Addis Ababa Institute of Technology
School of Graduate Studies
Faculty of Technology
Department of Civil Engineering

SHEAR STRENGTH CHARACTERISTICS OF SOILS IN ADAMA TOWN

A thesis submitted to the school of graduate studies of
Addis Ababa Institute of Technology in partial fulfillment of the
requirements for the Degree of
Master of Science in Civil Engineering

By
Genet Kassahun

Advisor:
Dr. Messele Haile

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Approved by Board of Examiners

1.	Advisor	Signature	Date
2.	External Examiner	Signature	Date
3.	Internal Examiner	Signature	Date
4.	Chairman	Signature	Date

Dedicated

to

Adama town

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Last but not least, I would like to thank my family for their encouragement and support. I would also like to thank my friends, my classmates and all who helped me in doing this research work.

Table of contents **Page**

List of symbols

c Cohesion

c' Cohesion in terms of effective stress

c_u Cohesion for undrained condition

Φ Angle of internal friction

Φ' Angle of internal friction in terms of effective stress

Φ_u Angle of internal friction for undrained condition

e Void ratio

s or τ Shear strength

τ_m Maximum shear strength

τ_c Constant shear strength

σ Normal stress

σ_1 Major principal stress

σ_3 Minor principal stress

γ_d Dry density

M Mass

W Water content

^oC Degree centigrade

List of abbreviations

ASTM American Society for Testing and Material
USCS Unified Soil Classification System
a.m.s.l above mean sea level
MER Main Ethiopian Rift
OMC Optimum moisture content
MDD Maximum dry density
N North
E East
Eq. Equation
LL Liquid Limit
PL Plastic Limit
PI or I_p Plasticity Index
kN Kilo Newton
kPa kilo Pascal
km kilometer
m meter
cm centimeter
µm micrometer
mm millimeter
S. No. Serial number
E.C Ethiopian calendar
MH Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
OH Organic clays of medium to high plasticity, organic silts
CH Inorganic clays of high plasticity, fat clays
OL Organic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
ML Inorganic silts and very fine sands, rock flour, silts or layer fine sands, or clayey silts with slight plasticity
SM Silty sands, sand-silt mixtures

List of figures **Page**

List of tables Page

List of appendices **Page**

Abstract

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

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

In this research shear strength characteristics of Adama soil is studied. The shear strength parameters (c and Φ) are studied using disturbed soil samples remolded with different densities and water contents in order to simulate the field condition. The shear strength test is done using Digital Direct/Residual Shear apparatus.

The result obtained from the shear strength tests shows that as the density of the soil increase the shear strength of the soil also increase. The cohesion of the soil is strongly affected by the water content of the soil where as the angle of internal friction of the soil is not significantly affected.

1. INTRODUCTION

1.1 General

Shear Strength of soils is the most important engineering property. This is because all stability analysis in the field of geotechnical engineering, whether they relate to foundation, stability of slopes cuts or earth dams, involve a basic knowledge of this engineering property of the soil. Shear strength may be defined as the resistance to shearing stresses and a consequent tendency for shear deformation.

Shear strength of soil is the most difficult to comprehend in view of the multitude of factors known to affect it. A lot of maturity and skill may be required on the part of the engineer in interpreting the results of the laboratory tests for application to the conditions in the field.

Basically, a soil derives its shear strength from the following:

(1) Resistance due to the interlocking of particles.
(2) Frictional resistance between the individual soil grains, which may be sliding friction, rolling friction, or both.
(3) Cohesion between soil particles.

Granular soils of sands may derive their shear strength from the first two sources, while cohesive soils or clays may derive their shear strength from the second and third sources. Highly plastic clays in undrained condition however may exhibit the third source alone for their shearing strength. Most natural soil deposits are partly cohesive and partly granular and as such, may fall into the two or all of the three categories just mentioned, from the point of view of shear strength.

1.2 Objective of the study

The main objective of this work is to study the shear strength parameters of soils in Adama town. Specifically, it is intended to investigate the effect of consistency/density and water content on shear strength parameters of soils in Adama town. The shear strength parameters are determined using different density and water content taken from compaction curve.

1.3 Methodology

In this thesis work, review of the literatures has been done for understanding the accepted theories and practices in the topic at hand. In order to have more information about the study area, environmental condition like climate, Physiology, drainage and geology of the study area are also been reviewed.

In this work, the type of study was mainly experimental. Routine soil test on number of soil samples are necessary for full understanding of shear strength of the soil. In order to minimize effort and cost and maximize the information content of the study, at the site where soil sampling is carried out, target soil sampling technique are employed. In this technique, the sampling points are assumed to be representative for the total study area.

According to the objective of the research, more emphasis was given to the laboratory test which greatly helps to reveal the nature and shear strength characteristics. The laboratory tests are done according to ASTM and BS standards. Disturbed soil samples are collected from different areas of Adama. A digital controlled Direct/Residual Shear apparatus was used to determine the shear strength parameters. The shear strength parameters are determine under different density and water content taken from dry and wet sides of compaction curves when the soil is remolded or disturbed from its natural conditions of moisture, density and structure. The samples of the soils are also tested at dry and submerged (saturated) conditions.

Based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed thoroughly. Finally, the findings and results of the research have been reported.

1.4 Scope of the study

The thesis work was done on soils found in Adama town. Disturbed sample of soils from ten different test pits was taken at depths of 2-3m. Shear strength behavior of these soils were studied in the laboratory under remolded condition with different density and water content.

1.5 Limitation of the study

It was initially intended to collect both disturbed and undisturbed soil samples but, due to the nature of the soil, it was difficult to collect undisturbed soil sample. Therefore all the laboratory tests are done using disturbed sample of soils.

1.6 Organization of the research

The thesis has a total of five Chapters. Chapter one deals with the general introduction of shear strength. It also includes the objective, methodology, scope and limitations, as well as organization of the thesis. Chapter two is totally devoted to literature review, to summarize compaction and shear strength of soil. Chapter three describes the background, climatic condition, physiology, drainage and geology of the study area. Chapter four summarizes all laboratory tests conducted and their results. Chapter five contains discussion of test results. Chapter six contains conclusion and recommendation as output of this particular work. Reference is placed at the end and appendices are added.

2. LITERATURE REVIEW

2.1Compaction of soil

Compaction is a process that brings an increase in soil density, accompanied by a decrease in air volume with no change in water content. The degree of compaction is measured by dry unit weight and depends on the water content and compactive effort (weight of hammer, number of impacts, weight of roller and number of passes). For a given compactive effort, the maximum dry density occurs at optimum water content.

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density as a percentage of the maximum density measured in a standard laboratory test, and the water content.

In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density [11].

2.1.1 Factors affecting compaction

A number of factors affect the degree of compaction these can be [3]:

- Nature and type of soil, i.e. sand or clay, grading, plasticity
- Water content at the time of compaction
- Site conditions, e.g. weather, type of site, layer thickness
- Compactive effort (weight, vibration, number of passes)

2.1.2 Dry density/water content relationship

The aim of the test is to establish the maximum dry density that may be attained for a given soil with a standard amount of compactive effort. When a series of samples of a soil are compacted at different water content the plot usually shows a distinct peak (Fig. 2.1).

- The maximum dry density occurs at an optimum water content
- The curve is drawn with axis of dry density and water content and the controlling values are values read off:
- Different curves are obtained for different compactive efforts

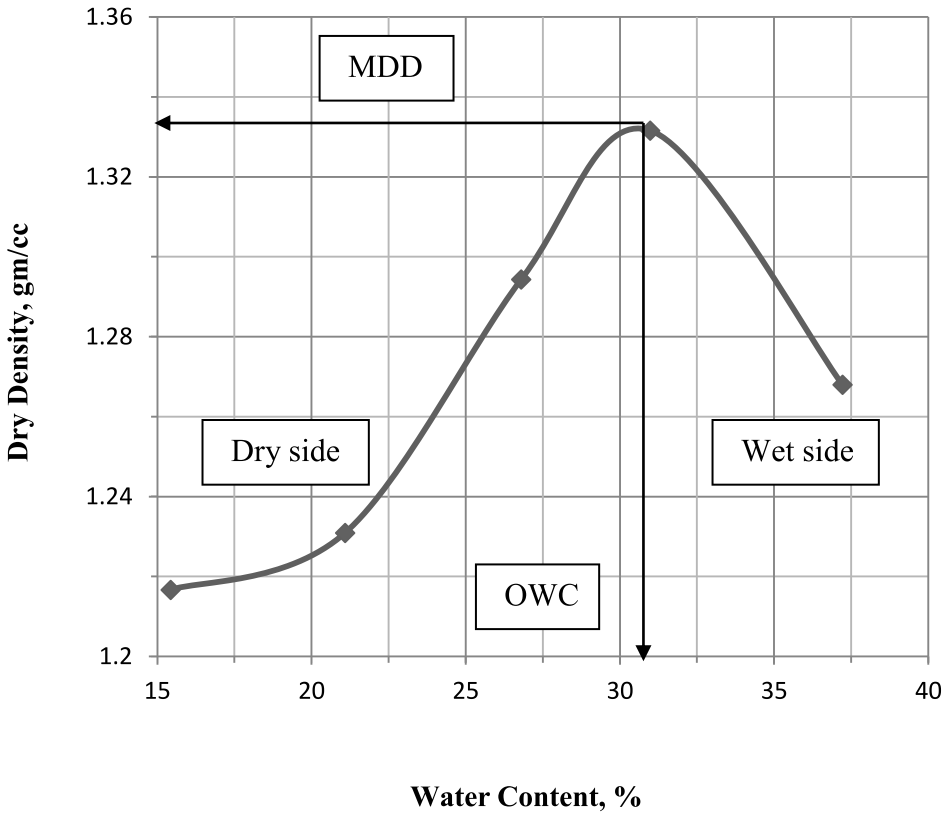

Fig. 2.1 MDD and OWC on compaction curve

Compacting soil at water content higher than or wet of the OWC results in a relatively dispersed soil structure or parallel particle orientations. The soil compacted lower than or dry of the OWC typically results in a flocculated soil structure or random particle orientations [11].

2.1.3 Effect of soil type on compaction

- Well-graded granular soils can be compacted to higher densities than uniform or silty soils.
- Cohesive soils have high air voids. These soils attain a relatively lower maximum dry density as compared to with cohesionless soils. Such soils require more water than cohesionless soils. Therefore the OMC content is high.
- As the percent of fines and the plasticity of a soil increases, the compaction curve becomes flatter and therefore less sensitive to moisture content. Equally, the maximum dry density will be relatively low [3].

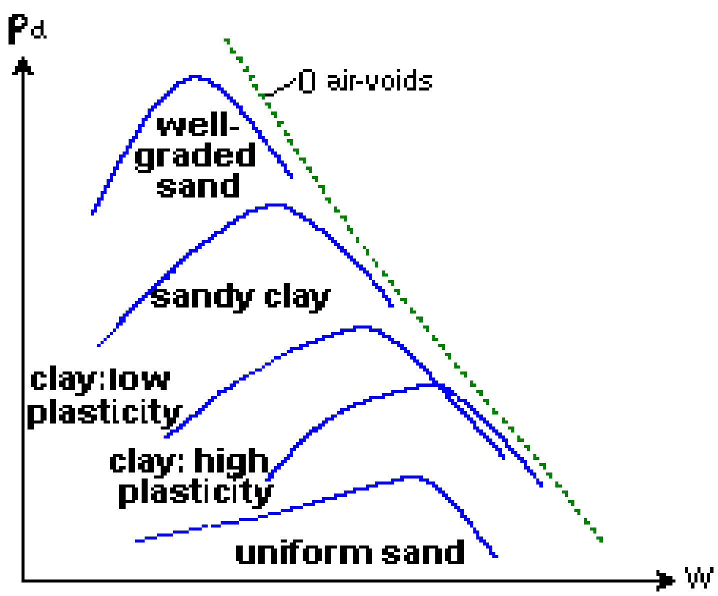

Fig. 2.2 Compaction curve for different types of soil [1]

2.2 Shear strength of soils

2.2.1 Introduction

One of the most important engineering properties of soil is its shear strength or ability to resist sliding along internal surfaces within a mass. The stability of a cut, the slope of an earth dam, the foundations of structures, the natural slopes of hillsides and other structures built on soil depend upon the shearing resistance offered by the soil along the probable surfaces of slippage. There is hardly a problem in the field of engineering which does not involve the shear properties of the soil in some way or another.

Shear strength is used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soils is a result of friction and interlocking of particles, and possibly bonding or cementation at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subject to shear strains [9].

2.2.2 Factors controlling shear strength of soils

The stress-strain relationship of soils, and therefore the shearing strength, is affected (Poulos 1989) by [9]:

1. **Soil composition (basic soil material)**: mineralogy, grain size and its distribution, shape of particles, pore fluid type and content, ions on grain and in pore fluid.
2. **State (initial)**: Defined by the initial void ratio, effective normal stress and shear stress (stress history). State can be described by terms such as: loose, dense, over consolidated, normally consolidated, stiff, soft, contractive, dilative, etc.
3. **Structure:** Refers to the arrangement of particles within the soil mass; the manner the particles are packed or distributed. Features such as

layers, joints, fissures, slickensides, voids, pockets, cementation, etc, are part of the structure. Structure of soils is described by terms such as: undisturbed, disturbed, remolded, compacted, cemented; flocculent, honey-combed, single-grained; flocculated, deflocculated; stratified, layered, laminated; isotropic and anisotropic.

4. **Loading conditions:** Effective stress path, i.e., drained, and undrained; and type of loading, i.e., magnitude, rate (static, dynamic), and time history (monotonic, cyclic).

2.2.3 The Coulomb Equation

Soils which are not purely granular exhibit an additional strength which is due to the cohesion between the particles. It is, therefore, customary to separate the shearing strength of such soils into two components, one due to the cohesion between the soil particles and the other due to the friction between them. The fundamental shear strength equation proposed by the French engineer Coulomb (1776) is

$$s = c + \sigma \tan\Phi \qquad (2.1)$$

This equation expresses the assumption that the cohesion c is independent of the normal pressure σ acting on the plane of failure. At zero normal pressure, the shear strength of the soil is expressed as

$$s = c \qquad (2.2)$$

The relationship between the various parameters of coulomb's equation is shown diagramatically in Fig 2.3.

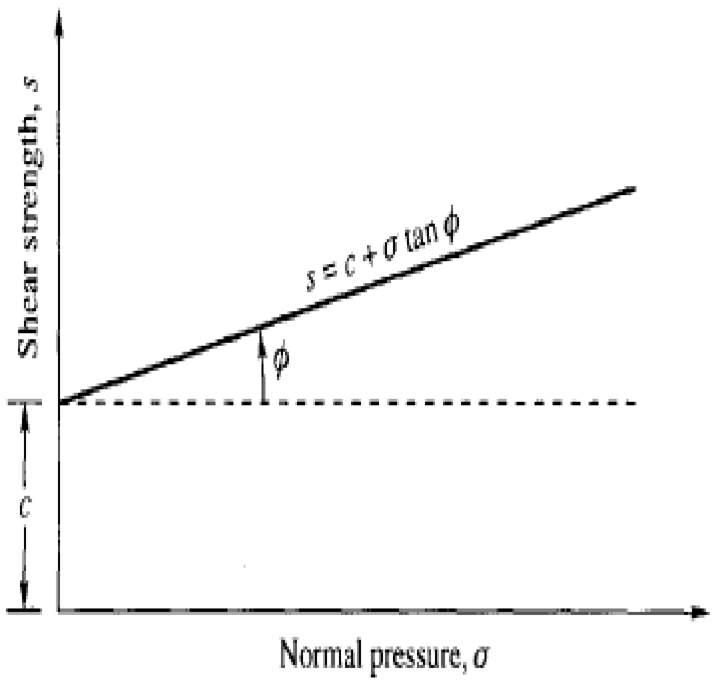

Fig 2.3 Figure showing Coulomb Law [9]

In Coulomb's equation c and Φ are empirical (shear strength) parameters, the values of which for any soil depends upon several factors; the most important of these are [1]:

1. The past history of the soil.
2. The initial state of the soil, i.e., whether it is saturated or unsaturated.
3. The permeability characteristics of the soil.
4. The conditions of drainage allowed taking place during the test.

Since c and Φ in Coulomb's Eq. (2.1) depend upon many factors, c is termed as apparent cohesion and Φ the angle of shearing resistance. For cohesionless soil c = 0, then Coulomb's equation becomes,

$$s = \sigma \tan\Phi \qquad (2.3)$$

2.2.4 Shear characteristics of cohesionless soils

The shear strength of cohesionless soils, such as sand and non- plastic silts, is mainly due to friction between particles. In dense sands, interlocking between particles also contributes significantly to the strength.

The stress-strain curve for dense sands exhibits a relatively high initial tangent modulus. The stress reaches a maximum value at its peak at a comparatively low strain and then decreases rapidly with an increasing strain and eventually becomes more or less constant. The stress-strain curve for loose sands exhibits a relatively low initial tangent modulus. At large strains, the stress becomes more or less constant [1].

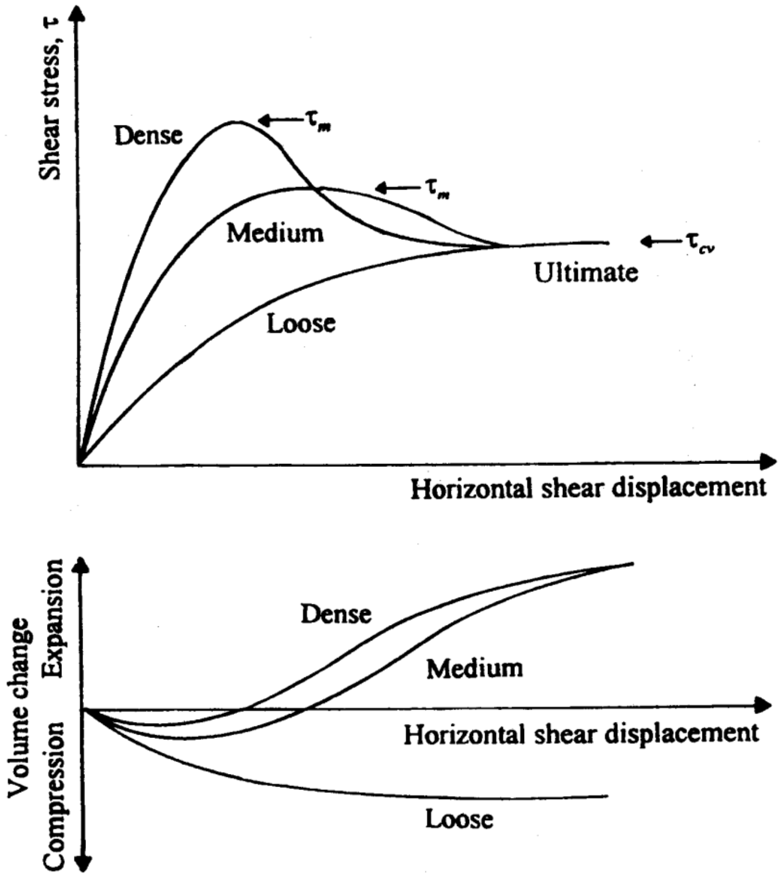

Fig 2.4 Typical direct shear test result in dense, medium and loose sands [5]

The dense sand shows initially a volume decrease in a drained test, but as the strain increases, the volume starts increasing. The loose sand shows a volume decrease throughout.

The factors that affect the shear strength of cohesionless soils are summarized below [1]:

1. **Shape of particles**. The shearing strength of sands with angular particles having sharp edges is greater than that with rounded particles, other parameters being identical.
2. **Gradation**. Well-graded sand exhibits greater shear strength than a uniform sand.
3. **Denseness**. The degree of interlocking increases with an increasing in density. Consequently, the greater the denseness, the greater the strength.
4. **Confining pressure**. The shear strength increases with an increase in confining pressure. However, for the range of pressures in the common field problems, the effect of confining pressure on the angle of shearing resistance is not significant [1].
5. **Deviator stress**. The angle Φ' decreases under very high stresses. As the maximum deviator stress is increased from 500 to 5000kN/m^2, the value of Φ' decreases by about 10%. This is due to the crushing of particles.
6. **Intermediate principal stress**. The intermediate principal stress affects the shear strength to a small extent. The friction angle for dense sands in the plane strain case is about 2^0 to 4^0 greater than that obtained from a true triaxial test. However, for loose sand, there is practically no difference in the two values.
7. **Loading**. The angle of shearing resistance of sand is independent of the rate of loading. The increase in the value of Φ' from the slowest to the fastest possible rate of loading is only about 1 to 2%.

8. **Vibration and repeated loading**. Repeated loading can cause significant changes. A stress much smaller than the static failure stress if repeated a large number of times can cause a very large strain and hence the failure.
9. **Type of minerals**. If the sand contains mica, it will have a large void ratio and a lower value of Φ'. However, it makes no difference whether the sand is composed of quartz or feldspar minerals.
10. **Capillary moisture**. The sand may have apparent cohesion due to capillary moisture. The apparent cohesion is destroyed as soon as the sand becomes saturated.

Table 2.1 gives the representative values of Φ' for different types of cohesionless soils.

Table 2.1 Representative values of Φ' for sands and silts [1]

S. No.	Soil	Φ'
1	Sand, round grains, uniform	27^0 to 34^0
2	Sand, angular, well-graded	33^0 to 45^0
3	Sandy gravels	35^0 to 50^0
4	Silty sand	27^0 to 34^0
5	Inorganic silt	27^0 to 35^0

2.2.5 Methods of determining shear strength parameters

The shear strength soils, either in the undisturbed or remolded states, may be determined by any of the following methods:

1. *Laboratory methods*
   (a) Direct or box shear test
   (b) Triaxial compression test
   (c) Unconfined compression test

2. *Field method*

Vane shear test or by any other indirect methods

Direct Shear Test

The direct shear test is widely used in geotechnical engineering in order to evaluate the shear strength characteristics of geomaterials.

The test is performed to determine the consolidated-drained shear strength of a sandy to silty soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance.

In direct shear tests the failure plane is pre-defined and the shear strength and deformation behaviour of soils can be studied only over a limited range of displacement.

The original form of apparatus for the direct application of shear force is the shear box. The apparatus consists of a square brass box split horizontally at the level of the centre of the soil sample, which is held between metal grilles and porous stones as shown in Fig. 2.5. Vertical load is applied to the sample as shown in the figure and is held constant during a test. A gradually increasing horizontal load is applied to the lower part of the box until the sample fails in shear. The test may be repeated with a few more samples having the same initial conditions as the first sample. Each sample is tested with a different vertical load.

Fig 2.5 Direct shear apparatus

The horizontal load is applied at a constant rate of strain. The lower half of the box is mounted on rollers and is pushed forward at a uniform rate by a motorized gearing arrangement. The upper half of the box bears against a steel proving ring, the deformation of which is shown on the dial gauge indicating the shearing force. To measure the volume change during consolidation and during the shearing process another dial gauge is mounted to show the vertical movement of the top platen. The horizontal displacement of the bottom of the box may also be measured by another dial gauge.

The soil to be tested in direct shear box may be either an undisturbed sample or made from compacted and remolded soil. The specimen may be prepared directly in the box and compacted. The test can be done both on dry and submerged soil sample.

The normal load is applied to give a normal stress. Shear load is then applied at a constant rate of strain. For drained test, the strain rate depends up on the type of soil. For sandy soil, it may be taken as 0.2mm/min; whereas for clayey soils, it is generally between 0.005 to 0.02mm/min [1].

The test is repeated under different normal stress as 50, 100, 200 and 400kN/m^2. The range of the normal stress should cover the range of loading in the field problem for which the shear parameters are required.

Advantages of Direct Shear Test

1. The direct shear machine is simple and fast to operate.
2. A thinner soil sample is used in the direct shear test thus facilitating drainage of the pore water quickly from a saturated specimen.
3. Direct shear test is much less expensive as compared to triaxial equipment.

3. DESCRIPTION OF THE STUDY AREA

3.1 Background

Adama is a central city in Oromiya regional state and a major city of Ethiopia. It is about 98km away from Addis Ababa in the southeast direction. Its approximate location is 8°33`35``N - 8°36`46``N latitude and 39°11`57``E - 39°21`15``E longitude. The city has an average altitude of 1,712m (5,617ft) above mean sea level (a.m.s.l).

The current total population of Adama district is 155,321 of which, 76,325 (49.14%) were female and 78,996 (50.86%) were male according to the 2007 population and housing census of Ethiopia [4].

Adama has a comfortable warm (occasionally a little bit hot) weather, virtually throughout the year. It is one of the fastest growing business centers, also a busy transportation center in Ethiopia. This city is suited along the road that connects Addis Ababa with Dire Dawa.

Adama is one of the most developing town, a conference center and a tourist resort in Ethiopia, it is expected that a lot of construction is going to be done in the future. However, very little work is done on investigating the engineering properties of soils in Adama. This is mainly due to the fact that many investigators have concentrated most of their efforts towards other towns of Ethiopia.

Some information shows that the surrounding countryside of Adama is renowned for its brown colored silty sand soil. But very little research has been done so far on the engineering characteristics of soils around this town.

3.2 Climatic conditions

In a mountainous tropical country like Ethiopia, altitude is the most important factor in controlling climate. It affects distribution of both temperature and rainfall. Generally, regions between 1500 - 2300 meters a.m.s.l categorized as 'woina dega' or sub tropical climate have temperatures that range between 15 - 20°C, areas between 500 - 1500 meters a.m.s.l i.e. 'kola' or tropical climate have 20 - 30°C and areas below 500 meters a.m.s.l. i.e. 'bereha' or desert climate have a temperature of 30°C and above [10].

The information indicated in Adama Master Plan (1995) reveals that the mean annual precipitation recorded for Adama is 822.5mm for the period of 39 years, 1952 to 1991. The mean annual rainfall for the period of 1998 to 2006 was computed to be 726.7mm. This figure is a little bit lower than the average total annual rainfall for most highland areas of Ethiopia (Alemneh, 1990; Messay, 2001).

Rainfall in this area is erratic in nature. There is a significant seasonal variation in the amount of rainfall. More than 67% of the mean annual rainfall occurs in the four rainy months: June, July, August and September. Some additional rains (about 23%) occur in the remaining dry months with mean monthly values of rainfall as low as zero millimetres [8].

Table 3.1 Mean Annual Rainfall in Centimetre (1998-2006)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total	Average
1998	11.8	25.6	105.2	19.8	49.3	55.3	196.5	220.6	144.7	132.8	0.0	0.0	**961.6**	**80.13**
1999	9.2	0.0	34.6	1.2	18.6	74	283.2	194.4	66.3	164.7	3.1	0.0	**849.3**	**70.78**
2000	0.0	0.0	20.2	16.1	51.5	60.8	355.1	269	133.6	85.7	57.8	12.9	**1062.7**	**88.56**
2001	0.0	6.2	108.3	28.7	177	51.2	216.8	145.3	107.8	1.7	0.0	6.6	**849.6**	**70.80**
2002	20.9	11.1	*	51.3	22.5	50.2	129.9	205.7	65.3	1.1	0.0	34.5	**592.5**	**53.86**
2003	46.5	69.1	151.2	88.9	3.6	75.2	235.6	279.7	122.8	0.0	5.3	48.8	**1126.7**	**93.89**
2004	28.8	3.3	77.4	53.1	1.9	63.3	114.4	227.3	77.1	58.6	12.8	1.6	**719.6**	**59.97**
2005	72.5	6.3	90.1	41.3	71.1	50.2	144.3	165	68.4	6.0	5.3	0.0	**720.5**	**60.04**
2006	17.6	88.4	64.6	88.7	27.8	58.7	173.5	225	128.8	10.1	0.5	28.5	**912.2**	**76.02**
Average	**23.1**	**23.3**	**81.5**	**43.2**	**47.1**	**59.9**	**205.5**	**214.7**	**101.6**	**51.2**	**9.4**	**14.8**	**866.1**	**72.70**

Source: National Metrological Service Agency (computed)

The town of Adama, with average altitude of 1,712 meters a.m.s.l., has mean minimum, mean maximum and mean average monthly temperatures of 13.1, 26.7 and 19.9°C respectively.

As indicated in Table 3.2 below, the highest temperature occurs just before or during the months of highest rainfall; whereas the least temperature occurs during the driest months: November, December and January. This may be because of the clear sky condition in the driest months, which lets the temperature escape to the upper layer of the atmosphere [8].

Table 3.2: Monthly mean maximum, minimum and average temperature in Adama town (1998 – 2007)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Mean Max (ºC)	26.7	28.9	29.3	29.9	31.1	29.8	26.2	25.7	27.1	27.6	27.0	25.9	26.7
Mean Min (ºC)	13.1	14.4	15.0	15.9	16.6	17.6	16.3	16.2	15.2	13.9	13.1	12.3	13.1
Average (ºC)	19.9	21.7	22.2	22.9	23.9	23.7	21.3	21.0	21.2	20.8	20.1	19.1	19.9

Source: National Metrological Service Agency (computed)

3.3 Physiology and Drainage

Adama is found within the Wonji Fault Belt, which is one of the main structural systems in the Ethiopian Rift Valley. Its physiographic condition is, therefore, mainly the result of volcano-tectonic activities that occurred in the past and also partly the result of the deposition of sediments, which are considered largely of fluvial and lacustrine origin. Adama is regarded as seismically active area concerning earthquake hazards.

The altitude of Adama varies from about 1600m to 1970m a.m.s.l. the only perennial river in the vicinity of Adama is Awash in to which all the streams in the town join [10].

3.4 Geology of the study area

3.4.1 Regional geology

The Ethiopian rift system which is part of the East African Rift system may be sub-divided in to three main sectors. These are: the south western Rift zone, the Main Ethiopian rift and Afar.

The Main Ethiopian Rift (MER) serves as a divide between the north western or Ethiopian plateau and the southeastern or Somalian plateau. According to many authors (Di paola, 1972; Mohr, 1986; and others) this rift is the result of tensional movements which affected the uplift Ethio-Somalian plateau.

Meyer etal., (1975) distinguished two main volcanic units in the northern part of the rift system. The first of these units is identified as "Nazret series" which includes a thick succession of ignimbrites, unwelded tuffs, ash flows, rhyolite and trachyte flows, according to Kazmin and Seifemichael (1978). The second volcanic unit is the young "Wonji series" built up mainly from extensive basaltic flows. Ignimbrites, rhyolite and trachyte flows, and pumice deposits are also found in this series [12].

3.4.2 Stratigraphy

It has been tried to reconstruct the composite stratigraphy of the area based mainly on lithologic correlation aided by available absolute age determination data and previous works.

The oldest volcanic rocks present in the area are represented by compact fiamme ignimbrite (I_1) which shows a contemporaneous emplacement with alternating flows of aphanitic dark basalt (B_1). These rocks are prominently exposed along north-northeast oriented faults in the area west and southwest of Nazret town.

The above sequence is followed by rhyolitic lava flows (R_1) which mainly formed the Boku Ridge and are associated with thin obsidian interlayerings.

The next stratigraphic is poorly welded lithic rich ignimbrite (I_2). The coarsely porphyritic vesicular basalt units (B_2) take a stratigraphic position above the I_2 unit. This vesicular porphyritic basalt unit in turn takes a stratigraphic position below the acidic volcanics (R_2) that formed the rhyolitic domes northeast and southeast of Nazret, and flows east of it. A particular section just west of Nazret (along road to Asseb) shows a white rhyolitic flow, which is believed to belong to this unit. Then comes is units that are products related to Gedemsa caldera. They are formed by ignimbrites, ash falls and flows pumice falls, and surges listed in a stratigraphic sequence from bottom to top as is displayed by sections in the northern part of the caldera.

The last phase of volcanic activity in the study area is represented by unwelded tuffs and basaltic cinder (and spatter) cones. Finally, the lacustrine and fluvial sediments represent the youngest deposit in the stratigraphic sequence [12].

3.4.3 Lithologic description

The rocks outcropping in the study area have been put in to six units mainly based on lithologic variations. These lithologic units are [12];

a) older pyroclastic deposits: which include poorly to intensely welded ignimbrites, ash flows and pumice fall deposits;
b) basic lava flows (basalts): consisting of an older aphanitic basalt flow and younger porphyritic vesicular basalts;
c) acidic lava flows: consisting of an older acidic lava flows which form the Boku Ridge;
d) younger pyroclastic deposits: which include ash flows and falls, pumice falls, ignimbrites and surge deposits which are products of the Gedemsa central volcano together with much younger unwelded tuff;
e) basaltic cinder and spatter products which form volcanic cones and associated basaltic lava flows; and finally
f) Reworked volcanics, laoustrine sediments, colluviums and alluvium sediments.

3.5 Map of Adama area

Adama is one of the largest and most populated towns in Oromiya National Regional State. The city has a total area of about 13,000 hectares, which has been subdivided into 14 urban kebele administrations [8].

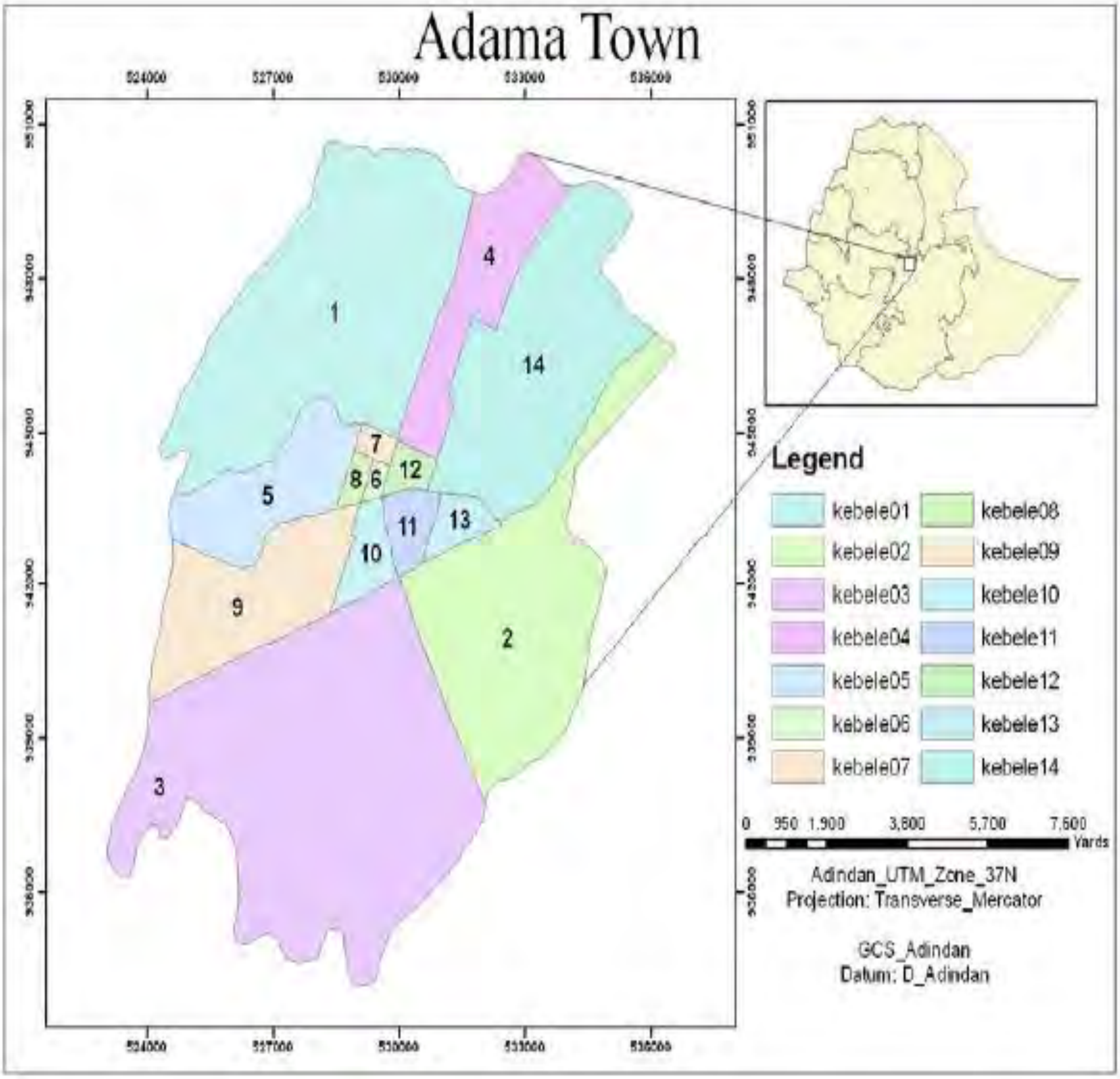

Fig. 3.1 Adama town in its National and Regional setting

4. LABORATORY TESTS AND RESULTS

4.1 General

The primary task of this study was to identify representative sample points which represent the total study area. Visual investigation and information from local residents was used for this purpose. About ten different pits are excavated by local labors. Depth of excavation was dependent on the existing condition of the ground. In some places boulder was encountered. On average, samples were generally taken at a depth of 2m to 3m.

About 30kg disturbed soil samples were collected from each sampling areas as summarized in Table 4.1 and shown in Fig 4.1. Soil samples are stored in plastic bags and transported to soil mechanics laboratory of AAiT for testing. All laboratory tests are done in the AAiT Geotechnical laboratory.

Table 4.1 Location of sample areas

Test Pit No.	Kebele	Location	Depth (m)	Northing	Easting	Elevation
1	04	Gichi	2.5	531856	945678	1653
2	12	Mazegaja	2.3	529976	944650	1615
3	09	Ketara	2.8	528655	943297	1612
4	01	Kechema	2.7	529233	945691	1641
5	03	Boku	2.5	530258	941824	1598
6	05	Cheffe	2.6	527055	943485	1643
7	14	Dibibisa	2.6	531379	944277	1604
8	02	Migira	2.3	530640	942118	1603
9	04	Sole	2.8	530683	946375	1634
10	03	Dabe	2.5	531303	939312	1633

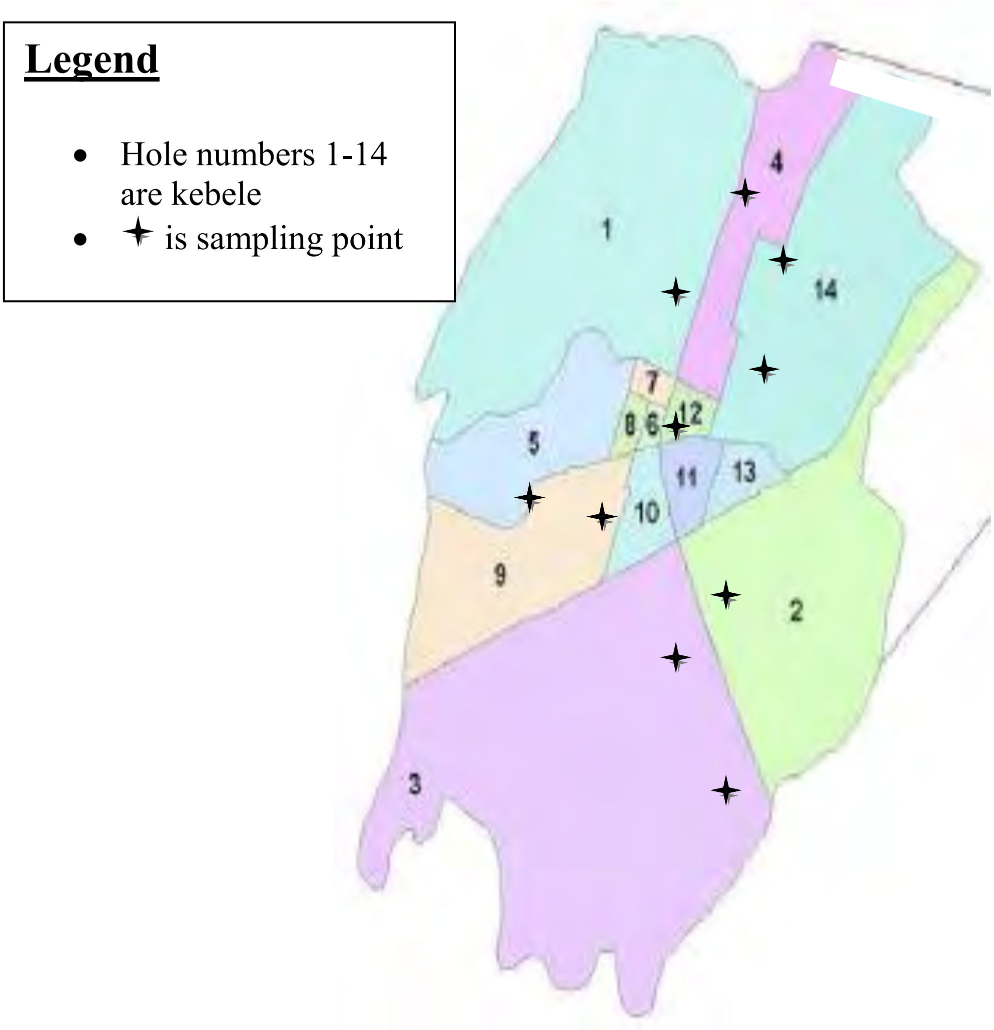

Fig 4.1 Location of sample area

Laboratory tests were conducted on disturbed soil samples. Tests such as grain size analysis, Atterberg limits and compaction were conducted on disturbed samples. Other test like direct shear tests were conducted on remolded samples. Laboratory tests were done according to ASTM and BS standards.

Soil samples were air dried and oven dried at 105^{0}c for the specific requirement of the test procedure. Soil remolding for the specified tests were done with standard compacting effort.

4.2 Particle size Analysis

Grain size analysis provide a useful classification system for soil, by determining the distribution of particle sizes in a given soil specimen. The distribution of particle sizes larger than 75 µm is determined by sieving while the distribution of particle size smaller than 75 µm (usually silt and clay) is determined by the sedimentation process using hydrometer analysis.

Wet preparation of soil samples is used to prepare a soil sample for particle size analysis when the coarse grained particles of a sample are soft and pulverize readily or when the fine particles are very cohesive and tend to resist removal from the coarse particles [2]. Due to the above reason wet preparation of soil sample for particle size analysis were used.

If the soil contains a substantial quantity (say, more than 5%) of fine particles, a wet sieve analysis is required. All lumps are broken into individual particles. A representative soil sample in the required quantity is taken, using a riffler, and air dried. The dried sample is taken in a tray and soaked with water. The sample is stirred and left for a soaking period of at least one hour. The slurry is then sieved through a 4.75mm sieve, and washed with a jet of water. The material retained on the sieve is the gravel fraction. It is dried in an oven, and sieved through set of coarse sieve.

The material passing through 4.75mm sieve is sieved through a 75µm sieve. The material is washed until the wash water becomes clear. The material retained on the 75µm sieve is collected and dried in an oven. It is then sieved through the set of fine sieves of the size 2mm, 1mm, 600µm, 425µm, 212µm, 150µm and 75µm. The material retained on each sieve is collected and weighted. The material that would have been retained on pan is equal to the total mass of soil minus the sum of the masses of material retained on all sieves.

The grain size distribution curve for the different soil samples are shown in the following figures. The grain size distribution and the corresponding grain size distribution curve are included in Appendix A.

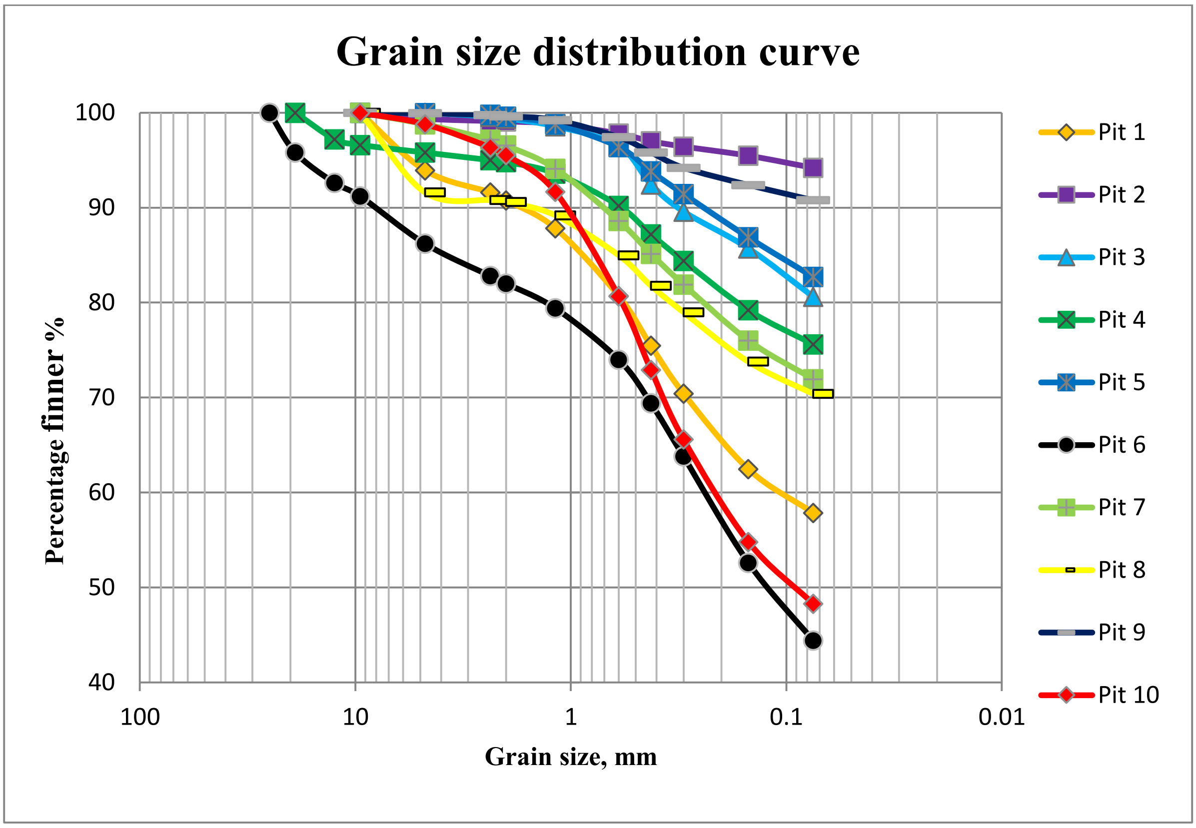

Fig. 4.2 Grain size distribution curve of soil sample for test pit 1-10

4.3 Atterberg limit test

The objective of the Atterberg limits test is to obtain basic index information about plasticity of the soil. It is the primary form of classification for fine grained soils.

Soil samples passing 425μm sieve were used for Atterberg limits determination. Casagrand's apparatus was used for the determination of liquid limit. For the determination of plastic limit a soil sample was rolled in to 3mm thread until it begins to crumble.

Dagnachew Debebe has done a thesis on investigating in to some of the engineering characteristics of soils in Adama town using the same sampling areas and the same soil samples. The test result of Atterberg limits and plasticity index for the ten soil samples taken from Dagnachew thesis is given in Table 4.2 [7].

Table 4.2 Result of Atterberg limits and plasticity index [7]

Test pit No.	Depth (m)	Liquid Limit, LL (%)	Plastic Limit Test, PL (%)	Plasticity Index, PI
01	2.5	38	26	12
02	2.3	48	35	13
03	2.8	73	39	34
04	2.7	39	30	9
05	2.5	47	33	14
06	2.6	29	21	8
07	2.6	35	28	7
08	2.3	31	24	7
09	2.8	57	26	31
10	2.5	30	25	5

4.4 Standard compaction test

Standard proctor compaction test is performed to determine the relationship between the moisture content and the dry density of a specific soil sample at a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Soil specimens, some sun dried and others air dried, passing the No. 4.75mm sieve was soaked overnight. Then, they were compacted in a cylindrical mold of 944cm^3 volume (10cm diameter and 12cm height) standard proctor mold by repeated blows from the mass of a hammer 2.5kg falling freely from a height of 30.5cm. The soils were compacted with different moisture content in three layers, each layer being subjected to 25 blows.

The laboratory test results and the corresponding compaction curves are included in Appendix B. After obtaining density and moisture of each compacted soil samples, the following relationships for dry density and moisture content are obtained.

Table 4.3 OMC and MDD results

Test pit No.	OMC, %	MDD, gm/cm^3	Wet density, gm/cm^3
01	25	1.46	1.83
02	26	1.47	1.86
03	26	1.37	1.73
04	24	1.51	1.88
05	31	1.33	1.74
06	20	1.62	1.95
07	26	1.47	1.85
08	29	1.44	1.85
09	37	1.26	1.72
10	20	1.43	1.72

4.5 Direct shear test

Direct shear test is performed to determine the consolidated-drained shear strength of a sandy to silty soil. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall.

The direct shear test is one of the common strength tests for soils. In the laboratory, a direct shear device will be used to determine the shear strength of a cohesionless soil (i.e. angle of internal friction (Φ) and cohesion (C)). The test is performed by deforming a specimen at a controlled strain rate on or near a single shear plane determined by the configuration of the apparatus.

From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific normal confining stress. After the experiment is run several times for various vertical-normal stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced. From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn and c and Φ values may be determined [2].

According to the scope and the objectives of this research the direct shear test is done on samples of soil remolded at different dry density and moisture content.

Samples of soil for the first group of test is remolded using the MDD and OMC. The test was done at submerged (saturated) condition. The c and Φ results are summarized in Table 4.3. The second and the third group of tests are done using samples of soil remolded with dry density and moisture content taken from the dry and wet side of a compaction curve accordingly. The two tests were done without saturating the sample. The C and Φ values with the corresponding moisture content and dry density are given in Table 4.4 and Table 4.5.

The stress-strain curve for the first, second and third group of test from the direct shear tests are included in Appendix C.

Table 4.4 C and Φ values of soils remolded with OMC and MDD

Test Pit No.	**Soil description**	**MDD, gm/cc**	**OMC, %**	**C, kPa**	**Φ,^{0}**
01	ML	1.46	25	10.82	29.38
02	ML	1.47	26	6.95	25.69
03	MH	1.37	26	7.01	23.16
04	ML	1.51	24	6.65	25.01
05	ML	1.33	31	18.25	30.21
06	SM	1.62	20	12.30	29.88
07	ML	1.47	26	8.91	29.17
08	ML	1.44	29	9.80	32.26
09	MH	1.26	37	7.61	23.83
10	SM	1.43	20	15.06	28.53

Table 4.5 C and Φ values of soils remolded with moisture content and dry density taken from the dry side of compaction curve

Test Pit No.	Soil description	Dry density, gm/cc	Moisture content, %	C, kPa	Φ,^{0}
01	ML	1.38	20	7.28	27.92
02	ML	1.46	20	5.63	24.40
03	MH	1.29	19	6.32	22.28
04	ML	1.42	20	5.75	22.93
05	ML	1.30	27	13.75	26.31
06	SM	1.53	17	10.8	28.28
07	ML	1.32	20	7.13	27.62
08	ML	1.33	22	6.82	28.01
09	MH	1.22	33	6.20	21.80
10	SM	1.43	20	11.32	26.80

Table 4.6 C and Φ values of soils remolded with moisture content and dry density taken from the wet side of compaction curve

Test Pit No.	Soil description	Dry density, gm/cc	Moisture content, %	C, kPa	Φ,^{0}
01	ML	1.42	29	6.85	26.18
02	ML	1.44	28	4.86	24.78
03	MH	1.31	37	6.27	22.86
04	ML	1.44	29	4.65	24.94
05	ML	1.30	35	10.65	27.21
06	SM	1.55	24	9.83	29.09
07	ML	1.38	31	6.28	25.96
08	ML	1.40	32	6.01	30.11
09	MH	1.20	44	5.86	20.55
10	SM	1.37	31	10.39	27.72

5. DISCUSSION OF TEST RESULTS

Soil Classification

Soil classification was done according to USCS (Unified Soil Classification System). “A-line” separates the ‘MH or OH’ and the ‘CH or OH’ designation.

The USCS shows that the soil samples from test pit 1, 2, 4, 5, 7 and 8 are classified as ML (Inorganic silts and very fine sands). The soil samples from test pit 3 and 9 are classified as MH (Inorganic silts). While the soil samples from test pit 6 and 10 are classified as silty sand type of soil.

The soil classification is summarized in Table 5.1 and Fig 5.1.

Table 5.1 USCS classification of soil samples

Test pit No.	Depth (m)	Soil type
01	2.5	ML (Inorganic silts and very fine sands)
02	2.3	ML (Inorganic silts and very fine sands)
03	2.8	MH (Inorganic silts)
04	2.7	ML (Inorganic silts and very fine sands)
05	2.5	ML (Inorganic silts and very fine sands)
06	2.6	SM (silty sands)
07	2.6	ML (Inorganic silts and very fine sands)
08	2.3	ML (Inorganic silts and very fine sands)
09	2.8	MH (Inorganic silts)
10	2.5	SM (silty sands)

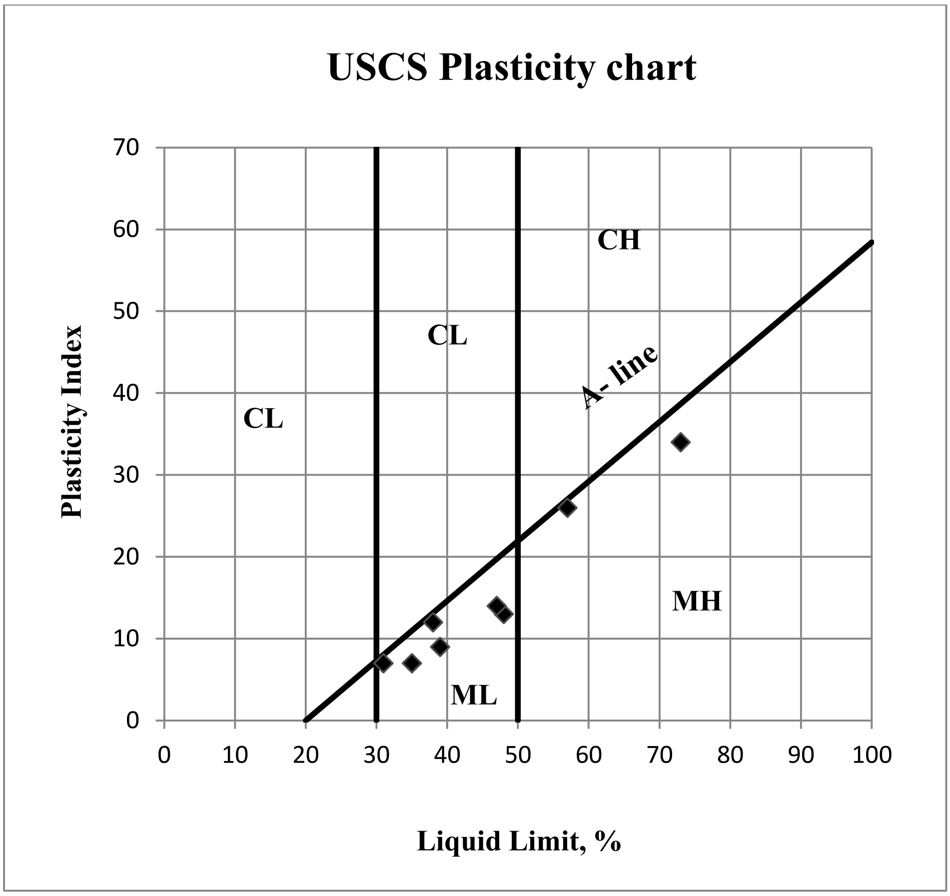

Fig 5.1 The USCS Plasticity chart classification of soil samples

Direct shear test

The direct shear test is done using soil sample from ten different test pits remolded with different density and water content. Samples of soil for the first group of test is remolded using the MDD and OMC. The second and the third group of tests are done using samples of soil remolded with dry density and moisture content taken from the dry and wet side of a compaction curve accordingly.

The range of c and Φ values of soils remolded with OMC and MDD are summarized in Table 5.2

Table 5.2 The c and Φ values of soils remolded with OMC and MDD

Type of soil	C (kPa)	$\Phi(^0)$
ML	6-18	25-32
MH	7-8	23-24
SM	12-15	28-30

The shear strength of the soil increase with an increase in the compactive effort till a critical degree of saturation is reached. With further increase in the compactive effort the shear strength decreases. Therefore the c and Φ values of soils remolded with OMC and MMD are greater than soils remolded with dry or wet of the OMC.

Compacting at water contents higher than (wet of) the OMC results in a relatively dispersed soil structure (parallel particle orientation) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling which results weak shear strength than soil compacted dry of optimum. The soil compacted lower than (dry of) the OMC typically results flocculated soil structure (random particle orientation) that has the opposite characteristics of the soil compacted wet of the OMC. Therefore the c values of soils remolded with water content lower than (dry of) the OMC are greater than soils remolded with water content higher than (wet of) the OMC (Fig 5.2).

On soil samples from test pit 3, 4, 6, 8 and 10 the Φ value increase in soil sample remolded with water content wet of the OMC than soils remolded with water content dry of OMC. While on soil samples from test pit 1, 5, 7 and 10 the Φ value decrease in soil sample remolded with water content wet of the OMC than soils remolded with water content dry of OMC (Fig 5.3). This indicates that the Φ values vary as the amount of water content varies.

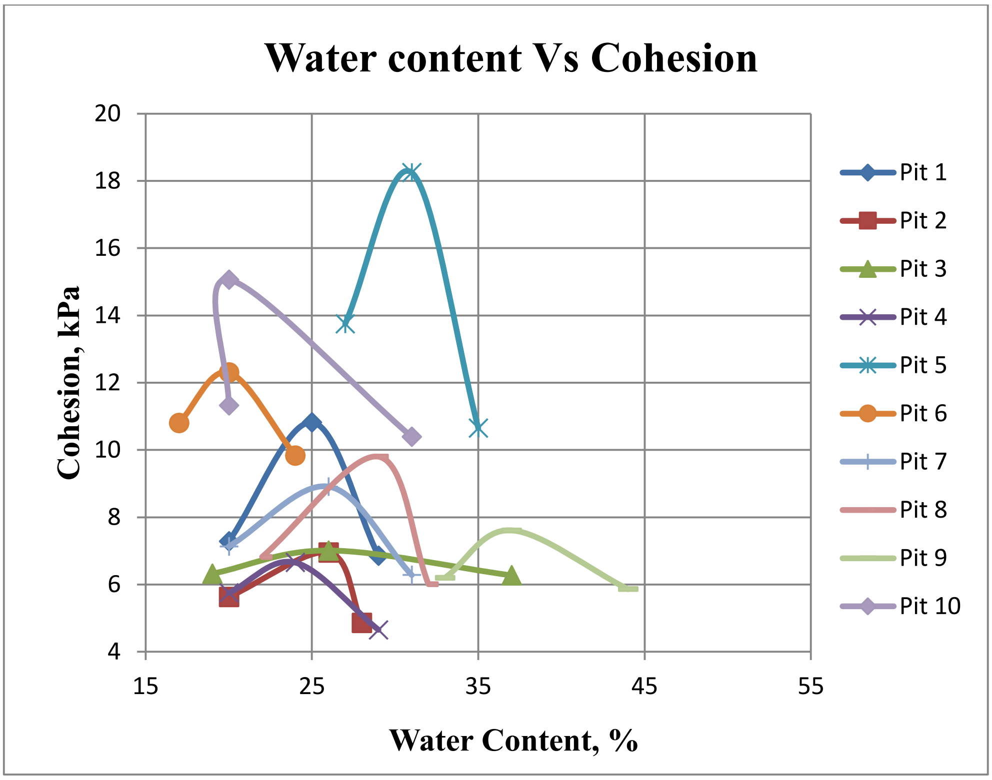

Fig 5.2 Water content Vs Cohesion

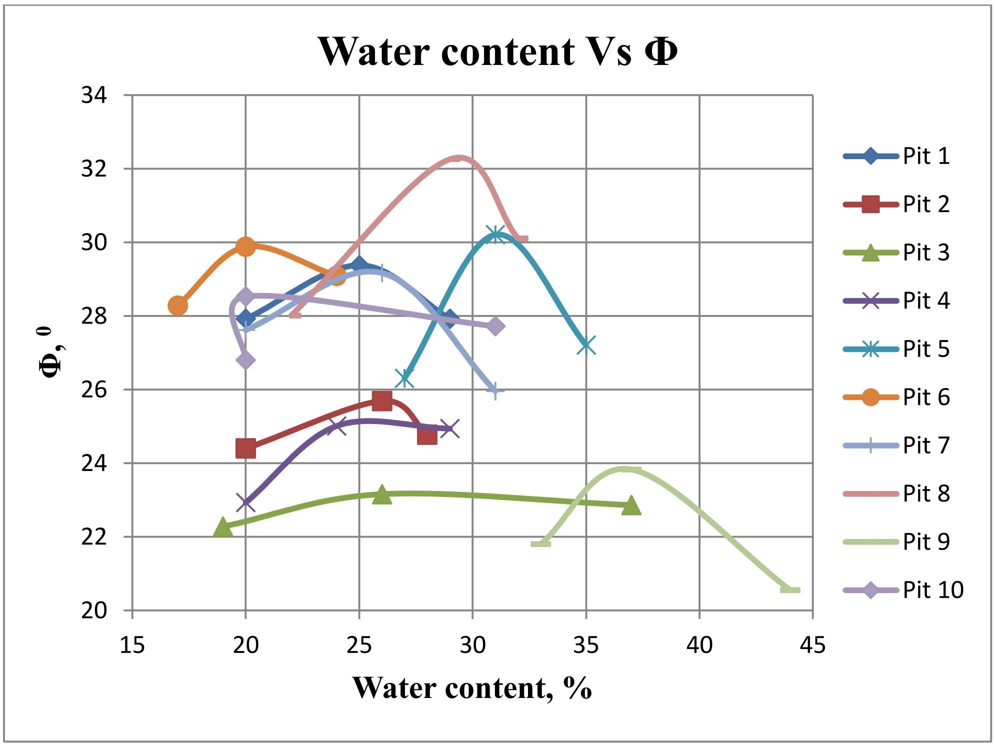

Fig 5.3 Water content Vs Φ

The variation of cohesion, C and angle of internal friction, Φ with the corresponding horizontal displacement for all the soil samples, are shown in the next two figures.

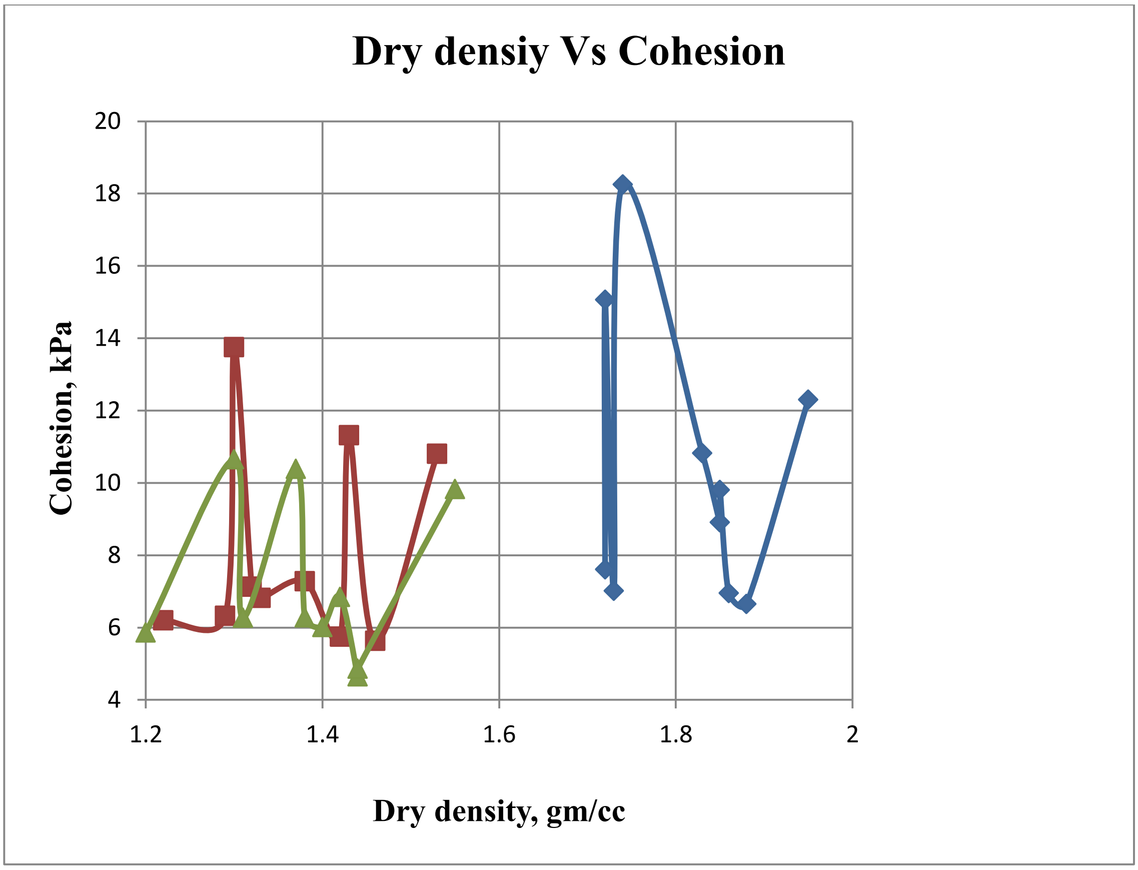

Fig 5.4 Dry density Vs Cohesion

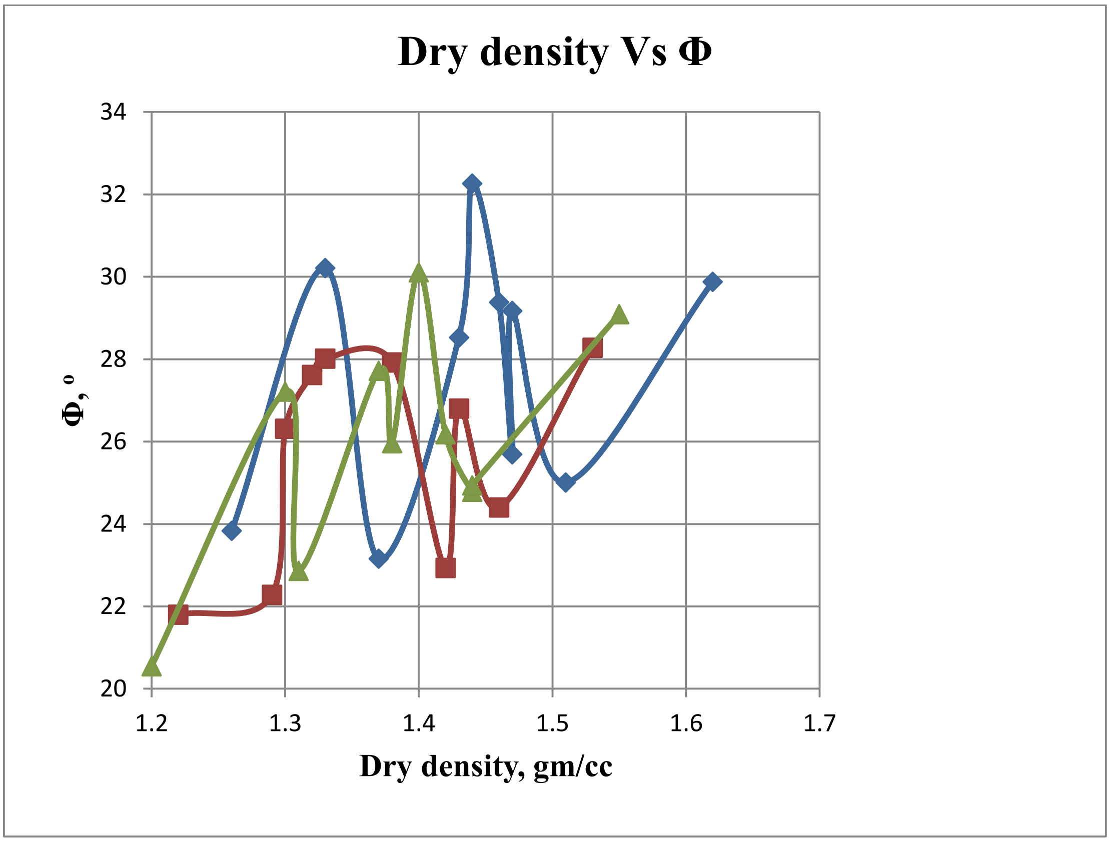

Fig 5.5 Dry density Vs Φ

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From the laboratory tests, the type of soil and the shear strength characteristics of Adama soils are concluded as follows.

1. The USCS shows that most of the Adama area is covered by inorganic silt and very fine sand (ML) and some of the places are covered by inorganic silt (MH) and silty sand (SM) type of soils.
2. For sample of soils remolded with OMC and MDD, the c value for ML type of soil ranges 6-18kPa, for MH type of soil ranges from 7-8kPa and for SM type of soil ranges from 12-15kPa.
3. For sample of soil remolded with OMC and MDD, the Φ value for ML type of soil ranges from 25^0-32^0, for MH type of soil ranges from 23^0-24^0 and for SM type of soil ranges from 28^0-30^0.
4. As it was expected the c and Φ values of soils remolded with OMC and MDD are greater than soils remolded with dry or wet of the OMC.
5. The c values of soils remolded with water contents lower than (dry of) the OMC are greater than soils remolded with water contents higher than (wet of) the OMC.
6. The Φ values increase in some soil samples remolded with water contents dry of the OMC than soil compacted wet of the OMC, while some other soil samples has the opposite characteristics. This shows Φ value is not strongly dependent on water content.

6.2 Recommendation

1. It is recommended that further researches can be conducted with increased number of soil samples from same place and additional areas that are not included in this research work.
2. This research topic can also be further employed by investigating shear strength characteristics of soils in Adama town on remolded soil samples with field density or using undisturbed soil samples.
3. Shear strength test is a very complicated and time taking test to conduct. Therefore, it is recommended if shear strength characteristics of Adama silty sand type of soils can be correlated with other engineering properties of soils for preliminary design purpose and similar projects like residential houses.

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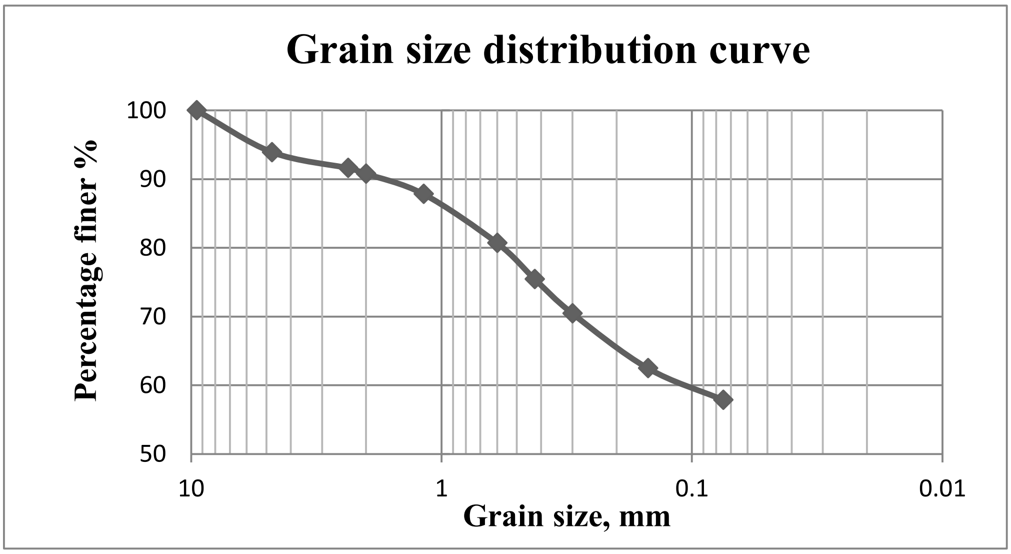
APPENDIX-A

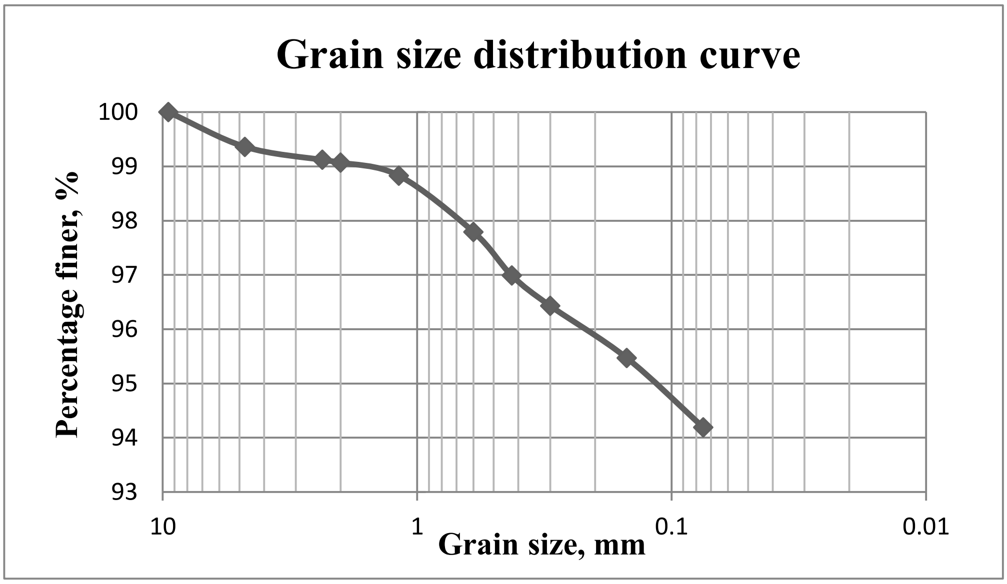
Particle Size Analysis
Sieve size test for pit # 1

Location: *Gichi*			**Job ref.**	*Thesis research*		
			Pit no.	*#1*		
Soil Description: *Inorganic silts*			**Sample no.**	*#1*		
			Depth	*2.5m*		
Test method: *ASTM D 422-63*			**Date**	*25/09/2001 E.C*		
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446	0.00	0.00	0.00	100.00
4.750	431	460	29.00	6.08	6.08	93.92
2.360	389	400	11.00	2.31	8.39	91.61
2.000	377	381	4.00	0.84	9.23	90.77
1.180	354	368	14.00	2.94	12.17	87.83
0.600	312	346	34.00	7.13	19.30	80.70
0.425	291	316	25.00	5.24	24.54	75.46
0.300	287	311	24.00	5.03	29.57	70.43
0.150	268	306	38.00	7.97	37.54	62.46
0.075	272	294	22.00	4.61	42.15	57.85
pan	254	241	276.00	57.85	100.00	0.00



Sieve size test for pit #2

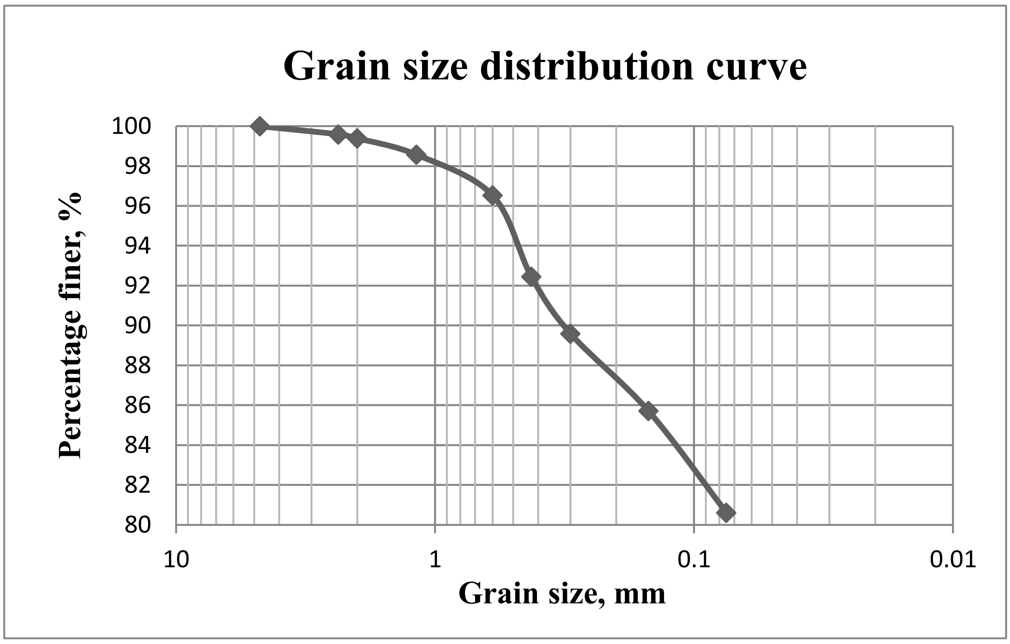
Location: *Mazegaja*			**Job ref.**	*Thesis research*		
			Pit no.	*#2*		
Soil Description: *Inorganic silts*			**Sample no.**	*#1*		
			Depth	*2.3m*		
Test method: *ASTM D 422-63*			**Date**	*25/09/2001 E.C*		
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446	0.00	0.00	0.00	100.00
4.750	431	439.00	8.00	0.64	0.64	99.36
2.360	389	392.00	3.00	0.24	0.88	99.12
2.000	378	378.65	0.650	0.05	0.93	99.07
1.180	355	358.00	3.00	0.24	1.17	98.83
0.600	313	326.00	13.00	1.04	2.21	97.79
0.425	291	301.00	10.00	0.80	3.01	96.99
0.300	287	294.00	7.00	0.56	3.57	96.43
0.150	268	280.00	12.00	0.96	4.53	95.47
0.075	259	275.00	16.00	1.28	5.81	94.19
pan	240	1419.22	1179.22	94.19	100.00	0.00



Sieve size test for pit #3

Location: *Ketera*		**Job ref.**	*Thesis research*
		Pit no.	*#3*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.8m*
Test method: *ASTM D 422-63*		**Date**	*25/09/2001 E.C*

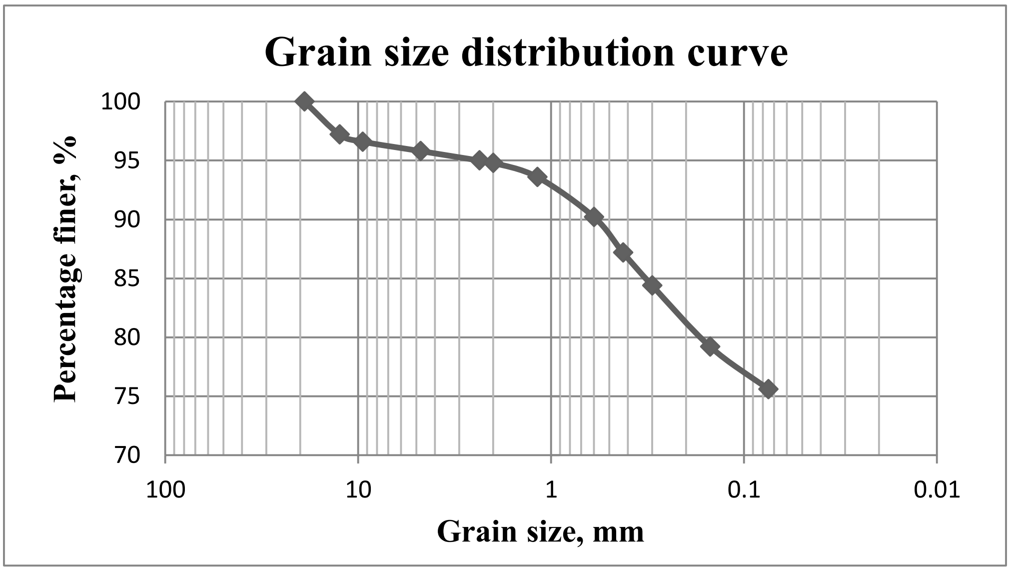
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
4.750	431	431	0.00	0.00	0.00	100.00
2.360	389	391	2.00	0.41	0.41	99.59
2.000	377	378	1.00	0.20	0.61	99.39
1.180	354	358	4.00	0.82	1.43	98.57
0.600	312	322	10.00	2.04	3.47	96.53
0.425	291	311	20.00	4.08	7.55	92.45
0.300	287	301	14.00	2.86	10.41	89.59
0.150	268	287	19.00	3.88	14.29	85.71
0.075	272	297	25.00	5.10	19.39	80.61
pan	254	240	395.00	80.61	100.00	0.00



Sieve size test for pit #4

Location: *Kechema*		**Job ref.**	*Thesis research*
		Pit no.	*#4*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.7m*
Test method: *ASTM D 422-63*		**Date**	*25/09/2001 E.C*

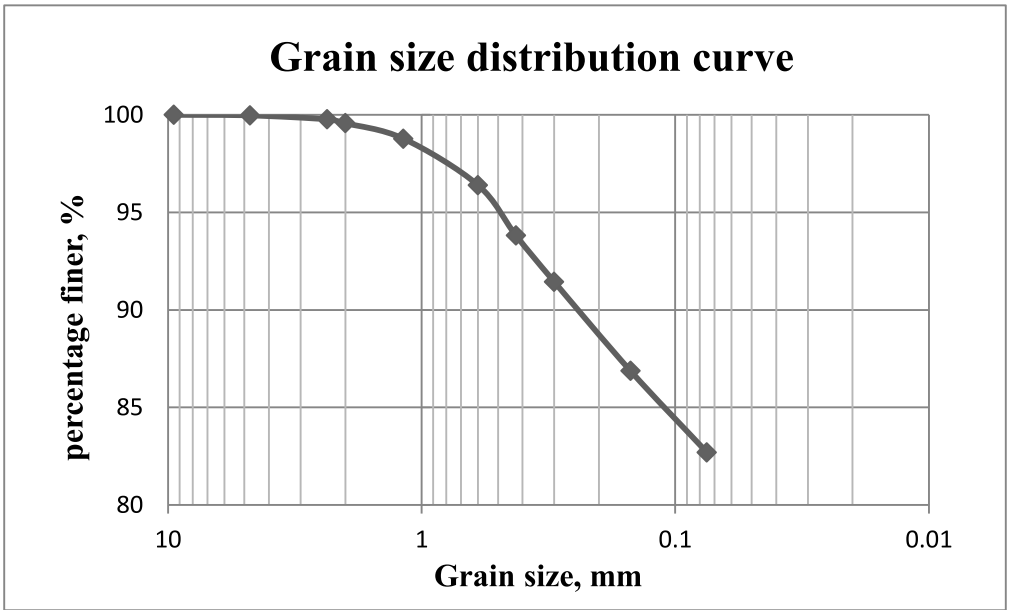
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
19.000	438	438	0.00	0.00	0.00	100.00
12.500	448	462	14.00	2.80	2.80	97.20
9.500	446	449	3.00	0.60	3.40	96.60
4.750	431	435	4.00	0.80	4.20	95.80
2.360	389	393	4.00	0.80	5.00	95.00
2.000	377	378	1.00	0.20	5.20	94.80
1.180	354	360	6.00	1.20	6.40	93.60
0.600	312	329	17.00	3.40	9.80	90.20
0.425	291	306	15.00	3.00	12.80	87.20
0.300	287	301	14.00	2.80	15.60	84.40
0.150	266	292	26.00	5.20	20.80	79.20
0.075	259	277	18.00	3.60	24.40	75.60
pan	240	618	378.00	75.60	100.00	0.00



Sieve size test for pit #5

Location: *Boku*	**Job ref.**	*Thesis research*
	Pit no.	*#5*
Soil Description: *Inorganic silts*	**Sample no.**	*#1*
	Depth	*2.5m*
Test method: *ASTM D 422-63*	**Date**	*25/09/2001 E.C*

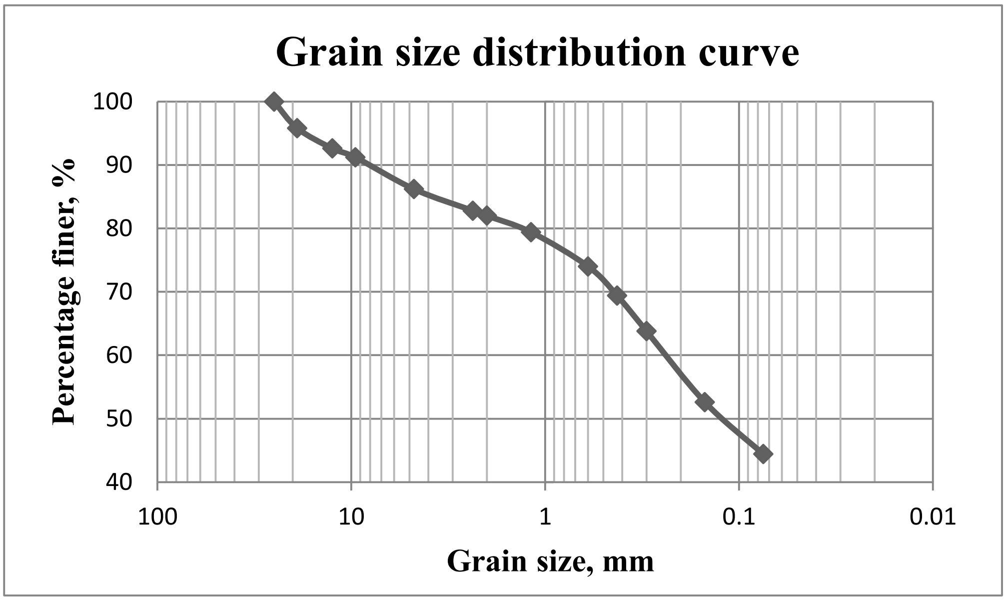
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446.00	0.00	0.00	0.00	100.00
4.750	431	431.17	0.17	0.03	0.03	99.97
2.360	389	390.00	1.00	0.20	0.23	99.77
2.000	378	378.00	1.00	0.20	0.43	99.57
1.180	355	358.00	4.00	0.79	1.22	98.78
0.600	313	324.00	12.00	2.38	3.60	96.40
0.425	291	304.00	13.00	2.58	6.18	93.82
0.300	287	299.00	12.00	2.38	8.56	91.44
0.150	268	289.00	23.00	4.57	13.13	86.87
0.075	259	280.00	21.00	4.17	17.30	82.70
pan	240	656.37	416.37	82.70	100.00	0.00



Sieve size test for pit #6

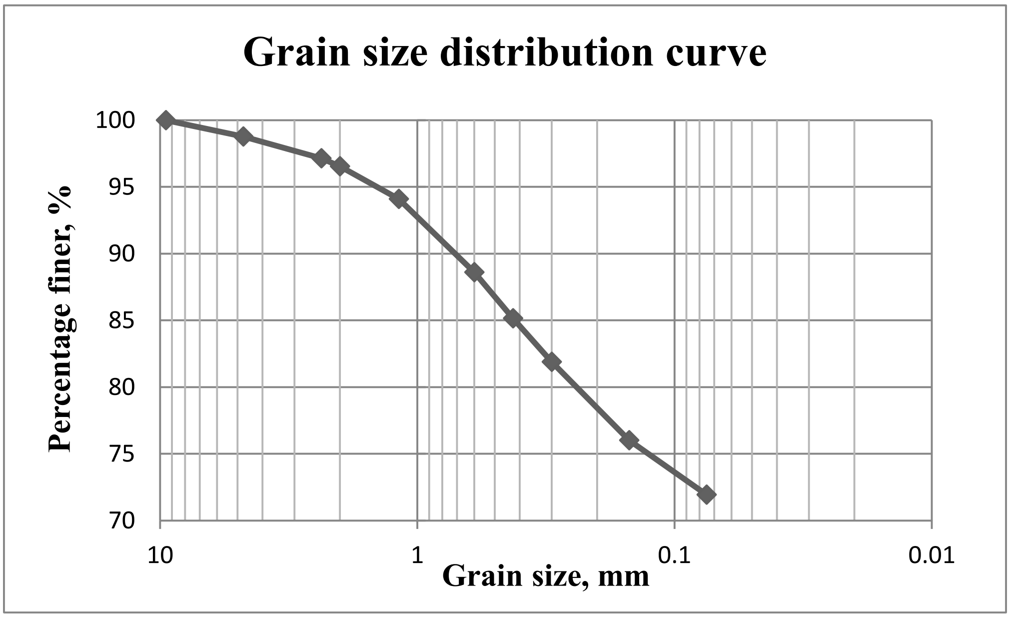
Location: *Chefe*		**Job ref.**	*Thesis research*
		Pit no.	*#6*
Soil Description: *Silty Sand*		**Sample no.**	*#1*
		Depth	*2.6m*
Test method: *ASTM D 422-63*		**Date**	*25/09/2001 E.C*

Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
25.000	446	446	0.00	0.00	0.00	100.00
19.000	438	459	21.00	4.20	4.20	95.80
12.500	448	464	16.00	3.20	7.40	92.60
9.500	446	453	7.00	1.40	8.80	91.20
4.750	431	456	25.00	5.00	13.80	86.20
2.360	389	406	17.00	3.40	17.20	82.80
2.000	377	381	4.00	0.80	18.00	82.00
1.180	354	367	13.00	2.60	20.60	79.40
0.600	312	339	27.00	5.40	26.00	74.00
0.425	291	314	23.00	4.60	30.60	69.40
0.300	287	315	28.00	5.60	36.20	63.80
0.150	268	324	56.00	11.20	47.40	52.60
0.075	272	313	41.00	8.20	55.60	44.40
pan	254	476	222.00	44.40	100.00	0.00



Sieve size test for pit #7

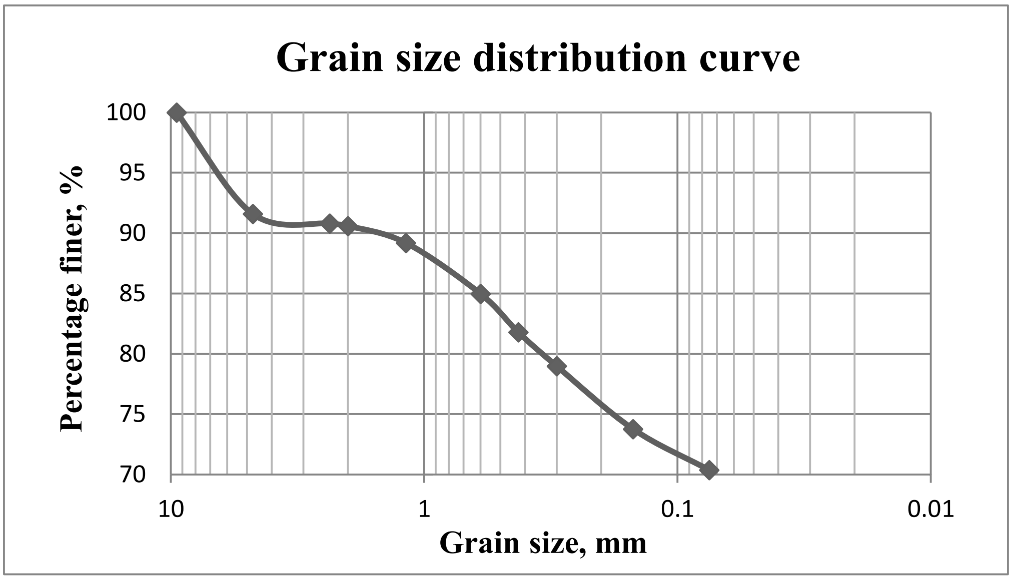
Location: *Dibibisa*			**Job ref.**		*Thesis research*	
			Pit no.		*#7*	
Soil Description: *Inorganic silts*			**Sample no.**		*#1*	
			Depth		*2.6m*	
Test method: *ASTM D 422-63*			**Date**		*25/09/2001 E.C*	
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446	0.00	0.00	0.00	100.00
4.750	431	437	6.00	1.22	1.22	98.78
2.360	389	397	8.00	1.63	2.85	97.15
2.000	377	380	3.00	0.61	3.46	96.54
1.180	354	366	12.00	2.44	5.90	94.10
0.600	312	339	27.00	5.49	11.39	88.61
0.425	291	308	17.00	3.46	14.85	85.15
0.300	287	303	16.00	3.25	18.10	81.90
0.150	266	295	29.00	5.89	23.99	76.01
0.075	272	292	20.00	4.07	28.06	71.94
pan	240	241	354.00	71.94	100.00	0.00



Sieve size test for pit #8

Location: *Migira*	**Job ref.**	*Thesis research*
	Pit no.	*#8*
Soil Description: *Inorganic silts*	**Sample no.**	*#1*
	Depth	*2.3m*
Test method: *ASTM D 422-63*	**Date**	*25/09/2001 E.C*

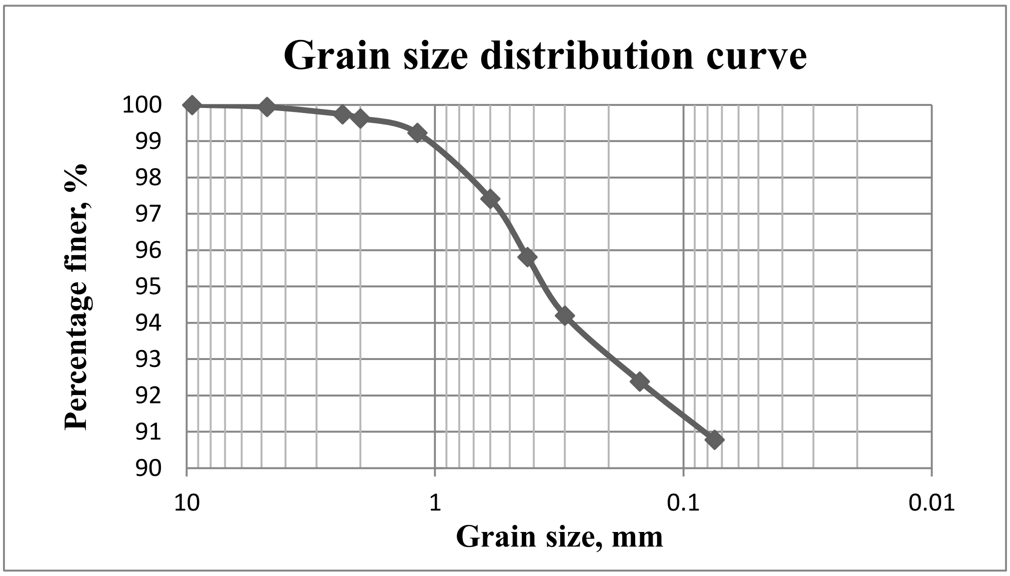
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446	0.00	0.00	0.00	100.00
4.750	431	473	42.00	8.41	8.41	91.59
2.360	389	393	4.00	0.80	9.21	90.79
2.000	378	379	1.00	0.20	9.41	90.59
1.180	355	362	7.00	1.40	10.81	89.19
0.600	313	334	21.00	4.21	15.02	84.98
0.425	291	307	16.00	3.20	18.22	81.78
0.300	287	301	14.00	2.80	21.02	78.98
0.150	268	294	26.00	5.21	26.23	73.77
0.075	259	470	17.00	3.40	29.63	70.37
pan	240	591.38	351.38	70.37	100.00	0.00



Sieve size test for pit #9

Location: *Sole*	**Job ref.**	*Thesis research*
	Pit no.	*#9*
Soil Description: *Inorganic silts*	**Sample no.**	*#1*
	Depth	*2.8m*
Test method: *ASTM D 422-63*	**Date**	*25/09/2001 E.C*

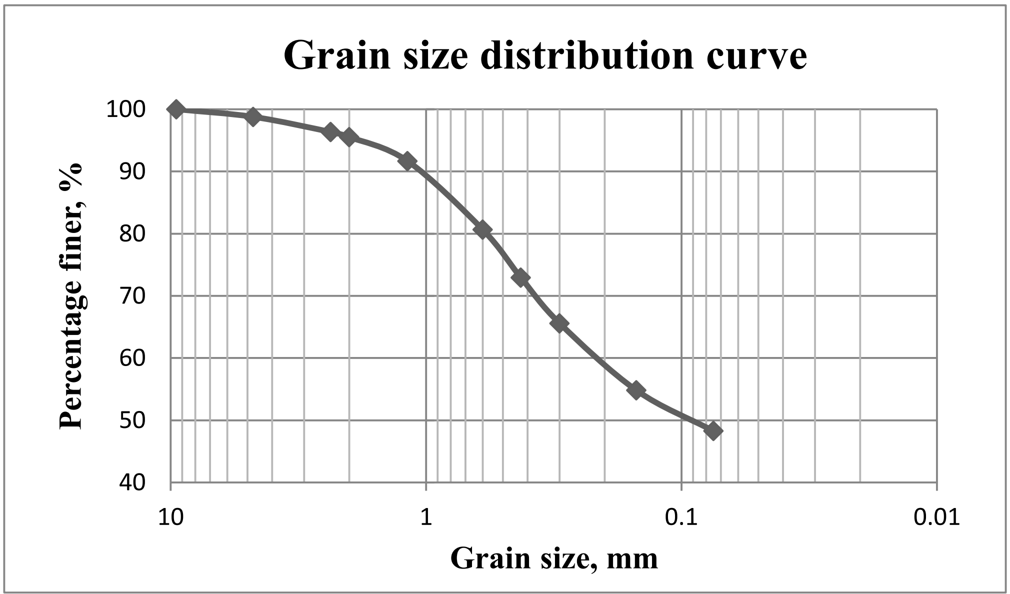
Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446.00	0.00	0.00	0.00	100.00
4.750	431	431.31	0.31	0.06	0.06	99.94
2.360	389	390.00	1.00	0.20	0.26	99.74
2.000	378	378.53	0.53	0.11	0.37	99.63
1.180	355	357.00	2.00	0.40	0.77	99.23
0.600	313	322.00	9.00	1.81	2.58	97.42
0.425	291	299.00	8.00	1.61	4.19	95.81
0.300	287	295.00	8.00	1.61	5.80	94.20
0.150	268	277.00	9.00	1.81	7.61	92.39
0.075	259	461.00	8.00	1.61	9.22	90.78
pan	240	692.51	452.51	90.78	100.00	0.00



Sieve size test for pit #10

Location: *Dabe*	**Job ref.**	*Thesis research*
	Pit no.	*#10*
Soil Description: *Silty Sand*	**Sample no.**	*#1*
	Depth	*2.5m*
Test method: *ASTM D 422-63*	**Date**	*25/09/2001 E.C*

Sieve opening (mm)	Mass of sieve (gm)	Mass of sieve + retained soil (gm)	Mass of retained soil (gm)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage passed (%)
9.500	446	446	0.00	0.00	0.00	100.00
4.750	431	437	6.00	1.22	1.22	98.78
2.360	389	401	12.00	2.44	3.66	96.34
2.000	377	381	4.00	0.81	4.47	95.53
1.180	354	373	19.00	3.87	8.34	91.66
0.600	312	366	54.00	11.00	19.34	80.66
0.425	291	329	38.00	7.74	27.08	72.92
0.300	287	323	36.00	7.33	34.41	65.59
0.150	268	321	53.00	10.79	45.20	54.80
0.075	272	304	32.00	6.52	51.72	48.28
pan	240	241	237.00	48.28	100.00	0.00

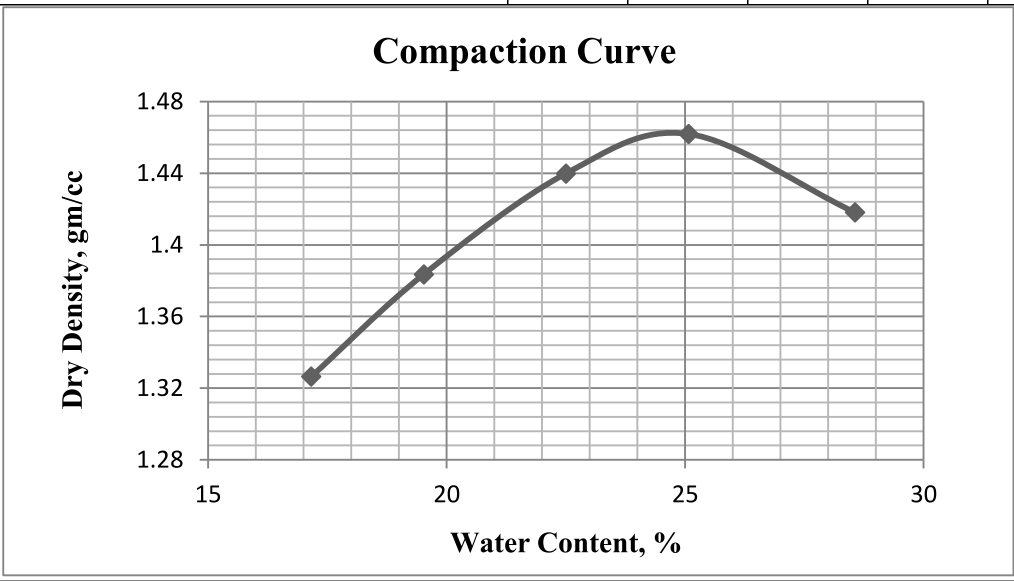


APPENDIX-B

Standard compaction test for pit #1

Location: *Gichi*				**Job ref.**	*Thesis research*
				Pit no.	*#1*
Soil Description: *Inorganic silts*				**Sample no.**	*#1*
				Depth	*2.5m*
Test method: *ASTM D 698-91*				**Date**	*15/11/2001 E.C*
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	10	27	44	8	71
Mass of Container, M_1 ,g	5.37	5.34	5.39	5.22	5.43
Mass of Container + Wet Soil, M_2 ,g	185.1	162.2	177.1	176.6	178.7
Mass of Container + Dry Soil, M_3 ,g	158.8	136.6	145.6	142.3	140.2
Mass of Water, M_2-M_3 ,g	26.32	25.63	31.55	34.35	38.49
Mass of Dry Soil, M_3-M_1 ,g	153.4	131.3	140.2	137.0	134.8
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	17.16	19.52	22.5	25.07	28.56
Density Determination					
Water content. Wo, %	17.16	19.52	22.50	25.07	28.56
Wt of soil + mold, g	7094	7188	7292	7353	7348
Wt of mold, g	5627	5627	5627	5627	5627
Wt of soil in mold, g	1467	1561	1665	1726	1721
Wet density, g/cc	1.554	1.653	1.764	1.828	1.823
Dry density, g/cc	1.326	1.384	1.439	1.462	1.418

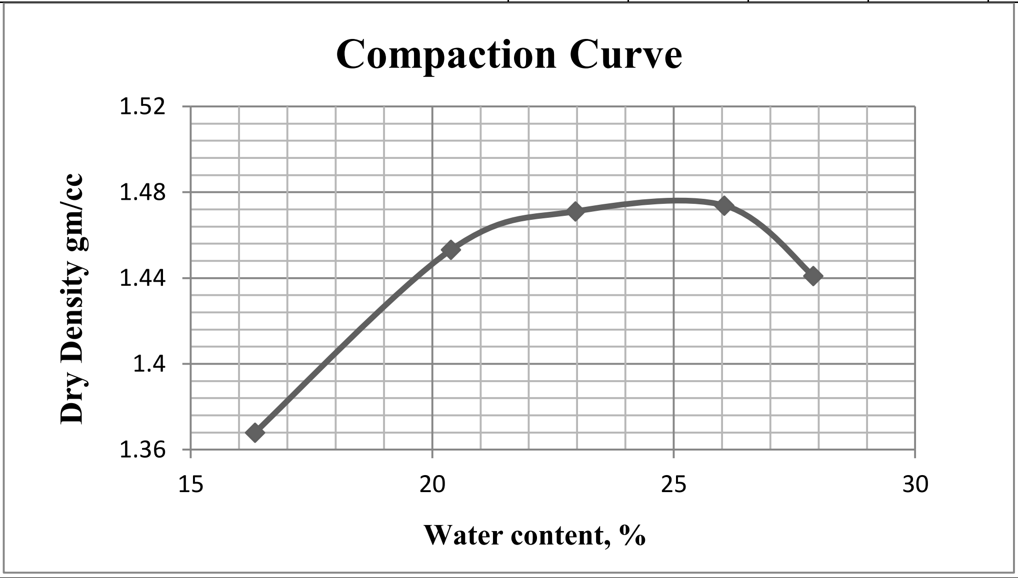


Optimum moisture Content	25%	***Maximum Dry Density***	1.46 g/cc

Standard compaction test for pit #2

Location: *Mazegaja*			**Job ref.**	*Thesis research*		
			Pit no.	*#2*		
Soil Description: *Inorganic silts*			**Sample no.**	*#1*		
			Depth	*2.3m*		
Test method: *ASTM D 698-91*			**Date**	*15/11/2001 E.C*		
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**		2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**		944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	33	89	15	36	80
Mass of Container, M_1 ,g	14.54	15.19	15.12	13.89	15.68
Mass of Container + Wet Soil, M_2 ,g	40.89	51.00	41.02	53.29	58.01
Mass of Container + Dry Soil, M_3 ,g	37.16	44.95	36.28	45.15	48.77
Mass of Water, M_2-M_3 ,g	3.73	6.04	4.73	8.14	9.24
Mass of Dry Soil, M_3-M_1 ,g	22.62	29.76	21.16	31.26	33.09
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	16.33	20.39	22.96	26.05	27.89
Density Determination					
Water content. Wo, %	16.33	20.39	22.96	26.05	27.89
Wt of soil + mold, g	7114	7263	7319	7365	7351
Wt of mold, g	5615	5615	5615	5615	5615
Wt of soil in mold, g	1499	1648	1704	1750	1736
Wet density, g/cc	1.591	1.749	1.808	1.857	1.842
Dry density, g/cc	1.367	1.453	1.471	1.473	1.440

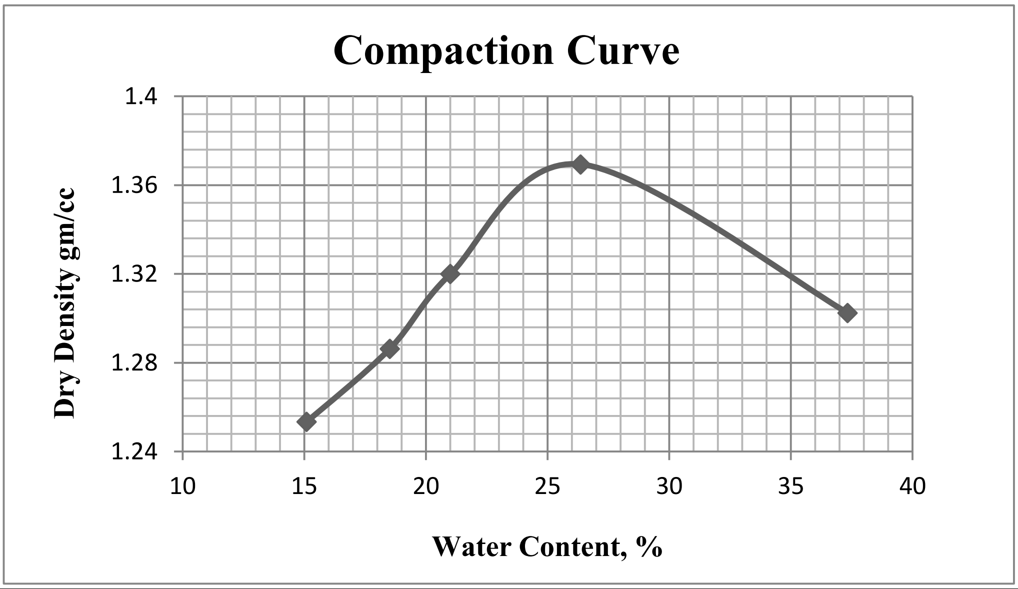


Optimum moisture Content	26%	***Maximum Dry Density***	1.47 g/cc

Standard compaction test for pit #3

Location: *Ketera*			**Job ref.**	*Thesis research*	
			Pit no.	*#3*	
Soil Description: *Inorganic silts*			**Sample no.**	*#1*	
			Depth	*2.8m*	
Test method: *ASTM D 698-91*			**Date**	*15/11/2001 E.C*	
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	26	80	33	66	35
Mass of Container, M_1 ,g	14.78	15.15	15.63	15.61	15.09
Mass of Container + Wet Soil, M_2 ,g	36.05	32.88	34.06	39.38	44.23
Mass of Container + Dry Soil, M_3 ,g	33.25	30.11	30.86	34.42	36.45
Mass of Water, M_2-M_3 ,g	2.79	2.77	3.20	4.96	7.77
Mass of Dry Soil, M_3-M_1 ,g	18.47	14.96	15.23	18.81	21.36
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	15.10	18.51	21.01	26.35	37.33
Density Determination					
Water content. Wo, %	15.10	18.51	21.01	26.35	37.33
Wt of soil + mold, g	6974	7051	7120	7245	7300
Wt of mold, g	5615	5615	5615	5615	5615
Wt of soil in mold, g	1359	1436	1505	1630	1685
Wet density, g/cc	1.442	1.524	1.597	1.730	1.788
Dry density, g/cc	1.253	1.286	1.321	1.369	1.302



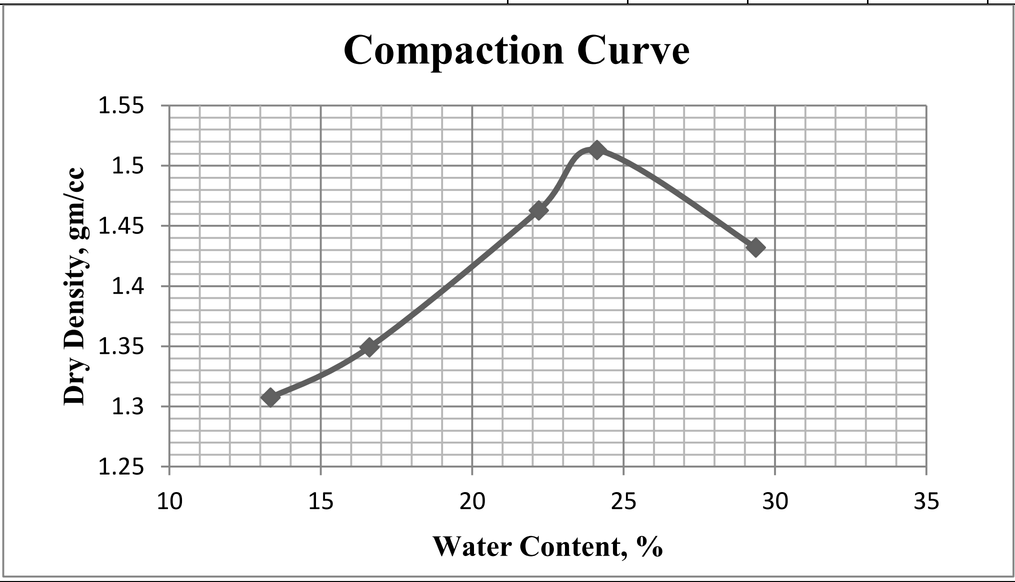
Optimum moisture Content	26%	***Maximum Dry Density***	1.37 g/cc

Standard compaction test for pit #4

Location: *Kechema*		**Job ref.**	*Thesis research*
		Pit no.	*#4*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.7m*
Test method: *ASTM D 698-91*		**Date**	*15/11/2001 E.C*

Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	46	14	24	30	76
Mass of Container, M_1 ,g	17.26	15.65	15.16	14.0	15.7
Mass of Container + Wet Soil, M_2 ,g	61.18	39.64	44.01	39.15	40.2
Mass of Container + Dry Soil, M_3 ,g	56.01	36.23	38.77	34.28	34.65
Mass of Water, M_2-M_3 ,g	5.17	3.41	5.24	4.87	5.55
Mass of Dry Soil, M_3-M_1 ,g	38.75	20.58	23.61	20.28	18.95
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	13.34	16.60	22.19	24.12	29.36
Density Determination					
Water content. Wo, %	13.34	16.60	22.19	24.12	29.36
Wt of soil + mold, g	7007	7093	7295	7380	7356
Wt of mold, g	5611	5611	5611	5611	5611
Wt of soil in mold, g	1396	1482	1684	1769	1745
Wet density, g/cc	1.481	1.573	1.787	1.877	1.852
Dry density, g/cc	1.307	1.349	1.463	1.513	1.432

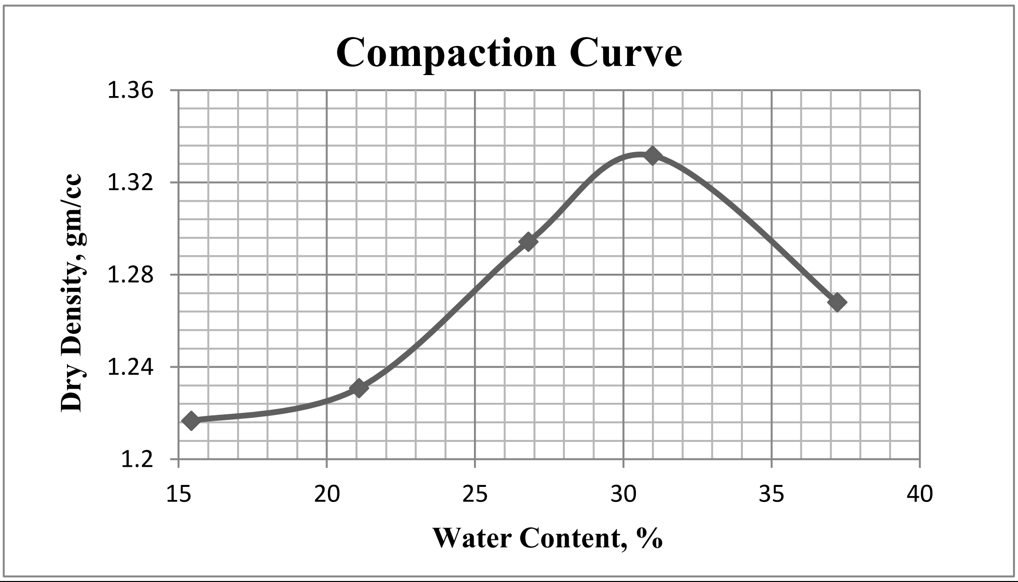


Optimum moisture Content	24%	***Maximum Dry Density***	1.51 g/cc

Standard compaction test for pit #5

Location: *Boku*			**Job ref.**	*Thesis research*	
			Pit no.	*#5*	
Soil Description: *Inorganic silts*			**Sample no.**	*#1*	
			Depth	*2.5m*	
Test method: *ASTM D 698-91*			**Date**	*15/11/2001 E.C*	
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	14	73	46	66	8
Mass of Container, M_1 ,g	18.31	14.81	17.18	15.64	15.49
Mass of Container + Wet Soil, M_2 ,g	52.56	50.16	56.49	53.75	63.11
Mass of Container + Dry Soil, M_3 ,g	48.03	44.00	48.18	44.73	50.21
Mass of Water, M_2-M_3 ,g	4.53	6.16	8.31	9.02	12.9
Mass of Dry Soil, M_3-M_1 ,g	29.72	29.19	31.0	29.09	34.72
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	15.43	21.08	26.79	30.98	37.21
Density Determination					
Water content. Wo, %	15.43	21.08	26.79	30.98	37.21
Wt of soil + mold, g	6938	7019	7161	7258	7254
Wt of mold, g	5615	5615	5615	5615	5615
Wt of soil in mold, g	1323	1404	1546	1643	1639
Wet density, g/cc	1.404	1.490	1.641	1.744	1.739
Dry density, g/cc	1.216	1.230	1.294	1.331	1.268



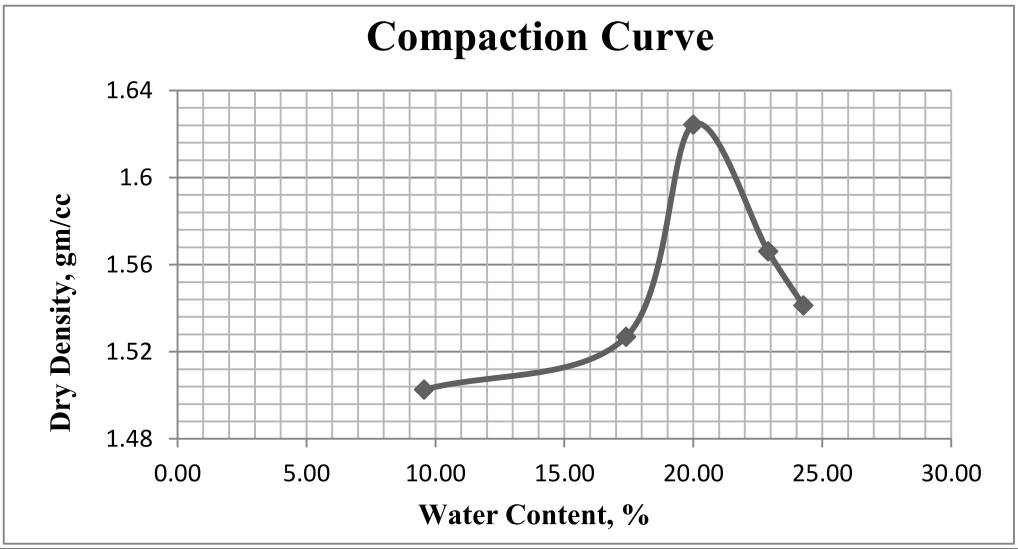
Optimum moisture Content	31%	***Maximum Dry Density***	1.33 g/cc

Standard compaction test for pit #6

Location: *Cheffe*	**Job ref.**	*Thesis research*
	Pit no.	*#6*
Soil Description: *Silty Sand*	**Sample no.**	*#1*
	Depth	*2.6m*
Test method: *Standard Compaction, ASTM D 698-91*	**Date**	*15/11/2001 E.C*

Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	47	77	49	41	71
Mass of Container, M_1 ,g	5.0	5.0	5.0	5.0	5.0
Mass of Container + Wet Soil, M_2 ,g	177	221	239	225	261
Mass of Container + Dry Soil, M_3 ,g	162	189	200	184	211
Mass of Water, M_2-M_3 ,g	15	32	39	41	50
Mass of Dry Soil, M_3-M_1 ,g	157	184	195	179	206
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	9.55	17.39	20.0	22.91	24.27
Density Determination					
Water content. Wo, %	9.55	17.39	20.0	22.91	24.27
Wt of soil + mold, g	7187	7325	7473	7450	7441
Wt of mold, g	5633	5633	5633	5633	5633
Wt of soil in mold, g	1554	1692	1840	1817	1808
Wet density, g/cc	1.646	1.792	1.949	1.924	1.915
Dry density, g/cc	1.502	1.526	1.624	1.566	1.541

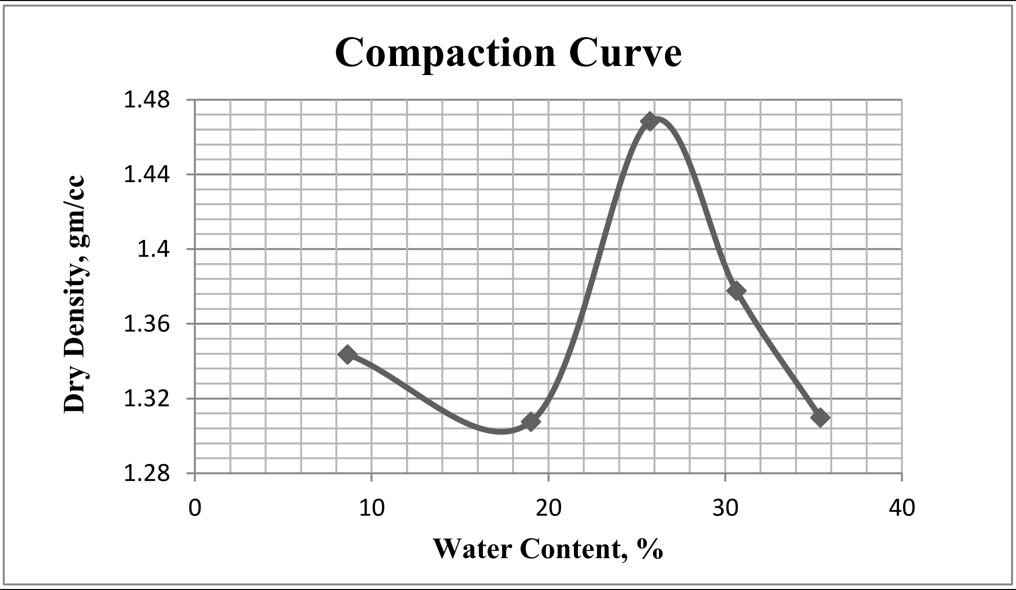


Optimum moisture Content	20%	***Maximum Dry Density***	1.62 g/cc

Standard compaction test for pit #7

Location: *Dibibisa*				**Job ref.**	*Thesis research*
				Pit no.	*#7*
Soil Description: *Inorganic silts*				**Sample no.**	*#1*
				Depth	*2.6m*
Test method: *ASTM D 698-91*				**Date**	*15/11/2001 E.C*
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	19	30	47	41	78
Mass of Container, M_1 ,g	5.0	5.0	5.0	5.0	5.0
Mass of Container + Wet Soil, M_2 ,g	181	174	176	231	292
Mass of Container + Dry Soil, M_3 ,g	167	147	141	178	217
Mass of Water, M_2-M_3 ,g	14	27	35	53	75
Mass of Dry Soil, M_3-M_1 ,g	162	142	136	173	212
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	8.64	19.01	25.74	30.64	35.38
Density Determination					
Water content. Wo, %	8.64	19.01	25.74	30.64	35.38
Wt of soil + mold, g	7008	7099	7373	7329	7304
Wt of mold, g	5630	5630	5630	5630	5630
Wt of soil in mold, g	1378	1469	1743	1699	1674
Wet density, g/cc	1.459	1.556	1.846	1.799	1.773
Dry density, g/cc	1.343	1.307	1.468	1.377	1.309

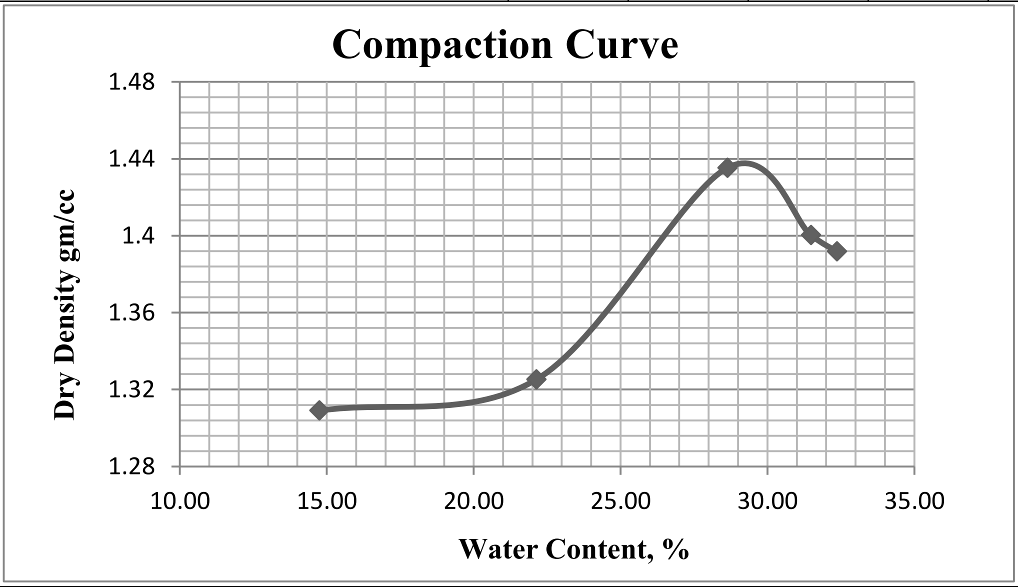


Optimum moisture Content	26%	***Maximum Dry Density***	1.47 g/cc

Standard compaction test for pit #8

Location: *Migira*			**Job ref.**	*Thesis research*		
			Pit no.	*#8*		
Soil Description: *Inorganic silts*			**Sample no.**	*#1*		
			Depth	*2.3m*		
Test method: *ASTM D 698-91*			**Date**	*15/11/2001 E.C*		
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**		2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**		944

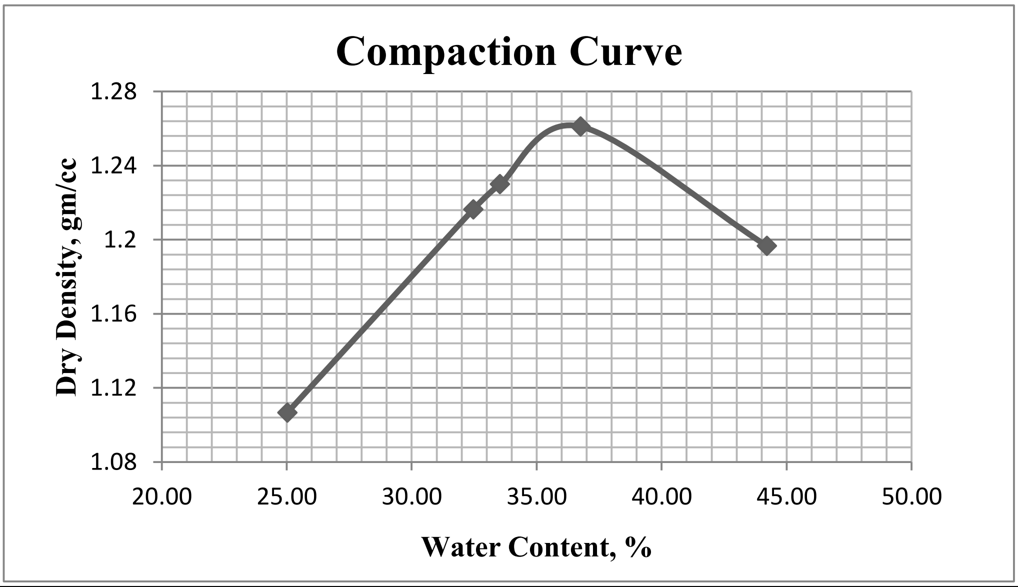
Water Content Determination					
Determination No	1	2	3	4	5
Container No	3	22	21	19	31
Mass of Container, M_1 ,g	13.95	15.54	15.64	15.64	14.81
Mass of Container + Wet Soil, M_2 ,g	50.21	53.68	58.47	46.16	49.37
Mass of Container + Dry Soil, M_3 ,g	45.55	46.77	48.94	38.85	40.92
Mass of Water, M_2-M_3 ,g	4.66	6.91	9.53	7.31	8.45
Mass of Dry Soil, M_3-M_1 ,g	31.6	31.23	33.30	23.21	26.11
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	14.75	22.14	28.64	31.48	32.36
Density Determination					
Water content. Wo, %	14.75	22.14	28.64	31.48	32.36
Wt of soil + mold, g	7036	7146	7361	7356	7357
Wt of mold, g	5618	5618	5618	5618	5618
Wt of soil in mold, g	1418	1528	1743	1738	1739
Wet density, g/cc	1.502	1.618	1.846	1.841	1.842
Dry density, g/cc	1.309	1.325	1.435	1.400	1.391



Optimum moisture Content	29%	***Maximum Dry Density***	1.44 g/cc

Standard compaction test for pit #9

Location: *Sole*		**Job ref.**	*Thesis research*		
		Pit no.	*#9*		
Soil Description: *Inorganic silts*		**Sample no.**	*#1*		
		Depth	*2.8m*		
Test method: *ASTM D 698-91*		**Date**	*15/11/2001 E.C*		
Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944
Water Content Determination					
Determination No	1	2	3	4	5
Container No	56	36	16	98	59
Mass of Container, M_1 ,g	14.86	14.86	15.69	14.80	15.55
Mass of Container + Wet Soil, M_2 ,g	48.39	37.80	50.52	43.82	58.63
Mass of Container + Dry Soil, M_3 ,g	41.68	32.17	41.77	36.02	45.43
Mass of Water, M_2-M_3 ,g	6.71	5.63	8.75	7.80	13.2
Mass of Dry Soil, M_3-M_1 ,g	26.82	17.31	26.08	21.22	29.88
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	25.02	32.46	33.53	36.76	44.20
Density Determination					
Water content. Wo, %	25.02	32.46	33.53	36.76	44.20
Wt of soil + mold, g	6921	7136	7177	7243	7244
Wt of mold, g	5615	5615	5615	5615	5615
Wt of soil in mold, g	1306	1521	1562	1628	1629
Wet density, g/cc	1.383	1.611	1.654	1.724	1.725
Dry density, g/cc	1.106	1.216	1.229	1.261	1.196



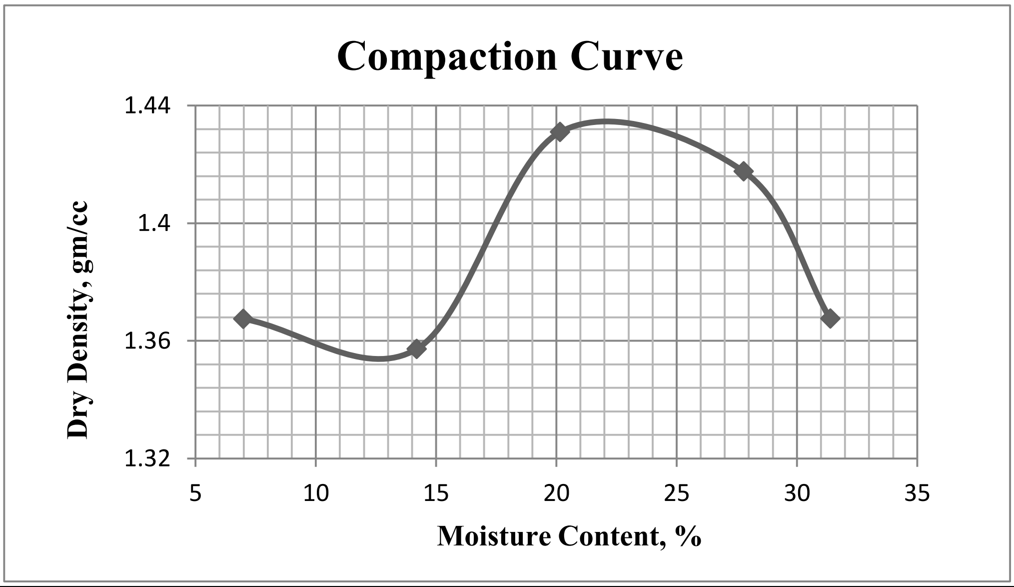
Optimum moisture Content	37%	***Maximum Dry Density***	1.26 g/cc

Standard compaction test for pit #10

Location: *Dabe*	**Job ref.**	*Thesis research*
	Pit no.	*#10*
Soil Description: *Silty Sand*	**Sample no.**	*#1*
	Depth	*2.5m*
Test method: *ASTM D 698-91*	**Date**	*15/11/2001 E.C*

Blows/layer	25	**No. of layers**	3	**Wt of hammer, Kg**	2.5
Mold diameter, cm	10	**Mold Height, cm**	12	**Volume, CC**	944

Water Content Determination					
Determination No	1	2	3	4	5
Container No	10	27	44	8	71
Mass of Container, M_1 ,g	5.0	5.0	5.0	5.0	5.0
Mass of Container + Wet Soil, M_2 ,g	189	174	166	212	386
Mass of Container + Dry Soil, M_3 ,g	177	153	139	167	295
Mass of Water, M_2-M_3 ,g	12	21	27	45	91
Mass of Dry Soil, M_3-M_1 ,g	172	148	134	162	290
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	6.98	14.19	20.15	27.78	31.38
Density Determination					
Water content. Wo, %	6.98	14.19	20.15	27.78	31.38
Wt of soil + mold, g	7011	7093	7253	7340	7326
Wt of mold, g	5630	5630	5630	5630	5630
Wt of soil in mold, g	1381	1463	1623	1710	1696
Wet density, g/cc	1.463	1.549	1.719	1.811	1.796
Dry density, g/cc	1.367	1.357	1.431	1.417	1.367



Optimum moisture Content	20%	***Maximum Dry Density***	1.43 g/cc

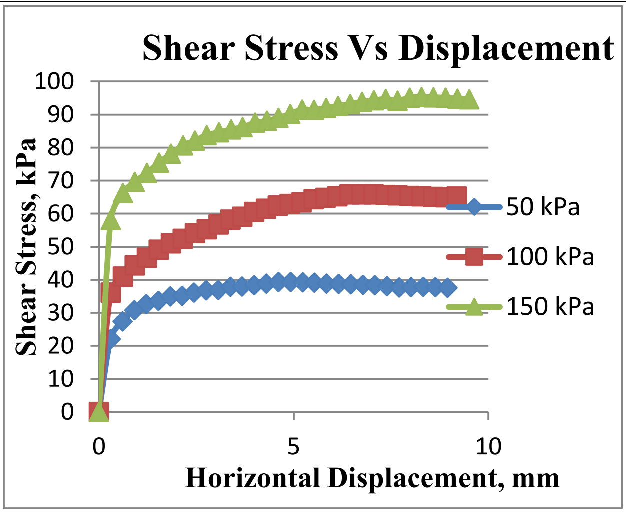
APPENDIX-C

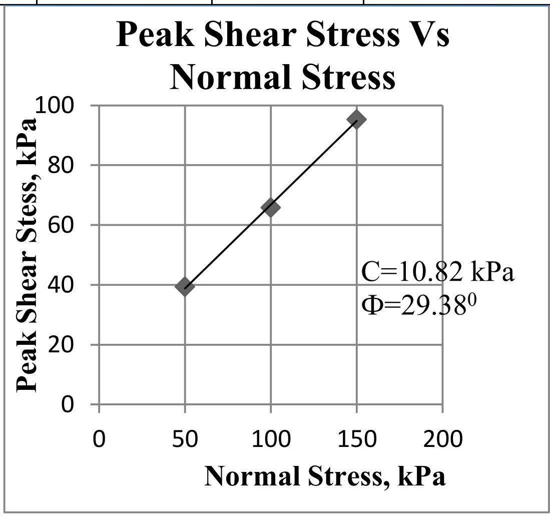
Direct Shear Test

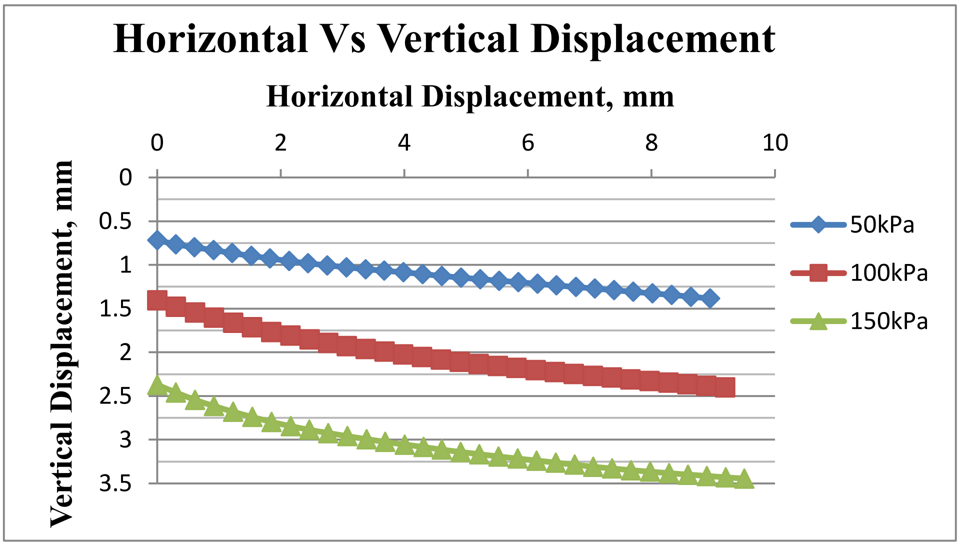
Location: *Gichi*		**Job ref.**	*Thesis research*
		Pit no.	*#1*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*26/04/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*25%*
Area	*3600mm²*	**Dry density**	*1.46gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.815*
Condition	*Submerged*	**Degree of saturation**	*81.61%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	39.3	65.8	95.3
Rate of shear displacement, mm/min	0.2	0.2	0.2



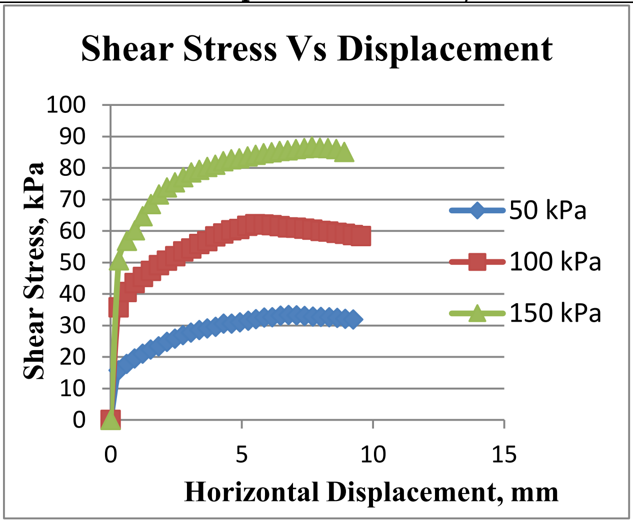


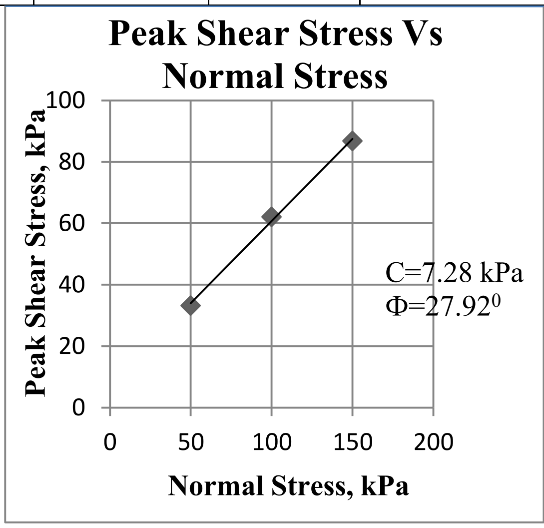


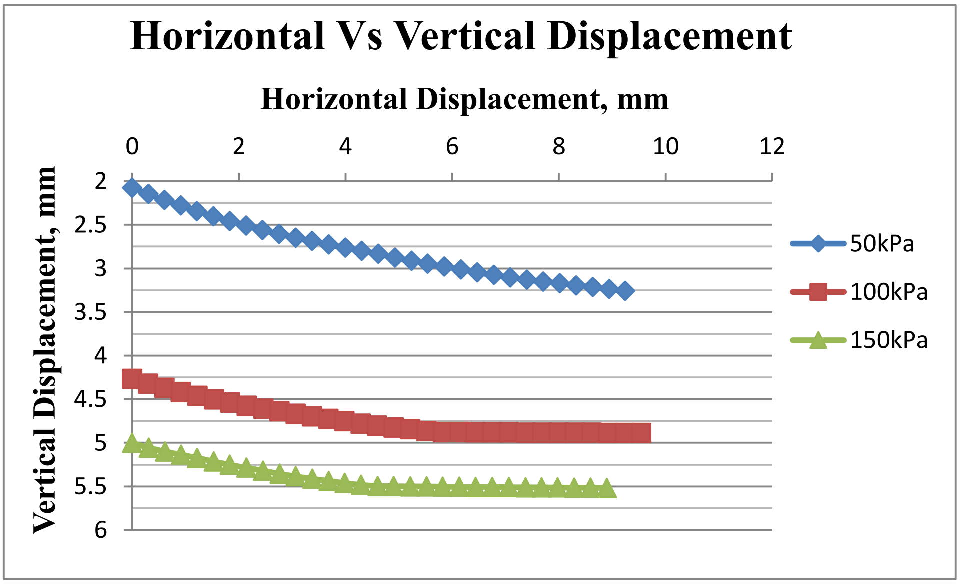
Location: *Gichi*		**Job ref.**	*Thesis research*
		Pit no.	*#1*
		Sample no.	*#2*
		Depth	*2.5m*
		Date	*27/04/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*20%*
Area	*3600mm²*	**Dry density**	*1.38gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.92*
Condition	*Dry*	**Degree of saturation**	*57.59%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	33.3	62.1	86.8
Rate of shear displacement, mm/min	0.2	0.2	0.2







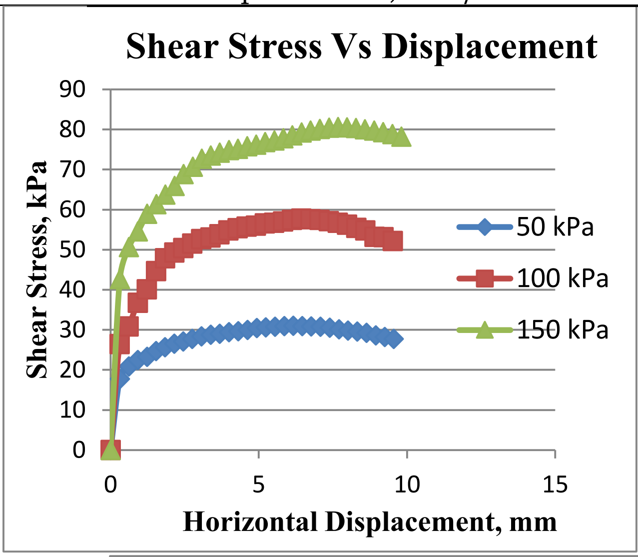
Location: *Gichi*	**Job ref.**	*Thesis research*
	Pit no.	*#1*
Soil Description: *Inorganic silts*	**Sample no.**	*#3*
	Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*	**Date**	*28/04/2011 E.C*

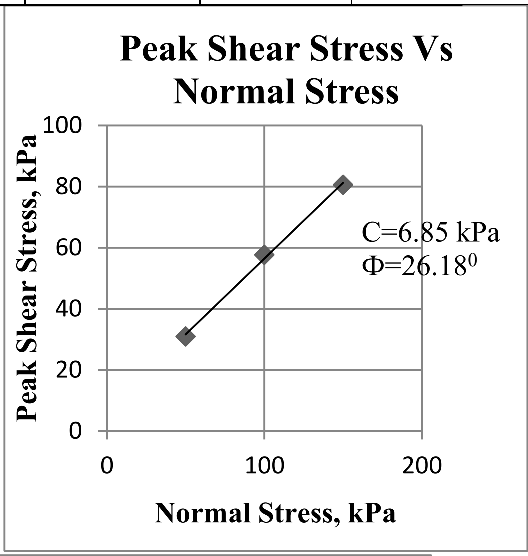
Specimen details

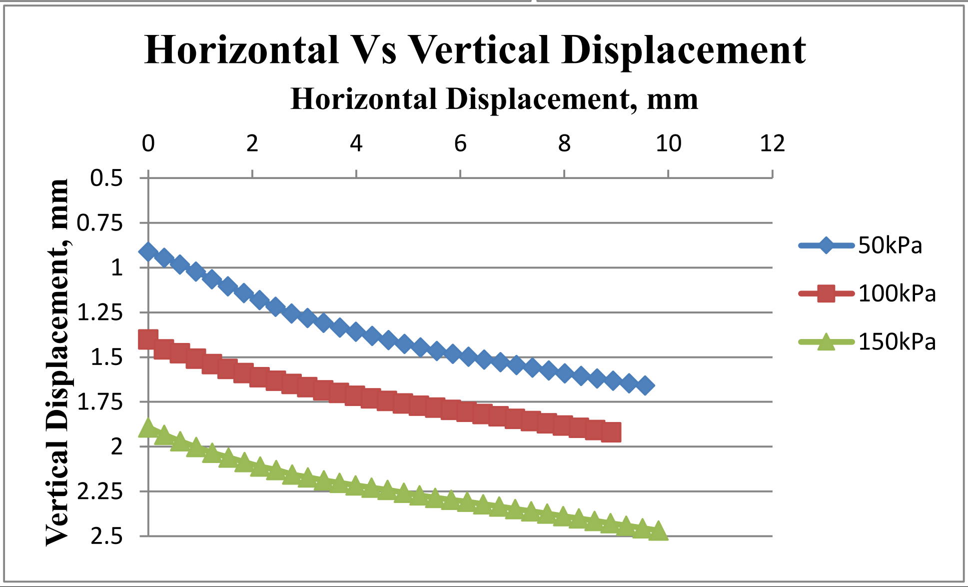
Initial height	*25mm*	**Moisture content**	*29%*
Area	*3600mm²*	**Dry density**	*1.42gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.866*
Condition	*Dry*	**Degree of saturation**	*87.50%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	31.0	57.7	80.6
Rate of shear displacement, mm/min	0.2	0.2	0.2



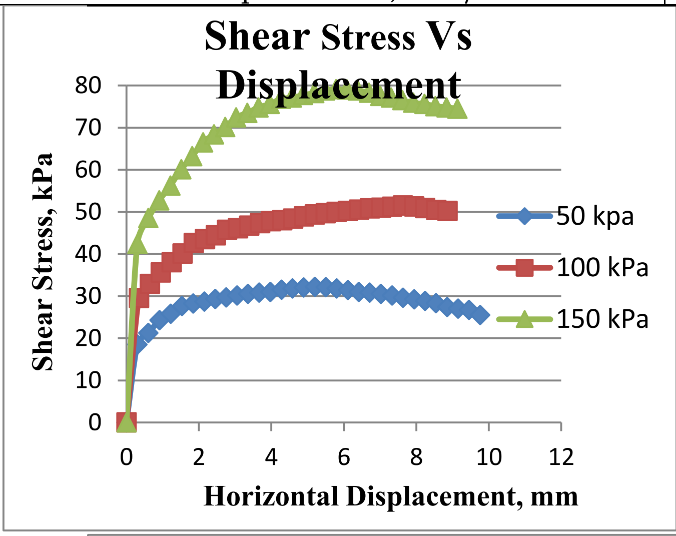


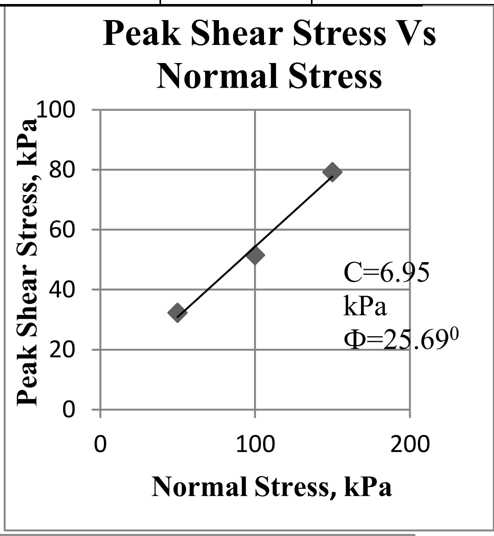


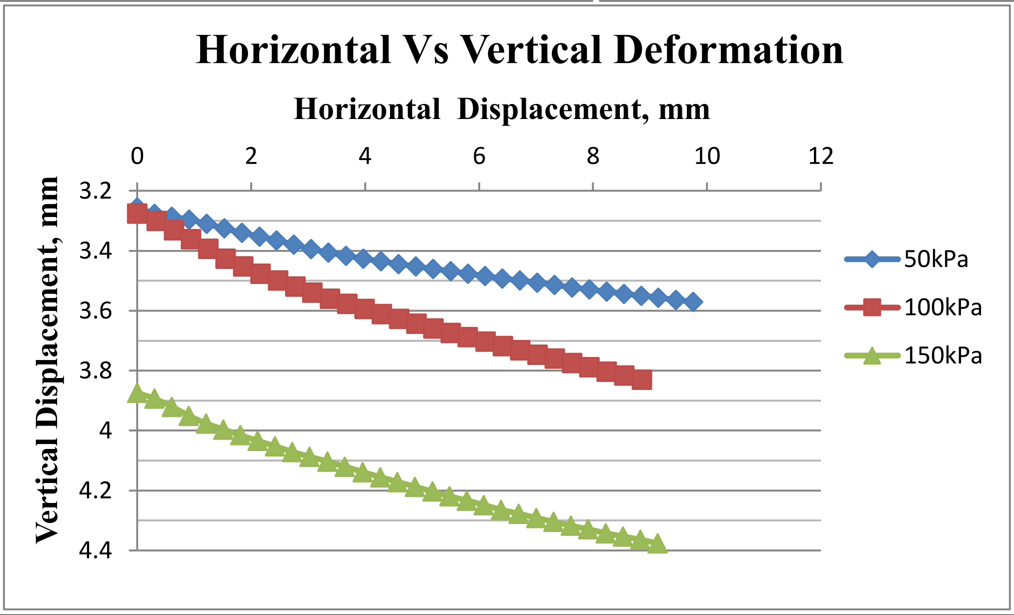
Location: *Mazegaja*		**Job ref.**	*Thesis research*
		Pit no.	*#2*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*29/04/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*26%*
Area	*3600mm²*	**Dry density**	*1.47gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.810*
Condition	*Submerged*	**Degree of saturation**	*85.76%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	32.2	51.5	79.1
Rate of shear displacement, mm/min	0.2	0.2	0.2



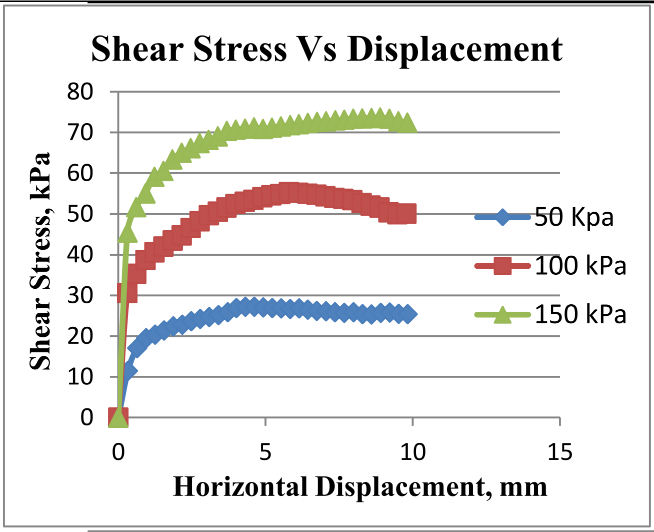


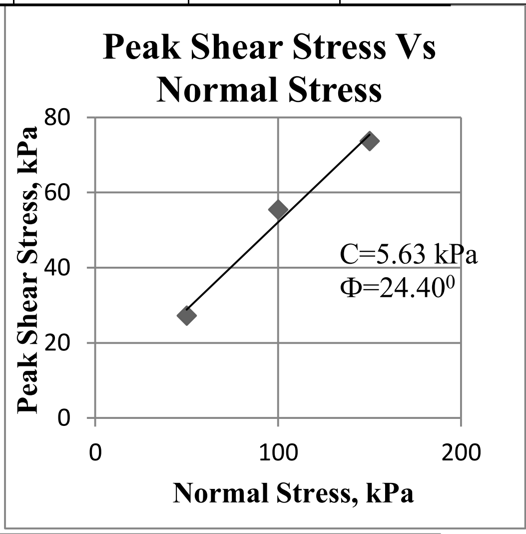


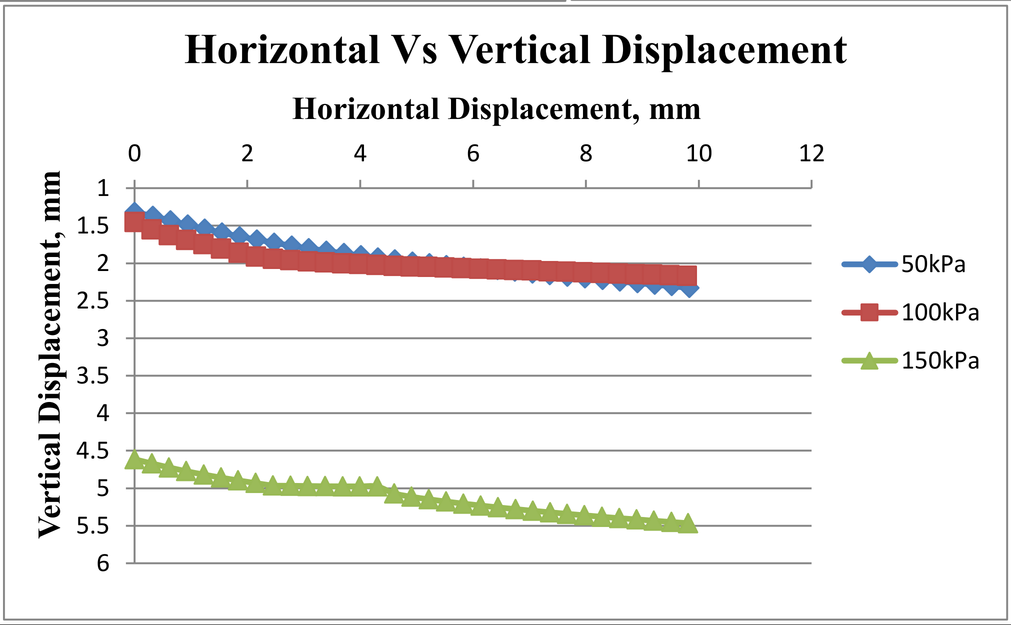
Location: *Mazegaja*		**Job ref.**	*Thesis research*
		Pit no.	*#2*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*30/04/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*20%*
Area	*3600mm²*	**Dry density**	*1.45gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.834*
Condition	*Dry*	**Degree of saturation**	*65.03%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.2	55.4	73.7
Rate of shear displacement, mm/min	0.2	0.2	0.2





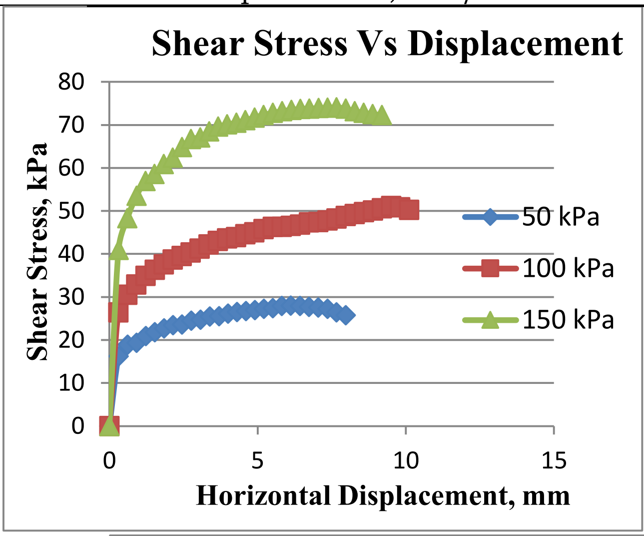


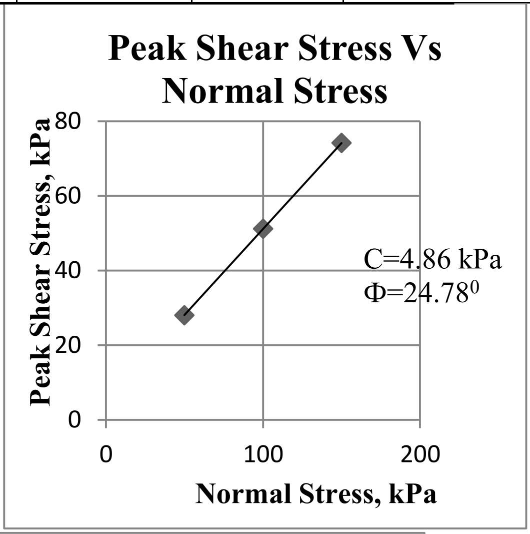
Location: *Mazegaja*			**Job ref.**	*Thesis research*
			Pit no.	*#2*
Soil Description: *Inorganic silts*			**Sample no.**	*#3*
			Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*			**Date**	*1/05/2011 E.C*

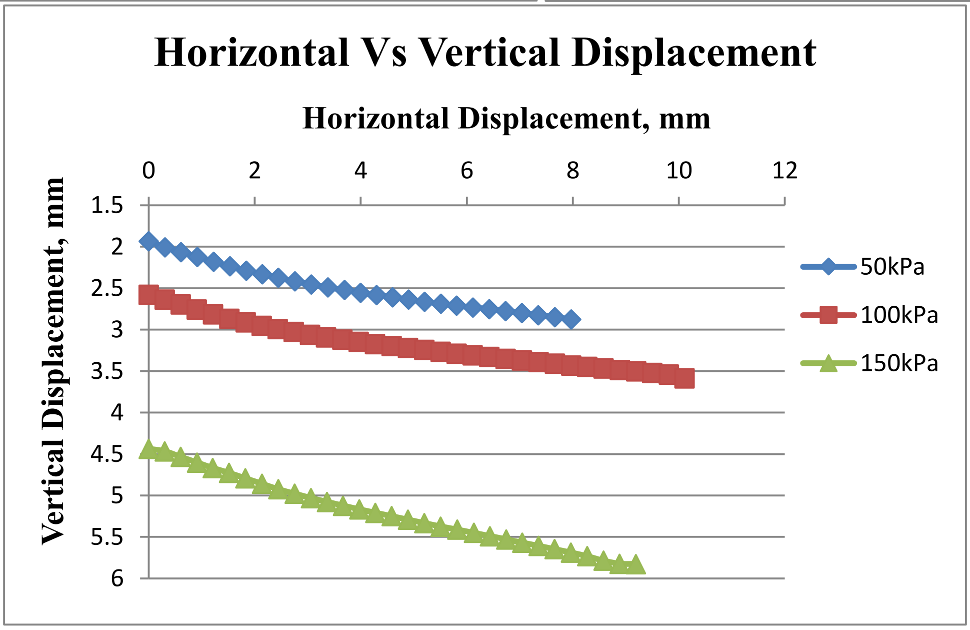
Specimen details			
Initial height	*25mm*	**Moisture content**	*28%*
Area	*3600mm²*	**Dry density**	*1.44gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.847*
Condition	*Dry*	**Degree of saturation**	*87.60%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	28	51.1	74.1
Rate of shear displacement, mm/min	0.2	0.2	0.2

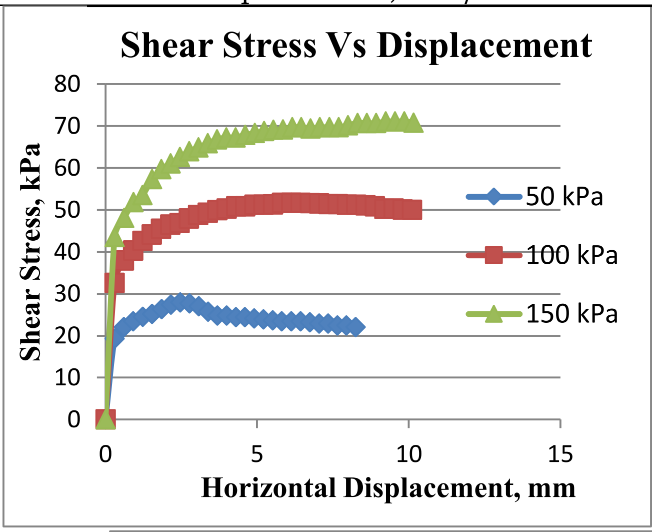


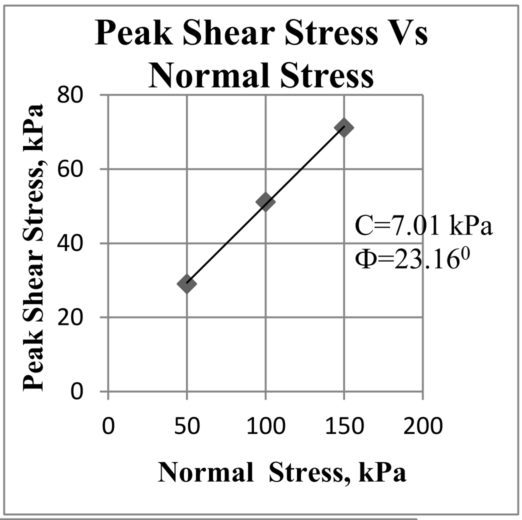


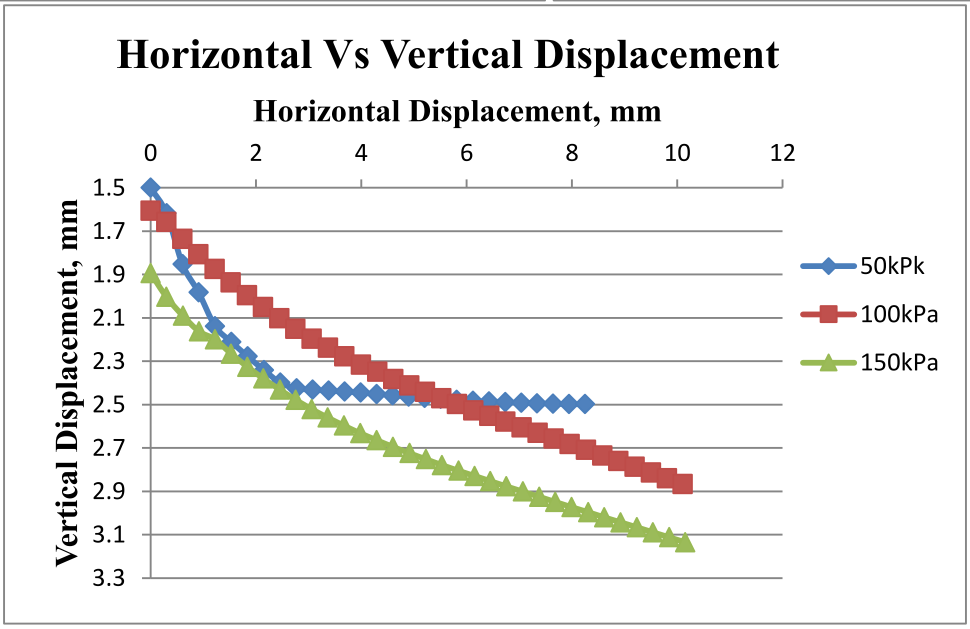


Location: *Ketara*		**Job ref.**	*Thesis research*
		Pit no.	*#3*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*2/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*26%*
Area	*3600mm²*	**Dry density**	*1.37gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.942*
Condition	*Submerged*	**Degree of saturation**	*74.58%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.9	51.7	71.1
Rate of shear displacement, mm/min	0.2	0.2	0.2



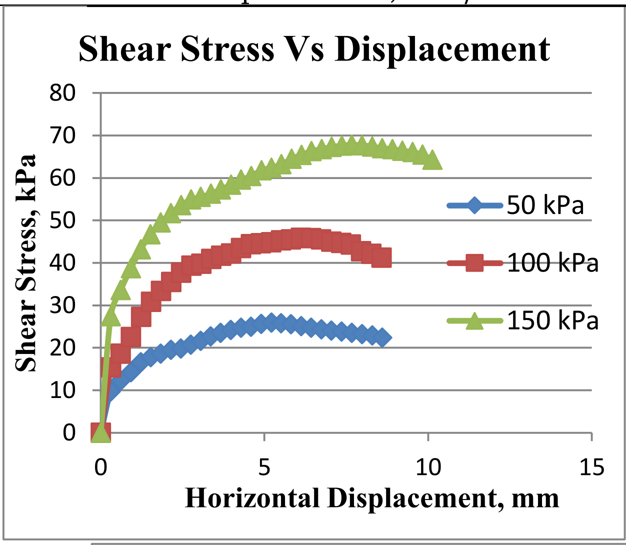


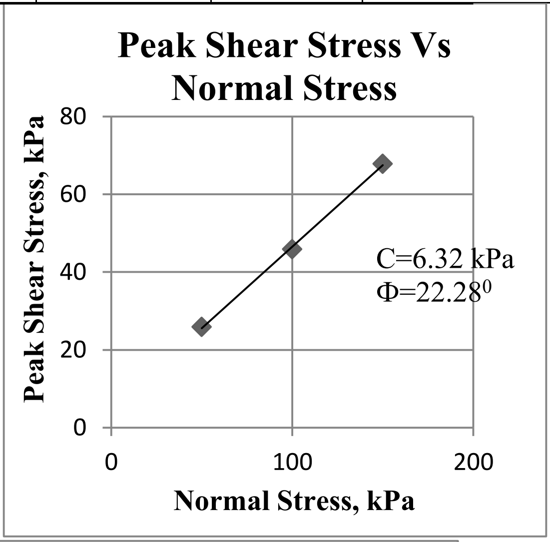


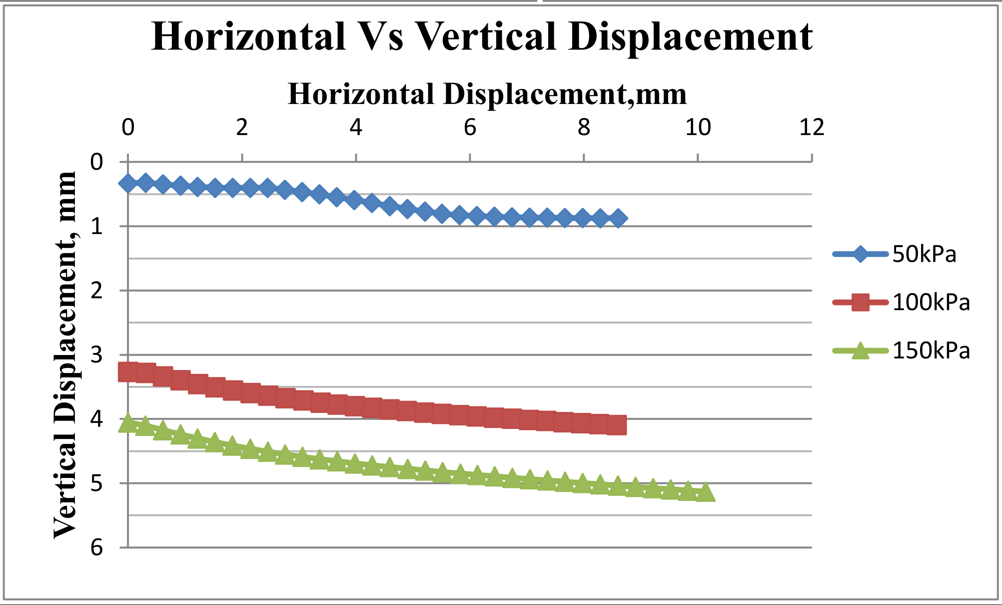
Location: *Ketara*		**Job ref.**	*Thesis research*
		Pit no.	*#3*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*3/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*19%*
Area	*3600mm²*	**Dry density**	*1.29gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.062*
Condition	*Dry*	**Degree of saturation**	*46.34%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	25.9	45.9	67.8
Rate of shear displacement, mm/min	0.2	0.2	0.2



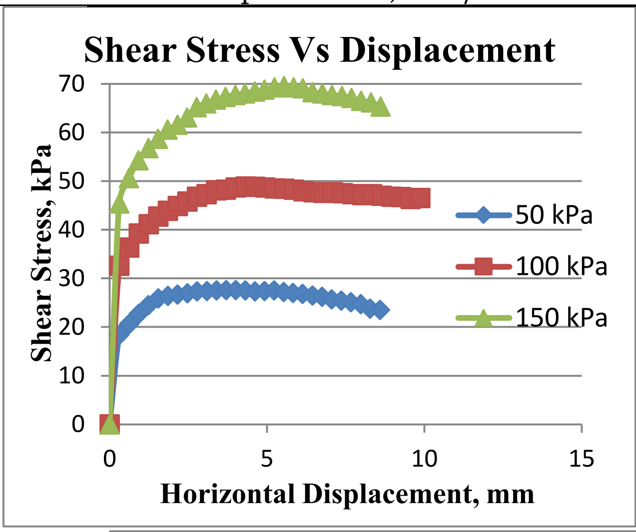


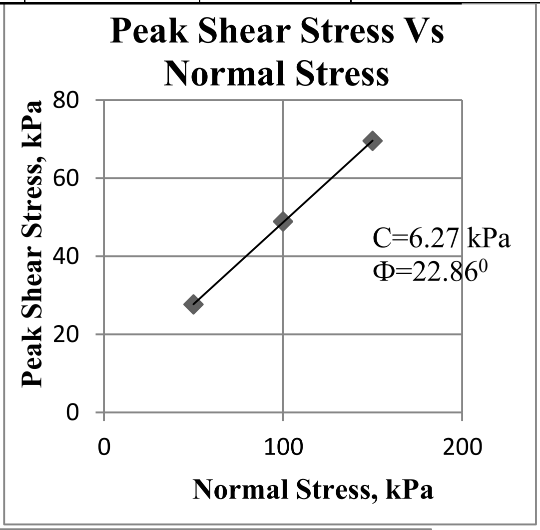


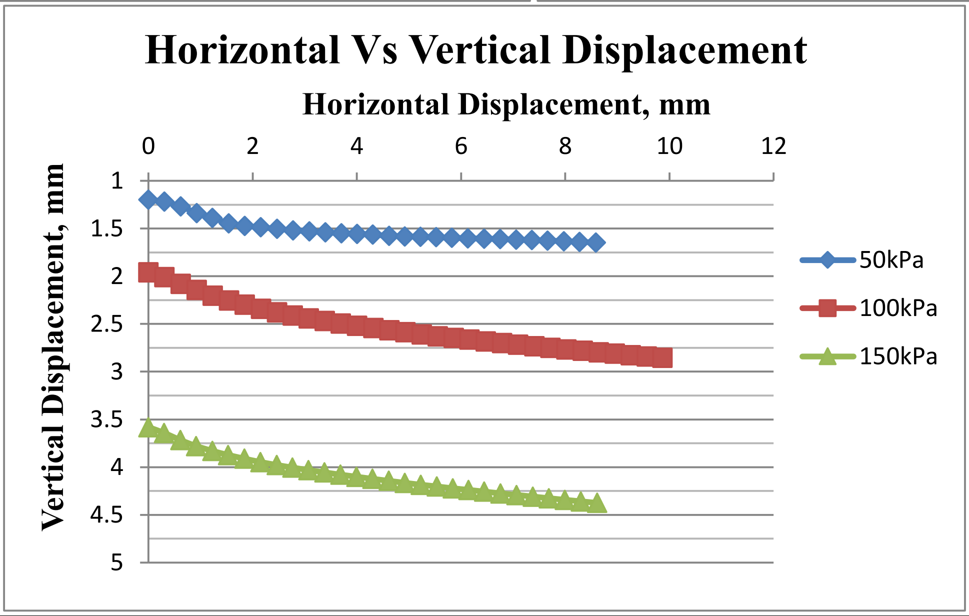
Location: *Ketara*		**Job ref.**	*Thesis research*
		Pit no.	*#3*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*4/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*37%*
Area	*3600mm²*	**Dry density**	*1.30gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.046*
Condition	*Dry*	**Degree of saturation**	*94.84%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.6	48.9	69.5
Rate of shear displacement, mm/min	0.2	0.2	0.2

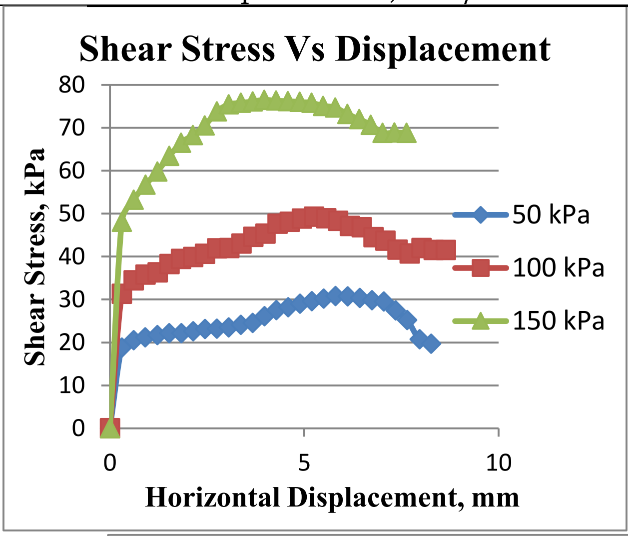


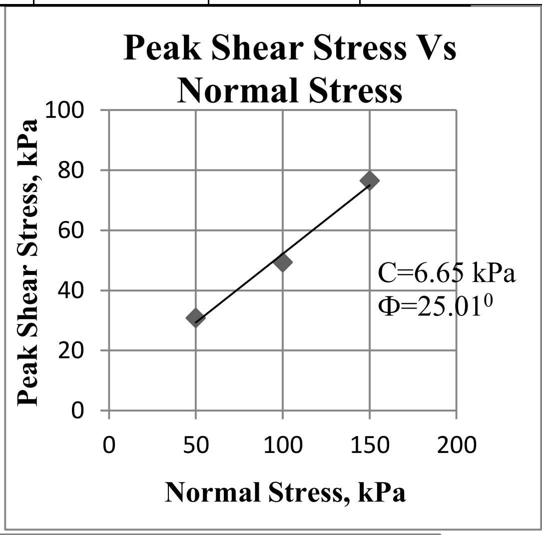


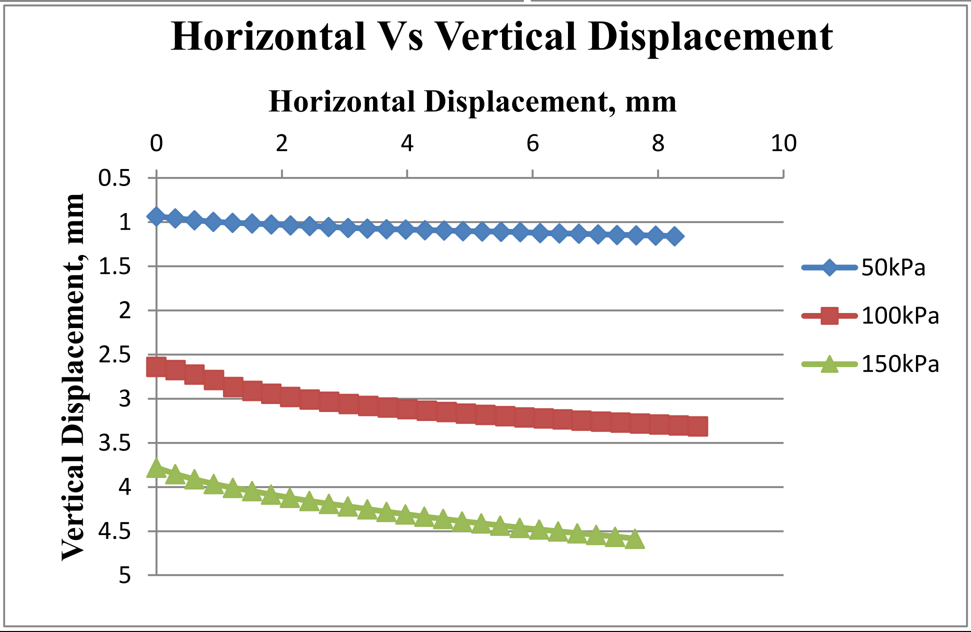


Location: *Kechema*		**Job ref.**	*Thesis research*
		Pit no.	*#4*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.7m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*5/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*24%*
Area	*3600mm²*	**Dry density**	*1.51gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.788*
Condition	*Submerged*	**Degree of saturation**	*82.57%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	30.8	49.3	76.5
Rate of shear displacement, mm/min	0.2	0.2	0.2



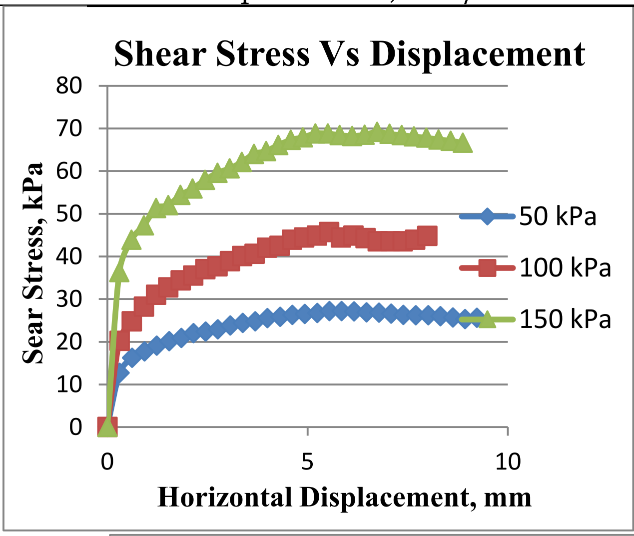


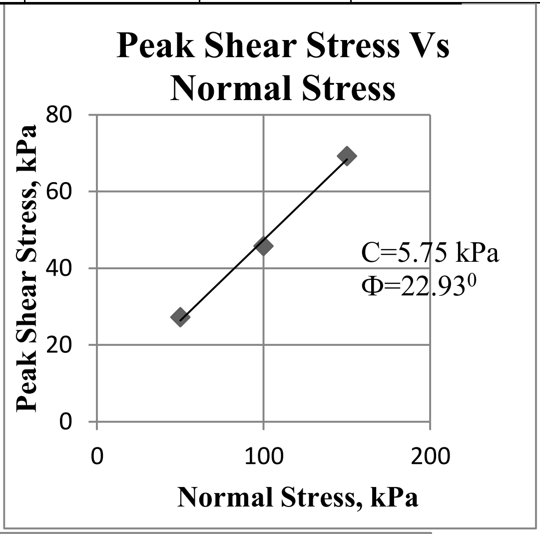


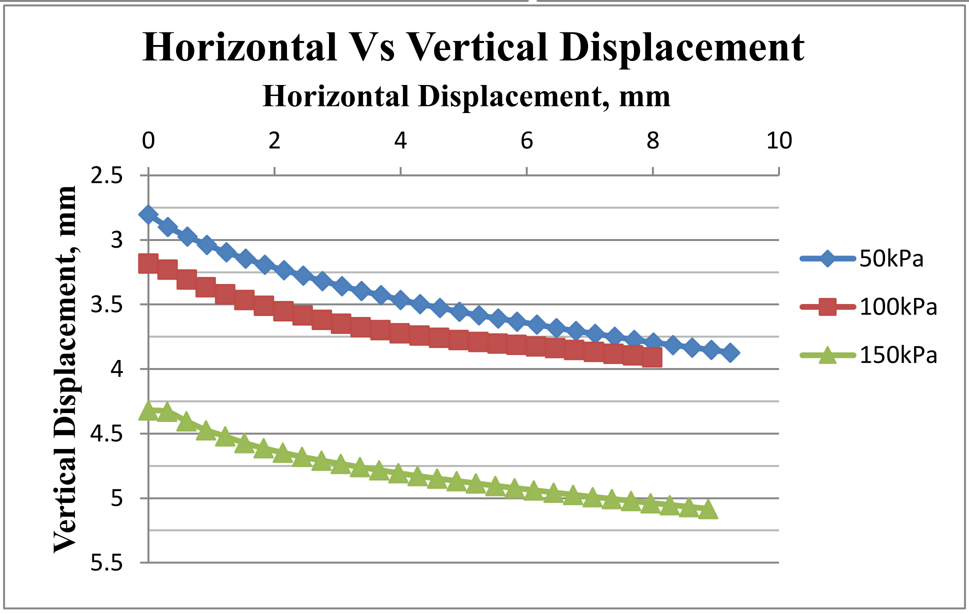
Location: *Kechema*		**Job ref.**	*Thesis research*
		Pit no.	*#4*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.7m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*6/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*20%*
Area	*3600mm²*	**Dry density**	*1.42gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.901*
Condition	*Dry*	**Degree of saturation**	*60.80%*

Test summery

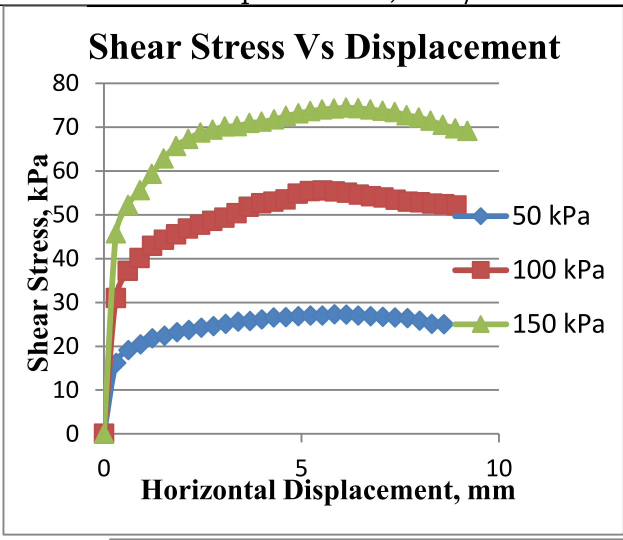
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.2	45.7	69.2
Rate of shear displacement, mm/min	0.2	0.2	0.2

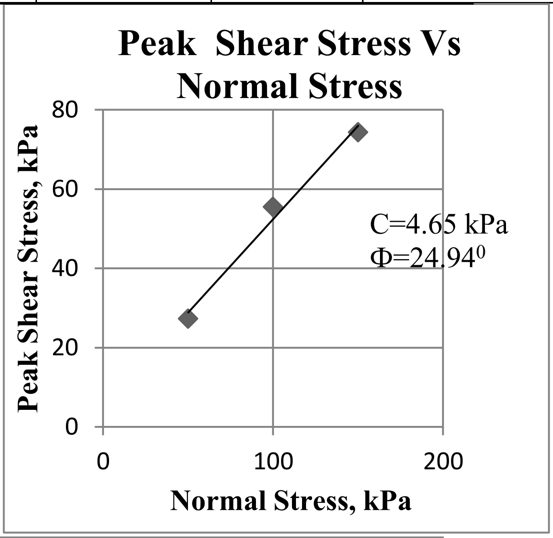


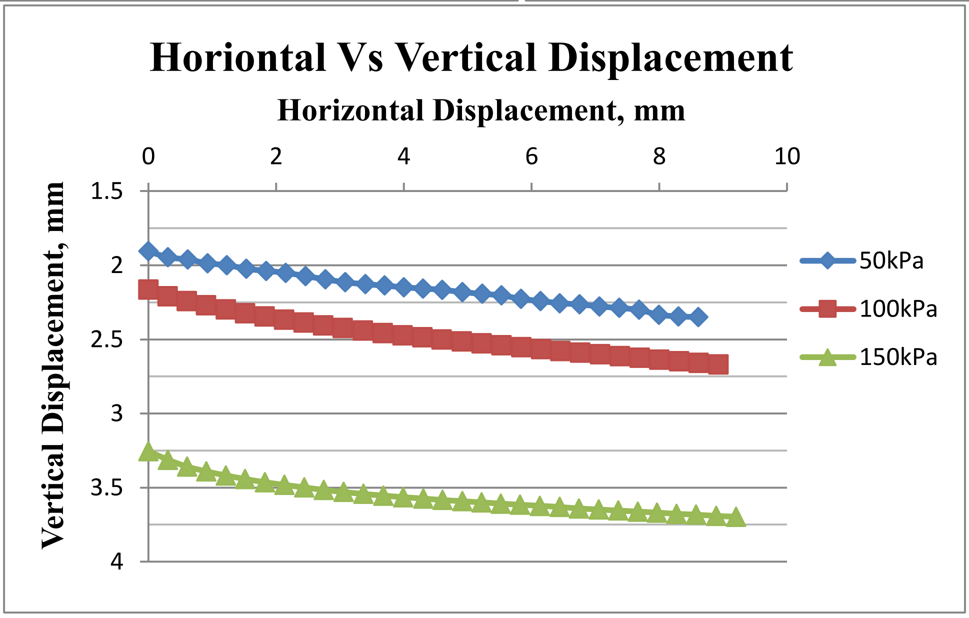




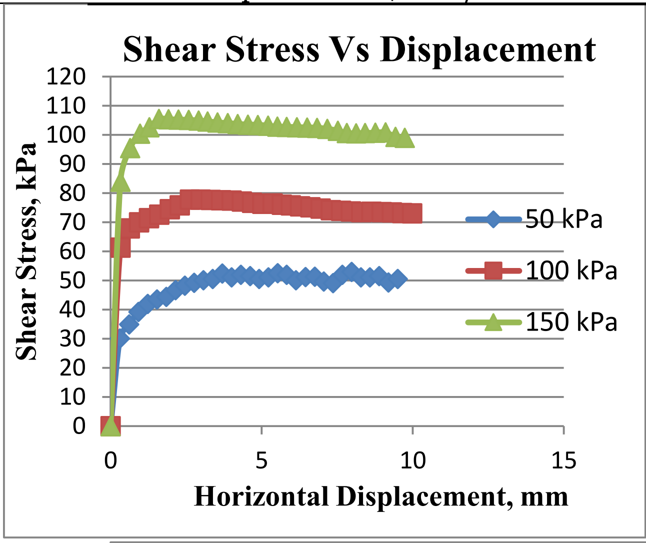
Location: *Kechema*		**Job ref.**	*Thesis research*
		Pit no.	*#4*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.7m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*7/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*29%*
Area	*3600mm²*	**Dry density**	*1.43gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.888*
Condition	*Dry*	**Degree of saturation**	*89.38%*
Test summery			
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.3	55.5	74.4
Rate of shear displacement, mm/min	0.2	0.2	0.2

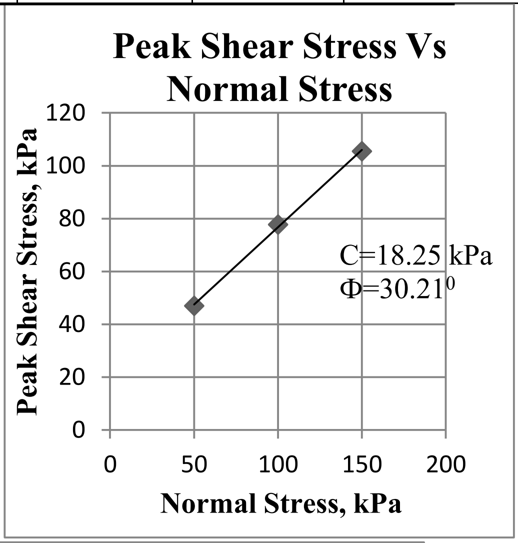


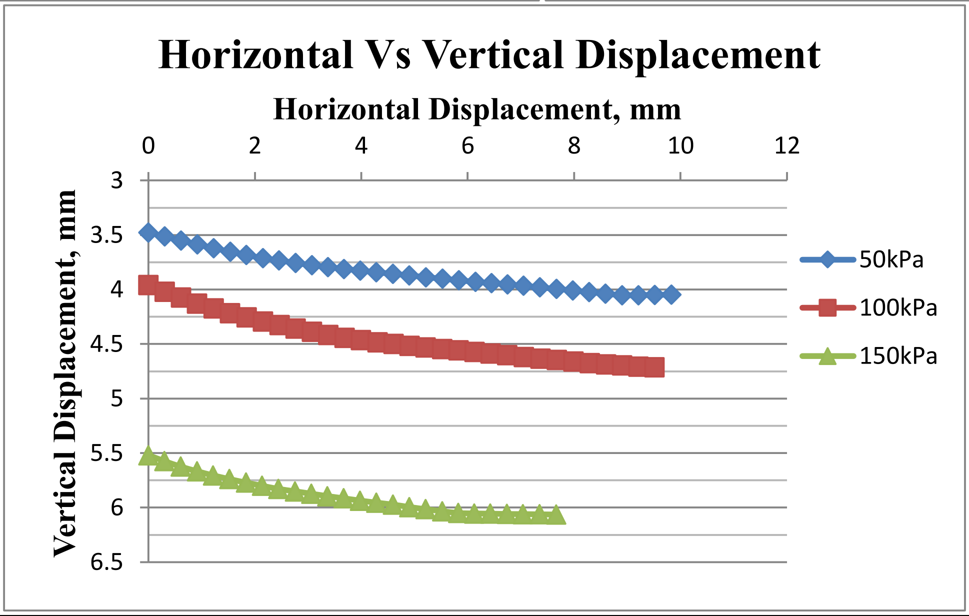




Location: *Boku*		**Job ref.**	*Thesis research*
		Pit no.	*#5*
		Sample no.	*#1*
		Depth	*2.5m*
		Date	*8/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*31%*
Area	*3600mm²*	**Dry density**	*1.33gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.955*
Condition	*Submerged*	**Degree of saturation**	*84.41%*
Test summery			
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	47.0	77.8	105.5
Rate of shear displacement, mm/min	0.2	0.2	0.2

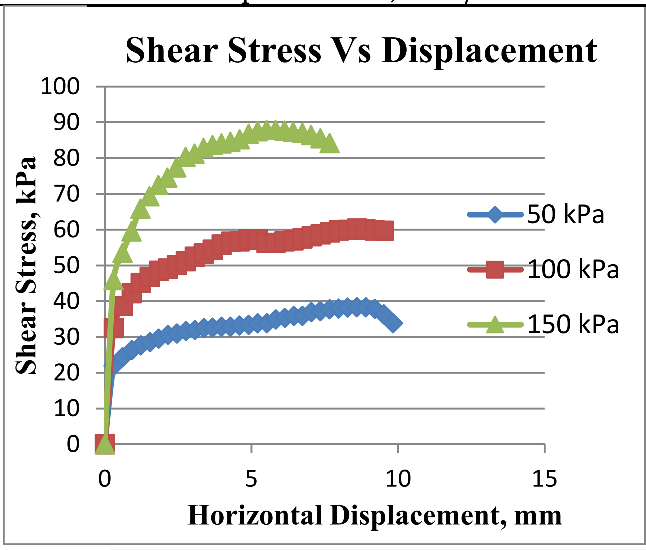


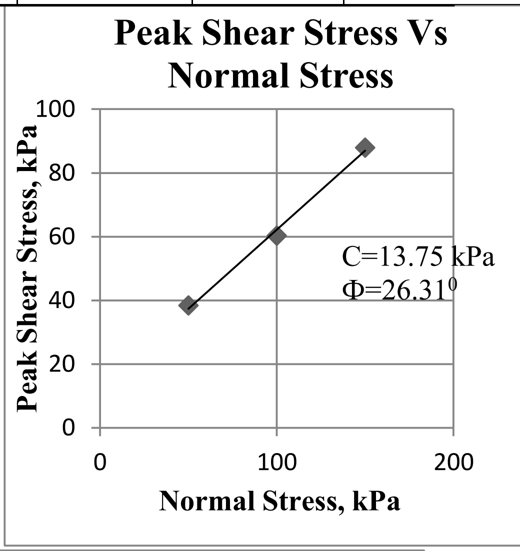


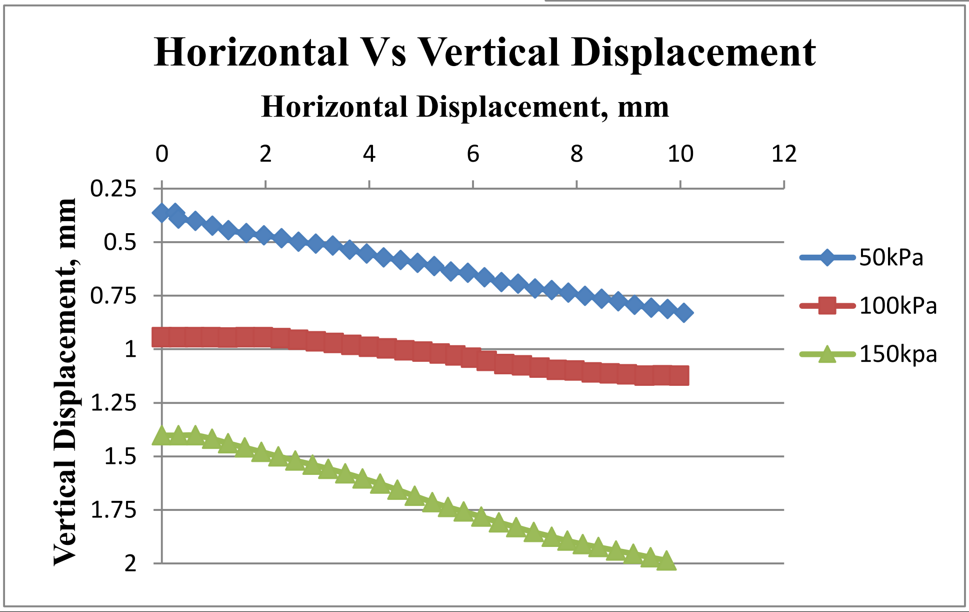


Location: *Boku*		**Job ref.**	*Thesis research*
		Pit no.	*#5*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*9/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*27%*
Area	*3600mm²*	**Dry density**	*1.29gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.016*
Condition	*Dry*	**Degree of saturation**	*68.62%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	38.3	60.3	87.9
Rate of shear displacement, mm/min	0.2	0.2	0.2



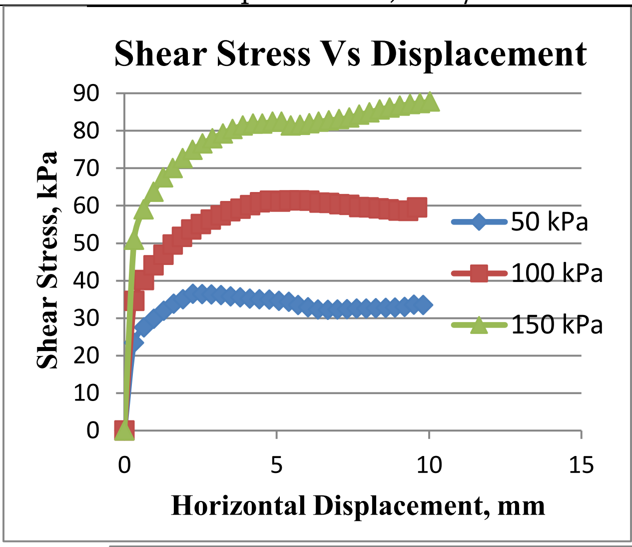


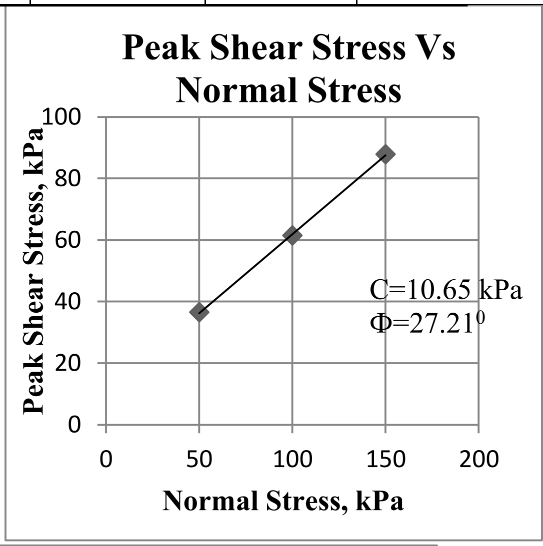


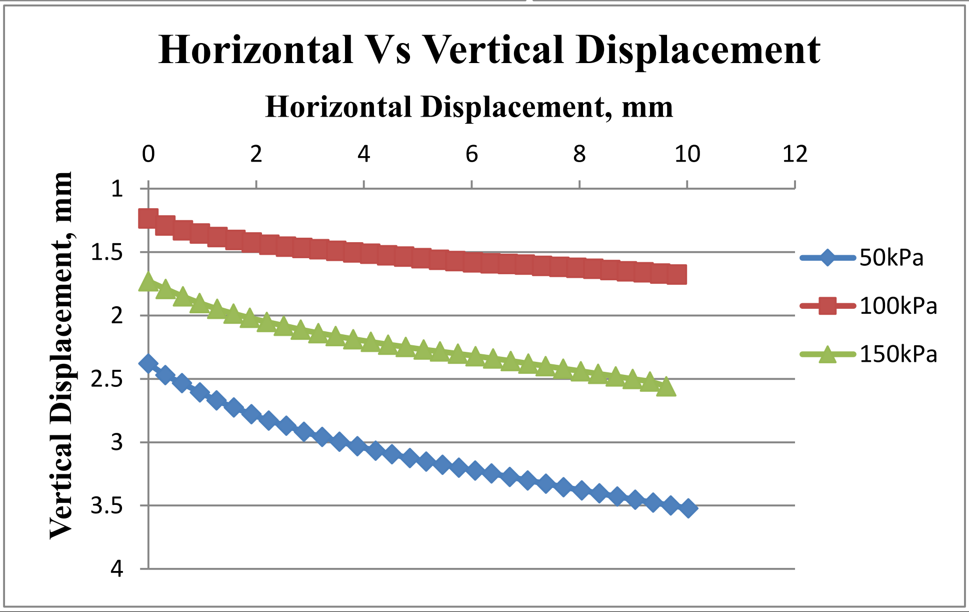
Location: *Boku*		**Job ref.**	*Thesis research*
		Pit no.	*#5*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*10/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*35%*
Area	*3600mm²*	**Dry density**	*1.30gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.000*
Condition	*Dry*	**Degree of saturation**	*91.0%*

Test summery

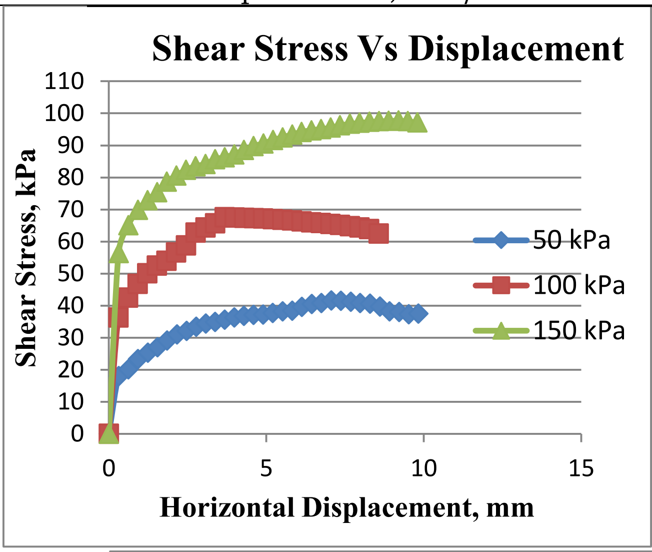
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	36.5	61.4	87.8
Rate of shear displacement, mm/min	0.2	0.2	0.2

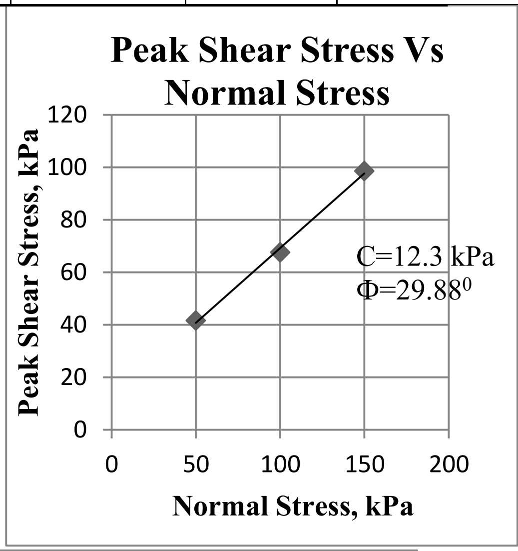


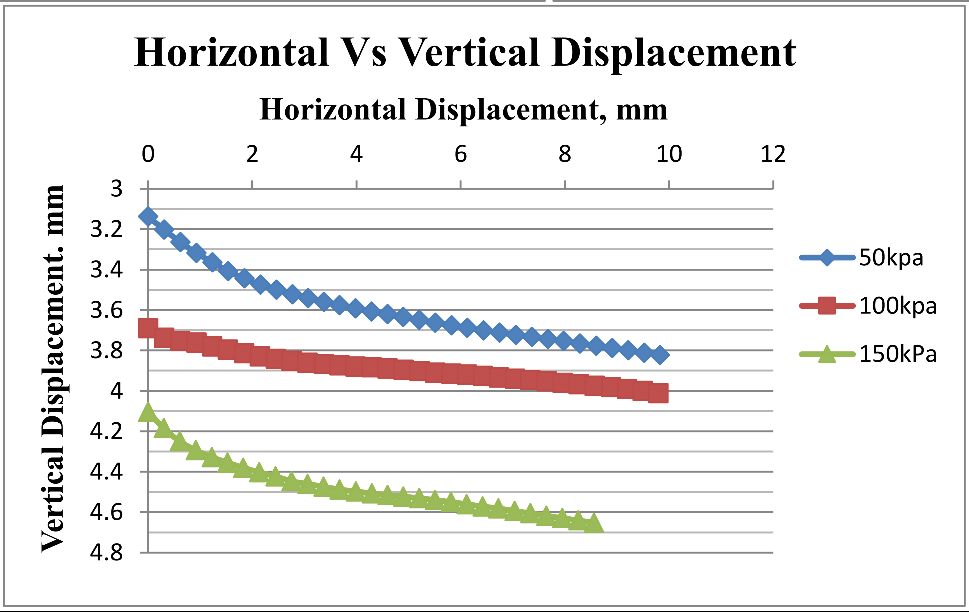




Location: *Cheffe*		**Job ref.**	*Thesis research*
		Pit no.	*#6*
Soil Description: *Silty Sand*		**Sample no.**	*#1*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*11/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*20%*
Area	*3600mm²*	**Dry density**	*1.62gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.660*
Condition	*Submerged*	**Degree of saturation**	*81.45%*
Test summery			
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	41.6	67.6	97.7
Rate of shear displacement, mm/min	0.2	0.2	0.2

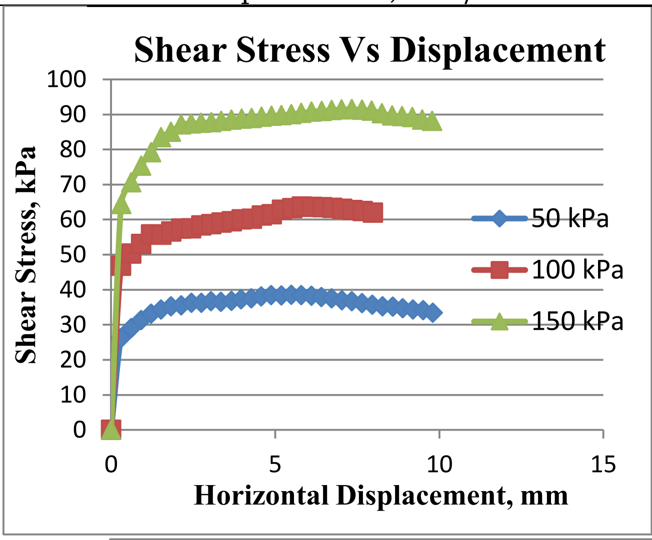


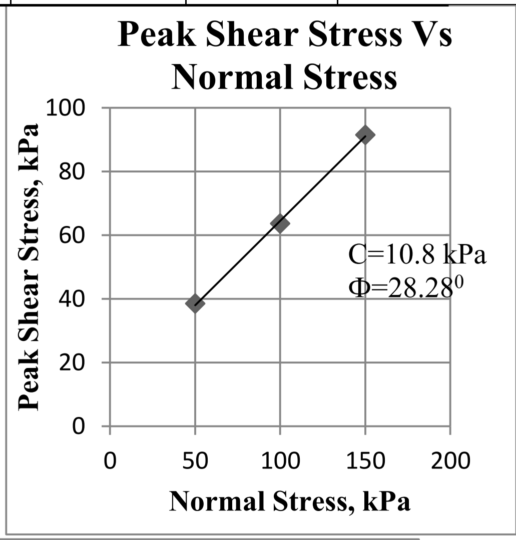


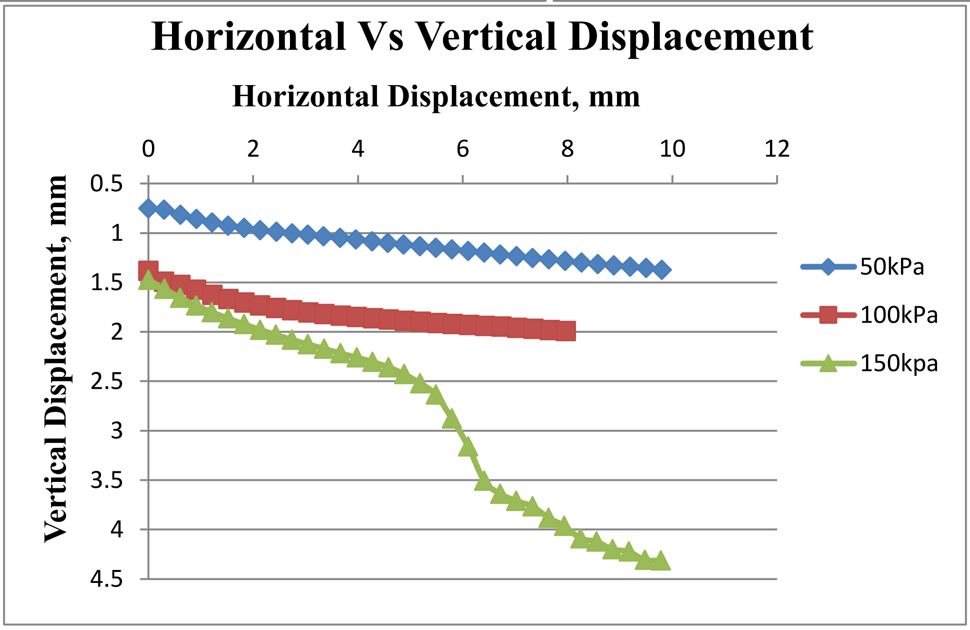


Location: *Cheffe*		**Job ref.**	*Thesis research*
		Pit no.	*#6*
Soil Description: *Silty Sand*		**Sample no.**	*#2*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*12/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*17%*
Area	*3600mm²*	**Dry density**	*1.53gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.758*
Condition	*Dry*	**Degree of saturation**	*61.74%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	38.5	63.7	91.5
Rate of shear displacement, mm/min	0.2	0.2	0.2







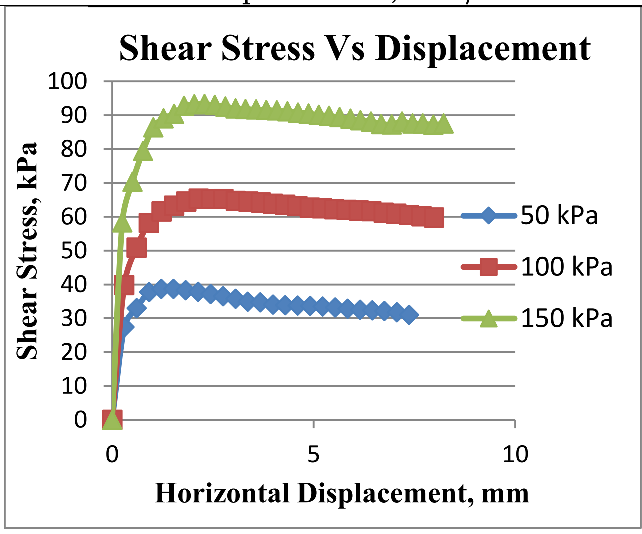
Location: *Cheffe*		**Job ref.**	*Thesis research*
		Pit no.	*#6*
Soil Description: *Silty Sand*		**Sample no.**	*#3*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*13/05/2011 E.C*

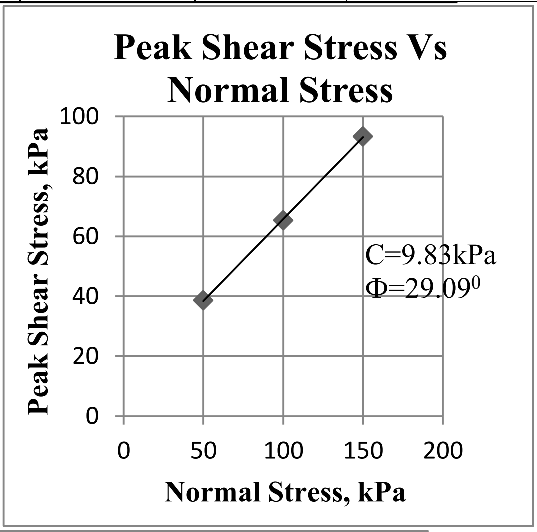
Specimen details

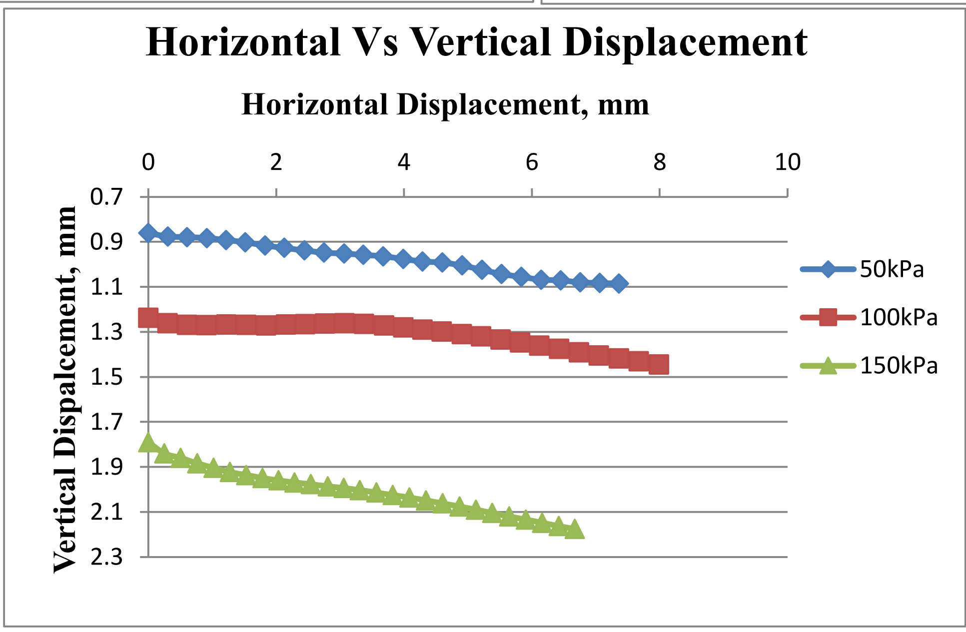
Initial height	*25mm*	**Moisture content**	*24%*
Area	*3600mm²*	**Dry density**	*1.54gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.747*
Condition	*Dry*	**Degree of saturation**	*87.53%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	38.6	65.3	93.3
Rate of shear displacement, mm/min	0.2	0.2	0.2

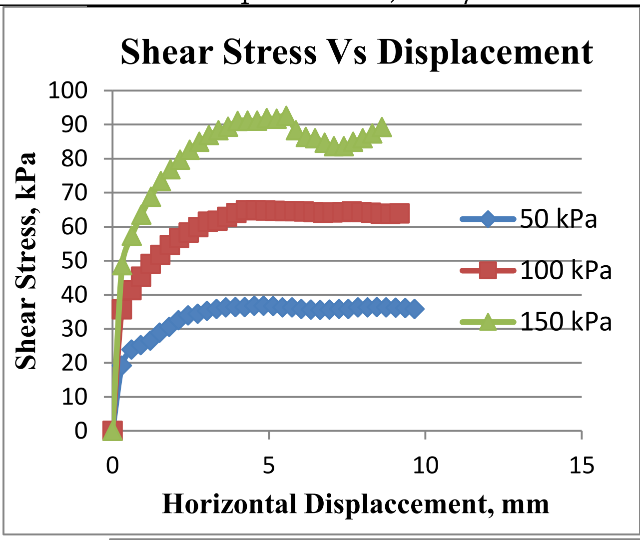


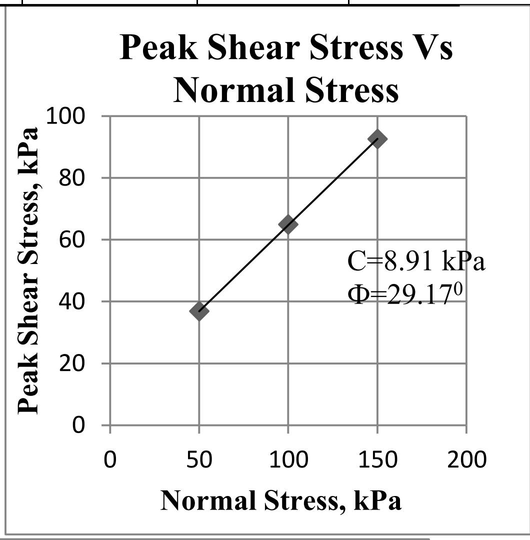


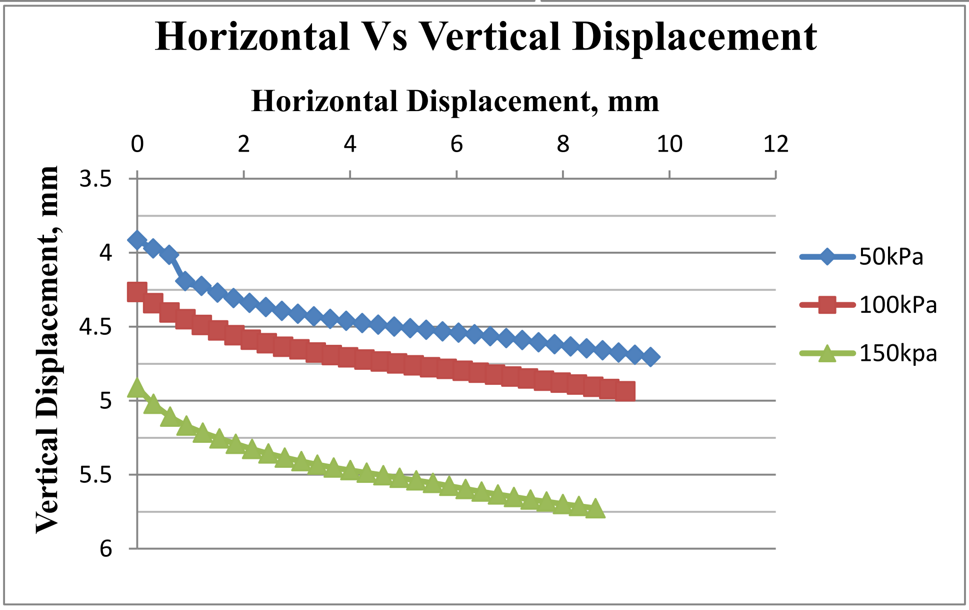


Location: *Dibibisa*		**Job ref.**	*Thesis research*
		Pit no.	*#7*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*14/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*26%*
Area	*3600mm²*	**Dry density**	*1.47gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.816*
Condition	*Submerged*	**Degree of saturation**	*84.06%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	36.8	64.9	92.6
Rate of shear displacement, mm/min	0.2	0.2	0.2







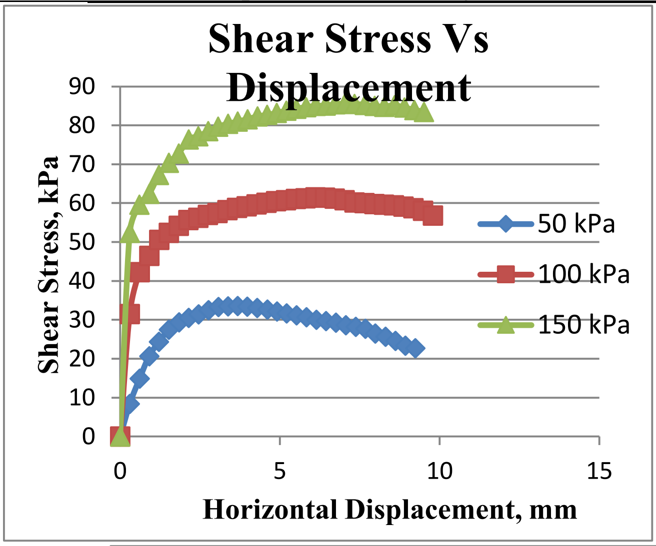
Location: *Dibibisa*		**Job ref.**	*Thesis research*
		Pit no.	*#7*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*15/05/2011 E.C*

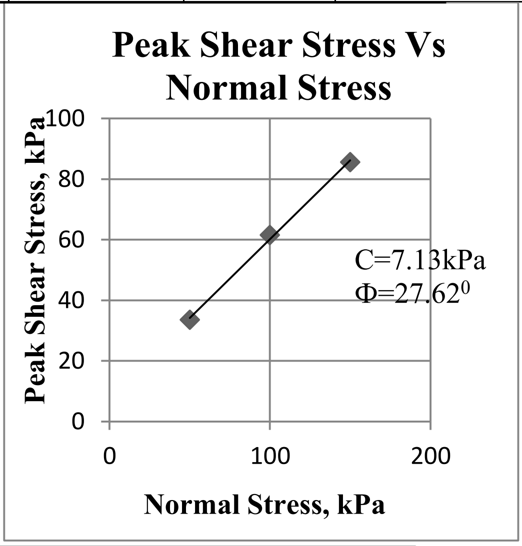
Specimen details

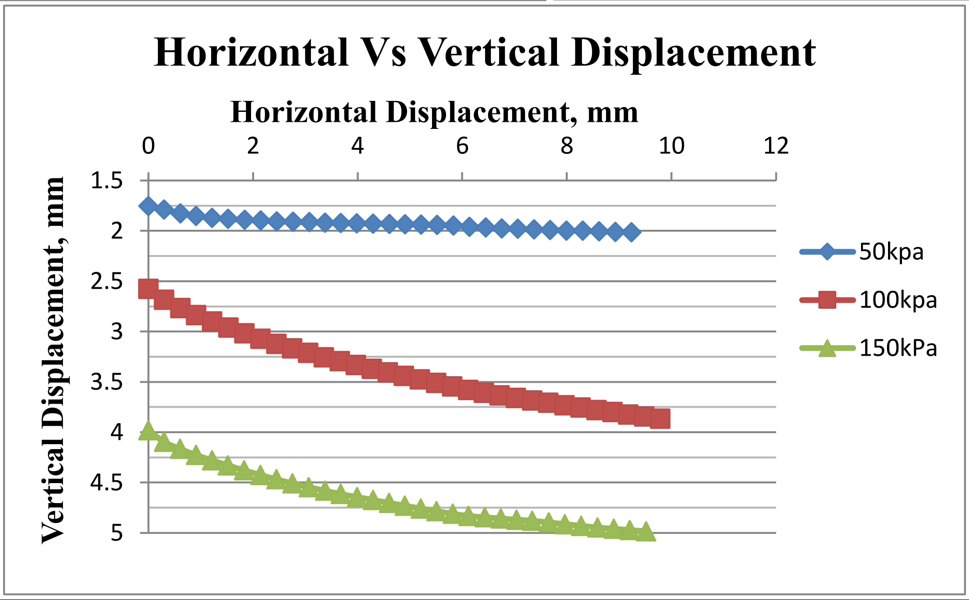
Initial height	*25mm*	**Moisture content**	*19%*
Area	*3600mm²*	**Dry density**	*1.31gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.038*
Condition	*Dry*	**Degree of saturation**	*48.86%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	33.6	61.5	85.6
Rate of shear displacement, mm/min	0.2	0.2	0.2

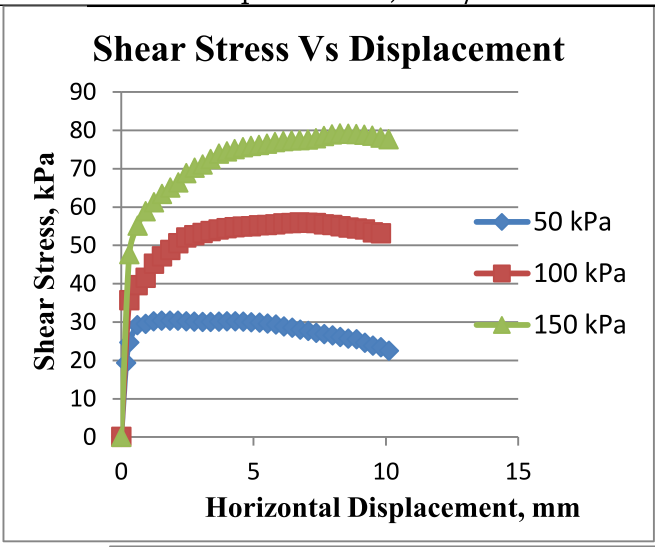


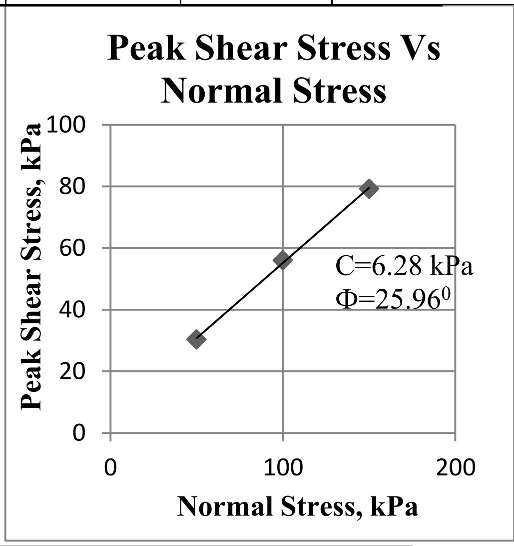


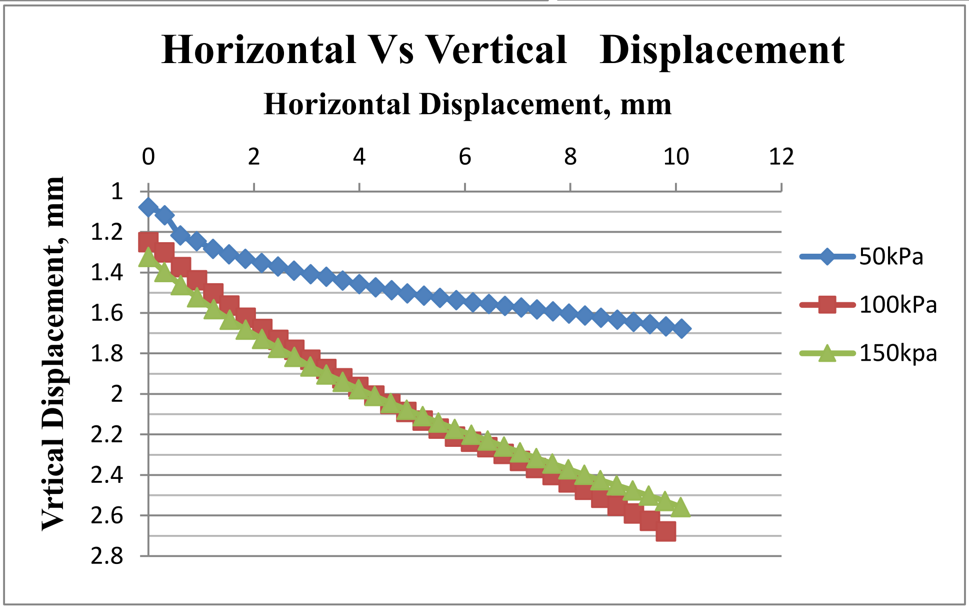


Location: *Dibibisa*		**Job ref.**	*Thesis research*
		Pit no.	*#7*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.6m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*16/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*31%*
Area	*3600mm²*	**Dry density**	*1.38gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.935*
Condition	*Dry*	**Degree of saturation**	*87.40%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	30.3	56	79.2
Rate of shear displacement, mm/min	0.2	0.2	0.2

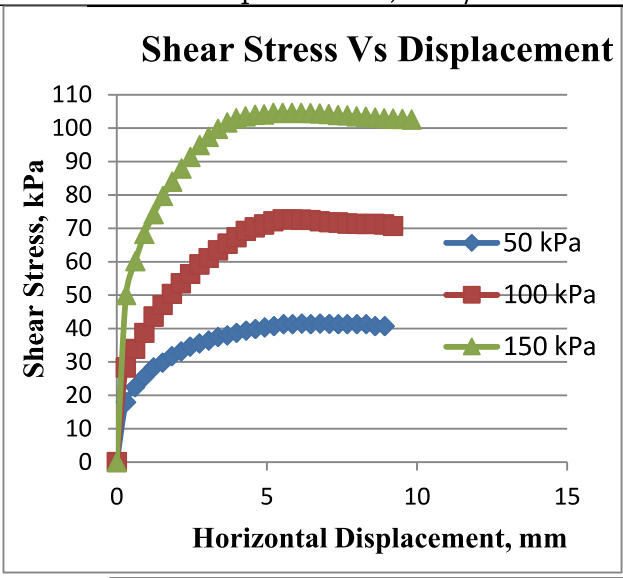


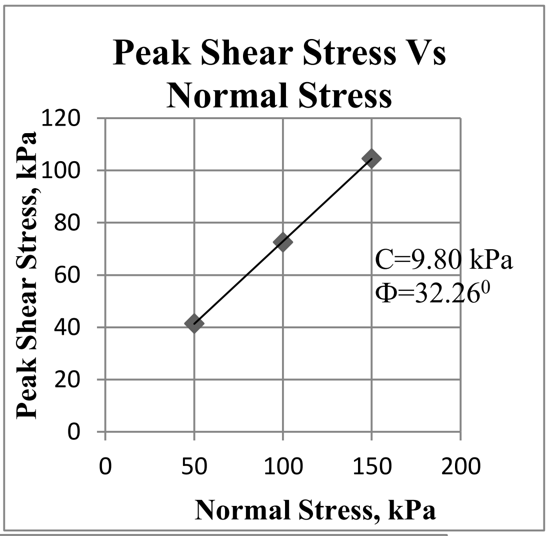


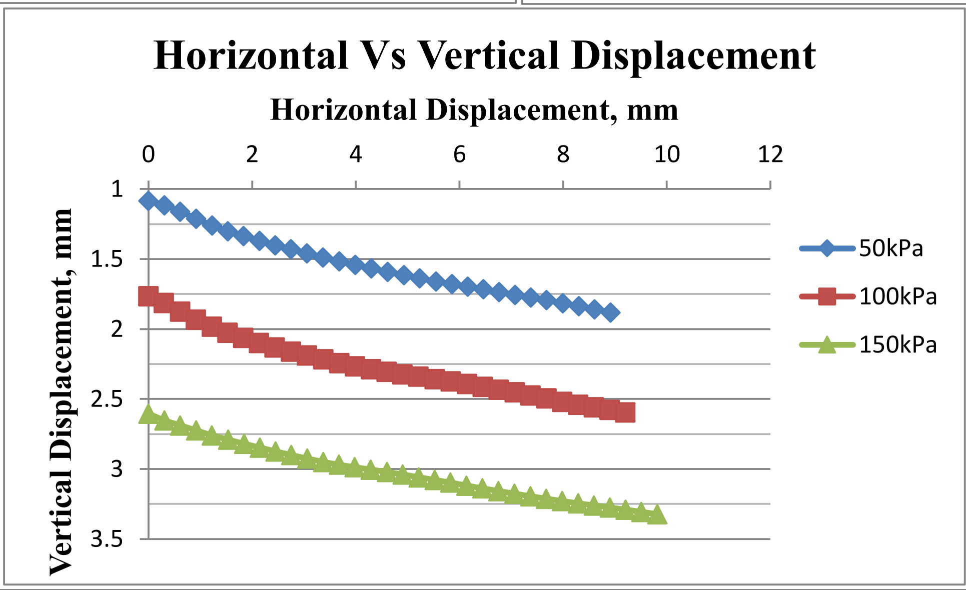


Location: *Migira*		**Job ref.**	*Thesis research*
		Pit no.	*#8*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*17/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*29%*
Area	*3600mm²*	**Dry density**	*1.44gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.868*
Condition	*Submerged*	**Degree of saturation**	*88.63%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	41.4	72.6	104.5
Rate of shear displacement, mm/min	0.2	0.2	0.2



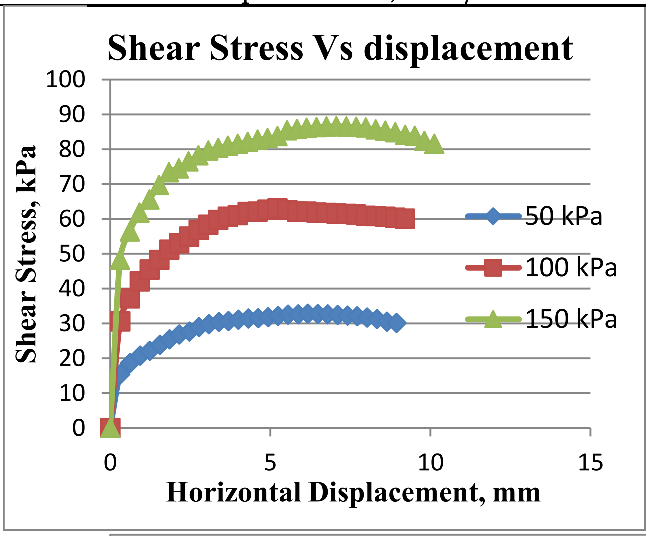


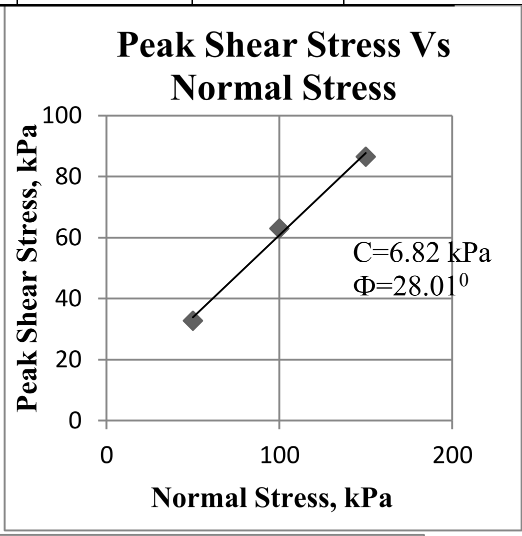


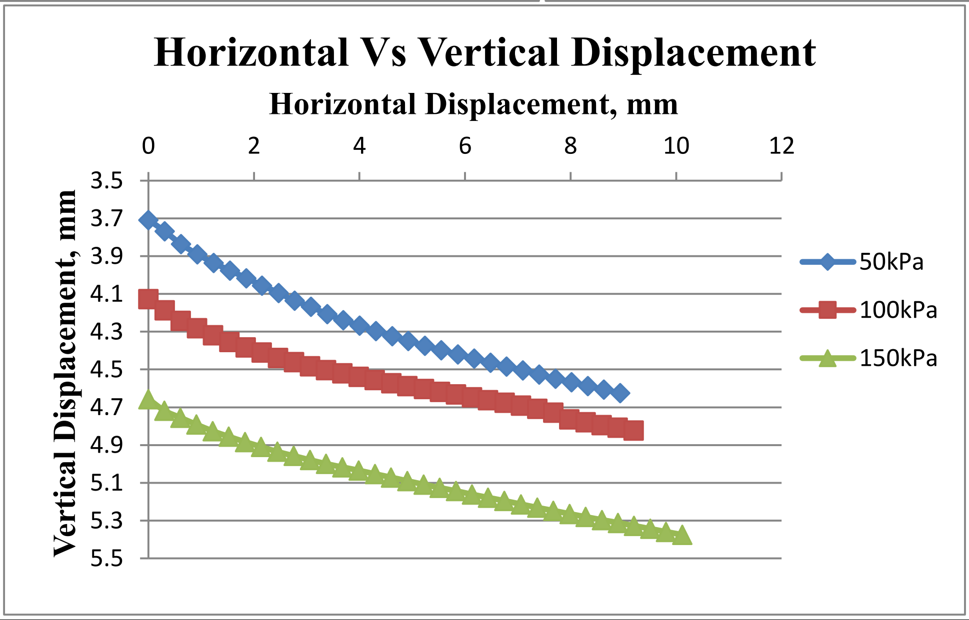
Location: *Migira*		**Job ref.**	*Thesis research*
		Pit no.	*#8*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*18/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*24%*
Area	*3600mm²*	**Dry density**	*1.33gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.023*
Condition	*Dry*	**Degree of saturation**	*58.14%*

Test summery

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	32.8	63.0	86.6
Rate of shear displacement, mm/min	0.2	0.2	0.2

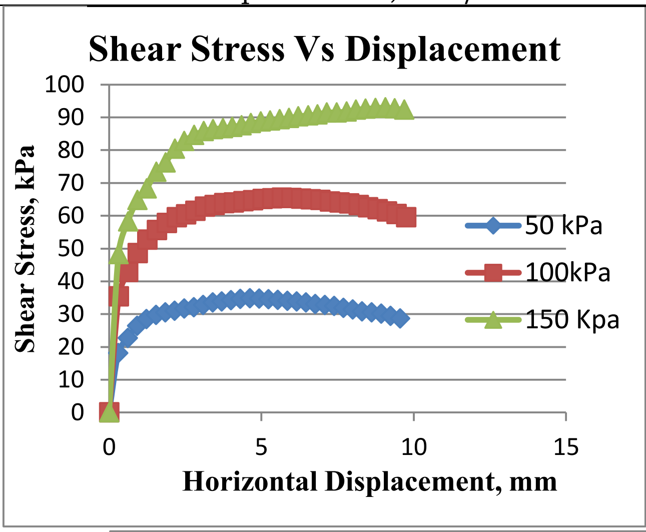


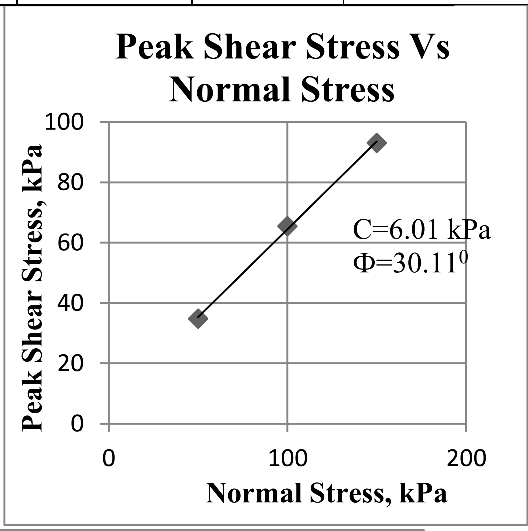


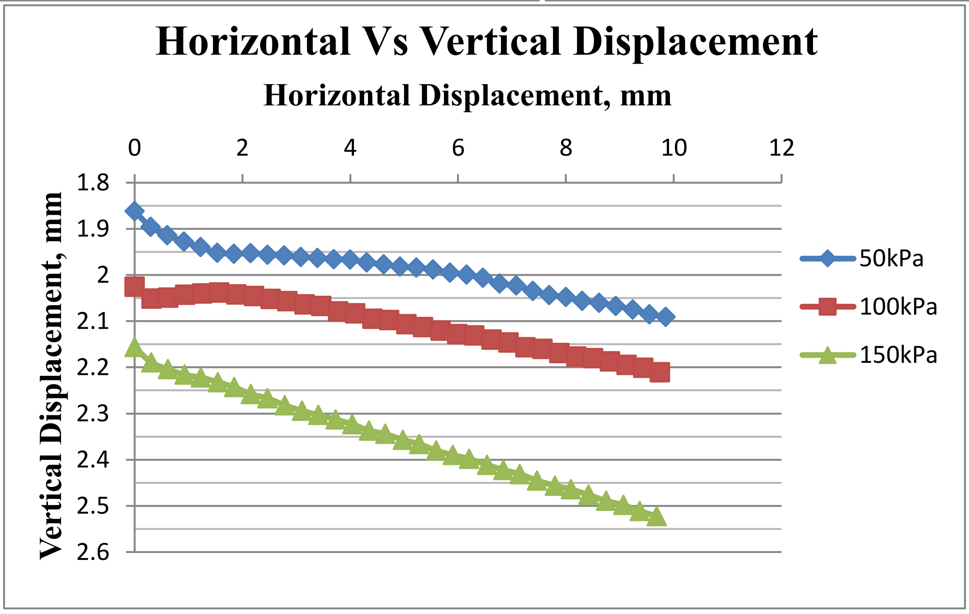


Location: *Migira*		**Job ref.**	*Thesis research*
		Pit no.	*#8*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.3m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*19/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*32%*
Area	*3600mm²*	**Dry density**	*1.40gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.921*
Condition	*Dry*	**Degree of saturation**	*91.96%*
Test summery			

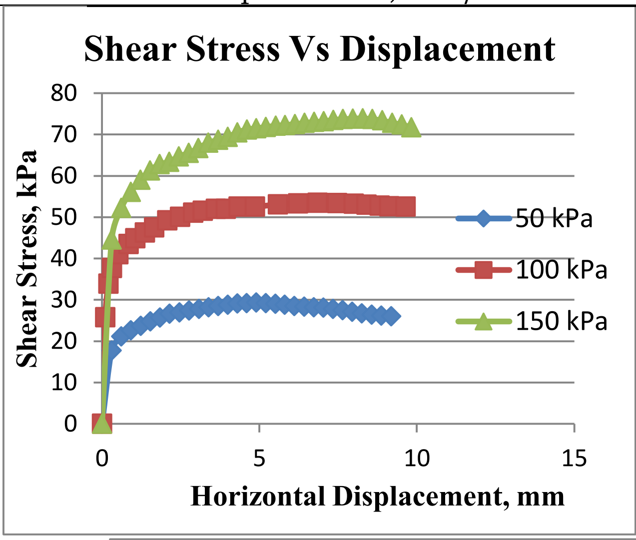
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	34.8	65.5	93
Rate of shear displacement, mm/min	0.2	0.2	0.2

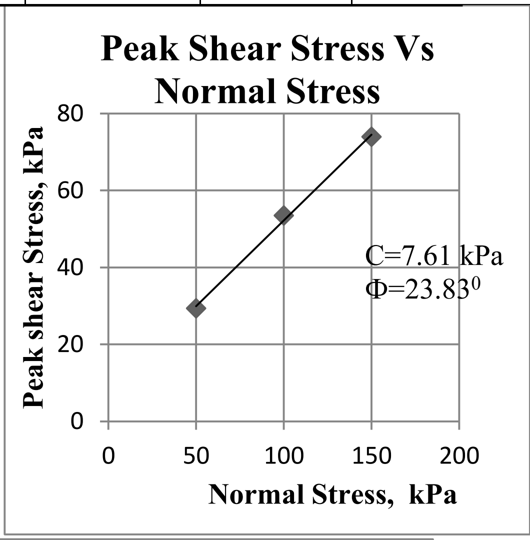


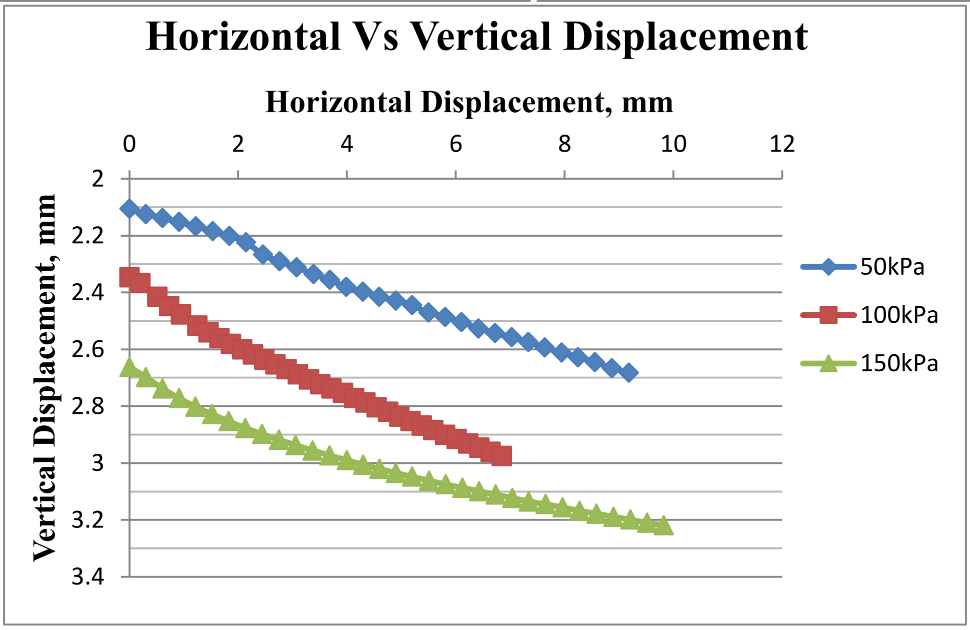




Location: *Sole*		**Job ref.**	*Thesis research*
		Pit no.	*#9*
Soil Description: *Inorganic silts*		**Sample no.**	*#1*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*20/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*37%*
Area	*3600mm²*	**Dry density**	*1.26gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.032*
Condition	*Submerged*	**Degree of saturation**	*91.31%*
Test summery			
Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	29.3	53.5	73.9
Rate of shear displacement, mm/min	0.2	0.2	0.2

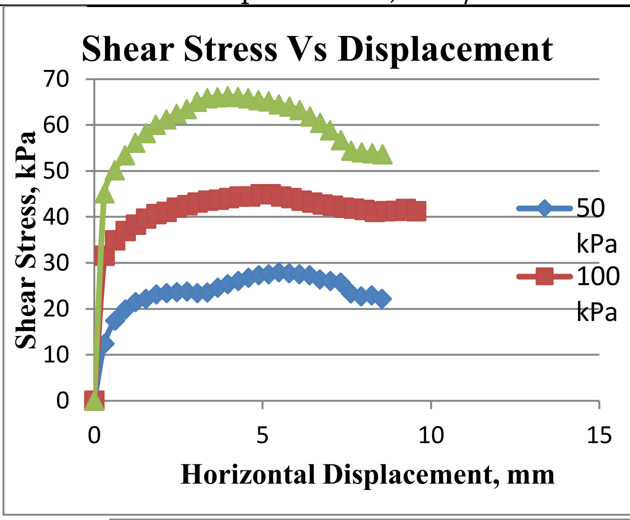


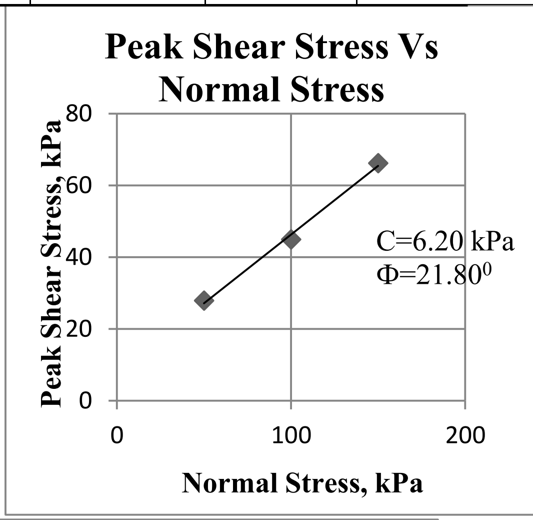


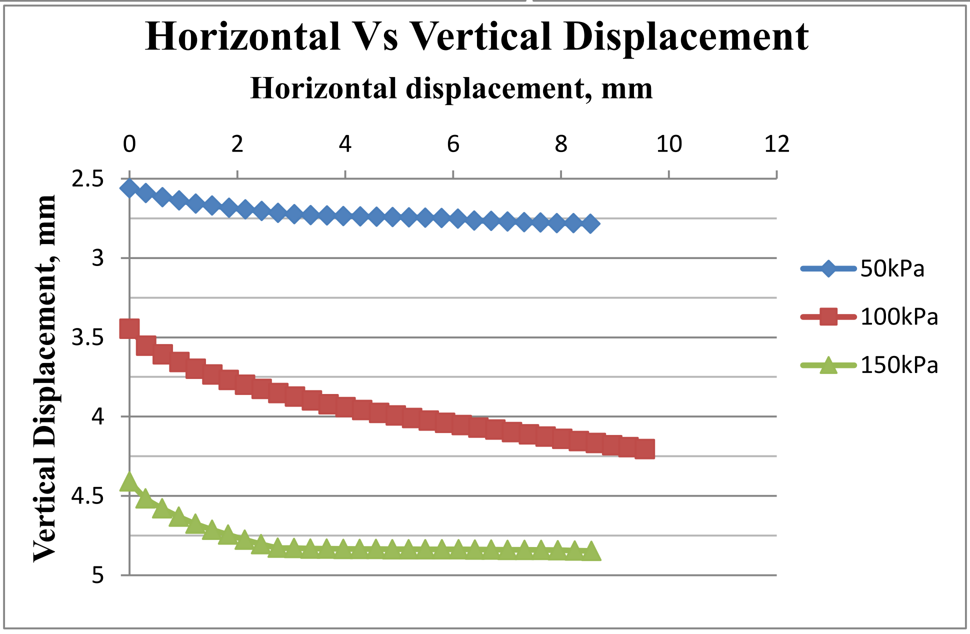


Location: *Sole*		**Job ref.**	*Thesis research*
		Pit no.	*#9*
Soil Description: *Inorganic silts*		**Sample no.**	*#2*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*21/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*33%*
Area	*3600mm²*	**Dry density**	*1.22gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.098*
Condition	*Dry*	**Degree of saturation**	*75.75%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	27.9	44.9	66.2
Rate of shear displacement, mm/min	0.2	0.2	0.2

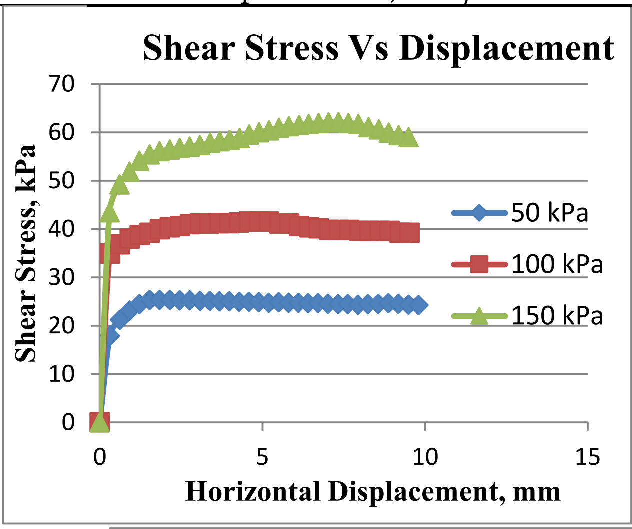


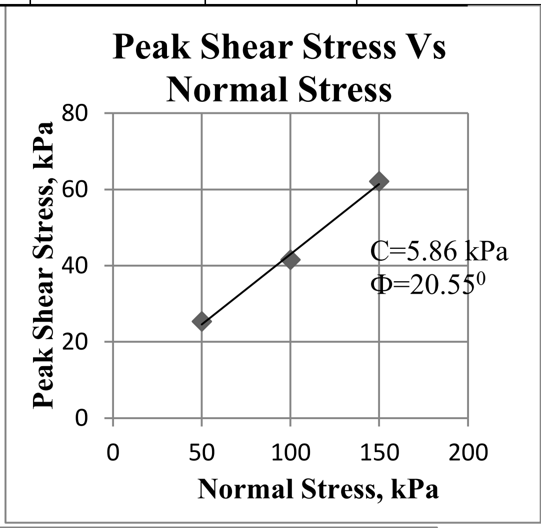


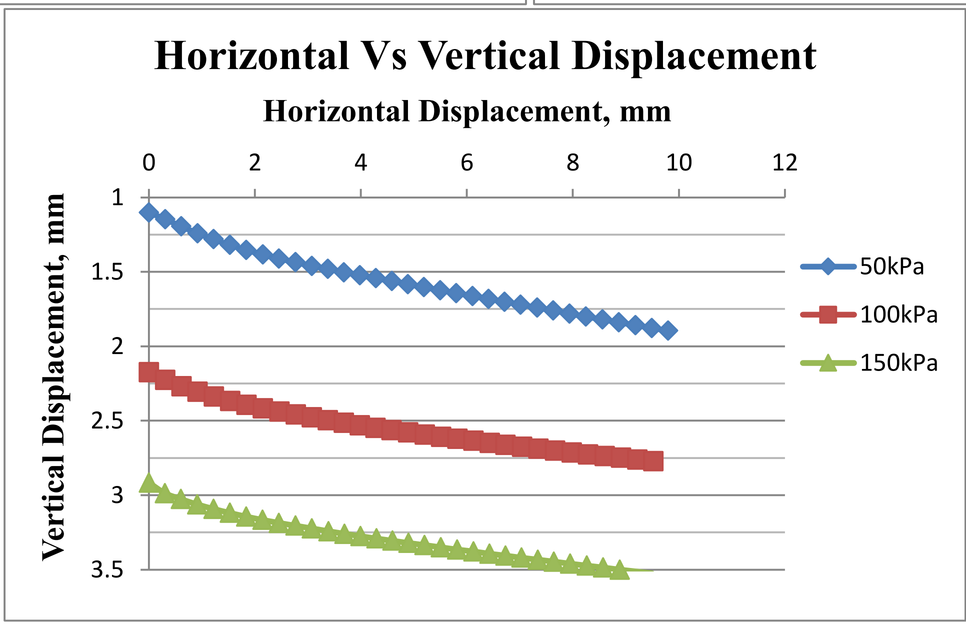


Location: *Sole*		**Job ref.**	*Thesis research*
		Pit no.	*#9*
Soil Description: *Inorganic silts*		**Sample no.**	*#3*
		Depth	*2.8m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*22/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*44%*
Area	*3600mm²*	**Dry density**	*1.20gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*1.133*
Condition	*Dry*	**Degree of saturation**	*99.84%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	25.3	41.5	62.1
Rate of shear displacement, mm/min	0.2	0.2	0.2

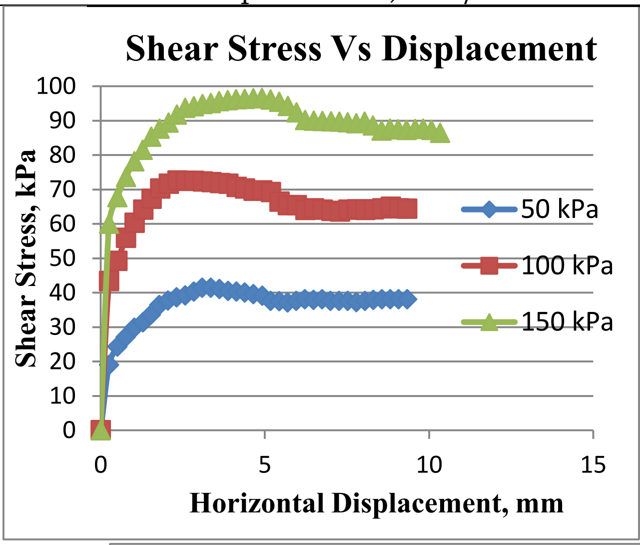


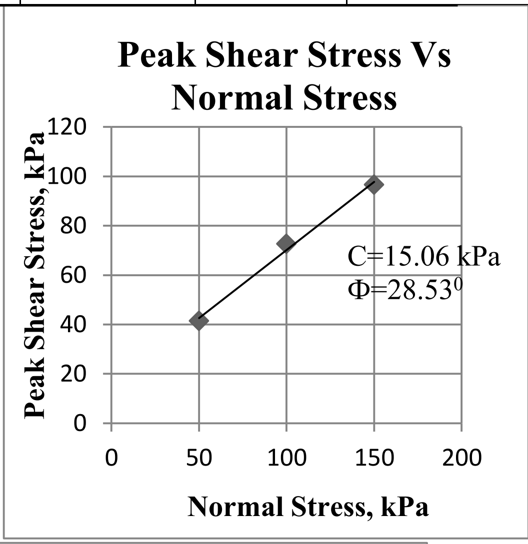


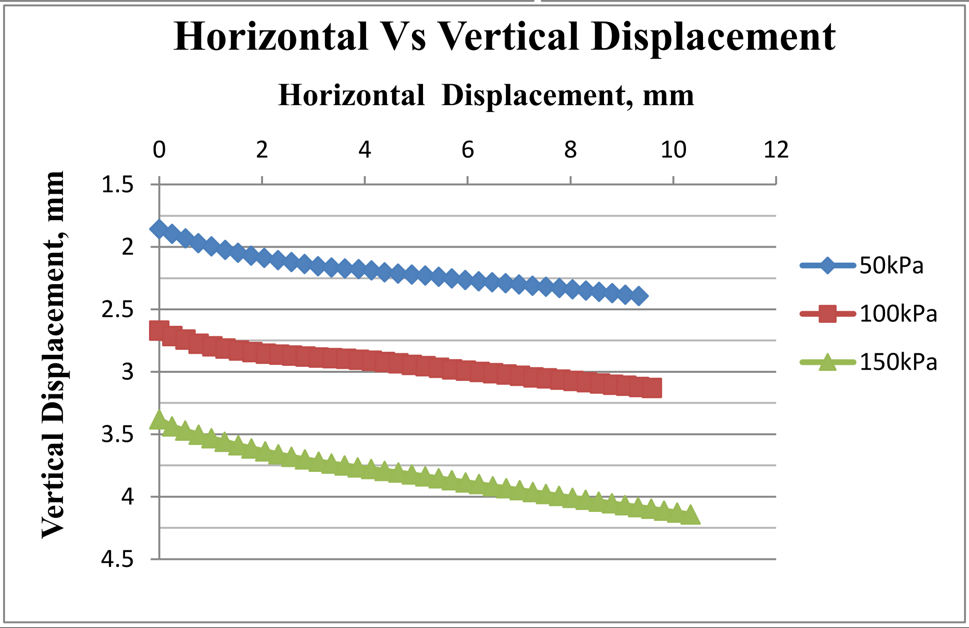


Location: *Dabe*		**Job ref.**	*Thesis research*
		Pit no.	*#10*
Soil Description: *Silty Sand*		**Sample no.**	*#1*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*23/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*20%*
Area	*3600mm²*	**Dry density**	*1.43gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.769*
Condition	*Submerged*	**Degree of saturation**	*66.44%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	41.4	72.6	96.6
Rate of shear displacement, mm/min	0.2	0.2	0.2

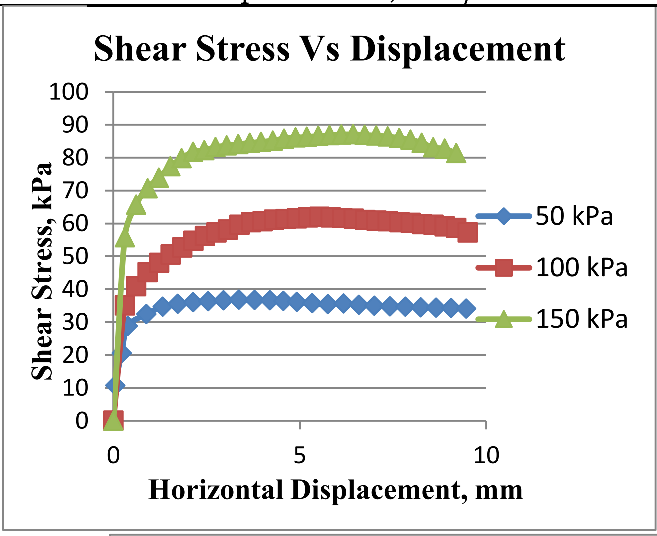


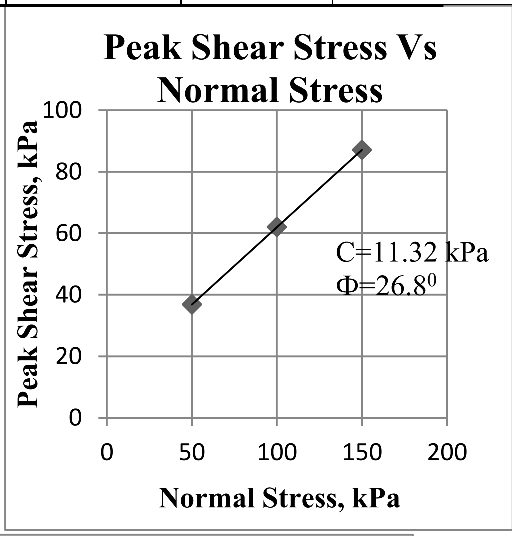


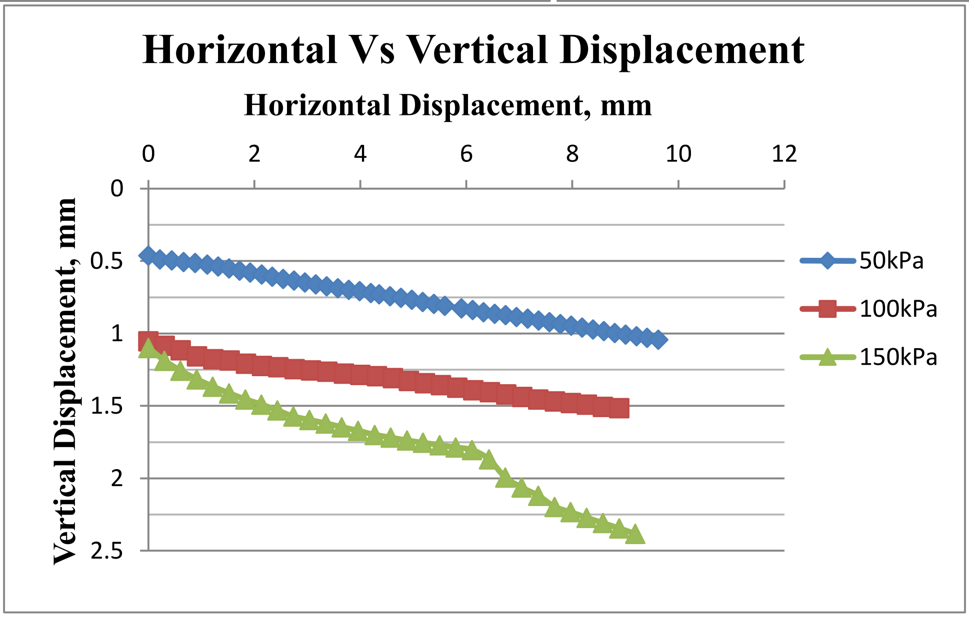


Location: *Dabe*		**Job ref.**	*Thesis research*
		Pit no.	*#10*
Soil Description: *Silty Sand*		**Sample no.**	*#2*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*24/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*14%*
Area	*3600mm²*	**Dry density**	*1.36gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.860*
Condition	*Dry*	**Degree of saturation**	*41.76%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	36.8	62	87.1
Rate of shear displacement, mm/min	0.2	0.2	0.2

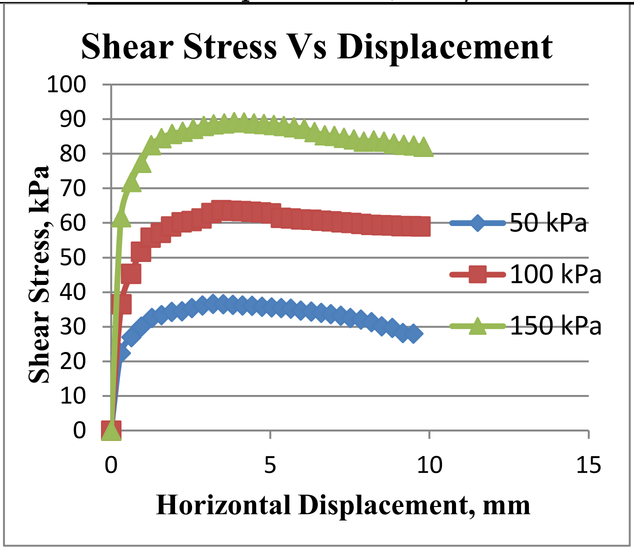


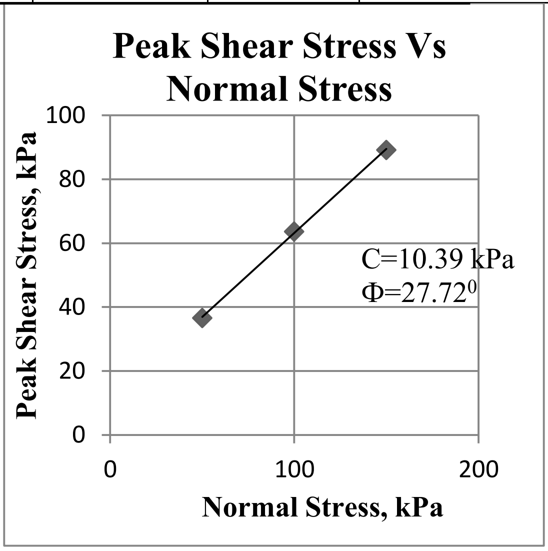


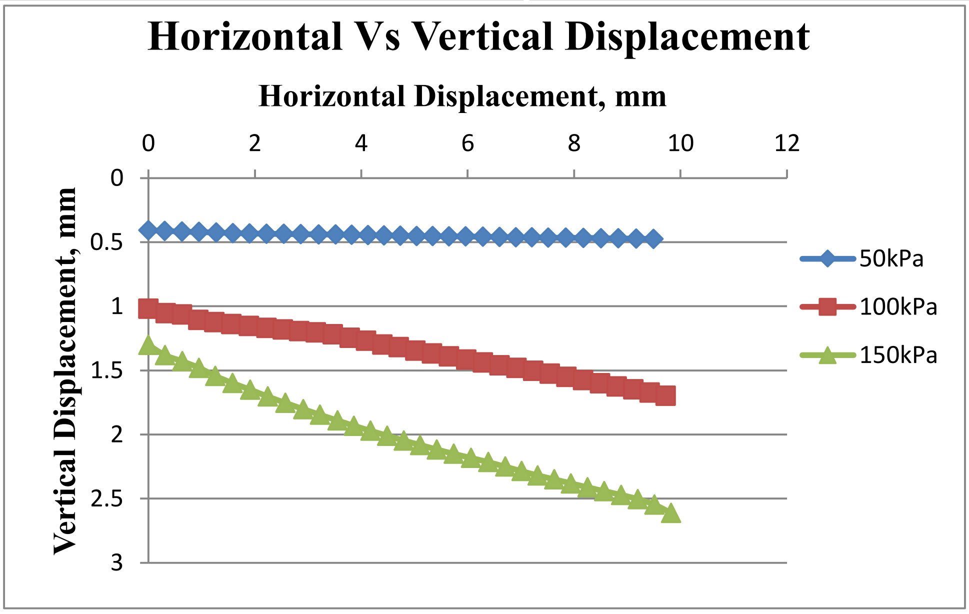


Location: *Dabe*		**Job ref.**	*Thesis research*
		Pit no.	*#10*
Soil Description: *Silty Sand*		**Sample no.**	*#3*
		Depth	*2.5m*
Test method: *BS 1377 Part 7 :1990*		**Date**	*25/05/2011 E.C*
Specimen details			
Initial height	*25mm*	**Moisture content**	*31%*
Area	*3600mm²*	**Dry density**	*1.37gm/cc*
Preparation	*Remolded*	**Initial void ratio**	*0.847*
Condition	*Dry*	**Degree of saturation**	*93.82%*
Test summery			

Reference	A	B	C
Applied normal stress, kPa	50.0	100.0	150.0
Peak strength, kPa	36.6	63.7	89.2
Rate of shear displacement, mm/min	0.2	0.2	0.2







DECLARATION

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

Name: Genet Kassahun

Signature _____________

Place	Faculty of Technology, Addis Ababa Institute of Technology, Addis Ababa.
Date	December, 2013