741.619	**< 0.0001**
Error	9	2.603	0.289		
Corrected Total	10	217.117			

Computed against model Y=Mean(Y)

Model parameters (Ls):

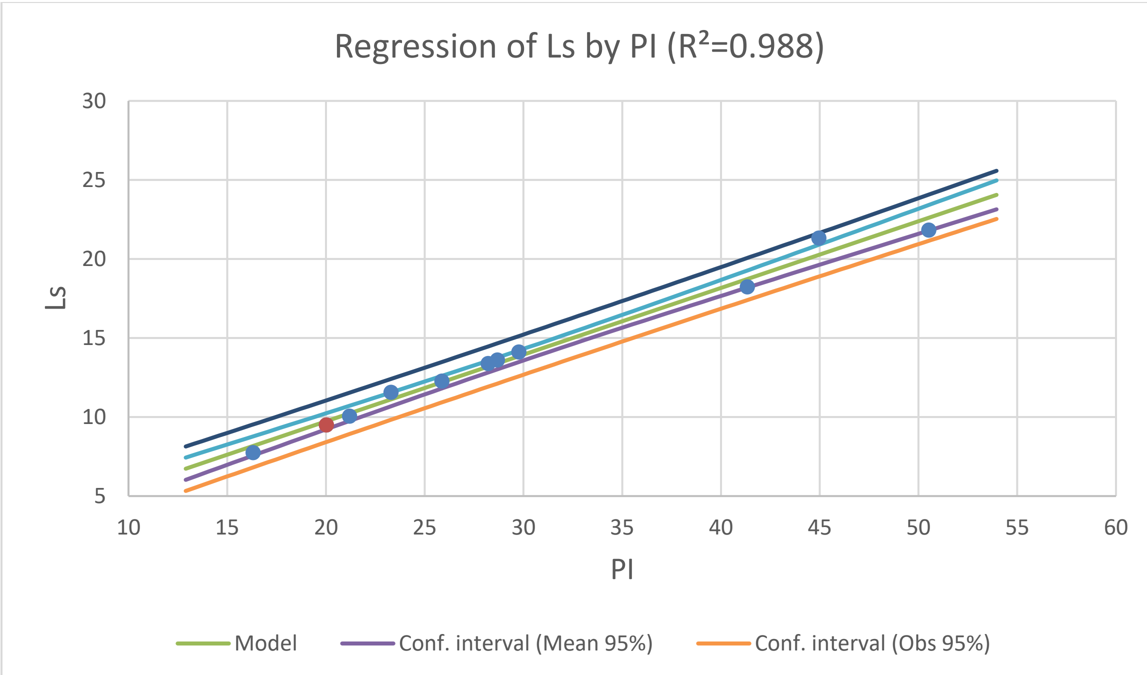
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1.288	0.493	2.614	**0.028**	0.173	2.402
PI	0.422	0.015	27.233	**< 0.0001**	0.387	0.457

Equation of the model (Ls):

Ls = 1.29+0.422*PI

Standardized coefficients (Ls):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.994	0.036	27.233	**< 0.0001**	0.911	1.077


Regression of Ls by PI (R^2=0.988)
Ls
PI
30
25
20
15
10
5
10
15
20
25
30
35
40
45
50
55
60
Model
Conf. interval (Mean 95%)
Conf. interval (Obs 95%)

Regression analysis between volumetric shrinkage and plastic index For ML or OL Soil classification

Summary statistics:

Variable	Observations	Obs. With missing data	Obs. Without missing data	Minimum	Maximum	Mean	Std. deviation
Vs	19	0	19	6.072	15.980	11.891	3.104
PI	19	0	19	4.360	14.820	9.119	2.903

Correlation matrix:

	PI	Vs
PI	**1**	0.976
Vs	0.976	**1**

Regression of variable Vs:

Goodness of fit statistics (Vs):

Observations	19.000
Sum of weights	19.000
DF	17.000
R^2	0.953
Adjusted R^2	0.951
MSE	0.476
RMSE	0.690
MAPE	4.409
DW	0.665
Cp	2.000
AIC	-12.210
SBC	-10.321
PC	0.058

Analysis of variance (Vs):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	165.346	165.346	347.229	**< 0.0001**
Error	17	8.095	0.476		
Corrected Total	18	173.441			

Computed against model Y=Mean(Y)

Model parameters (Vs):

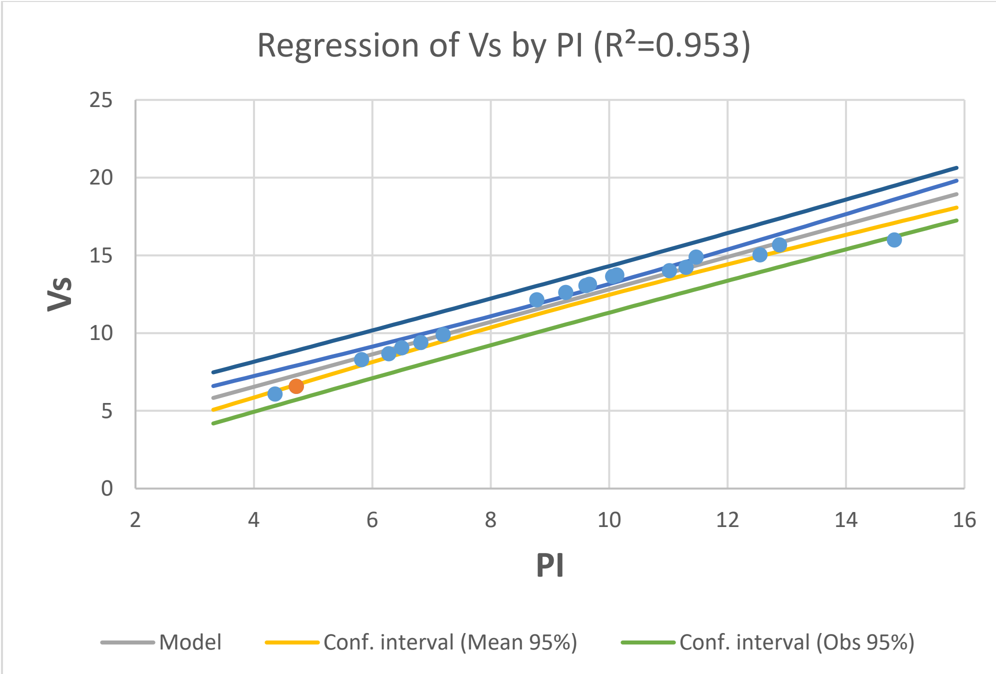
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	2.370	0.535	4.431	**0.000**	1.242	3.499
PI	1.044	0.056	18.634	**< 0.0001**	0.926	1.162

Equation of the model (Vs):

Vs = 2.37+1.04*PI

Standardized coefficients (Vs):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.976	0.052	18.634	**< 0.0001**	0.866	1.087


Regression of Vs by PI (R^2=0.953)
25
20
15
10
5
0
Vs
2
4
6
8
10
12
14
16
PI
Model
Conf. interval (Mean 95%)
Conf. interval (Obs 95%)

Regression analysis between volumetric shrinkage and plastic index

For combine CL or OL & MH or OH Soil classification

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviati
Vs	11	0	11	16.410	24.030	19.651	2.424
PI	11	0	11	16.320	50.530	30.022	10.976

Correlation matrix:

	PI	Vs
PI	**1**	0.985
Vs	0.985	**1**

Regression of variable Vs:

Goodness of fit statistics (Vs):

Observations	11.000
Sum of weights	11.000
DF	9.000
R^2	0.971
Adjusted R^2	0.968
MSE	0.190
RMSE	0.435
MAPE	1.517
DW	2.767
Cp	2.000
AIC	-16.503
SBC	-15.707
PC	0.042

Analysis of variance (Vs):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	57.046	57.046	300.984	**< 0.0001**
Error	9	1.706	0.190		
Corrected Total	10	58.752			

Computed against model Y=Mean(Y)

Model parameters (Vs):

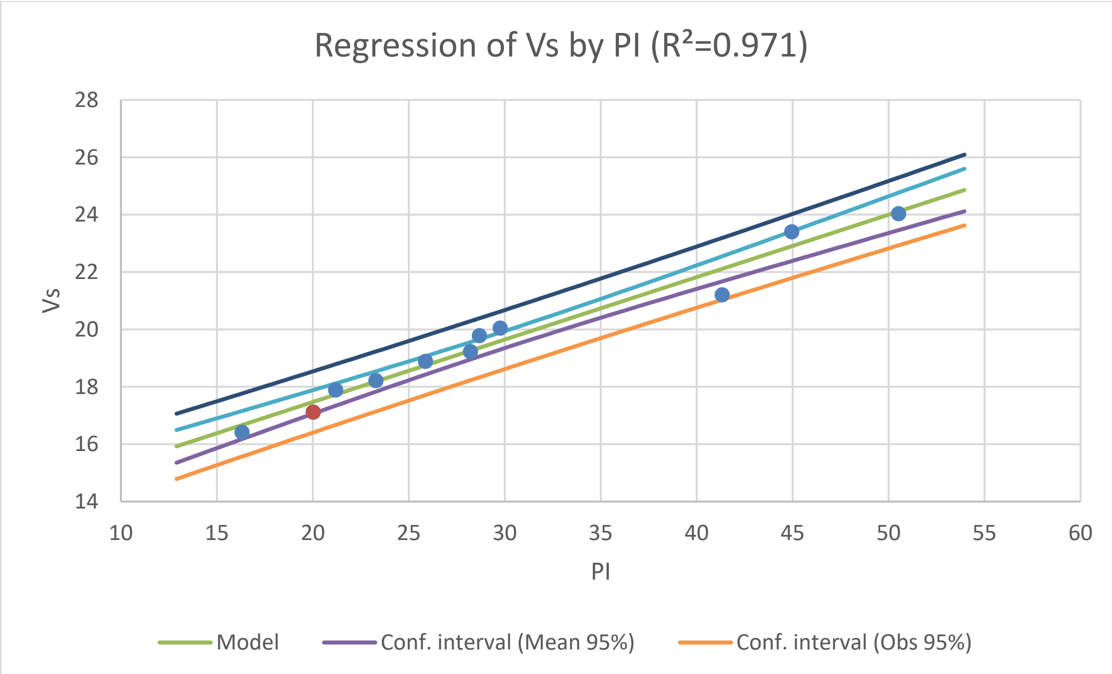
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	13.118	0.399	32.894	**< 0.0001**	12.216	14.020
PI	0.218	0.013	17.349	**< 0.0001**	0.189	0.246

Equation of the model (Vs):

Vs = 13.12+0.22*PI

Standardized coefficients (Vs):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.985	0.057	17.349	**< 0.0001**	0.857	1.114



General Regression analysis between linear shrinkage with plastic index

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean
LS	30	0	30	2.066	23.948	7.911
PI	30	0	30	4.360	50.530	16.783

Correlation matrix:

Variables	PI	LS
PI	**1.000**	0.999
LS	0.999	**1.000**

Regression of variable LS:

Goodness of fit statistics:

Observations	30.000
Sum of weights	30.000
DF	28.000
R^2	0.998
Adjusted R^2	0.998
MSE	0.078
RMSE	0.279
MAPE	1.286
DW	2.181
Cp	2.000
AIC	-74.657
SBC	-71.855
PC	0.003
Press RMSE	0.325

Analysis of variance:

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	959.426	959.426	12323.346	< 0.0001
Error	28	2.180	0.078		
Corrected Total	29	961.606			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis:

Source	DF	Sum of squares	Mean squares	F	Pr > F
PI	1	959.426	959.426	12323.346	< 0.0001

Type III Sum of Squares analysis:

Source	DF	Sum of squares	Mean squares	F	Pr > F
PI	1	959.426	959.426	12323.346	< 0.0001

Model parameters:

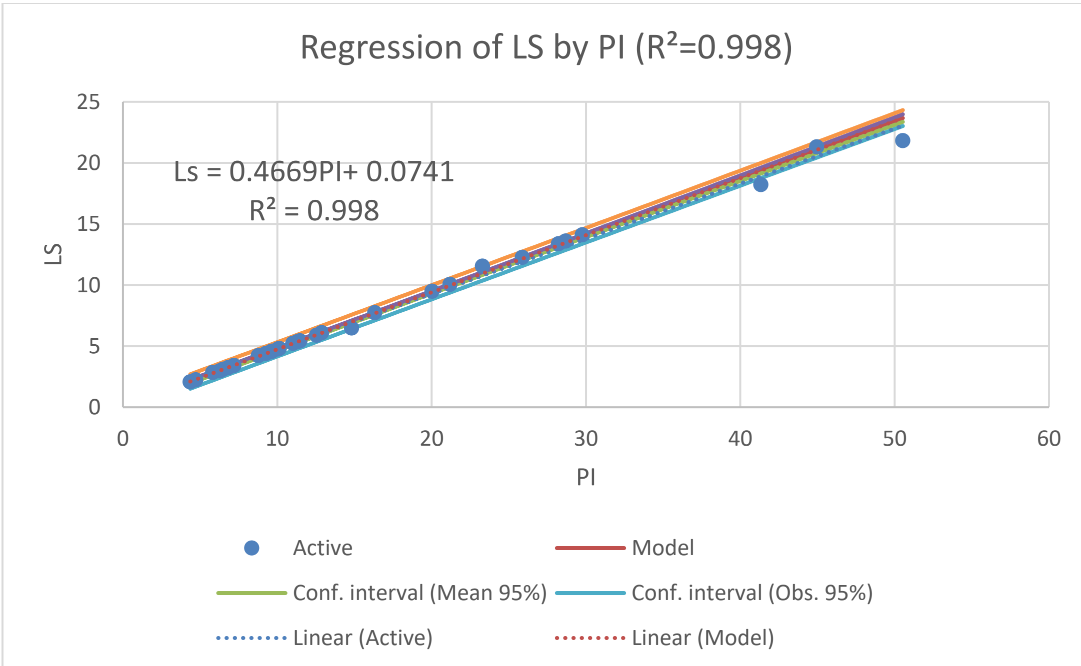
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	0.074	0.087	0.851	0.402	-0.104	0.252
PI	0.467	0.004	111.011	< 0.0001	0.458	0.476

Equation of the model:

LS = 0.0741+0.467*PI

Standardized coefficients:

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.999	0.009	111.011	< 0.0001	0.980	1.017



General Regression analysis between volumetric shrinkage and plastic index

Summary statistics:

Variable	Observations	Obs. With missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Vs	30	0	30	6.072	24.030	14.737	4.740
PI	30	0	30	4.360	50.530	16.783	12.318

Correlation matrix:

Variables	PI	Vs
PI	**1.000**	0.916
Vs	0.916	**1.000**

Regression of variable Vs:

Goodness of fit statistics:

Observations	30.000
Sum of weights	30.000
DF	28.000
R^2	0.978
Adjusted R^2	0.833
MSE	3.762
RMSE	1.940
MAPE	14.381
DW	0.176
Cp	2.000
AIC	41.678
SBC	44.480
PC	0.185
Press RMSE	2.123

Analysis of variance:

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	546.319	546.319	145.226	< 0.0001
Error	28	105.332	3.762		
Corrected Total	29	651.651			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis:

Source	DF	Sum of squares	Mean squares	F	Pr > F
PI	1	546.319	546.319	145.226	< 0.0001

Type III Sum of Squares analysis:

Source	DF	Sum of squares	Mean squares	F	Pr > F
PI	1	546.319	546.319	145.226	< 0.0001

Model parameters:

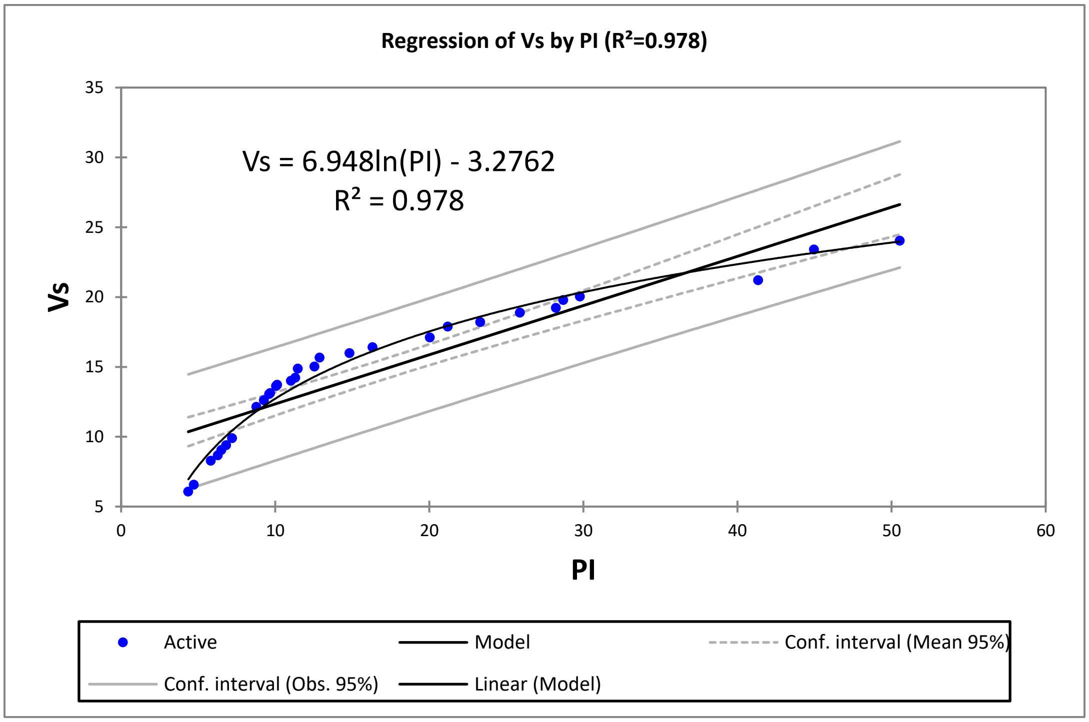
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	8.823	0.605	14.580	< 0.0001	7.583	10.062
PI	0.352	0.029	12.051	< 0.0001	0.292	0.412

Equation of the model:

Vs = 8.83+0.35*PI

Standardized coefficients:

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
PI	0.916	0.076	12.051	< 0.0001	0.760	1.071


Regression of Vs by PI (R²=0.978)
Vs = 6.948ln(PI) - 3.2762
R² = 0.978
Vs
PI
35
30
25
20
15
10
5
0
10
20
30
40
50
60
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)
Linear (Model)

Laboratory test Result				Newly developed linear and volumetric shrinkage				
LL	PI	LS	VS	Ls = 0.197+0.449PI	Ls = 0.4669PI– 0.0074	Vs = 2.37+1.04 PI	Vs = 6.948lnPI - 3.2762	Soil classification
27.13	4.36	2.07	6.07	2.15	2.11	6.90	6.95	ML or OL
27.88	4.72	2.24	6.56	2.32	2.28	7.28	7.51	ML or OL
31.00	5.82	2.84	8.28	2.81	2.79	8.42	8.96	ML or OL
31.13	6.28	2.98	8.67	3.02	3.01	8.90	9.49	ML or OL
31.80	6.50	3.11	9.04	3.12	3.11	9.13	9.73	ML or OL
32.90	6.82	3.23	9.39	3.26	3.26	9.46	10.06	ML or OL
33.86	7.20	3.41	9.89	3.43	3.44	9.86	10.44	ML or OL
37.75	8.78	4.22	12.13	4.14	4.17	11.50	11.82	ML or OL
37.40	9.27	4.39	12.61	4.36	4.40	12.01	12.20	ML or OL
38.00	9.61	4.55	13.05	4.51	4.56	12.36	12.45	ML or OL
34.00	9.67	4.58	13.13	4.54	4.59	12.43	12.49	ML or OL
35.48	10.06	4.77	13.63	4.71	4.77	12.83	12.76	ML or OL
36.50	10.13	4.80	13.72	4.75	4.80	12.91	12.81	ML or OL
38.00	11.02	5.22	14.00	5.14	5.22	13.83	13.40	ML or OL
39.15	11.30	5.36	14.22	5.27	5.35	14.12	13.57	ML or OL
42.13	11.47	5.44	14.88	5.35	5.43	14.30	13.68	ML or OL
46.19	12.55	5.89	15.02	5.83	5.93	15.42	14.30	ML or OL
42.50	12.88	6.10	15.66	5.98	6.09	15.77	14.48	ML or OL
44.70	14.82	6.48	15.98	6.85	6.99	17.78	15.46	ML or OL

Laboratory test Result				Newly developed linear and volumetric shrinkage				
LL	PI	LS	VS	Ls= 1.29+0.422PI	Ls = 0.4669PI – 0.0074	Vs=13.12+ 0.22PI	Vs = 6.948lnPI - 3.2762	Soil classification
47.95	16.32	7.73	16.41	8.18	7.69	15.71	16.13	CL or OL& MH or OH
46.70	20.03	9.49	17.11	9.74	9.43	16.53	`17.55	CL or OL& MH or OH
46.90	21.20	10.05	17.88	10.24	9.97	16.78	17.94	CL or OL& MH or OH
56.40	23.30	11.55	18.21	11.12	10.95	17.25	18.60	MH or OH& CL or OL
59.85	25.88	12.27	18.88	12.21	12.16	17.81	19.33	MH or OH& CL or OL
61.87	28.22	13.37	19.22	13.20	13.25	18.33	19.93	MH or OH& CL or OL
62.60	28.69	13.60	19.78	13.40	13.47	18.43	20.05	MH or OH& CL or OL
58.80	29.77	14.11	20.04	13.85	13.97	18.67	20.30	MH or OH& CL or OL
85.80	41.34	18.22	21.20	18.74	19.38	21.21	22.58	MH or OH& CL or OL
90.30	44.96	21.31	23.40	20.26	21.07	22.01	23.17	MH or OH& CL or OL
98.53	50.53	21.82	24.03	22.61	23.67	23.24	23.98	MH or OH& CL or OL

Laboratory test Result				Newly Developed linear &volumetric shrinkage for ML or OL				Literature developed linear and volumetric shrinkage			
LL	PI	LS	VS	Linear Shrinkage	Volumetric Shrinkage	Ls by PI Variance	Vs by PI Variance	BS1377, (1967) IP=2.13Ls	Variance	Head KH 1992 Vs=0.67PI+3.963	Variance
27.13	4.36	2.07	6.07	2.15	6.90	-0.09	-0.83	2.05	0.10	6.87	0.03
27.88	4.72	2.24	6.56	2.32	7.28	-0.08	-0.72	2.22	0.10	7.11	0.17
31.00	5.82	2.84	8.28	2.81	8.42	0.03	-0.14	2.73	0.08	7.84	0.58
31.13	6.28	2.98	8.67	3.02	8.90	-0.04	-0.24	2.95	0.07	8.15	0.75
31.80	6.50	3.11	9.04	3.12	9.13	-0.01	-0.09	3.05	0.07	8.30	0.83
32.90	6.82	3.23	9.39	3.26	9.46	-0.03	-0.08	3.20	0.06	8.51	0.95
33.86	7.20	3.41	9.89	3.43	9.86	-0.02	0.03	3.38	0.05	8.77	1.09
37.75	8.78	4.22	12.1	4.14	11.50	0.08	0.63	4.12	0.02	9.82	1.68
27.40	9.27	4.39	12.6	4.36	12.01	0.03	0.60	4.35	0.01	10.15	1.86
38.00	9.61	4.55	13.0	4.51	12.36	0.04	0.69	4.51	0.00	10.37	1.99
34.00	9.67	4.58	13.1	4.54	12.43	0.04	0.70	4.54	0.00	10.41	2.01
35.48	10.06	4.77	13.6	4.71	12.83	0.05	0.80	4.72	-0.01	10.67	2.16
36.50	10.13	4.80	13.7	4.75	12.91	0.06	0.82	4.76	-0.01	10.72	2.19
38.00	11.02	5.22	14.0	5.14	13.83	0.08	0.17	5.17	-0.03	11.31	2.52
39.15	11.30	5.36	14.2	5.27	14.12	0.08	0.10	5.31	-0.04	11.50	2.62
42.13	11.47	5.44	14.8	5.35	14.30	0.09	0.58	5.38	-0.03	11.61	2.69
46.19	12.55	5.89	15.0	5.83	15.42	0.06	-0.40	5.89	-0.06	12.33	3.09
42.50	12.88	6.10	15.6	5.98	15.77	0.12	-0.11	6.05	-0.07	12.55	3.21
44.70	14.82	6.48	15.9	6.85	17.78	-0.37	-1.80	6.96	-0.11	13.85	3.93

Laboratory test Result				Newly Developed linear &volumetric shrinkage for combined CL or OL& MH or OH				Literature developed linear and volumetric shrinkage			
LL	PI	LS	VS	Linear Shrinkage	Volumetric Shrinkage	Ls by PI Variance	Vs by PI Variance	BS1377, (1967) IP=2.13Ls	Variance	Head KH1992 Vs=0.67PI+3.963	Variance
47.9	16.3	7.73	16.4	8.18	15.71	-0.44	0.70	7.66	0.52	14.85	0.86
46.7	20.0	9.49	17.1	9.74	16.53	-0.25	0.58	9.40	0.34	17.32	-0.80
46.9	21.2	10.05	17.8	10.24	16.78	-0.19	1.10	9.95	0.29	18.10	-1.32
56.4	23.3	11.55	18.2	11.12	17.25	0.43	0.96	10.94	0.18	19.50	-2.26
59.8	25.8	12.27	18.8	12.21	17.81	0.05	1.07	12.15	0.06	21.22	-3.41
61.8	28.2	13.37	19.2	13.20	18.33	0.18	0.89	13.25	-0.05	22.79	-4.46
62.6	28.6	13.60	19.7	13.40	18.43	0.20	1.35	13.47	-0.07	23.10	-4.67
58.8	29.7	14.11	20.0	13.85	18.67	0.26	1.37	13.98	-0.13	23.82	-5.15
85.8	41.3	18.22	21.2	18.74	21.21	-0.52	-0.01	19.41	-0.67	31.54	-10.32
90.3	44.9	21.31	23.4	20.26	22.01	1.04	1.39	21.11	-0.85	33.95	-11.94
98.5	50.5	21.82	24.0	22.61	23.24	-0.79	0.79	23.72	-1.11	37.67	-14.43

Table 4. 2 Comparison between newly developed to existing correlation with variance

Checking validity of result of correlation developed for tendaho road project

Project :- Addis Ababa City Government Bureau of Labour & Social Affairs Social Protection Fund and Productive Safety Net Agency

for building of Two Warehouse(1,750ca.m**)**

LL	PI	LS	Ls = 1.29+0.422PI	varience	Soil classification
68.45	32.56	22.89	15.03	7.86	MH or OH
71.00	34.54	22.89	15.87	7.02	MH or OH
74.90	35.29	22.89	16.18	6.71	MH or OH
75.65	39.25	22.89	17.85	5.04	MH or OH
60.40	25.94	22.89	12.24	10.65	MH or OH
72.05	28.51	23.21	13.32	9.89	MH or OH
80.70	29.50	23.21	13.74	9.47	MH or OH
81.20	27.43	23.21	12.87	10.34	MH or OH
79.60	39.22	23.21	17.84	5.37	MH or OH
80.60	41.59	23.21	18.84	4.37	MH or OH

Project Tepi-Mizan Road Project

LL	PI	Vs	Vs=13.12+0.22PI	varience	Soil classification
65.15	25.25	19.86	18.68	1.19	MH or OH
55.6	21.91	19.42	17.94	1.48	MH or OH
62.7	22.96	19.52	18.17	1.35	MH or OH
63.4	23.8	19.64	18.36	1.28	MH or OH

5.0 CONCLUSIONS AND DISCUSSION

According to the output of statistical analysis, there exist a good correlation between linear shrinkage with plastic index as well as volumetric shrinkage with plastic index , Moreover, from the comparison result it can be seen that the newly developed correlation equation between linear shrinkage with plastic index as well as volumetric shrinkage with plastic index is closer to the laboratory linear and volumetric shrinkage value in laboratory and also .I observe linear volumetric shrinkage value depends on plastic index value from analysis result from both classified and general soil type value nearly similar.

This indicated that the correlation can be reliably used to predict linear and volumetric shrinkage value in Tendaho access road project. Nevertheless it should be noted that the behavior of fine grain soil are sensitive care should be taken in using the correlations as most of the correlations were site and condition specific and their use for other soils requires careful examination and engineering decision.

In relation to this, during the study it was tried to add the effect of the organic content as well as free swell characteristics of the representative samples on the correlation relation. The property of fine grain soil depends on their mineralogy as well as their surface tension so important to consider effect of mineralogy and free sell on the relation between linear shrinkage with plastic index as well as volumetric shrinkage with plastic index

However, it is noticed that the organic content content and free swell value obtained from test result were small so it has no effect on the correlation relation.

6.0 RECOMMENDATION

- ✓ The correlation developed in this study is applicable for locally used sub grade soils. It is recommended that studies to be made in different parts of the country and see the relationship with respect to location. This in a course of time and with a strong data base can be used to facilitate quick evaluation of road sub-grades based on simple test results.
- ✓ Further studies are also recommended on different types of soil, to see how the Relationship of these parameters behave.
- ✓ It is also recommended to check the applicability of the PI– Shrinkage relation for other, sub base and base courses.

ANNEX

ANNEX-2 Description of XLstat software

Results for linear regression in XLSTAT

- ✓ Summary of the variables selection: Where a selection method has been chosen, XLSTAT displays the selection summary. For a stepwise selection, the statistics corresponding to the different steps are displayed. Where the best model for a number of variables varying from p to q has been selected, the best model for each number or variables is displayed with the corresponding statistics and the best model for the criterion chosen is displayed in bold.
- ✓ Goodness of fit statistics: The statistics relating to the fitting of the regression model are shown in this table:
- ✓ Observations: The number of observations used in the calculations. In the formulas shown below, n is the number of observations.
- ✓ Sum of weights: The sum of the weights of the observations used in the calculations. In the formulas shown below, W is the sum of the weights.
- ✓ DF: The number of degrees of freedom for the chosen model (corresponding to the error part).
- ✓ R^2: The determination coefficient for the model. This coefficient, whose value is between 0 and 1, is only displayed if the constant of the model has not been fixed by the user. The R^2 is interpreted as the proportion of the variability of the dependent variable explained by the model. The nearer R^2 is to 1, the better is the model. The problem with the R^2 is that it does not take into account the number of variables used to fit the model.
- ✓ Adjusted R^2: The adjusted determination coefficient for the model. The adjusted R^2 can be negative if the R^2 is near to zero. This coefficient is only calculated if the constant of the model has not been fixed by the user. The adjusted R^2 is a correction to the R^2 which takes into account the number of variables used in the model.
- ✓ MSE: The mean of the squares of the errors (MSE).
- ✓ RMSE: The root mean square of the errors (RMSE) is the square root of the MSE.

- ✓ MAPE: The Mean Absolute Percentage Error.
- ✓ DW: The Durbin-Watson statistic. This coefficient is the order 1 autocorrelation coefficient and is used to check that the residuals of the model are not auto correlated, given that the independence of the residuals is one of the basic hypotheses of linear regression. The user can refer to a table of Durbin-Watson statistics to check if the independence hypothesis for the residuals is acceptable.
- ✓ Cp: Mallows Cp coefficient. The nearer the Cp coefficient is to p*, the less the model is biased.
- ✓ AIC: Akaike's Information Criterion. This criterion, proposed by Akaike (1973) is derived from the information theory and uses Kullback and Leibler's measurement (1951). It is a model selection criterion which penalizes models for which adding new explanatory variables does not supply sufficient information to the model, the information being measured through the MSE. The aim is to minimize the AIC criterion.
- ✓ SBC: Schwarz's Bayesian Criterion. This criterion, proposed by Schwarz (1978) is similar to the AIC, and the aim is to minimize it.
- ✓ PC: Amemiya's Prediction Criterion. This criterion, proposed by Amemiya (1980) is used, like the adjusted R^2 to take account of the parsimony of the model.
- ✓ Press RMSE: Press' statistic is only displayed if the corresponding option has been activated in the dialog box. Press's RMSE can then be compared to the RMSE. A large difference between the two shows that the model is sensitive to the presence or absence of certain observations in the model
- ✓ Type I SS table: It is used to visualize the influence that progressively adding explanatory variables has on the fitting of the model, as regards the sum of the squares of the errors (SSE), the mean of the squares of the errors (MSE), Fisher's F, or the probability associated with Fisher's F. The lower the probability, the larger the contribution of the variable to the model, all the other variables already being in the model. The sums of squares in the Type I table always add up to the model SS. Note: the order in which the variables are selected in the model influences the values obtained.

- ✓ Type III SS table: It is used to visualize the influence that removing an explanatory variable has on the fitting of the model, all other variables being retained, as regards the sum of the squares of the errors (SSE), the mean of the squares of the errors (MSE), Fisher's F, or the probability associated with Fisher's F. The lower the probability, the larger the contribution of the variable to the model, all the other variables already being in the model. Note: unlike Type I SS, the order in which the variables are selected in the model has no influence on the values obtained.
- ✓ Analysis of variance table: It is used to evaluate the explanatory power of the explanatory variables. Where the constant of the model is not set to a given value, the explanatory power is evaluated by comparing the fit (as regards least squares) of the final model with the fit of the rudimentary model including only a constant equal to the mean of the dependent variable. Where the constant of the model is set, the comparison is made with respect to the model for which the dependent variable is equal to the constant which has been set.
- ✓ The parameters of the model table: It displays the estimate of the parameters, the corresponding standard error, the Student's t, the corresponding probability, as well as the confidence interval
- ✓ Model equation: The equation of the model is then displayed to make it easier to read or re-use the model.
- ✓ Standardized coefficients table: The table of standardized coefficients is used to compare the relative weights of the variables. The higher the absolute value of a coefficient, the more important the weight of the corresponding variable. When the confidence interval around standardized coefficients has value 0 (this can be easily seen on the chart of normalized coefficients), the weight of a variable in the model is not significant.
- ✓ Predictions and residuals table: The predictions and residuals table shows, for each observation, its weight, the value of the qualitative explanatory variable, if there is only one, the observed value of the dependent variable, the model's prediction, the residuals, the confidence intervals together with the adjusted prediction if the corresponding options have been activated in the dialog box.

Two types of confidence interval are displayed: a confidence interval around the mean (corresponding to the case where the prediction would be made for an infinite number of observations with a set of given values for the explanatory variables) and an interval around the isolated prediction (corresponding to the case of an isolated prediction for the values given for the explanatory variables). The second interval is always greater than the first, the uncertainty being larger. If validation data have been selected, they are displayed at the end of the table.

- ✓ The table of influence diagnostics displays for each observation, its weight, the corresponding residual, the standardized residual (divided by the RMSERMSE), the studentized residual, the deleted residual, the studentized deleted residual, thee leverage, the Mahalanobis distance, the Cook's D, the CovRatio, the DFFit, the standardized DFFit, the DFBetas (one per model coefficient) and the standardized DFBetas

Reference

1. Chen FH, Ma GS (1987) Swelling and shrinkage behavior of expansive soils. In: Proceedings of the sixth international conference on expansive soils, vol 1. New Delhi, pp 120–129
2. Head KH (1992) Manual of soil laboratory testing 1: soil classification and compaction tests. Pentech Press, London
3. Holtz WG (1959) Expansive clays—properties and problems. QJ Colo Sch Min 54(4):89–125
4. Alemayehu, T. and Mesfine, L., "Soil mechanics," Addis Ababa, 1999
5. Department of scientific and industrial research, "Soil mechanics for road engineers," England, 1964
6. Lambe, T.W., "Soil testing for engineers," New York, 1951
7. ASTM, "special procedures for testing soil and rock for engineering purposes," Philadelphia 1996
8. AASHTO soil testing manual
9. British standard (BS) 1377: Part 2:1990 Methods of testing soils for civil engineering
10. Site Investigation Manual, Special Investigations, Ethiopian Roads Authority (ERA), 2002
11. Tendaho Sugarcane Expansion Irrigation Project, Inception Report, Geotechnical Site Investigation, Water Resources Development Authority (July 2012)
12. Technical Task Force for Tendaho Dam, Assessment of Technical Problems Around the Dam and Proposed Mitigation Measures, Water Resources Development Authority (March 2011)
13. Tefera et al, 1996, Geological Map of Ethiopia (1:2,000,000),Geological Survey of Ethiopia, Addis Ababa, Ethiopia
14. XLSTAT training manual

15. Whitlow, R. (2001) Basic Soil Mechanics. Prentice Hall, London

16. Dorota Izdebska-Mucha • Emilia Wo´jcik,2013 Testing shrinkage factors: comparison of methods and correlation with index properties of soils

17. Minstry of water and energy, Tendaho Road Project Geotechnical investigation