ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

EFFECT OF STRAIN RATE ON THE STRESS- STRAIN RELATIONSHIP AND SHEAR STRENGTH OF ADDIS ABABA RED CLAY SOIL

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

By
Admassu Tirualem

Advisor:
Dr. Hadush Seged

July 2011

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

A thesis submitted to the school of graduate studies of
Addis Ababa University in partial fulfillment of the requirements for the Degree
of
Master of Science in Civil Engineering
By
Admassu Tirualem

Approved by Board of Examiners

1. __________________ __________________ __________________
Advisor Signature Date

2. __________________ __________________ __________________
External Examiner Signature Date

3. __________________ __________________ __________________
Internal Examiner Signature Date

4. __________________ __________________ __________________
Chairman Signature Date

Acknowledgement

My first thank goes to almighty God who has given me good teachers, friends and family who are the part taker of this thesis research and who also gave me courage, health and support throughout my study and to carry out this research work.

I am very grateful for my advisor, Dr. Hadush Seged, who has encouraged, directed, and given me academic advisory throughout the research work with good heart and patient.

I would also like to thank Professor Alemayehu Teferra, Dr. Samule Taddese and Dr. Messele Haile for their valuable comments during the proposal and progress report presentation which have contributed for the successful completion of the research work.

Contents

List of Symbols

$\mathring{A}$	Angstrom units
B	Skempton’s pore pressure parameter
C	Total Cohesion of soil in KPa
C'	Effective cohesion of soil in KPa
D	Diameter
G_s	Specific gravity of soil specimen
t_{90}	Time at 90% consolidation
U_w	Pore water pressure
ΔV	Change in Volume of the specimen
r	Strain rate
w_o	Initial moisture content
ε	strain
ϕ	Angle of internal friction
ϕ'	Angle of internal friction/effective
σ_c	Confining stress
σ_1, σ_1'	Total and effective major principal stress
σ_3, σ_3'	Total and effective minor principal stress
$\Delta\sigma_a$	Deviator stress
τ	Shear stress

List of Abbreviations

BP	Back pressure
BS	British Standard
CP	Cell pressure
LL	Liquid Limit
PP	Pore pressure
PI	Plasticity Index
PL	Plastic Limit
CD	Consolidated Drained test
CU	Consolidated Undrained test
UU	Unconsolidated Undrained test
OMC	Optimum moisture content
MDD	Maximum dry density

List of Tables

List of Figures

Abstract

This research work tries to see the effect of strain rate on stress-strain relationship and shear strength of red clay of Addis Ababa. It is tried to identify the effect of strain rate by conducting a series of triaxial compression test on remolded soil samples. All the specimens were compacted at OMC with standard compaction apparatus. Besides basic tests have been done to identify the soil type.

The triaxial tests were done on samples of 38mm and height of twice the diameter. The type of triaxial test employed was Consolidated Undrained/CU/ with pore pressure measurement and with the effective consolidation pressure of 250 kPa, 350 kPa and 450 kPa. After saturation and consolidation stage, the specimen were axially loaded at a rate of strain varying from 0.001mm/ min to 1mm/min. A total of twelve triaxial CU tests were run. Data presented includes consolidation data, pore pressure observation, stress-strain relationship and modified Mohr failure envelop diagram. The results of triaxial tests were used to examine the stress-strain relationship and shear strength parameters.

The results show that strain rate affects both the stress-strain relationship and strength of soil. As the strain rate increases the strength of soil also increases, but the strain rate has more pronounced effect on the cohesion and little effect on angle of internal friction of the soil. The values of cohesion obtained from modified failure envelope for strain rate 0.001mm/min, 0.01mm/min, 0.1mm/min, and 1mm/min are 40.82kPa, 44.76kPa, 52.80kPa and 102.51kPa for total stress and 31.21kPa, 36.95kPa, 41.87kPa and 78.6kPa for effective stress. The values of angle of internal friction obtained from modified failure envelope for strain rate 0.001mm/min, 0.01mm/min, 0.1mm/min, and 1mm/min are 14.17^{o}, 14.35^{o}, 14.11^{o}, and 14.28^{o} for total stress and 22.4^{o}, 22.07^{o}, 21.54^{o}, and 21.19^{o} for effective stress.

1. INTRODUCTION

1.1. General

The shear strength is one of the most important engineering properties of a soil in the stability of many foundation engineering related problems such as bearing capacity of shallow and deep foundation, the stability of slope, dams and embankments and lateral earth pressure on retaining wall.

Many factors affect the shear strength of the soil. Among these are strain rate. All viscous and plastic material offer resistance to shearing strain varying with the speed at which shearing strain are applied. A considerable research works have been done to determine the shear strength parameters of clay in the country. The purpose of this research is to show how strain rate affects the stress-strain relationship and shear strength characteristics of clay.

The strength of cohesive soils is affected by the rate at which the external load is applied. Bearing capacity of foundation is also affected by the rate of loading since it is a function of shear strength. For instance, the loading rate while driving pile significantly affects the strength soil. However, the current understanding of the results of varying strain rate on soil behavior is often ignored in design, field studies, laboratory testing and soil mechanics frameworks.

Three types of laboratory strength tests are available in our laboratory where strain rate plays significant role in its determination. These are the direct shear test, triaxial compression test and unconfined compression test. The main task of this thesis is to conduct consolidated undrained triaxial compression test for different strain rate on remolded fine grained soil samples.

1.2. Objective of the Study

The main objective of this thesis research is to study the effect of strain rate on the stress-strain relationship and shear strength parameter of Addis Ababa red clay soil obtained from Consolidated Undrained (CU) triaxial compression tests.

1.3. Methodology

In this thesis, as a method to perform the intended research work, review of literatures have been done for revising the accepted theories and practices in the topic areas at hand. As part of methodology to perform the research, sample collection and series of laboratory tests to reveal different natures and behavior have been carried out.

Based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed. Finally, the findings and results of the research have been reported. The different activities that were carried out in this research are classified into three phases: pre-field work, field work and post field work. Each of the three steps comprises different activities. The main activities in the pre-field work were literature review and field preparation. During the field work stage, visual identification of soils around the study area and sampling were made.

The main objective of the research is to show the effect of strain rate on shear strength of clay by conducting laboratory strength tests considering different strain rates. Therefore, due to simplicity and sampling convenience remolded sample from specific location have been considered in this study.

During post field work, laboratory tests on collected samples were conducted and some of the geotechnical properties were determined. The triaxial tests were done on samples of 38mm diameter and height of twice the diameter. The type of triaxial test employed was Consolidated Undrained/CU/ with pore water pressure measurement and with the effective consolidation pressure of 250 kPa, 350 kPa and 450 kPa. After saturation and consolidation stage, the specimen were axially loaded at a rate of strain varying from 0.001mm/ min to 1mm/min.

The strain rates were selected in such a way that the slow strain rate is determined using BS standard and then a range of strain rates are chosen referring this slow strain rate. Accordingly, the reference strain rate was calculated to be 0.1mm/min. Two strain rates (0.01mm/min and 0.001mm/min) are taken below the reference strain rate and are considered as slow strain rates. In a similar manner the higher strain rates (1mm/min and 10mm/min) are taken above the reference strain rate. A total of twelve triaxial CU tests were run.

The maximum deviator stress or deviator stress at 20% strain was taken as failure criterion in the research. These results together with the visual identification and field test results were analyzed and interpreted.

1.4. Scope of the study

The current research work focuses on Northern Addis Ababa where red clay soil is dominantly found specifically around Addisu Gebeya (Tadesse, S., 1989, Hailemariam, A., 1992, Semma, T., 2009, and Merihun, L., 2010). Disturbed sample were collected from this site at a depth of 2.5m.

Stress-strain relationship and strength parameters of the red clay soil were studied in the laboratory using triaxial machine of on remolded soil sample with different strain rate.

1.5. Limitation of the study

It was initially intended to conduct fifteen triaxial test using five different strain rates within a semester. Due to electric power problem at the national level, failure of triaxial machines to perform and insufficient number of laboratory equipments to accommodate large number of students cause delay on the duration of the research work and cause to reduce the number of samples to be conducted.

The lack of the triaxial machine to measure the pore water pressure at the center of the specimen hinder to see the effect of strain rate on the variation of pore water pressure within the triaxial specimen.

1.6. Organization of the thesis

The thesis has a total of six Chapters. Chapter one deals with the general behavior of soils as the back ground. It also includes the objective of the thesis work, scope and limitations of the thesis, as well as organization of the thesis. Chapter two is totally devoted to literature review, to summarize the nature of soil formation and behavior of soils under loading and different situations. Chapter three shows the existing and conventional theories, practices and approaches to study mechanical behavior of soil in the laboratory. Chapter four summarizes all laboratory tests conducted and their results. The results and findings are discussed in Chapter five. Chapter six contains conclusion and indicates points for further researches. Appendix-A comprises all laboratory index tests. The detail information and results for laboratory triaxial test are attached in appendix-B. The reference section, which lists down the books and academic materials that have been reviewed, is dedicated for citation to acknowledge the materials and authors.

2. LITERATURE REVIEW

2.1. Red clay soil

2.2.1. General

Clay refers for soil particles finer than 2 microns (0.002mm) and has the property of plasticity when mixed with some amount of water. Plasticity refers for the behavior of material that deforms in shape and keeps its deformation even after the removal of the pressure that primarily caused the deformation.

Clayey soil may contain clay minerals as well as non clay minerals. The non clay minerals that found in clay are quartz, feldspar or mica of clay size. Clay minerals are mostly in the form of sheets; their thickness is relatively smaller than width and length of the sheets, their surface area is so larger than their volume. As the result the behavior of clay is governed by the surface forces (Terzaghi, K. and Peck, R.B., 1967).

Clayey soil behavior is attributed to the properties of clay minerals that found in the specific soil. Therefore, it is vital to know the behavior of clay minerals for understanding the engineering behavior of fine grained soils.

2.2.2. Clay Minerals

Clay minerals are small group of minerals that constitute clay soils together with other minerals. Most of clay minerals are formed from two basic units known as octahedral and silica sheets. The octahedral units consist of aluminum, magnesium or iron embedded between two layers of oxygen or hydroxyl layers. The silica sheet consist tetrahedron of four oxygen atoms and one silicon atom in between.

Most of the clay minerals are the product of chemical weathering of rock forming minerals like feldspar and mica. The clay minerals include Illite, Kaolinite, Montmorillonite, Halloysite and Vermiculite; however, the first three are the major ones.

2.2.2.1. Illite

Illite is made up of octahedral sheet bonding with two silica sheets: one at the top and another at the bottom. The illite layers are bonded by potassium ions. Illite particles range from 50Å to 500Å in thickness and have specific surface area of about $80m^2/g$.

2.2.2.2. Kaolinite

Kaolinite is composed of a single tetrahedron sheet and single aluminum octahedral sheet combined in a unit so as the tips of the silica tetrahedron and one of the layers of the octahedral sheet form a common layer. The association of a silica tetrahedral sheet with aluminum octahedral sheet forms one layer of Kaolinite. The thickness of Kaolinite layer is about 7Å. The Kaolinite mineral is formed by stacking the layers of 7Å thick one above the other with the base of silica sheet bonding the hydroxyls of the octahedral sheet by hydrogen bond. Since the hydrogen bonds are relatively strong, therefore, the mineral is stable and water cannot enter between the sheets to expand the unit cells.

2.2.2.3. Montmorillonite

Montmorillonite has similar structure to illite. The structure has one octahedral sheet sandwiched between two silica sheets and bonded with weak Vander walls forces. Large amount of water is attracted in to the space between the layers and causing the layers to expand significantly. Montmorillonite particles have the lateral dimension of 1000Å to 5000Å and thickness of 10 Å to 50 Å, and its specific area is about $800m^2/g$.

2.2.3. Origin and Mineral Composition of Ethiopian Red Clay soils

According to the study of Morin and Parry (1971), the Ethiopian red clay soils have formed as residual from basaltic volcanic rocks in places with plenty of rainfall and good drainage. The principal clay minerals that constitute the Ethiopian red clay are kaolinite and halloysite. Montmorillonite is also found in the Ethiopian red clay as accessory or less amount than as in Ethiopian black clay.

The Ethiopian red clay is found to be acidic, which is similar to that of other tropical soils. The cation exchange capacity is from 30 to 77 milli-equivalents per 100g. The Ethiopian red clay soils do not show wide range index properties as other tropical soils. They have also generally lower clay contents, liquid limits and plasticity indices (Morin, W.J., and Parry, W.T., 1971).

The shrinkage limit of the red clay varies from 10% to 30%. Morin and Parry (1971) have also indicated that the volume change tendency of the Ethiopian red clay soil is also significant at the lower moisture content. However, red clay soils are less expansive than the Ethiopian black clay soils because of high amount of kaolinite and halloysite relative to montmorillonite.

The unconfined compressive strength of the red clay soil varies from 147 to 251KPa and has even more strength (Morin, W.J., and Parry, W.T., 1971). The Ethiopian red clay soils have similar densities, however, lower dry density than other tropical soils when compacted according to AASHTO standard. The red clay soil show less plasticity but some are near to the dividing line between low plasticity and high plasticity groups (Morin, W.J., and Parry, W.T., 1971). The summery of the properties of Ethiopian red clay soil is shown below.

Table 2.1 Properties of Ethiopian red clay soils (Morin and Parry 1971).

Properties	**Values/Results**
Parent Rock	Olivine basalt, Basalt, Trachyte,
Rain fall, cm/yr	122-234
Temperature, °F	57-68
Drainage	Fair – good
Principal Clay minerals	Kaolinite,Hallysite,Montmorillonite
PH Value	5.1-6.8
Principal Cations	Calcium,magnesium, potassium
Cation Exchange capacity,m.e./100g	30-77
Clay (2µ), %	34-76
Liquid Limit, %	44-66
Plasticity Index, %	14-30
Shrinkage Limit, %	10-30
Specific gravity	2.61-2.91
Organic Content, %	1-4
Compaction Test: Max Density g/cc Optimum Moisture Content, %	1.185-1.698 38-29
CBR Test Value	6-9
Unconfined Compressive Strength, kPa.	147-251
Expansion Pressure, kPa	21-958

2.2. Mechanical Behavior of Soils

2.2.1. Strength and Deformation Behavior

Frictional resistance between soil particles in contact has basic responsibility for strength of the soil. The effective stress for a given type of soil determines the magnitude of frictional resistance. The effective stress is controlled by the applied stress, physical and chemical forces of interaction and the volume change tendency of the soil.

The most important factors affecting the strength of saturated clay are drainage conditions, disturbance (manifested by a change in effective stress and loss of cementation), over consolidation ratio and creep effects. The strength of cohesion less soil depends mostly on relative density, effective minor principal stress and test type. The peak strength of clay may considerably be greater than the strength after very large strain or shear displacement.

Increase in plasticity results in decreases with the residual friction angle. The residual strength is the shear strength along a well-defined failure surface at large displacement. It is independent of stress history and original structure. For a given set of testing conditions it depends only on effective stress.

When clays are over-consolidated, they may exhibit higher strength than that of normally consolidated clays. The strength envelop of the two types of clays at the same effective stress depends up on a type of clay, drainage conditions during shearing and amount of over consolidation.

2.2.2. Stress–Strain Behavior

The stress-strain behaviors of soils are different for different types and condition of soils. Soils like some quick clay, cemented soils, heavily over consolidated clays and dense sands have brittle nature. But Remolded and insensitive clays, and loose sands have ductile nature (Mitchell, J. K., 1976).

Increasing in pre shear consolidation pressure increases the modules of deformation as well as strength of clay soils. An increase in confining pressure has also similar effect for cohesion less soils.

The pore water pressure of saturated clay increases while shearing, if drainage is not allowed. The amount of pore water pressure increment is dependent on interaction between fabric and stress state and the ease with which shear deformation can develop overall changes or transfer of normal stress from soil structure to the pore water pressure (Mitchell, J. K., 1976).

For constant value of total minor principal stress the magnitude of the pore pressure developed in undrained loading may depend more on the strain than on the stress (Mitchell, J. K., 1976).

2.2.3. Soil Remolding

Soil as construction and foundation material can be used in its natural or undisturbed state or remolded state to meet the specific requirement such as to obtain satisfactory engineering properties like shear strength, compressibility, or permeability.

When the soil is remolded, the fabric of soil is progressively disrupted and the behavior of the soil is altered. Depending on the size and strength of the soil particle, particle arrangement may alter the water retention and mechanical behavior of the soil and make it different from that of undisturbed soil of the same mineralogy.

Natural soils show various structures, characterized by structural units, such as porous block, fissures, earth worm holes and root channels. They differ from remolded soils, namely the soil with the same mineralogy from which the structures are removed by compacting, in a number of important aspects.

The mechanical behavior of natural soils is predominantly influenced by inter-particle bonding. These materials are often referred to as natural structured soils/undisturbed soils.

To identify the extra features in the mechanical behavior of natural soils arising from soil structure, it is widely accepted to compare it with remolded soil of the same mineralogy as a reference state.

As indicated in BS 1377-1, in the laboratory soil remolding can be done by compacting the soil in to a mold at specified moisture content by applying specified compacting effort and also by compacting the soil in to the mold at specified moisture content, to achieve specified dry density.

The two types of commonly practiced laboratory compaction tests are Standard Compaction test and Modified Compaction test. Generally it is accepted to use standard compaction test to simulate the field compaction for routine foundation and embankment design. Whenever needed to simulate heavy compacting effort in the field, the modified compaction test shall be used in the laboratory.

2.3. Effect of Strain Rate

Typical curve relating the undrained shear strength with the strain rate is given in the Figure 2.3.1 below (Skempton A.W. and Bishop A.W., 1954).

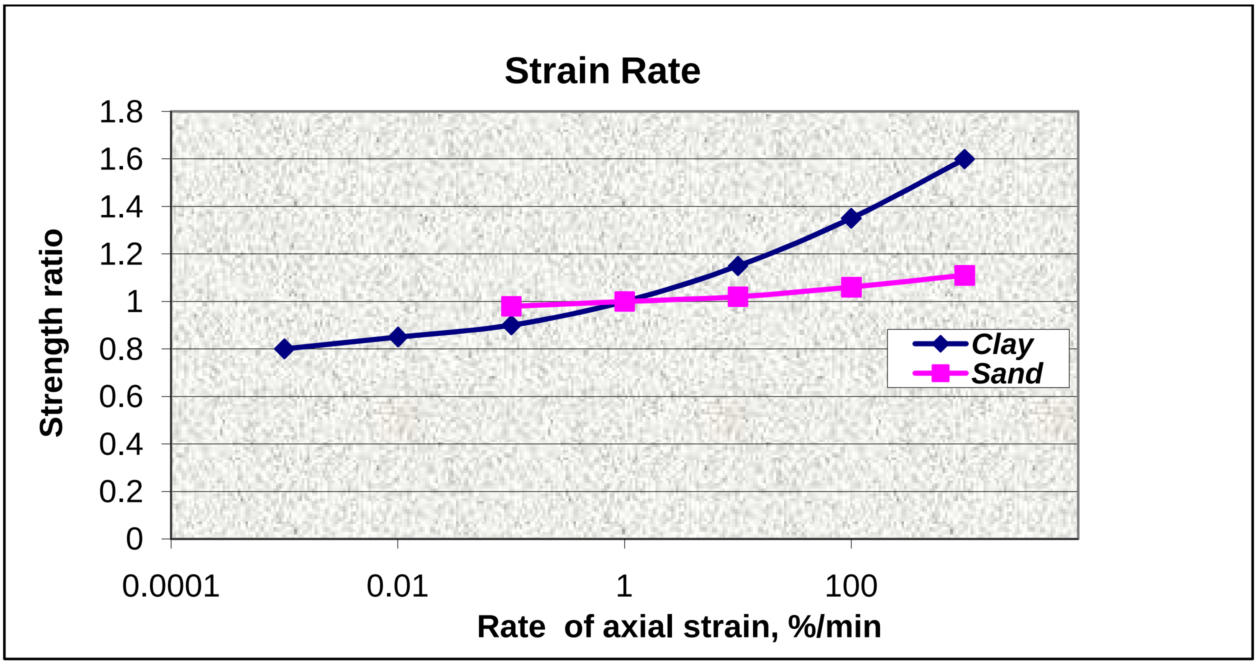


Fig.2.3. 1 The Strength ratio Vs Rate of Axial Strain (Skempton A.W. and Bishop A.W., 1954)

The strength of sand is almost independent of strain rate, but the strength of clay is more sensitive to strain rate. In addition, a further reduction in strain rate would produce little further decrease in the strength.

The maximum principal stress difference in the compression tests decreases with a decrease in strain rate (Nakase,A. and Kamei,T.,1986).

Regarding the influence of strain rate on movement of soil particles during shear, Richardson, A.M. and Whitman, R.V., 1963 have explained that, at faster strain rate, adjacent soil particles find it more difficult to move relatively, and unless restrained by increased effective stress, will tend to ride up over one another.

The strain rate for shearing saturated soils under condition is usually determined so as to ensure at least 95% equalization of pore pressure set in the specimens.

The magnitude of excess pore pressure at any particular strain rate is found to be smaller as the strain rate increases (Nakase, A. and Kamei,T.,1986).This difference in the pore water pressure response may be due to a difference in the degree of equalization of pore pressure in the soil specimen.

Casagrande, A. and Shannon, W.L., 1951 also suggested that a rate- effect upon strength might be caused by a change in the excess pore pressure generated during the shear process.

It is well known that cohesive soil show different pore pressure response to different strain rate even in undrained triaxial tests. It has been shown by several research workers that pore pressure distribution is not uniform in triaxial specimen in undrained tests.

Whitman, R.V. 1960 observed that non uniformity in strain in a triaxial specimen, larger in the middle and smaller at the ends, was responsible for local variation in water content. He also obtained interesting relationship between pore pressure and axial strain which is pore pressure at the center was higher than that at the ends and the pore pressure at the ends was higher in slower tests than in quick tests.

3. LABORATORY TESTS TO DETERMINE MECHANICAL BEHAVIOR OF SOILS

3.1. General

It would be possible to determine the elastic constants E (Young's modulus) and ν (Poisson's ration) from a simple test, if the soil were isotropic and linearly elastic. Generally, such a simple approach is not possible with soils. Therefore, it becomes important to conduct different types of tests that are designed to study stress-strain behavior during specific type of loading. The most common types of tests used to study stress-strain behavior of soil are described below.

3.2. Triaxial Test

The triaxial test is the most common test used to determine the stress-strain behavior of soil. A saturated cylindrical specimen of soil is first subjected to a confining pressure σ_c with equal stresses in all surfaces of the specimen. Then the axial stress is increased, $\Delta\sigma_a$, until the specimen fails. Since there is no shearing stress on the sides of the cylindrical specimen, the axial stress $\sigma_c+\Delta\sigma_a$ and confining stress σ_c are the major and minor principal stresses, σ_1 and σ_3 , respectively. The increment of axial stress, $\Delta\sigma_a=\sigma_1 - \sigma_3$, is the deviator stress.

3.1.1. Size of specimen

The soil cylinder is commonly about 38 mm in diameter and from 75 to 100 mm in length. Specimens about 75 mm in diameter and from 150 to 200 mm long are also encountered frequently. Much large specimens are used in the testing of soils containing gravel. Generally the length of triaxial specimens is about twice of the diameter.

3.1.2. Confining Pressure

The pressure vessel is usually composed of a transparent cylinder/cell with metal end pieces. Either gas or liquid under pressure is used to apply the confining pressure, although the use of liquid, usually de-aired water is preferable.

The soil is encased by a flexible membrane or jacket and two end caps, thus the confining fluid does not penetrate in to the pore spaces.

3.1.3. Axial Loading

In standard triaxial test, the soil is failed by increasing the axial stress while holding the confining pressure constant. Axial force is applied to the loading piston either by means of dead weights, controlled stress test, or by geared or hydraulic loading press, controlled strain test.

3.1.4. Control of pressure in pore spaces

If a dry soil specimen is completely sealed, and if the volume of the soil changes during loading, there must be some change in the volume and pressure of the air occupying the pores of the soil. A drainage system, consisting of a porous stone plus a passage to outside of the pressure vessel, is usually provided so that air can move into or out of the soil and there by prevent the pressure change. The drainage provision will prove to be of great importance during tests on soils containing water.

3.1.5. Measurement of Volume Changes

It is not easy to make accurate measurement of the changes in the volume of dry soil, either as the confining pressure or the additional axial stress is applied. When a soil is saturated with water, change in volume during a triaxial test can be determined by measuring the volume of water that flows into or out of the specimen.

4. LABORATORY TEST RESULTS

4.1. General

Soil samples were collected from Addisu Gebeya, where red clay soils are known to be found. A test pit was excavated at the site and disturbed sample was taken. The moisture content was determined immediately after sampling and transporting it to laboratory by warping with plastic bag to avoid moisture loss. Disturbed samples were air dried to constant moisture and sieved with different sieve sizes after pulverizing depending on the requirement of specific test procedures.

Different laboratory tests were conducted on the soil sample according to the need. Among these are Atterberg limits, particle size analysis, specific gravity, free swell, compaction and triaxial compression were conducted on disturbed samples.

Disturbed soil samples were air dried and oven dried at 105 degree centigrade according to the need for the type of specific requirement of the test procedure. Soil remolding for the specified tests were done at OMC and MDD with standard compacting effort.

4.2. Specific Gravity Determination

Specific gravity which is the measure of heaviness of the soil particles were determined by the method of small pychnometer method using a soil sample passing 2mm sieve and oven dried at 105 degree centigrade. The specific gravity is determined to be 2.76(Appendix A).

4.3. Atterberg limits

Soil samples passing 425 micrometer sieve were used for Atterberg limits determination. Casagrand's apparatus were 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. The liquid limit and plastic index is calculated to be 66% and 32% respectively.

4.4. Free Swell

Swelling tendency was also determined from the samples passing 425 micrometer sieve and oven dried. The 10ml of soil sample was put in water for 24 hours and swelling was examined as percentage of volume change to the original volume. The results obtained are as follows.

Table 4.4.1 Free Swell

Pit Location	Free swell, %	Swelling tendency
Addisu Gebeya1	32	Moderate

4.5. Particle Size Analysis/Hydrometer test

An oven dried sample passing 75 micrometer sieve was used for particle size analysis. Sodium hexametaphospate was used as dispersing agent and mechanical stirrer was also used. An average laboratory temperature was 20 degree centigrade. H151 ASTM standard hydrometer was employed. The test was conducted According to ASTM D422 and the results obtained are plotted blow.

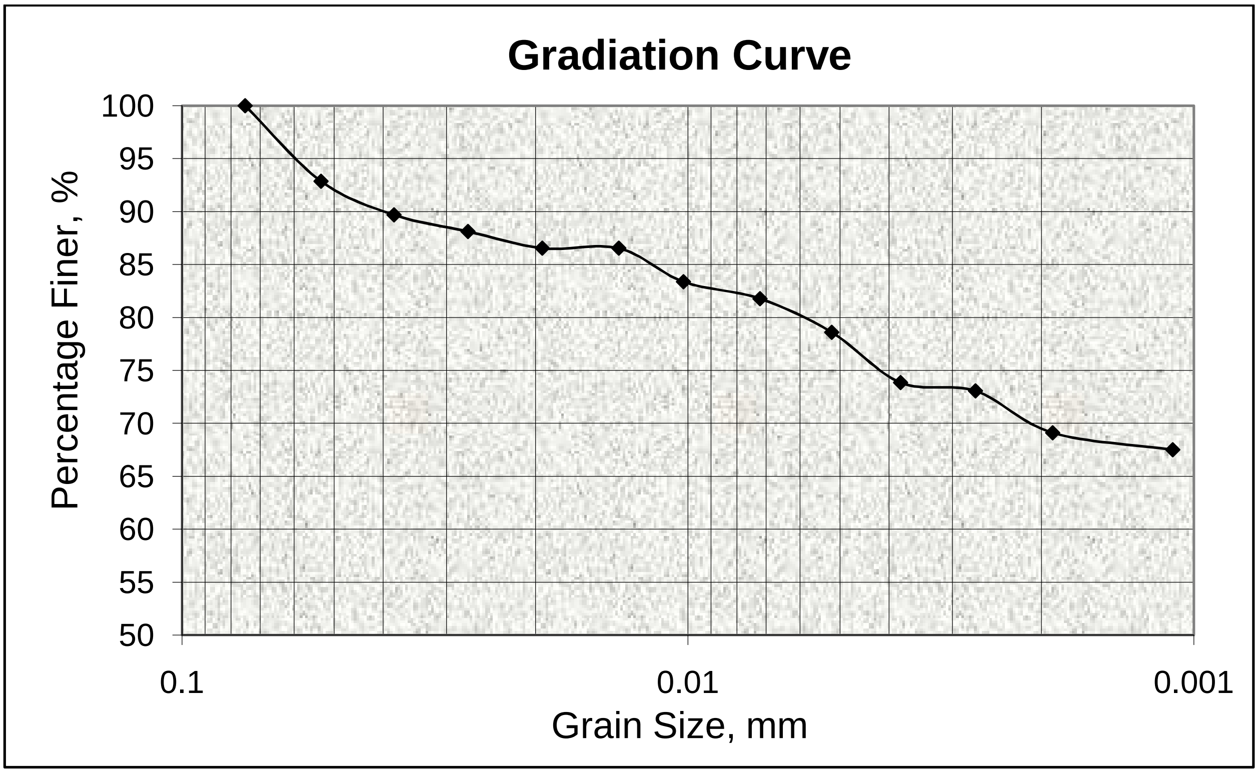


Fig. 4. 1 Particle Size distribution curve.

4.6. Standard compaction

Standard proctor compaction test which simulates light compacting effort was used to obtain the moisture-dry density relationship of the specific soil samples. It is done in a 4 inches diameter mold with a 2 kg rammer falling from 305 mm height. The soil was compacted with different moisture content in three layers each suffering 25 blows. After obtaining the density and moisture of the each compacted soil sample, the following relationships for dry density and moisture content are obtained.

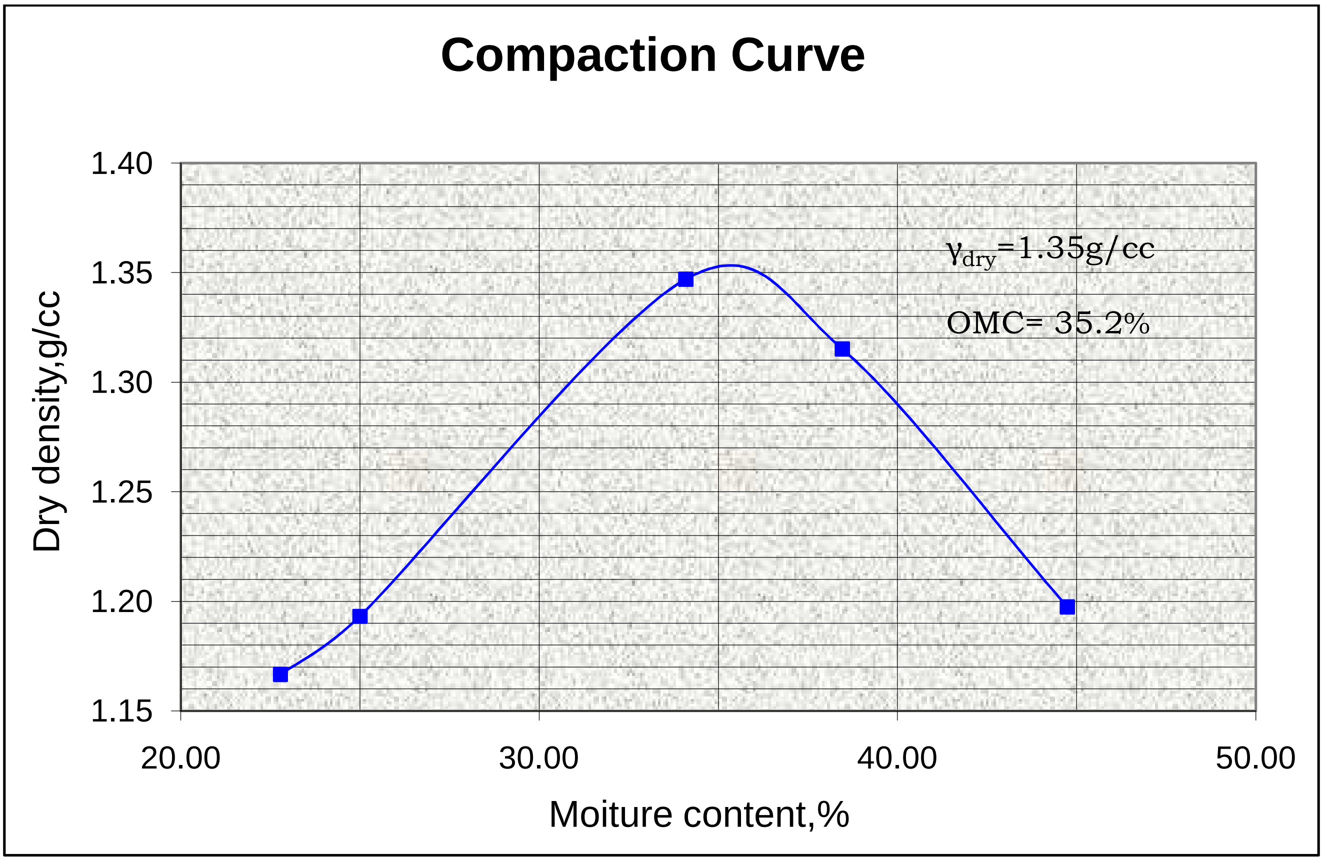


Fig. 4. 2 Standard compaction curve.

From the compaction curve, the optimum moisture content and the maximum dry density is determined to be 35.2% and 1.35g/cc, respectively.

4.7. Triaxial compression Test

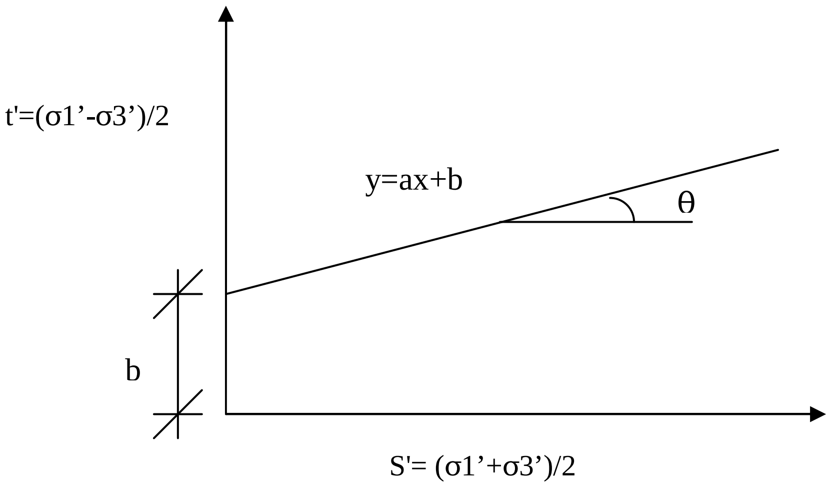
Triaxial compression test was conducted to study the stress-strain and strength behavior on remolded soil specimens of diameter 38mm and height is twice the diameter.

CU test was employed for the advantage of time, pore water measurement, and ability to determine both total stress and effective stress parameters. Under this test three main stages called saturation, consolidation and compression/shearing were performed.

Saturation was done according to BS 1137 part 8 clause 5.3, saturation by increment of cell pressure and back pressure. Pore pressure parameter B was checked at each cell pressure increment as controlling mechanism for saturation and for the B value of 0.95 and more; it was considered as the soil was saturated. 50 kPa of cell pressure increment and 10 kPa of back pressure difference from cell pressure were used for saturation. It was seen that the soil was saturated for the back pressure of 290 kPa to 300 kPa.

Consolidation stage was performed for the selected effective consolidation pressures of 250 kPa, 350 kPa and 450 kPa to bring the soil at three different effective stresses. Consolidation stages were continued until 95% or more excess pore pressure dissipates and volume change was almost ceased. It is worth noting here that indicating information like time for 100% consolidation obtained from consolidation stage was used in compression stages for calculating slow strain rate to adjust the machine speed. Shearing or compression was done as final stage by calculated axial displacement rate and continued until about 20% of axial strain and one of the failure criterion stated in BS 1137, part 8 clause 1.2.8 (maximum deviator stress, maximum effective principal stress ratio and shearing under constant pore pressure) was clearly observed.

As stated in BS 1377, the modified failure envelop method was employed to determine the effective shear strength parameters. This method was employed to use the advantage of convenience and to eliminate the difficulty of obtaining tangent line for three points on three circles of Mohr's failure diagram (Arora, K.r., 1997).



$\Phi' = \sin^{-1}(\tan\theta)$
$C' = b/(\cos\Phi')$

Fig. 4. 3 **Modified Failure Envelop**

Mohr-Coulomb failure criterion:

$$\frac{(\sigma_1'-\sigma_3')}{2}=\frac{(\sigma_1'+\sigma_3')}{2}*\sin\phi'+c'\cos\phi' \Rightarrow y=ax+b$$

$$a=\tan\theta=\sin\phi', b=c'\cos\phi'$$

Some of the results obtained are shown below and detail test data and results are attached in the appendix.

4.8. CU Triaxial Compression Test Result for Strain Rate of 0.001mm/min

Table 4.8.1 **Triaxial Consolidation Test Results for Strain Rate 0.001mm/min**

Consolidation Stage Result			
Location:	***Addisu Gebeya***	Job ref.	***Thesis research***
Soil Description:	Red brown clay	Pit no.	***#1***
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8		Sample no.	***#1***
		Depth	***2.5m***
Undisturbed Sample			

Effective Consolidation Pressure 150 kPa			**Effective Consolidation Pressure 250 kPa**			**Effective Consolidation Pressure 350 kPa**		
Initial Condition	CP, kPa	***550***	**Initial Condition**	CP, kPa	***650***	**Initial Condition**	CP, kPa	***750***
	BP, kPa	**300**		BP, kPa	***300***		BP, kPa	**400**
	PP, kPa	***0.1***		PP, kPa	***329.4***		PP, kPa	***738***
Final Condition	PP, kPa	***-222.1***	**Final Condition**	PP, kPa	**301**	**Final Condition**	PP, kPa	**413**
	ΔVolume, ml	***3.41***		ΔVolume, ml	***0.8***		ΔVolume, ml	***4.3***
	% Consolidation	**95**		% Consolidation	**95**		% Consolidation	**96**
Sqrt. Time	**ΔVolume, ml**	**PP, kPa**	**Sqrt. Time**	**ΔVolume, ml**	**PP, kPa**	**Sqrt. Time**	**Δ vol, ml**	**PP, kPa**
0.30	-0.006	531.68	0.00	-0.04	629.4	0.29	0.00	766.61
0.37	-0.006	530.23	0.37	0.00	630.21	0.36	-0.75	766.42
0.46	-0.702	331.4	0.46	-0.54	322.26	0.44	-1.08	375.06
0.56	-0.740	331.8	0.56	-0.70	321.58	0.54	-1.16	374.19
0.69	-0.785	331.9	0.69	-0.83	321.2	0.66	-1.19	374
0.84	-0.760	320.7	0.84	-0.94	321.53	0.81	-1.26	373.42
1.03	-0.791	320.7	1.03	-1.05	320.91	1.00	-1.37	372.94
1.26	-0.830	320.9	1.26	-1.18	320.72	1.22	-1.49	372.84
1.54	-0.874	321	1.54	-1.31	320.52	1.49	-1.57	372.65
1.89	-0.951	321.1	1.89	-1.47	320.62	1.83	-1.65	372.55
2.32	-1.021	321.2	2.32	-1.64	320.52	2.24	-1.78	372.45
2.84	-1.047	321.3	2.84	-1.80	320.62	2.74	-1.89	372.45
3.47	-1.142	321.4	3.47	-2.00	320.43	3.36	-2.07	372.07
4.25	-1.308	321.3	4.25	-2.26	320.52	4.11	-2.26	372.07
5.21	-1.525	321.5	5.21	-2.54	320.52	5.04	-2.48	372.07
6.38	-1.653	321.4	6.38	-2.89	320.33	6.17	-2.73	372.26
7.82	-1.889	321.4	7.82	-3.36	320.62	7.56	-3.06	372.26
9.57	-2.247	321.3	9.57	-3.86	320.62	9.26	-3.48	372.26
11.72	-2.540	321.1	11.72	-4.44	320.81	11.34	-3.93	372.36
14.36	-2.872	320.8	14.36	-4.99	320.81	13.89	-4.32	372.55

17.59	-3.198	320.9	17.59	-5.32	320.81	17.01	-4.68	372.65
21.54	-3.357	321.1	21.54	-5.45	320.81	20.83	-5.02	372.07
26.38	-3.415	321.5	26.38	-5.55	320.33	25.51	-5.16	371.78
32.31	-3.415	322.1	32.31	-5.60	319.86	31.25	-5.25	371.39

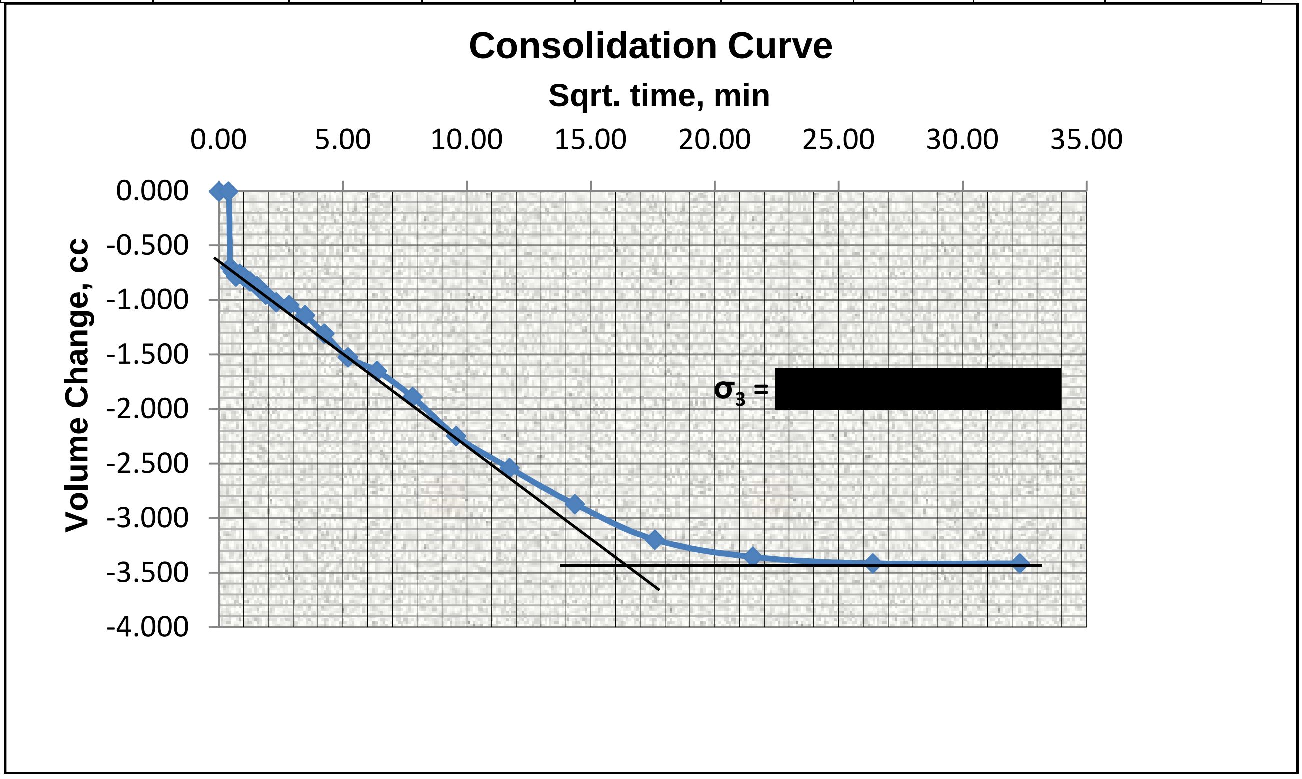


Fig. 4.4 **Consolidation Curve for Effective Consolidation Pressure of 250KPa.**

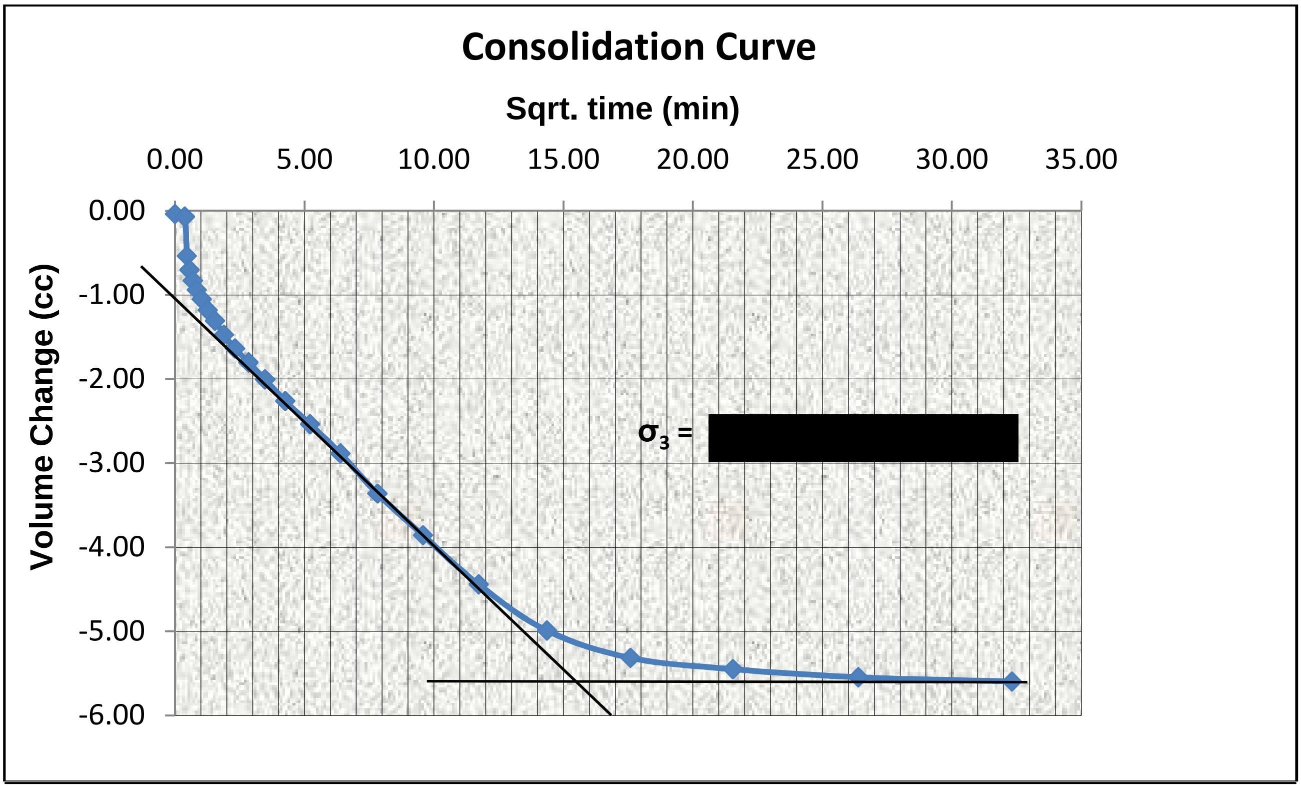


Fig. 4.5 **Consolidation Curve for Effective Consolidation Pressure of 350KPa.**

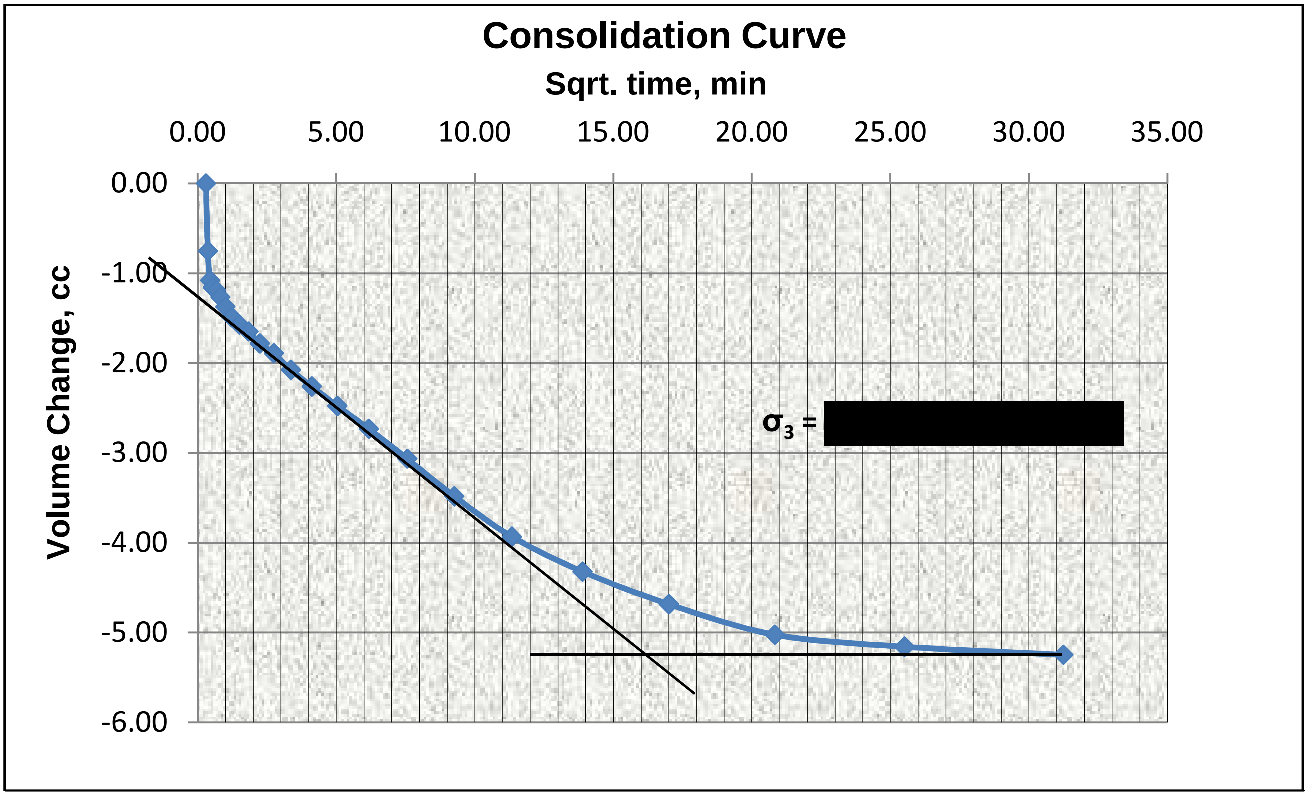


Fig. 4.6 Consolidation Curve for Effective Consolidation Pressure of 450KPa.

Fig. 4.4 to 4.6 shows the consolidation curve obtained from triaxial consolidation test result (Table 4.8.1) for stain rate of 0.001mm/min and effective consolidation pressure 250kPa, 350kPa and 450kPa. The other test results and curves are shown in the Appendix B.

Table 4.8.2 Compression Test Result for Effective Consolidation Pressure 250KPa

Compression Stage Result for 250KPa Eff. Consolidation Pressure

Location: *Addisu Gebeya*	Job ref.	Thesis research
Soil Description: *Red brown clay*	Pit No.	1
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8	Sample No.	1
	Depth	2.5m
CP = 250kPa		

Displ.(mm)	Strain(%)	Load (N)	Δσ(kPa)	PP (kPa)	ΔPP(kPa)
0.00	0.00	0.00	0.00	310.00	0.00
0.35	0.00	15.10	13.30	316.28	6.28
0.57	0.01	63.32	55.61	320.29	10.29
0.77	0.01	78.10	68.40	323.53	13.53
0.95	0.01	94.70	82.75	327.94	17.94
1.14	0.02	114.80	100.05	334.80	24.80
1.34	0.02	133.30	115.86	342.64	32.64
1.54	0.02	151.40	131.23	351.95	41.95
1.74	0.02	161.20	139.34	357.83	47.83
1.95	0.03	175.20	151.01	363.22	53.22
2.15	0.03	190.50	163.76	368.61	58.61
2.36	0.03	202.30	173.39	374.00	64.00
2.57	0.03	213.10	182.13	381.35	71.35
2.77	0.04	220.40	187.83	387.72	77.72
2.98	0.04	226.20	192.23	395.07	85.07
3.18	0.04	235.00	199.15	401.44	91.44
3.39	0.05	240.80	203.48	406.34	96.34
3.58	0.05	247.86	208.86	411.24	101.24
3.80	0.05	253.69	213.14	415.65	105.65
4.00	0.05	258.50	216.57	420.06	110.06
4.20	0.06	262.83	219.57	423.09	113.09
4.40	0.06	266.13	221.71	425.67	115.67
4.58	0.06	269.92	224.28	428.45	118.45
4.79	0.06	275.88	228.56	431.04	121.04
4.99	0.07	279.25	230.70	432.83	122.83
5.19	0.07	283.20	233.27	434.02	124.02
5.37	0.07	286.51	235.41	434.62	124.62
5.56	0.07	289.93	237.55	435.01	125.01
5.79	0.08	292.99	239.26	435.21	125.21
5.97	0.08	295.32	240.54	434.37	124.37
6.20	0.08	299.46	243.11	434.27	124.27
6.41	0.09	302.49	244.83	433.29	123.29
6.62	0.09	305.54	246.54	432.80	122.80
6.83	0.09	306.50	246.54	432.31	122.31
7.04	0.09	310.64	249.11	431.82	121.82
7.24	0.10	313.16	250.39	431.33	121.33

7.45	0.10	317.91	253.39	430.84	120.84
7.66	0.10	317.82	252.53	430.35	120.35
7.86	0.10	320.41	253.82	429.86	119.86
8.07	0.11	321.94	254.24	429.37	119.37
8.27	0.11	325.07	255.96	427.90	117.90
8.47	0.11	327.16	256.81	427.41	117.41
8.67	0.12	328.67	257.24	426.92	116.92
8.87	0.12	330.76	258.10	426.92	116.92
9.06	0.12	330.64	257.24	426.43	116.43
9.27	0.12	335.01	259.81	426.43	116.43
9.47	0.13	337.68	261.09	426.43	116.43
9.67	0.13	339.26	261.52	426.43	116.43
9.86	0.13	339.71	261.09	425.94	115.94
10.04	0.13	341.76	261.95	424.96	114.96
10.20	0.14	343.73	262.81	425.94	115.94
10.38	0.14	344.14	262.38	425.45	115.45
10.58	0.14	345.74	262.81	425.45	115.45
10.80	0.14	348.65	264.09	424.96	114.96
11.02	0.15	349.85	264.09	424.47	114.47
11.23	0.15	351.55	264.52	424.96	114.96
11.44	0.15	352.70	264.52	423.49	113.49
11.60	0.15	351.86	263.24	423.49	113.49
11.79	0.16	355.81	265.38	423.00	113.00
11.96	0.16	355.60	264.52	422.02	112.02
12.18	0.16	356.87	264.52	421.12	111.12
12.40	0.17	358.69	264.95	421.12	111.12
12.62	0.17	361.13	265.80	420.37	110.37
12.85	0.17	360.71	264.52	419.88	109.88
13.06	0.17	360.16	263.24	419.63	109.63
13.24	0.18	364.73	265.80	419.13	109.13
13.26	0.18	364.89	265.80	419.13	109.13
13.45	0.18	365.41	265.38	417.89	107.89
13.67	0.18	366.69	265.38	417.64	107.64
13.88	0.19	367.39	264.95	416.40	106.40
14.09	0.19	369.24	265.38	416.65	106.65
14.30	0.19	371.13	265.80	416.15	106.15
14.51	0.19	371.19	264.95	416.89	106.89
14.70	0.20	371.77	264.52	416.15	106.15
14.89	0.20	374.73	265.80	416.89	106.89
15.07	0.20	375.28	265.38	416.65	106.65
15.27	0.20	373.51	263.24	416.89	106.89
15.46	0.21	377.76	265.38	415.90	105.90
15.66	0.21	379.02	265.38	416.40	106.40
15.87	0.21	379.76	264.95	414.91	104.91
16.07	0.21	380.45	264.52	414.16	104.16

16.28	0.22	383.40	265.65	414.91	104.91
16.48	0.22	381.20	263.24	415.15	105.15
16.68	0.22	384.10	264.33	415.15	105.15
16.87	0.22	385.00	264.09	414.66	104.66
17.09	0.23	386.47	264.09	414.91	104.91
17.29	0.23	384.90	262.08	413.66	103.66
17.50	0.23	387.90	263.17	414.16	104.16
17.70	0.24	386.40	261.24	414.16	104.16
17.91	0.24	389.40	262.33	414.41	104.41
18.11	0.24	392.40	263.40	415.15	105.15
18.31	0.24	393.20	263.02	413.91	103.91
18.51	0.25	392.40	261.54	413.42	103.42
18.72	0.25	390.20	259.12	414.16	104.16
18.93	0.25	393.20	260.14	414.41	104.41
19.13	0.26	394.00	259.74	414.91	104.91
19.33	0.26	396.20	260.24	415.15	105.15
19.54	0.26	390.20	255.35	414.66	104.66
19.74	0.26	389.40	253.92	413.91	103.91
19.93	0.27	394.00	256.02	415.40	105.40
20.13	0.27	390.20	252.62	414.66	104.66

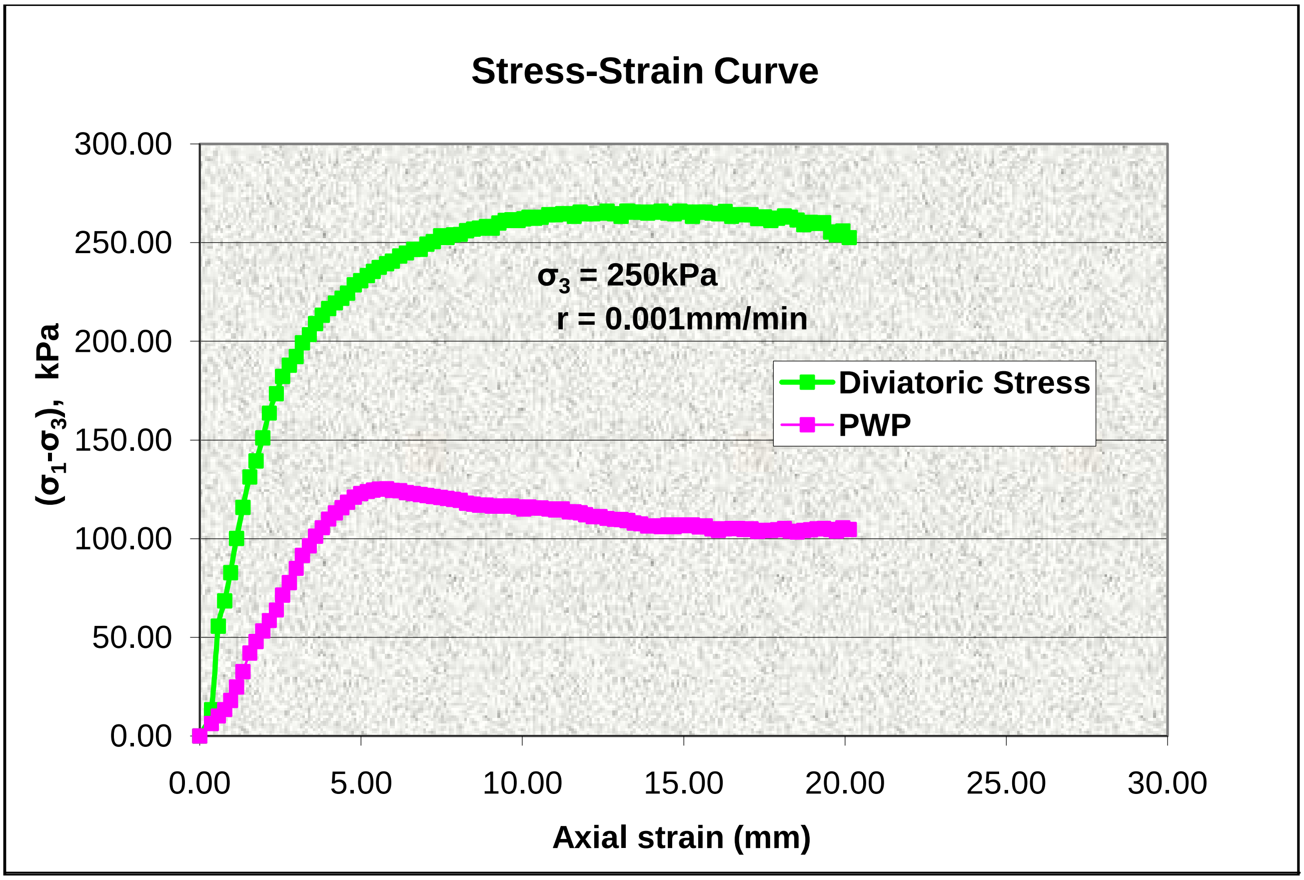


Fig. 4. 7 **Stress-Strain Curves for Effective Consolidation Pressure 250 kPa and Strain Rate 0.001mm/min**

Fig. 4.7 shows the stress-strain and PWP Vs strain curve obtained from triaxial compression test data (Table 4.8.2) for stain rate of 0.001mm/min and effective consolidation pressure 250kPa. The other test data results and curves are shown in the Appendix B.

5. DISCUSSION OF TEST RESULTS

According to BS Standard the time for 100% consolidation obtained from consolidation curve was used in compression stage for calculating and adjusting the machine speed. Fig.4.1 to Fig.4.3 illustrate a plot of volume change (ΔV) versus square root of time obtained from consolidation stage of triaxial test. The time for 100% consolidation was calculated from the graph for all tests and found to be similar (t_{100} = 272.25min) for the three confining pressures in all tests. Thus, the strain rates calculated from BS 1137, Part 8 Clause 1.2.8 have also similar results (r=0.1mm/sec).

A plot of deviatoric stress versus axial strain with the same strain rate and different confining pressure are shown from Fig.5.1 to Fig. 5.4. From these graphs it is observed that an increase in confining pressure shifts the stress–strain curve upward. From these graphs it can also be seen that change in strain rate does not affect the relationship that an increase in effective consolidation pressure shifts the stress-strain curve upward. Fig.5.5 to Fig.5.8 shows the induced pore water pressure versus axial strain. Here there also a shift in pore water pressure-axial strain curve as confining pressure increases with confining pressure. Here also strain rate does not affect this relationship

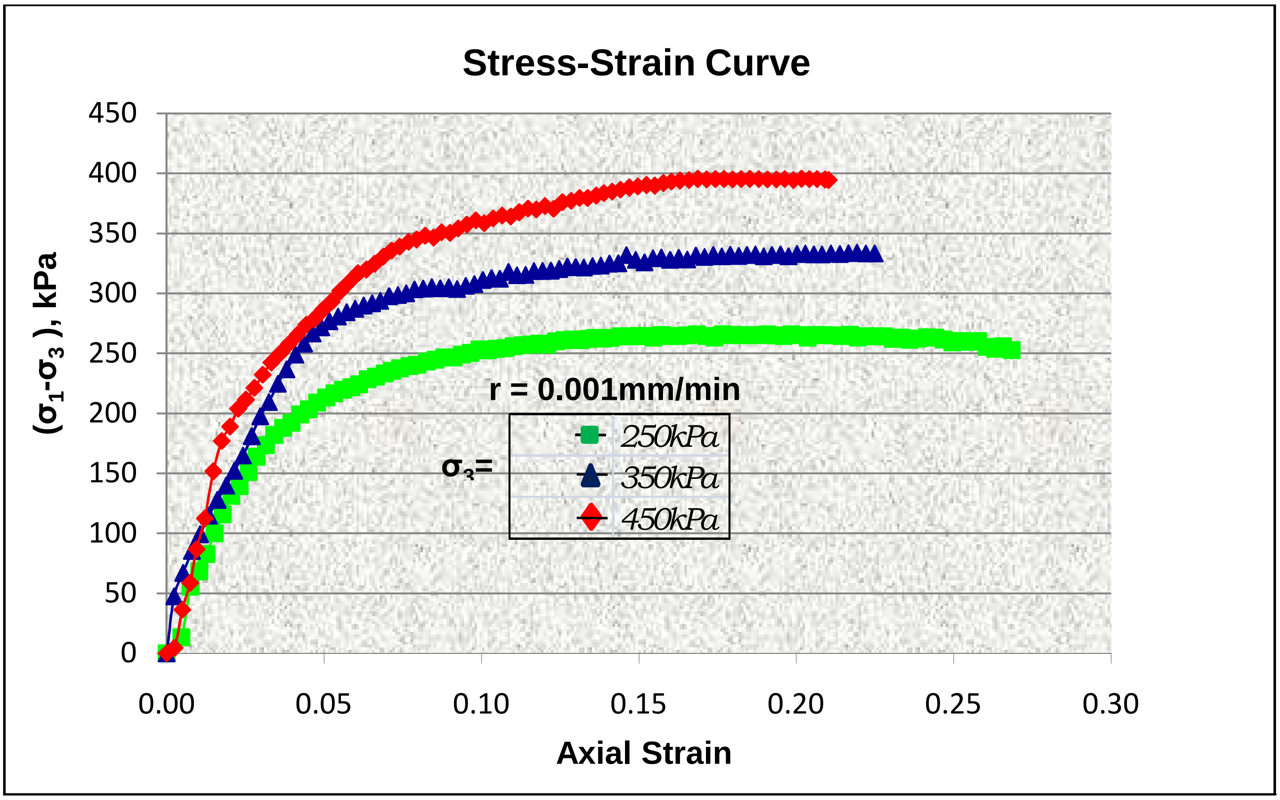


Fig.5. 1 Stress-Strain Curves for Strain Rate Of 0.001mm/min under Different Effective Consolidation Pressure.

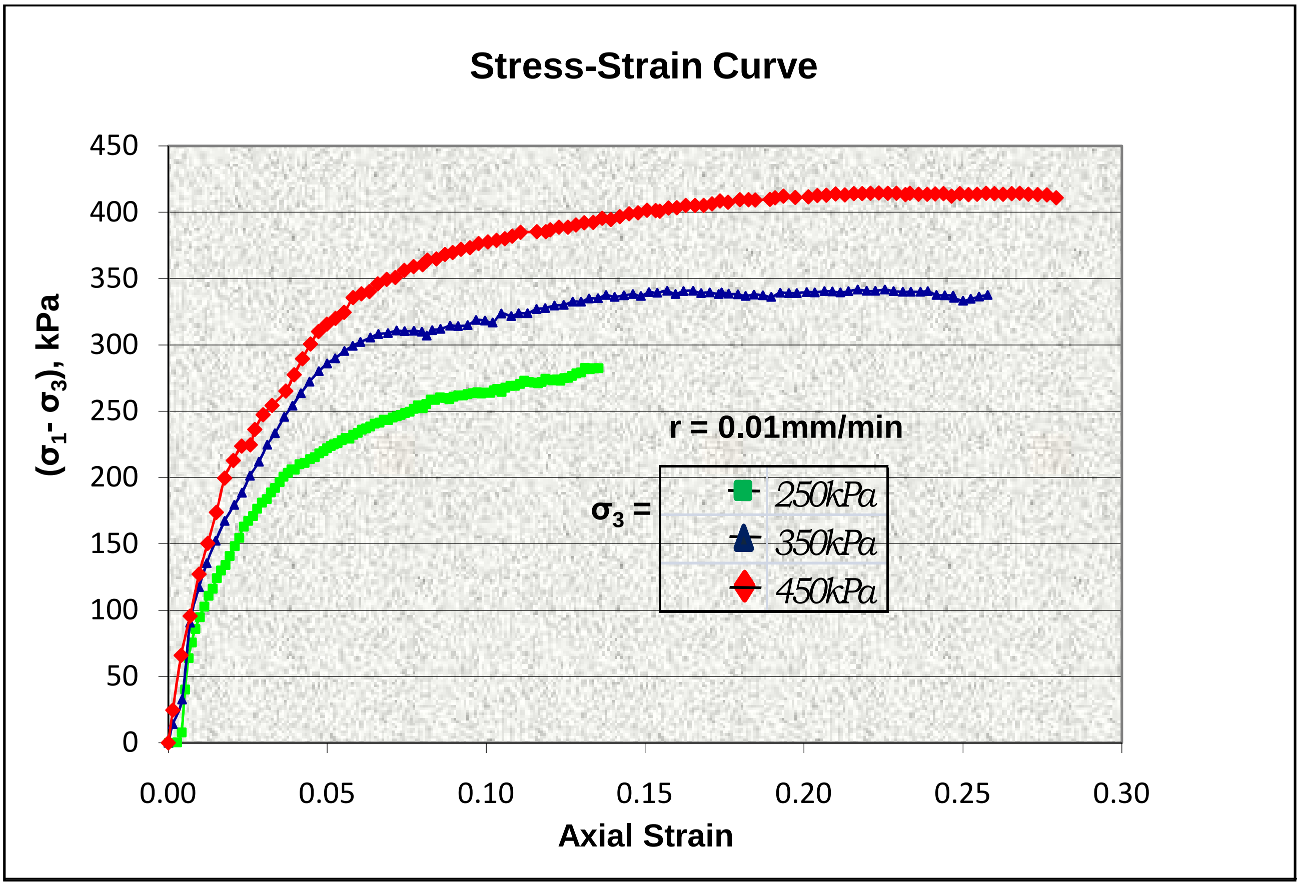


Fig.5. 2 Stress-Strain Curves for Strain Rate of 0.01mm/min under Different Effective Consolidation Pressure.

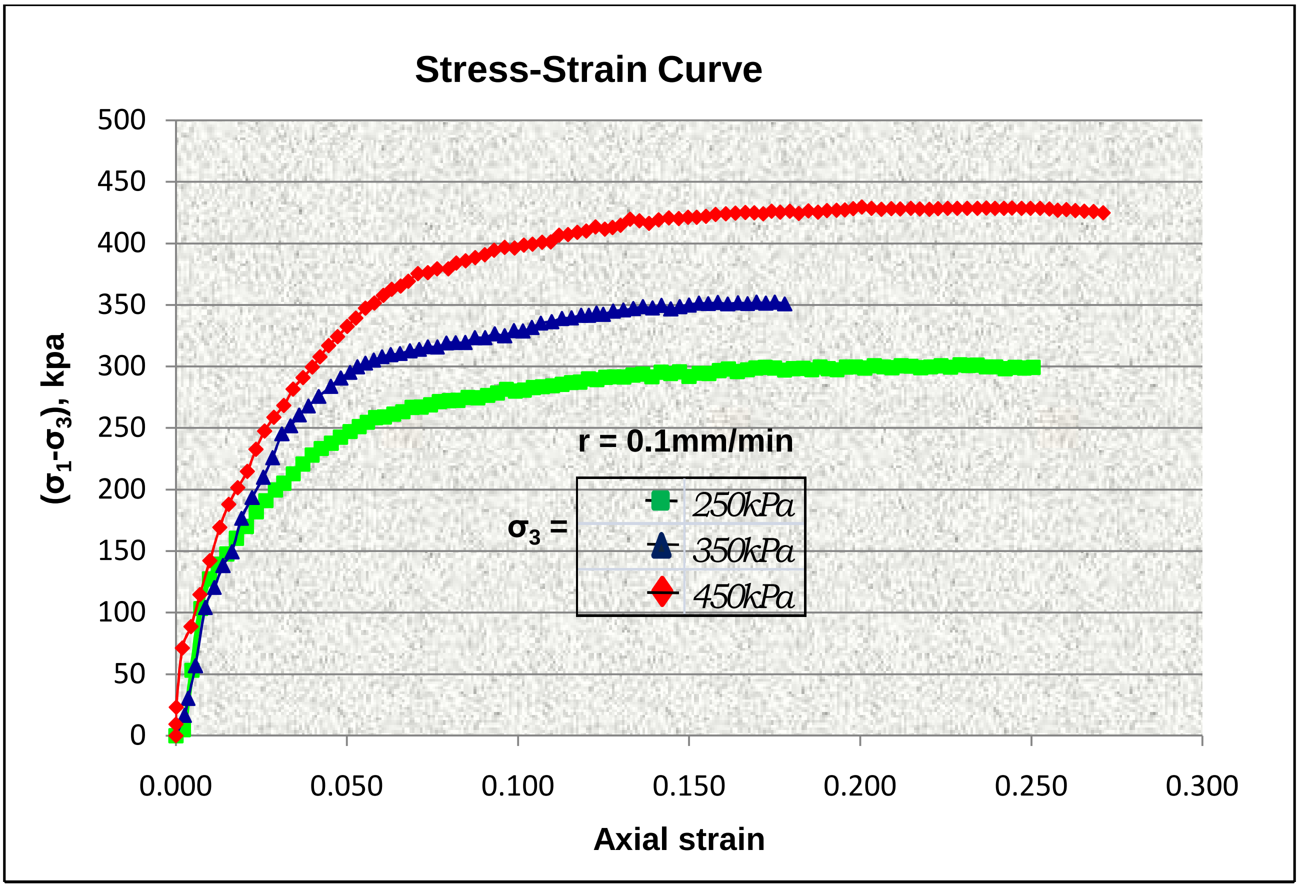


Fig.5. 3 Stress-Strain Curves for Strain Rate of 0.1mm/min under Different Effective Consolidation Pressure.

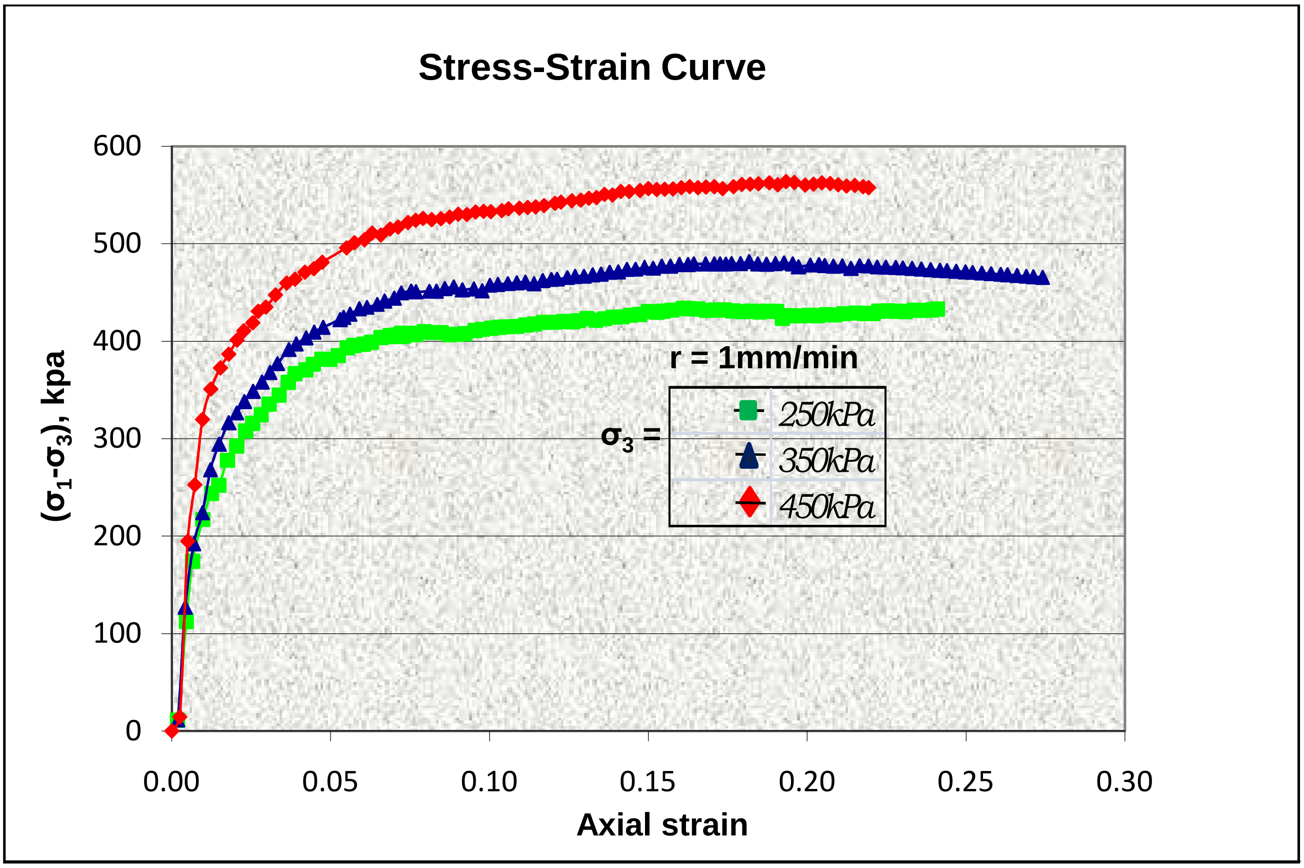


Fig.5. 4 Stress-Strain Curves for Strain Rate of 1mm/min of Different Effective Consolidation Pressure.

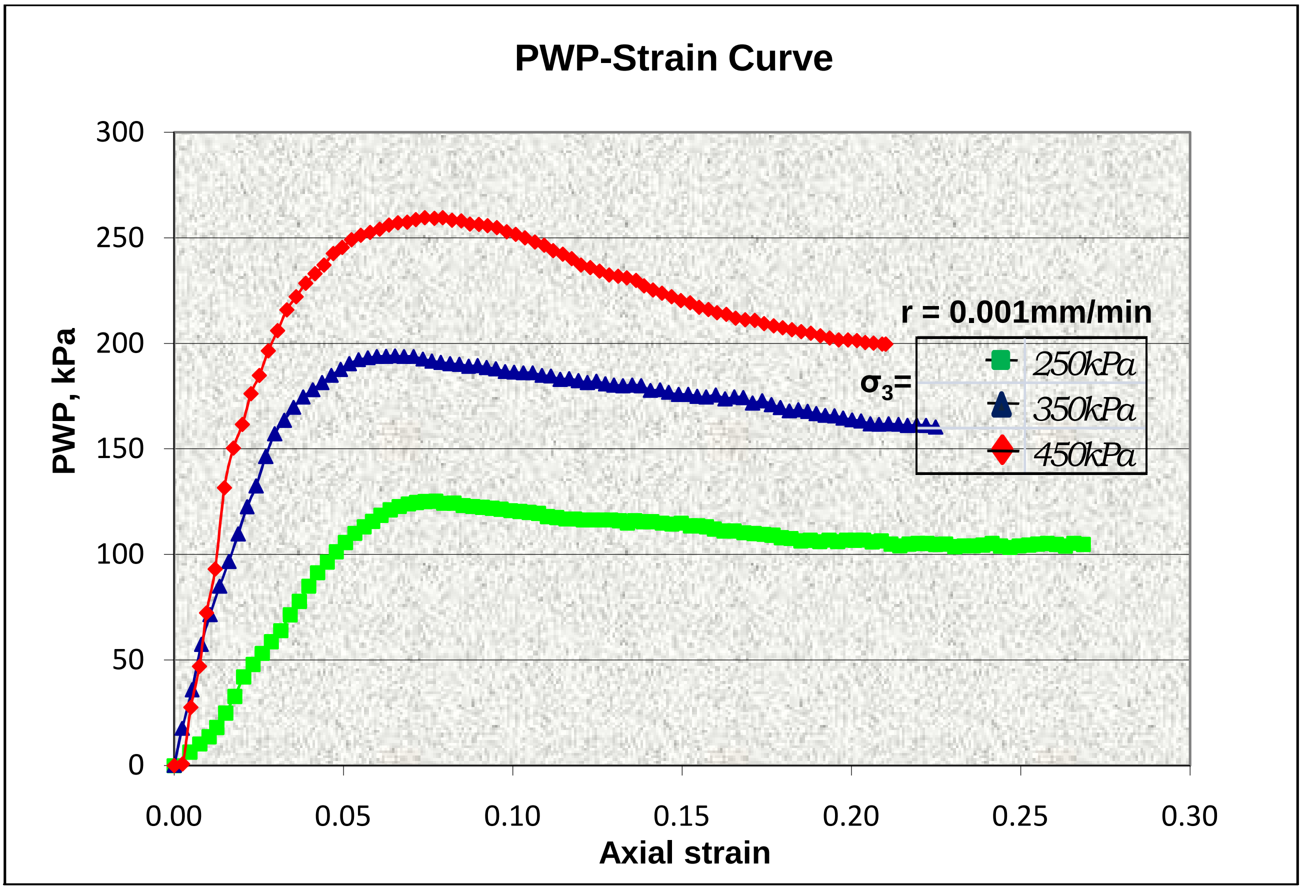


Fig.5. 5 PWP-Strain Curves for Strain Rate of 0.001mm/min under different Effective Consolidation Pressure.

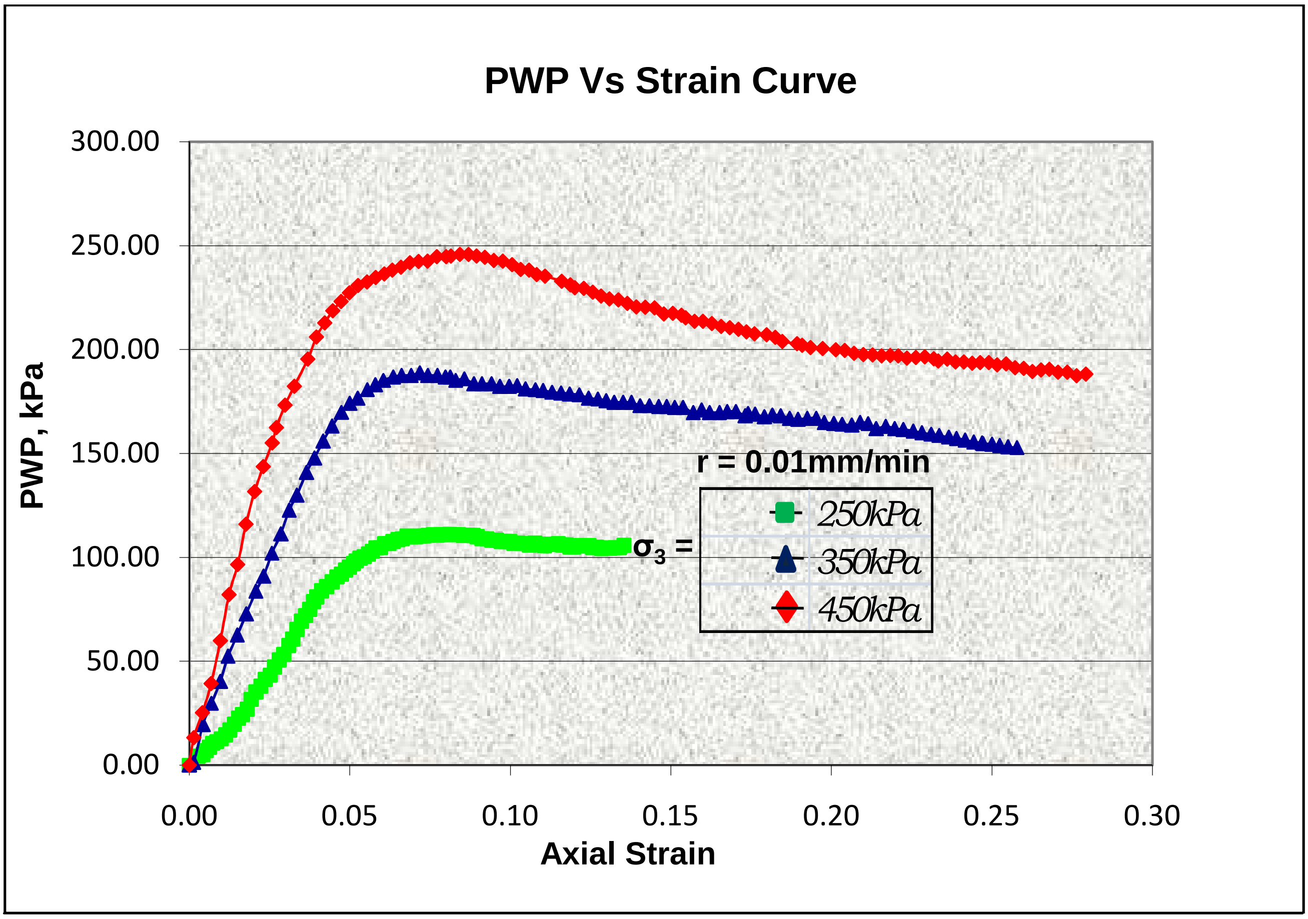


Fig.5. 6 PWP-Strain Curves for Strain Rate of 0.01mm/min under different Effective Consolidation Pressure.

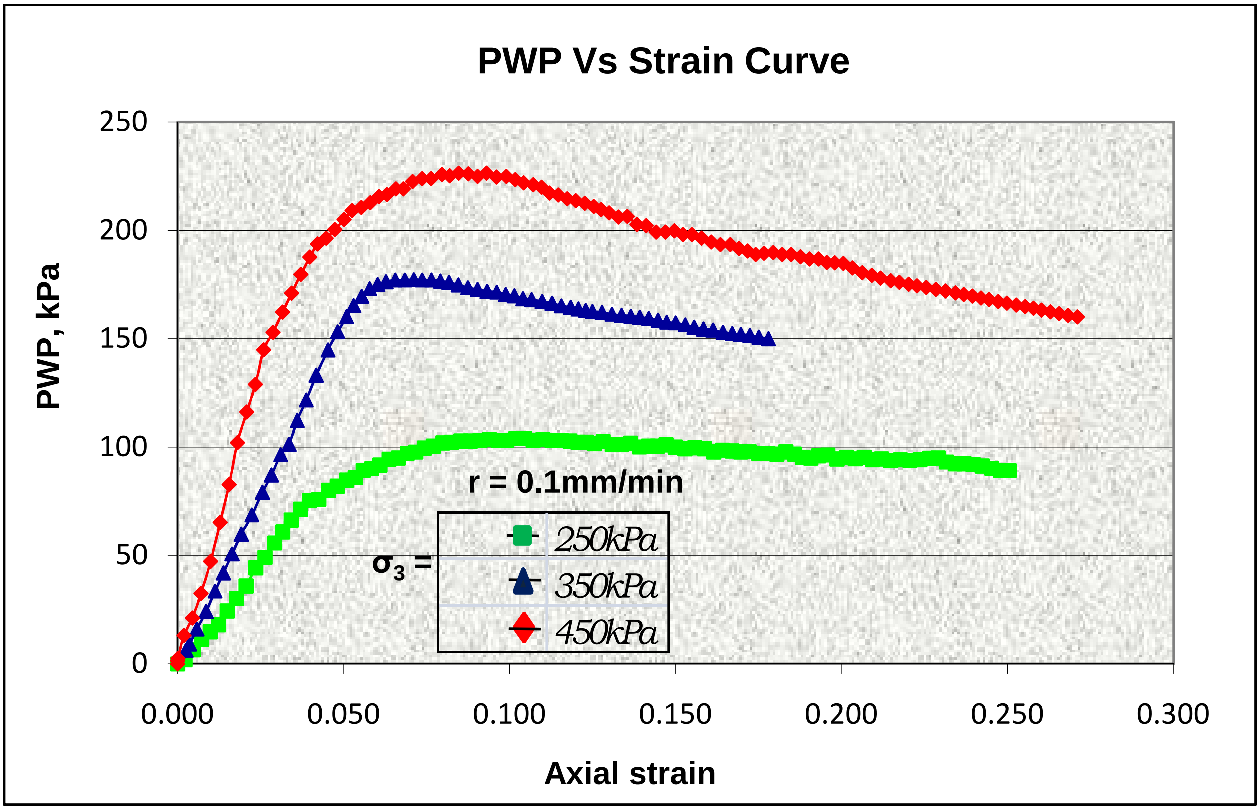


Fig.5.7 PWP-Strain Curves for Strain Rate of 0.1mm/min under Different Effective Consolidation Pressure.

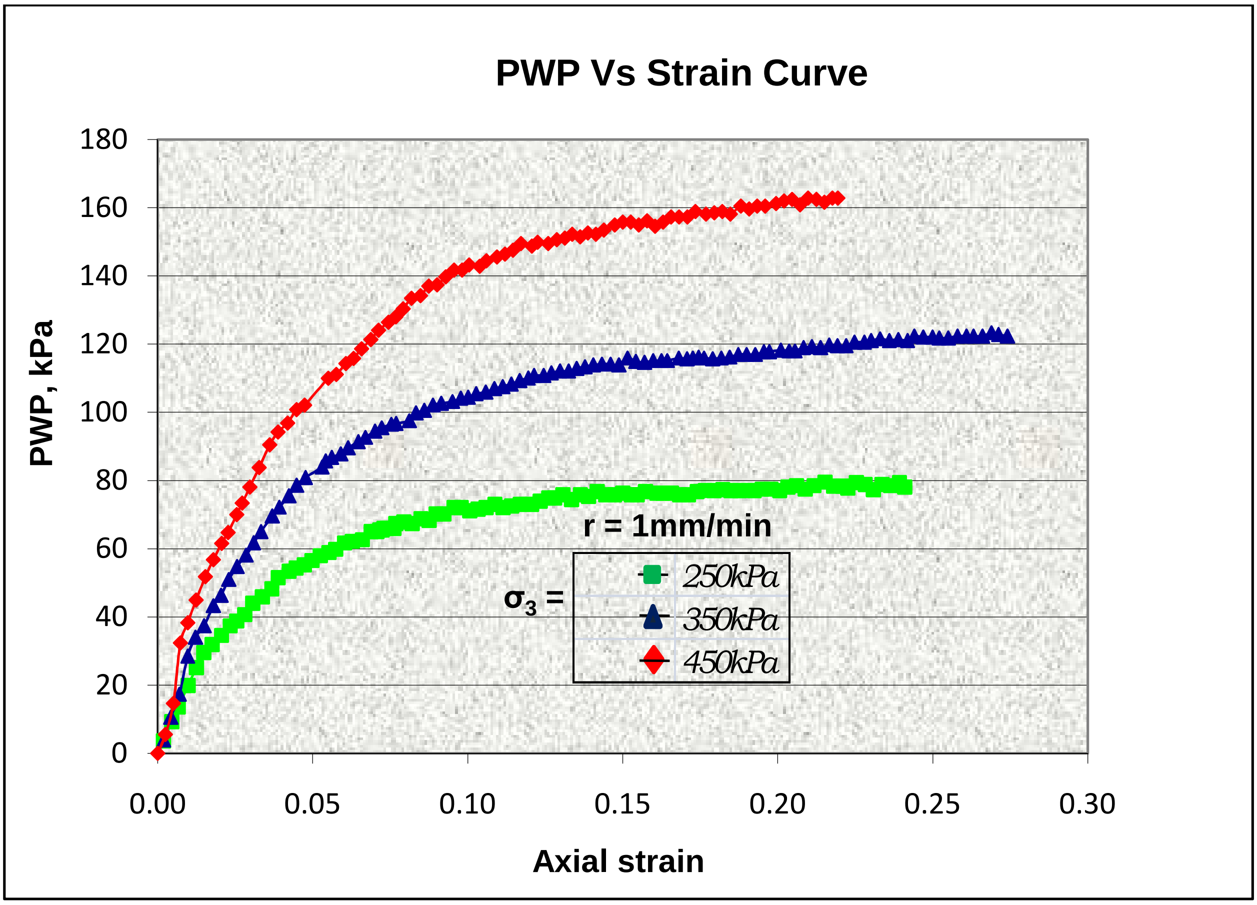


Fig.5. 8 PWP-Strain Curves for Strain Rate of 1mm/min under Different Effective Consolidation Pressure.

Plots of induced pore water pressure versus axial strain with the same confining pressure at different strain rate are shown from Fig. 5.9 to Fig. 5.11. From the graph, it is observed that the pore water pressure induced by the axial loading decreases as strain rate increases. This may be due to the difference in equalization of pore water pressure within the soil. The increase in pore water pressure is not significant for the slow strain rates. Besides, the inability to develop negative pore water pressure (as indicated by the difference in the shape of the pore water pressure axial strain curve) for higher strain rate is due to the lower period of time to produce suction (cavitation) with in the soil during the compression of triaxial test. The time to complete a triaxial test for compression stage using strain rate obtained from BS (0.1mm/min) is between 2.8mm/min- 3.6mm/min. While the time required for strain rate below BS (0.01mm/min and 0.001mm/min)is 13hr- 15hr and 3days-5days respectively. Around 30min is enough to complete a triaxial compression test for higher strain rate i.e 1mm/min.

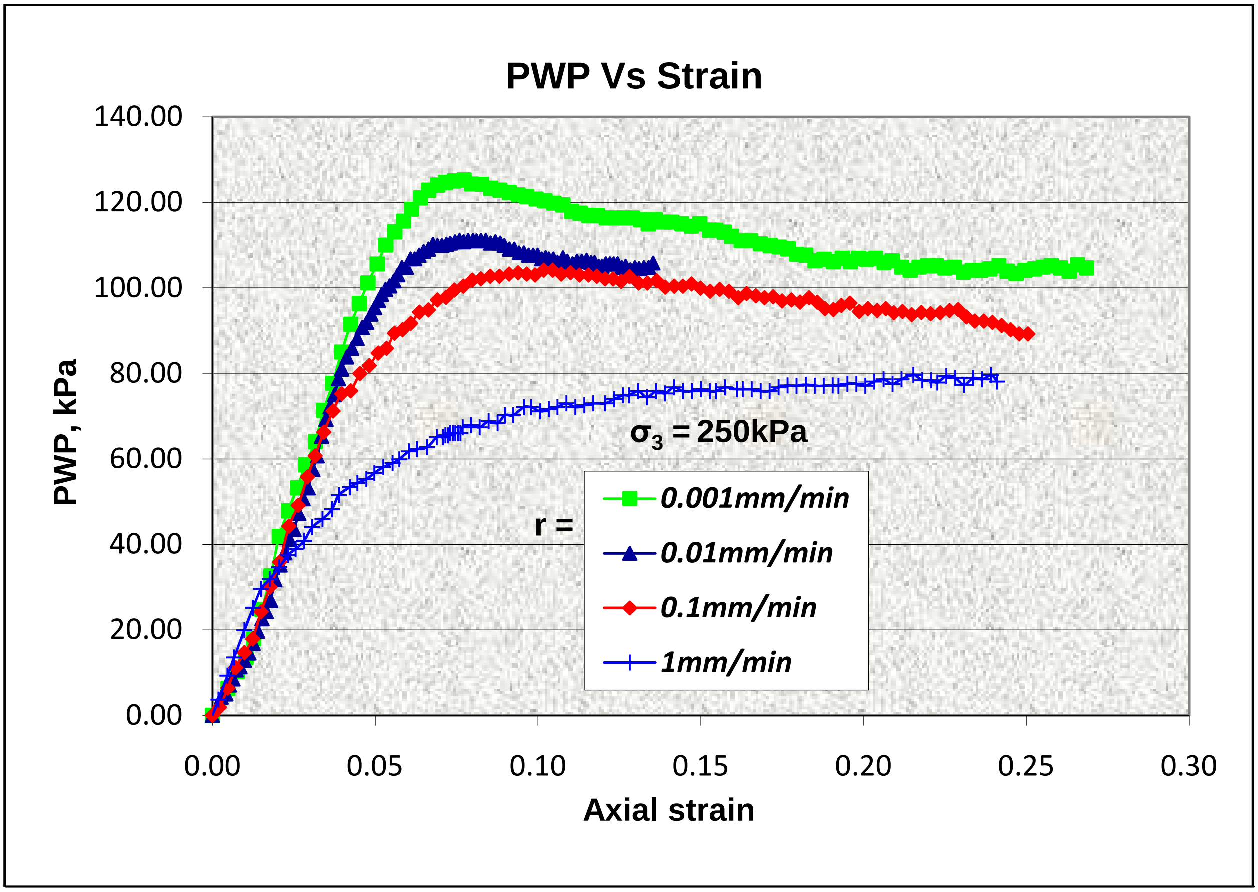


Fig.5. 9 PWP-Strain Curves for 250kPa Effective Consolidation Pressure under Different Strain Rate.

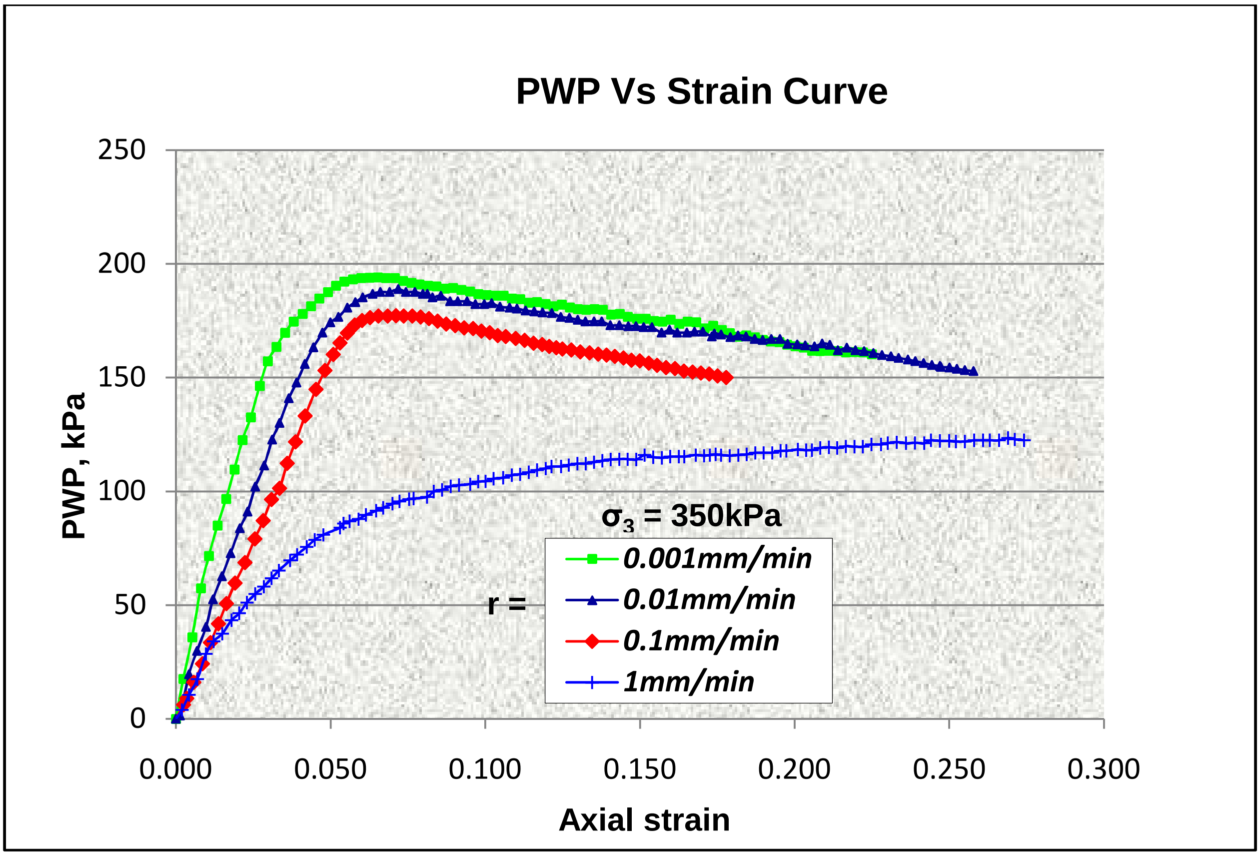


Fig.5. 10 PWP-Strain Curves for 350kPa Effective Consolidation Pressure under Different Strain Rate.

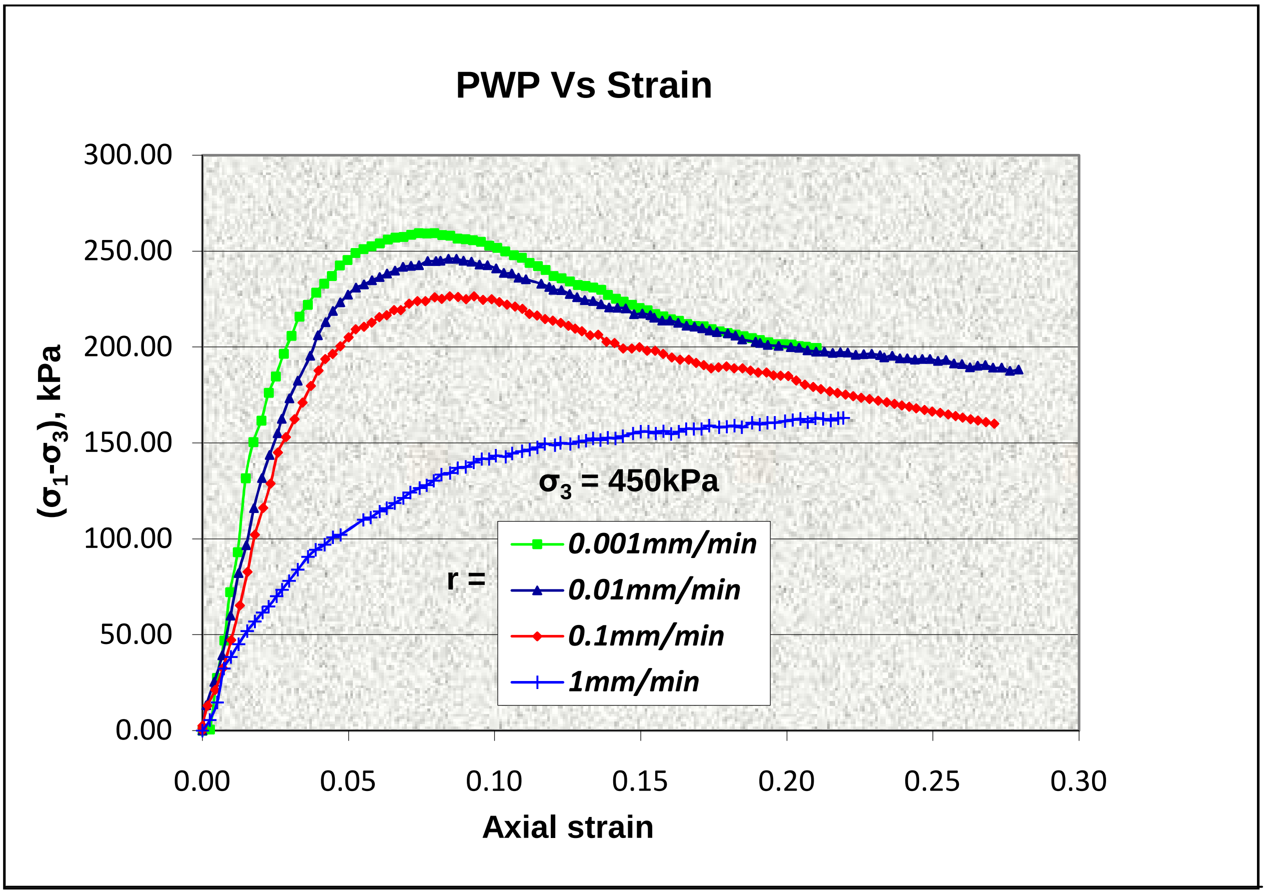


Fig.5. 11 PWP-Strain Curves for 450kPa Effective Consolidation Pressure under Different Strain Rate.

Fig. 5.12 to Fig. 5.14 show that the stress–strain curves for the same confining pressure under different strain rate. These plots show how strain rate affects the stress–strain behavior of the soil. From the graph it is observed that strain rate has a clear impact on the stress–strain relationship, i.e. as strain rate increase, the stress induced due to the axial loading also increases for the same confining pressure. This may be due to the decrease in pore water pressure as illustrated from Fig. 5.15 to Fig. 5.17. This difference is not as such significant for the slow strain rates.

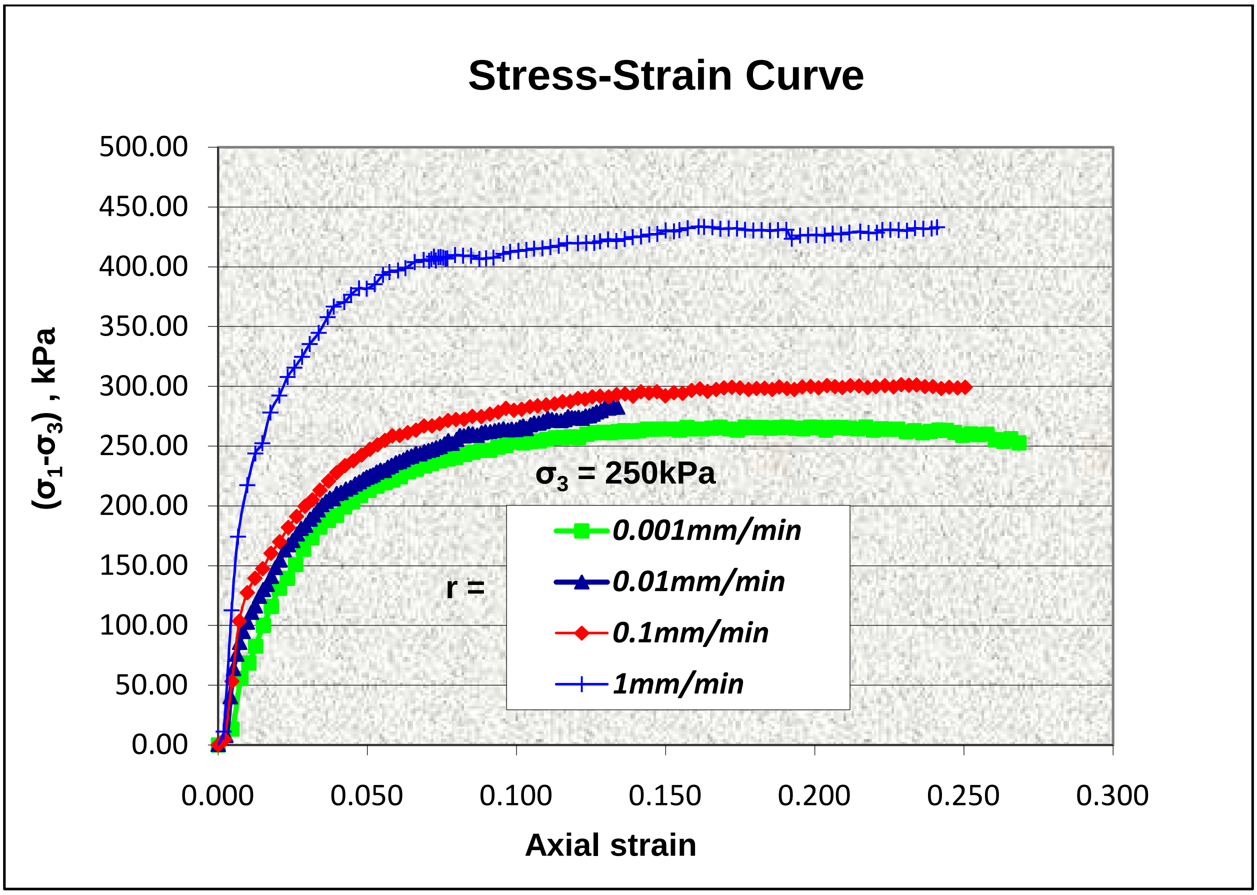


Fig.5. 12 Stress-Strain Curves for 250kPa Effective Consolidation Pressure under Different Strain Rate.

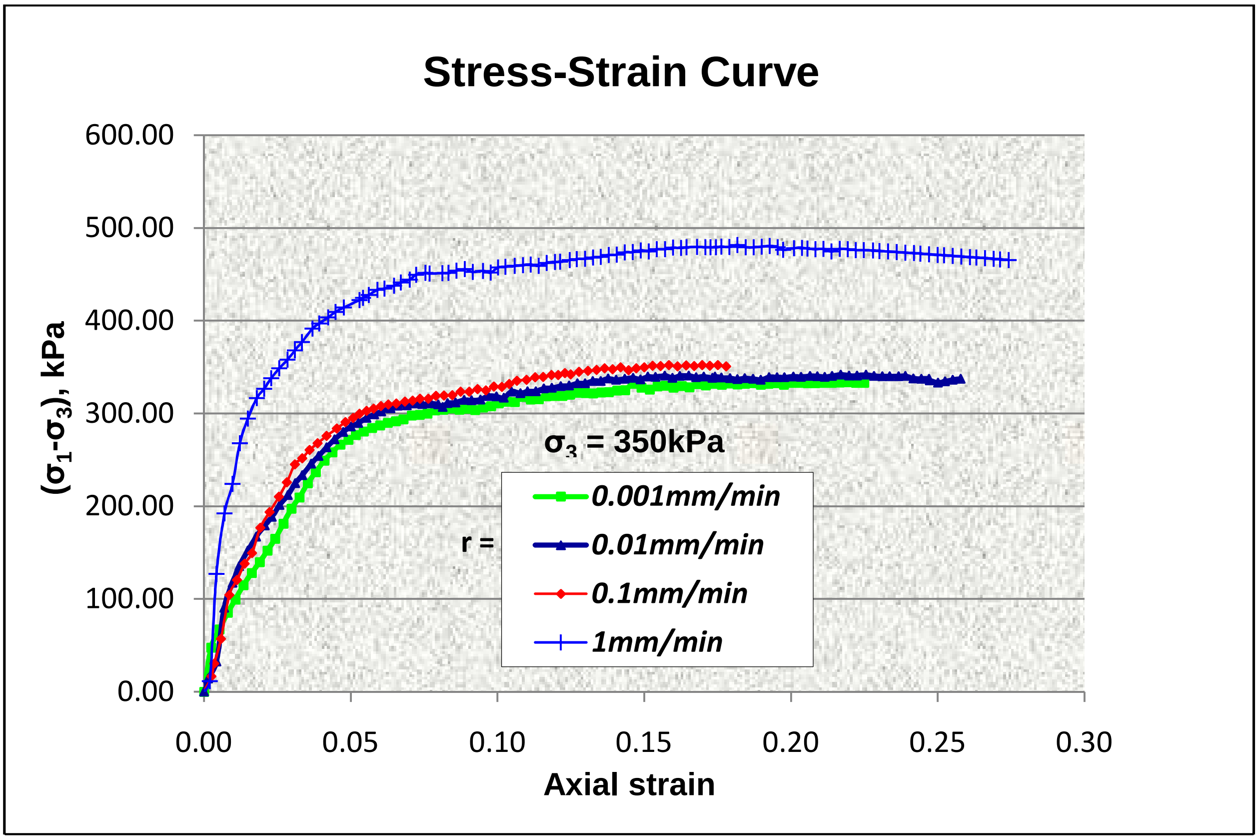


Fig.5. 13 Stress-Strain Curves for 350kPa Effective Consolidation Pressure under Different Strain Rate

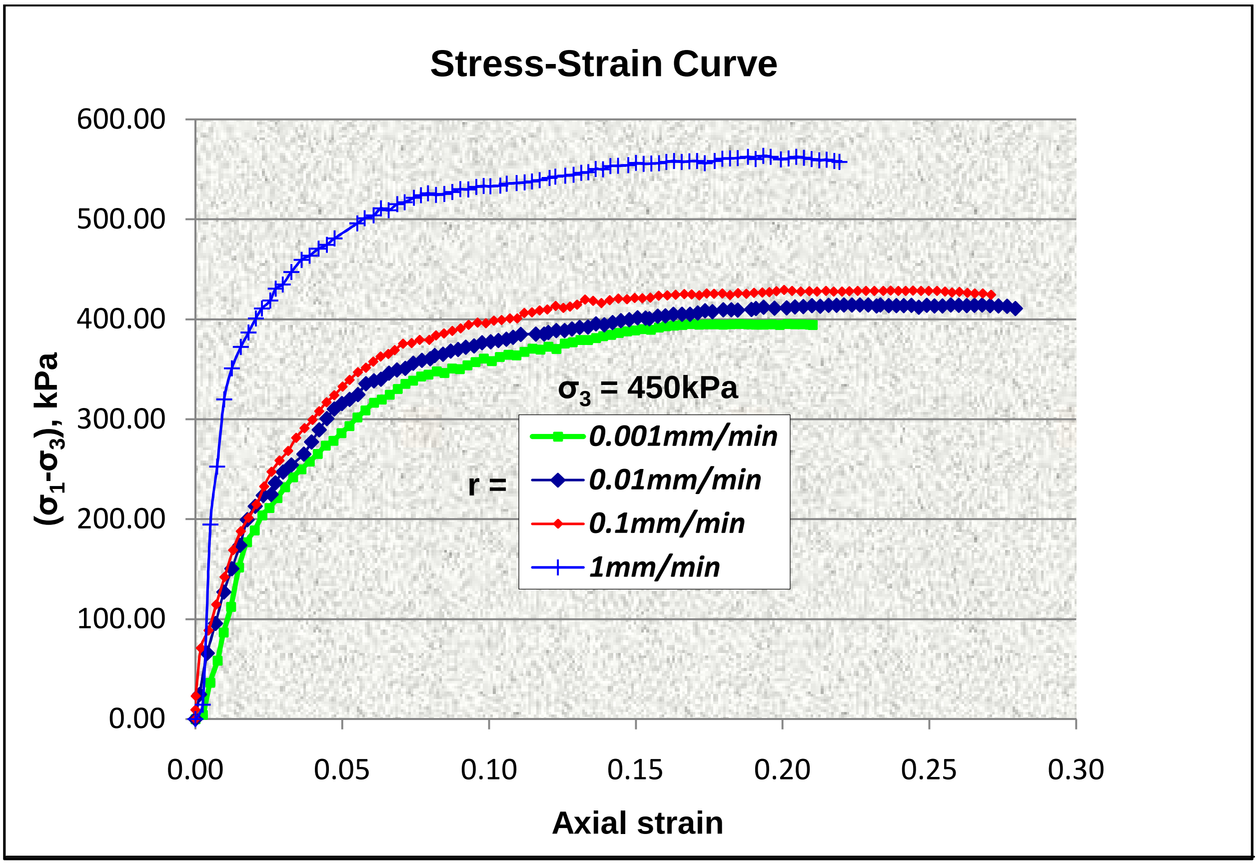


Fig.5. 14 Stress-Strain Curves for 450kPa Effective Consolidation Pressure under Different Strain Rate

The modified Mohr envelop method was employed to determine effective shear strength parameters. Table 5.1 to Table 5.1 show the modified failure envelops for different strain rates. The shear strength parameters are determined from these graphs. It is observed that, the shear strength of the soil increases as strain rate increases. According to the measured parameters, the strain rate has no discernible effect on the angle of internal friction. The increase in shear strength is attributed to the increase in cohesion of the soil.

Modified Mohr Failure Envelope for Total Stress

Table 5. 1 **Conditions at Failure for Strain Rate of 0.001mm/min**

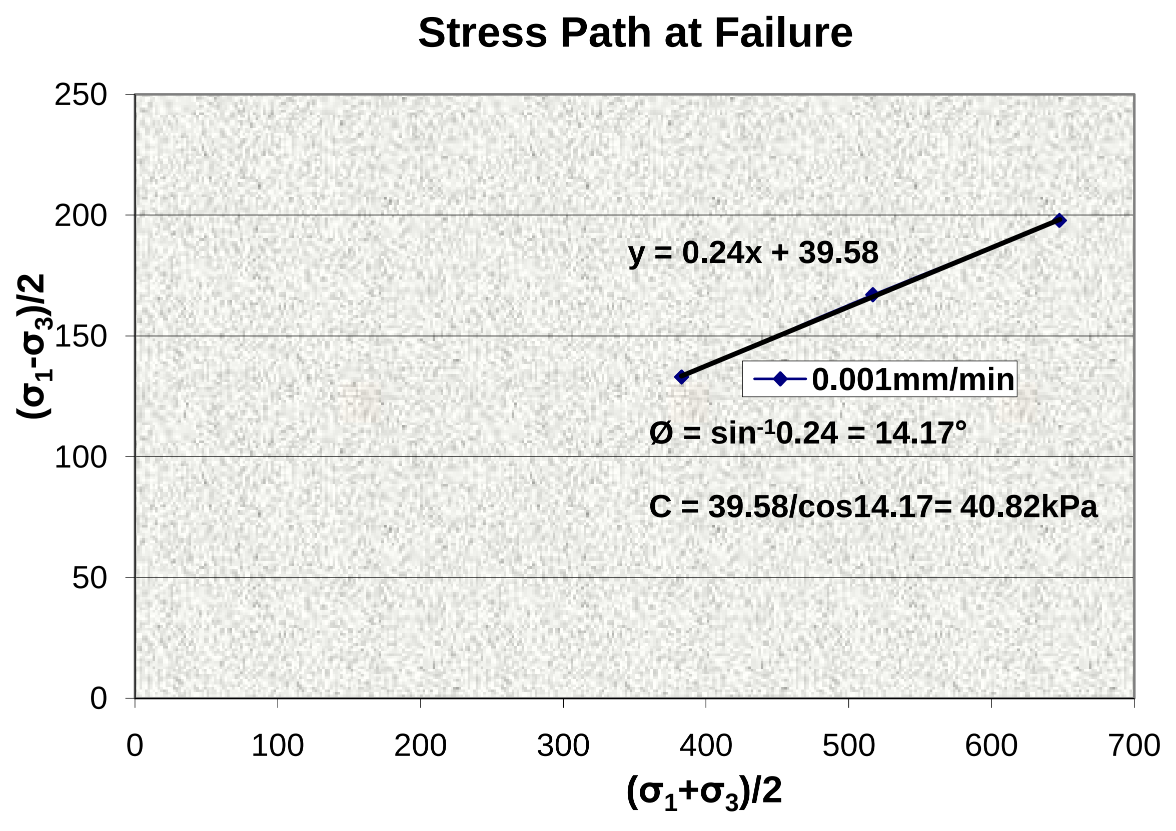
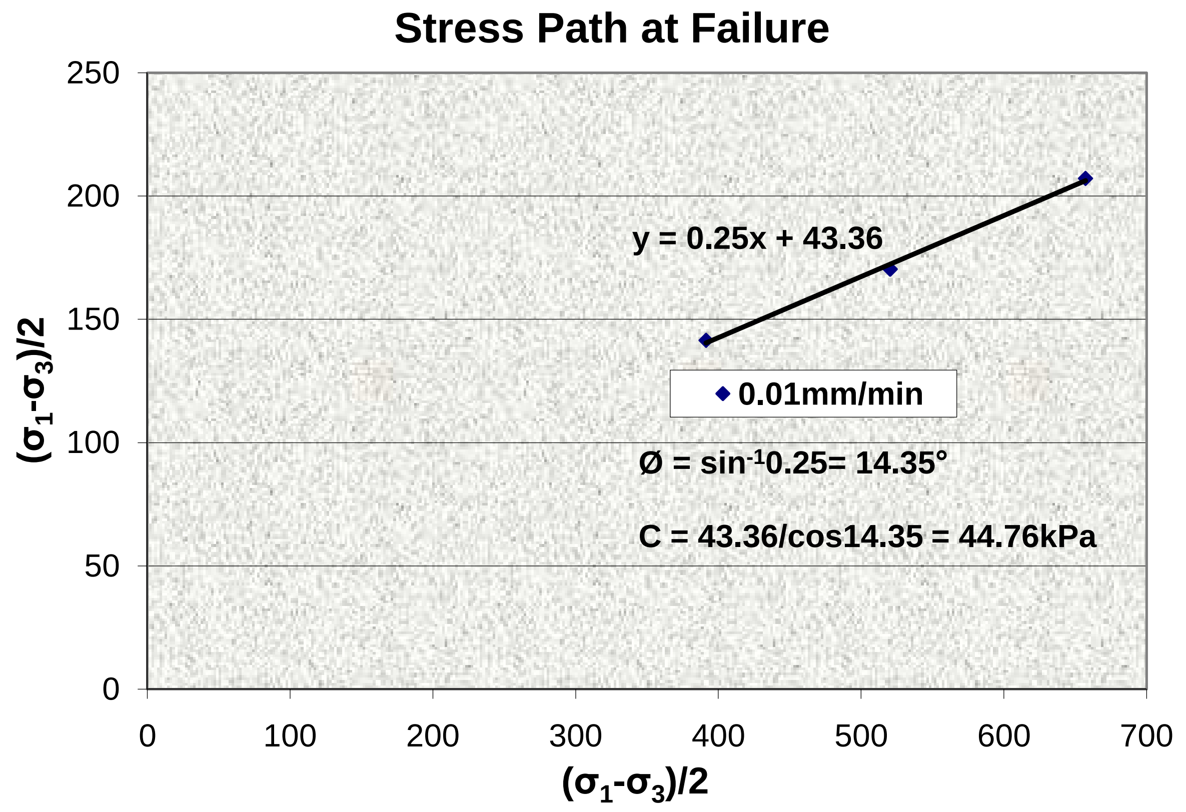
<table>
<tr><th>Effective Consolidation Pressure</th><th>Pore Pressure at Failure, kPa</th><th>Deviator Stress at Failure,Δσa, kPa</th><th>$(\sigma_1+\sigma_3)/2$</th><th>Total Angle of internal Friction, Φ</th><th>Total Cohesion, C, kPa</th></tr>
<tr><td>Addisu Gebeya</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>250kPa</td><td>106.15</td><td>265.80</td><td>382.90</td><td rowspan="3"><i>14.17°</i></td><td rowspan="3"><i>40.82</i></td></tr>
<tr><td>350kPa</td><td>161.316</td><td>333.94</td><td>516.97</td></tr>
<tr><td>450kPa</td><td>201.32</td><td>395.44</td><td>647.72</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td colspan="3"><i>Φ = 14.17°</i></td><td></td><td colspan="2"><i>C = 40.82kPa</i></td></tr>
</table>

Table 5. 2 **Conditions at Failure for Strain Rate of 0.01mm/min**

Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure,$\Delta\sigma a$, kPa**	$(\sigma_1+\sigma_3)/2$	**Total Angle of internal Friction, Φ**	**Total Cohesion, C, kPa**
Addisu Gebeya					
250kPa	104.76	282.75	391.38	***14.35°***	***44.76kPa***
350kPa	160.76	340.61	520.30		
450kPa	195.85	414.37	657.19		



Φ = 14.35°		***C =44.76kPa***

Table 5. 3 **Conditions at Failure for Strain Rate of 0.1mm/min**

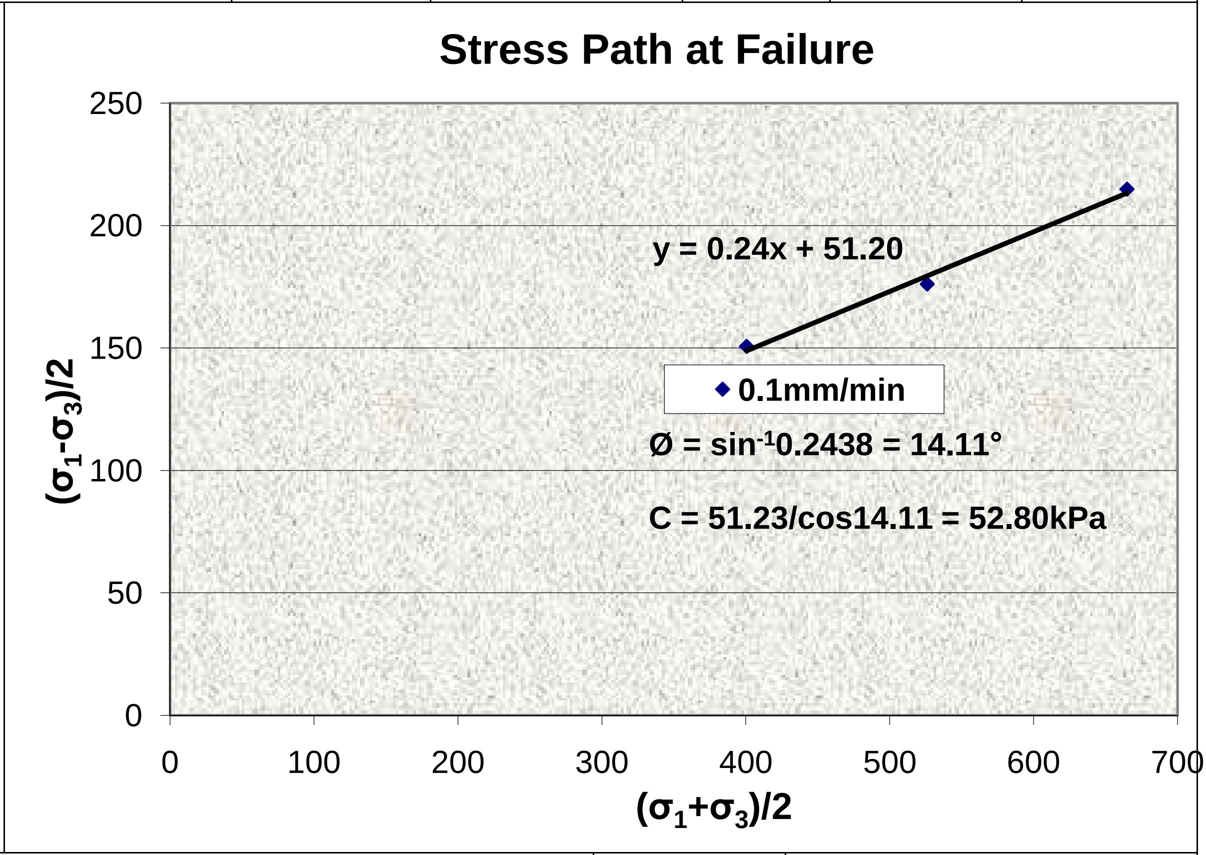
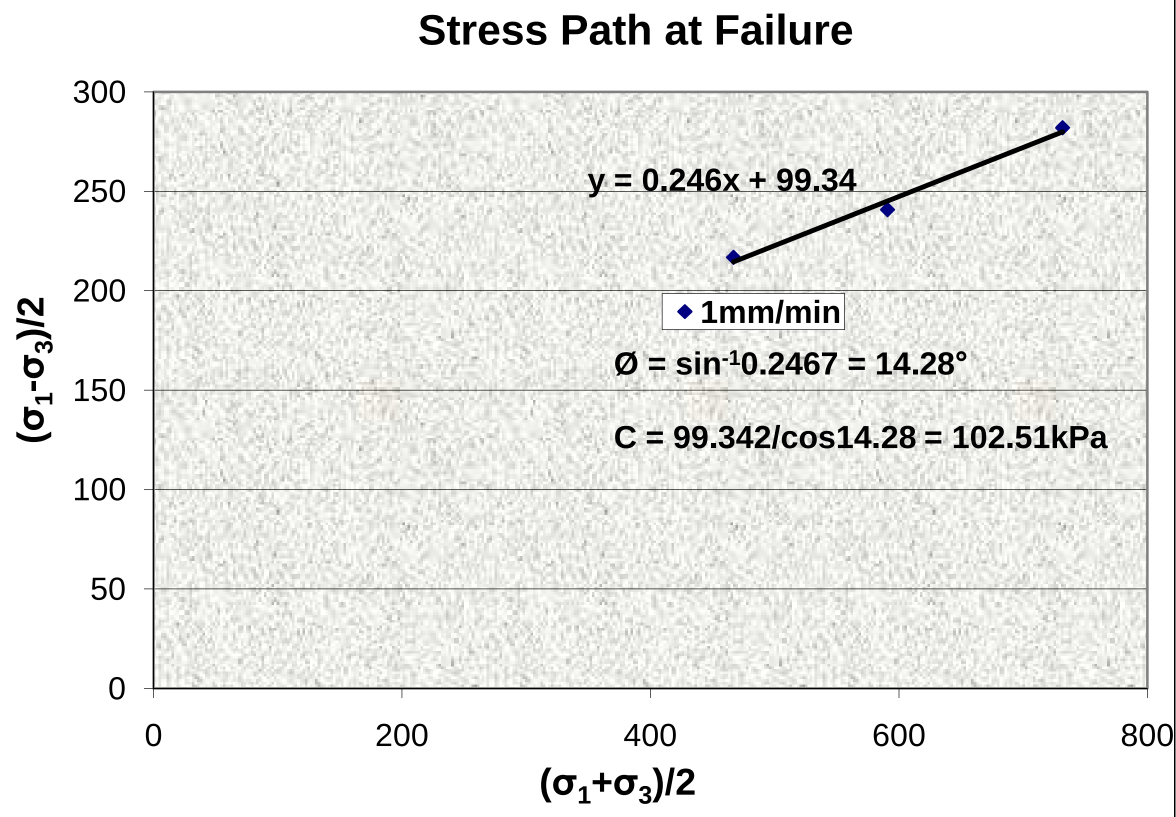
Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure,Δσa, kPa**	$(\sigma_1+\sigma_3)/2$	**Total Angle of internal Friction, Φ**	**Total Cohesion, C, kPa**
Addisu Gebeya					
250kPa	94.93	301.26	400.63	***14.11°***	***52.08***
350kPa	154.92	352.19	526.09		
450kPa	184.78	429.76	664.88		
 Ø = sin-10.2438 = 14.11° C = 51.23/cos14.11 = 52.80kPa					
Φ = 14.11°				***C =52.08kPa***	

Table 5. 4 **Conditions at Failure for Strain Rate of 1mm/min**

Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure,Δσa, kPa**	$(\sigma_1+\sigma_3)/2$	**Total Angle of internal Friction, Φ'**	**Total Cohesion, C', kPa**
Addisu Gebeya					
250kPa	76.28	433.55	466.77	***14.28***	***102.51***
350kPa	115.98	481.47	590.73		
450kPa	160..49	563.7	731.89		

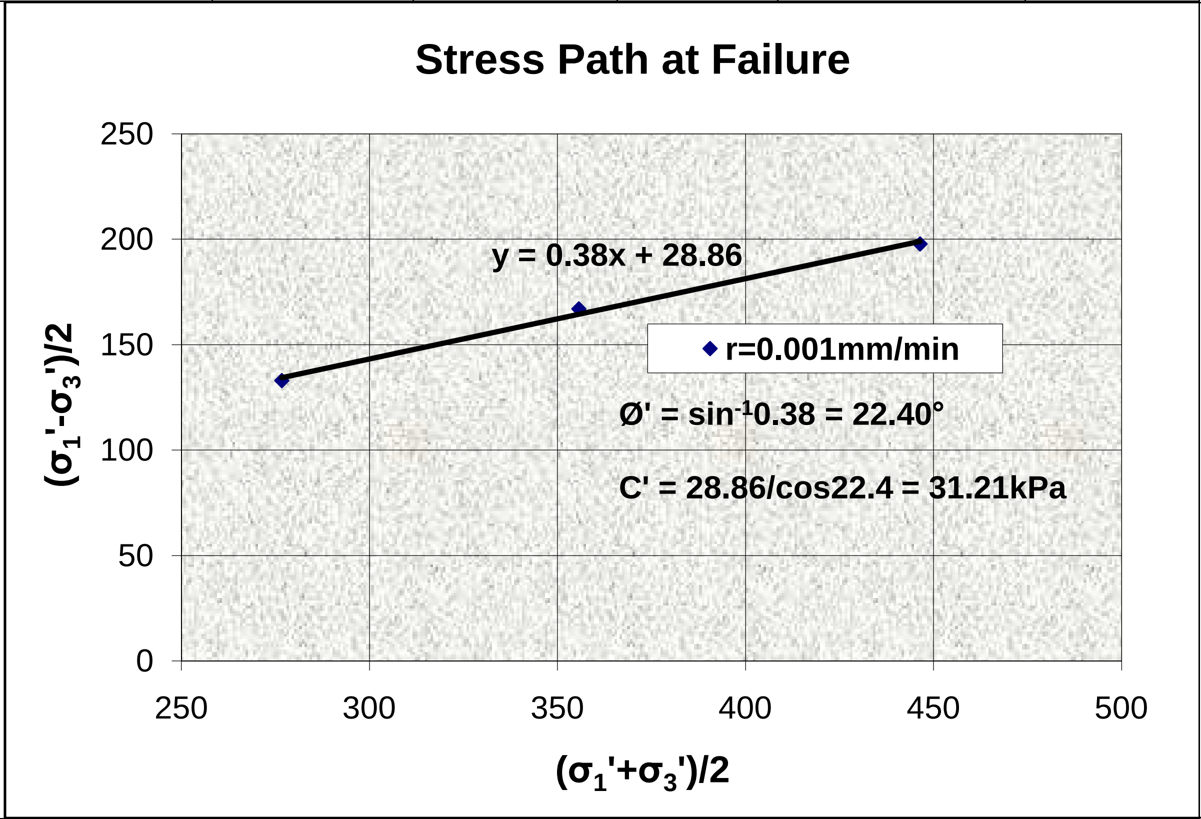


Φ = 14.28		***C =102.51kPa***

Modified Mohr Failure Envelope for effective stress

Table 5. 5 **Conditions at Failure for Strain Rate of 0.001mm/min**

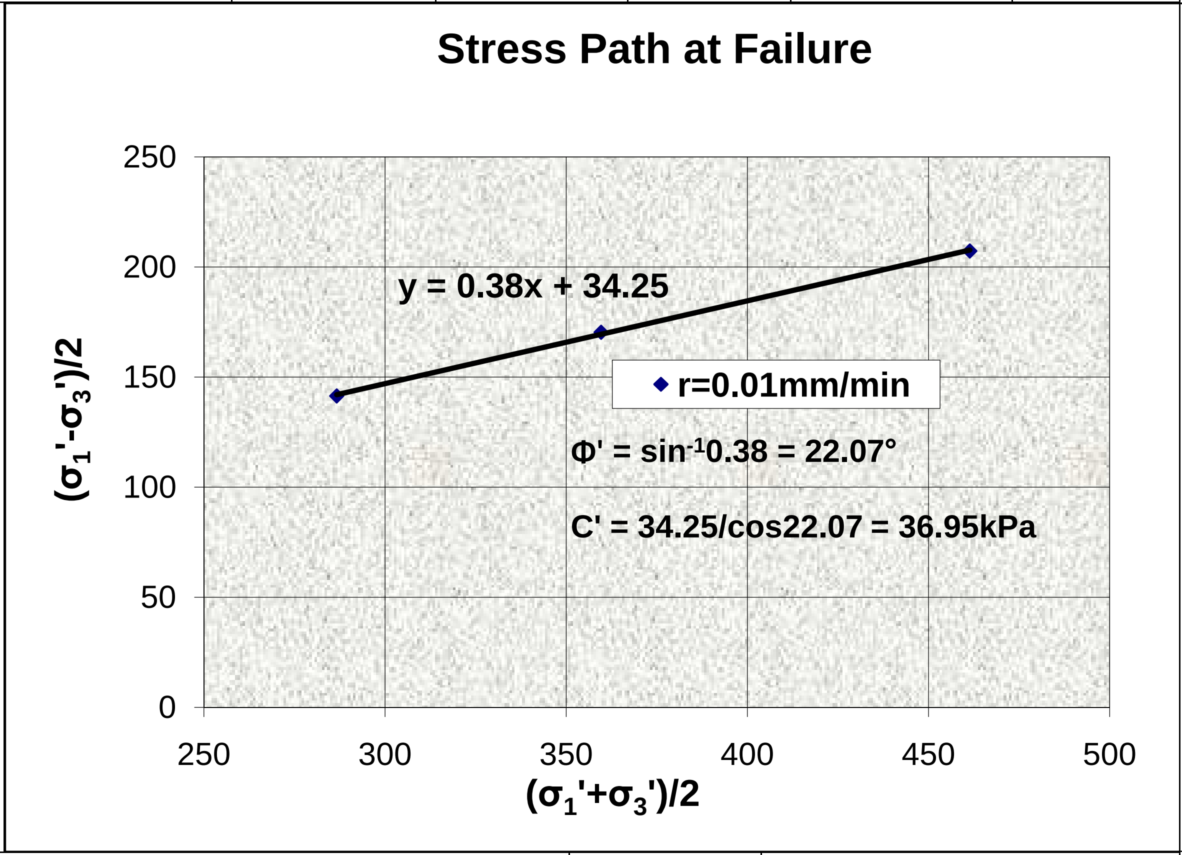
Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure, $\Delta\sigma_a$, kPa**	$(\sigma_1'+\sigma_3')/2$	**Effective Angle of internal Friction, Φ'**	**Effective Cohesion, C', kPa**
Addisu Gebeya					
250kPa	106.15	265.80	276.75	***22.4°***	***31.21***
350kPa	161.316	333.94	355.65		
450kPa	201.32	395.44	446.40		



θ' = 22.4°		***C' =31.21kPa***

Table 5. 6 **Conditions at Failure for Strain Rate of 0.01mm/min**

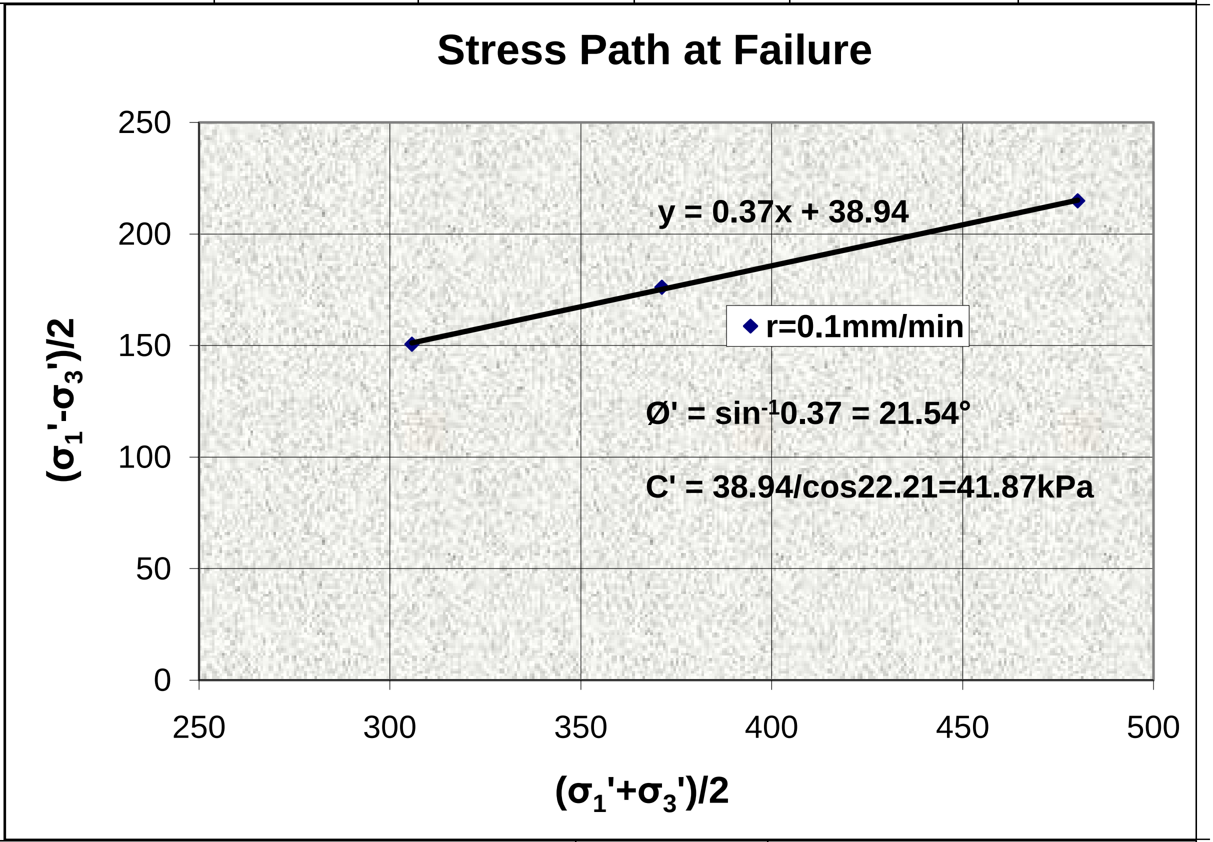
Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure,$\Delta\sigma a$, kPa**	$(\sigma_1'+\sigma_3')/2$	**Effective Angle of internal Friction, Φ'**	**Effective Cohesion, C', kPa**
Addisu Gebeya					
250kPa	104.76	282.75	286.62	***22.07°***	***36.95***
350kPa	160.76	340.61	359.56		
450kPa	195.85	414.37	461.36		



Φ' = 22.07°		***C' =36.95kPa***

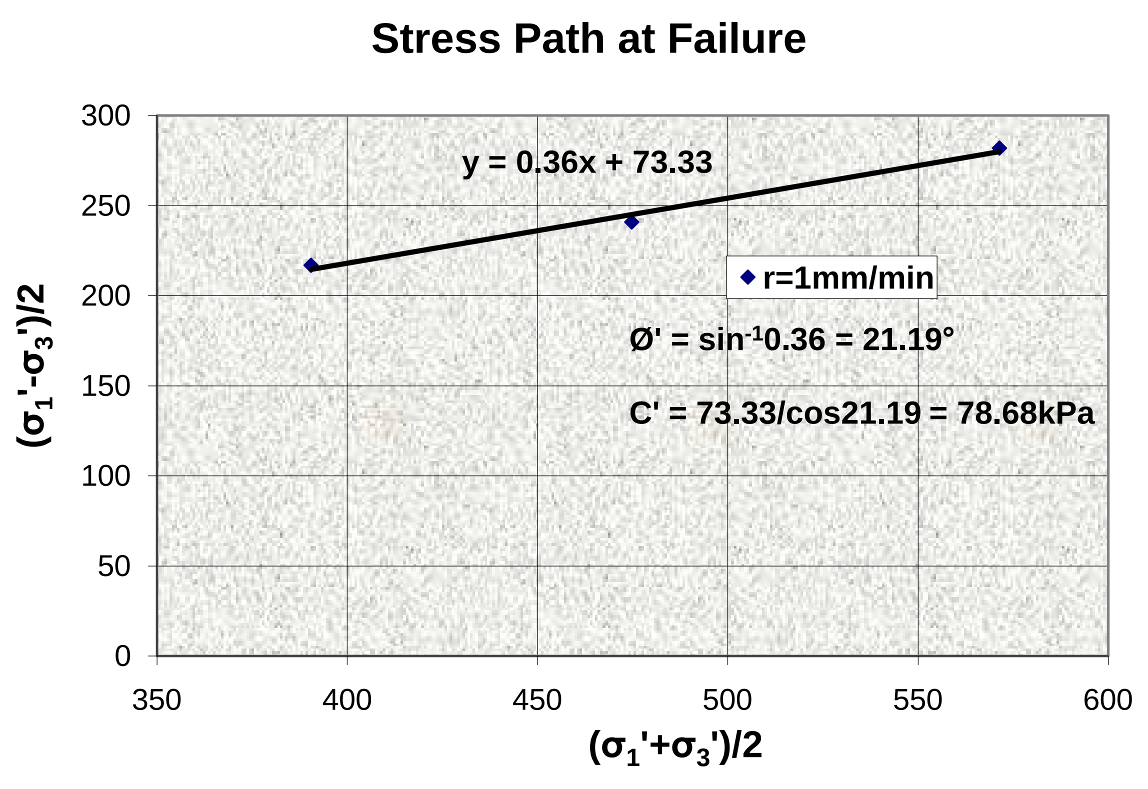
Table 5. 7 **Conditions at Failure for Strain Rate of 0.1mm/min**

Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure,Δσa, kPa**	$(\sigma_1'{+}\sigma_3')/2$	**Effective Angle of internal Friction, Φ'**	**Effective Cohesion, C', kPa**
Addisu Gebeya					
250KPa	94.93	301.26	305.70	***21.54°***	***41.87***
350KPa	154.92	352.19	371.17		
450KPa	184.78	429.76	480.10		



Φ' = 21.54		***C' =41.87kPa***

Table 5. 8 **Conditions at Failure for Strain Rate of 1mm/min**

Effective Consolidation Pressure	**Pore Pressure at Failure, kPa**	**Deviator Stress at Failure, $\Delta\sigma a$, kPa**	$(\sigma_1'+\sigma_3')/2$	**Effective Angle of internal Friction, Φ'**	**Effective Cohesion, C', kPa**
Addisu Gebeya					
250kPa	76.28	433.55	390.49	***21.19***	***78.68***
350kPa	115.98	481.47	474.76		
450kPa	160..49	563.7	571.39		
					
Φ' = 21.19°				***C' =78.60kPa***	

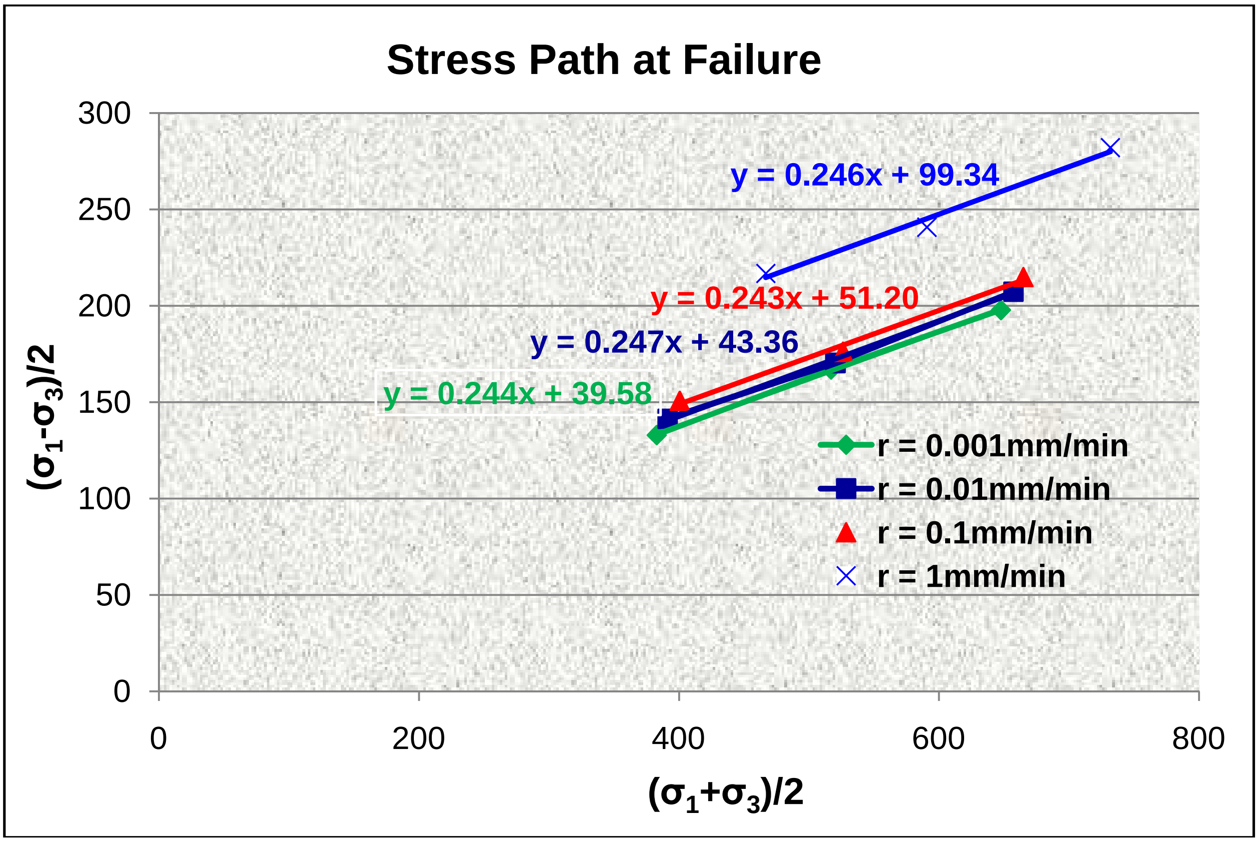


Fig.5. 15 Modified Failure Envelop Comprising all Strain Rates for Total Stress

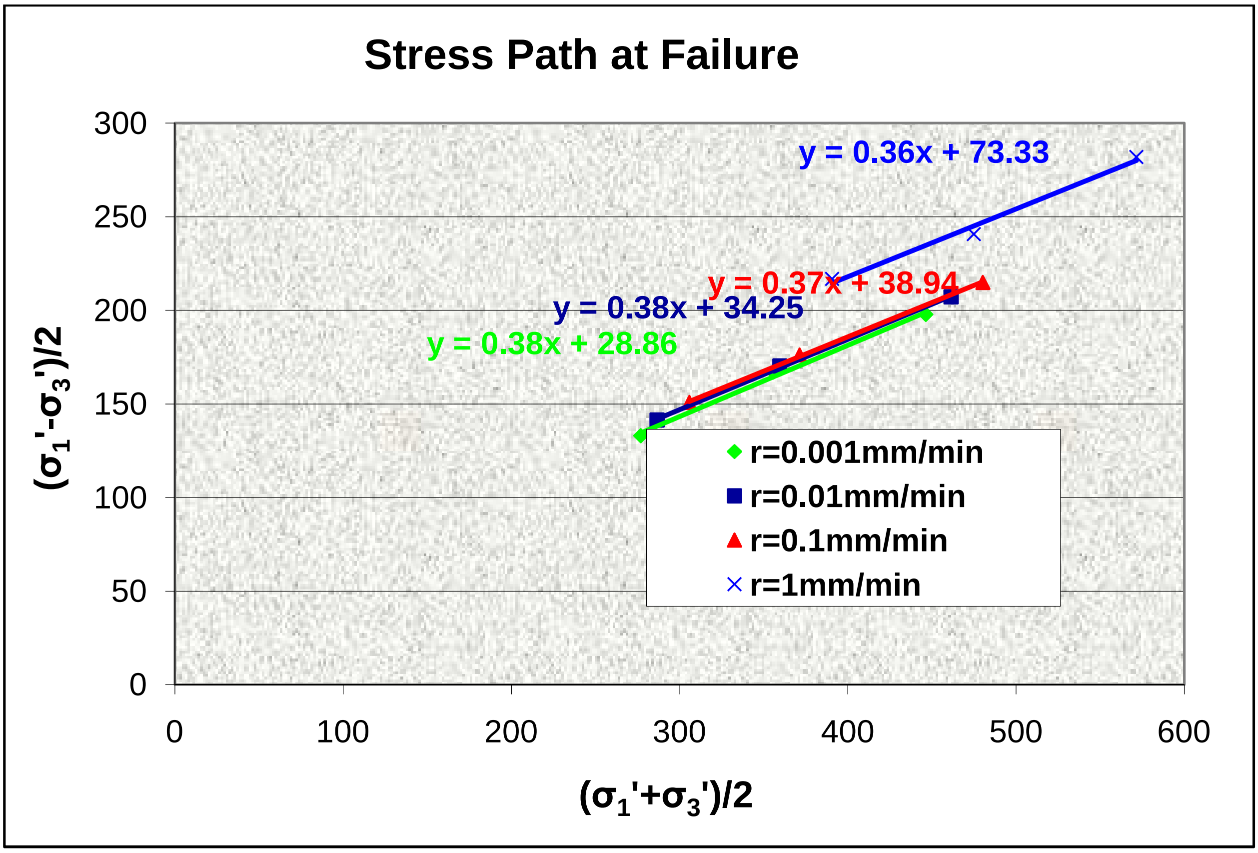


Fig.5. 16 Modified Failure Envelop Comprising all Strain Rates for Effective Stress

Fig. 5.15 and Fig. 5.16 show modified failure envelopes which comprises a graph of total stress and effective stress for all strain rates. Both graph show that slow strain rates have more or less similar failure envelop. Even though the curve for higher strain rate (1mm/min) has similar trend in failure envelop with the slow strain rates, it shifts noticeably upward. Hence the increase in shear strength is attributed to the increase in cohesion of the soil.

Even though similar results of shear strength parameter are obtained in tests conducted with the slow strain rate, the time required to complete the test considerably varies. The time taken to complete triaxial test for compression stage using strain rate obtained from BS (0.1mm/min) is between 2.8hr-3.6hr. While the time required for strain rate below BS i.e. 0.01mm/min and 0.001mm/min is 13-15hr and 3-5days respectively. Considering the time taken to complete compression stages, strain rate recommended by BS is enough in order to achieve the required equalization of pore water pressure.

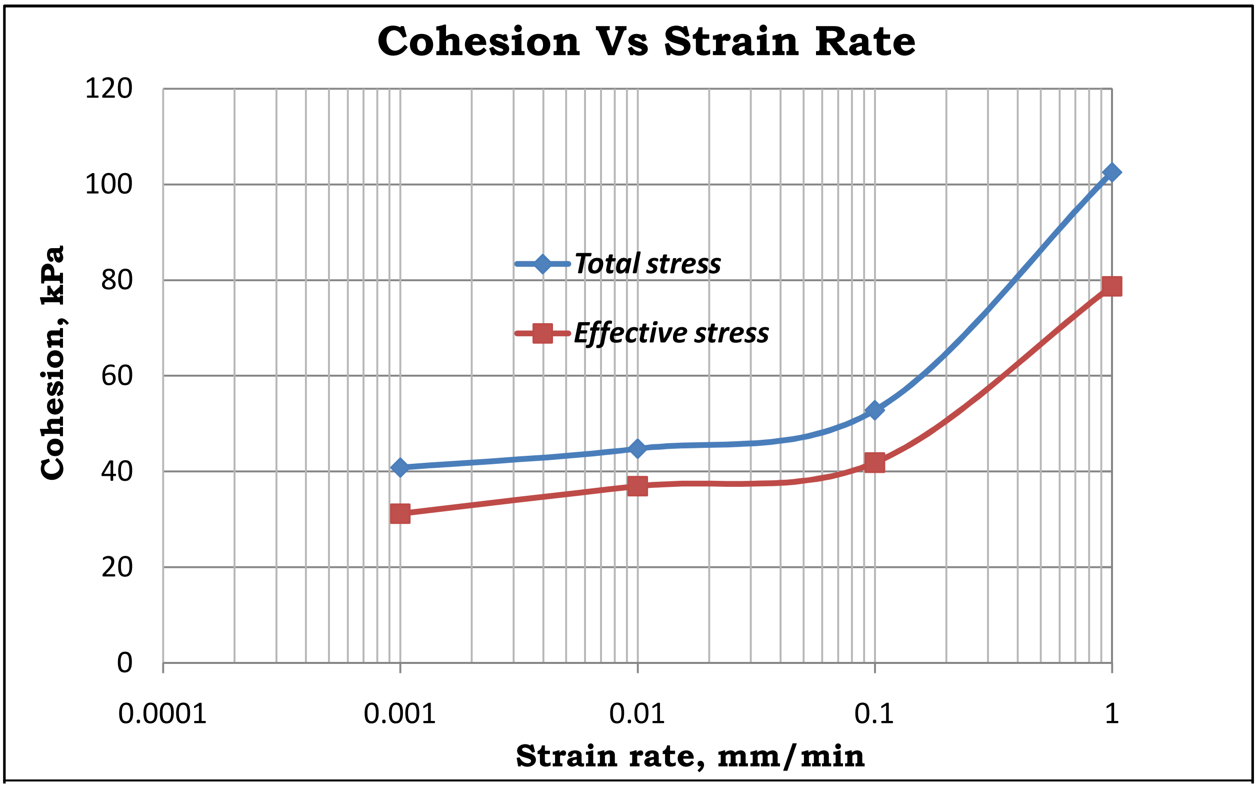


Fig.5. 17 Relationship between Cohesion and Strain rate

A plot which shows the relationship between Cohesion and Strain rate in log scale is illustrated in Fig.5.17. The graph show strain rate has an impact on cohesion i.e. cohesion increases as strain rate increases. But the effect is not as such significant for slow strain rates (those recommended below BS).

It is known that as moisture content of the soil increases the cohesion of the soil decreases. In the undrained compression test, there is a local variation of water content with in the triaxial specimen, higher in the middle and lower at the ends, due to the non-uniformity of strain in the specimen. Migration of water from the ends towards the center of the center of the specimen increases as strain rate increases which is indicated by the decrease in pore water pressure (Fig.5.9 to Fig.5.11). As a result the cohesion of the soil of the soil increases as strain rate increase.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

From the laboratory test consolidated Undrained triaxial test carried out with different strain rate, the following conclusion can be drawn:

- The stress developed due to the axial loading increases with the increase in strain rate whereas the induced pore water pressure decreases.
- Effective angle of internal friction was independent of strain rate while cohesion is highly affected strain rate.
- In order to achieve reasonable equalization of pore pressure in undrained test, a strain rate recommended by BS standard should be employed.

6.2. Recommendations for Further Research

The author recommends that further researches be carried out on red clay soils found in Addis Ababa that are not included in this research. This research topic may also be further extended on undisturbed samples for different location of Addis Ababa where red clay soils are found.

References

1. Arora, K.r., Soil Mechanics and Foundation Engineering, Standard publishers and distributors, Delhi, 1997.
2. ASTM Vol. 0408, Standard test methods for soil and rock, American Standard for Testing and Materials, USA, 1998.
3. BS1377, Methods of test for soil for engineering purpose, British Standard, UK, 1990.
4. Casagrande, A. and Shannon, W.L., stress-deformation and strength characteristics under dynamic loads, ICSMFE,1948.
5. Hailermariam, Abzo, Investigation in to shear strength characteristics of red clay soils, MSc Thesis, Addis Ababa University, 1992.
6. Merihun, Lukas, Effect of Remolding on Mechanical Behavior of Addis Ababa red clay soil, MSc Thesis, Addis Ababa University, 2010.
7. Mitchell, J. K., Fundamentals of soil behavior, John Willey & Sons, California – Berkley , 1976.
8. Morin, W.J., and Parry, W.T., Geotechnical Properties of Ethiopian Volcanic Soils, Geotechnique Vol. 21, No 3, 223-232, 1971.
9. Nakas, A. and Kamei, T., Influence of Strain rate on undrained shear strength characteristics of Ko-consolidated cohesive soils, Soils and Foundation,1986.
10. Richardson, A.M. and Whitman, R.V., Effect of strain rate up on undrained shear resistance of a saturated remolded fat clay, geotechnique, 1963.
11. Samuel, Tadesse, Investigation in to some of engineering properties of Addis Ababa red clay soil, MSc Thesis, Addis Ababa University, 1989.
12. Semma, T., A study on the stress-strain behavior of undisturbed Addis Ababa Red clay soil using constitutive models and FEM, MSc Thesis, Addis Ababa University, 2009.
13. Skempton, A.W. and Bishop, A.W., Soils, North Holland, publ.,1954.
14. Terzaghi, K. and Peck, R.B. , Soil mechanics in Engineering Practice, John Willey & Sons, New York, 1967.
15. Whitman, R.V., The Behavior of Soil under Transient Loading, Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, London, 1970.

DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Hadush Seged 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: Admassu Tirualem

Signature _____________

Place Faculty of Technology,
Addis Ababa University,
Addis Ababa.
Date November, 2011

APPENDIX A

Index Tests

1. Specific Gravity Determination

Table A1 Specific gravity test

Location: ***Addisu Gebeya***	Job ref.	***Thesis research***	
	Pit no.	***#1***	
Soil Description: ***Red brown clay***	Sample no.	***#1***	
	Depth	***2.5m***	
Test method: Small pyknometer BS 1377-2:1990:8.3	Date	***7/09/2002E.C***	
Specimen ref.	#1	#2	
Pyknometer number	P9	P10	
Mass of bottle + soil + water ($m3$) g	154.73	151.12	
Mass of bottle + soil ($m2$) g	58.32	54.82	
Mass of bottle full of water ($m4$) g	149.07	145.36	
Mass of bottle ($m1$) g	49.41	45.68	
Mass of soil ($m2 - m1$) g	8.92	9.14	
Mass of water in full bottle ($m4 - m1$) g	99.66	99.68	
Mass of water used ($m3 - m2$) g	96.41	96.30	
Volume of soil particles ($m4 - m1$) – ($m3 - m2$) mL	3.25	3.38	
Specific Gravity ($m2 - m1$)/(($m4 - m1$) – ($m3 - m2$))	2.75	2.71	
Average	2.73		

2. *Free swell test*

Table A2 Free swell test

Location: ***Addisu Gebeya Area***	Job ref.	***Thesis research***
	Pit no.	***#1***
Soil Description: ***Red brown clay***	Sample no.	***#1***
	Depth	***2.5m***
Test method: BS 1377-2:1990:6.4	Date	***7/09/2002E.C***
Test no.	1	2
Initial Volume, ml	10.00	10.00
Final Volume, ml	13.40	13.20
Free Swell, %	33.00	31.00
Average %	***32***	

3. Atterberg limits Determination

Table A3 Liquid Limit test

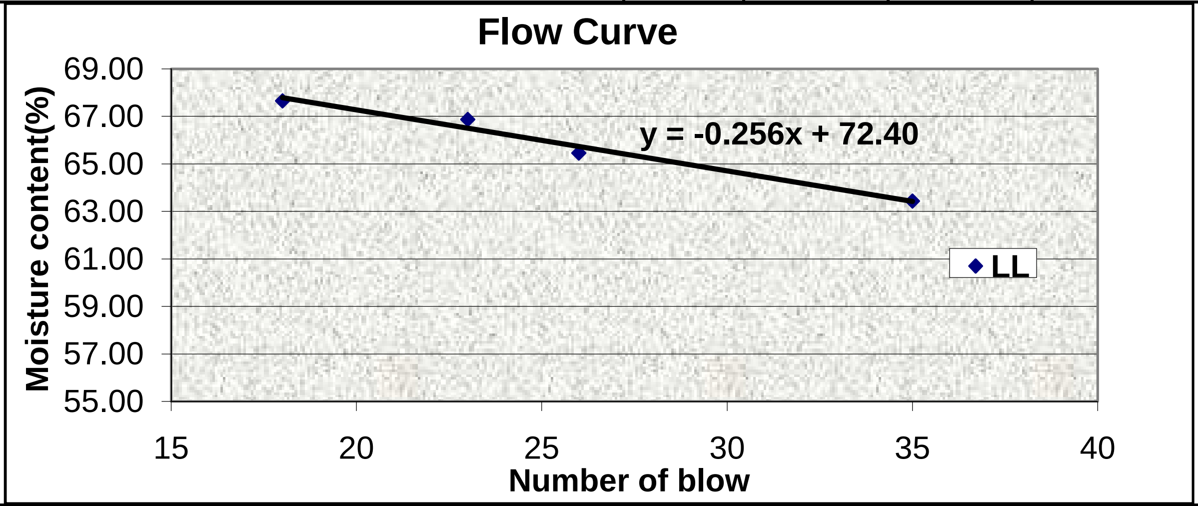
Location: ***Addisu Gebeya***	Job ref.	***Thesis research***
	Pit no.	***#1***
Soil Description: ***Red brown clay***	Sample no.	***#1***
	Depth	***2.5m***
Test method: Small pyknometer BS 1377-2:1990:8.3	Date	***8/09/2002E.C***

Plastic Limit test

Test no.	#1	#2	#3	#4
Container no.	D22	H4	46	26
Mass of wet soil + container (m_2) g	19.59	19.42	20.31	23.24
Mass of dry soil + container (m_3) g	18.68	18.55	19.18	21.42
Mass of container (m_1) g	15.76	15.77	15.63	15.62
Mass of moisture (m_2- m_3)g	0.91	0.87	1.13	1.82
Mass of dry soil (m_3- m_1)g	2.93	2.78	3.55	5.8
Moisture content = (m_2-m_3)/(m_3- m_1)*100, %	31.06	31.29	31.83	31.38
Average, %	***39.39***			

Liquid Limit test

Test no.	#1	#2	#3	#4
Number of blows	18	23	26	35
Container no.	53	D9	A36	69
Mass of wet soil + container (m_2) g	42.06	42.10	42.38	44.01
Mass of dry soil + container (m_3) g	31.88	31.68	31.58	32.59
Mass of container (m_1) g	15.83	15.76	15.43	15.71
Mass of moisture (m_2- m_3)g	10.18	10.42	10.8	11.42
Mass of dry soil (m_3- m_1)g	16.05	15.92	16.15	16.55
Moisture content(m_2-m_3)/(m_3- m_1)*100, %	63.43	65.45	66.87	67.65



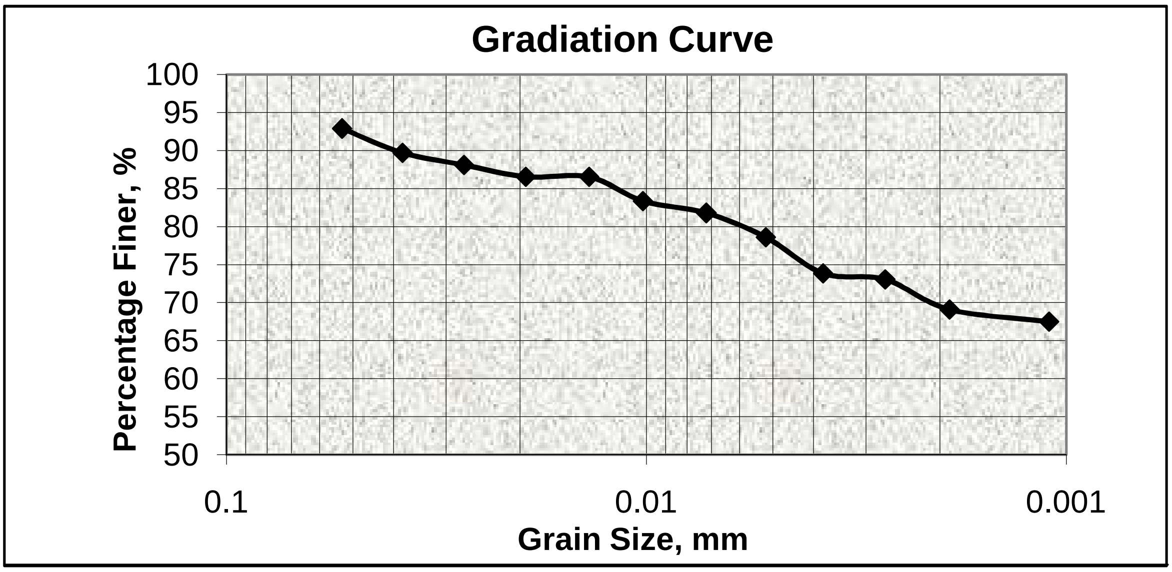
LL=-10.52*LN(25)+95.288=65.98	PL=31.39	PI=LL-PL=34.59	

4. Particle Size Analysis

Table A4 Hydrometer test

Location: ***Addisu Gebeya area***	Job ref.	***Thesis research***
	Pit no.	***#1***
Soil Description: ***Red brown clay***	Sample no.	***#1***
	Depth	***2.5m***
Test method: Hydrometer, ASTM D 422-63	Date	***12/9/2002E.C***
	Specific Gravity	**2.71**
Lab Temperature: 20 degree centigrade	Composite correction	**-0.0027**
	K Value	**0.01340**

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)
0.5	1.0320	-0.0027	1.0293	7.84	0.01340	0.0531	92.87
1	1.0310	-0.0027	1.0283	8.10	0.01340	0.0381	89.70
2	1.0305	-0.0027	1.0278	8.23	0.01340	0.0272	88.11
4	1.0300	-0.0027	1.0273	8.36	0.01340	0.0194	86.53
8	1.0300	-0.0027	1.0273	8.36	0.01340	0.0137	86.53
15	1.0290	-0.0027	1.0263	8.63	0.01340	0.0102	83.36
30	1.0285	-0.0027	1.0258	8.76	0.01340	0.0072	81.78
60	1.0275	-0.0027	1.0248	9.03	0.01340	0.0052	78.61
120	1.0260	-0.0027	1.0233	9.42	0.01340	0.0038	73.85
240	1.0258	-0.0027	1.0231	9.49	0.01340	0.0027	73.06
480	1.0245	-0.0027	1.0218	9.82	0.01340	0.0019	69.10
1440	1.0240	-0.0027	1.0213	9.95	0.01340	0.0011	67.51



5. Compaction Test

Table A5 Standard compaction test

Location:	***Addisu Gebeya Area***	Job ref.	***Thesis research***
		Pit no.	***#1***
Soil Description:	***Red brown clay***	Sample no.	***#1***
		Depth	***2.5m***
Test method:	Standard Compaction, ASTM D 698-91	Date	***15/11/2001E.C***

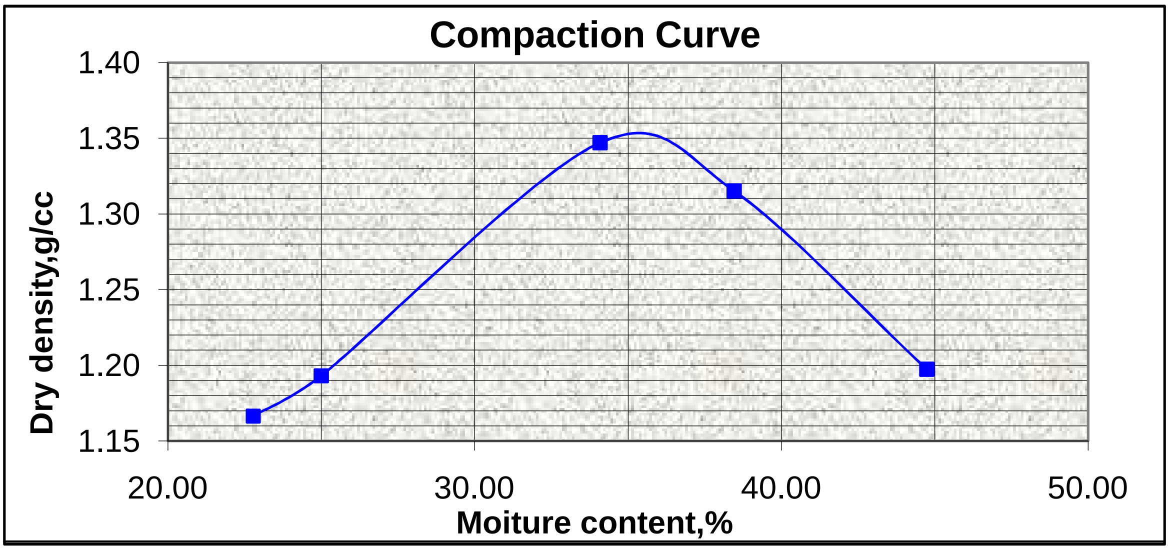
Blows/layer	**25**	**No. of layers**	**3**	**Wt of hammer, Kg**	**2.5**
Mold dia, cm	**10.16**	**Mold Ht, cm**	**12**	**Vol, CC**	**972.88**

Water Content Determination

Determination No	1	2	3	4	5
Container No	5	5	5	5	5
Mass of Container, M_1 ,g	5	5	5	5	5
Mass of Container + Wet Soil, M_2 ,g	78	75	75	70	70
Mass of Container + Dry Soil, M_3 ,g	66..5	63	60	55	53
Mass of Water, M_2-M_3 ,g	11.5	12	15	15	17
Mass of Dry Soil, M_3-M_1 ,g	50.5	48	44	39	38
Moisture Content, $w=(M_2-M_3)/(M_3-M_1)*100$, %	22.77	25	34.09	38.46	44.74

Density Determination

Water content. Wo, %	22.77	25	34.09	38.46	44.74
Wt of soil + mold, g	6988	7044	7341	7355	7272
Wt of mold, g	5636	5636	5636	5636	5636
Wt of soil in mold, g	1352	1408	1705	1719	1636
Wet density, g/cc	1.43	1.49	1.81	1.82	1.73
Dry density, g/cc	1.17	1.19	1.35	1.32	1.20



Optimum moisture Content	**35.1%**	***Maximum Dry Density***	**1.355 g/cc**

APPENDIX B

1. Triaxial Compression Test Results

1.1. Triaxial compression test result for Strain rate 0.001mm/min

Table B1 Consolidation Stage Result for Effective consolidation pressure of 250KPa, 350KPa, and 450KPa

Location: ***Addisu Gebeya***		Job ref.	***Thesis research***
Soil Description: Red brown clay		Pit no.	***#1***
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8		Sample no.	***#1***
		Depth	***2.5m***

Undisturbed Sample								
Effective Consolidation Pressure 150 KPa			**Effective Consolidation Pressure 250 KPa**			**Effective Consolidation Pressure 350 KPa**		
Initial Condition	CP, KPa	***550***	**Initial Condition**	CP, KPa	***650***	**Initial Condition**	CP, KPa	***750***
	BP, KPa	**300**		BP, KPa	***300***		BP, KPa	**400**
	PP, KPa	***0.1***		PP, KPa	***329.4***		PP, KPa	***738***
Final Condition	PP, KPa	***-222.1***	**Final Condition**	PP, KPa	**301**	**Final Condition**	PP, KPa	**413**
	ΔVolume, ml	***3.41***		ΔVolume, ml	***0.8***		ΔVolume, ml	***4.3***
	% Consolidation	**95**		% Consolidation	**95**		% Consolidation	**96**
Sqrt. Time	**ΔVolume, ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume, ml**	**PP, KPa**	**Sqrt. Time**	**Δ vol, ml**	**PP, KPa**
0.30	-0.006	531.68	0.00	-0.04	629.4	0.29	0.00	766.61
0.37	-0.006	530.23	0.37	0.00	630.21	0.36	-0.75	766.42
0.46	-0.702	331.4	0.46	-0.54	322.26	0.44	-1.08	375.06
0.56	-0.740	331.8	0.56	-0.70	321.58	0.54	-1.16	374.19
0.69	-0.785	331.9	0.69	-0.83	321.2	0.66	-1.19	374.41
0.84	-0.760	320.7	0.84	-0.94	321.53	0.81	-1.26	373.42
1.03	-0.791	320.7	1.03	-1.05	320.91	1.00	-1.37	372.94
1.26	-0.830	320.9	1.26	-1.18	320.72	1.22	-1.49	372.84
1.54	-0.874	321.0	1.54	-1.31	320.52	1.49	-1.57	372.65
1.89	-0.951	321.1	1.89	-1.47	320.62	1.83	-1.65	372.55
2.32	-1.021	321.2	2.32	-1.64	320.52	2.24	-1.78	372.45
2.84	-1.047	321.3	2.84	-1.80	320.62	2.74	-1.89	372.45
3.47	-1.142	321.4	3.47	-2.00	320.43	3.36	-2.07	372.07
4.25	-1.308	321.3	4.25	-2.26	320.52	4.11	-2.26	372.07
5.21	-1.525	321.5	5.21	-2.54	320.52	5.04	-2.48	372.07
6.38	-1.653	321.4	6.38	-2.89	320.33	6.17	-2.73	372.26
7.82	-1.889	321.4	7.82	-3.36	320.62	7.56	-3.06	372.26
9.57	-2.247	321.3	9.57	-3.86	320.62	9.26	-3.48	372.26
11.72	-2.540	321.1	11.72	-4.44	320.81	11.34	-3.93	372.36
14.36	-2.872	320.8	14.36	-4.99	320.81	13.89	-4.32	372.55
17.59	-3.198	320.9	17.59	-5.32	320.81	17.01	-4.68	372.65
21.54	-3.357	321.1	21.54	-5.45	320.81	20.83	-5.02	372.07
26.38	-3.415	321.5	26.38	-5.55	320.33	25.51	-5.16	371.78
32.31	-3.415	322.1	32.31	-5.60	319.94	31.25	-5.25	371.39

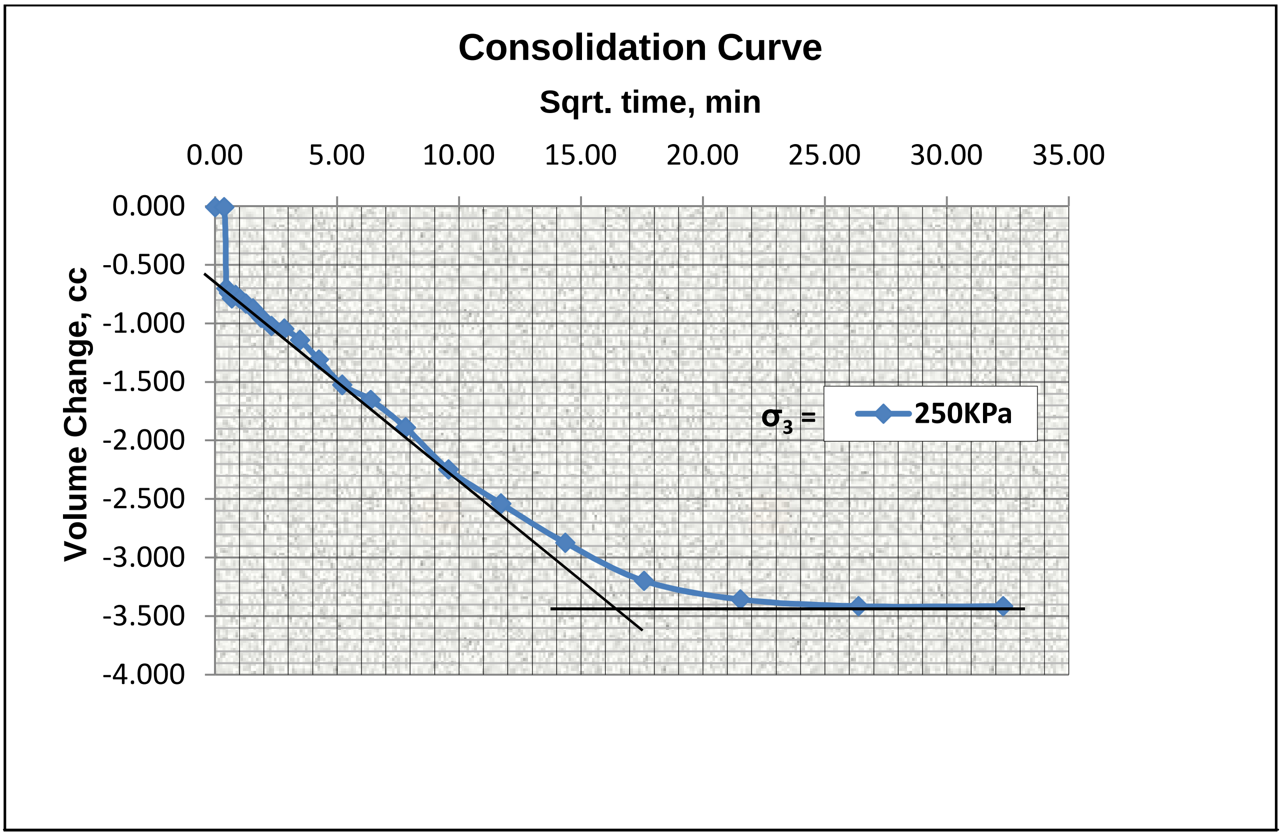


Fig. B1 Consolidation Curve for Effective Consolidation Pressure of 250KPa.

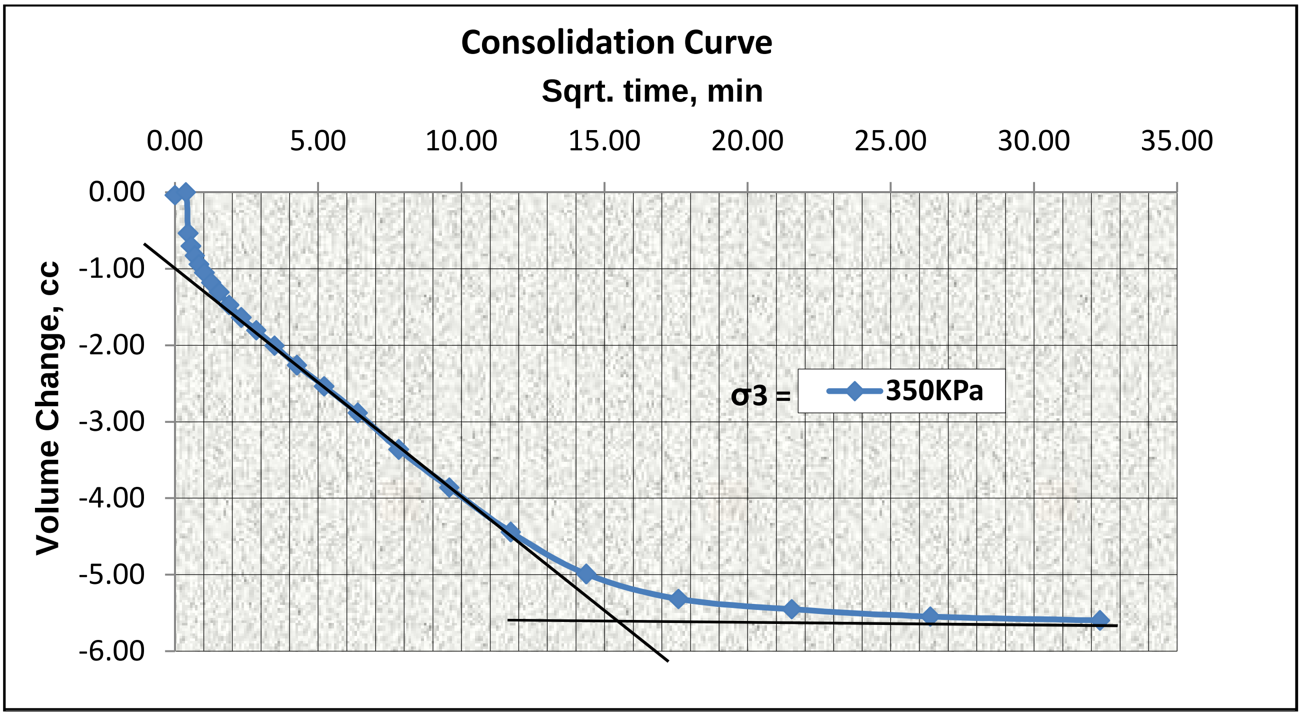


Fig. B2 Consolidation Curve for Effective Consolidation Pressure of 350KPa.

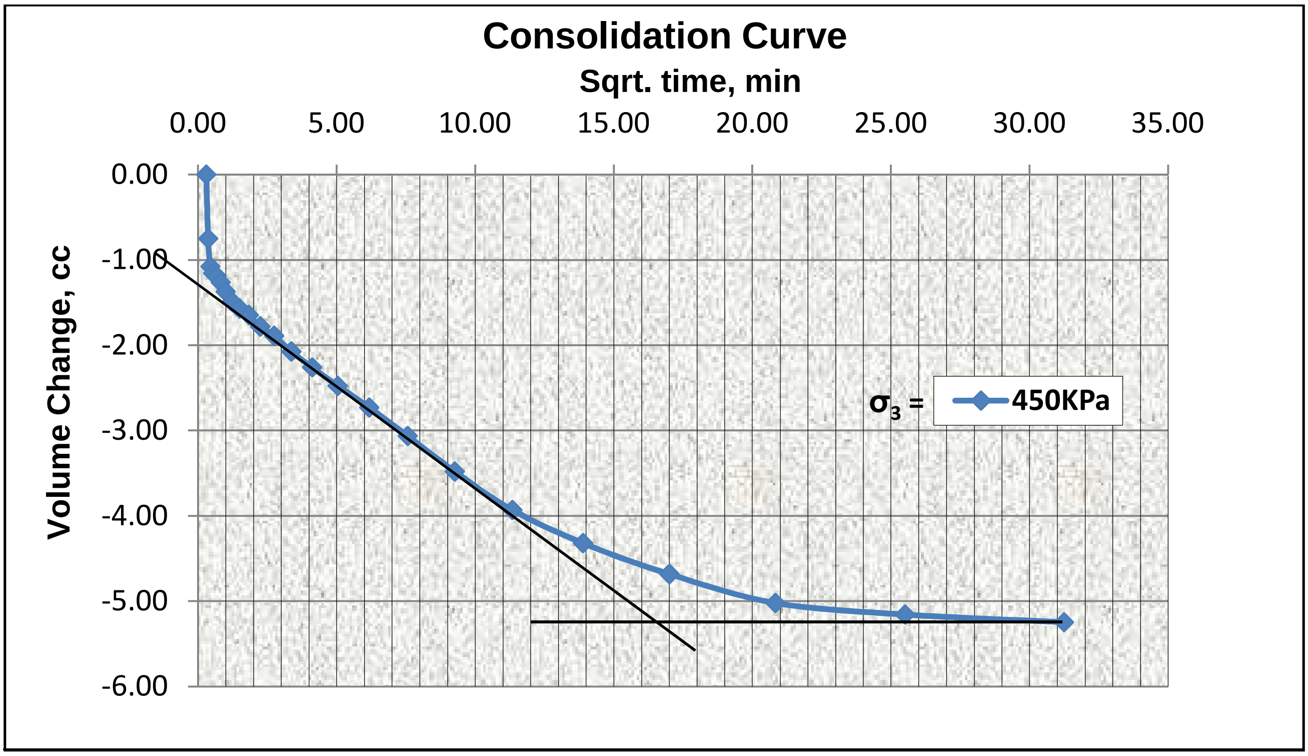


Fig. B3 Consolidation Curve for Effective Consolidation Pressure of 450KPa.

Table B2 Compression Stage Result for 250KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8				Sample No.	1
				Depth	2.5m
CP = 250KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.00	0.00	0.00	310.00	0.00
0.35	0.00	15.10	13.30	316.28	6.28
0.57	0.01	63.32	55.61	320.29	10.29
0.77	0.01	78.10	68.40	323.53	13.53
0.95	0.01	94.70	82.75	327.94	17.94
1.14	0.02	114.80	100.05	334.80	24.80
1.34	0.02	133.30	115.86	342.64	32.64
1.54	0.02	151.40	131.23	351.95	41.95
1.74	0.02	161.20	139.34	357.83	47.83
1.95	0.03	175.20	151.01	363.22	53.22
2.15	0.03	190.50	163.76	368.61	58.61
2.36	0.03	202.30	173.39	374.00	64.00
2.57	0.03	213.10	182.13	381.35	71.35
2.77	0.04	220.40	187.83	387.72	77.72
2.98	0.04	226.20	192.23	395.07	85.07
3.18	0.04	235.00	199.15	401.44	91.44
3.39	0.05	240.80	203.48	406.34	96.34
3.58	0.05	247.86	208.86	411.24	101.24
3.80	0.05	253.69	213.14	415.65	105.65
4.00	0.05	258.50	216.57	420.06	110.06
4.20	0.06	262.83	219.57	423.09	113.09
4.40	0.06	266.13	221.71	425.67	115.67
4.58	0.06	269.92	224.28	428.45	118.45
4.79	0.06	275.88	228.56	431.04	121.04
4.99	0.07	279.25	230.70	432.83	122.83
5.19	0.07	283.20	233.27	434.02	124.02
5.37	0.07	286.51	235.41	434.62	124.62
5.56	0.07	289.93	237.55	435.01	125.01
5.79	0.08	292.99	239.26	435.21	125.21
5.97	0.08	295.32	240.54	434.37	124.37
6.20	0.08	299.46	243.11	434.27	124.27
6.41	0.09	302.49	244.83	433.29	123.29
6.62	0.09	305.54	246.54	432.80	122.80
6.83	0.09	306.50	246.54	432.31	122.31
7.04	0.09	310.64	249.11	431.82	121.82
7.24	0.10	313.16	250.39	431.33	121.33
7.45	0.10	317.91	253.39	430.84	120.84
7.66	0.10	317.82	252.53	430.35	120.35

7.86	0.10	320.41	253.82	429.86	119.86
8.07	0.11	321.94	254.24	429.37	119.37
8.27	0.11	325.07	255.96	427.90	117.90
8.47	0.11	327.16	256.81	427.41	117.41
8.67	0.12	328.67	257.24	426.92	116.92
8.87	0.12	330.76	258.10	426.92	116.92
9.06	0.12	330.64	257.24	426.43	116.43
9.27	0.12	335.01	259.81	426.43	116.43
9.47	0.13	337.68	261.09	426.43	116.43
9.67	0.13	339.26	261.52	426.43	116.43
9.86	0.13	339.71	261.09	425.94	115.94
10.04	0.13	341.76	261.95	424.96	114.96
10.20	0.14	343.73	262.81	425.94	115.94
10.38	0.14	344.14	262.38	425.45	115.45
10.58	0.14	345.74	262.81	425.45	115.45
10.80	0.14	348.65	264.09	424.96	114.96
11.02	0.15	349.85	264.09	424.47	114.47
11.23	0.15	351.55	264.52	424.96	114.96
11.44	0.15	352.70	264.52	423.49	113.49
11.60	0.15	351.86	263.24	423.49	113.49
11.79	0.16	355.81	265.38	423.00	113.00
11.96	0.16	355.60	264.52	422.02	112.02
12.18	0.16	356.87	264.52	421.12	111.12
12.40	0.17	358.69	264.95	421.12	111.12
12.62	0.17	361.13	265.80	420.37	110.37
12.85	0.17	360.71	264.52	419.88	109.88
13.06	0.17	360.16	263.24	419.63	109.63
13.24	0.18	364.73	265.80	419.13	109.13
13.26	0.18	364.89	265.80	419.13	109.13
13.45	0.18	365.41	265.38	417.89	107.89
13.67	0.18	366.69	265.38	417.64	107.64
13.88	0.19	367.39	264.95	416.40	106.40
14.09	0.19	369.24	265.38	416.65	106.65
14.30	0.19	371.13	265.80	416.15	106.15
14.51	0.19	371.19	264.95	416.89	106.89
14.70	0.20	371.77	264.52	416.15	106.15
14.89	0.20	374.73	265.80	416.89	106.89
15.07	0.20	375.28	265.38	416.65	106.65
15.27	0.20	373.51	263.24	416.89	106.89
15.46	0.21	377.76	265.38	415.90	105.90
15.66	0.21	379.02	265.38	416.40	106.40
15.87	0.21	379.76	264.95	414.91	104.91
16.07	0.21	380.45	264.52	414.16	104.16
16.28	0.22	383.40	265.65	414.91	104.91
16.48	0.22	381.20	263.24	415.15	105.15

16.68	0.22	384.10	264.33	415.15	105.15
16.87	0.22	385.00	264.09	414.66	104.66
17.09	0.23	386.47	264.09	414.91	104.91
17.29	0.23	384.90	262.08	413.66	103.66
17.50	0.23	387.90	263.17	414.16	104.16
17.70	0.24	386.40	261.24	414.16	104.16
17.91	0.24	389.40	262.33	414.41	104.41
18.11	0.24	392.40	263.40	415.15	105.15
18.31	0.24	393.20	263.02	413.91	103.91
18.51	0.25	392.40	261.54	413.42	103.42
18.72	0.25	390.20	259.12	414.16	104.16
18.93	0.25	393.20	260.14	414.41	104.41
19.13	0.26	394.00	259.74	414.91	104.91
19.33	0.26	396.20	260.24	415.15	105.15
19.54	0.26	390.20	255.35	414.66	104.66
19.74	0.26	389.40	253.92	413.91	103.91
19.93	0.27	394.00	256.02	415.40	105.40
20.13	0.27	390.20	252.62	414.66	104.66

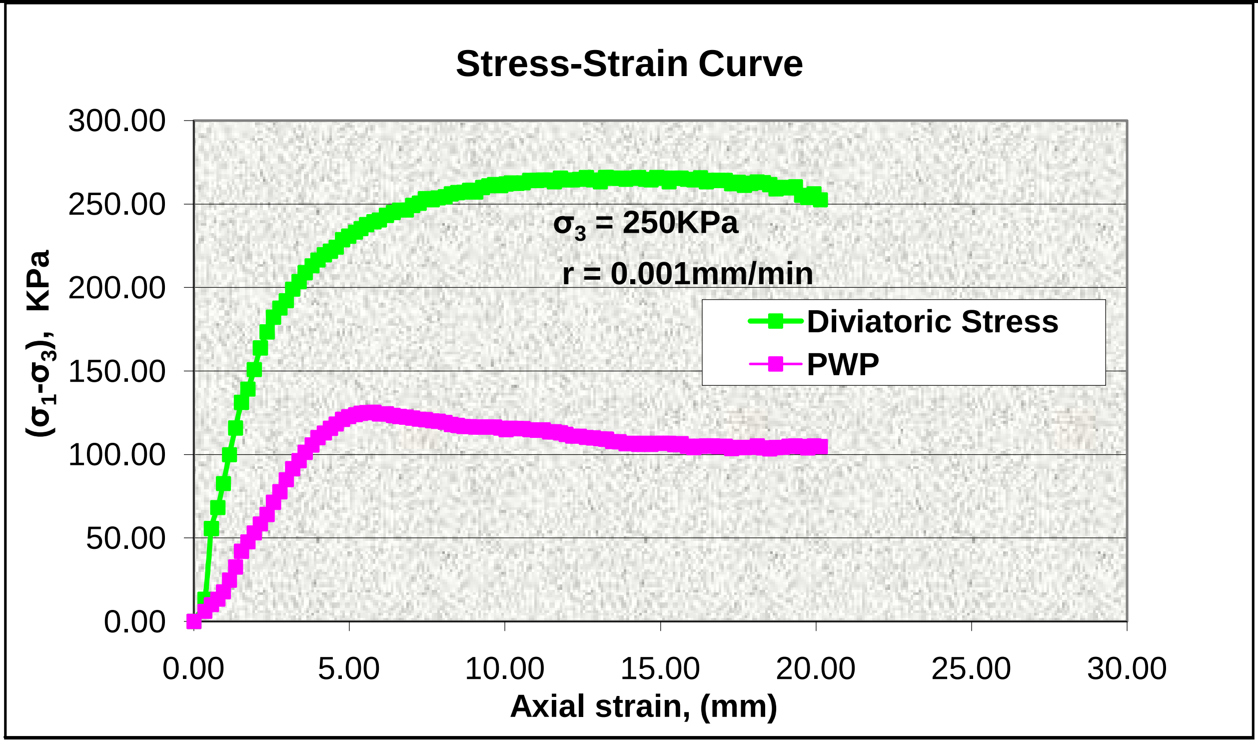


Fig. B4 Stress-Strain Curves for Effective Consolidation Pressure 250KPa and strain rate 0.001mm/min

Table B3 Compression stage Result for 350KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 350KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	23.027	0.00
0.18	0.002	53.80	47.59	40.61	17.59
0.39	0.005	76.10	67.13	58.87	35.84
0.60	0.008	97.00	85.33	80.37	57.34
0.80	0.011	113.30	99.40	94.57	71.54
1.01	0.013	131.20	114.78	107.96	84.93
1.21	0.016	146.70	127.98	119.72	96.70
1.42	0.019	160.70	139.80	132.71	109.68
1.61	0.022	175.50	152.28	145.63	122.60
1.82	0.024	190.55	164.88	155.53	132.50
2.03	0.027	209.90	181.10	169.43	146.41
2.23	0.030	229.65	197.59	180.17	157.14
2.44	0.033	244.20	209.51	186.53	163.50
2.65	0.035	262.65	224.68	192.71	169.68
2.86	0.038	277.50	236.71	197.66	174.63
3.07	0.041	292.85	249.06	201.06	178.03
3.27	0.044	304.50	258.23	204.46	181.43
3.48	0.046	315.25	266.59	207.86	184.83
3.68	0.049	322.30	271.76	210.64	187.62
3.88	0.052	329.25	276.87	213.43	190.40
4.08	0.054	334.80	280.73	215.28	192.26
4.29	0.057	340.15	284.38	216.21	193.18
4.49	0.060	344.40	287.11	216.83	193.80
4.69	0.063	348.85	289.99	216.92	193.90
4.89	0.065	352.00	291.77	217.14	194.11
5.09	0.068	355.55	293.89	216.83	193.80
5.30	0.071	361.30	297.74	216.83	193.80
5.51	0.073	363.55	298.71	215.59	192.57
5.71	0.076	366.30	300.11	214.66	191.64
5.90	0.079	371.35	303.38	214.05	191.02
6.11	0.081	373.40	304.13	213.43	190.40
6.32	0.084	376.00	305.34	213.12	190.09
6.52	0.087	375.70	304.19	212.19	189.16
6.72	0.090	378.00	305.16	212.50	189.47
6.92	0.092	377.30	303.70	211.57	188.55
7.13	0.095	381.80	306.39	210.95	187.93
7.33	0.098	384.80	307.88	209.72	186.69
7.53	0.100	390.10	311.18	209.41	186.38

7.74	0.103	393.20	312.70	209.10	186.07
7.94	0.106	393.90	312.32	209.10	186.07
8.14	0.109	402.20	317.92	207.86	184.83
8.35	0.111	400.00	315.22	207.55	184.53
8.55	0.114	401.50	315.44	206.01	182.98
8.75	0.117	406.80	318.65	206.32	183.29
8.95	0.119	408.30	318.83	205.39	182.36
9.15	0.122	409.80	319.04	204.46	181.43
9.35	0.125	412.80	320.42	205.08	182.05
9.55	0.127	416.60	322.40	203.84	180.82
9.74	0.130	417.40	322.04	203.22	180.20
9.94	0.133	418.10	321.61	202.91	179.89
10.15	0.135	421.10	322.90	203.22	180.20
10.34	0.138	422.70	323.14	202.91	179.89
10.55	0.141	426.40	324.93	200.75	177.72
10.76	0.143	428.00	325.08	201.06	178.03
10.95	0.146	438.50	332.05	199.82	176.80
11.18	0.149	434.80	328.11	198.89	175.87
11.38	0.152	433.20	325.84	198.89	175.87
11.59	0.154	439.30	329.37	197.97	174.94
11.79	0.157	441.60	330.06	197.66	174.63
11.99	0.160	440.35	328.04	198.59	175.56
12.20	0.163	444.02	329.68	196.73	173.70
12.40	0.165	443.69	328.37	197.66	174.63
12.61	0.168	449.58	331.65	197.35	174.32
12.81	0.171	449.29	330.34	194.75	171.72
13.03	0.174	453.05	331.98	195.80	172.78
13.23	0.176	453.20	330.99	193.95	170.93
13.43	0.179	456.47	332.30	192.63	169.60
13.63	0.182	456.60	331.32	191.04	168.01
13.82	0.184	458.97	331.98	191.57	168.54
14.03	0.187	461.41	332.63	190.77	167.74
14.23	0.190	460.63	330.99	189.71	166.68
14.42	0.192	463.49	331.98	188.91	165.89
14.62	0.195	465.97	332.63	188.65	165.62
14.82	0.198	465.16	330.99	187.59	164.56
15.02	0.200	469.48	332.96	186.79	163.76
15.22	0.203	471.51	333.29	186.26	163.23
15.42	0.206	472.19	332.63	184.93	161.91
15.61	0.208	473.74	332.63	184.67	161.64
15.83	0.211	476.38	333.29	184.93	161.91
16.04	0.214	477.64	332.96	184.67	161.64
16.24	0.217	480.24	333.62	184.14	161.11
16.45	0.219	482.37	333.94	184.34	161.32
16.66	0.222	483.14	333.29	184.14	161.11
16.87	0.225	484.90	333.29	183.34	160.32

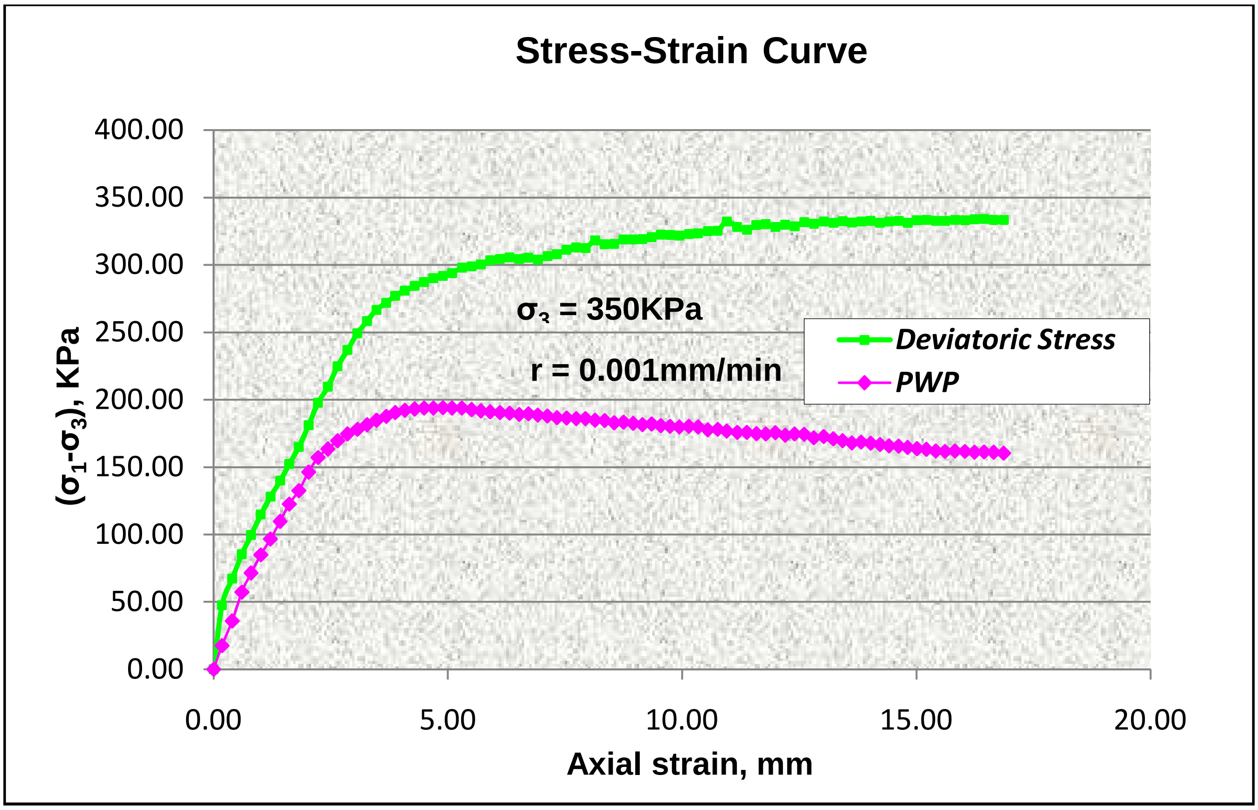


Fig. B5 Stress-Strain Curves for Effective Consolidation Pressure 450 KPa and starin rate 0.001mm/min

Table B 4 Compression stage Result for 450 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 450KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.000	0.00	0.00	0.00	82.47	0.00
0.188	0.00	5.08	4.50	83.13	0.66
0.372	0.00	41.18	36.37	109.99	27.52
0.560	0.01	66.63	58.69	129.48	47.01
0.713	0.01	98.67	86.74	154.71	72.24
0.906	0.01	128.20	112.41	175.48	93.01
1.112	0.01	173.50	151.71	214.06	131.59
1.311	0.02	202.90	176.94	232.91	150.44
1.510	0.02	217.30	188.98	244.11	161.64
1.704	0.02	235.10	203.92	258.56	176.09
1.886	0.03	244.20	211.29	267.23	184.76
2.086	0.03	256.30	221.15	278.99	196.52
2.289	0.03	269.90	232.24	288.42	205.95
2.493	0.03	282.29	242.22	298.41	215.94
2.704	0.04	292.30	250.08	304.53	222.06
2.914	0.04	302.10	257.71	310.87	228.40
3.121	0.04	312.00	265.39	315.47	233.00
3.322	0.04	322.70	273.73	319.51	237.04
3.523	0.05	329.50	278.71	324.98	242.51
3.724	0.05	339.52	286.38	327.86	245.39
3.929	0.05	348.54	293.14	331.60	249.13
4.135	0.06	359.99	301.89	333.62	251.15
4.339	0.06	369.59	309.05	335.06	252.59
4.555	0.06	379.79	316.61	336.50	254.03
4.755	0.06	384.70	319.79	338.52	256.05
4.956	0.07	391.56	324.56	339.62	257.15
5.159	0.07	399.92	330.53	339.91	257.44
5.356	0.07	407.32	335.70	341.11	258.64
5.552	0.07	412.34	338.88	341.97	259.50
5.761	0.08	418.44	342.86	341.68	259.21
5.951	0.08	422.03	344.85	341.97	259.50
6.156	0.08	427.19	348.03	340.82	258.35
6.357	0.08	426.48	346.44	340.53	258.06
6.550	0.09	433.09	350.82	339.05	256.58
6.750	0.09	433.86	350.42	338.76	256.29
6.943	0.09	439.54	354.00	338.19	255.72
7.148	0.10	444.83	357.18	337.33	254.86

7.364	0.10	450.72	360.76	335.35	252.88
7.564	0.10	449.07	358.38	334.19	251.72
7.774	0.10	455.47	362.35	332.47	250.00
7.990	0.11	459.95	364.74	330.45	247.98
8.195	0.11	460.36	363.94	329.01	246.54
8.396	0.11	466.29	367.52	326.42	243.95
8.606	0.11	471.81	370.71	324.69	242.22
8.805	0.12	472.22	369.91	322.67	240.20
9.010	0.12	477.25	372.70	319.51	237.04
9.217	0.12	475.68	370.31	318.35	235.88
9.426	0.13	484.38	375.88	316.63	234.16
9.635	0.13	487.47	377.07	314.90	232.43
9.833	0.13	492.04	379.46	314.32	231.85
10.028	0.13	493.52	379.46	313.46	230.99
10.231	0.14	497.66	381.45	312.31	229.84
10.410	0.14	501.58	383.39	309.71	227.24
10.610	0.14	504.83	384.67	307.70	225.23
10.807	0.14	508.63	386.39	306.26	223.79
11.019	0.15	512.58	388.10	304.53	222.06
11.223	0.15	515.35	388.95	302.80	220.33
11.426	0.15	518.71	390.24	301.65	219.18
11.625	0.16	519.62	389.70	299.63	217.16
11.830	0.16	524.17	391.84	298.48	216.01
12.022	0.16	527.49	393.12	297.04	214.57
12.228	0.16	530.37	393.98	296.18	213.71
12.439	0.17	532.73	394.40	294.45	211.98
12.650	0.17	535.77	395.32	293.59	211.12
12.862	0.17	536.93	394.83	293.30	210.83
13.070	0.17	539.10	395.09	291.86	209.39
13.276	0.18	541.11	395.25	290.71	208.24
13.478	0.18	542.30	394.82	289.84	207.37
13.682	0.18	544.69	395.25	288.98	206.51
13.891	0.19	546.60	395.28	288.11	205.64
14.103	0.19	548.45	395.24	287.25	204.78
14.311	0.19	549.73	394.81	286.10	203.63
14.521	0.19	551.63	394.81	284.95	202.48
14.721	0.20	554.06	395.23	284.08	201.61
14.925	0.20	554.73	394.37	284.08	201.61
15.120	0.20	558.04	395.44	283.79	201.32
15.306	0.20	559.48	395.23	282.93	200.46
15.490	0.21	561.21	395.22	282.64	200.17
15.682	0.21	562.41	394.79	282.06	199.59
15.762	0.21	562.56	394.37	282.06	199.59
15.764	0.21	562.58	394.36	282.06	199.59

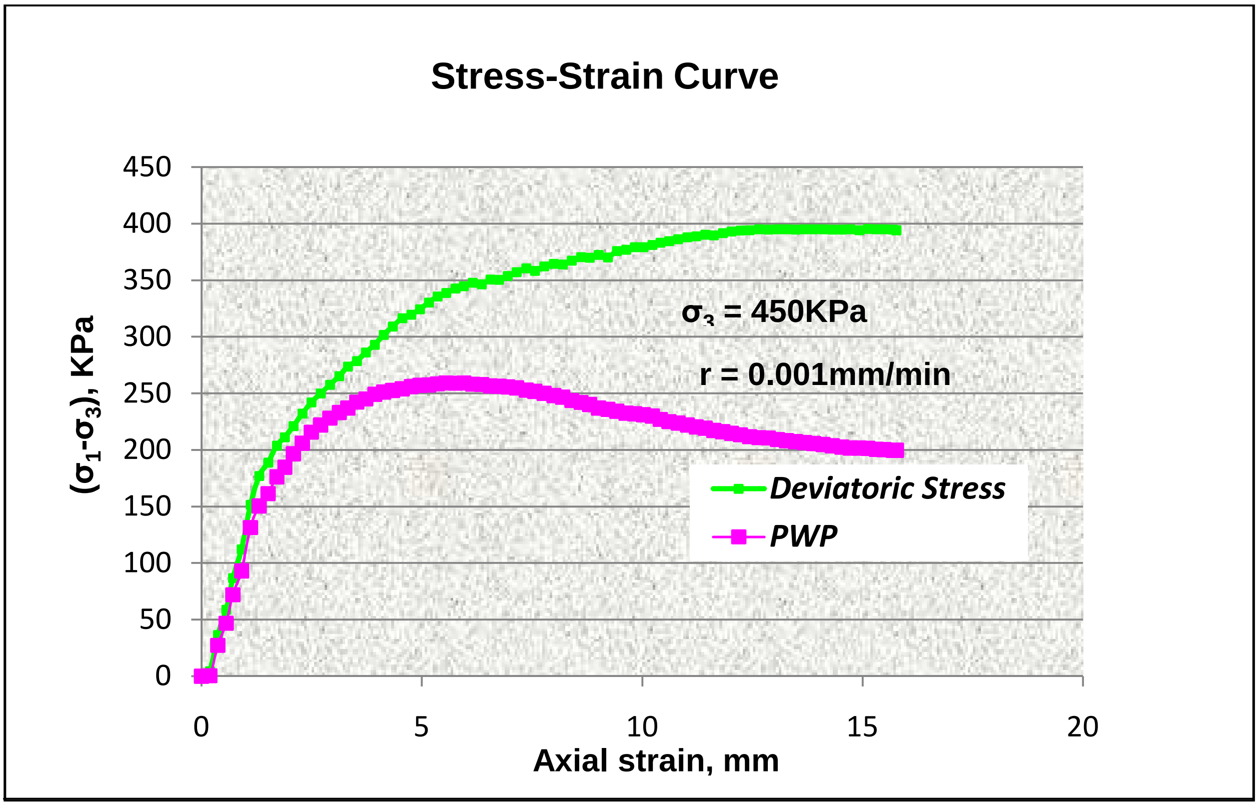


Fig. B6 Stress-Strain Curves for Effective Consolidation Pressure 450KPa and strain rate 0.001mm/min

1.2. Triaxial Compression Test Result for Strain Rate 0.01mm/Min

Table B5 Consolidation Stage Result for Effective consolidation pressure of 250KPa, 350KPa, and 450KPa

Table B5 Consolidation Stage Result for Effective consolidation pressure of 250KPa, 350KPa, and 450KPa			
Location:	***Addisu Gebeya***	Job ref.	***Thesis research***
Soil Description:	Red brown clay	Pit no.	***#1***
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8		Sample no.	***#1A***
		Depth	***2.5m***
Remolded Sample			

Effective Consolidation Pressure 150 KPa			**Effective Consolidation Pressure 250 KPa**			**Effective Consolidation Pressure 350 KPa**		
Initial Condition	CP, KPa	***550***	**Initial Condition**	CP, KPa	***650***	**Initial Condition**	CP, KPa	***750***
	BP, KPa	**300**		BP, KPa	***300***		BP, KPa	**335**
	PP, KPa	***530.69***		PP, KPa	***626.17***		PP, KPa	***658***
Final Condition	PP, KPa	**307.83**	**Final Condition**	PP, KPa	**307.43**	**Final Condition**	PP, KPa	**348**
	ΔVolume ,ml	***4.39***		ΔVolume, ml	***5.34***		ΔVolume, ml	***6.16***
	% Cosolidation	**97.7**		% Cosolidation	**96.7**		% Cosolidation	**96.1**
Sqrt. Time	**ΔVolume,ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume ,ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume ,ml**	**PP, KPa**
0.00	4.39	530.69	0.29	5.51	626.17	0.36	6.52	727.14
0.44	3.61	310.05	0.36	4.82	626.36	0.44	5.83	310.82
0.54	3.59	309.57	0.44	4.59	308.41	0.54	5.83	310.05
0.66	3.54	309.37	0.54	4.54	308.02	0.66	5.66	309.57
0.81	3.49	309.18	0.66	4.49	307.45	0.81	5.57	309.18
1.00	3.43	309.08	0.81	4.42	307.25	1.00	5.44	308.99
1.22	3.37	309.08	1.00	4.33	307.16	1.22	5.32	308.79
1.49	3.30	308.99	1.22	4.27	307.06	1.49	5.27	308.60
1.83	3.26	308.79	1.49	4.19	306.96	1.83	5.10	309.28
2.24	3.16	308.70	1.83	4.10	306.77	2.24	4.97	308.22
2.74	3.10	308.51	2.24	3.96	306.77	2.74	4.93	308.22
3.36	2.96	308.51	2.74	3.81	306.58	3.36	4.72	308.12
4.11	2.75	308.60	3.36	3.63	306.67	4.11	4.46	308.02
5.04	2.60	308.51	4.11	3.45	306.58	5.04	4.11	308.22
6.17	2.34	308.51	5.04	3.19	306.67	6.17	3.81	308.31
7.56	2.02	308.79	6.17	2.95	306.77	7.56	3.38	308.70
9.26	1.64	308.60	7.56	2.60	306.77	9.26	3.00	308.89
11.34	1.28	308.60	9.26	2.13	307.06	11.34	2.44	309.28
13.89	0.93	308.79	11.34	1.62	307.06	13.89	1.88	309.57
17.01	0.63	308.79	13.89	1.11	307.16	17.01	1.41	310.05
20.83	0.27	308.51	17.01	0.57	306 95	20.83	0.91	310.34
25.51	0.07	308.41	20.83	0.26	307.12	25.51	0.48	310.05
31.25	0.00	307.83	25.51	0.17	307.43	31.25	0.36	309.47

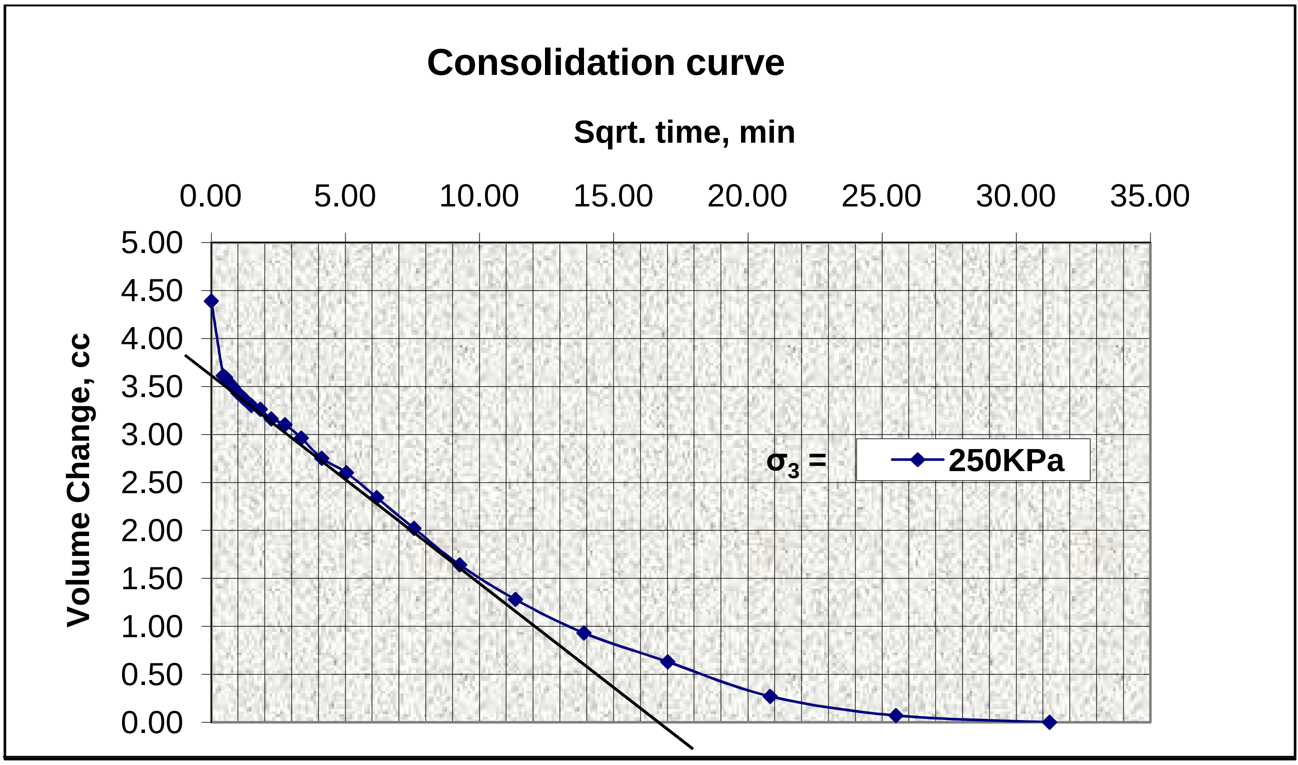


Fig. B7 Consolidation Curve for Effective Consolidation Pressure of 250KPa.

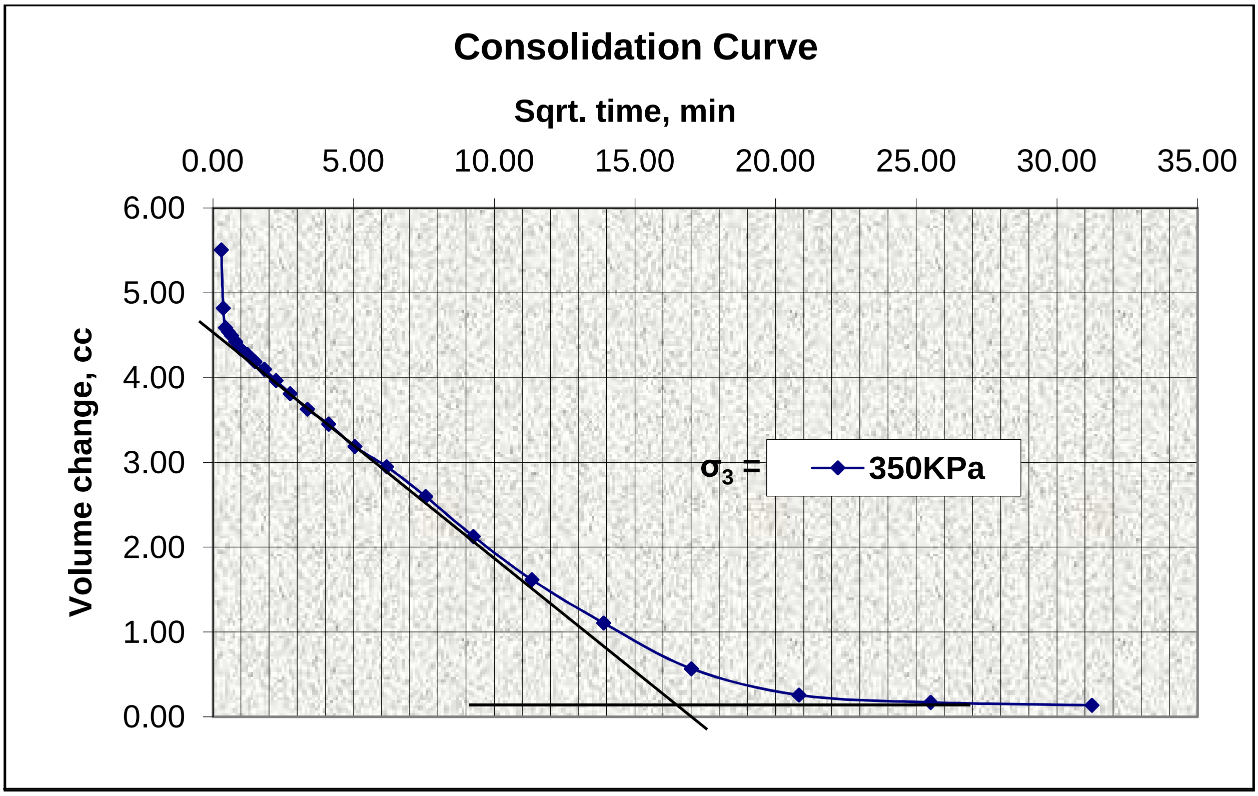


Fig. B8 Consolidation Curve for Effective Consolidation Pressure of 350KPa.

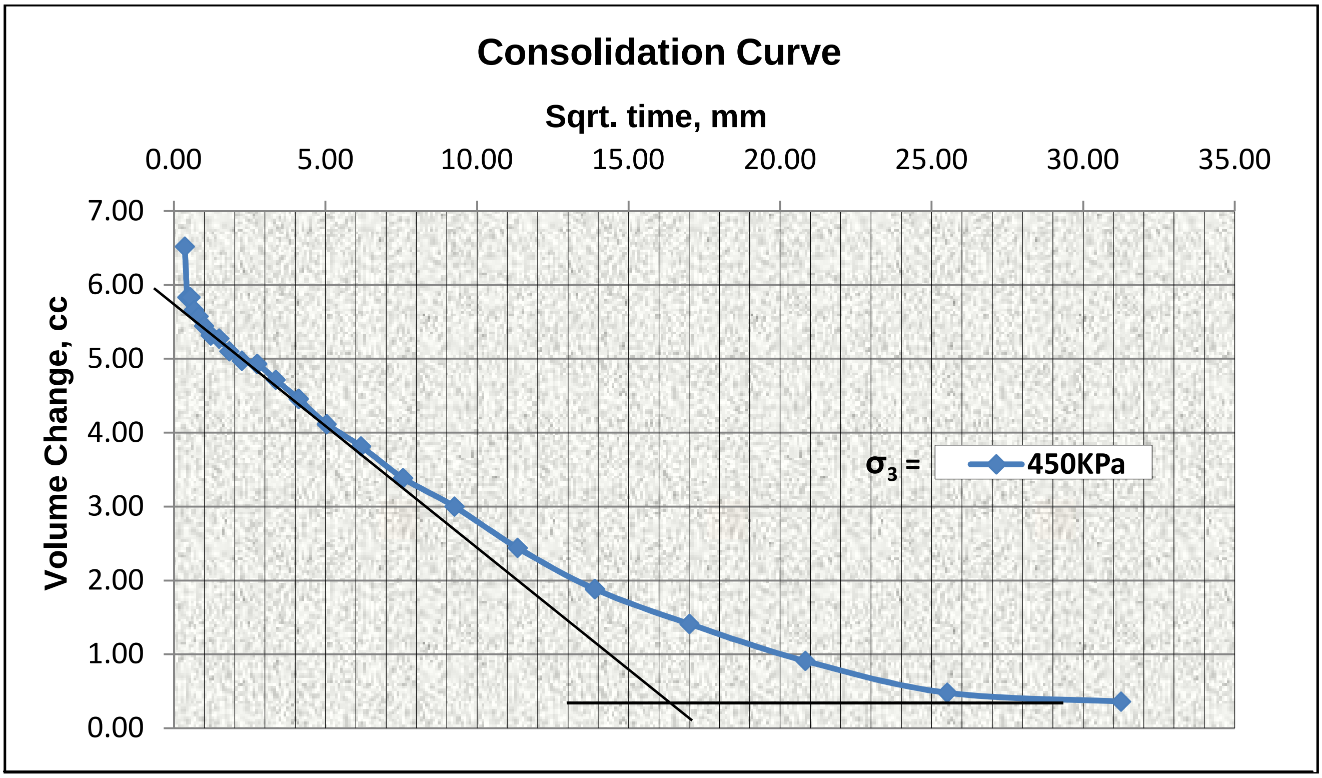


Fig. B9 Consolidation Curve for Effective Consolidation Pressure of 450KPa.

Table B6 Compression Stage Result for 250 KPa Effective Consolidation Pressure

<table>
<tr><td colspan="4">Location: <i>Addisu Gebeya</i></td><td>Job ref.</td><td>Thesis research</td></tr>
<tr><td colspan="4">Soil Description: <i>Red brown clay</i></td><td>Pit No.</td><td>1</td></tr>
<tr><td colspan="4" rowspan="2">Test method: <i>CU with measurement of pore water pressure, BS 1377: Clause 8</i></td><td>Sample No.</td><td>1</td></tr>
<tr><td>Depth</td><td>2.5m</td></tr>
<tr><td colspan="4">CP = 250KPa</td><td></td><td></td></tr>
<tr><th>Displ.(mm)</th><th>Strain(%)</th><th>Load (N)</th><th>Δσ(KPa)</th><th>PP (KPa)</th><th>ΔPP(KPa)</th></tr>
<tr><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>314.00</td><td>0.00</td></tr>
<tr><td>0.20</td><td>0.00</td><td>0.60</td><td>0.53</td><td>318.22</td><td>4.22</td></tr>
<tr><td>0.31</td><td>0.00</td><td>8.90</td><td>7.84</td><td>319.03</td><td>5.03</td></tr>
<tr><td>0.39</td><td>0.01</td><td>45.80</td><td>40.32</td><td>321.10</td><td>7.10</td></tr>
<tr><td>0.47</td><td>0.01</td><td>72.70</td><td>63.93</td><td>322.53</td><td>8.53</td></tr>
<tr><td>0.55</td><td>0.01</td><td>86.30</td><td>75.82</td><td>324.65</td><td>10.65</td></tr>
<tr><td>0.63</td><td>0.01</td><td>97.90</td><td>85.91</td><td>325.40</td><td>11.40</td></tr>
<tr><td>0.74</td><td>0.01</td><td>108.20</td><td>94.81</td><td>326.83</td><td>12.83</td></tr>
<tr><td>0.84</td><td>0.01</td><td>117.50</td><td>102.82</td><td>328.55</td><td>14.55</td></tr>
<tr><td>0.94</td><td>0.01</td><td>127.00</td><td>110.98</td><td>330.84</td><td>16.84</td></tr>
<tr><td>1.04</td><td>0.01</td><td>133.30</td><td>116.32</td><td>333.70</td><td>19.70</td></tr>
<tr><td>1.14</td><td>0.02</td><td>142.60</td><td>124.28</td><td>336.57</td><td>22.57</td></tr>
<tr><td>1.24</td><td>0.02</td><td>149.40</td><td>130.03</td><td>338.29</td><td>24.29</td></tr>
<tr><td>1.34</td><td>0.02</td><td>154.40</td><td>134.19</td><td>340.86</td><td>26.86</td></tr>
<tr><td>1.44</td><td>0.02</td><td>162.40</td><td>140.95</td><td>345.73</td><td>31.73</td></tr>
<tr><td>1.56</td><td>0.02</td><td>171.20</td><td>148.36</td><td>349.17</td><td>35.17</td></tr>
<tr><td>1.66</td><td>0.02</td><td>178.70</td><td>154.63</td><td>352.03</td><td>38.03</td></tr>
<tr><td>1.77</td><td>0.02</td><td>188.70</td><td>163.05</td><td>355.18</td><td>41.18</td></tr>
<tr><td>1.88</td><td>0.03</td><td>194.00</td><td>167.38</td><td>357.47</td><td>43.47</td></tr>
<tr><td>1.99</td><td>0.03</td><td>198.50</td><td>171.00</td><td>361.20</td><td>47.20</td></tr>
<tr><td>2.09</td><td>0.03</td><td>205.30</td><td>176.62</td><td>364.63</td><td>50.63</td></tr>
<tr><td>2.20</td><td>0.03</td><td>210.80</td><td>181.07</td><td>367.21</td><td>53.21</td></tr>
<tr><td>2.31</td><td>0.03</td><td>214.40</td><td>183.88</td><td>371.51</td><td>57.51</td></tr>
<tr><td>2.41</td><td>0.03</td><td>220.60</td><td>188.94</td><td>374.66</td><td>60.66</td></tr>
<tr><td>2.51</td><td>0.03</td><td>224.90</td><td>192.35</td><td>379.24</td><td>65.24</td></tr>
<tr><td>2.62</td><td>0.03</td><td>230.20</td><td>196.61</td><td>383.25</td><td>69.25</td></tr>
<tr><td>2.71</td><td>0.04</td><td>235.40</td><td>200.78</td><td>386.11</td><td>72.11</td></tr>
<tr><td>2.81</td><td>0.04</td><td>239.20</td><td>203.74</td><td>388.97</td><td>74.97</td></tr>
<tr><td>2.90</td><td>0.04</td><td>242.50</td><td>206.30</td><td>392.70</td><td>78.70</td></tr>
<tr><td>2.98</td><td>0.04</td><td>242.50</td><td>206.08</td><td>394.99</td><td>80.99</td></tr>
<tr><td>3.09</td><td>0.04</td><td>247.80</td><td>210.25</td><td>397.85</td><td>83.85</td></tr>
<tr><td>3.21</td><td>0.04</td><td>249.30</td><td>211.17</td><td>399.86</td><td>85.86</td></tr>
<tr><td>3.34</td><td>0.04</td><td>253.10</td><td>214.02</td><td>402.15</td><td>88.15</td></tr>
<tr><td>3.45</td><td>0.05</td><td>255.30</td><td>215.54</td><td>404.73</td><td>90.73</td></tr>
<tr><td>3.55</td><td>0.05</td><td>259.10</td><td>218.43</td><td>405.87</td><td>91.87</td></tr>
<tr><td>3.65</td><td>0.05</td><td>261.40</td><td>220.06</td><td>407.88</td><td>93.88</td></tr>
</table>

3.74	0.05	264.40	222.32	409.31	95.31
3.83	0.05	266.70	223.98	411.03	97.03
3.90	0.05	268.20	225.02	412.46	98.46
3.99	0.05	269.70	225.98	413.60	99.60
4.08	0.05	272.70	228.18	414.46	100.46
4.18	0.06	275.00	229.80	415.61	101.61
4.27	0.06	275.00	229.51	417.04	103.04
4.36	0.06	278.80	232.38	418.76	104.76
4.47	0.06	281.00	233.86	418.76	104.76
4.56	0.06	284.10	236.13	420.76	106.76
4.66	0.06	285.60	237.05	420.76	106.76
4.76	0.06	287.80	238.53	421.62	107.62
4.87	0.06	290.90	240.73	422.48	108.48
4.97	0.07	292.40	241.60	423.05	109.05
5.08	0.07	295.40	243.72	424.20	110.20
5.18	0.07	295.40	243.35	423.91	109.91
5.29	0.07	298.40	245.45	423.91	109.91
5.39	0.07	299.90	246.34	424.20	110.20
5.48	0.07	301.50	247.32	424.44	110.44
5.58	0.07	303.70	248.75	424.77	110.77
5.69	0.08	305.20	249.60	425.06	111.06
5.79	0.08	308.30	251.77	424.77	110.77
5.89	0.08	312.00	254.44	425.06	111.06
6.00	0.08	309.80	252.24	425.06	111.06
6.08	0.08	314.30	255.60	425.01	111.01
6.19	0.08	318.90	258.94	425.06	111.06
6.29	0.08	318.90	258.53	425.06	111.06
6.40	0.09	321.90	260.55	424.49	110.49
6.52	0.09	321.90	260.12	424.77	110.77
6.63	0.09	321.10	259.06	424.49	110.49
6.73	0.09	324.10	261.10	423.91	109.91
6.84	0.09	325.70	261.95	423.05	109.05
6.95	0.09	326.40	262.08	423.05	109.05
7.06	0.09	327.90	262.87	422.20	108.20
7.17	0.10	329.40	263.62	422.20	108.20
7.28	0.10	331.00	264.47	421.62	107.62
7.38	0.10	330.20	263.45	421.62	107.62
7.49	0.10	331.70	264.22	421.62	107.62
7.59	0.10	331.70	263.84	420.76	106.76
7.67	0.10	334.70	265.89	421.05	107.05
7.75	0.10	336.20	266.78	420.76	106.76
7.85	0.10	334.00	264.63	420.76	106.76
7.95	0.11	338.50	267.82	419.90	105.90
8.07	0.11	340.80	269.15	421.05	107.05
8.17	0.11	341.50	269.28	420.19	106.19

8.29	0.11	343.80	270.61	419.62	105.62
8.40	0.11	347.60	273.17	420.19	106.19
8.51	0.11	346.80	272.09	420.19	106.19
8.62	0.11	346.80	271.63	420.48	106.48
8.72	0.12	346.80	271.22	419.90	105.90
8.80	0.12	348.30	272.06	419.90	105.90
8.89	0.12	352.10	274.64	419.05	105.05
8.97	0.12	351.40	273.76	419.05	105.05
9.06	0.12	351.40	273.40	419.62	105.62
9.16	0.12	352.90	274.18	419.62	105.62
9.24	0.12	352.10	273.19	419.62	105.62
9.34	0.12	355.10	275.13	419.62	105.62
9.43	0.13	355.90	275.38	418.76	104.76
9.52	0.13	358.20	276.77	419.05	105.05
9.63	0.13	361.20	278.62	418.19	104.19
9.73	0.13	362.90	279.47	418.76	104.76
9.83	0.13	367.70	282.75	418.47	104.47
9.94	0.13	367.00	281.73	418.76	104.76
10.05	0.13	368.50	282.42	418.76	104.76
10.15	0.14	369.20	282.51	419.79	105.79

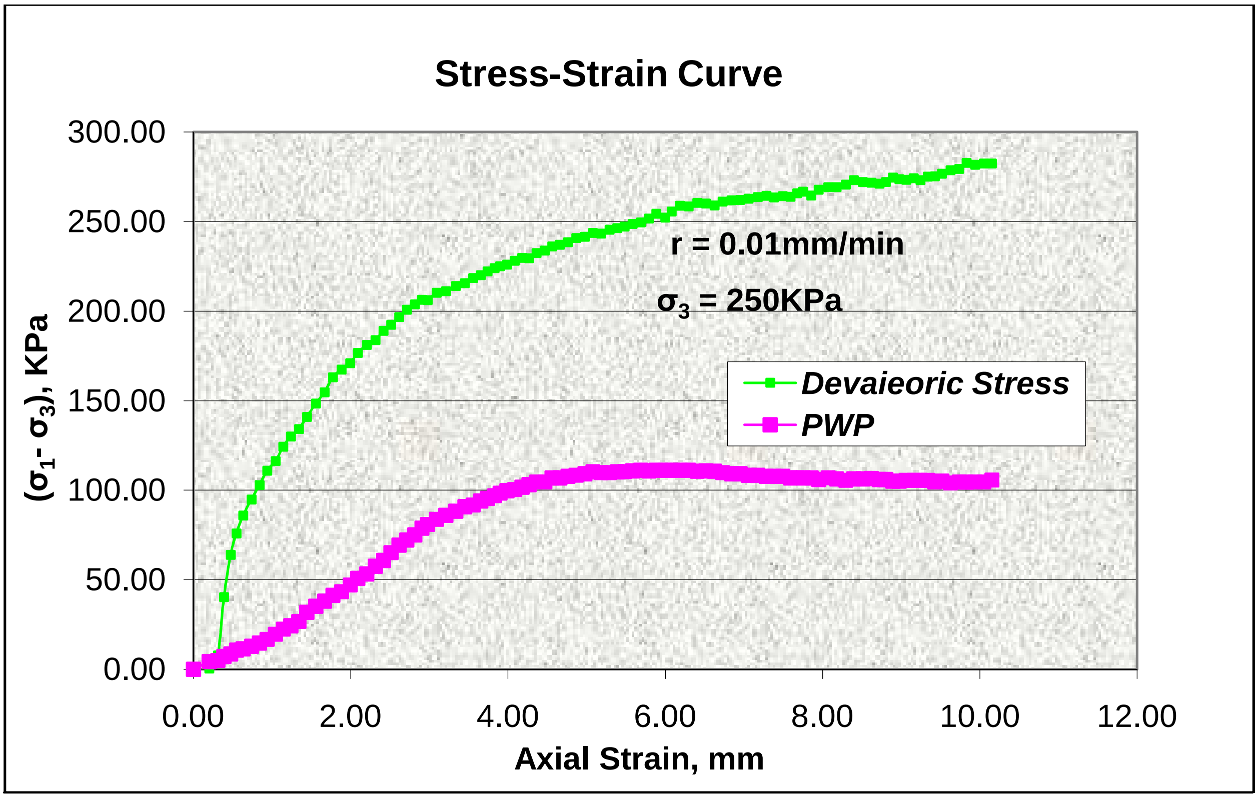


Fig. B10 Stress-Strain Curves for Effective Consolidation Pressure 250KPa and strain rate 0.01mm/min

Table B7 Compression Stage Result for 350KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 350 KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.000	0.000	0.00	0.00	308.99	0.00
0.102	0.001	15.90	14.08	310.34	1.35
0.319	0.004	36.90	32.58	328.52	19.53
0.513	0.007	102.69	90.44	338.75	29.76
0.726	0.010	133.63	117.35	349.29	40.30
0.902	0.012	154.47	135.33	361.46	52.47
1.117	0.015	174.20	152.18	371.60	62.61
1.329	0.018	191.94	167.19	381.75	72.76
1.553	0.021	206.47	179.30	392.70	83.71
1.734	0.023	217.41	188.34	400.01	91.02
1.927	0.026	232.75	201.09	410.96	101.97
2.138	0.029	245.88	211.82	420.29	111.30
2.331	0.031	261.39	224.59	431.65	122.66
2.512	0.033	272.20	233.29	438.96	129.97
2.736	0.036	287.50	245.64	449.91	140.92
2.926	0.039	297.99	253.94	456.81	147.82
3.129	0.042	310.03	263.46	464.92	155.93
3.333	0.044	321.19	272.16	472.23	163.24
3.552	0.047	331.51	280.05	478.72	169.73
3.749	0.050	339.39	285.91	483.18	174.19
3.936	0.052	344.85	289.75	485.62	176.63
4.156	0.055	352.43	295.21	489.67	180.68
4.348	0.058	357.98	299.04	492.11	183.12
4.532	0.060	362.40	301.94	494.14	185.15
4.766	0.064	367.92	305.52	495.76	186.77
4.956	0.066	372.15	308.20	496.57	187.58
5.180	0.069	373.97	308.72	496.56	187.57
5.387	0.072	377.60	310.79	497.79	188.80
5.575	0.074	377.83	310.15	496.56	187.57
5.793	0.077	379.56	310.58	496.56	187.57
5.984	0.080	379.49	309.67	495.75	186.76
6.099	0.081	376.85	307.00	495.75	186.76
6.221	0.083	382.41	310.97	494.13	185.14
6.423	0.086	384.63	311.87	494.94	185.95
6.649	0.089	389.05	314.41	492.50	183.51
6.834	0.091	389.68	314.07	492.50	183.51

7.061	0.094	391.90	314.81	492.50	183.51
7.259	0.097	397.93	318.72	491.29	182.30
7.473	0.100	398.55	318.20	491.29	182.30
7.656	0.102	397.78	316.73	491.69	182.70
7.853	0.105	407.51	323.53	490.07	181.08
8.087	0.108	406.62	321.70	489.66	180.67
8.264	0.110	410.35	323.79	489.26	180.27
8.478	0.113	411.77	323.87	488.45	179.46
8.684	0.116	416.99	326.96	488.04	179.05
8.889	0.119	419.21	327.68	487.64	178.65
9.111	0.121	422.93	329.48	487.23	178.24
9.331	0.124	425.04	330.02	485.61	176.62
9.542	0.127	429.56	332.45	485.20	176.21
9.739	0.130	430.98	332.55	484.39	175.40
9.930	0.132	435.40	334.98	483.58	174.59
10.137	0.135	436.82	335.00	483.58	174.59
10.327	0.138	441.34	337.48	483.58	174.59
10.533	0.140	440.95	336.11	481.96	172.97
10.747	0.143	444.03	337.33	481.96	172.97
10.965	0.146	446.75	338.24	481.55	172.56
11.152	0.149	446.04	336.72	481.55	172.56
11.341	0.151	451.42	339.77	481.15	172.16
11.537	0.154	452.00	339.16	481.15	172.16
11.771	0.157	455.72	340.69	478.71	169.72
11.968	0.160	453.86	338.24	479.93	170.94
12.157	0.162	458.10	340.38	478.71	169.72
12.385	0.165	460.09	340.61	478.71	169.72
12.570	0.168	459.31	339.03	479.12	170.13
12.772	0.170	461.52	339.56	479.12	170.13
12.990	0.173	461.42	338.30	477.09	168.10
13.054	0.174	463.59	339.54	478.31	169.32
13.218	0.176	463.52	338.59	477.90	168.91
13.438	0.179	464.22	337.90	476.68	167.69
13.624	0.182	464.14	336.82	477.49	168.50
13.819	0.184	467.05	337.85	477.09	168.10
14.029	0.187	467.76	337.20	475.87	166.88
14.223	0.190	467.67	336.07	475.47	166.48
14.435	0.192	473.57	339.12	475.87	166.88
14.644	0.195	474.97	338.95	475.87	166.88
14.831	0.198	476.39	338.91	473.84	164.85
15.062	0.201	479.38	339.72	473.44	164.45
15.253	0.203	480.54	339.47	473.03	164.04
15.481	0.206	483.69	340.38	472.63	163.64
15.669	0.209	484.78	340.08	473.97	164.98
15.857	0.211	485.45	339.47	473.34	164.35

16.048	0.214	488.34	340.38	471.00	162.01
16.268	0.217	491.93	341.60	472.03	163.04
16.477	0.220	492.36	340.69	470.97	161.98
16.686	0.222	494.13	340.69	470.54	161.55
16.911	0.225	497.38	341.61	469.73	160.74
17.115	0.228	497.28	340.34	468.92	159.93
17.334	0.231	498.67	340.00	468.27	159.28
17.521	0.234	500.07	339.85	467.65	158.66
17.747	0.237	502.26	339.99	466.90	157.91
17.923	0.239	504.36	340.37	466.15	157.16
18.124	0.242	502.06	337.62	465.40	156.41
18.325	0.244	503.45	337.36	464.47	155.48
18.521	0.247	504.85	337.13	464.03	155.04
18.543	0.247	502.54	335.45	463.72	154.73
18.755	0.250	500.93	333.12	463.40	154.41
18.933	0.252	504.63	334.52	462.78	153.79
19.130	0.255	509.02	336.25	462.22	153.23
19.337	0.258	512.71	337.43	461.78	152.79

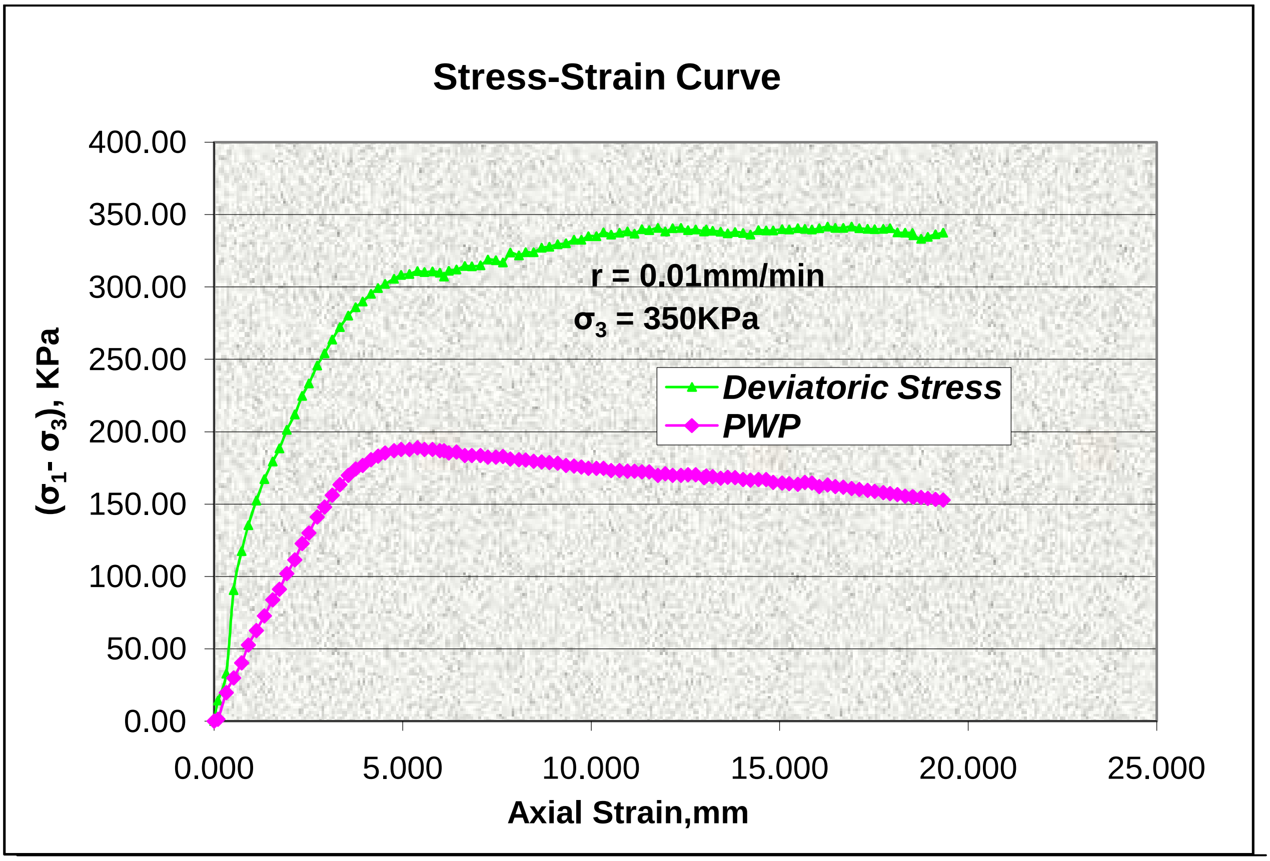


Fig. B11 Stress-Strain Curves for Effective Consolidation Pressure 350KPa and strain rate 0.01mm/min

Table B8 Compression Stage Result for 450 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.50
CP = 450KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.000	0.000	0.00	0.00	316.7	0.00
0.103	0.001	27.83	24.67	329.95	13.25
0.303	0.004	74.46	65.82	341.99	25.29
0.510	0.007	108.44	95.59	355.97	39.27
0.722	0.010	144.62	127.12	376.64	59.94
0.929	0.012	171.59	150.41	398.75	82.05
1.130	0.015	198.80	173.79	413.27	96.57
1.325	0.018	228.91	199.58	432.60	115.90
1.528	0.020	244.86	212.90	448.29	131.59
1.730	0.023	257.96	223.67	460.38	143.68
1.934	0.026	259.82	224.66	471.75	155.05
2.037	0.027	273.60	236.24	479.23	162.53
2.238	0.030	287.16	247.27	489.87	173.17
2.449	0.033	296.24	254.34	499.07	182.37
2.768	0.037	310.07	265.04	512.13	195.43
2.965	0.040	325.36	277.36	522.77	206.07
3.164	0.042	340.65	289.59	529.55	212.85
3.354	0.045	354.43	300.51	535.44	218.74
3.541	0.047	366.73	310.12	539.86	223.16
3.737	0.050	374.29	315.65	543.99	227.29
3.940	0.053	380.34	319.84	547.53	230.83
4.149	0.055	387.14	324.60	549.30	232.60
4.356	0.058	401.44	335.60	551.36	234.66
4.556	0.061	405.97	338.43	553.13	236.43
4.740	0.063	409.00	340.06	554.90	238.20
4.943	0.066	417.32	345.98	556.37	239.67
5.150	0.069	422.61	349.33	558.43	241.73
5.358	0.071	425.63	350.78	559.02	242.32
5.563	0.074	433.43	356.15	559.32	242.62
5.783	0.077	438.20	358.94	561.38	244.68
5.999	0.080	441.52	360.53	561.38	244.68
6.112	0.081	446.15	363.71	561.68	244.98
6.320	0.084	448.97	364.90	562.56	245.86
6.523	0.087	454.23	368.09	562.56	245.86
6.706	0.089	457.42	369.68	561.68	244.98
6.905	0.092	461.72	372.06	561.09	244.39
7.114	0.095	464.62	373.26	559.61	242.91

7.321	0.098	470.02	376.44	559.32	242.62
7.538	0.101	473.02	377.63	557.55	240.85
7.740	0.103	475.94	378.83	555.19	238.49
7.940	0.106	478.86	380.02	554.90	238.20
8.114	0.108	482.62	382.01	552.83	236.13
8.309	0.111	487.56	384.80	551.95	235.25
8.696	0.116	490.92	385.19	549.59	232.89
8.904	0.119	492.46	385.19	547.93	231.23
9.009	0.120	495.28	386.78	546.48	229.78
9.216	0.123	499.39	388.77	546.24	229.54
9.426	0.126	500.99	388.77	544.29	227.59
9.619	0.128	504.53	390.37	542.52	225.82
9.814	0.131	508.10	391.96	541.16	224.46
10.025	0.134	510.27	392.35	540.67	223.97
10.233	0.136	516.06	395.54	538.98	222.28
10.443	0.139	516.18	394.34	537.29	220.59
10.656	0.142	521.02	396.73	537.04	220.34
10.868	0.145	525.36	398.72	536.80	220.10
11.084	0.148	528.19	399.52	533.82	217.12
11.294	0.151	532.57	401.50	534.14	217.44
11.496	0.153	533.74	401.11	533.17	216.47
11.598	0.155	534.07	400.71	531.96	215.26
11.804	0.157	539.00	403.10	530.36	213.66
12.001	0.160	541.22	403.49	530.36	213.66
12.210	0.163	545.16	405.09	529.20	212.50
12.425	0.166	547.03	405.09	527.81	211.11
12.629	0.168	548.82	405.09	527.24	210.54
12.828	0.171	552.20	406.28	526.37	209.67
13.016	0.174	556.86	408.47	525.22	208.52
13.203	0.176	557.30	407.55	524.36	207.66
13.487	0.180	562.39	409.39	523.78	207.08
13.687	0.182	564.22	409.39	522.63	205.93
13.852	0.185	565.32	409.08	520.61	203.91
14.200	0.189	569.40	409.69	519.46	202.76
14.318	0.191	572.21	410.91	518.79	202.09
14.511	0.193	575.74	412.13	517.71	201.01
14.794	0.197	577.17	411.22	517.17	200.47
15.103	0.201	580.57	411.52	516.63	199.93
15.316	0.204	583.94	412.44	516.23	199.53
15.527	0.207	586.45	412.74	514.96	198.26
15.749	0.210	589.95	413.66	514.28	197.58
15.962	0.213	591.21	413.05	514.15	197.45
16.176	0.216	594.67	413.97	513.61	196.91
16.375	0.218	596.69	413.97	513.85	197.15
16.566	0.221	599.20	414.35	513.68	196.98

16.767	0.224	601.29	414.37	512.53	195.83
16.974	0.226	603.23	414.23	512.87	196.17
17.185	0.229	605.39	414.20	513.14	196.44
17.394	0.232	606.25	413.28	512.32	195.62
17.499	0.233	608.70	414.20	511.26	194.56
17.705	0.236	609.99	413.59	512.05	195.35
17.903	0.239	612.11	413.60	510.68	193.98
18.095	0.241	614.35	413.71	510.68	193.98
18.291	0.244	616.76	413.90	510.11	193.41
18.479	0.246	616.08	412.08	510.39	193.69
18.679	0.249	621.02	413.91	510.42	193.72
18.878	0.252	622.30	413.30	509.34	192.64
19.084	0.254	624.91	413.51	509.88	193.18
19.294	0.257	628.35	414.22	507.98	191.28
19.497	0.260	630.18	413.92	507.70	191.00
19.700	0.263	632.03	413.62	506.07	189.37
19.900	0.265	634.74	413.88	506.89	190.19
20.093	0.268	637.50	414.23	507.16	190.46
20.297	0.271	638.94	413.62	505.80	189.10
20.514	0.274	641.02	413.32	505.80	189.10
20.730	0.276	643.10	413.02	504.17	187.47
20.949	0.279	642.30	410.84	504.92	188.22

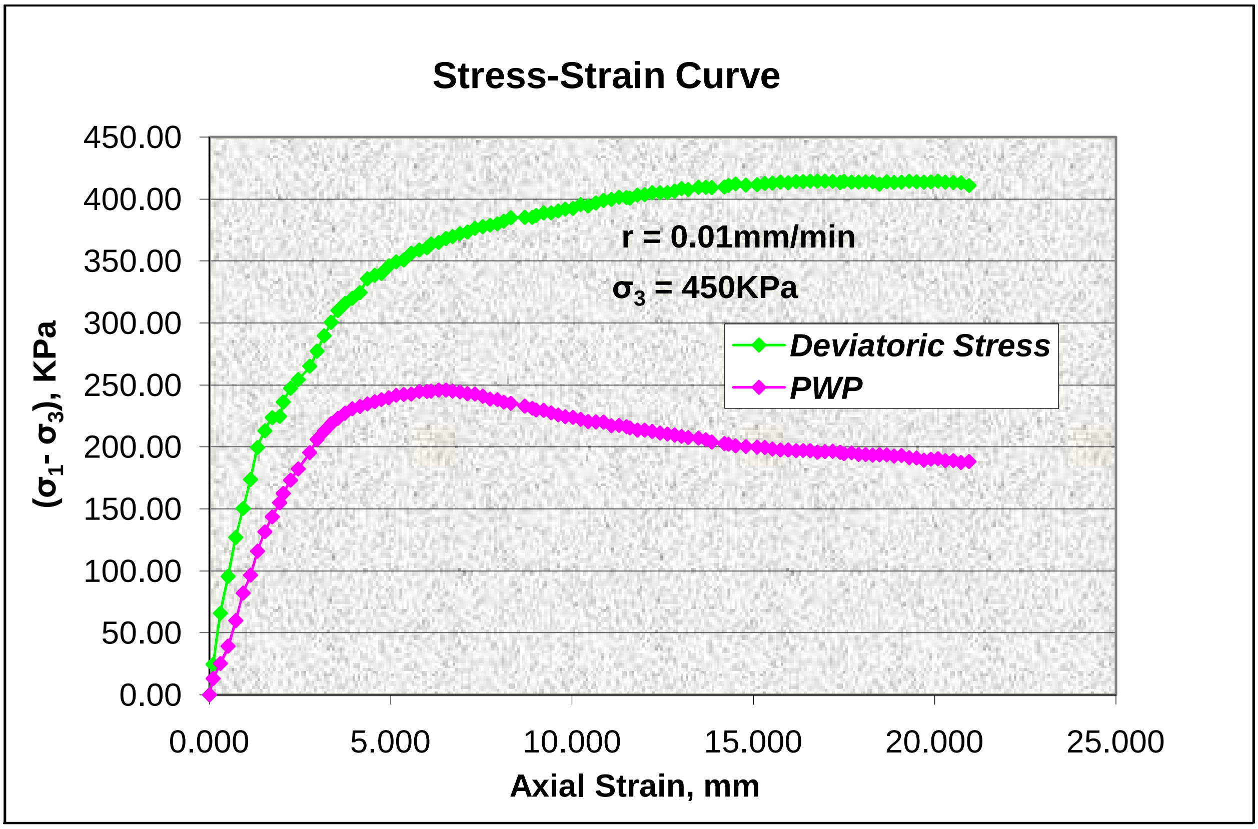


Fig. B12 Stress-Strain Curves for Effective Consolidation Pressure 450KPa and strain rate 0.01mm/min

1.3 Triaxial compression test result for stain rate of 0.1mm/min

Table B9 Consolidation Stage Result for Effective consolidation pressure of 250KPa, 350KPa, and 450KPa

Location: ***Addisu Gebeya***		Job ref.	***Thesis research***
Soil Description: Red brown clay		Pit no.	***#1***
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8		Sample no.	***#1***
		Depth	***2.5m***

Remolded Sample								
Effective Consolidation Pressure 250 KPa			**Effective Consolidation Pressure 350 KPa**			**Effective Consolidation Pressure 450 KPa**		
	CP, KPa	***550***	**Initial Condition**	CP, KPa	***650***	**Initial Condition**	CP, KPa	***750***
	BP, KPa	**300**		BP, KPa	***300***		BP, KPa	**300**
	PP, KPa	***350.9***		PP, KPa	***630.89***		PP, KPa	***721.94***
Final Condition	PP, KPa	**126.5**	Final Condition	PP, KPa	**310.63**	Final Condition	PP, KPa	**315.92**
	ΔVolume,ml	***4.8***		ΔVolume,ml	***5.41***		ΔVolume,ml	***6.83***
	% Consolidation	**95%**		% Consolidation	**98**		% Consolidation	**99.9**
Sqrt. Time	**ΔVolume, ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume,ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume, ml**	**PP, KPa**
0.29	4.90	350.90	0.00	5.53	630.89	0.30	6.87	721.94
0.36	4.84	350.61	0.36	5.75	630.89	0.37	6.88	721.84
0.44	4.37	127.08	0.44	5.06	311.30	0.46	5.81	318.24
0.54	4.31	126.79	0.54	5.02	310.72	0.56	5.70	317.47
0.66	4.23	126.60	0.66	5.02	310.34	0.69	5.63	317.08
0.81	4.13	126.41	0.81	4.97	309.95	0.84	5.57	316.79
1.00	4.05	126.31	1.00	4.93	309.85	1.03	5.51	316.60
1.22	3.97	126.21	1.22	4.80	309.76	1.26	5.44	316.41
1.49	3.89	126.12	1.49	4.76	309.57	1.54	5.35	316.21
1.83	3.80	126.02	1.83	4.59	309.37	1.89	5.17	315.92
2.24	3.75	125.83	2.24	4.37	309.37	2.32	5.01	315.73
2.74	3.61	125.73	2.74	4.20	309.18	2.84	4.87	315.73
3.36	3.32	125.92	3.36	3.99	309.08	3.47	4.70	315.54
4.11	3.26	125.83	4.11	3.81	309.18	4.25	4.50	315.44
5.04	2.98	125.92	5.04	3.51	309.18	5.21	4.19	315.44
6.17	2.70	126.41	6.17	3.13	309.28	6.38	3.83	315.54
7.56	2.27	126.12	7.56	2.74	309.47	7.82	3.28	315.64
9.26	1.95	126.31	9.26	2.23	309.66	9.57	2.87	315.64
11.34	1.45	126.31	11.34	1.75	309.85	11.72	2.12	315.92
13.89	1.04	126.79	13.89	1.28	310.14	14.36	1.60	316.12
17.01	0.74	126.60	17.01	0.68	311.11	17.59	1.13	315.73
20.83	0.35	127.27	20.83	0.25	310.82	21.54	0.55	316.60
25.51	0.17	127.08	25.51	0.19	310.82	26.38	0.15	316.41
31.25	0.10	126.50	31.25	0.12	310.63	32.31	0.00	315.92

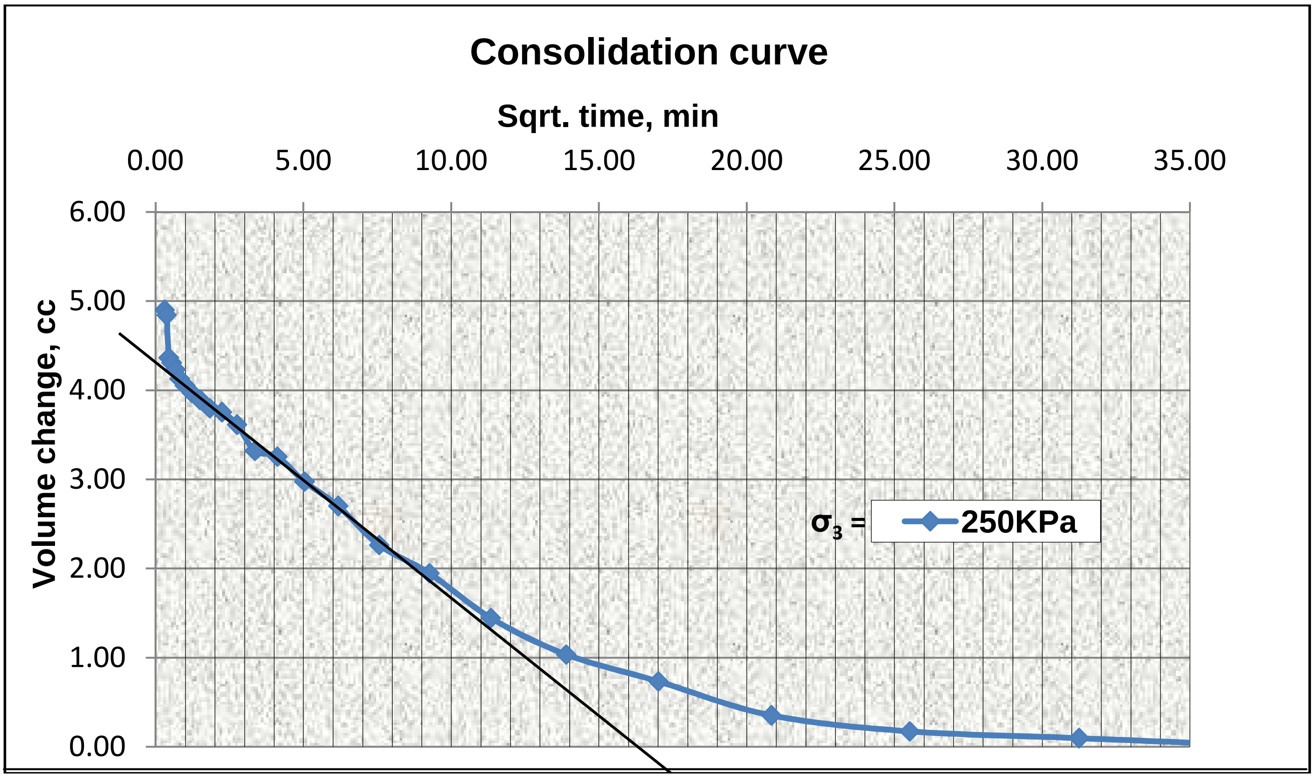


Fig. B13 Consolidation Curve for Effective Consolidation Pressure of 250KPa.

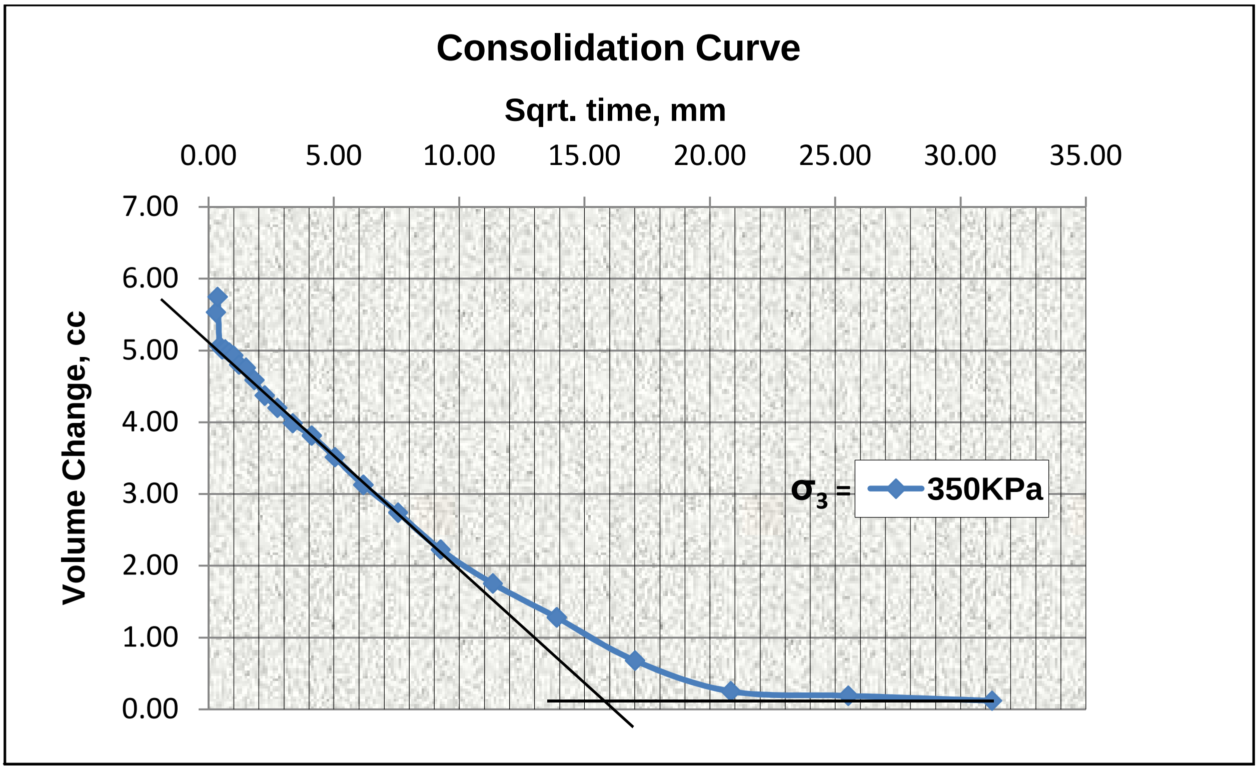


Fig. B14 Consolidation Curve for Effective Consolidation Pressure of 350KPa.

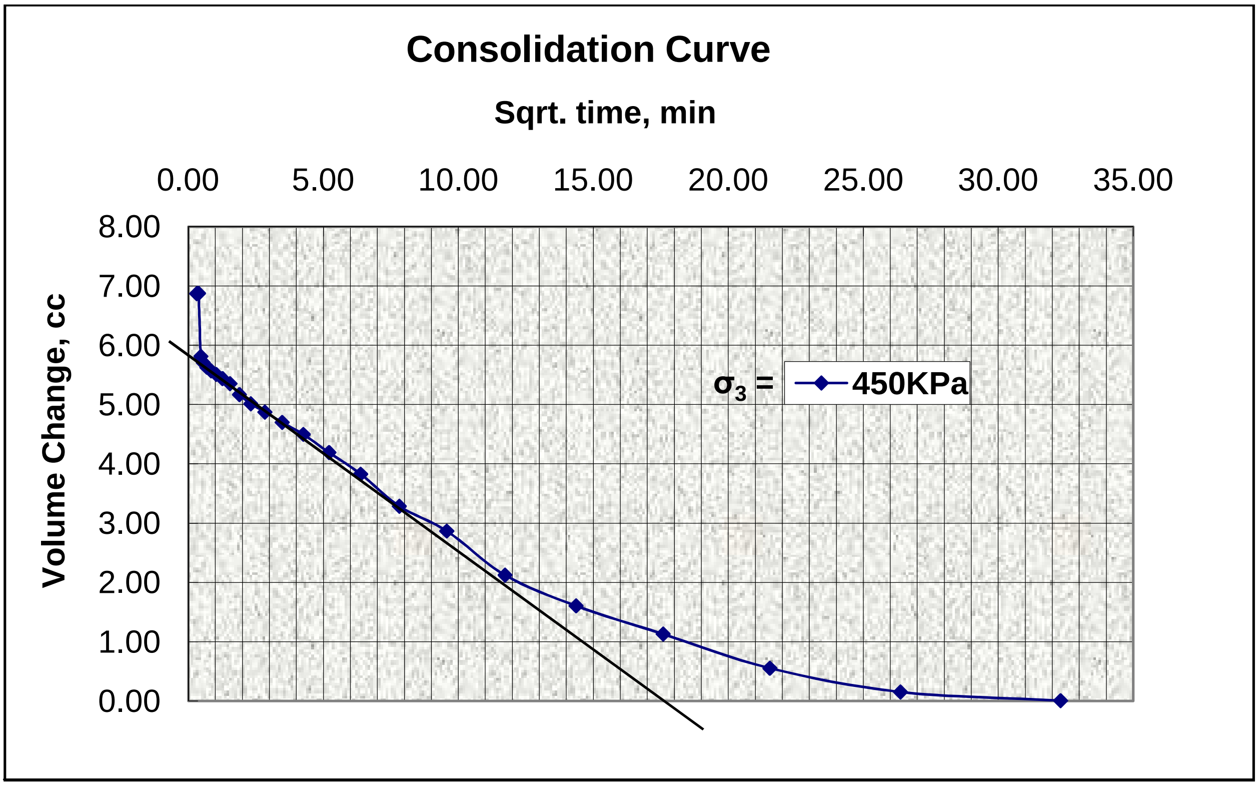


Fig. B15 Consolidation Curve for Effective Consolidation Pressure of 450KPa.

Table B10 Compression Stage Result for 250 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 250KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	307.35	0.00
0.16	0.002	5.50	4.86	309.26	1.91
0.35	0.005	60.60	53.38	313.75	6.40
0.54	0.007	117.90	103.59	318.48	11.13
0.74	0.010	145.30	127.32	322.07	14.72
0.92	0.012	159.40	139.32	325.25	17.90
1.12	0.015	169.30	147.59	331.62	24.27
1.33	0.018	184.40	160.30	337.41	30.06
1.55	0.021	196.20	170.05	343.19	35.84
1.76	0.024	210.50	181.91	351.58	44.23
1.97	0.026	221.80	191.12	356.50	49.15
2.18	0.029	232.40	199.67	363.16	55.81
2.37	0.032	239.20	205.00	368.08	60.73
2.56	0.034	249.20	212.99	373.57	66.22
2.78	0.037	259.00	220.72	378.56	71.21
2.98	0.040	268.16	227.88	382.59	75.24
3.19	0.042	275.64	233.57	383.26	75.91
3.40	0.045	281.23	237.59	387.29	79.94
3.61	0.048	287.95	242.56	389.20	81.85
3.82	0.051	294.42	247.30	392.09	84.74
4.01	0.053	299.75	251.08	393.25	85.90
4.19	0.056	305.06	254.87	396.72	89.37
4.38	0.058	310.11	258.42	397.59	90.24
4.57	0.061	311.52	258.89	399.03	91.68
4.77	0.064	315.26	261.26	401.64	94.29
4.98	0.066	318.78	263.39	402.22	94.87
5.18	0.069	323.74	266.71	404.53	97.18
5.38	0.072	324.94	266.94	405.11	97.76
5.57	0.074	328.18	268.84	406.85	99.50
5.78	0.077	332.32	271.44	407.71	100.36
5.98	0.080	334.18	272.15	409.16	101.81
6.18	0.082	335.45	272.39	409.45	102.10
6.40	0.085	339.41	274.75	410.03	102.68
6.62	0.088	340.21	274.52	410.03	102.68
6.83	0.091	343.94	276.65	410.61	103.26
7.04	0.094	347.06	278.30	410.90	103.55
7.24	0.096	352.21	281.62	410.61	103.26

7.43	0.099	351.16	279.96	410.32	102.97
7.63	0.102	353.08	280.67	411.47	104.12
7.84	0.105	356.86	282.80	411.47	104.12
8.03	0.107	359.09	283.75	410.61	103.26
8.25	0.110	361.15	284.46	410.90	103.55
8.46	0.113	363.50	285.41	410.32	102.97
8.66	0.115	366.73	287.06	410.32	102.97
8.85	0.118	368.09	287.30	410.03	102.68
9.04	0.121	372.51	289.90	409.45	102.10
9.23	0.123	372.94	289.43	409.45	102.10
9.41	0.126	376.13	291.09	408.87	101.52
9.61	0.128	378.16	291.80	409.99	102.64
9.82	0.131	378.77	291.32	408.50	101.15
10.02	0.134	382.11	292.98	408.50	101.15
10.23	0.136	384.28	293.69	408.99	101.64
10.43	0.139	383.00	291.80	407.50	100.15
10.64	0.142	388.89	295.35	407.75	100.40
10.84	0.144	388.86	294.40	407.75	100.40
11.03	0.147	391.63	295.58	408.25	100.90
11.24	0.150	388.20	292.03	407.25	99.90
11.46	0.153	393.00	294.64	406.51	99.16
11.68	0.156	393.73	294.16	407.00	99.65
11.90	0.159	398.28	296.53	406.51	99.16
12.11	0.161	401.51	297.95	405.02	97.67
12.30	0.164	399.88	295.82	406.01	98.66
12.52	0.167	403.51	297.48	405.51	98.16
12.71	0.170	406.37	298.66	405.02	97.67
12.91	0.172	408.33	299.13	405.27	97.92
13.12	0.175	409.04	298.66	404.27	96.92
13.33	0.178	408.51	297.24	404.52	97.17
13.53	0.180	411.14	298.19	404.02	96.67
13.74	0.183	412.85	298.42	405.02	97.67
13.93	0.186	412.82	297.48	404.02	96.67
14.11	0.188	416.69	299.37	402.53	95.18
14.30	0.191	416.33	298.19	402.28	94.93
14.48	0.193	416.60	297.48	403.28	95.93
14.69	0.196	420.66	299.37	403.77	96.42
14.90	0.199	422.79	299.84	401.79	94.44
15.10	0.201	422.56	298.66	402.53	95.18
15.31	0.204	426.73	300.55	402.03	94.68
15.51	0.207	427.14	299.84	402.53	95.18
15.70	0.209	427.14	298.90	401.54	94.19
15.90	0.212	430.98	300.55	401.79	94.44
16.11	0.215	432.19	300.32	401.04	93.69
16.33	0.218	431.74	298.90	401.58	94.23

16.54	0.221	434.70	299.84	401.29	93.94
16.76	0.224	437.40	300.55	401.54	94.19
16.98	0.226	437.63	299.61	402.04	94.69
17.18	0.229	441.56	301.26	402.28	94.93
17.37	0.232	442.33	300.79	400.55	93.20
17.56	0.234	444.14	301.03	399.55	92.20
17.77	0.237	443.99	299.84	399.56	92.21
17.97	0.240	445.58	299.84	399.31	91.96
18.18	0.242	444.74	298.19	398.56	91.21
18.38	0.245	447.78	299.13	397.56	90.21
18.59	0.248	448.70	298.66	396.57	89.22
18.78	0.250	450.96	299.13	396.57	89.22

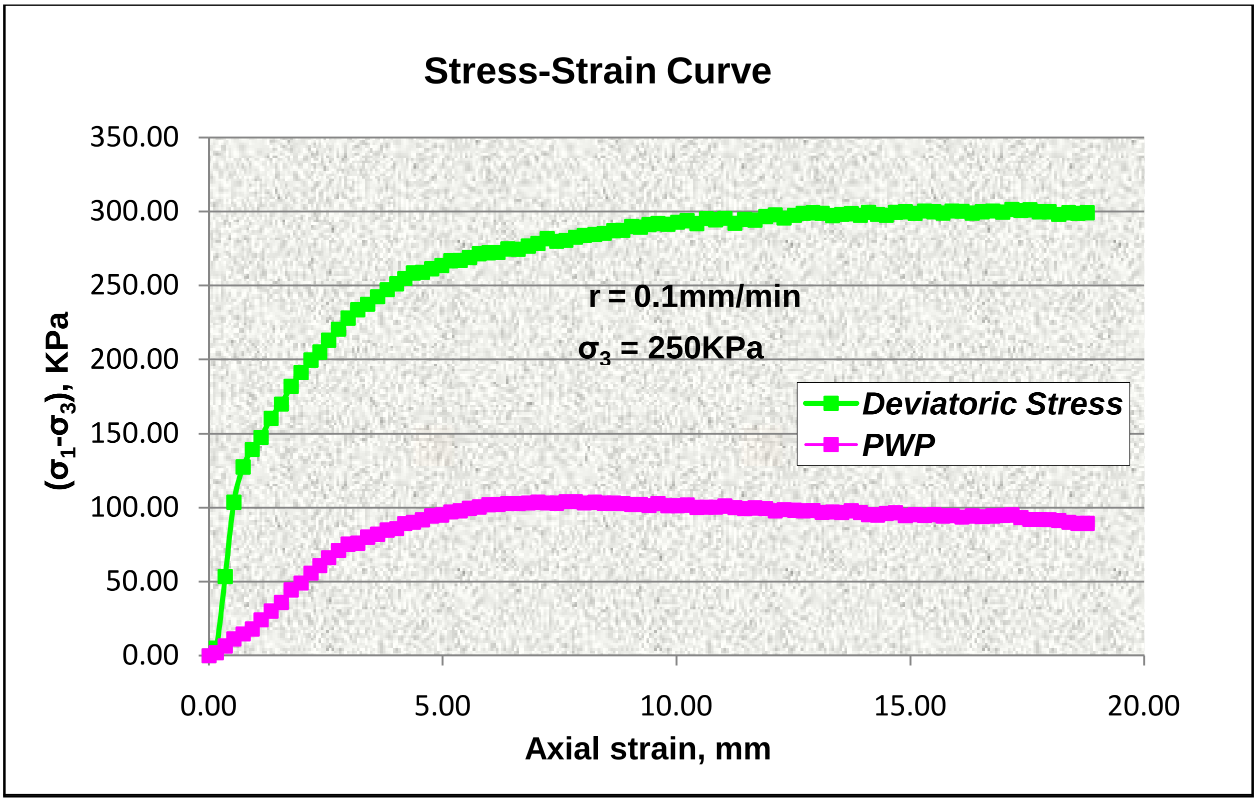


Fig. B16 Stress-Strain Curves for Effective Consolidation Pressure 250KPa and strain rate 0.1mm/min

Table B11 Compression Stage Result for 350 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 350KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	309.43	0.00
0.19	0.002	18.83	16.65	315.62	6.19
0.26	0.004	34.32	30.33	318.44	9.01
0.43	0.006	64.54	56.90	325.37	15.94
0.64	0.009	118.59	104.26	333.59	24.16
0.84	0.011	137.33	120.42	342.93	33.50
1.03	0.014	158.02	138.19	351.26	41.83
1.23	0.016	171.40	149.50	360.06	50.63
1.44	0.019	203.00	176.57	369.11	59.68
1.67	0.022	223.22	193.53	378.08	68.65
1.91	0.025	243.12	210.09	388.51	79.08
2.12	0.028	262.08	225.85	396.53	87.10
2.32	0.031	285.39	245.23	405.84	96.41
2.51	0.033	293.68	251.70	410.71	101.28
2.70	0.036	304.83	260.58	421.76	112.33
2.90	0.039	314.21	267.85	431.15	121.72
3.13	0.042	324.40	275.66	442.53	133.10
3.39	0.045	335.18	283.78	454.28	144.85
3.61	0.048	344.35	290.64	462.58	153.15
3.81	0.051	350.65	295.14	469.60	160.17
3.98	0.053	356.82	299.64	474.70	165.27
4.15	0.055	361.38	302.71	479.01	169.58
4.33	0.058	365.14	305.08	482.52	173.09
4.52	0.060	369.49	307.92	484.43	175.00
4.71	0.063	372.49	309.58	485.71	176.28
4.91	0.065	374.72	310.52	486.50	177.07
5.13	0.068	378.47	312.66	486.50	177.07
5.33	0.071	381.01	313.84	486.66	177.23
5.52	0.074	384.63	315.97	486.50	177.07
5.73	0.076	385.49	315.73	486.50	177.07
5.93	0.079	390.68	319.05	486.03	176.60
6.13	0.082	392.11	319.28	485.39	175.96
6.34	0.085	393.60	319.52	484.27	174.84
6.55	0.087	399.51	323.31	482.99	173.56
6.77	0.090	400.79	323.31	482.20	172.77
6.99	0.093	405.89	326.38	481.24	171.81

7.20	0.096	405.40	324.96	480.92	171.49
7.41	0.099	411.67	328.99	479.80	170.37
7.61	0.101	412.58	328.75	479.17	169.74
7.80	0.104	417.35	331.59	477.89	168.46
8.00	0.107	423.04	335.14	477.41	167.98
8.24	0.110	426.06	336.33	476.61	167.18
8.46	0.113	430.79	338.93	475.82	166.39
8.67	0.116	432.76	339.40	474.54	165.11
8.88	0.118	436.87	341.53	473.90	164.47
9.05	0.121	437.98	341.53	473.10	163.67
9.22	0.123	441.56	343.43	472.47	163.04
9.37	0.125	441.02	342.24	471.99	162.56
9.58	0.128	445.85	344.85	471.51	162.08
9.81	0.131	448.61	345.79	470.71	161.28
10.03	0.134	451.68	346.98	470.23	160.80
10.23	0.136	455.28	348.63	469.75	160.32
10.44	0.139	455.20	347.45	469.28	159.85
10.64	0.142	459.40	349.58	468.80	159.37
10.85	0.145	457.13	346.74	468.00	158.57
11.04	0.147	461.04	348.63	467.04	157.61
11.25	0.150	464.09	349.82	466.74	157.31
11.46	0.153	467.87	351.48	465.84	156.41
11.67	0.156	468.75	351.00	464.75	155.32
11.88	0.158	471.59	351.95	463.80	154.37
12.10	0.161	471.62	350.77	463.39	153.96
12.32	0.164	474.56	351.71	462.33	152.90
12.53	0.167	475.20	351.00	461.84	152.41
12.73	0.170	478.32	352.19	461.35	151.92
12.93	0.172	478.91	351.48	460.94	151.51
13.13	0.175	481.42	352.19	460.12	150.69
13.34	0.178	481.16	350.77	459.39	149.96

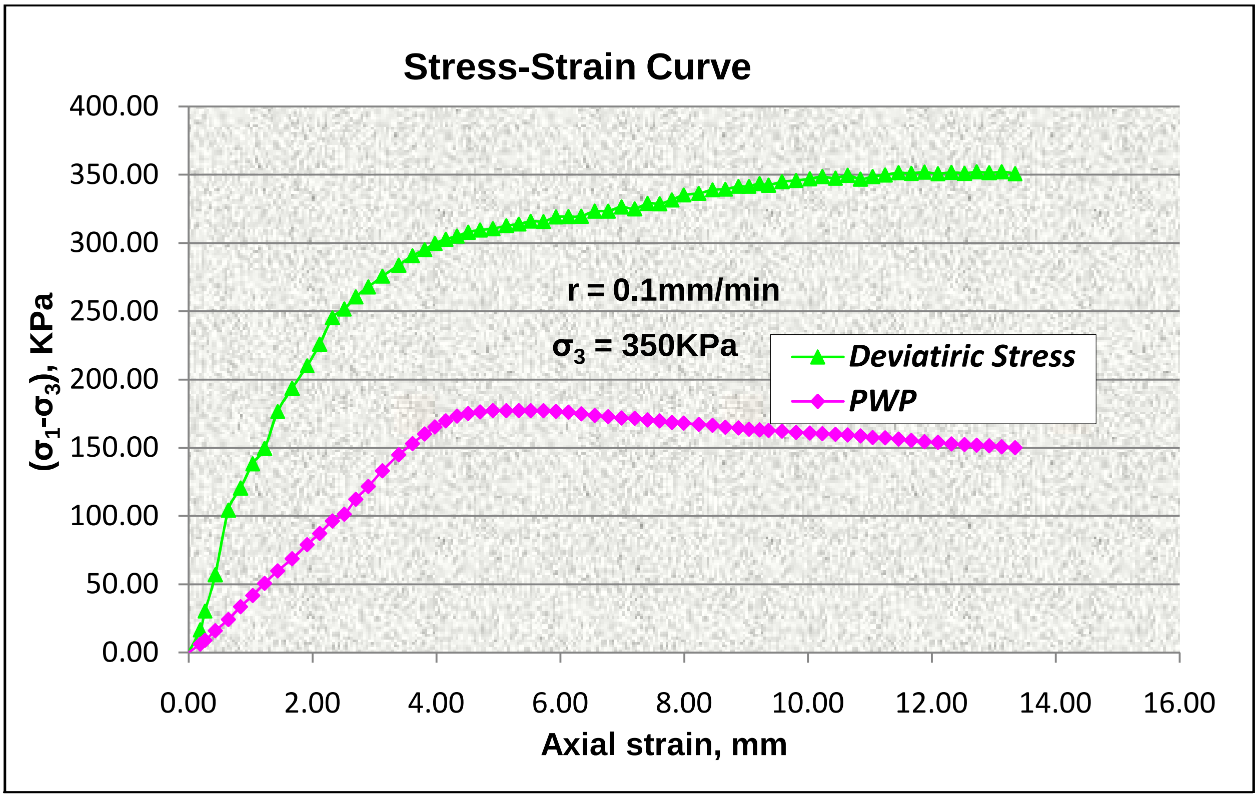


Fig. B17 Stress-Strain Curves for Effective Consolidation Pressure 350KPa and strain rate 0.1mm/min

Table B12 Compression Stage Result for 450 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*	Job ref.	Thesis research
Soil Description: *Red brown clay*	Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*	Sample No.	1
	Depth	2.5m
CP = 450KPa		

Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	318.04	0.00
0.00	0.000	10.60	9.41	319.24	1.20
0.01	0.000	26.08	23.15	320.55	2.51
0.14	0.002	80.27	71.11	331.11	13.07
0.33	0.004	100.47	88.78	339.14	21.10
0.52	0.007	130.05	114.62	350.52	32.48
0.74	0.010	161.69	142.09	365.24	47.20
0.96	0.013	193.07	169.17	383.31	65.27
1.16	0.015	215.06	187.92	400.70	82.66
1.35	0.018	231.10	201.42	420.11	102.07
1.56	0.021	247.10	214.75	434.16	116.12
1.75	0.023	268.40	232.65	446.87	128.83
1.94	0.026	286.22	247.45	462.93	144.89
2.15	0.029	300.16	258.77	470.96	152.92
2.37	0.032	312.22	268.37	480.33	162.29
2.57	0.034	328.34	281.43	489.03	170.99
2.78	0.037	340.53	291.02	497.73	179.69
2.99	0.040	351.38	299.45	505.70	187.66
3.16	0.042	362.15	307.89	511.78	193.74
3.35	0.045	373.75	316.91	514.45	196.41
3.55	0.047	383.39	324.19	518.47	200.43
3.75	0.050	394.51	332.62	523.04	205.00
3.94	0.053	403.51	339.32	527.17	209.13
4.15	0.055	414.08	347.18	528.61	210.57
4.35	0.058	420.51	351.57	530.78	212.74
4.54	0.061	429.01	357.70	533.56	215.52
4.73	0.063	436.11	362.66	534.53	216.49
4.93	0.066	440.54	365.32	537.20	219.16
5.09	0.068	446.20	369.13	537.20	219.16
5.31	0.071	455.30	375.51	540.55	222.51
5.52	0.074	457.50	376.17	541.93	223.89
5.73	0.076	462.80	379.39	541.89	223.85
5.97	0.080	464.30	379.30	543.90	225.86
6.15	0.082	471.10	383.86	543.16	225.12
6.35	0.085	474.90	385.82	544.40	226.36
6.56	0.088	479.50	388.34	544.09	226.05
6.77	0.090	484.00	390.80	542.97	224.93

6.98	0.093	490.00	394.45	544.40	226.36
7.20	0.096	494.60	396.83	542.68	224.64
7.42	0.099	495.30	396.10	542.97	224.93
7.62	0.102	499.90	398.58	541.50	223.46
7.82	0.104	502.10	399.19	540.03	221.99
8.03	0.107	505.90	400.95	539.14	221.10
8.22	0.110	507.40	401.00	537.96	219.92
8.40	0.112	515.70	406.46	535.31	217.27
8.59	0.115	518.00	407.07	534.42	216.38
8.79	0.117	521.80	408.82	532.66	214.62
8.99	0.120	524.80	409.95	531.77	213.73
9.20	0.123	530.90	413.41	530.59	212.55
9.40	0.125	530.10	411.53	529.12	211.08
9.57	0.128	533.10	412.80	527.64	209.60
9.75	0.130	536.90	414.61	526.17	208.13
9.95	0.133	545.20	419.67	524.11	206.07
10.16	0.135	545.20	418.36	524.40	206.36
10.37	0.138	544.33	416.32	520.71	202.67
10.58	0.141	549.74	419.08	520.14	202.10
10.80	0.144	553.82	420.74	517.25	199.21
11.02	0.147	554.96	420.18	517.25	199.21
11.22	0.150	558.10	421.22	517.82	199.78
11.41	0.152	559.49	421.01	516.09	198.05
11.62	0.155	562.42	421.84	516.09	198.05
11.83	0.158	566.52	423.49	514.36	196.32
12.05	0.161	569.24	424.04	512.62	194.58
12.26	0.164	571.90	424.60	511.47	193.43
12.48	0.166	574.66	425.15	511.47	193.43
12.68	0.169	576.08	424.87	509.73	191.69
12.87	0.172	576.77	424.04	508.58	190.54
13.06	0.174	581.11	425.98	506.84	188.80
13.25	0.177	582.15	425.42	507.42	189.38
13.46	0.179	584.89	425.98	507.84	189.80
13.65	0.182	584.49	424.32	506.84	188.80
13.86	0.185	589.14	426.25	506.95	188.91
14.07	0.188	590.01	425.42	505.80	187.76
14.27	0.190	593.49	426.53	504.80	186.76
14.48	0.193	595.89	426.80	504.80	186.76
14.66	0.195	598.32	427.24	503.22	185.18
14.84	0.198	601.28	428.07	503.02	184.98
15.04	0.200	605.11	429.39	502.82	184.78
15.24	0.203	605.66	428.31	500.62	182.58
15.46	0.206	606.93	427.63	498.42	180.38
15.68	0.209	609.73	428.03	497.22	179.18
15.87	0.212	611.56	427.91	496.02	177.98

16.11	0.215	614.80	428.47	494.82	176.78
16.30	0.217	616.03	427.91	494.02	175.98
16.51	0.220	617.82	427.63	493.22	175.18
16.70	0.223	620.66	428.18	492.42	174.38
16.91	0.226	623.31	428.46	491.62	173.58
17.13	0.228	625.40	428.32	490.82	172.78
17.34	0.231	627.85	428.39	490.02	171.98
17.57	0.234	630.42	428.46	489.22	171.18
17.76	0.237	632.75	428.61	488.42	170.38
17.96	0.239	634.69	428.46	487.62	169.58
18.15	0.242	636.72	428.40	486.82	168.78
18.33	0.244	639.07	428.61	486.02	167.98
18.54	0.247	641.22	428.46	485.22	167.18
18.73	0.250	643.38	428.40	484.42	166.38
18.94	0.253	645.80	428.43	483.62	165.58
19.15	0.255	647.30	427.84	482.82	164.78
19.33	0.258	648.10	426.97	482.02	163.98
19.52	0.260	651.10	427.50	481.22	163.18
19.72	0.263	651.94	426.53	480.42	162.38
19.91	0.265	653.38	425.98	479.62	161.58
20.11	0.268	655.60	425.85	478.82	160.78
20.33	0.271	656.40	424.70	478.02	159.98

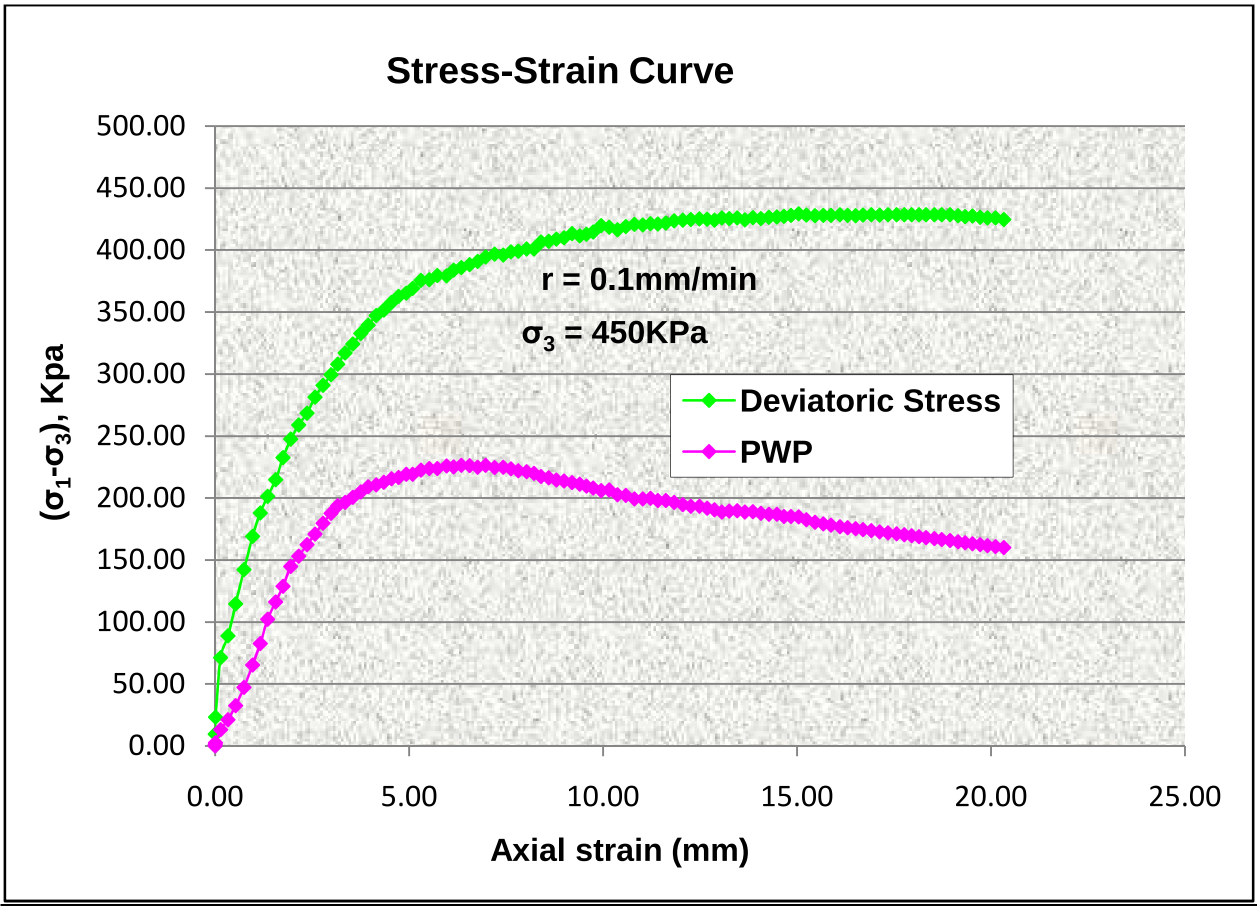


Fig. B18 Stress-Strain Curves for Effective Consolidation Pressure 450KPa and strain rate 0.1mm/min.

1.4 Triaxial compression test result for strain rate 1mm/min

Table B13 Consolidation Stage Result for Effective consolidation pressure of 250KPa, 350KPa, and 450KPa

Location:	***Addisu Gebeya***	Job ref.	***Thesis research***
Soil Description:	Red brown clay	Pit no.	***#1***
Test method: CU with measurement of pore water pressure, BS 1377: Clause 8		Sample no.	***#1***
		Depth	***2.5m***

Remolded Sample								
Effective Consolidation Pressure 250 KPa			**Effective Consolidation Pressure 350 KPa**			**Effective Consolidation Pressure 450 KPa**		
Initial Condition	CP, KPa	***550***	**Initial Condition**	CP, KPa	***650***	**Initial Condition**	CP, KPa	***750***
	BP, KPa	**300**		BP, KPa	***300***		BP, KPa	**300**
	PP, KPa	***530.69***		PP, KPa	***626.17***		PP, KPa	***727.14***
Final Condition	PP, KPa	**307.83**	**Final Condition**	PP, KPa	**307.64**	**Final Condition**	PP, KPa	**309.47**
	ΔVolume, ml	***3.9***		ΔVolume ,ml	***4.79***		ΔVolume ,ml	***5.98***
	% Consolidation	**97**		% Consolidation	**97**		% Consolidation	**99**
Sqrt. Time	**ΔVolume, ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume,ml**	**PP, KPa**	**Sqrt. Time**	**ΔVolume,ml**	**PP, KPa**
0.00	3.90	530.69	0.29	4.85	626.17	0.36	6.52	727.14
0.44	3.61	310.05	0.36	4.84	626.36	0.44	5.73	310.82
0.54	3.59	309.57	0.44	4.24	308.41	0.54	5.59	310.05
0.66	3.54	309.37	0.54	4.24	308.02	0.66	5.49	309.57
0.81	3.49	309.18	0.66	4.24	307.45	0.81	5.49	309.18
1.00	3.43	309.08	0.81	4.20	307.25	1.00	5.40	308.99
1.22	3.37	309.08	1.00	4.11	307.16	1.22	5.40	308.79
1.49	3.30	308.99	1.22	4.07	307.06	1.49	5.27	308.60
1.83	3.26	308.79	1.49	3.94	306.96	1.83	5.23	309.28
2.24	3.16	308.70	1.83	3.86	306.77	2.24	5.10	308.22
2.74	3.10	308.51	2.24	3.73	306.77	2.74	4.97	308.22
3.36	2.96	308.51	2.74	3.56	306.58	3.36	4.84	308.12
4.11	2.75	308.60	3.36	3.47	306.67	4.11	4.59	308.02
5.04	2.60	308.51	4.11	3.30	306.58	5.04	4.29	308.22
6.17	2.34	308.51	5.04	3.08	306.67	6.17	3.99	308.31
7.56	2.02	308.79	6.17	2.74	306.77	7.56	3.60	308.70
9.26	1.64	308.60	7.56	2.44	306.77	9.26	3.17	308.89
11.34	1.28	308.60	9.26	2.01	307.06	11.34	2.65	309.28
13.89	0.93	308.79	11.34	1.58	307.06	13.89	2.01	309.57
17.01	0.63	308.79	13.89	1.24	307.16	17.01	1.45	310.05
20.83	0.27	308.51	17.01	0.81	307.31	20.83	0.99	310.34
25.51	0.07	308.41	20.83	0.42	307.53	25.51	0.63	310.05
31.25	0.00	307.83	25.51	0.17	307.64	31.25	0.54	309.47
			31.25	0.14	307.76			
			38.27	0.06	307.64			

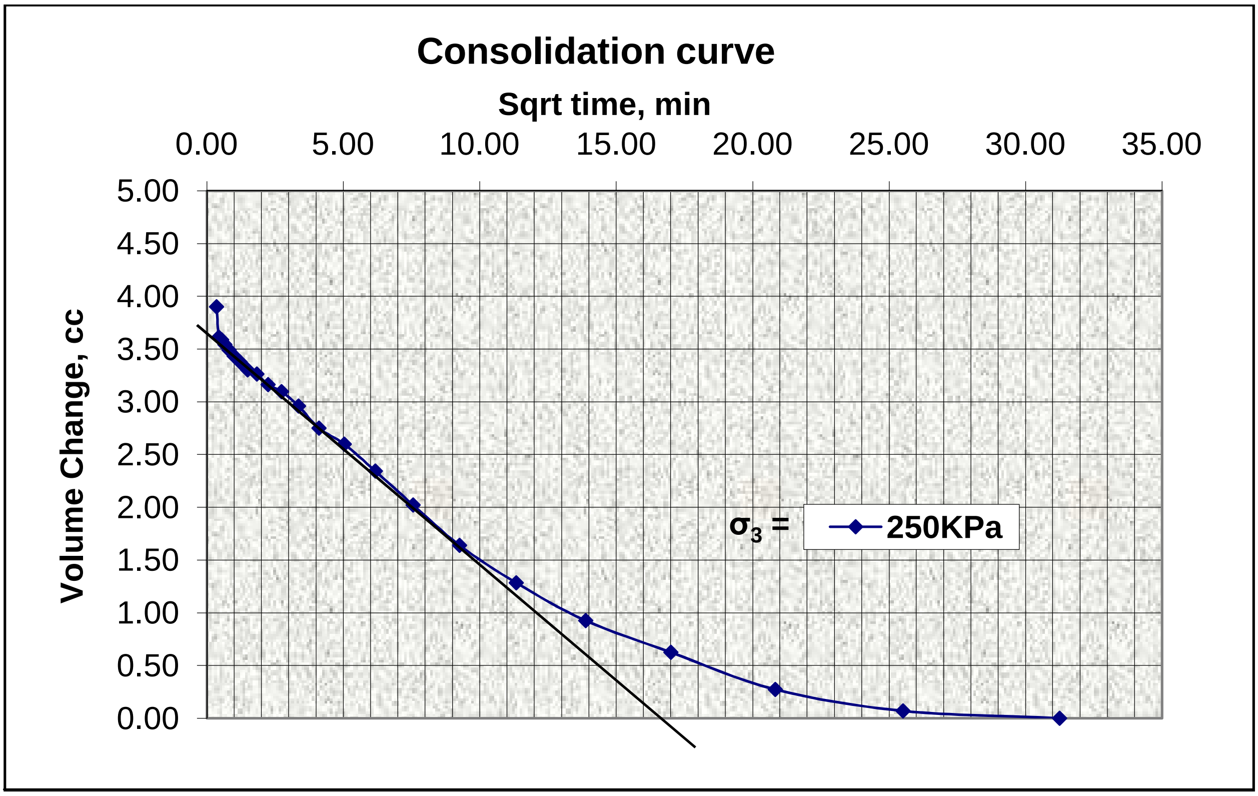


Fig. B19 Consolidation Curve for Effective Consolidation Pressure of 250KPa.

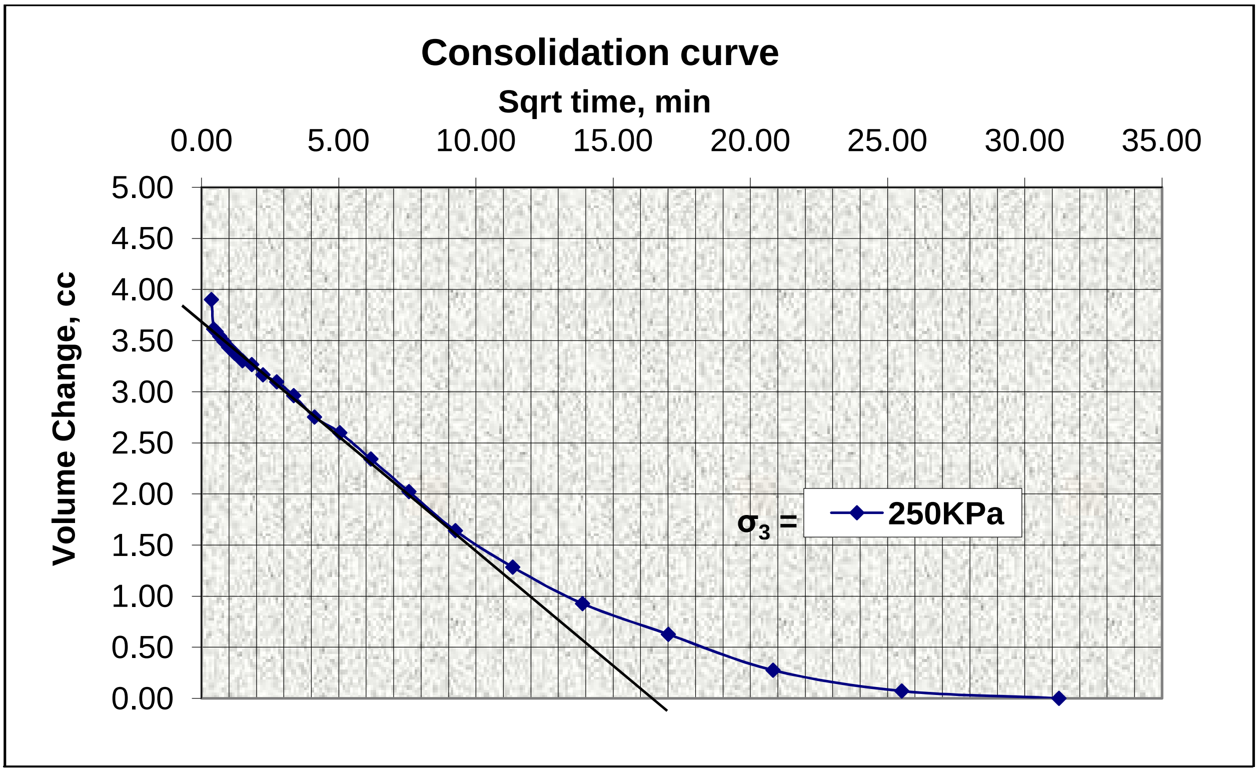


Fig. B20 Consolidation Curve for Effective Consolidation Pressure of 350KPa.

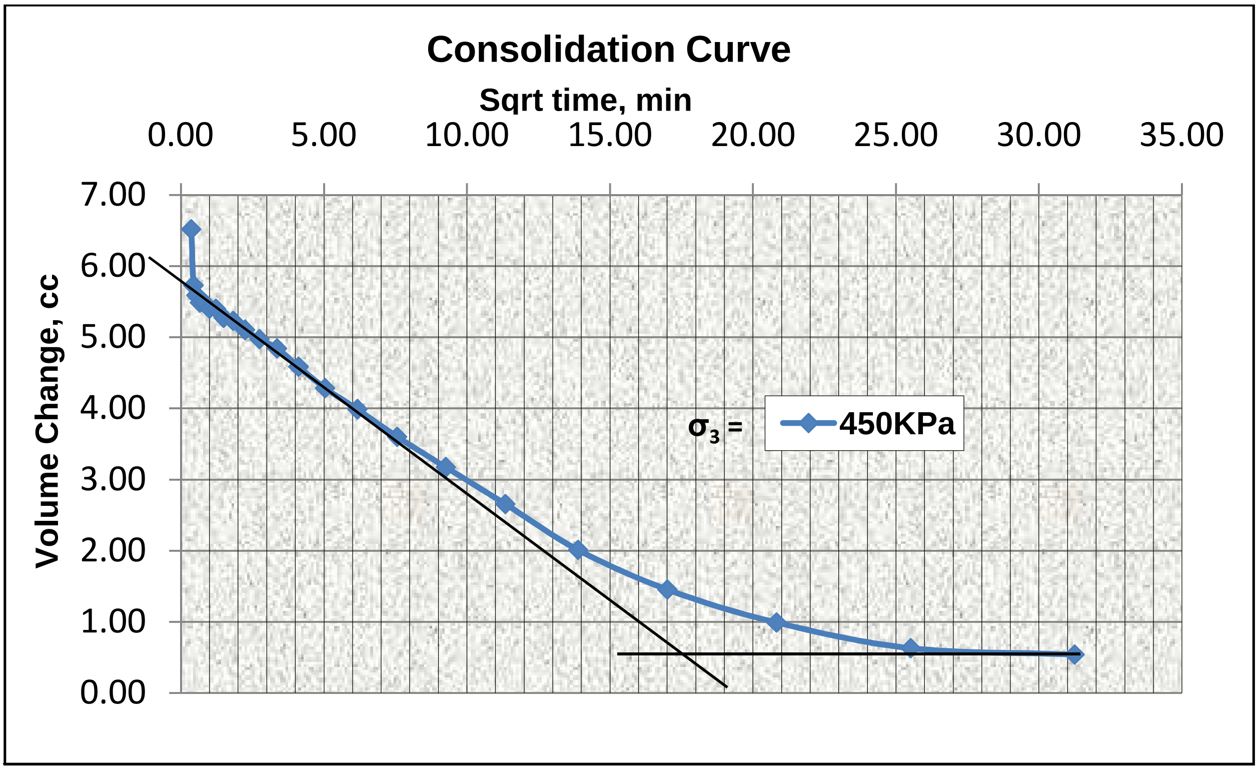


Fig. B21 Consolidation Curve for Effective Consolidation Pressure of 450KPa.

Table B14 Compression Stage Result for 250 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 250KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.00	0.00	0.00	308.41	0.00
0.14	0.00	12.85	11.35	312.08	3.66
0.34	0.00	127.79	112.57	317.71	9.30
0.50	0.01	198.12	174.16	322.01	13.60
0.74	0.01	248.02	217.34	328.34	19.93
0.94	0.01	279.03	243.84	333.54	25.13
1.12	0.01	289.61	252.48	338.00	29.59
1.32	0.02	319.86	278.09	340.30	31.89
1.54	0.02	337.25	292.33	343.11	34.70
1.75	0.02	356.16	307.84	345.91	37.50
1.91	0.03	365.99	315.62	347.31	38.90
2.11	0.03	377.33	324.53	349.18	40.77
2.30	0.03	390.94	335.36	352.45	44.04
2.53	0.03	403.04	344.63	354.32	45.91
2.75	0.04	419.68	357.77	356.66	48.25
2.91	0.04	431.02	366.64	359.93	51.52
3.17	0.04	437.07	370.44	361.80	53.39
3.34	0.04	445.39	376.59	362.73	54.32
3.55	0.05	452.95	381.89	363.67	55.26
3.73	0.05	453.71	381.53	365.07	56.66
3.93	0.05	459.76	385.53	366.47	58.06
4.15	0.06	470.34	393.22	367.40	58.99
4.31	0.06	474.12	395.49	368.34	59.93
4.53	0.06	477.15	396.78	370.21	61.80
4.71	0.06	480.93	398.89	370.67	62.26
4.94	0.07	488.49	403.80	371.14	62.73
5.16	0.07	492.27	405.64	373.48	65.07
5.31	0.07	492.27	404.81	373.48	65.07
5.36	0.07	494.54	406.35	373.95	65.54
5.43	0.07	497.56	408.46	373.95	65.54
5.47	0.07	493.78	405.08	374.41	66.00
5.54	0.07	497.56	407.79	374.41	66.00
5.60	0.07	498.32	408.08	374.41	66.00
5.66	0.08	498.32	407.72	374.41	66.00
5.71	0.08	497.56	406.77	374.41	66.00
5.76	0.08	498.32	407.11	375.81	67.40
5.96	0.08	502.86	409.67	376.28	67.87

6.16	0.08	503.61	409.09	375.81	67.40
6.36	0.08	505.13	409.10	377.22	68.81
6.56	0.09	503.61	406.66	376.75	68.34
6.74	0.09	505.56	407.20	378.62	70.21
6.93	0.09	507.39	407.56	378.62	70.21
7.17	0.10	513.44	410.94	380.49	72.08
7.34	0.10	516.63	412.43	380.49	72.08
7.55	0.10	519.26	413.27	379.55	71.14
7.75	0.10	521.93	414.16	380.02	71.61
7.94	0.11	524.62	415.08	380.49	72.08
8.15	0.11	526.55	415.33	381.42	73.01
8.36	0.11	529.61	416.45	380.49	72.08
8.56	0.11	532.57	417.48	380.95	72.54
8.77	0.12	536.96	419.61	381.42	73.01
9.05	0.12	539.21	419.62	381.42	73.01
9.25	0.12	541.46	420.05	382.36	73.95
9.46	0.13	542.87	419.81	383.29	74.88
9.60	0.13	545.91	421.28	383.29	74.88
9.81	0.13	549.88	423.00	384.22	75.81
10.01	0.13	549.86	421.65	382.82	74.41
10.22	0.14	553.70	423.24	384.22	75.81
10.43	0.14	557.62	424.88	383.76	75.35
10.63	0.14	559.94	425.28	385.16	76.75
10.84	0.14	563.91	426.92	384.22	75.81
11.05	0.15	566.36	427.39	384.22	75.81
11.25	0.15	572.04	430.28	384.69	76.28
11.46	0.15	572.99	429.59	384.22	75.81
11.60	0.15	575.60	430.61	384.22	75.81
11.80	0.16	579.56	432.17	385.16	76.75
12.08	0.16	583.96	433.55	384.69	76.28
12.22	0.16	585.00	433.37	384.69	76.28
12.42	0.17	586.31	432.91	384.69	76.28
12.63	0.17	586.79	431.83	384.22	75.81
12.84	0.17	588.89	431.94	384.22	75.81
13.04	0.17	590.98	432.04	385.16	76.75
13.25	0.18	591.43	430.92	385.63	77.22
13.46	0.18	592.76	430.44	385.49	77.08
13.66	0.18	594.91	430.55	385.75	77.34
13.87	0.18	596.16	430.00	385.49	77.08
14.08	0.19	599.19	430.73	385.49	77.08
14.28	0.19	601.29	430.77	385.63	77.22
14.42	0.19	592.43	423.46	385.49	77.08
14.63	0.20	598.11	426.06	386.00	77.59
14.84	0.20	600.42	426.24	386.00	77.59
15.04	0.20	602.84	426.49	385.49	77.08

15.25	0.20	604.41	426.12	386.51	78.10
15.46	0.21	608.55	427.56	387.02	78.61
15.66	0.21	610.15	427.19	386.00	77.59
15.87	0.21	614.18	428.52	387.03	78.62
16.14	0.22	618.06	429.22	388.05	79.64
16.35	0.22	618.91	428.30	386.77	78.36
16.56	0.22	621.40	428.50	386.77	78.36
16.70	0.22	626.01	430.66	386.26	77.85
16.90	0.23	628.57	430.90	387.79	79.38
17.11	0.23	630.34	430.57	387.28	78.87
17.32	0.23	632.08	430.22	385.75	77.34
17.52	0.23	637.22	432.16	387.28	78.87
17.73	0.24	638.98	431.79	387.02	78.61
17.94	0.24	641.69	432.06	387.96	79.55
18.07	0.24	644.60	432.97	386.51	78.10

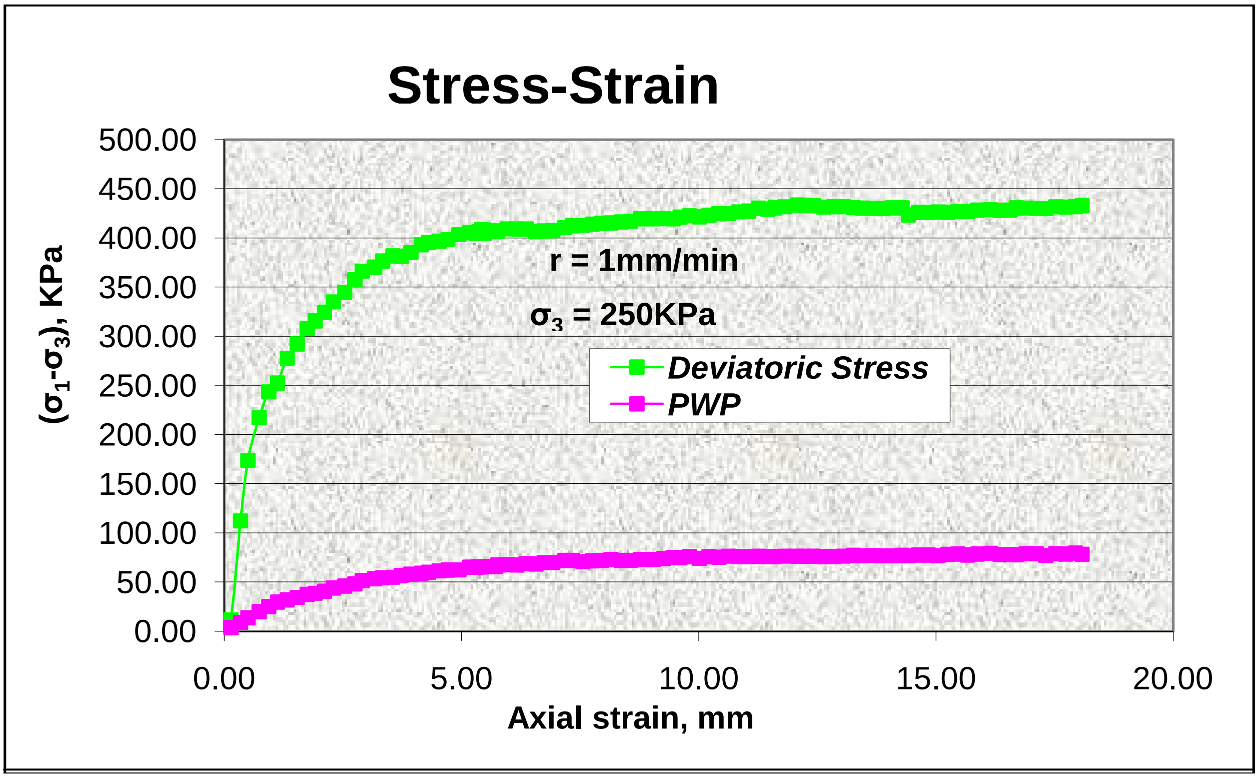


Fig. B22 Stress-Strain Curves for Effective Consolidation Pressure 250KPa and strain rate 1mm/min

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 350 KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	308.99	0.00
0.14	0.002	12.83	11.36	312.95	3.96
0.32	0.004	143.87	127.03	319.57	10.58
0.52	0.007	218.32	192.25	326.34	17.35
0.73	0.010	255.18	224.09	337.55	28.56
0.91	0.012	305.96	268.01	343.05	34.06
1.12	0.015	336.98	294.36	346.43	37.44
1.35	0.018	363.35	316.41	352.31	43.32
1.53	0.020	375.76	326.39	355.38	46.39
1.72	0.023	390.12	338.02	359.99	51.00
1.92	0.026	403.32	348.48	363.83	54.84
2.14	0.028	415.70	358.13	367.13	58.14
2.32	0.031	428.14	367.91	370.73	61.74
2.50	0.033	439.76	376.98	374.06	65.07
2.77	0.037	458.36	391.44	378.66	69.67
2.94	0.039	466.11	397.13	381.22	72.23
3.17	0.042	475.06	403.44	384.55	75.56
3.36	0.045	483.17	409.25	387.62	78.63
3.58	0.048	490.54	414.25	389.92	80.93
3.98	0.053	502.57	422.03	392.99	84.00
4.06	0.054	506.07	424.46	394.78	85.79
4.21	0.056	511.11	427.79	395.80	86.81
4.43	0.059	519.25	433.27	396.83	87.84
4.61	0.061	522.37	434.75	398.62	89.63
4.85	0.065	527.77	437.73	400.41	91.42
5.03	0.067	533.19	441.12	401.69	92.70
5.25	0.070	538.65	444.19	403.48	94.49
5.42	0.072	546.42	449.52	404.50	95.51
5.65	0.075	550.67	451.50	405.52	96.53
5.77	0.077	550.69	450.78	405.78	96.79
6.09	0.081	553.75	451.19	406.55	97.56
6.25	0.083	555.32	451.41	408.85	99.86
6.45	0.086	559.98	453.87	409.62	100.63
6.66	0.089	563.87	455.61	411.15	102.16
6.86	0.092	561.92	452.69	411.66	102.67
7.13	0.095	565.44	453.73	412.18	103.19
7.33	0.098	564.57	451.72	413.20	104.21

7.51	0.100	573.30	457.47	413.46	104.47
7.70	0.103	575.90	458.25	414.48	105.49
7.94	0.106	578.91	459.03	414.96	105.97
8.15	0.109	581.77	459.85	416.01	107.02
8.35	0.111	584.51	460.62	416.52	107.53
8.55	0.114	584.19	458.96	417.29	108.30
8.76	0.117	590.09	462.15	418.32	109.33
8.96	0.120	593.46	463.35	419.08	110.09
9.10	0.121	595.09	463.66	419.85	110.86
9.34	0.125	599.37	465.31	419.85	110.86
9.52	0.127	602.51	466.46	420.62	111.63
9.73	0.130	604.74	466.66	421.13	112.14
9.94	0.133	608.58	468.15	421.13	112.14
10.14	0.135	611.17	468.72	421.90	112.91
10.34	0.138	615.83	470.80	422.38	113.39
10.54	0.141	618.14	471.10	422.92	113.93
10.75	0.143	623.43	473.61	423.18	114.19
10.95	0.146	625.76	473.86	423.18	114.19
11.16	0.149	630.27	475.74	422.92	113.93
11.37	0.152	631.08	474.82	424.97	115.98
11.57	0.154	636.02	476.98	423.94	114.95
11.78	0.157	638.16	477.03	423.69	114.70
11.98	0.160	642.41	478.64	424.20	115.21
12.19	0.163	644.48	478.61	424.20	115.21
12.33	0.164	646.63	479.16	424.20	115.21
12.60	0.168	649.74	479.36	424.97	115.98
12.81	0.171	651.66	479.19	424.71	115.72
12.94	0.173	653.22	479.27	424.97	115.98
13.08	0.174	654.44	479.11	425.22	116.23
13.22	0.176	656.79	479.76	424.97	115.98
13.43	0.179	658.72	479.57	424.71	115.72
13.63	0.182	663.56	481.47	424.97	115.98
13.84	0.185	662.65	479.19	425.22	116.23
14.04	0.187	664.63	479.01	425.99	117.00
14.25	0.190	667.82	479.68	425.99	117.00
14.46	0.193	671.10	480.40	425.99	117.00
14.66	0.195	671.81	479.28	426.76	117.77
14.80	0.197	669.15	476.29	426.76	117.77
15.07	0.201	674.80	478.12	427.27	118.28
15.28	0.204	677.80	478.60	427.01	118.02
15.42	0.206	678.05	477.67	427.01	118.02
15.62	0.208	679.45	477.00	428.04	119.05
15.83	0.211	682.24	477.30	428.29	119.30
16.04	0.214	680.74	474.59	428.04	119.05
16.24	0.217	687.23	477.44	428.80	119.81

16.45	0.219	689.20	477.13	428.55	119.56
16.65	0.222	690.17	476.12	428.55	119.56
16.86	0.225	692.54	476.07	429.57	120.58
17.09	0.228	694.65	475.60	429.57	120.58
17.26	0.230	696.00	475.17	430.08	121.09
17.48	0.233	697.80	474.58	430.59	121.60
17.70	0.236	699.60	473.99	430.08	121.09
17.92	0.239	701.40	473.38	430.34	121.35
18.14	0.242	703.20	472.77	430.08	121.09
18.30	0.244	704.55	472.30	431.36	122.37
18.52	0.247	706.35	471.67	431.11	122.12
18.74	0.250	708.15	471.03	431.11	122.12
18.91	0.252	709.50	470.54	430.85	121.86
19.13	0.255	711.30	469.89	430.85	121.86
19.35	0.258	713.10	469.22	431.36	122.37
19.57	0.261	714.90	468.55	431.36	122.37
19.73	0.263	716.25	468.03	431.36	122.37
19.95	0.266	718.05	467.34	431.36	122.37
20.17	0.269	719.85	466.64	432.39	123.40
20.34	0.271	721.20	466.11	431.87	122.88
20.56	0.274	723.00	465.39	431.36	122.37

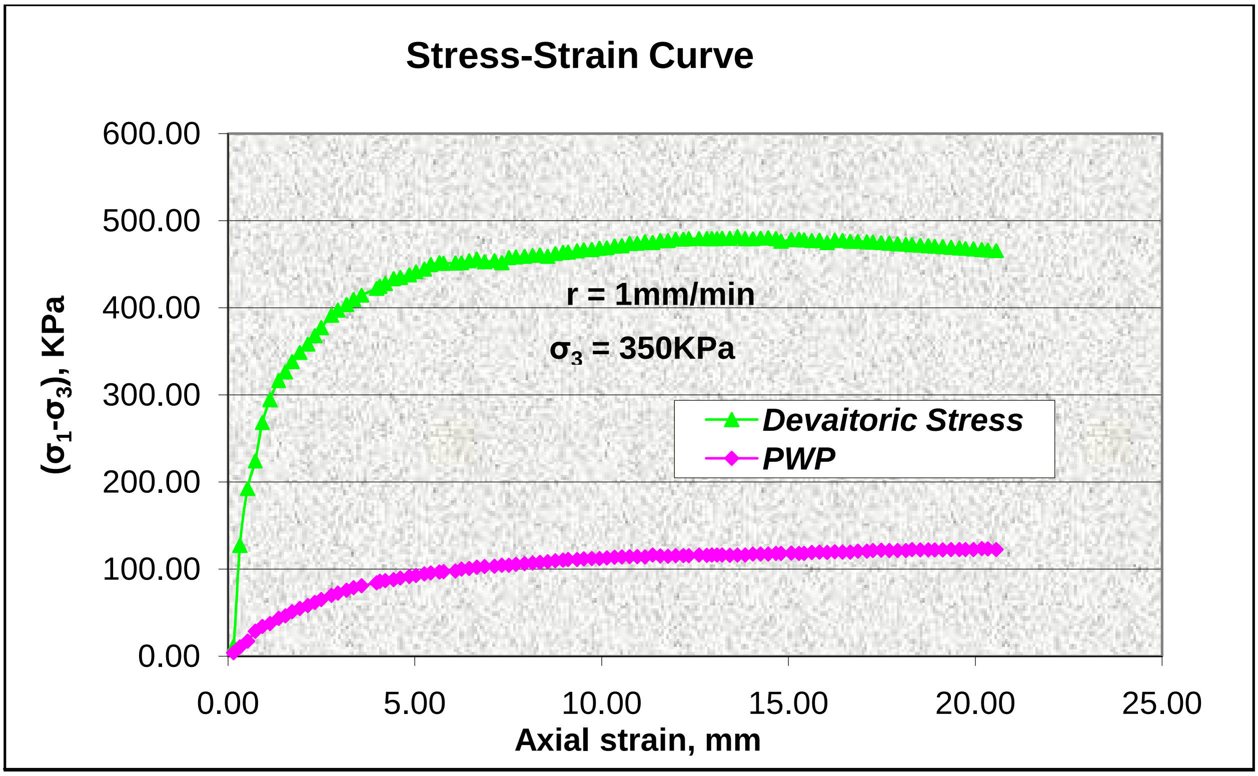


Fig. B23 Stress-Strain Curves for Effective Consolidation Pressure 350KPa and strain rate 1mm/min

Table B15 Compression Stage Result for 450 KPa Effective Consolidation Pressure

Location: *Addisu Gebeya*				Job ref.	Thesis research
Soil Description: *Red brown clay*				Pit No.	1
Test method: *CU with measurement of pore water pressure, BS 1377: Clause 8*				Sample No.	1
				Depth	2.5m
CP = 450KPa					
Displ.(mm)	**Strain(%)**	**Load (N)**	**Δσ(KPa)**	**PP (KPa)**	**ΔPP(KPa)**
0.00	0.000	0.00	0.00	310.98	0.00
0.19	0.003	16.44	14.55	316.49	5.51
0.38	0.005	220.54	194.75	325.66	14.68
0.55	0.007	286.63	252.53	343.36	32.38
0.73	0.010	363.87	319.81	349.34	38.36
0.93	0.012	400.33	350.91	356.00	45.02
1.15	0.015	426.21	372.45	362.80	51.82
1.35	0.018	443.76	386.77	367.78	56.80
1.55	0.021	461.32	401.01	372.60	61.62
1.70	0.023	473.55	410.77	375.77	64.79
1.91	0.025	484.32	418.90	380.98	70.00
2.05	0.027	498.83	430.65	384.36	73.38
2.23	0.030	504.98	434.88	389.10	78.12
2.45	0.033	521.06	447.35	394.81	83.83
2.71	0.036	537.18	459.52	401.51	90.53
2.91	0.039	543.35	463.51	405.26	94.28
3.14	0.042	553.44	470.62	407.85	96.87
3.36	0.045	559.62	474.46	411.77	100.79
3.55	0.047	568.89	480.99	413.16	102.18
4.13	0.055	591.28	495.89	420.98	110.00
4.32	0.058	599.05	501.06	422.16	111.18
4.55	0.061	604.55	504.00	425.29	114.31
4.74	0.063	614.51	510.96	426.85	115.87
4.94	0.066	613.89	509.00	429.59	118.61
5.16	0.069	623.19	515.07	432.33	121.35
5.34	0.071	627.15	516.97	435.07	124.09
5.58	0.074	634.96	521.64	437.42	126.44
5.76	0.077	639.63	524.09	438.99	128.01
5.94	0.079	643.59	526.00	441.34	130.36
6.14	0.082	643.78	524.61	444.47	133.49
6.36	0.085	646.98	525.54	445.25	134.27
6.56	0.087	650.96	527.24	447.99	137.01
6.76	0.090	656.45	530.11	448.38	137.40
6.97	0.093	658.14	529.88	450.73	139.75
7.17	0.096	663.25	532.36	452.69	141.71
7.36	0.098	666.26	533.31	452.69	141.71
7.53	0.100	667.56	532.98	454.25	143.27
7.79	0.104	671.06	533.74	453.86	142.88

7.95	0.106	675.20	535.76	455.43	144.45
8.21	0.109	678.54	536.35	456.60	145.62
8.40	0.112	681.49	537.08	457.38	146.40
8.60	0.115	684.38	537.79	458.56	147.58
8.79	0.117	688.00	539.06	460.52	149.54
9.05	0.121	693.55	541.30	459.73	148.75
9.19	0.123	696.74	542.60	460.91	149.93
9.45	0.126	701.09	543.85	460.52	149.54
9.66	0.129	704.24	544.56	461.69	150.71
9.85	0.131	708.84	546.49	462.08	151.10
10.03	0.134	711.80	547.27	463.26	152.28
10.22	0.136	718.05	550.46	462.47	151.49
10.41	0.139	719.61	550.08	463.65	152.67
10.60	0.141	726.20	553.43	463.26	152.28
10.80	0.144	728.68	553.64	464.43	153.45
11.06	0.147	732.65	554.40	465.99	155.01
11.25	0.150	737.56	556.41	466.78	155.80
11.45	0.153	738.64	555.53	466.78	155.80
11.64	0.155	741.21	555.75	465.99	155.01
11.84	0.158	743.93	556.07	467.17	156.19
12.03	0.160	748.15	557.50	465.60	154.62
12.23	0.163	751.58	558.33	466.78	155.80
12.42	0.166	752.63	557.36	468.34	157.36
12.62	0.168	756.11	558.20	468.34	157.36
12.81	0.171	758.94	558.54	468.34	157.36
13.01	0.173	758.32	556.33	469.91	158.93
13.27	0.177	764.23	558.31	469.13	158.15
13.46	0.179	770.10	560.82	469.52	158.54
13.66	0.182	772.87	561.06	469.91	158.93
13.85	0.185	775.61	561.26	469.13	158.15
14.11	0.188	780.70	562.54	471.47	160.49
14.31	0.191	780.23	560.40	470.69	159.71
14.50	0.193	787.20	563.59	471.47	160.49
14.70	0.196	788.42	562.65	471.47	160.49
14.96	0.199	788.20	560.06	472.26	161.28
15.15	0.202	792.11	561.02	473.04	162.06
15.35	0.205	796.89	562.56	473.43	162.45
15.54	0.207	798.34	561.74	471.87	160.89
15.74	0.210	799.01	560.37	473.82	162.84
15.93	0.212	799.64	558.97	473.43	162.45
16.13	0.215	803.57	559.86	472.65	161.67
16.32	0.218	804.20	558.44	473.82	162.84
16.45	0.219	804.65	557.52	473.89	162.91

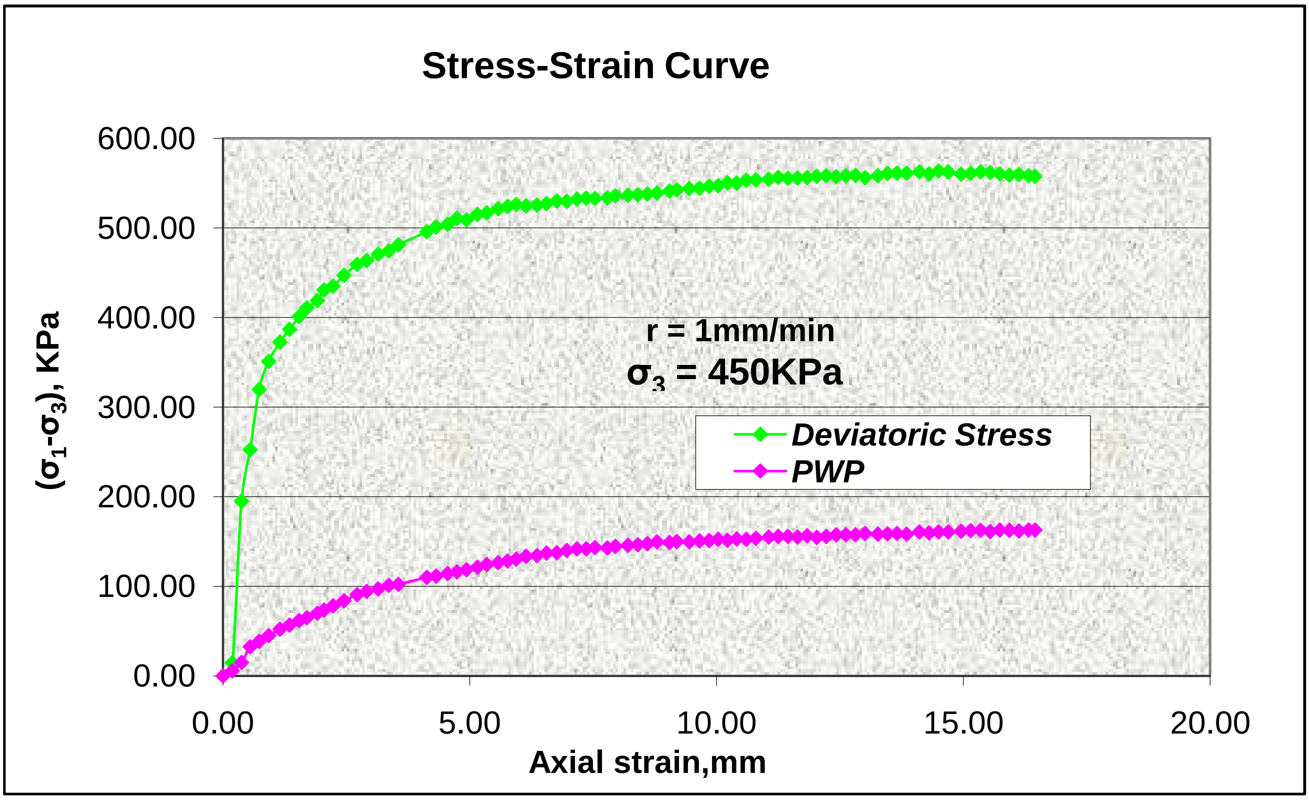


Fig. B24 Stress-Strain Curves for Effective Consolidation Pressure 450KPa and strain rate 1mm/min.