ADAMA SCINCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE
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STUDY ON SOME STATIC AND DYNAMIC PROPERTIES OF SOILS COMMONLY FOUND IN DIRE DAWA TOWN

A Thesis Submitted to the Graduate School of Civil Engineering and Architecture of Adama Science and Technology University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering [Geotechnical Engineering]

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APPROVAL PAGE

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LIST OF NOTATIONS AND ABBREVIATIONS

DDU	Dire Dawa university;
CTF	Cotton textile factory;
MPS	Melka primary school;
DB	Dechato bridge;
AG	Abune Gergores;
TF	Tony farm;
NCF	National cement factory;
ASTM	American Society for testing and Materials;
AASHTO	American Association of State Highway and Transportation Officials;
A_{loop}	Loop area;
A_{Δ}	Area of triangle;
D	Damping ratio;
G/G_{max}	Modulus reduction;
G_{sec}	Secant shear modulus;
k	Dimensionless quantity (exponential parameter);
LVDT	Linear Variable Differential Transformer, displacement sensor;
OCR	Over consolidation ratio;
P_c	Pre-consolidation pressure;
P_o	Present effective vertical pressure;
w	Natural water content;
σ'_o	Effective confining stress;
σ'_v	Vertical effective stress;
γ	Strain amplitude;
c	Cohesion between particles;
e	Void ratio;
G	Dynamic shear modulus;
G_{max}	Maximum Dynamic shear modulus;
LL	Liquid limit;
OCR	Over consolidation ratio;
PL	Plastic Limit;

W_D	Dissipated energy;
Ws	Maximum strain energy;
ν_s	Shear wave velocity;
γ^e_t	Elastic threshold strain;
σ	Normal stress;
σ_m	Mean normal stress;
τ	Shear stress;
ϕ	Angle of internal friction;
K_0	Coefficient of earth pressure at rest;
MH	Inorganic elastic silt;
ML	Inorganic silt;
SM	Silty sand;
SP	Poorly graded sand;
C_c	Coefficient of curvature;
C_u	Coefficient of uniformity

TABLE OF CONTENTS PAGES

ACKNOWLEDGEMENTS II
LIST OF NOTATIONS AND ABBREVIATION III
LIST OF TABLES VII
LIST OF FIGURES VIII
ABSTRACT X
1. INTRODUCTION 1
1.1 Background of the Study 1
1.2 Problem Statement of the Study 2
1.3 Objectives of the Study 2
1.3.1 General Objective 2
1.3.2 Specific Objectives 2
1.4 Scope of the Study 3
1.5 Outcomes of the Study 3
1.6 Outline of the Study 3
2. LITERATURE RIVEW 4
2.1 General 4
2.2 Important Physical Properties of Soils 4
2.3 Shear Strength of Soils 4
2.3.1 Introduction 4
2.3.2 Shear Characteristics of Cohesionless Soils 5
2.3.3 Methods of Determining Shear Strength Parameters 5
2.4 Shear Stress-Shear Strain Behaviour of Cyclically Loaded Soils 6
2.5 Dynamic Material Parameters 7
2.5.1 Shear Modulus 7
2.5.2 Damping Ratio 7
2.5.3 Strain Dependency of Dynamic Parameters 8
2.5.4 Methods of Determining Shear Modules and Damping Characteristics 11
2.5.5 Parameters Affecting Shear Modulus and Damping Ratio in Soils 13
2.5.6 Shear Modulus and Damping Ratio Values of Sand 18
2.6 Previously Conducted Soil Dynamic Property Tests in Ethiopia 19

3. DESCRIPITION OF STUDY AREA AND EXPERIMENTAL TECHNIQUES 21
3.1 Description of Study Area 21
3.1.1 Geologic and Seismic Settings 21
3.2 Experimental Techniques 22
3.2.1 Sample Materials 22
3.2.2 Cyclic Simple Shear Apparatus and Testing 23
4. RESULTS AND DISCUSSIONS 27
4.1 Index Properties Test 27
4.2 Classification Characteristics 30
4.3 Summary 32
4.4 Compaction Test 32
4.5 Direct Shear Test Results 33
4.5.1 Variation of Shear Strength Parameters with Soil and Loading Condition 36
4.6 1D- Consolidation Test Results 37
4.7 Simple Cyclic Shear Test Results and Values of Shear Modulus and Damping Ratio 37
4.7.1 Shear Stress-Shear Strain Relationships and Hysteresis Loop 37
4.7.2 Computation of Shear Modulus and Damping Ratio Values 42
4.8 Shear Modules and Damping Ratio Values for Different Cases.. 46
4.8.1 Effect of Confining Pressure on Shear Modulus and Damping Ratio 46
4.8.2 Effect of Shear Strain Amplitude on Shear Modulus and Damping Ratio 49
4.8.3 Effect of Soil Type on Shear Modulus and Damping Ratio 51
4.8.4 Effect of Number of Loading Cycles on Shear Modulus and Damping Ratio 53
4.9 Estimation of Low Amplitude Shear Modulus, G_{max} and Values of Modulus Reduction. . 54
4.10 Comparison of Modulus Reduction and Dampig Ratio Values for Different Cases. 55
5. CONCULUSIONS AND RECOMMENDATIONS.. 59
5.1 CONCULUSIONS.. 59
5.2 RECOMMENDATIONS 60
6. REFERENCES.. 61
APPENDIXCES.. 64

LISTS OF TABLES **PAGES**

Table 2.1 Empirical values of exponential parameter (k) by Hardin and Drnevich 11
Table 2.2 Values of K_2max 11
Table 2.3 Test procedures for measuring moduli and damping characteristics 12
Table 2.4 Factors affecting stiffness and damping of natural soils 13
Table 2.5 Modulus reduction and damping ratio values of soils in Ethiopia 20
Table 3.1 Summary of loading and test conditions and sample type used for cyclic tests 26
Table 4.1 Summary of index property test results 28
Table 4.2 Classifications of soils based on USCS classification system 31
Table 4.3 Classifications of soils based on AASHTO classification system 32
Table 4.4 Summary of optimum moisture content and maximum dry density 33
Table 4.5 Summary of silt soil shear strength parameter values 35
Table 4.6 Summary of sand soil shear strength parameter values 36
Table 4.7 Computation of TF silt soil shear modulus and damping ratio at 100 kPa axial stress for 2.5% shear strain 43
Table 4.8 Typical shear modulus and damping ratio of TF silt soil at 100kPa axial stress for different strain levels. 44
Table 4.9 Typical shear modulus and damping ratio of AG sand soil at 100kPa axial stress for different strain levels 45
Table 4.10 Maximum shear modulus and modulus reduction values 54

LISTS OF FIGURES **PAGES**

Figure 2.1 Idealized cyclic stress - strain loop. 7
Figure 2.2 Normalized modulus and damping curves with different zones of cyclic shearing strain amplitude for soil 9
Figure 2.3 Variation of shear modulus with shearing strain amplitude for Berlin sand under various confining pressures 14
Figure 2.4 Variation of damping ratios with shear strain and number of loading cycles. 15
Figure 2.5 Variation of shear modulus number of loading cycles 16
Figure 2.6 Variation of damping ratio with number of loading cycles 16
Figure 2.7 Effects of confining pressure on the strain-dependent shear modulus 17
Figure 2.8 Effects of confining pressure on the strain-dependent damping ratio 18
Figure 2.9 Variation of shear modulus with shear strain for sand 19
Figure 2.10 Variation of damping ratios with shear strain for sand 19
Figure 3.1 Seismic hazard map of Ethiopia based on the GSHAP data for a return period of 475 years 22
Figure 3.2 Location of sample materials 23
Figure 3.3 Model 31-WF7500 cyclic direct simple shear apparatus used for the cyclic tests 24
Figure 3.4 Earthquakes loading of a soil element 24
Figure 4.1 Summary of grain size distribution curves. 29
Figure 4.2 Plasticity chart of the study area soils according to USCS classification. 30
Figure 4.3 Plasticity chart of soil in the study area according to AASHTO classification 31
Figure 4.4 Typical shear stress vs horizontal displacement of AG sand soil 34
Figure 4.5 Typical shear stress vs normal stress of AG sand soil 34
Figure 4.6 Pre-consolidation pressure result of TF silt soil 37
Figure 4.7 Typical hysteresis loop of TF silt soil under 100 kPa axial stress for 2.5% shear strain 38
Figure 4.8 Typical 5th cycle hysteresis loop of TF silt soil at 100 kPa axial stress for different shear strain level 39
Figure 4.9 Hysteresis loop of TF silt soil showing the effect of shear strain amplitude on the hysteresis loop at 100kPa axial stress 40

Figure 4.10 Typical 5th cycle hysteresis loop of AG sand soil at 100 kPa axial stress for different shear strain levels. 41
Figure 4.11 Hysteresis loop of AG sand showing the effect of shear strain levels on the hysteresis loop at 100 kPa axial stress 42
Figure 4.12 Hysteresis loop and energy dissipation with triangular area……………………..…..42
Figure 4.13 Variation of shear modulus (a) and damping ratio (b) of AG sand soil with confining pressure………………………………………………..…........47
Figure 4.14 Variation of shear modulus (a) and damping ratio (b) of TF silt soil with confining pressure……………………………………………….......................48
Figure 4.15 Variation of shear modulus (a) and damping ratio (b) of TF silt soil with shear strain amplitude ………………………………………………………..…..49
Figure 4.16 Variation of shear modulus and damping ratio of AG sand with shear strain amplitude... 50
Figure 4.17 Variation of shear modulus and damping ratio with soil type 51
Figure 4. 18 Variation of shear modulus and damping ratio of AG sand soil with number of loading cycles 52
Figure 4. 19 Variation of shear modulus and damping ratio of TF silt soil with number of loading cycles 53
Figure 4.20 Comparison of modulus reduction and damping ratio values of AG sand soil with koka sand 55
Figure 4.21 Comparison of modulus reduction and damping ratio values of TF silt soil with local silt 56
Figure 4.22 Comparison of modulus reduction and damping ratio values of TF silt soil with local silt sand soil 57

ABSTRACT

The behavior of soils under static and/or dynamic loadings is strongly influenced by the static and/or dynamic properties of local soil deposits. Of those static and dynamic properties, the shear strength and the shear modulus and damping ratio of soils are critical to the evaluation of geotechnical engineering problems. In this thesis, it was aimed to study the shear strength, shear modulus and damping ratio of soils commonly found in Dire Dawa, after characterizing the soil using the index properties. Effects of strain amplitude, confining pressure, material type and loading cycles on shear modulus and damping ratio values were also investigated.

The shear strength parameters (c and ϕ) were determined using strain-controlled direct shear test on soil specimens remolded with different densities and water contents in order to simulate the ground condition. To determine the shear modulus and damping ratio, strain controlled cyclic simple shear tests on remolded samples were performed. The tests were carried out as a function of cyclic shear strain amplitudes of 0.01%, 0.1%, 1%, 2.5% and 5% under the axial pressures of 100kPa, 200kPa and 400kPa.

According to the results of this study, the soils in Dire Dawa town are low plastic silt and poorly graded sand. The values of shear strength parameters (c and ϕ) of the sand range between 1kPa to 9kPa and $26^0$to 28^0 respectively. And the values of shear strength parameters (c and ϕ) of the silt range between 28kPa to 43kPa and 15^0 to 25^0 respectively. The cohesion of the soil is strongly affected by the water content of the soil, while the angle of internal friction of the soil is not significantly affected. The values of shear modulus and damping ratio of the sand range between 1MPa to 38MPa and 3% to 24% respectively. And the values of shear modulus and damping ratio of the silt range between 1MPa to 14MPa and 3% to 29% respectively. The shear modulus increases with confining pressure and loading cycles for a given shear strain amplitude, but the damping ratio decreasing with them. The modulus reduction and damping ratio values of the silt soil are close to the corresponding local values, but the modulus reduction values of the sand are lower than the corresponding local values, especially at lower strains.

Keywords: - Shear modulus, Damping ratio, Cyclic simple shear test, Shear strength, Shear strain

1. INTRODUCTION

1.1 Background of the Study

Static and dynamic geotechnical characterization of local soil is crucial in prediction and analysis of soil mechanical behavior, which is required for the analysis of geotechnical engineering problems [3].

Soil behavior under static loading is influenced by the static properties of local soil deposits. Of those static properties, the static shear strength is critical to the evaluation of geotechnical engineering problems such as foundation or soil structure stability analyses (degree of safety) against the failure [4]. On the other hand, soil behavior under dynamic loading is primarily influenced by the dynamic properties that control wave propagation, particularly the soil stiffness (shear modulus) and material damping (damping ratio). These are required to evaluate the dynamic response of soils and soil-structure systems or settlement of ground or structures associated with the deformation of soils due to the strong ground motions [23]. .

Static loads remain unchanged over space and time, while dynamic load represents loading conditions which vary both in their direction and magnitude. But pure dynamic loads do not occur in nature, it is always a combination of static and dynamic loadings. Damage due to dynamic loading (e.g. earthquake strong motions) such as building collapse, loose of bearing capacity, excessive settlement, and failure in earth and earth retaining structures substantially influenced by the response of soil deposits. Looking at a particular area, the intensity of ground motion highly depends on the magnitude of the earthquake associated to the mechanical properties of the ground material.

Consequently, determination of shear strength, shear modulus and damping ratio with respect the soil conditions for a site is utmost critical and important aspect of geotechnical engineering problems [3].

In this thesis, the static and dynamic properties of soils commonly found in Dire Dawa are investigated. Since, static and dynamic properties of soils commonly found in Dire Dawa have not been investigated so far. As well, some physical properties have been determined for better characterization of the soil.

1.2 Problem Statement of the Study

Dire Dawa is a commercial and industrial center located on the Addis Ababa- Djibouti railroad. At present there is dramatic increase in population. This increase in population has been accompanied by an equally strong growth in the number of civil engineering infrastructure constructions. Hence, geotechnical investigation on the engineering property of soil is very essential. Because these data are very important for civil engineers in preliminary design and in designing civil engineering structures for future construction projects in the town.

In the town there is rapid construction of railroad, cement industries, food factory, airport, industrial and commercial buildings and planned dry port. The town is found near the most seismically hazardous area where many earthquakes have previously occurred [31]. Hence, there is a probability of earth quake damages. In the town, the design and construction of geotechnical engineering structures is done without considering seismic loads and providing appropriate mitigation of railway and machine foundation induced vibrations. The proximity of significant earthquakes Dire Dawa obviously leads to the question of how much damage will be sustained by the buildings and other infrastructures constructed or being constructed.

For that reason, it is essential to know the ground response of soil deposits in addition to the requirement of strict structural earthquake design guidelines in order to minimize damages due to earthquake loading.

1.3 Objectives of the Study

1.3.1 General Objective

The main objective of this thesis is to determine the static and dynamic properties of soils commonly found in Dire Dawa town from laboratory tests, and to provide useful guide in the selection of soil characteristics for analysis of geotechnical engineering problems.

1.3.2 Specific Objectives

- ✓ To determine the index properties and characterize the soils
- ✓ To determine the shear strength properties
- ✓ To determine the shear modulus and damping ratio of the typical soils of Dire Dawa
- ✓ To investigate effect of various parameters on shear modulus and damping ratio of the typical soils of Dire Dawa

1.4 Scope of the Study

This study is limited to the determination of shear strength, shear modulus and damping ratio of soils commonly found in Dire Dawa, after characterizing the soil using the index properties from seven test pits.

The shear tests have been conducted using the direct shear machine and the cyclic test using the simple cyclic shear machine, both on remolded specimens.

1.5 Outcomes of the Study

Results obtained will provide input for performance based design of foundations and earth retaining structures, design of foundation for machinery and vibratory equipment, design of retaining walls and embankments, analysis of soil-structure interactions numerical and analytical modeling of soil deposits mechanical behaviors in the study area. In addition results will be used for feasibility study of geotechnical engineering problems.

1.6 Outline of the Study

This research work is divided in to five Parts. In **Part one** back ground of the study, overview of the study area, objectives, problem statement and scope of the work are presented. **Part two** deals with a literature review. This includes physical characteristics, shear strength, shear modulus and damping ratio of soils and their influencing parameters. **Part three** briefly discusses about the study methodology and description of the study area. In **Part four** test results are presented, analyzed and discussed. Investigation on parameters influencing shear strength and strain dependent shear modulus and damping ratio values and Comparisons with previously conducted research works related to the present research are also emphasized. **Part five** highlights the conclusions and recommendations which incorporate the researcher's ultimate findings and opinions to the study area. Finally, detail calculations of index property tests, pre consolidation pressure, shear strength parameters (c and ϕ) and damping ratio and shear modulus are included in appendix.

2. LITERATURE REVIEW

2.1 General

In engineering practice, soil properties can be divided into static and dynamic soil properties according to the loading type to which soil are subjected. Soil exhibits two different engineering properties under static load and dynamic load.

In recent years, much progress has been made in the development of analytical procedures for evaluating the response of soil deposits and ground failure. Fruitful application of such procedures for determining ground response and failure are essentially dependent on the incorporation of typical soil properties in the analysis. Consequently, considerable effort has also been directed toward the determination of soil properties for use in these analytical procedures.

The soil response and ground failure are strongly influenced by mechanical properties of soil deposits [23]. Site response is primarily influenced by the dynamic properties that control wave propagation, particularly stiffness and damping [35]. Ground failure is influenced by those properties but also by the shear strength of the soil [4]. Thus, the shear modulus and damping characteristics of cyclically loaded soils are critical to the evaluation of Geotechnical earthquake engineering problems at a wider strain level.

2.2 Important Physical Properties of Soils

The most important parameters used to designate soil properties for static and dynamic analysis of geotechnical engineering problems are; field density, specific gravity, plasticity index, grain size distribution, and moisture-density relationship of soils ([4], [3]).

2.3 Shear Strength of Soils

2.3.1 Introduction

The shear strength of soils is an important aspect in geotechnical engineering problems involving either compacted or natural soils such as the bearing capacity of shallow foundations and piles, the stability of the slopes of dams and embankments and lateral earth pressure on retaining walls [4].

The purpose of shear strength testing is to establish representative values for the shear strength parameters (i.e., the cohesion and angle of internal friction) in terms of total or effective stresses under known test condition.

The cohesion is attributable to the resultant of inter particle forces which are mainly associated with the clay-size particle of soils and will vary with the particle size of the particle and the distance separating them. Some of the inter particle forces which contributes to soil cohesion includes are Valence forces associated with surface, ionic forces associated with ions dissociated from polar materials, dipole forces and moments associated with polar material and molecular attraction or van der Waals forces [3].

The angle of internal friction include the effect of interlocking. The interlocking effect itself is affected to some degree by the shape of particles and the grain–size distribution. The interlocking action varies with the density and the angle of internal friction increases with increase in density. Other well-investigated influencing factors include parameters of the testing procedure like displacement rate have some effects. Too high displacement rates cause pore water pressure that will influence test results [4]. Consequently, soils seldom exhibit unique strength parameters and obtaining accurate values is not a trivial task.

2.3.2 Shear Characteristics of Cohesionless Soils

The shear strength of cohesionless soils, such as sand and non-plastic silts, is mainly due to friction between particles.

The stress-strain for dense sands exhibits a relatively high initial tangent modulus. The stress reaches a maximum value at its peak at a comparatively low strain and then decreases rapidly with an increasing strain and eventually becomes more or less constant. The stress-strain curve for loose sands exhibits a relatively low initial tangent modulus [5].

The shear strength of cohesionless soils is governed by shape of particles, confining pressure, water content, vibration and repeated loading, void ratio, confining pressure, intermediate principal stress and rate of loading. The shear strength of cohesionless soils increases with an increase in confining pressure and density [5].

2.3.3 Methods of Determining Shear Strength Parameters

Three types of laboratory tests are commonly used to determine shear characteristics of soils. These tests are the direct shear test, the triaxial compression test and the unconfined compression test. The direct shear test is more convenient for cohesionless soils [3]. In this study direct shear test is used.

On a direct shear test, at least three specimens should be tested at different confining pressure that represent the stress level that the soil sample is undertaken at the field. For low confining pressure, the friction angle tends to be higher than for high confining pressure. The reason of this phenomenon is the curvature that the Mohr coulombs envelop presents at low confining pressures. Considering that, when a friction angle is reported, it is also important to report the normal stresses used for the computation of the frictional resistance [4]. The range of the normal stress should cover the range of loading in the field problems for which the shear parameter are required. Selecting appropriate strain rate is essential during specimen shearing. Selection of strain rate depends upon the characteristics of soil. Usually, it is between 0.005mm/min to 0.2mm/min.

The soil specimens to be tested in direct shear may be either an undisturbed sample or remolded. Test can be conducted on either dry or submerged condition, for which the shear parameters are required. In this study, the sample materials were prepared by adding water till optimum water content reached for the sand and in-situ moisture for the silt soil. In addition, In order to investigate the effects of moisture content and void ratio on the shear strength parameters, sample materials were compacted at different moisture contents. Several test were conducted for drained conditions under 50, 100, 200, 300 and 400 kPa axial stress in accordance with ASTM D 6528 -07 [5].

2.4 Shear Stress- Shear Strain Behavior of Cyclically Loaded Soils

The behavior of soil under symmetrical cyclic loading is nonlinear and hysteretic. The representation of such behavior in the stress-strain plane resembles a loop, which is either closed or open depending on loading conditions.

A comprehensive general stress-strain relation for soil is extremely complicated simply because of the large number of parameters that affect the behavior of soils (Hardin and Drnevich) [37]. Dynamic soil properties are affected by various factors such as strain amplitude, confining pressure, void ratio, over consolidation ratio, loading frequency, temperature, anisotropic stress, and so forth.

In practice, equivalent-linear soil material modeling is widely used to simulate true nonlinear soil behavior. Generally, the cyclic nonlinear behavior of the soil is defined by a loading-unloading curve which is governed by Masing’s rule [32]. The idealized hysteretic stress-strain behavior is shown in Figure 2.1.

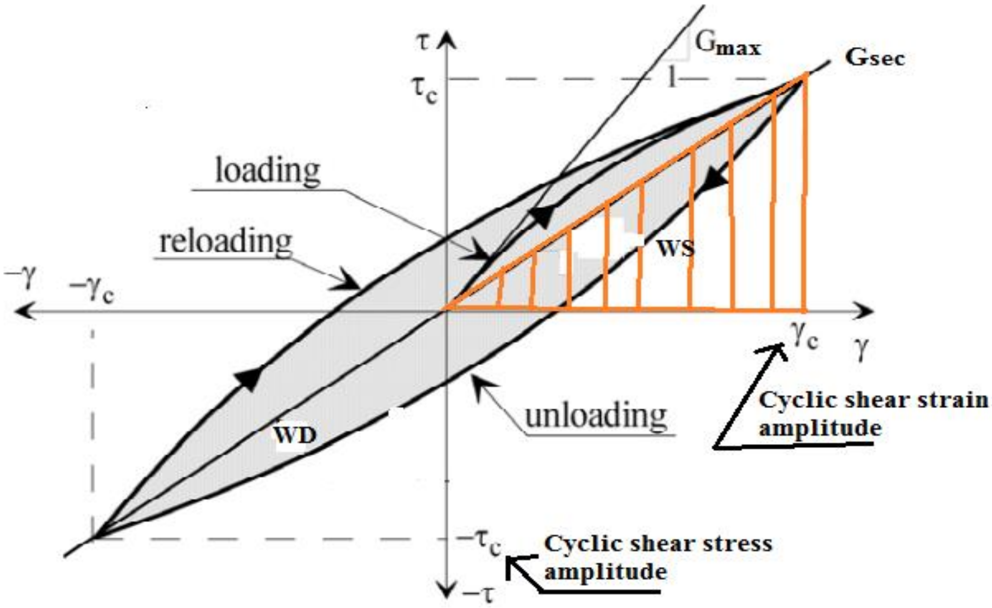


Figure 2.1 Idealized cyclic stress - strain loop [32]

2.5 Dynamic Material Parameters

There are two material parameters used for characterizing cyclic soil behavior. These parameters are shear modulus, G and material damping, D.

2.5.1 Shear Modulus, G

It is a quantitative description of soil stiffness. Soil stiffness is governed by strain levels. Shear modulus at low strain levels represented by shear wave velocity directly related to small-strain shear modulus (G_{max}). At moderate to high strains, the secant shear modulus (G_{sec}) or equivalent shear modulus is used to represent the soil stiffness [18]. Secant shear modulus (G_{sec}) is computed from the extreme points of the hysteretic stress-strain loop. The most reliable method of producing representative moduli has been to evaluate the difference in maximum and minimum stress applied during a loop, and the difference in maximum and minimum strain developed in that loop. The ratio of these two values has been used throughout for shear modulus calculation.

$$G = \frac{\tau}{\gamma} \text{---} [2.1]$$

The shear stress and shear strain were evaluated from lateral force and lateral LVDT test results.`

$$Shear \text{ stress, } \tau = \frac{Shear \text{ force}}{Area \text{ of sample}} = \frac{Shear \text{ force}}{\pi 35^2} 10^2$$

$$Shear \text{ strain, } \gamma = \frac{Lateral \text{ displacment}}{Height \text{ of sample } after \text{ consolidation}}$$

2.5.2 Damping Ratio, D

The material damping ratio represents energy dissipated by the soil. Mechanisms that contribute to material damping are friction between soil particles, strain rate effect, and nonlinear soil behavior. It is defined as the damping coefficient divided by the critical damping coefficient. Theoretically, there should be no dissipation of energy in the linear elastic range. However, even at very low strain levels, there is always some energy dissipation measured in laboratory specimens [19]. The damping ratio at very low strain levels is a constant value and is referred to as the small-strain damping ratios D_{min}. Damping is used in several dynamic analysis procedures to provide realistic motion attenuation. Thus damping is calculated using the area of the actual stress strain loop as shown below [19].

$$D = \frac{W_D}{4\pi W_s} \text{---[2.2]}$$

where, W_D= energy dissipated in one cycle of loading, and W_S = maximum strain energy stored during the cycle. As shown in Figure 2.1, the area inside the hysteresis loop is W_D [A_{loop}], and the area of the triangle is W_S [A_Δ].

$$A_{loop} = \frac{1}{2} \sum_{i=1}^{n} (\tau_i - \tau_{i+1})(\gamma_{i+} \gamma_{i+1})$$

$$A_\Delta = 0.5(S * L)$$

2.5.3 Strain Dependency of Dynamic Parameters

In static soil mechanics, very small strains are usually not studied. Indeed their impact on foundations and structures is negligible. However, as soon as a dynamic load is applied to the soil, inertial forces can become significantly great whenever deformation motion is rapid enough, which means their influence cannot be neglected even at strains as small as 10^{-6}.

Experimental observations have shown that the secant shear modulus and damping ratio are strongly influenced by the shear strain amplitude ([19], [26], [34]). Both shear modulus and damping ratio are functions of shear strain and categorized in to two strain ranges [32]. Below an elastic threshold strain (γ^e_t) commonly said to be in the small-strain or linear strain range, the shear modulus and material damping ratio are constant and independent of shearing strain amplitude. Above γ^e_t commonly known nonlinear range, the shear modulus and material damping ratio of soil are dependent on the level of the shearing strain, soil remains non-linear and will begin experiencing permanent deformation or plastic and eventually reach an unstable condition [19]. In the literature, the value of γ^e_t is often taken as 10^{-3}%. But, in general γ^e_t vary with soil type [20].

As the strain increases the secant shear modulus will decrease. Modulus degradation with cyclic strain is exemplified by means of modulus reduction curve. The modulus reduction curve normalizes the shear modulus (G) with respect the maximum shear modulus (G_{max}) by G/G_{max} and is commonly referred to as the modulus ratio. As the soil element drops stiffness with the amplitude of strain, its ability to dampen dynamic force increases. This is due to the energy dissipated in the soil by friction, heat or plastic yielding. The relationship of shear strain to damping is inversely proportional to the modulus reduction curve as show in Figure 2.2 [25].

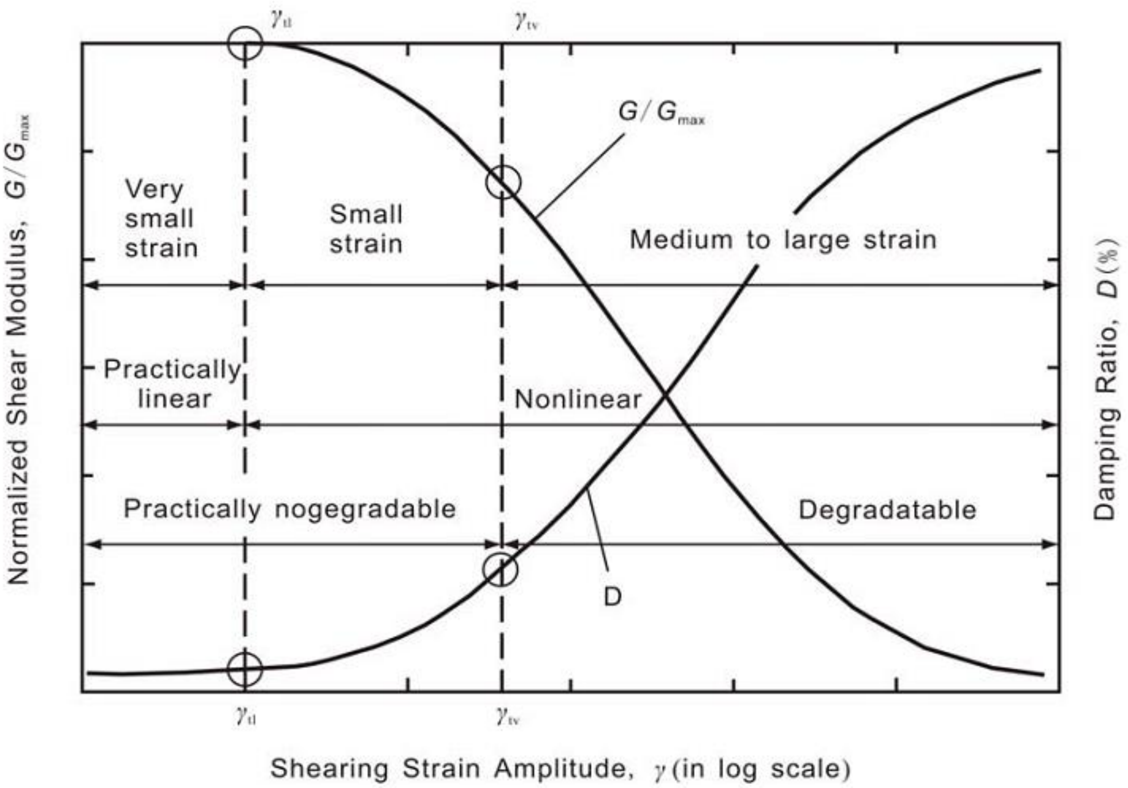


Figure 2.2 Normalized modulus and damping curves with different zones of cyclic shearing strain amplitude for soil [25

2.5.3.1 Small-Strain Behavior of Soils

The maximum shear modulus, modulus of reduction and damping ratio of the soil are important parameters for dynamic analysis of the soil.

The small-strain behavior of soils is linear, an increase in the shearing strain causes a linear increase in the shearing stress, and the shear modulus is constant with shearing strain as long as the shearing strain is less than 10^{-3}% [18].

Shear modulus at low strain levels represented by shear wave velocity directly related to small-strain shear modulus, G_{max}:

$$G_{\max} = \rho v_s^2 \text{ ---[2.3]}$$

where ρ = mass density of soil

Confining pressure together with void ratio are recognized as the very important parameters which influence the small-strain shear modulus of soil [19]. Accordingly, a considerable number of empirical relationships have been proposed for estimating initial shear modulus (at essentially zero strain) for different kind of soils: And with no shear wave velocity data, G_{max} can be computed from site-specific investigations or available correlations.

Hardin and Drnevich [18] have shown that for all soils the G_{max} may be calculated by the following equation.

$$G_{\max} = 3.23X \frac{(2.97-e)^2}{(1+e)} \mathrm{X(OCR)}^{\mathrm{k}} (\sigma'_{\mathrm{o}})^{\mathrm{k_o}} \text{ --[2.4]}$$

$$\sigma'_o = \frac{(\sigma'_{\mathrm{v}} + 2\mathrm{k_o}\sigma'_{\mathrm{v}})}{3}$$

where: e = void ratio

OCR = over consolidation ratio

σ'_o = mean effective stress

σ'_v = effective vertical stress

K_o =coefficient of lateral earth pressure at rest

k =dimensionless quantity which is a function of PI.

Table 2.1 Empirical values of exponential parameter (k) by Hardin and Drnevich [18]

PI	0	20	40	60	80	>100
K	0	0.18	0.13	0.41	0.48	0.5

Seed and Idriss [33] have shown that for sands the G_{max} may be calculated by the following equation.

$$G_{\max} = 1000 k_{2\max}(\sigma_m^{'})\text{--}[2.5]$$

where, σ'_m is mean effective consolidation stress and equal to:-

$$\sigma'_m = \frac{\sigma'_v + 2\sigma'_h}{3}$$

where, σ'_v is vertical effective consolidation stress and σ'_h is horizontal effective consolidation stress and K_{2max} is an empirical factor.

In Equation [2.5], the units of G_{max} and σ'_m are pounds per square feet. The mean effective stress, σ'_m, was estimated by assuming that $\sigma'_v = \sigma'_{vc}$ and $\sigma'_h = k_o\sigma'_v$, where k_o is the coefficient of earth pressure at rest. The values of K_{2max} vary according to void ratio as presented in Table 2.2 [33].

Table 2.2 Values of K_{2max} [33]

K_2max	70	60	51	44	39
e	0.4	0.5	0.6	0.7	0.8

The important utility of this parameter is that it can be used as a varying parameter with respect to strain making the soil response represent the real modulus degradation in soil behavior. This parameter is used in defining the stiffness matrices for finite element analysis of earth structures and foundation soils.

2.5.4 Methods of Determining Shear Modules and Damping Characteristics

A wide variety of procedures, including laboratory and field tests have been used to determine both shear modules and damping characteristics. Laboratory tests have some advantages over in situ tests. Laboratory tests generally enable to measure properties with a high accuracy, they allow for the controlled drainage of pore water, they allow to measure properties at other confining stress than those in situ and they can reach high strain levels, which allows measuring the nonlinearity of the material [20]. On the other hand, laboratory tests require soil sampling, which inevitably leads to disturbance of the soil. Furthermore, laboratory tests measure soil properties in discrete points only. Due to the heterogeneous nature of the soil, laboratory tests may yield results that are not representative for the entire test site [19].

The different test procedures for computing shear modules and damping characteristics and the approximate ranges of strain within which they have been used are summarized in Table 2.3.

Table 2.3 Test procedures for measuring moduli and damping characteristics [19]

General procedures	Test condition	Approximate strain range	Properties that may be determined
Determination of hysteretic stress strain relationships	Torsional shear	10^{-2} to 5%	Shear Modulus; Damping
	Simple shear		Shear Modulus; Damping
	Triaxial compression		Shear Modulus; Damping
Forced vibration	Longitudinal	10^{-4} to 10^{-2}%	Shear Modulus; Damping
	Torsional vibrations		Shear Modulus; Damping
	Shear vibrations-lab		Shear Modulus; Damping
	Shear vibrations-field		Shear Modulus
Free vibration tests	Longitudinal	10^{-3} to 1%	Shear Modulus; Damping
	Torsional vibrations		Shear Modulus; Damping
	Shear vibrations-lab		Shear Modulus; Damping
	Shear vibrations-field		Shear Modulus
Field wave velocity measurements	Compression waves	5×10^{-4}%	Shear Modulus
	Shear waves		Shear Modulus

2.5.5 Parameters Affecting Shear Modulus and Damping Ratio in Soils

Thus stiffness and damping properties are generally characterized by shear modulus, represented by modulus reduction curve and damping ratio, represented by damping curve of soil which decreases and increases with the strain respectively [32]. To well understand the nature of dynamic soil properties, the influence factors should be completely investigated. Dynamic soil properties are affected by various factors such as soil type, plasticity index, cyclic strain amplitude, frequency of loading cycle, effective confining pressure, over consolidation ratio, and number of loading cycles ([32], [37]). Table 2.4 presents effects of each factor on shear modulus and damping ratio of soil.

Table 2.4 Factors affecting stiffness and damping of natural soils [32]

Affecting factor	G_{max}	G/G_{max}	D
Confining pressure	Increase with σ_o	Stays constant or increase with σ_o	Stays constant or decrease with σ_o
Void ratio, e	Decrease with e	Increase with e	Decrease with e
Geologic age, t	Increase with, t	May increase with t	Decrease with t
Cementation, c	Increase with , c	May increase with , c	May decreases with , c
Over consolidation, OCR	Increase with OCR	Not affected	Not affected
Plasticity index , PI	Increase with pI	Increase with PI	Decrease with PI
Cyclic Strain	-	Decrease with γc	Increase with γc
Number of loading cycles	Decrease with, at large γ.	Decrease with, N at large	Not significant at modera γ and N
Strain rate	Increase with strain rate	G increases with, G/Gma probably not affected	Stays constant, or may increase

In this study, the effects of shear strain amplitude, effective stress level, loading frequency, number of cycles and void ratio on shear modulus and damping ratio of cohesionless soils are addressed.

2.5.5.1 Shearing Strain Amplitude

Experimental observations have shown, in many different laboratory or in situ conditions, that the secant shear modulus and damping ratio are strongly influenced by the shear strain amplitude. The shear modulus keeps at a highest value as long as the shearing strain is less than one certain value because of the linearity of the curve in nature.

As known, the shear modulus decreases and damping ratio increases as shearing strain amplitude increases. Many researchers ([32], [34], [39]) have reported that the effect of shearing strain amplitude vary with confining pressure. Hardin [37] reported that the effect of shear strain on shear modulus decreases if effective axial stress increases (Figure 2.3). It has the same trend for damping ratio, in other words, the damping curve shifts to the right lower location as the confining pressure increases (Figure 2.4).

In this study shear modulus and damping ratio were determined at medium to large strain level ranges.

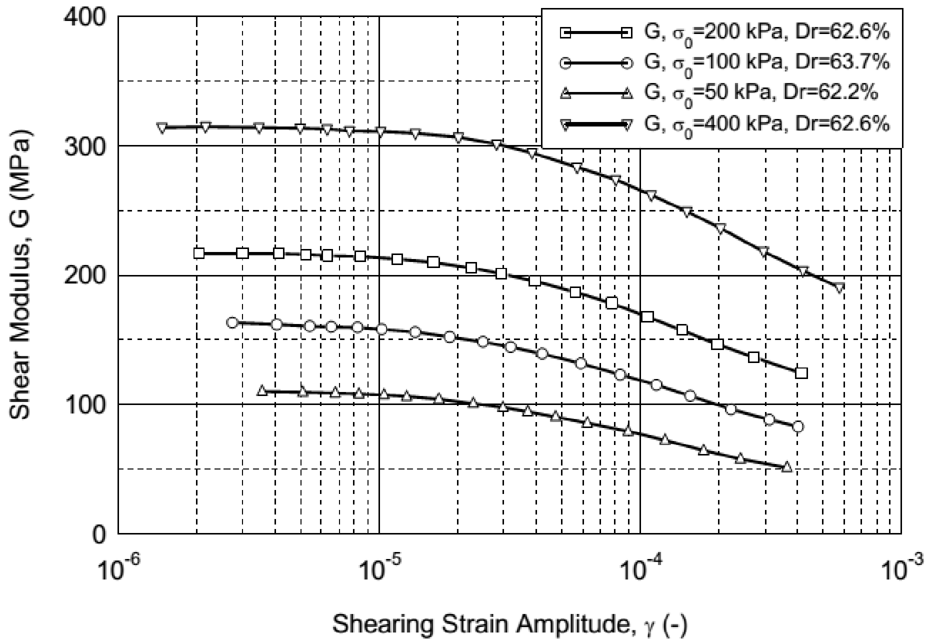


Figure 2.3 Variation of shear modulus with shearing strain amplitude for Berlin sand under various confining pressures [37]

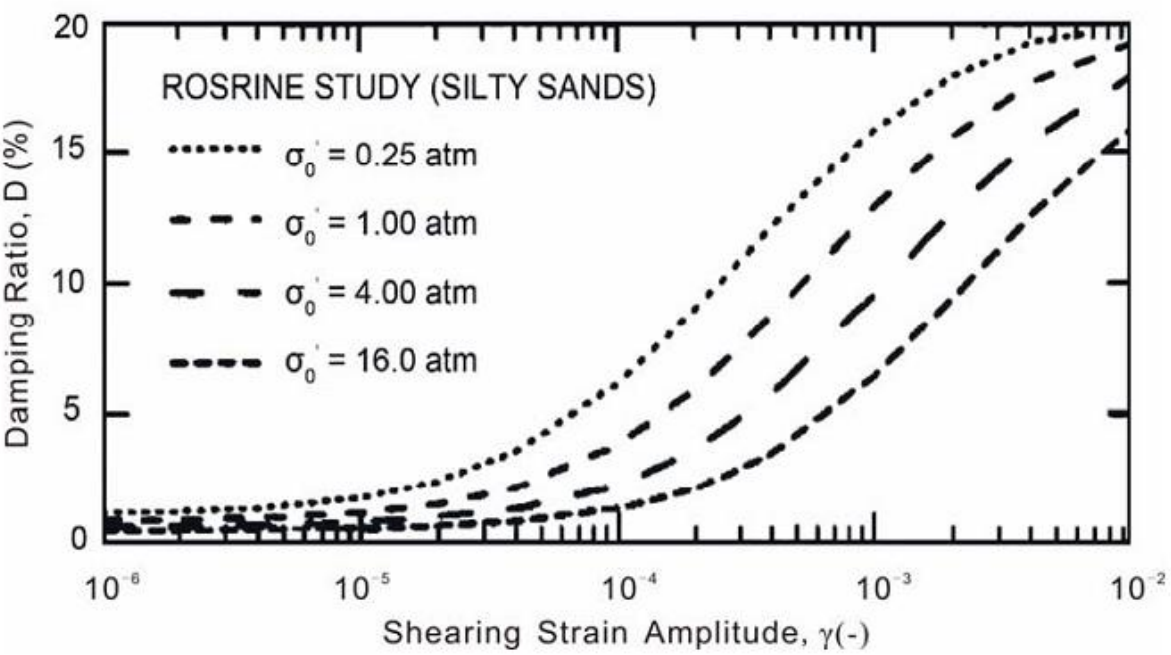


Figure 2.4 Effect of confining pressure on damping curve for silty sand [37]

2.5.5.2 Number of Loading Cycles

Silver and Seed [32] measured the shear modulus and damping ratio of dry sands at cycles of loading, and indicated that, in general, the shear modulus slightly increased and damping ratio significantly decreased with increasing number of loading cycles as shown in Figures 2.5 and 2.6. As shown in these figures, the primary increase in shear modulus and decrease in damping ratio occurred within the first 10 cycles of loading. Other several investigations reported that shear modulus the shear modulus moderately increased the damping ratio might strongly decrease as the increase of number of cycles of sand and silt soils [26]. In most seismic events, the number of significant cycles is likely to be less than 20 and for all practical purposes, the shear modulus and damping ratio values determined at 5th cycles [22]. In this study shear modulus and damping ratio were determined at 5th loading cycles.

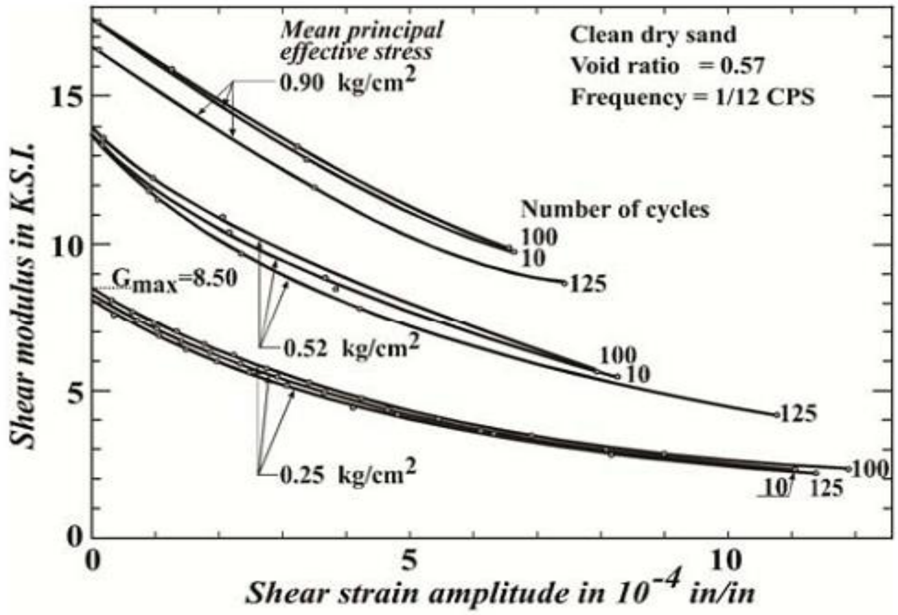


Figure 2.5 Variation of shear modulus with number of loading cycles [26]

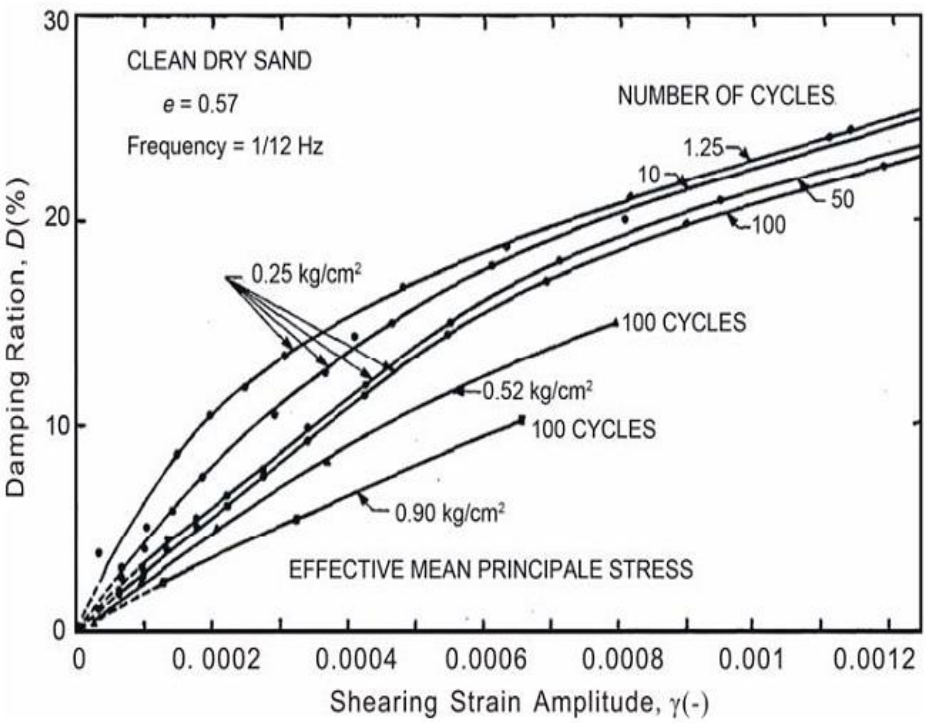


Figure 2.6 Variation of damping ratio with number of loading cycles [26]

2.5.5.3 Loading Frequency

Several investigations had revealed that loading frequency or strain rate of different cyclic loadings may range from 0.01 to 100 Hz. And they conclude that loading frequency has only small or no influence on small-strain shear modulus for cohesionless soils [19].

It is common practice to carry out laboratory cyclic tests at a frequency range of 0.1 to 2 Hz. Mostly the frequency of 1 Hz is preferred [22]. In this study, a frequency of 1 Hz is used.

2.5.5.4 Confining Pressure

The effects of confining pressure are admittedly assumed as one of the two very important factors (another is void ratio) which significantly influence the maximum shear modulus of sandy [18].

The shear modulus increases and damping ratio decreases as confining pressure increases (Figures 2.7 and 2.8) [18].This is due to the influence of confining pressure resulting to lesser void ratio by densification of soil sample. The small-strain shear modulus, G_{max} decreases with increasing void ratio. However effect of void ratio has no significant influence on damping ratio at any shearing strain amplitude under all confining pressures [25].

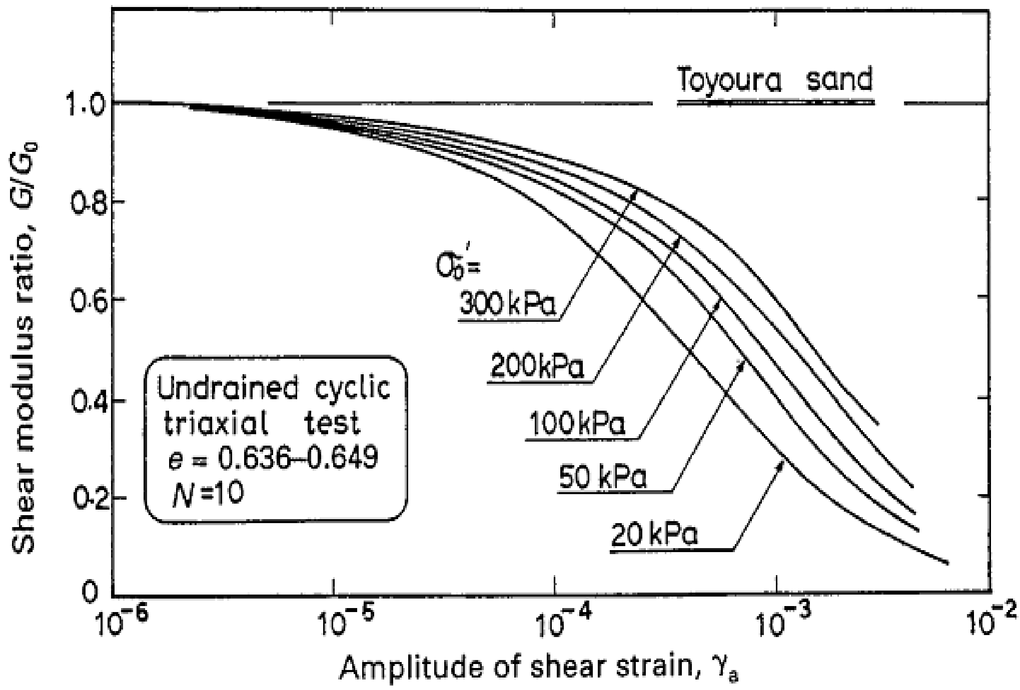


Figure 2.7 Effects of confining pressure on the strain-dependent shear modulus [18]

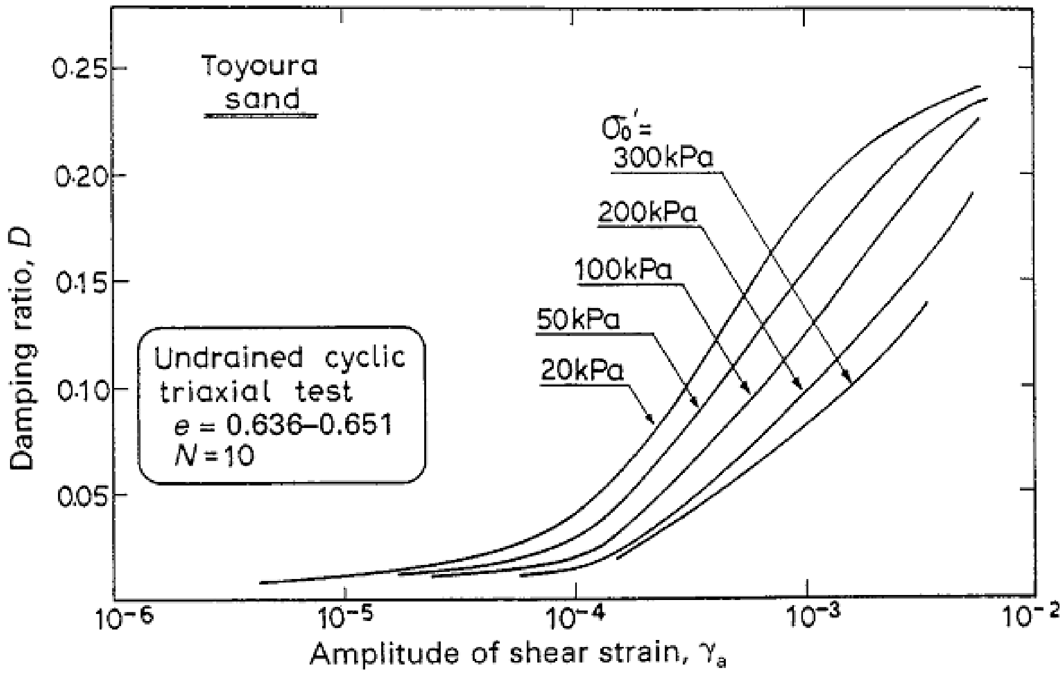


Figure 2.8 Effects of confining pressure on the strain-dependent damping ratio [18]

From the addressed influencing factors of shear modulus and damping ratio of cohesionless soils, sand and silts, shearing strain amplitude, void ratio and confining pressure are the primary affecting parameters.

2.5.6 Values of Shear Modulus and Damping Ratio of Sand

The shear modulus and damping ratio as a function of shear strain of sand was determined by a number of investigators using different laboratory testing procedures under different factors [34].

All investigation have shown that modulus values for sands are strongly influenced by the confining pressure, the strain amplitude and the void ratio (or relative density) but not significantly by variations in grain size characteristics. The damping characteristics of sand is basically affected by shear strain, effective mean principal stress, void ratio and number of cycles. Based on these studies, Bolten and Indries presented the range of values of shear modulus and damping ratios shown in Figures 2.9 and 2.10 respectively [34].

Well-known curves for dynamic properties of silt soils are infrequent compared to sand soils.

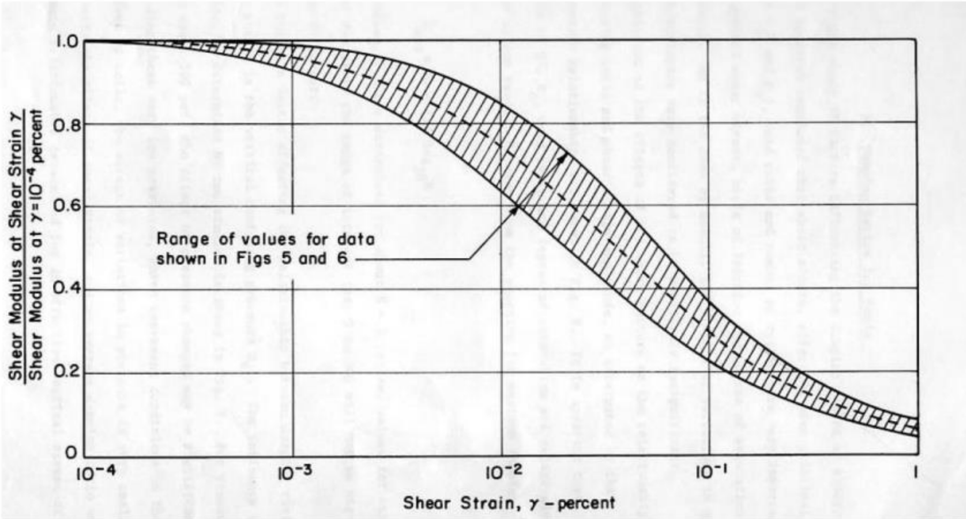


Figure 2.9 Variation of shear modulus with shear strain for sand [34]

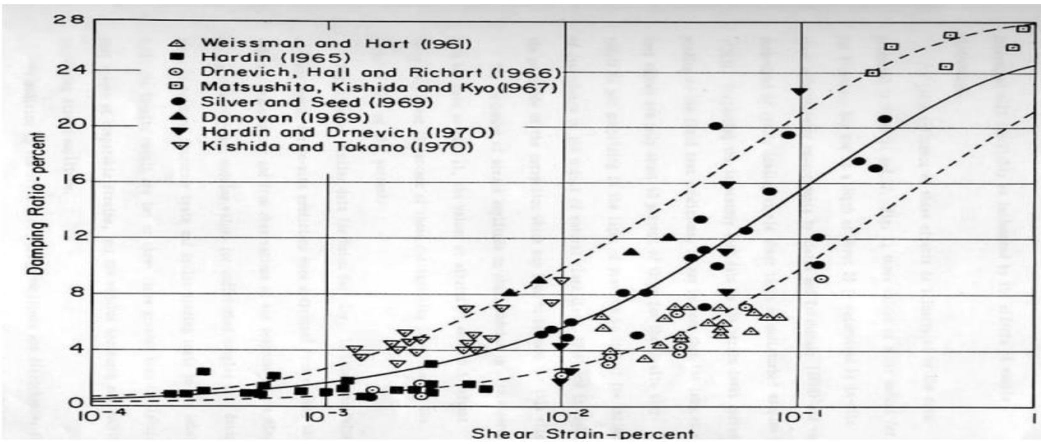


Figure 2.10 Variation of damping ratios with shear strain for sand [34]

2.6 Previously Conducted Soil Dynamic Property Tests in Ethiopia

Studies on sand in Koka [16] and silt soils in Modjo [17], Adama [15], Ziway [27], Hawasa [14] and Arba Minch [11] showed that the shear modulus and damping ratio of local silt and sand soils are pointedly affected by confining pressure, shear strain amplitude and number of loading cycles. As the confining pressure increases, the shear modulus increase and damping ratio decreases due to the compactness of soil sample. Shear modulus decreases and damping ratio increase with increase in cyclic shear strain amplitude. Shear modulus reduction values of local silt soils are comparable with the other literature values except for lower strain levels due to testing conditions. The modulus reduction values of local sand soil are located lower than the other literature values of sand soil especially at lower strains but agree at higher strains. The damping ratio values of local silt soil are slightly lower than the other literature values due to effects of testing conditions [27]. The damping values of local sand soils are almost similar with the other literature values of sand soil. The findings of the researchers are presented in Table 2.5.

Table 2.5 Modulus reduction and damping ratio values of soils in Ethiopia

Study area	Shear strain [%]	Normalized shear modulus			Damping ratio [%]		
		Confining pressure					
		100kPa	200kPa	400kPa	100kPa	200kPa	400kPa
Ziway silt soil	0.01	0.21	0.3	0.35	6.09	5.5	2.85
	0.1	0.12	0.17	0.21	8.82	8.01	4.44
	1	0.07	0.1	0.11	15.52	14.67	10.6
	2.5	0.06	0.07	0.08	19.45	18.65	14.26
	5	0.04	0.05	0.07	23.29	21.99	17.68
Adama silt soil	0.01	0.33	0.33	0.36	4.80	4.21	4.21
	0.1	0.19	0.23	0.23	10.67	7.02	7.02
	1	0.13	0.13	0.15	11.84	9.52	9.52
	2.5	0.05	0.07	0.11	17.76	15.82	15.82
	5	0.03	0.04	0.05	27.32	22.63	22.63
Modjo silty soil	0.01	0.33	0.37	0.39	5.01	2.88	1.46
	0.1	0.15	0.17	0.19	8.29	5.21	3.04
	1	0.06	0.07	0.09	15.91	11.82	9.68
	3	0.04	0.05	0.07	19.66	15.58	13.19
	5	0.02	0.04	0.05	23.25	19.14	16.42
Hawasa silty soil	0.01	0.19	0.23	0.26	4.56	3.68	2.93
	0.1	0.13	0.17	0.19	11.66	5.34	3.13
	1	0.09	0.09	0.13	16.64	13.08	4.46
	3	0.04	0.05	0.07	17.79	14.6	10.67
	5	0.01	0.02	0.03	28.91	19.54	13.83
Dry Koka sand soil	0.01	0.43	0.50	0.62	3.67	2.98	2.09
	0.1	0.27	0.28	0.47	10.56	5.87	2.99
	1	0.14	0.21	0.30	15.89	12.56	3.89
	3	0.12	0.20	0.24	17.09	14.23	9.06
	5	0.13	0.16	0.16	20	17.9	14.04

3 DESCRIPITION OF STUDY AREA AND EXPERIMENTAL TECHNIQUES

3.1 Description of Study Area

Dire Dawa was founded in 1902 by "Chemen defer Franco-Ethiopian" railroad, which was built by the French between the years 1897-1917.Dire Dawa town is located in the eastern part of the country specifically lying between 900 27' and 900 49'N latitudes and between 4100 38' and 4200 19'E longitudes and the town is 515 Km from Addis Ababa the capital city of Ethiopia [42].

Dire Dawa is the second largest and oldest urbanized center in Ethiopia, next to Addis Ababa, having a total population about 398,000. Dire Dawa town is located at center of Ethio-Djibouti railway. This gives Dire Dawa city the advantage of being a commercial town. It has an enormous development potential, industries mainly comprise food-processing plants, textile, international airport, cement factory and planned Dry port [42].

Dire Dawa has a total area of about 66,017Ha of which the south and south-eastern part of the city which is characterized by a chain of mountains and upland covering 45%; low lying flat land accounting for 40% of the land area; and the remaining 15% is covered by gorges, valley and River terraces (42). Because of its tropical location Dire Dawa is experiencing high temperature throughout the year with minor seasonal variations and seasonal bimodal distribution rainfall. Generally it is grouped in the Kola and semi-kola climatic zone with an average monthly temperature 24.8 degree Celsius and an average annual rainfall amounts to 604 mm.

3.1.1 Geologic and Seismic Settings

Geologically, the study area comprises of Precambrian with high grade metamorphic rocks (gneiss, pegmatite and granodiorite), Jurassic Adigrat sandstone and Hamaliei limestone with varies thicknesses and compositions which are located in the upper most part of the area. And the geological formation of the area is a function of geomorphologic settings. Outcrops of Precambrian rocks, Adigrat sandstone, Hamanalei limestone, upper sandstone and basalts mostly covered the escarpment while the down thrown plain is dominantly covered by alluvial deposits [13

The major soil types exhibit a general relationship with altitude, climate and vegetation. Generally, the soils of the valley are developed on recent alluvial sediments derived from the adjacent mountain ranges [42].

The area consists of three tectonic units; the plateau, the escarpment and the depression. The plateau and escarpment is dominated by E-W or ENE-WSW trending faults and perpendicular to the drainage system in the area. The blocks are downthrown to the north and form the boundary of the rift system. Abrupt change in slope gradient on the escarpment causes decreases in velocity of surface water, which has resulted in forming fans at the foot of the escarpment.

The town is found near the most seismically hazardous areas and categorized to “medium” risk seismic hazard having PGA, 0.8-2.4m/s^2 (Figure 3.1) [40]. It is very near to main fault lines of Wonji fault, Nazret fault, Addis-Ambo-Ghedo fault and FilWoha fault, where many earthquakes have previously occurred [31].

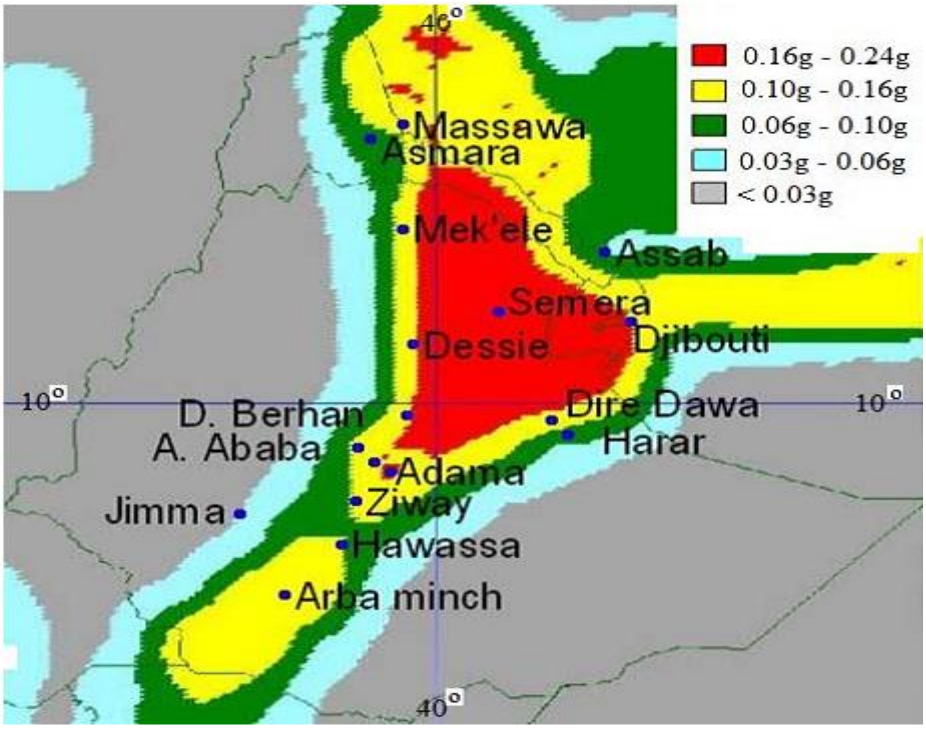


Figure 3.1 Seismic hazard map of Ethiopia based on the GSHAP data for a return period of 475 years [40]

3.2 Experimental Techniques

3.2.1 Sample Materials

In this study, soil samples were collected from selected locations in the study area (Figure 3.2). Before sampling, visual site investigations were made to consider the different soil types and to sample evenly in the study area. Accordingly seven test pits were excavated to the depth of 1.5m to 4m as most of the foundation constructions are founded around this depth. From the test pits undisturbed and disturbed soil samples were collected at any depth wherever there was a soil layer change. Then, several field and laboratory tests were conducted on the collected samples.

Field tests consisted in-situ density determination using the core cutter method according to the designation ASTM D in-place water content. Collected disturbed soil samples from each layer were used to determine index properties and characterize the soil in order to select typical soil materials for direct shear and cyclic simple shear tests. Hence, two typical soils are selected to conduct direct shear and cyclic simple shear tests.

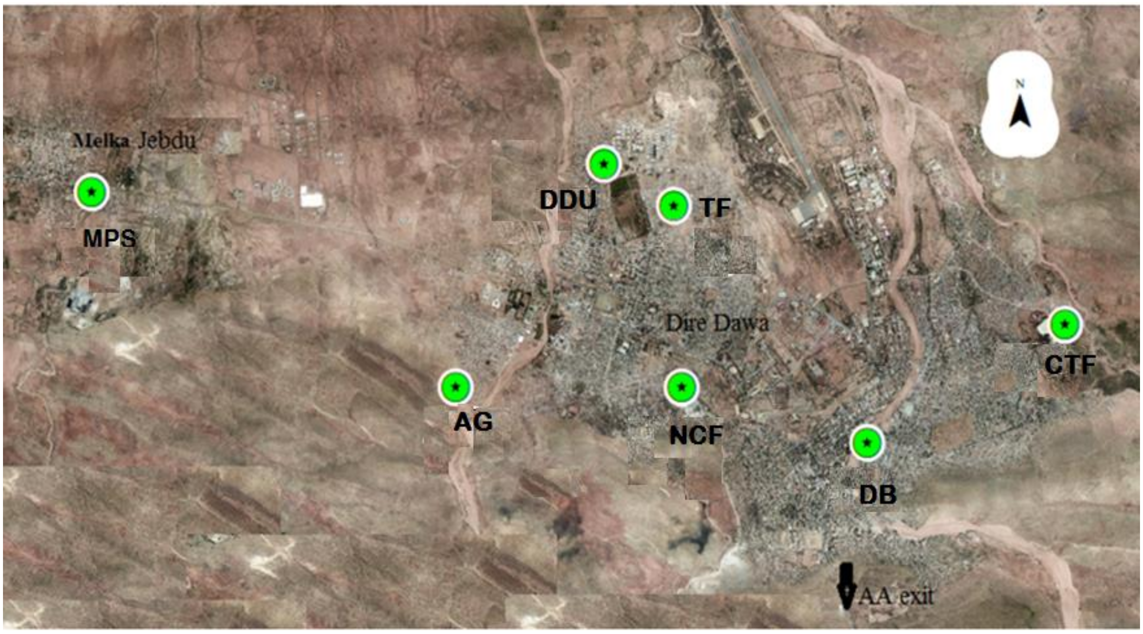


Figure 3.2 Location of sample material

3.2.2 Cyclic Simple Shear Apparatus and Testing

Cyclic simple shear testing is useful in the study of stress-strain relationships and the shear strength for a range of soil types. The simple shear test apparatus allows shear tests at a constant height or constant volume by adjusting the vertical load. The pore water pressure that would occur in undrained conditions with constant normal stress is equal to the resulting change in vertical stresses. The system is controlled by the UTS004 software application program [38].

The cyclic simple shear apparatus is often used in soil dynamics as it can simulate loading conditions to research the stability under seismic events at high range strain amplitude, the test can be used to determine the shear modulus and material damping ratio [19].

It is not possible to avoid variations from the aspired constant stress state at the border of the specimen [32]. The irregular distribution of normal and shear stresses in border areas is notably higher at high deformation levels.

When comparing results from the cyclic simple shear tests with results from the cyclic triaxial tests, the different stress states in both tests have to be considered. At the same normal stress acting on failure plane the mean principal stress σ_m differs between both tests. In cyclic triaxial test it equals the consolidation stress σ_c, but in a cyclic shear test $\sigma_m = 1/ (3 (\sigma_1 + 2\sigma_2))$ with $\sigma_2 = K_0\sigma_1$ [38].

There are several types of cyclic direct simple shear apparatus**.** In this study model 31-WF7500 was used, which is found in the Geotechnical laboratory of Addis Ababa Institute of Technology shown in Figure 3.3.

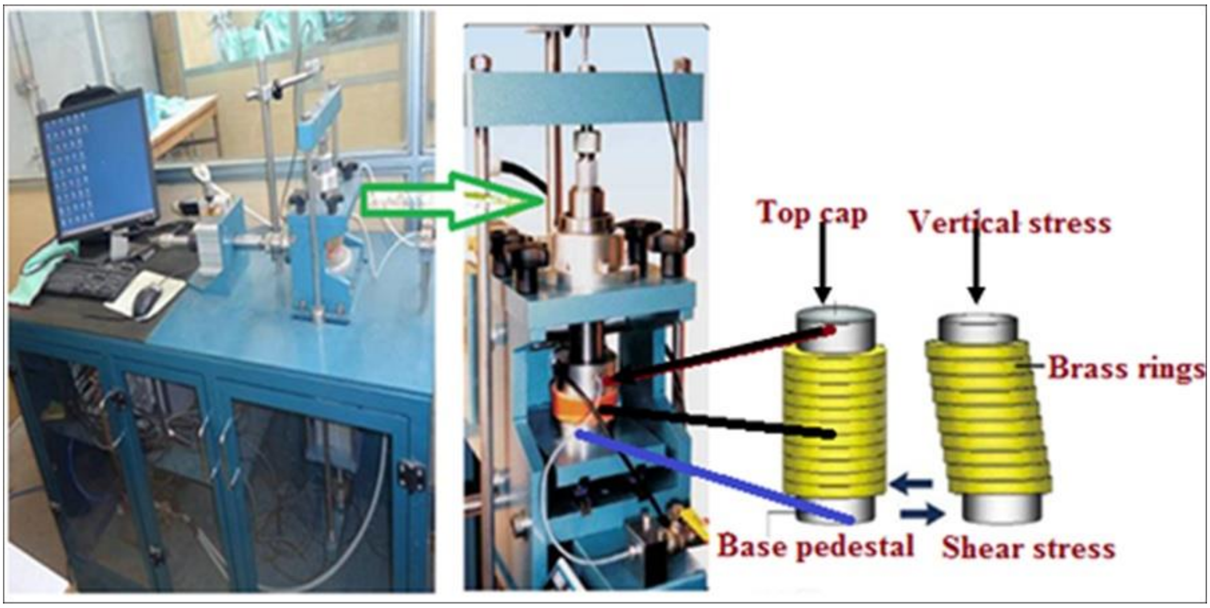


Figure 3.3 Model 31-WF7500 cyclic direct simple shear apparatus used for the cyclic tests [37]

The simple shear test is also the laboratory test which best fits an earthquake loading, as shown in Figure 3.4 [37].

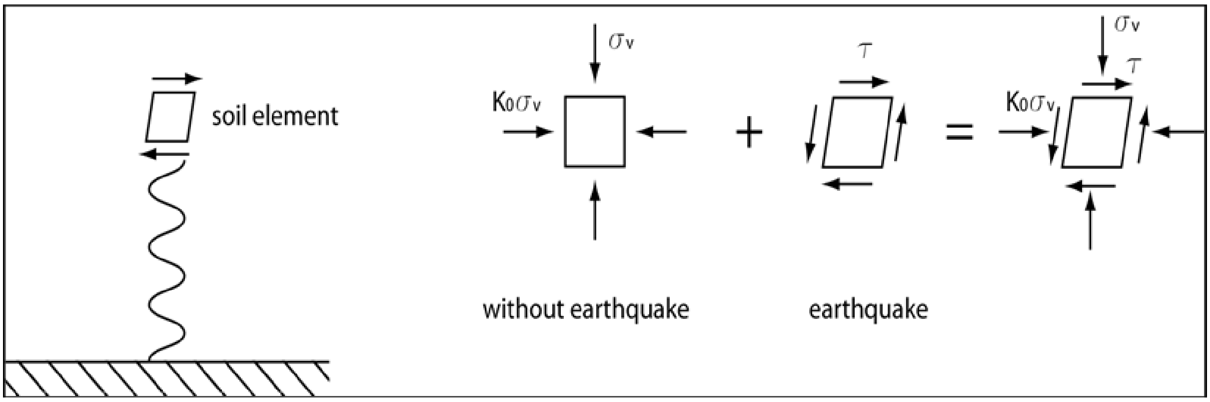


Figure 3.4 Earthquakes loading of a soil element [37]

3.2.3.1 Testing procedures

In this study cyclic direct simple shear test was done according to the standard ASTM D 6528 -07. The test consists three phases; Specimen preparation and setting up the test apparatus, consolidation, and constant-volume shearing at high strain amplitude ranges between [0.01% to 5%].

***Specimen preparation and setting up the test apparatus*: -** Pulverized samples sieved on sieve No. 4(4.75mm), and then known weight of soil is taken and mixed with water that equal to percentage of natural water content for silt soil and OMC for sand soils. The specimen is then remolded in a mold to attain field density and natural moisture content for silt and MDD and OMC for sand soil. From this remolded specimen, 20mm height and 70mm diameter of sample is prepared; and then placed in rubber membrane which is mounted on bottom plate of cyclic direct simple shear machine which is confined by brass rings to control lateral deformation of sample during consolidation stage.

Consolidation:-done by applying normal stress to a pre-selected value that is larger than the effective consolidation pressure in situ as this is done to manifest over burden pressures. In this study 100kPa, 200kPa and 400kPa axial stresses are used for consolidation. The consolidation stage is manually terminated by the operator once consolidation of the specimen is determined to be complete.

Axial stress and specimen displacements (axial and lateral) data are measured over time while the lateral loading (shear) axis is held stationary and logged by the system. Logged data is also displayed to the operator in the form of charts and tables.

***Cyclic shearing stage*:-**After consolidation phase, constant-volume cyclic shearing of specimen begins. The horizontal load history acting on specimen is considered as a sinusoidal waveform, triangular or rectangular. The strain ranges are between 0.01% and 5% and 0.5mm-2mm amplitude range. In most seismic events the number of significant cycles is likely to be less than 20. The dynamic behavior of soils is relatively insensitive to the frequency of applied cyclic loading within the range of 0.5 to 2 Hz. In this study, the frequency of cyclic load is 1.0 Hz, strain range between 0.01% to 5% [0.01%, 0.1%, 1%, 2.5% and 5%] and 40 number of cycles is used. Both lateral force and specimen displacements are measured for each loading cycle. Measured data is obtained from 50 sample points captured over a single cycle period. The shear modulus and damping ratio are determined at 5^{th} cycles. Nevertheless, the form of the load applied by motors may not follow the ideal sinusoidal waveform due to the quality of load control system. The problem of achieving an ideal waveform is particularly important for cyclic load-controlled tests on soils whose response is excessively nonlinear, whereas the simple manual control of strain or displacement rate in a cyclic displacement-controlled test provides very satisfactory results (Doroudian and Vucetic) [20]. In this study strain controlled test has been carried out. Summary of loading and test conditions and sample type used for cyclic tests is shown in Table 3.1.

Table 3.1 Summary of loading and test conditions and sample type used for cyclic tests

Sampling location	Soil type	Sample type	Test condition	Shear strain amplitude [%]	Axial stress [kPa]
AG	Sand	Remolded to OMC	Undrained	[0.01, 0.1, 1, 2.5 & 5]	100
				[0.01, 0.1, 1, 2.5 & 5]	200
				[0.01, 0.1, 1, 2.5 & 5]	400
TF	Silt	Remolded to field Condition	Undrained	[0.01, 0.1, 1, 2.5 & 5]	100
				[0.01, 0.1, 1, 2.5 & 5]	200
				[0.01, 0.1, 1, 2.5 & 5]	400

4. RESULTS AND DISCUSSIONS

4.1 Index Properties Test

Index property tests are conducted to characterize soils under consideration and to gain a better understanding on the behavior of soils under static and dynamic loading condition.

The basic index properties done in this study are listed below.

- ✓ In situ density and moisture content
- ✓ Specific gravity
- ✓ Grain size analysis and
- ✓ Atterberg`s limits

All tests were conducted according to ASTM procedures. ASTM D 854-02 standard test for specific gravity of soil solids by water pycnometer, ASTM D 422 standard test method for particle size analysis of soils, ASTM D 4318-00 standard test methods for liquid limit, plastic limit, and plasticity index of soils, ASTM D 698-98 standard test method for laboratory compaction and ASTM D 293-00 field density of soil. The In situ Density and moisture content was determined to investigate field condition. The sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles. The grain-size distribution curves soils under consideration are shown in Fig.4.1. Details of the index properties tests are shown on Appendix A-1 to A-4 and Summary of the test results are presented in Table 4.1.

Table 4.1 Summary of index properties test results

Sampling Location	Sampling Depth [m]	ρ bulk [g/cm^3]	ρ dry [g/cm^3]	w [%]	Gs	Void ratio ,e	LL [%]	PL [%]	PI [%]	Grain size analysis					
										Gravel	Sand	Silt	Clay	C_u	C_c
DDU	1.5	1.31	1.15	13.6	2.55	1.21	18.00	0.00	0.00	2.48	75.03	12.32	10.15	-	-
	3.5	1.33	1.10	20.96	2.65	1.40	31.00	28.00	3.00	2.11	40.85	34.85	22.18	-	-
TF	2.0	1.43	1.10	30.75	2.62	1.39	52.00	37.00	15.00	0.22	15.62	42.48	41.67	-	-
	4.0	1.46	1.19	22.43	2.66	1.23	37.00	34.00	3.00	3.08	15.39	61.71	19.81	-	-
NCF	3.0	1.44	1.29	11.50	2.65	1.05	-	-	-	3.05	91.7	5.18	0.00	6.00	0.66
DB	3.0	1.36	1.23	10.53	2.70	1.19	-	-	-	2.05	93.21	4.74	Nil	5.00	0.91
CTF	2.5	1.43	1.17	22.65	2.61	1.23	31.00	27.00	4.00	8.26	38.71	42.46	10.58	-	-
MPS	3.0	1.38	1.17	17.23	2.61	1.23	38.00	30.00	8.00	1.73	21.08	58.19	19.04	-	-
AG	3.0	-	-	-	2.69	0.60	-	-	-	3.86	92.00	4.27	Nil	5.33	0.75

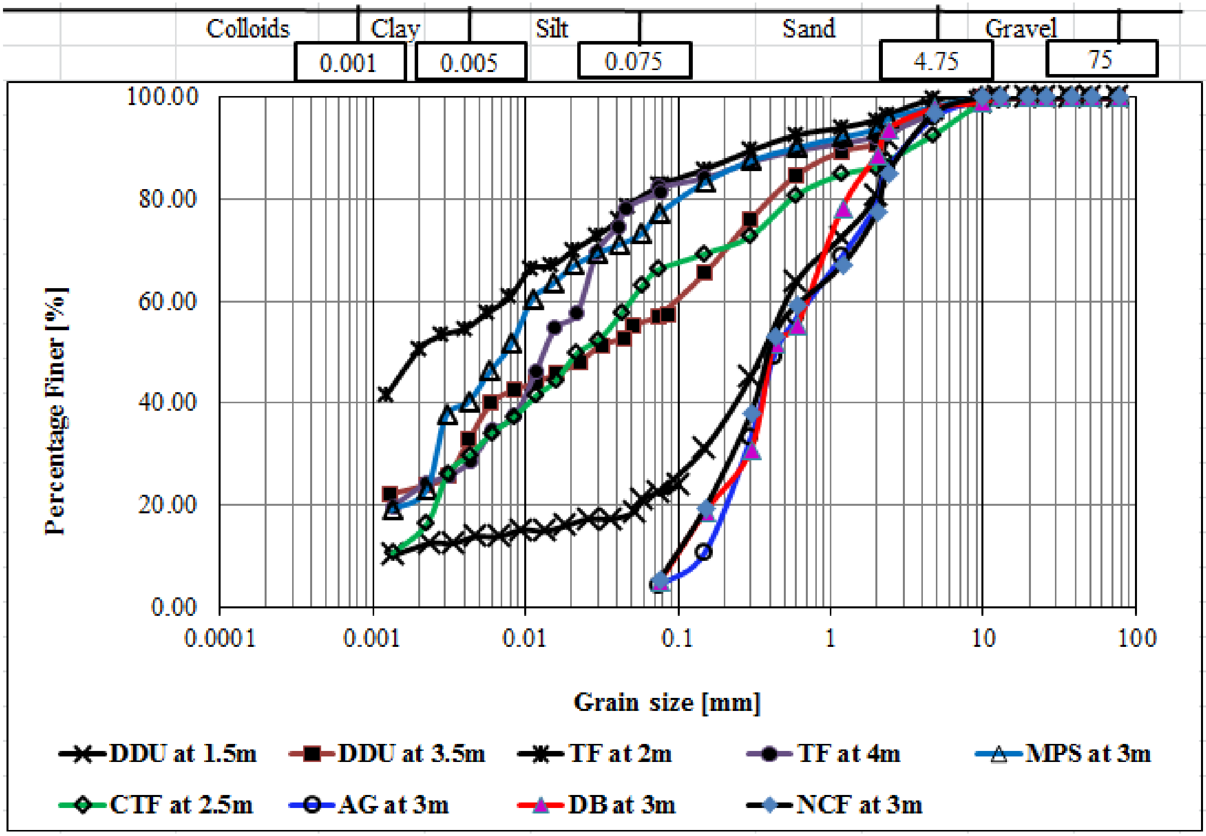


Figure 4.1 Summary of grain size distribution curves

From the results of this study (Table 4.1) the field test results showed that the field bulk density of the soil range between 1.31 g/cm^3 and 1.46 g/cm^3 with an in-situ water content of 11% to 31 %. The water content is a rotten test as part of Atterberg limits, compaction, consolidation, shear strength and cyclic tests for this study. In situ density results were used in sample preparation for shear strength, consolidation test of silt and cyclic tests to simulate field soil condition.

According to the results of grain size analysis, Dire Dawa soils are low plastic silt and poorly graded sand. The sand soil presents a coefficient of uniformity (C_u) of 5 to 6 and a coefficient of curvature (C_c) 0.66 to 0.91. Despite the fact the sand presents a well distribution of their particles size (Figure 4.1), it did not meet the requirement of the coefficient of uniformity and the coefficient of curvature of well graded sand [3]. And the silt soil presents a liquid limit range of 18 % to 52%, plastic limit ranges from 27% to 37% and plastic index ranges from 3% to 15%. These shows low plastic except one sample from Tony farm at 2m with high plasticity, which is with 52% liquid limit. In general, all soils considered in this study were found to be poorly graded sand and low-plastic silt soils [4].

4.2 Classification Characteristics

USCS classification system: - Based on this classification, according to ASTM D 2487, Dire Dawa soil is categorized as fine and coarse grained soils. Most of the fine grained soil of the study area falls in ML region in the plasticity chart (Figure 4.2) and the coarse grained soil was classified as poorly graded sand. Accordingly, poorly graded sand and low plastic silt are the typical Dire Dawa soils.

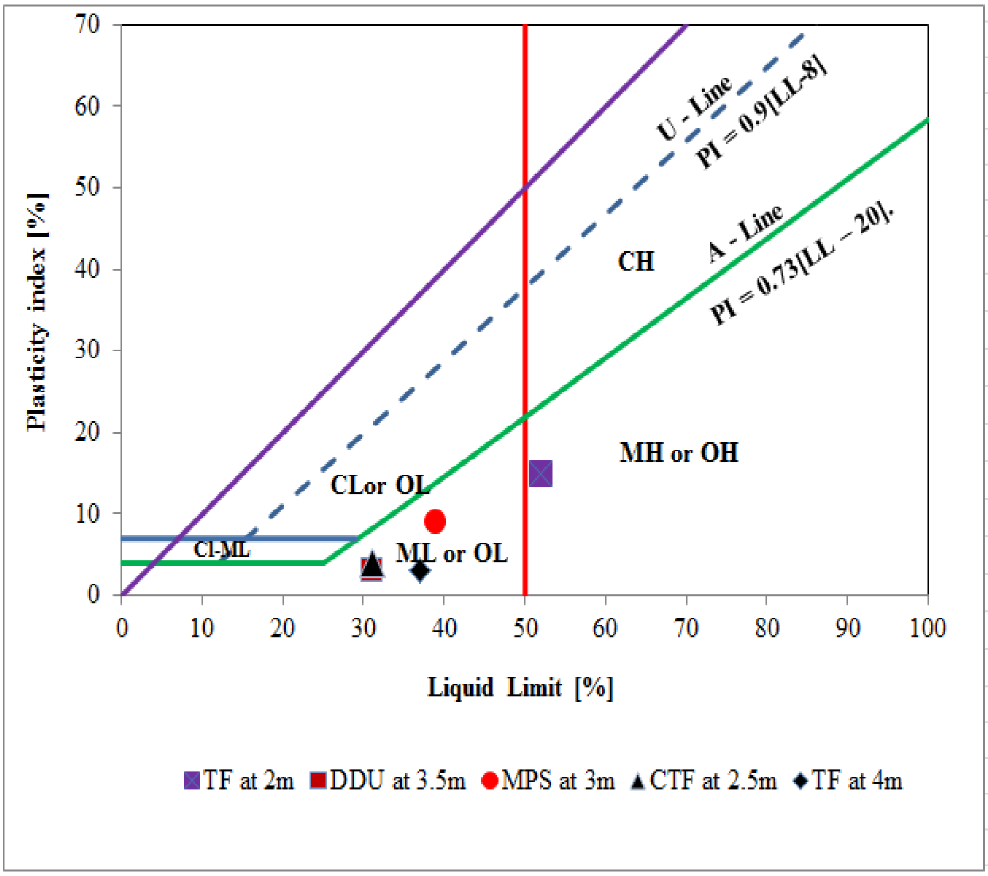


Figure 4.2 Plasticity chart of the study area soils according to USCS

Table 4.2 Classifications of soils based on USCS classification system

Sampling Location	Sampling depth[m]	Particles passing No.200 in [%]	Type of soil, in terms of Particles passing No.200	Fine grained			Coarse grained					
				LL[%]	PI[%]	Type	D_{10}	D_{30}	D_{60}	C_C	C_U	Type
DDU	1.50	20.48	Coarse	18.00	-	SM						
DDU	3.50	57.03	Fine	31.00	3.00	ML						
TF	2.00	84.15	Fine	52.00	15.00	MH						
	4.00	81.52	Fine	37.00	3.00	ML						
MPS	3.00	77.23	Fine	38.00	8.00	ML						
CTF	2.50	53.02	Fine	31.00	4.00	ML						
DB	3.00	4.74	Coarse				0.14	0.30	0.70	0.91	5.00	SP
NCF	3.00	5.18	Coarse				0.10	0.20	0.60	0.66	6.00	SP
AG	3.00	4.27	Coarse				0.15	0.30	0.80	0.75	5.33	SP

AASTHO Classification system:- According to this classification, the usual types of significant constituent materials are moreover silt and sand soils as show in Figure 4.3 and Table 4.3.

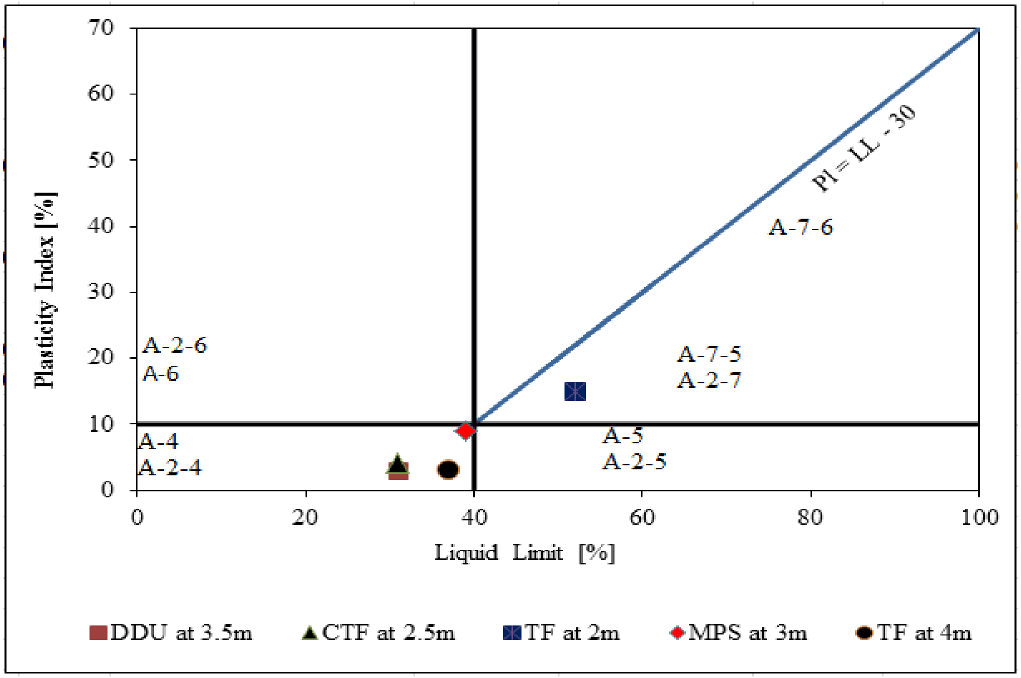


Figure 4.3 Plasticity chart of soil in the study area according to AASHTO classification

Table 4.3 Classifications of soils based on AASHTO Classification system

Sampling location	Sampling depth [m]	Percent of passing on sieve No.			LL [%]	PI [%]	Group
		10	40	200			
DDU	3.50	90.87	81.13	57.03	31.00	3.00	A-4
TF	2.00	95.66	91.48	82.98	52.00	15.00	A-7-5
	4.00	92.26	88.63	82.50	37.00	3.00	A-4
DB	3.00	88.76	51.6	4.74	-	-	A-3
NCF	3.00	77.41	53.14	5.18	-	-	A-3
MPS	3.00	93.86	87.59	73.92	38.00	8.00	A-4
AG	3.00	79.00	51.29	4.27	-	-	A-3
CTF	2.50	86.28	77.65	66.24	31.00	4.00	A-4

4.3 Summary

A great emphasis was given on visual description and index properties test to characterize and select typical soils in the study on shear strength, and dynamic properties (shear modulus and damping ratio) of soils found in Dire Dawa town.

According to index properties test results and interpretation, dominant soils of the study area are low plastic silt and poorly graded sand. Hereafter, the study concentrated on the shear strength and dynamic properties (shear modulus and damping ratio) of silt and sand soils of Dire Dawa town. Accordingly, representative samples were taken for direct shear and cyclic tests.

4.4 Compaction Test

Compaction increases soil unit weight, thereby producing important mechanical effect; an increase in shear strength and stiffness [4]. The test was done according ASTM D698-98 standard method .From the Standard Proctor test results, the values of maximum dry density (MDD) of Dire Dawa soil ranges from 1.28 g/cm^3 to 1.87 g/cm^3 and the optimum moisture content (OMC) ranges 10.8% to 38.3%. A detail of the compaction test is shown under Appendix A-5. The summary of the test results are shown in Table 4.4.

Table 4.4 Summary of optimum moisture content and maximum dry density

Sampling Location	DDU		TF		NCF	DB	CTF	AG	MPS
Sampling Depth [m]	1.50	3.50	2.00	4.00	3.00	3.00	2.50	3.00	3.00
OMC [%]	19.74	35.30	38.30	29.70	14.00	13.80	28.50	10.80	25.80
MDD [%]	1.52	1.33	1.33	1.31	1.60	1.72	1.41	1.71	1.50

Generally, coarse grained soils can be compacted to a higher dry density than fine gained soils for the same compaction effort. And well graded soils can attain higher dry density than poorly graded soils. Fine grained soils attain much less dry density than coarse grained soils for the some compactive effort [4]. This can also be observed from Table 4.4. Therefore as the amount of coarser particles increases the dry density will increase too. Do to that samples from AG, NCF and DB shows higher dry density as compared to the other samples. In this study compaction test (MDD and OMC) results was used for remolding of the sand soil for direct shear and cyclic tests.

4.5 Direct Shear Test Results

Direct shear test has been conducted to determine the shear strength parameters of low plastic silt and poorly graded sand soils of the study area.

The variations of ϕ and c, which have been derived from the peak shear values, with soil state condition such as density, water content, soil types and loading conditions, are also presented on this section. The computed values are tabulated in Tables 4.5 and 4.6. The direct shear test results and detail calculations are presented under Appendix-C. Typical shear stress vs horizontal displacement and shear stress vs normal stress are shown in Figures 4.4 and 4.5 respectively.

From the direct shear test results, the values of shear strength parameters (c and ϕ) of sand soil ranges between 1 kPa to 9 kPa and 26^0 to 28^0 respectively. And the values of shear strength parameters (c and ϕ) of silt soil ranges between 28 kPa to 43 kPa and 15^0 to 25^0 respectively, which are within the reasonable value of corresponding soils [4].

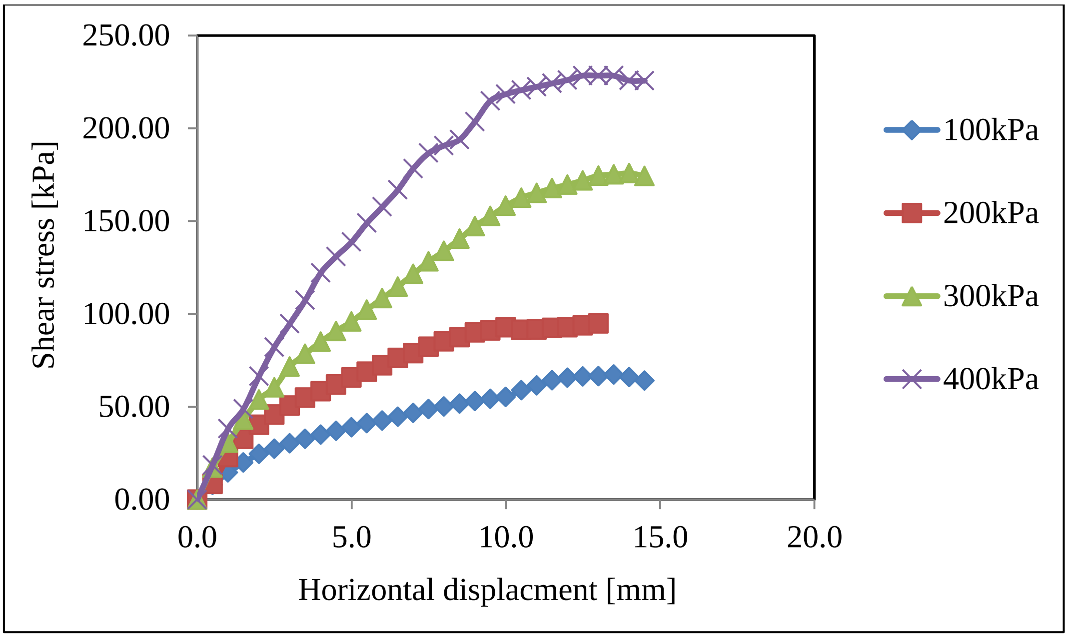


Figure 4.4 Typical shear stress vs horizontal displacement of AG sand soil

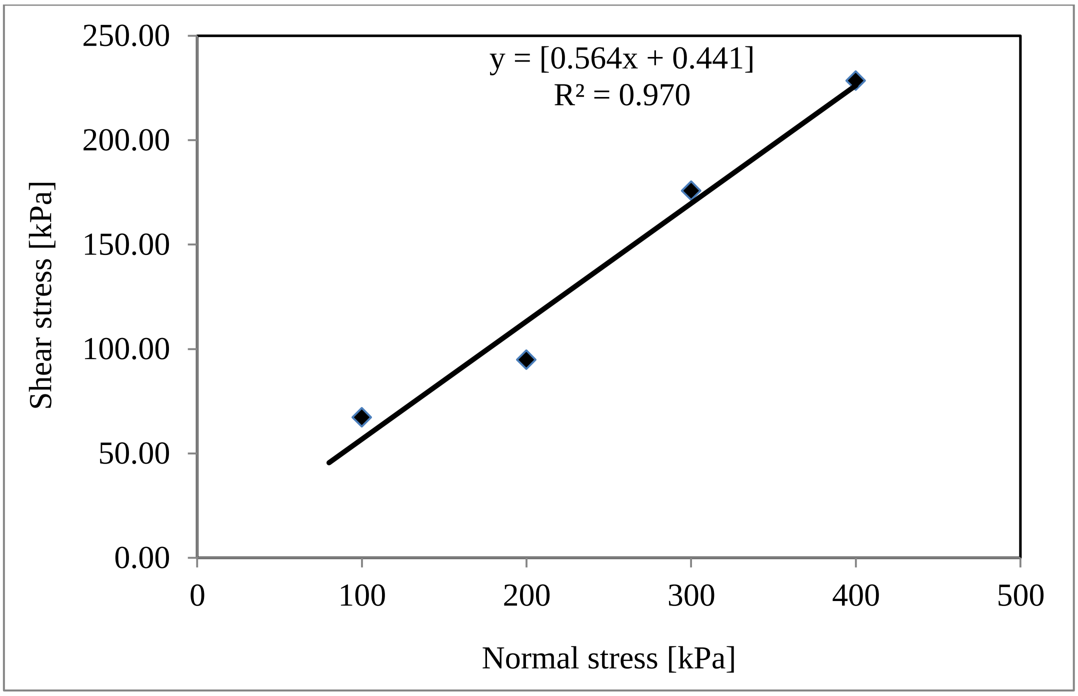


Figure 4.5 Typical shear stress vs normal stress of AG sand soil

Table 4.5 Summary of sand soil shear strength parameter values

Sampling location	Applied normal stress [kPa]	Rate of strain [mm/min]	Dry unit weight [kN/m^3]	Wet unit weight [kN/m^3]	Shear stress at failure [kPa]	Water content [%]	Friction angle [Degrees]	Cohesion [kPa]
	100				56.00			
	200				101.80			
	300				159.44			
	400		18.36	20.33	209.30	10.50	27.30	2.25
	100				67.24			
	200				94.82			
	300				175.76			
	400		18.17	19.74	228.42	8.50	26.56	1.00
	100				64.34			
	200				128.20			
	300				152.00			
	400		17.97	20.62	187.18	14.40	26.97	4.70
	100				52.45			
	200				130.48			
	300	0.2	18.36	20.33	168.37	10.50	27.00	5.09
	100				50.00			
	200				100.24			
AG	300	0.1	18.36	20.33	158.00	10.50	28.36	4.25
	50				45.31			
	100				61.60			
	200				112.78			
DB	300	0.2	16.89	19.25	186.65	13.50	26.01	9.05

Table 4.6 Summary of silt soil shear strength parameters values

Sampling location.	Sample condition	Applied normal stress [kPa]	Displacement rate	Dry unit weight [kN/m^3]	Wet unit weight[kN/m^3]	Estimated void Ratio	Shear stress at failure [kPa]	Water content [%]	Friction angle [Degrees]	Cohesion [kPa]
TF	Remolded to OMC	100	0.2	13.16	17.38	0.98	70.49	32.00	15.38	43.42
		200					99.65			
		300					125.66			
	Remolded to w	100		11.69	14.34	1.23	58.10	22.43	24.84	27.92
		200					126.15			
		300					164.10			

4.5.1 Variations of Shear Strength Parameters with Soil and Loading Condition

The values obtained from the direct shear tests were analyzed with respect to the effects of compaction moisture content, density, soil type and displacement rates shown in Tables 4.5 and 4.6. It has been observed that the shear strength parameter, angle of internal frication of remolded sand slightly decreases with moisture beyond OMC, density and displacement rates. But the variation with displacement rate is petty. Therefore, the shear strength of the soil increases till a critical degree of saturation is reached.

The shear strength parameters of the remolded soils vary with water content and density (Table 4.6). But the water content has a stronger impact on the cohesion than the angle of internal frication [4]. The silt soil presents a high frictional resistance, when remolded to field density. It could be due to its physical properties such as angularity and particles size distribution that provides a good packing to the soil specimen. Besides at OMC the silt soil registered high cohesion. The variation of strength parameters of remolded silt with displacement rate has been found somewhat lesser. Usually, the sand soil registered high angle of internal frication than the silt soil.

4.6 1D- Consolidation Test Results

The purpose of conducting this test here is for determination of pre-consolidation pressure of silt soil, which is used for the computation of maximum shear modulus ([3], [22]). The plot of void ratio versus logarithm of pressure is shown in Figure 4.6. From the plot the pre-consolidation pressure of the silt soil is 70 kPa. Detail calculation of pre-consolidation pressure is shown under Appendix-B.

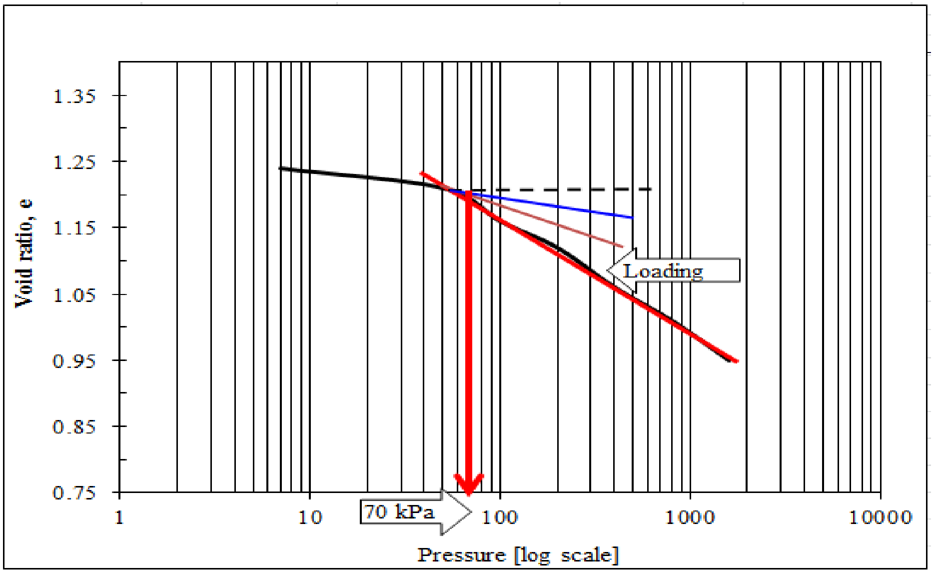


Figure 4.6 Pre-consolidation pressure result of TF silt soil

4.7 Simple Cyclic Shear Test Results and Values of Shear Modulus and Damping Ratio

Direct determination of shear stress-shear strain relationship were used for obtaining shear modulus and damping ratio at high strain amplitude range using simple cyclic shear test. The values of shear modulus and damping ratio were determined from hysteresis loop at the 5th cycle. The shear modulus and damping ratio values determined at 5th cycle is likely to provide reasonable values for all practical purpose. In most seismic events, the number of significant cycles is likely to be less than 20 [22]. In this study, the number of cycles used in a test is 40 cycles in order to investigate variation of shear modulus and damping ratio with number of shear cycles. The hysteresis loops are plotted using the shear stress and shear strain values.

4.7.1 Shear Stress-Shear Strain Relationships and Hysteresis Loop

The hysteresis loops of each cycle were plotted using the shear stress and shear strain values obtained from 50 raw data points as shown in Figure 4.7. The shear stress and shear strain values were computed based on the raw data (lateral shear force and lateral displacement) obtained in Excel from cyclic simple shear test. Then, Hysteresis Loops are plotted using the shear stress and shear strain values. The raw data (lateral shear force and lateral displacement) obtained from cyclic simple shear test are shown under Appendix-D.

The shape and size of the hysteresis loops is affected by the strain levels [19]. This is shown in Figures 4.8 and 4.9 for the silt soil and in Figures 4.10 and 4.11 for the sand soil. The line connecting the tips of the hysteresis loop rotate clockwise implying a decrease in shear modulus, where the shear strain increases. The width of the hysteresis loop gets wider too. Hence, the damping effect of the soil increases.

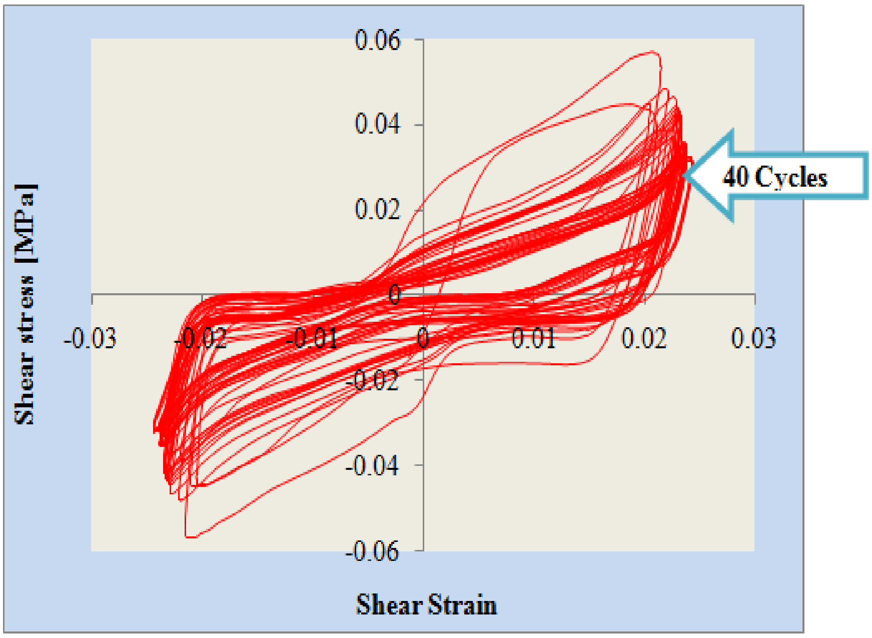


Figure 4.7 Typical hysteresis loop of TF silt soil under 100 kPa axial stress for 2.5% shear strain

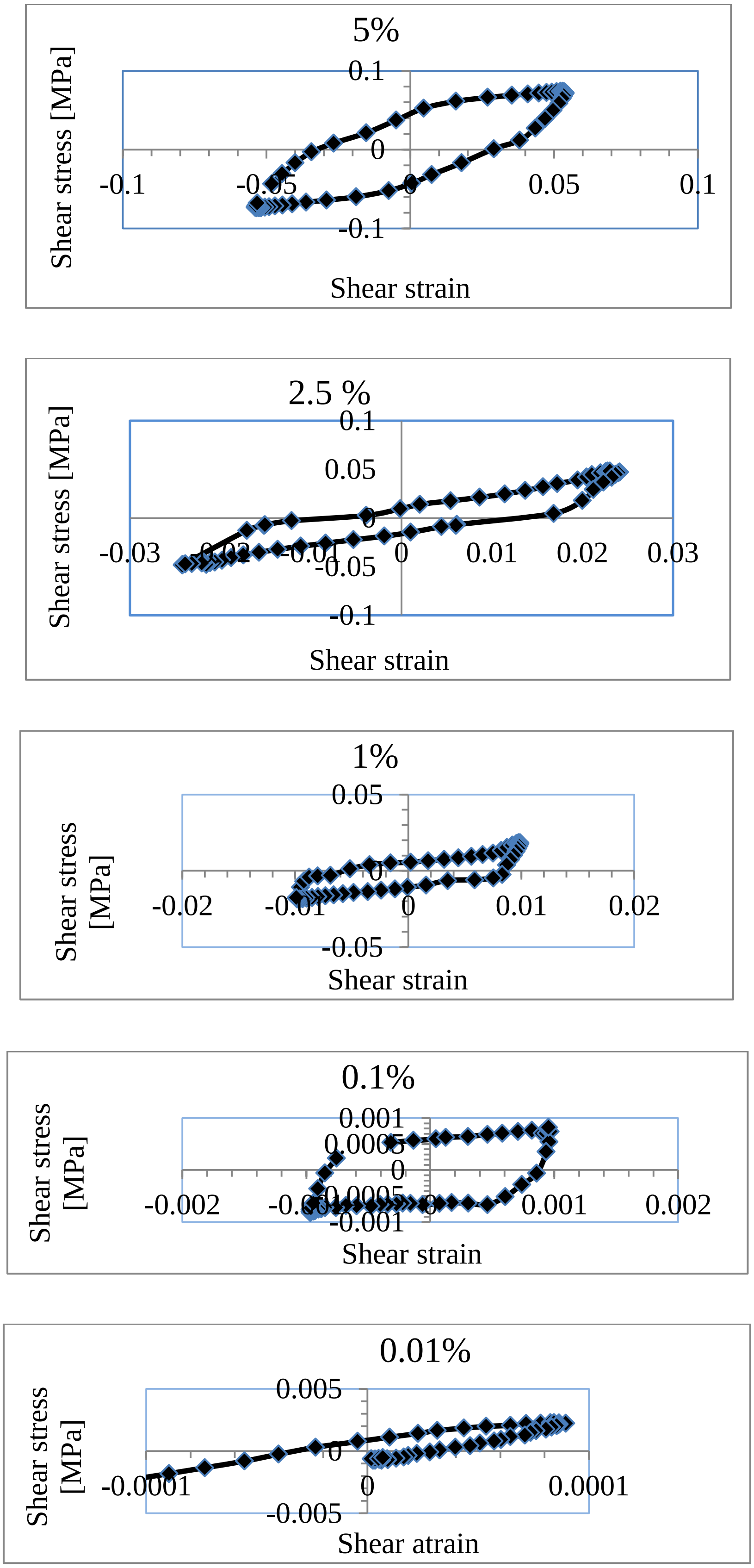


Figure 4.8 Typical 5th cycle hysteresis loop of TF silt soil at 100 kPa axial stress for different shear strain levels

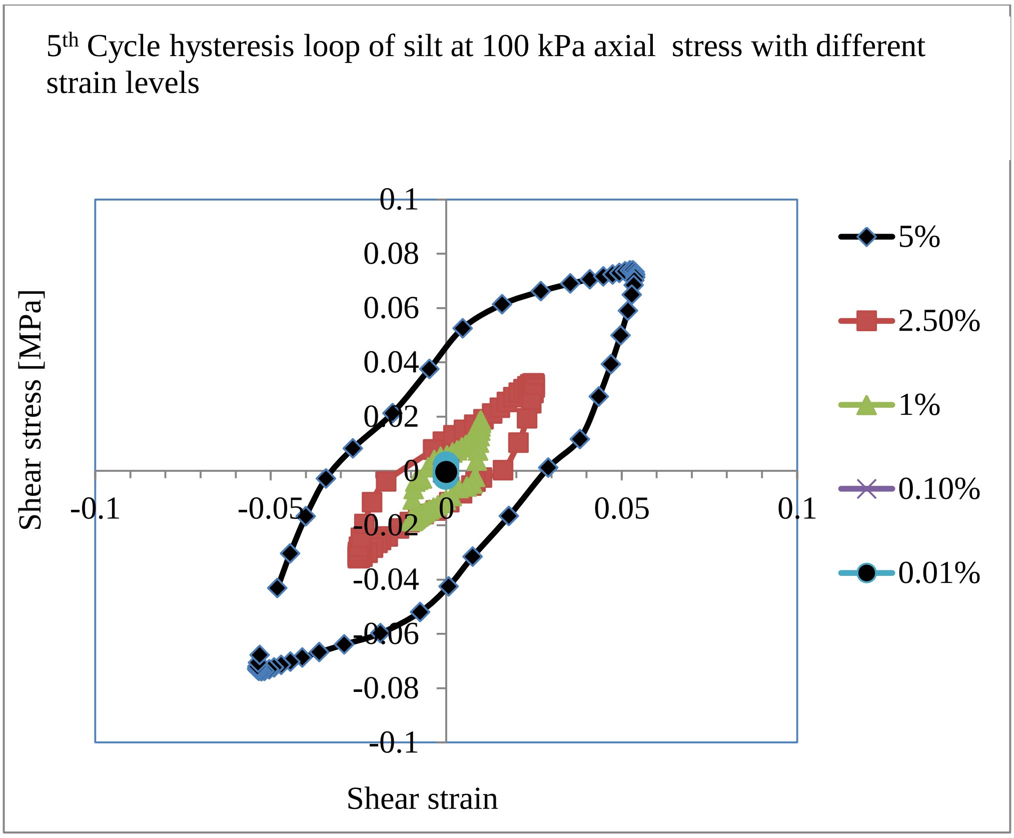


Figure 4.9 Hysteresis loop of TF silt soil showing the effect of shear strain amplitude on the hysteresis loop at 100kPa axial stress

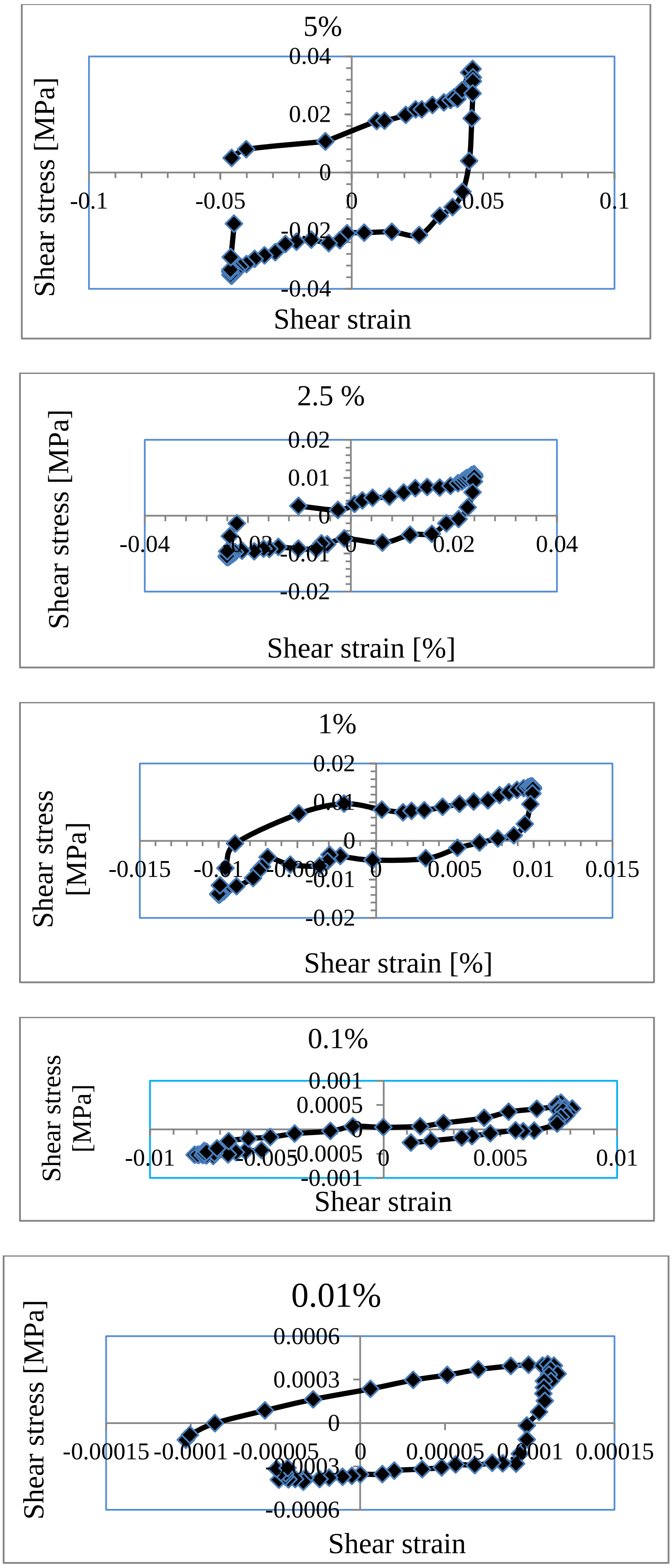


Figure 4.10 Typical 5th cycle hysteresis loop of AG sand soil at 100 kPa axial stress for different shear strain levels

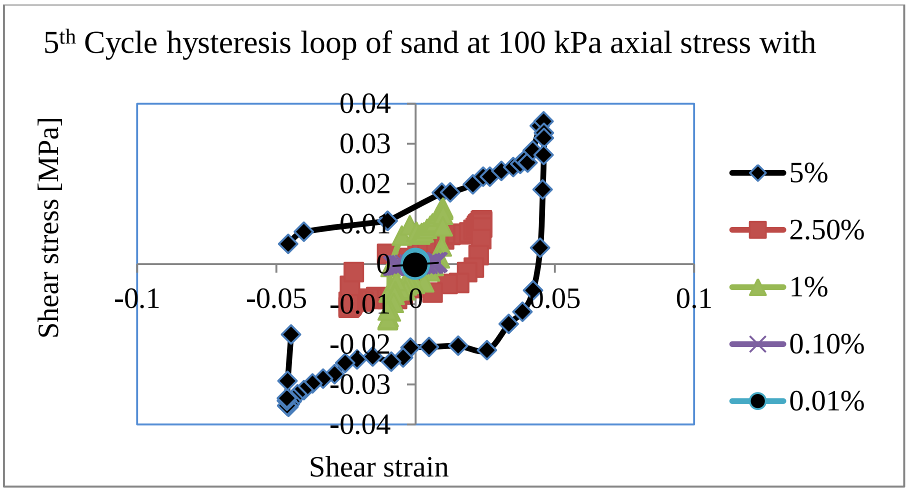


Figure 4.11 Hysteresis loop of AG sand showing the effect of shear strain levels on the hysteresis loop at 100 kPa axial stress

The hysteresis loops of silt and sand soil at 200 and 400 kPa axial stress for different shear strain levels are shown under Appendix-D.

4.7.2 Computation of Shear Modulus and Damping Ratio Values

The shear modulus and damping ratio values of the silt and sand soils are computed from the shear stress-shear strain hysteresis loops, using Equations 2.1 and 2.2 respectively [19]. A typical calculation is presented in Table 4.7, using the hysteresis loop shown in Figure 4.12.

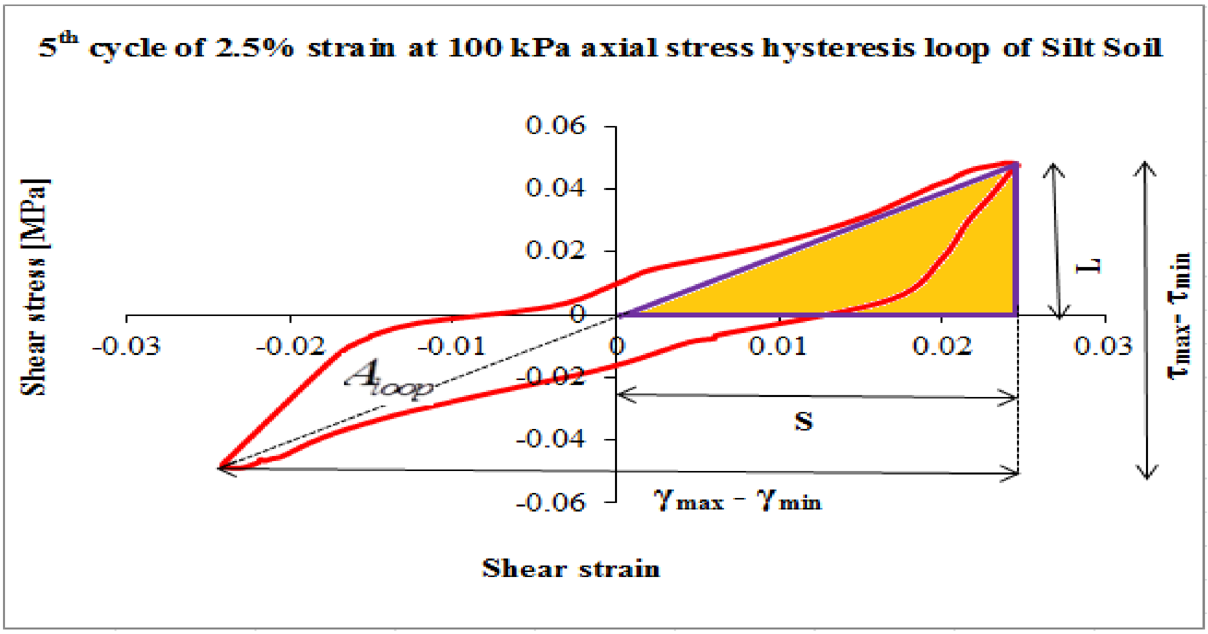


Figure 4.12 Hysteresis loop and energy dissipation with triangular area

Table 4.7 Computation of TF silt soil shear modulus and damping ratio at 100 kPa axial stress for 2.5% shear strain

<table>
<tr><td colspan="9">Shear modulus, G [MPa]</td></tr>
<tr><td>L</td><td>S</td><td>$\tau_{\max}$</td><td>τ_{min}</td><td>$\tau_{\max} - \tau_{\min} = \Delta\tau$</td><td>$\gamma_{\max}$</td><td>$\gamma_{\min}$</td><td>$\gamma_{\max} - \gamma_{\min} = \Delta\gamma$</td><td>$G[MPa] = \frac{\Delta\tau}{\Delta\gamma}$</td></tr>
<tr><td>0.048</td><td>0.025</td><td>0.048</td><td>-0.048</td><td>0.096</td><td>0.025</td><td>-0.025</td><td>0.050</td><td>1.92</td></tr>
<tr><td colspan="9">Damping ratio, D [%]</td></tr>
<tr><td colspan="5">$A_{loop} = \frac{1}{2}\sum_{i=1}^{n}(\tau_i - \tau_{i+1})(\gamma_i + \gamma_{i+1})$</td><td colspan="2">$A_\Delta = 0.5(S*L)$</td><td colspan="2">$D[\%] = \frac{A_{loop}}{4\pi A_\Delta} * 100$</td></tr>
<tr><td colspan="5">0.001203</td><td colspan="2">0.0006</td><td colspan="2">16.12</td></tr>
</table>

where, $\Delta\tau$ is the difference between the maximum and minimum values of shear stress (τ_{max}- τ_{min}) and $\Delta\boldsymbol{\gamma}$ is the difference between the maximum and the minimum values of shear strain ($\boldsymbol{\gamma}_{max}$-$\boldsymbol{\gamma}_{min}$).

Based on Table 4.7, the values of shear modulus and damping ratio of each cycle in a test are determined. Typical shear modulus and damping ratio of TF silt and AG sand soils at 100 kPa axial stress for different shear strain levels are shown in Tables 4.8 and 4.9.

Table 4.8 Shear modulus and damping ratio values of TF silt soil at 100 kPa axial stress for different shear strain levels

Strain level	0.01	0.10	1.00	2.50	5.00	0.01	0.10	1.00	2.50	5.00
Cycle No.	Shear modulus [MPa]					Damping ratio [%]				
1	3.69	3.02	2.26	1.72	0.62	5.46	12.97	17.06	20.25	31.56
2	4.73	3.59	2.92	1.78	0.68	5.15	11.86	16.19	19.96	30.39
3	4.19	3.82	3.49	2.25	0.59	5.02	11.26	17.21	22.57	30.32
4	3.78	3.81	3.53	2.36	0.76	3.24	11.80	17.05	12.21	31.91
5	3.86	3.34	3.04	1.92	0.79	4.56	11.66	16.64	16.12	28.91
6	4.63	2.93	3.34	2.22	0.75	3.98	11.66	17.36	17.93	29.87
7	4.56	3.19	3.26	1.63	0.76	4.02	10.58	15.09	10.31	28.41
8	5.81	3.99	3.09	2.10	0.73	3.39	10.21	15.94	17.04	29.46
9	4.67	3.41	2.93	2.54	0.73	3.88	11.87	15.24	19.42	28.66
10	4.77	3.39	3.09	2.03	0.72	3.91	10.42	14.98	17.04	29.10
11	4.92	3.65	2.97	2.50	0.70	4.01	10.59	14.52	19.25	29.10
12	5.64	3.92	2.97	2.05	0.69	4.11	12.71	14.10	17.18	29.01
13	5.29	3.72	2.90	2.47	0.70	3.56	10.33	14.92	12.39	29.15
14	5.10	3.71	2.85	1.98	0.69	3.59	13.40	14.01	16.98	28.68
15	5.54	3.73	3.00	2.45	0.68	3.04	11.49	14.29	18.97	29.50
16	5.01	3.44	2.88	1.97	0.68	4.08	14.05	14.29	16.99	28.89
17	5.61	3.55	2.99	2.42	0.67	4.94	12.62	14.02	18.34	29.68
18	4.73	3.36	2.92	1.94	0.66	4.30	13.22	14.10	17.01	28.85
19	5.42	3.52	3.23	2.41	0.67	4.74	12.56	13.83	16.86	29.67
20	5.02	3.41	3.19	2.29	0.79	4.30	11.89	13.78	16.97	29.24
21	5.52	3.43	2.84	2.40	0.77	5.14	12.92	13.76	16.67	29.31
22	4.95	3.43	2.99	1.93	0.57	5.55	13.57	14.15	16.92	29.25
23	5.39	3.52	2.90	2.38	0.64	5.68	14.82	14.01	15.66	28.77
24	5.34	3.50	2.99	1.93	0.69	5.07	14.41	13.90	16.89	29.67
25	5.09	3.39	2.86	2.30	0.70	5.33	14.88	13.89	15.68	28.79
26	5.15	3.52	2.95	1.94	0.80	5.03	13.10	13.85	15.62	29.09
27	5.15	3.45	2.91	2.08	0.81	5.48	15.20	13.87	15.91	28.51
28	5.34	3.52	2.94	2.11	0.59	4.74	14.98	13.56	14.59	29.02
29	5.34	3.49	2.87	2.09	0.67	5.13	13.81	14.33	14.03	28.21
30	5.22	3.44	2.84	1.91	0.69	5.23	12.48	13.60	13.17	28.71
31	5.27	3.67	2.98	2.10	0.79	5.77	13.35	13.91	13.87	28.36
32	5.15	3.43	2.88	2.00	0.88	4.77	13.35	13.86	13.47	28.54
33	5.56	3.61	2.96	1.90	0.73	4.72	12.66	13.73	12.07	28.41
34	5.03	3.45	2.85	2.10	0.81	5.52	13.85	13.85	12.07	28.20
35	5.41	3.68	2.96	2.00	0.85	4.53	12.90	13.68	14.14	28.34
36	5.10	3.50	2.88	1.92	0.79	4.59	13.93	13.62	12.56	27.94
37	5.64	3.47	2.92	2.07	0.80	3.11	11.88	13.56	12.68	28.21
38	5.16	3.61	3.12	2.01	0.74	3.53	10.48	13.98	14.48	27.60
39	5.53	3.71	2.87	1.92	0.73	3.06	10.36	13.47	14.05	27.93
40	5.12	4.04	3.42	2.08	0.89	3.11	10.03	13.66	14.01	27.98

Table 4.9 Shear modulus and damping ratio values of AG sand soil at 100kPa axial stress for different strain levels

Strain level	**0.01**	**0.1**	**1**	**2.5**	**5**	**0.01**	**0.1**	**1**	**2.5**	**5**
Cycles No.	**Shear modulus, G [Mpa]**					**Damping Ratio, D [%]**				
1	10.18	6.59	5.01	2.65	1.09	5.69	10.65	18.34	20.03	25.60
2	11.60	6.46	5.03	3.12	1.39	4.76	10.07	18.03	19.61	25.29
3	12.90	6.59	6.83	3.17	1.45	4.60	10.67	17.51	19.73	26.01
4	7.99	6.20	6.01	3.22	1.58	4.69	9.59	17.23	19.38	25.81
5	11.02	6.50	5.30	3.09	1.34	4.91	10.58	17.82	18.98	24.32
6	11.64	6.85	5.03	3.02	1.65	4.10	10.58	17.67	19.60	24.88
7	9.47	6.49	5.13	3.10	1.46	4.66	9.30	17.69	20.10	24.96
8	13.37	6.97	7.30	3.12	1.38	4.57	10.20	17.52	19.22	24.27
9	9.54	6.63	6.77	3.09	1.85	4.19	10.66	17.73	18.95	23.32
10	11.57	6.31	5.19	3.11	1.81	4.65	10.58	16.42	19.32	23.38
11	11.78	7.24	6.37	3.30	1.83	5.12	10.02	16.07	18.77	22.98
12	13.12	7.58	5.84	3.04	1.73	4.73	11.01	16.76	17.82	24.08
13	11.44	7.58	5.48	3.09	1.80	4.93	10.43	16.92	19.42	25.77
14	10.22	7.42	5.05	3.25	1.72	4.30	8.20	16.67	19.14	24.28
15	10.96	7.88	4.93	3.13	1.65	5.01	11.49	16.22	19.35	24.88
16	11.65	8.05	5.50	3.13	1.65	4.51	9.76	14.59	19.76	23.61
17	10.86	8.39	5.09	3.18	1.64	4.17	7.76	14.34	19.84	24.27
18	11.58	9.28	4.63	3.13	1.57	4.58	11.27	14.85	19.33	22.49
19	10.59	7.63	4.84	3.10	1.56	4.82	8.62	14.03	19.88	23.98
20	10.81	9.06	5.25	3.03	1.59	4.21	7.74	14.70	19.21	21.60
21	11.64	9.61	5.38	3.03	1.57	4.15	11.56	14.80	19.24	23.15
22	10.86	8.18	5.91	3.03	1.57	4.02	9.63	14.62	19.18	22.06
23	10.95	8.13	5.81	2.99	1.55	4.31	7.88	14.40	18.49	22.58
24	11.40	9.83	5.71	2.94	1.53	4.05	10.86	13.80	19.98	20.48
25	10.30	9.26	6.04	2.95	1.51	4.82	10.42	13.12	18.33	22.30
26	11.88	9.50	5.86	2.96	1.55	4.34	9.77	13.37	18.62	19.41
27	10.81	9.81	5.83	3.01	1.51	4.58	8.60	13.16	18.92	23.26
28	11.16	8.82	5.73	2.96	2.20	4.94	10.18	12.60	18.92	25.53
29	11.16	9.52	5.59	3.01	1.64	4.34	10.07	13.09	19.99	21.57
30	11.43	9.43	5.66	3.03	1.57	3.95	8.53	13.21	19.91	21.27
31	11.69	9.55	5.75	3.10	1.62	4.03	8.60	13.83	18.13	20.57
32	11.57	9.52	6.09	3.08	1.68	3.87	10.75	13.42	19.35	19.09
33	13.03	10.08	5.85	3.07	1.64	4.12	8.45	13.54	19.72	19.65
34	10.71	9.93	5.68	3.10	1.62	3.85	7.46	13.14	19.72	19.95
35	12.29	9.73	5.80	3.12	1.65	3.49	9.62	13.31	19.22	19.56
36	11.85	9.85	5.90	3.20	1.66	4.00	8.95	12.88	19.17	19.60
37	11.52	10.61	5.34	3.13	1.66	3.37	9.07	12.56	18.54	18.98
38	12.53	11.13	6.89	3.18	1.65	3.30	9.12	13.03	18.25	19.35
39	12.03	10.84	6.59	3.23	1.68	3.26	9.13	12.43	18.30	19.26
40	12.30	10.43	7.45	3.29	1.63	3.19	9.10	12.40	18.02	19.20

The shear modulus and damping ratio values of TF silt and AG sand soils under 200 kPa and 400 kPa axial stress for different strain levels are shown under Appendix-D

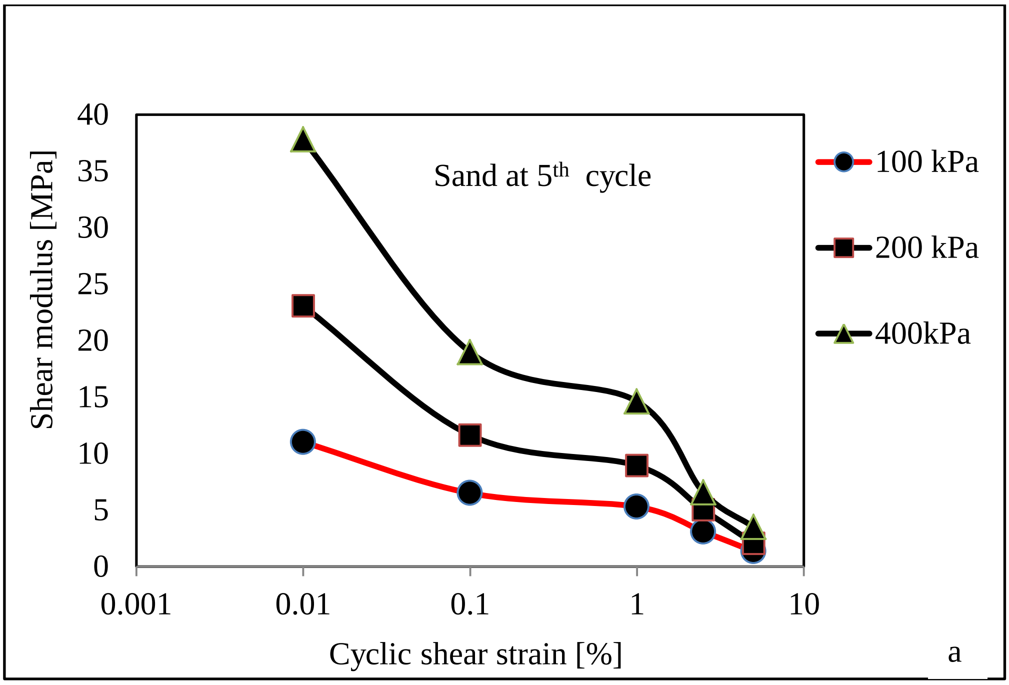
4.8 Shear Modules and Damping Ratio Values for Different Cases

In this study, the values of shear modulus and damping ratio are plotted as a function of the cyclic shear strain, at different axial stress and soil types. The values of shear modulus and damping ratio are also plotted as a function of the cycle numbers at different shear strain and axial stress to assess their effects.

4.8.1 Effect of Confining Pressure on Shear Modulus and Damping Ratio

Confining pressure is the rotten affecting parameter of shear modulus and damping ratio values of soils [18]. From Figures 4.13 (a) and 4.14 (a), while the confining pressure is different, the shear modulus increases with confining pressure. The reason is that plastic strain of soils in low confining pressure is increasing faster than that in high confining pressure [29]. The increment in shear modulus is more visible on the sand soil than the silt soil. The obtained curves are closer when shearing strain is increasing, so it indicates that in the condition of larger shear strain, the confining pressure has little influence.

As shown Figures 4.13 (b) and 4.14 (b), the damping ratio decreases with the confining pressure. The reason is that in soil dynamics, energy loose is expected by the damping ratio, and when the confining pressure increases.



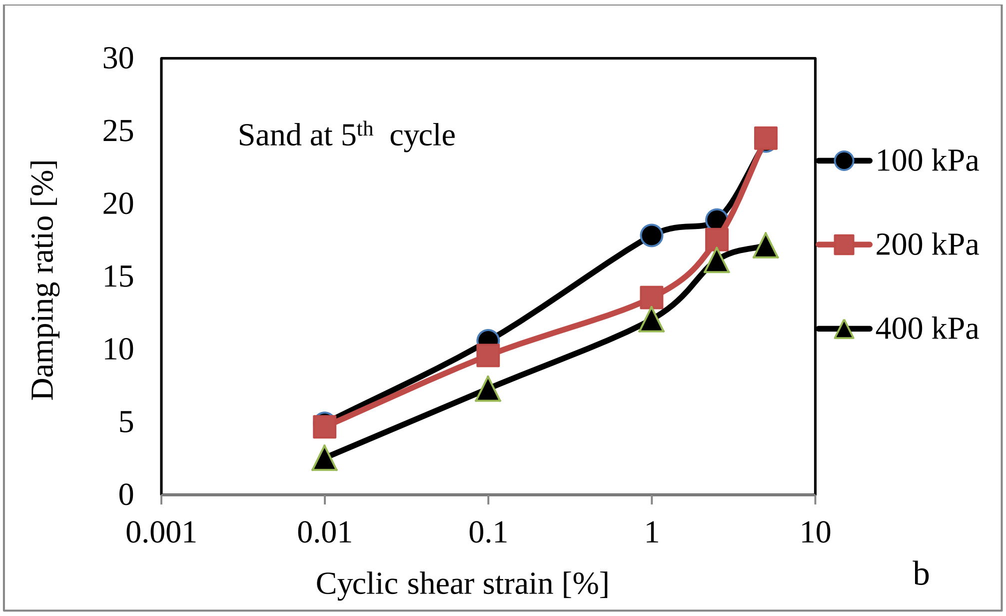
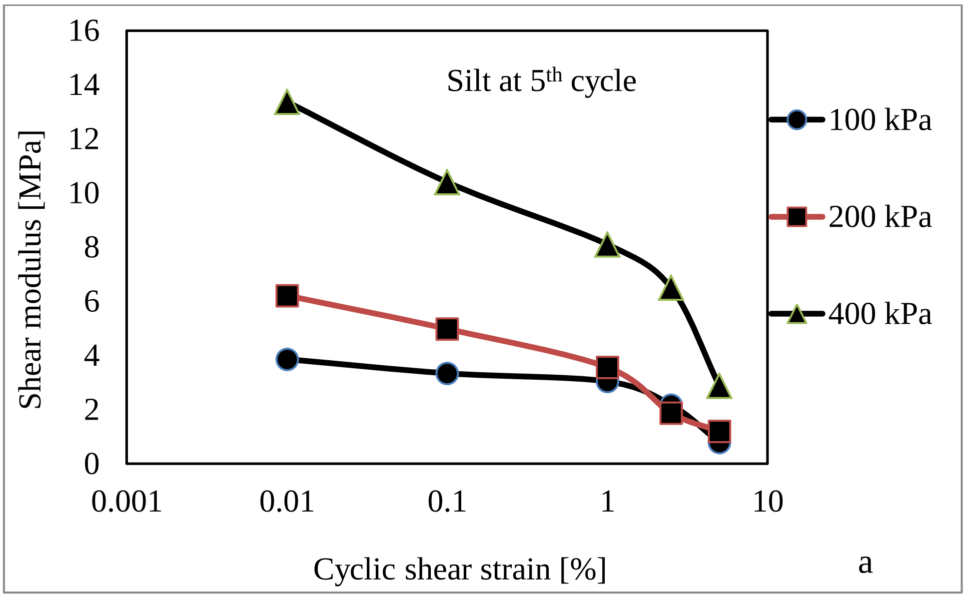


Figure 4.13 Variation of shear modulus (a) and damping ratio (b) of AG sand soil with confining pressure



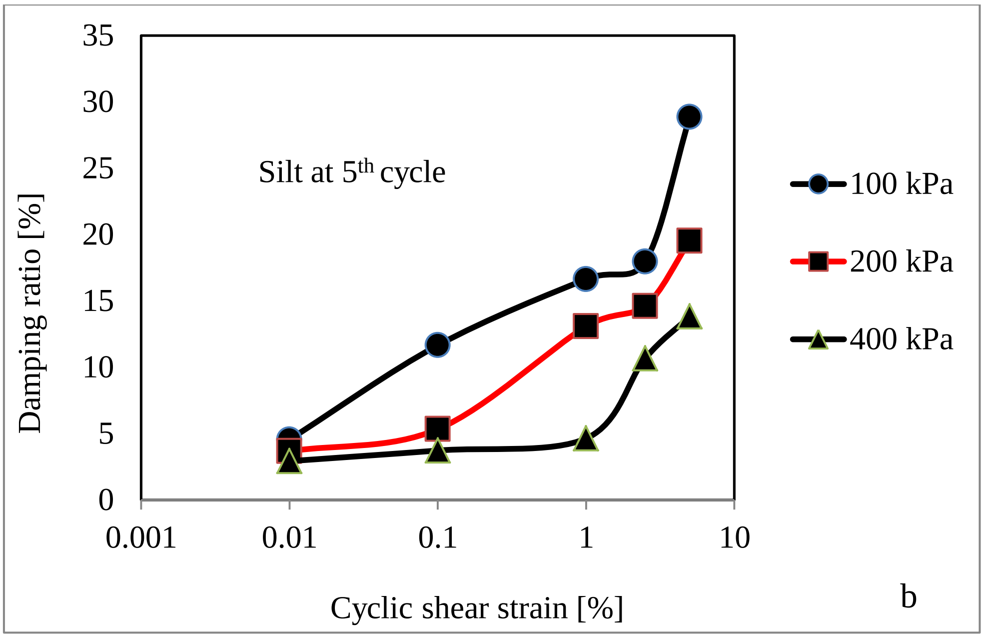


Figure 4.14 Variation of shear modulus (a) and damping ratio (b) of TF silt soil with confining pressure

4.8.2 Effect of Shear Strain Amplitude on Shear Modulus and Damping Ratio

Shear modulus and damping ratio of cyclically loaded soils vary significantly with the amplitude of shear strain due to nonlinear deformation characteristics [19]. Figures 4.15 (a and b) and 4.16 (a and b) show that the variations of shear modulus and damping ratio of sand and silt soils with shear strain. It was observed that shear modulus decreases and damping ratio increases with increasing cyclic shear strain.

The effect of cyclic shear strain amplitude depends upon several factors such as number of cycles [18]. As shown Figures 4.15 (a) and 4.16 (a) the effect of shear strain on shear modulus decreases as number of cycle increases. It has the same trend for damping ratio.

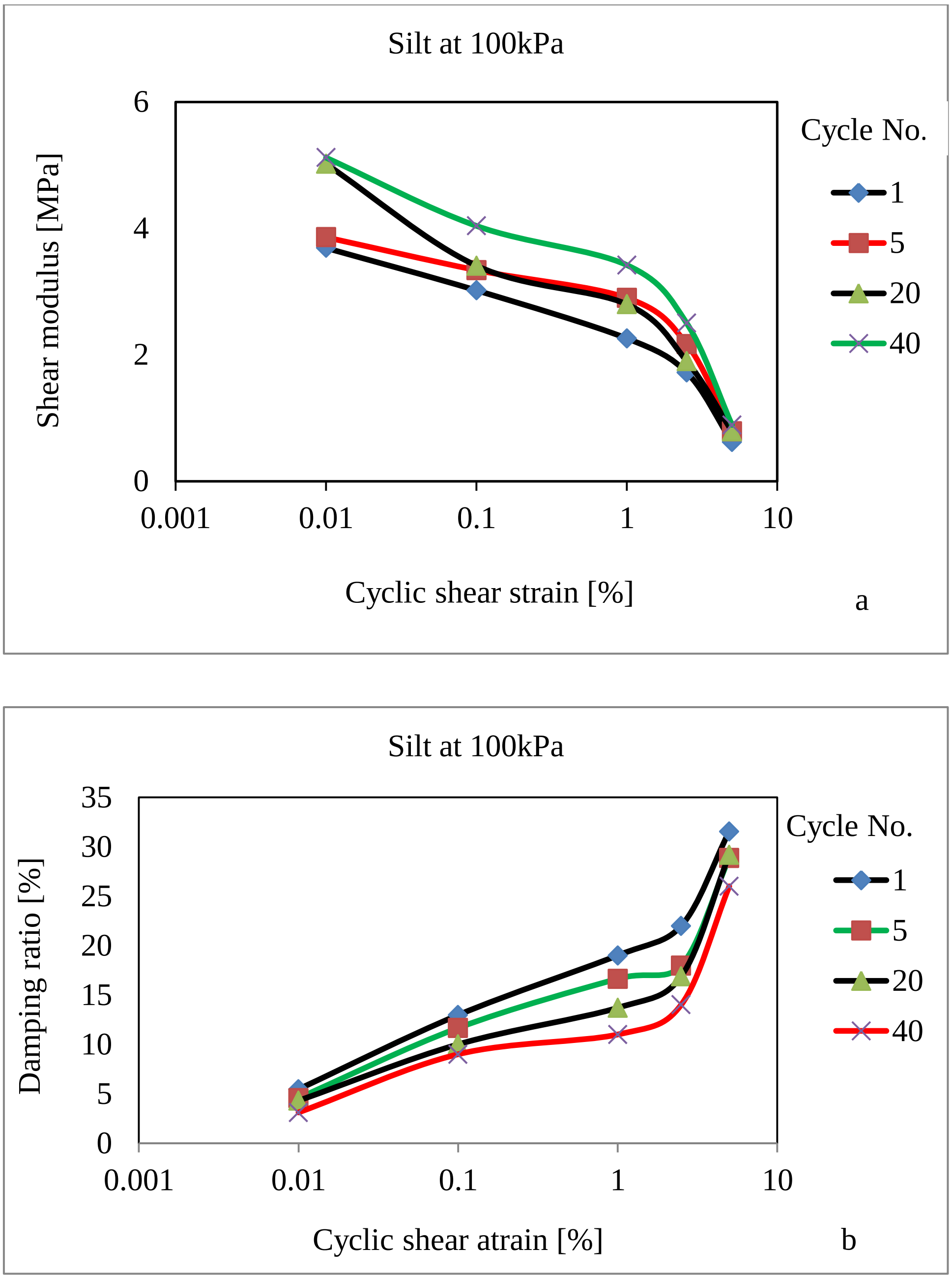
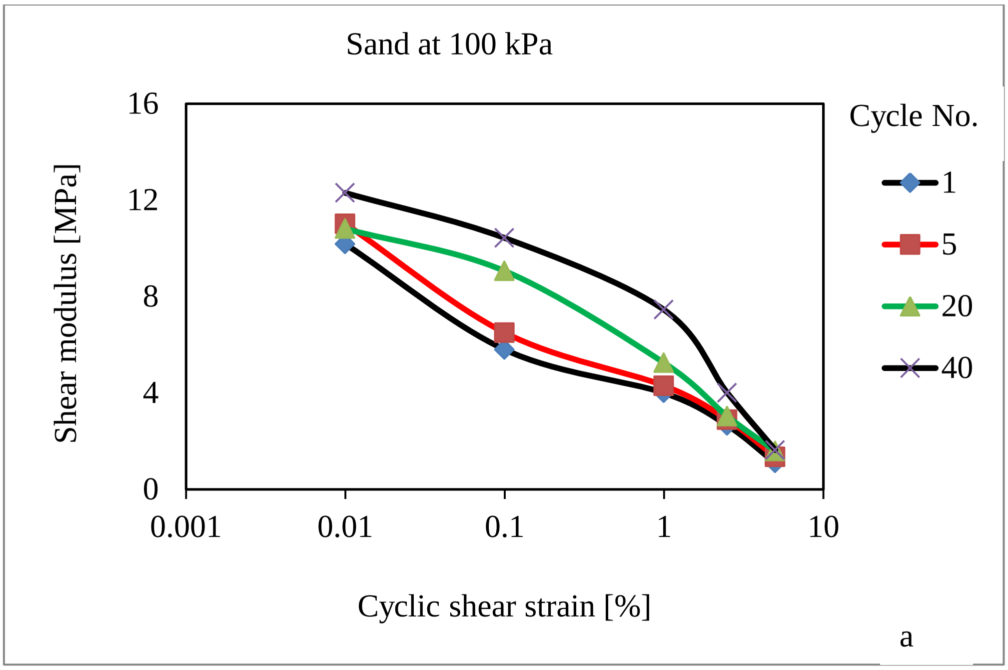


Figure 4.15 Variation of shear modulus (a) and damping ratio (b) of TF silt soil with cyclic shear strain amplitude



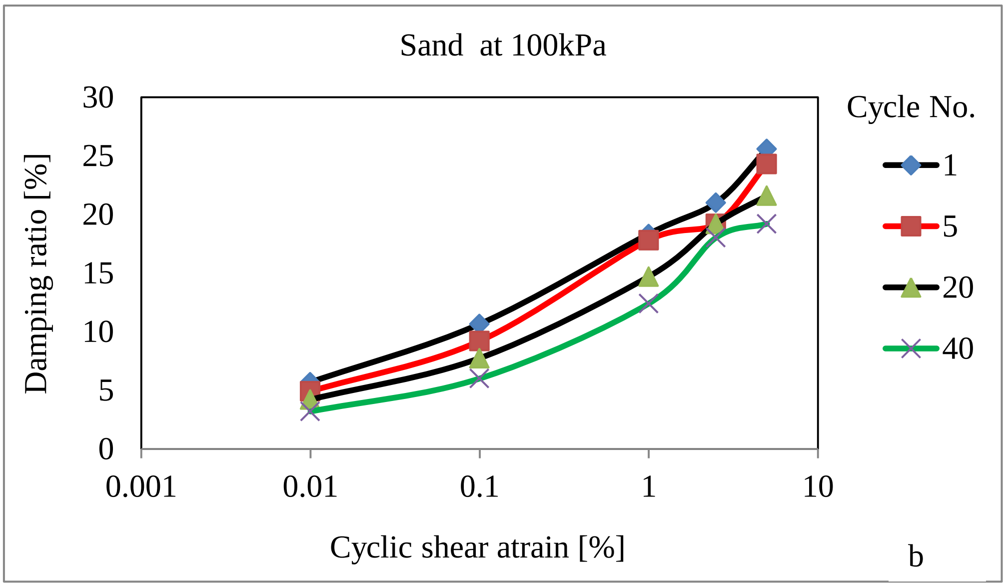


Figure 4.16 Variation of shear modulus (a) and damping ratio (b) of AG sand soil with cyclic shear strain amplitude

4.8.3 Effect of Soil Type on Shear Modulus and Damping Ratio

Coarser materials show good resistance to cyclic shear under high confining stress [25]. Figure 4.17 (a and b) show that the shear modulus values of the sand are higher than the silt soils, especially at maximum confining stress. However, the damping ratio is almost in the same range. Soil type has no significant influence on damping ratio at any shearing strain amplitude under all confining pressures.

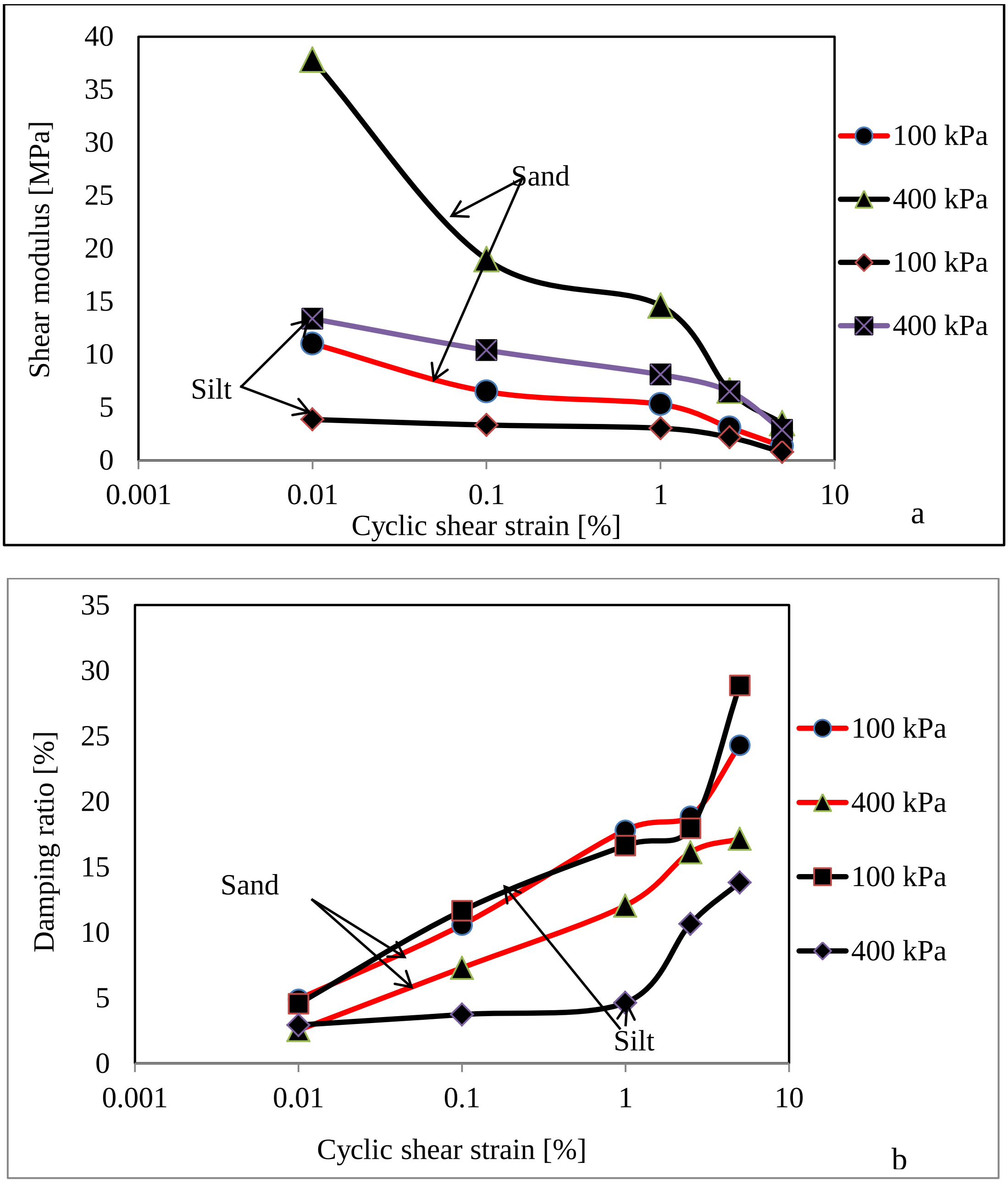


Figure 4.17 Variation of shear modulus (a) and damping ratio (b) with soil type

4.8.4 Effect of Number of Loading Cycles on Shear Modulus and Damping Ratio

Figures 4.18 (a and b) and 4.19 (a and b) shows that the shear modulus increases with increasing number of cycle. However, the damping ratio decreases with increasing number of cycles. The effect of number of cycles with increase axial loads shows slight difference on the shear modulus and damping ratio values of both soils [32]. ASTM D3999 indicates that the values determined at 5th cycle are likely to provide reasonable values for all practical purposes [32]. Accordingly, in this research values determined at 5th cycle are considered for analysis purposes.

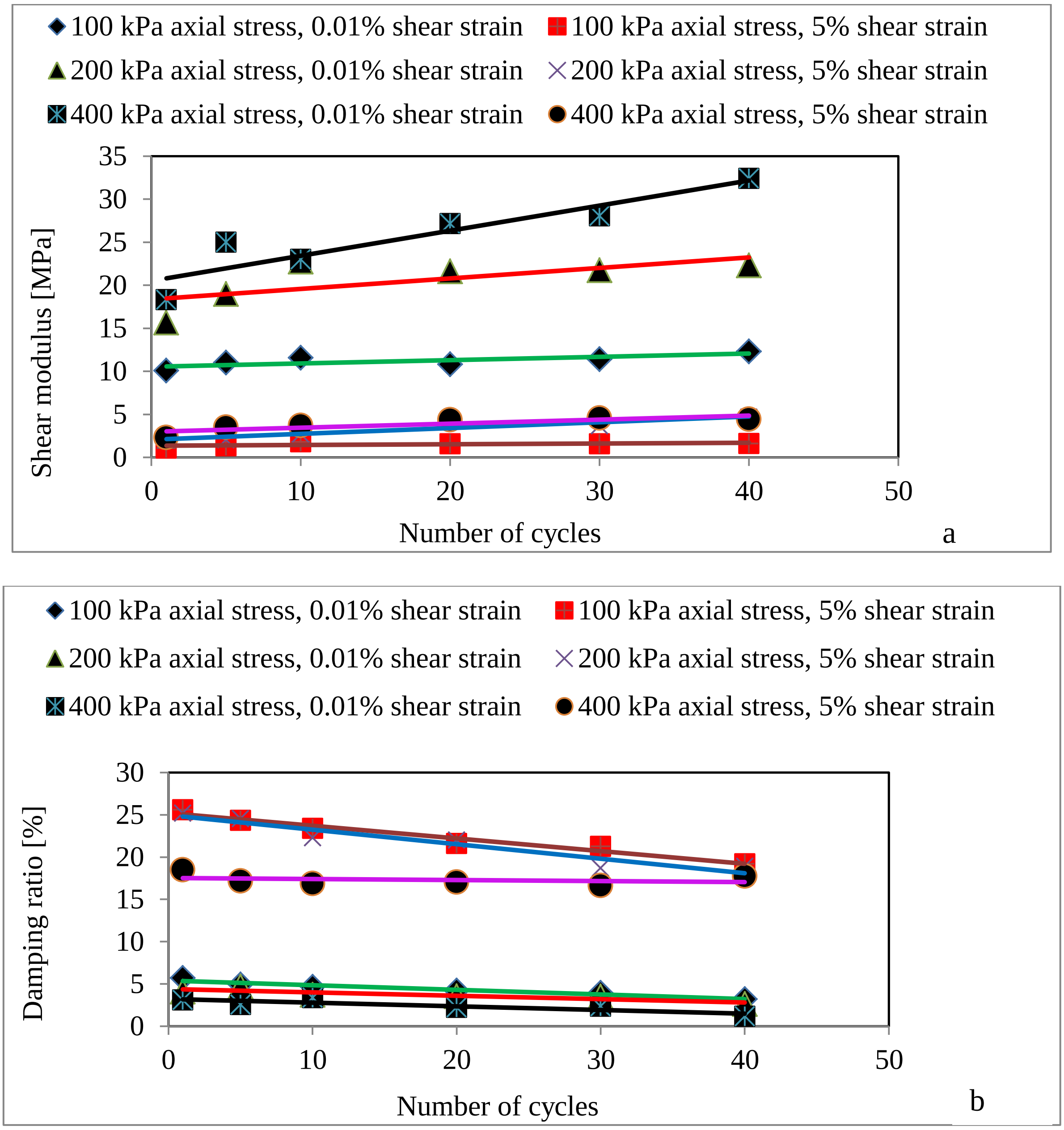


Figure 4.18 Variation of shear modulus (a) and damping ratio (b) of AG sand soil with number of loading cycles

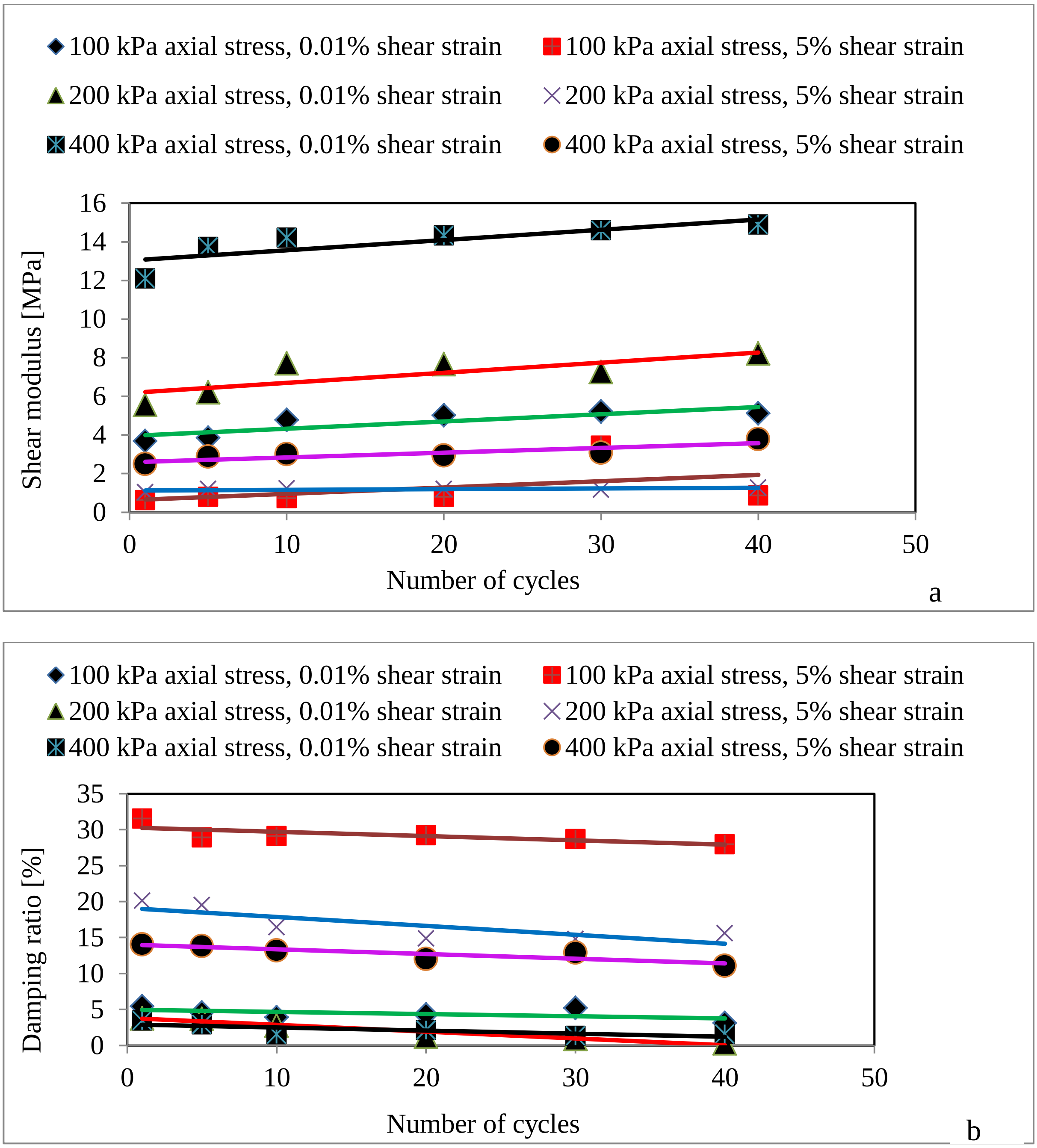


Figure 4.19 Variation of shear modulus (a) and damping ratio (b) of TF silt soil with number of loading cycles

4.9 Estimation of Low Amplitude Shear Modulus, G_{max} and Values of Modulus Reduction, G/G_{max}

The maximum shear modulus, G_{max} which corresponds to very low strain levels cannot be determined from cyclic simple shear tests. Hence one cannot measure shear modulus and damping values at low strain levels using simple shear test, since cyclic simple shear test is a high strain test [0.01 to 5%]. In this study the values of G_{max} of silt and sand soils are determined using Equations 2.4 and 2.5 rewritten below respectively, and used to obtain the normalized shear modulus or modulus reduction values at 5th cycle for different case comparisons ([18], [32]).

$$G_{\max} = 3.23\frac{(2.97-e)^2}{(1+e)} * (OCR)^k (\sigma_o^{'})^{k_o} \text{-------------------}[2.4]$$

$$G_{\max} = 1000 K_{2\max} (\sigma_m^{'})^{0.5} \text{-----------------------------------}[2.5]$$

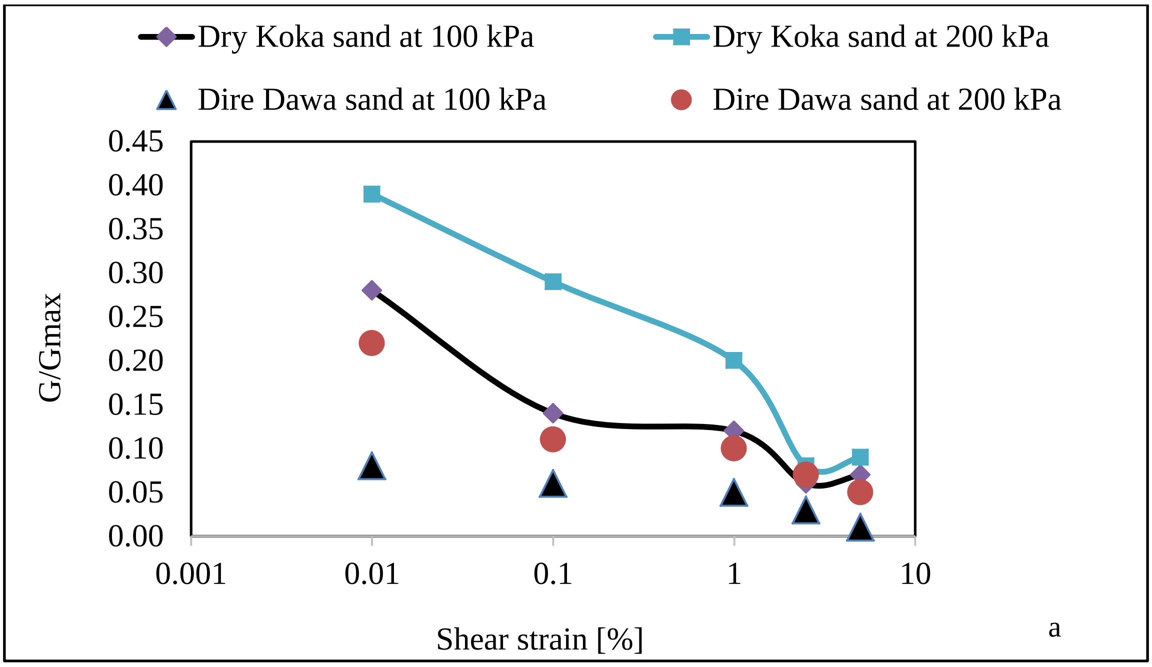
The computed values of maximum shear modulus and normalized shear modulus values at 5th cycle of the silt and sand soils are tabulated in Table 4.10. Detail calculations are presented under Appendix-E.

Table 4.10 Maximum shear modulus and modulus reduction values

Axial load [kPa]	Shear strain [%]	AG sand soil			TF silt soil		
		G_{max} [kPa]	G/G_{max}	D [%]	G_{max} [kPa]	G/G_{max}	D [%]
100	0.01	416,392.00	0.70	4.91	17,200.00	0.23	4.56
	0.1		0.05	10.58		0.19	11.66
	1		0.04	17.82		0.18	16.64
	2.5		0.03	18.98		0.13	17.97
	5		0.01	24.32		0.05	28.91
200	0.01	624,120.00	0.22	4.68	24,300.00	0.26	3.68
	0.1		0.11	9.58		0.21	5.34
	2.5		0.07	17.54		0.08	14.60
	5		0.05	24.52		0.05	19.54
400	0.01	825,140.00	0.25	2.45	34,360.00	0.40	2.93
	0.1		0.15	7.30		0.30	3.13
	2.5		0.1	16.13		0.19	10.67
	5		0.08	17.15		0.08	13.83

4.10 Comparison of Modulus Reduction and Damping Ratio Values for Different Cases

Modulus reduction and damping ratio values of Dire Dawa sand soil are compared with the curves developed for local sand; Dry Koka sand [16]. And the values of Dire Dawa silt soil are compared with the local silt and silty sand soils of Hawassa [14], Adama [15] and Ziway [27].



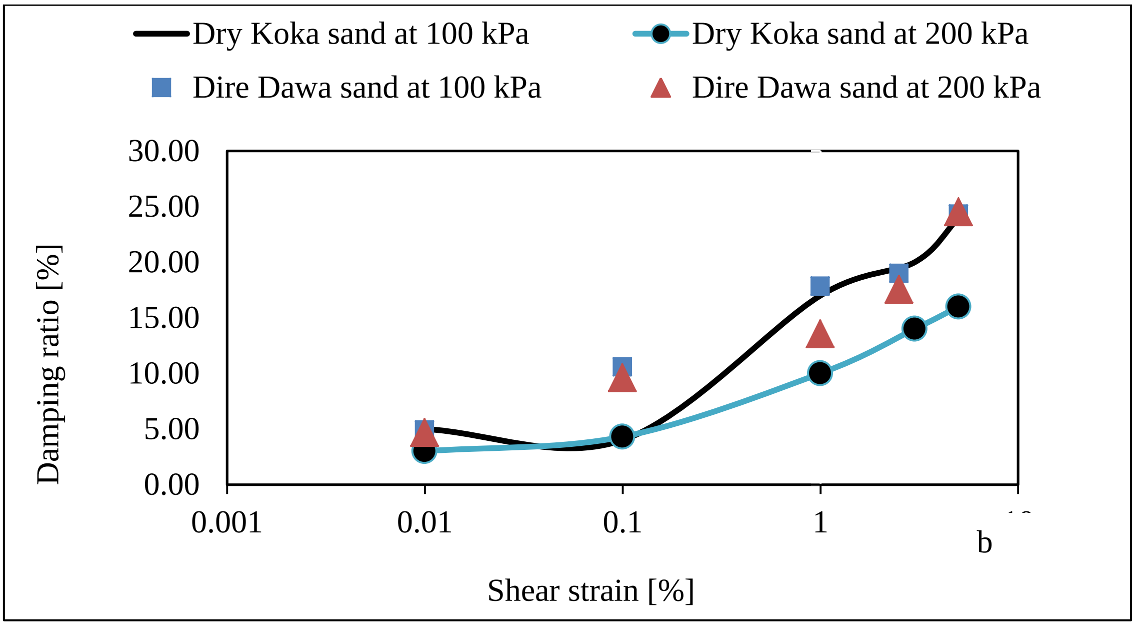


Figure 4.20 Comparison of modulus reduction (a) and damping ratio (b) values of AG sand soil with Koka sand [16]

Figure 4.20 (a), show that the modulus reduction value curves of Dire Dawa sand soil are lower than the Dry Koka sand soil curves.

In Figure 4.20 (b), the obtained damping ratio curves for the sand soil are slightly higher than the dry koka sand curves. This shows that, the effect of testing conditions and material characteristics on damping ratio is minimal compared to shear modulus.

In general, it can be said that the results of modulus reduction values of Dire Dawa sand soil are lower than the corresponding local values.

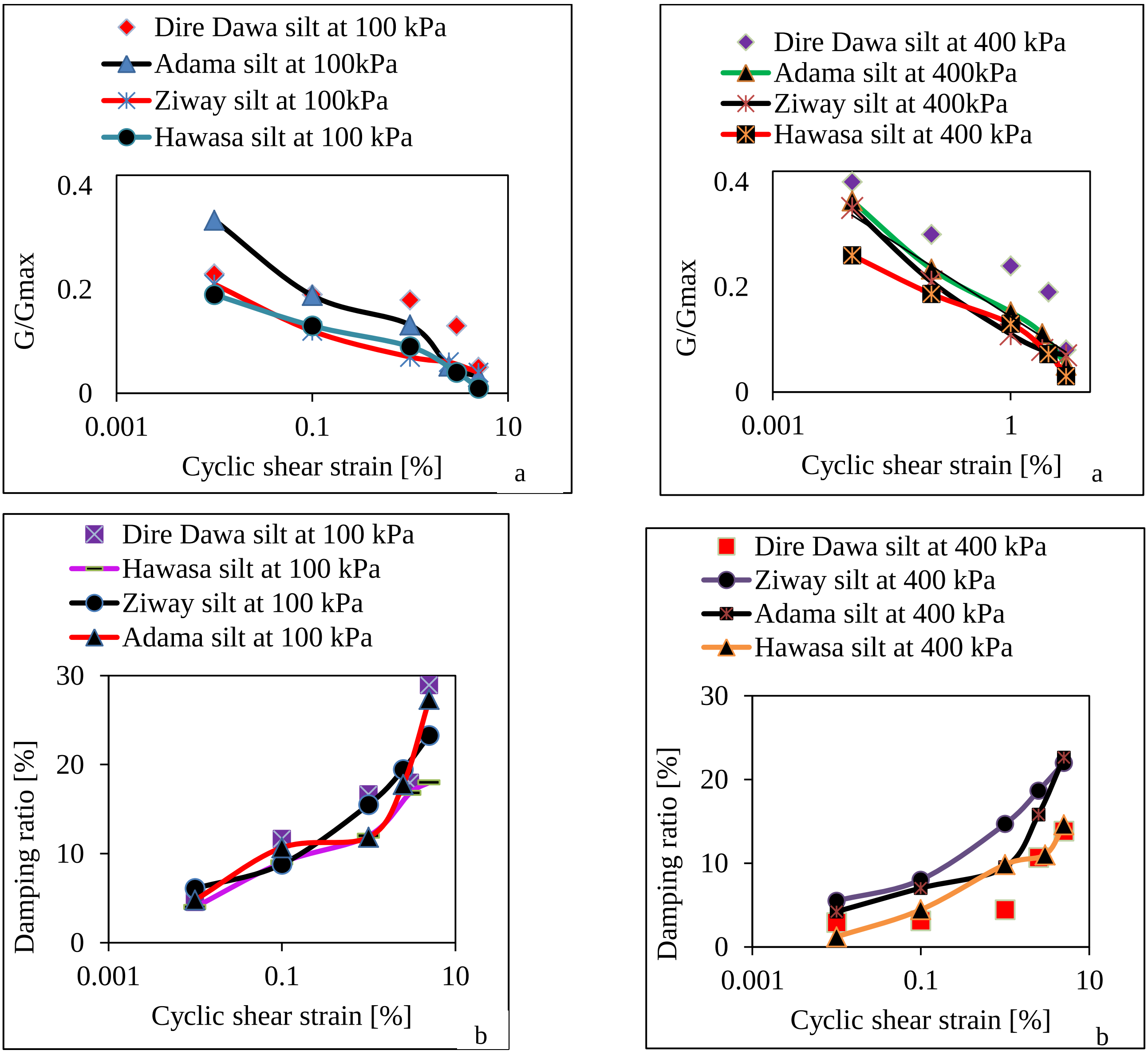


Figure 4.21 Comparison of modulus reduction (a) and damping ratio (b) values of TF silt soil with local silt [14], [15], [27]

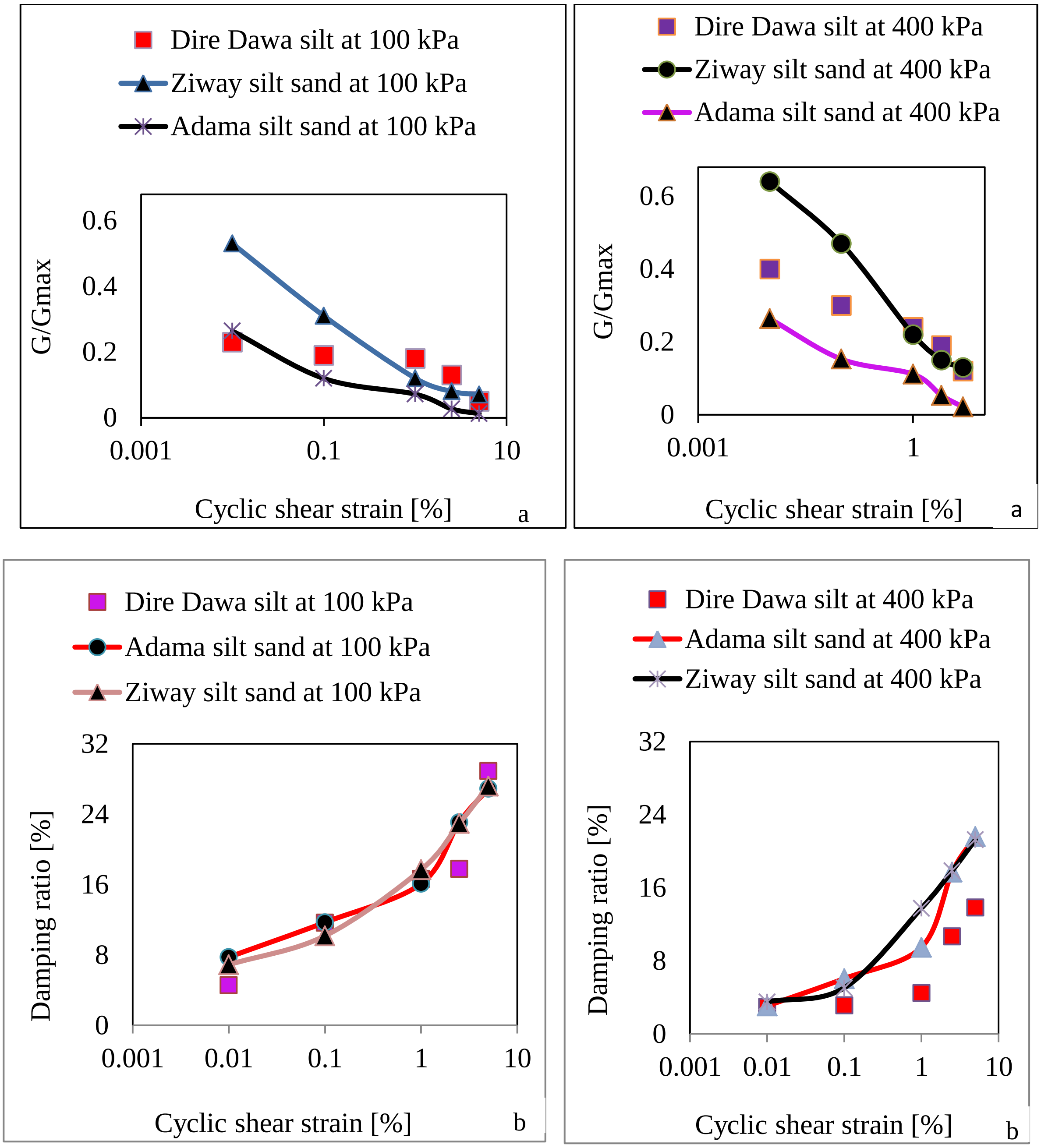


Figure 4.22 Comparison of modulus reduction (a) and damping ratio (b) values of TF silt soil with local silty sand soil [15], [27]

Comparison of Dire Dawa silt soil modulus reduction values curves with the local silt and silty sand soil curves are presented in Figures 4.21 (a) and 4.22 (a). It has been seen that, the modulus reduction curves of the silt soil are in a good agreement with the Ziway, Adama and Hawassa silt soil curves. The modulus reduction values for silt soil are expected to be below the silty sand. From Figure 4.22 (a), the modulus reduction values are lower than Ziway and Adama silty sand soil curves, which is in a good agreement with international values [25].

Figures 4.21 (b) and 4.22 (b) show that the computed damping ratio curves are moreover agree with the Ziway, Adama and Hawassa silt and silty sand soil curves.

In general, it can be said that the results of shear modulus reduction and damping ratio values of Dire Dawa silt soil are comparable with previously published corresponding local silt soil values.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigates the static properties (shear strength) and dynamic properties (shear modulus and damping ratio) of Dire Dawa typical soils, from laboratory tests on remolded specimens. The dynamic properties are addressed based on cyclic simple shear tests. The effects of different factors on the dynamic properties were also addressed.

On the bases of all the experimental results, the following are drawn.

- ✓ The soils in Dire Dawa town are mostly low plastic silt and poorly graded sand.
- ✓ The shear strength parameter (c and ϕ) values of sand from direct shear test results range between 1 kPa to 9 kPa and 26^0 to 28^0 respectively.
- ✓ The shear strength parameter (c and ϕ) values of silt from direct shear test results range between 28 kPa to 43 kPa and 15^0 to 25^0 respectively.
- ✓ The influences of some factors on shear strength parameters based on the analysis, the shear strength parameters of both soils vary with density. The cohesion of the soil is strongly affected by the water content of the soil, while the angle of internal friction of the soil is not significantly affected.
- ✓ The values of shear modulus and damping ratio of the sand range between 1MPa to 38MPa and3% to 24% respectively.
- ✓ The values of shear modulus and damping ratio of the silt range between 1MPa to 14MPa and 3% to 29% respectively.
- ✓ The obtained modulus reduction values of sand show slight difference with those suggested in the previous study on local sand, but the damping ratio show a good agreement. This shows that, the effect of testing conditions and material characteristics on damping ratio are minimal compared to shear modulus.
- ✓ The obtained modulus reduction and damping ratio values of silt soil agree with those suggested in the previous study on local silt.
- ✓ The influences of some factors of shear modulus based on the analysis, the shear modulus increases with confining pressure and number of shearing cycles, but it decreases with shear strain amplitude for a given shear strain amplitude.
- ✓ The influences of some factors of damping ratio based on the analysis, the damping ratio decreases with confining stress and number of shearing cycles, but it increases with shear strain amplitude, which agrees with those suggested in literature.

5.2 Recommendations

From the findings of the study, the following are recommended.

- ✓ The shear strength parameters were determined using the direct shear apparatus. Due to lack of measuring the pore-water pressure and the plane of shear is predetermined as horizontal; the results can be affected by end and side effects of the rigid box and there is subsequent doubt about the stress distribution with in the sample. Thus, it is important to supplement these results by triaxial test results.
- ✓ In this study the shear modulus and damping ratio of Dire Dawa typical soils were studied. Furthermore, liquefaction characteristics of the poorly graded sand especially under saturation condition should be investigated.
- ✓ The low strain shear modulus, G_{max} were computed from existing correlations in the literature. A reliable values and better comparisons would be obtained if G_{max} is determined from dynamic field tests.
- ✓ Because of time and budget constraints soil samples were collected only from seven test pits. A better static and dynamic characterization would be obtained if investigation is done on large number of samples.

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APPENDIXCES

APPENDIX A. Index property tests

Appendix A-1 Field tests

Table I.1 Field density

field density compution																
Sampling Location	DDU				DB		TF				MPS		NCF		CTF	
Sampling depth [m]	1.50		3.50		3.00		2.00		4.00		3.00		3.00		2.50	
Determination No.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Internal diameter of core cutter in cm	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
Internal height of core cutter in cm	9.50	10.00	9.50	10.00	10.00	9.50	9.50	10.00	9.50	10.00	9.50	10.00	9.50	10.00	9.50	10.00
Volume of core cutter (V) in cm3	144.47	152.07	144.47	152.07	144.47	152.07	144.47	152.07	144.47	152.07	144.47	152.07	144.47	152.07	144.47	152.07
Weight of core cutter (w1) in g	165.00	175.00	165.00	175.00	165.00	175.00	165.00	175.00	165.00	175.00	165.00	175.00	165.00	175.00	165.00	175.00
Weight of core cutter + soil (w2) in g	349.80	380.00	354.80	380.00	388.00	356.40	382.00	384.00	385.00	390.00	363.45	386.20	374.00	394.67	372.00	392.45
weight of soil (w2- w1) in g	184.80	205.00	189.80	205.00	213.00	191.40	217.00	209.00	220.00	215.00	198.45	211.20	209.00	219.67	207.00	217.45
Bulk density of soil [ρb] = w2-w1/ v in g/cm3	1.28	1.35	1.31	1.35	1.40	1.32	1.50	1.37	1.52	1.41	1.37	1.39	1.45	1.44	1.43	1.43
Average value	1.31		1.33		1.36		1.44		1.47		1.38		1.45		1.43	
Moisture contents (w) in %	14.53	12.79	20.82	21.12	10.26	10.81	30.75	30.38	22.41	22.45	17.24	17.22	11.51	11.50	21.96	23.28
Dry density of soil [ρd]= 100 ρb/100+w	1.12	1.20	1.09	1.11	1.27	1.20	1.15	1.05	1.24	1.15	1.17	1.18	1.30	1.30	1.17	1.16
Average value in g/cm3	1.16		1.10		1.23		1.10		1.20		1.18		1.30		1.17	

Table I.2 Field moisture content

Field moisture compution																
Sampling Location	DDU								DB				MPS			
Sampling depth [m]	1.50				3.50				3.00				3.00			
Determination No.	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Container No	26B	2C	12H	12H	1B	2T	2B	LL	2C	15T	KH	TT	26B	2C	12H	23
Mass of container, g	20.00	25.00	15.50	15.70	25.00	15.70	15.70	20.00	15.50	20.00	15.50	20.00	20.00	25.00	15.50	15.70
Mass of container + Wet soil, g	51.02	67.10	69.80	70.20	50.00	67.10	69.80	73.45	38.00	58.40	48.60	54.87	89.00	74.30	92.60	65.78
Mass of container + Dry soil, g	46.80	61.56	63.68	63.98	45.80	58.00	60.50	64.00	35.75	55.00	45.60	51.23	78.46	67.34	81.26	58.43
Mass of water, g	4.22	5.54	6.12	6.22	4.20	9.10	9.30	9.45	2.25	3.40	3.00	3.64	10.54	6.96	11.34	7.35
Mass of dry soil, g	26.80	36.56	48.18	48.28	20.80	42.30	44.80	44.00	20.25	35.00	30.10	31.23	58.46	42.34	65.76	42.73
Water content, %	15.75	15.15	12.70	12.88	20.19	21.51	20.76	21.48	11.11	9.71	9.97	11.66	18.03	16.44	17.24	17.20
Ave. moisture content, % =	14.53		12.79		20.82		21.12		10.26		10.81		17.24		17.22	

Field moisture compution																
Sampling Location	TF								NCF				CTF			
Sampling depth [m]	2.00				4.00				3.00				2.50			
Determination No.	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Container No	26B	2C	12H	2B	1B	2T	2B	TL	26B	2C	12H	45	1B	2T	2B	LL
Mass of container, g	20.00	25.00	15.50	15.70	25.00	15.70	15.70	20.00	20.00	25.00	15.50	15.70	25.00	15.70	15.70	20.00
Mass of container + Wet soil, g	92.00	72.00	69.80	68.70	95.00	60.00	69.80	56.78	72.00	54.20	83.30	65.45	64.30	48.98	56.78	64.89
Mass of container + Dry soil, g	75.40	61.20	56.50	57.00	82.40	52.00	59.60	50.23	66.30	51.60	75.80	60.70	57.34	42.56	49.80	55.60
Mass of water, g	16.60	10.80	13.30	11.70	12.60	8.00	10.20	6.55	5.70	2.60	7.50	4.75	6.96	6.42	6.98	9.29
Mass of dry soil, g	55.40	36.20	41.00	41.30	57.40	36.30	43.90	30.23	46.30	26.60	60.30	45.00	32.34	26.86	34.10	35.60
Water content, %	29.96	29.83	32.44	28.33	21.95	22.04	23.23	21.67	11.30	10.77	12.44	10.56	21.52	23.90	20.47	26.10
Ave. moisture content, % =	30.75		30.38		22.41		22.45		11.50		11.50		21.96		23.28	

Appendix A-2 Specific gravity

Table II.1 Specific gravity computations

Specifif Gravity test																						
Sampling Location	DDU				TF				AG		DB				MPS				CTF		NCF	
Sampling depth [m]	1.50		3.50		2.00		4.00		3.00		1.00		3.00		1.50		3.00		3.00		3.00	
[A] Calibration of pycnometer																						
Pycnometer No.	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Weight of dry, clean pycnometer, wp (g)	47.90	63.40	47.90	63.40	47.90	63.40	47.90	63.40	47.90	63.80	46.30	47.23	45.35	49.88	49.01	48.41	45.35	49.88	46.12	61.98	48.78	51.54
Weight of pycnometer + water, wpw (g)	147.40	163.20	147.10	162.80	147.10	162.20	147.30	162.50	147.00	162.20	144.84	149.47	144.83	149.47	148.65	148.39	144.83	149.43	147.70	162.14	144.83	149.47
Observed temperature of water, Ti (oc)	18.20	17.70	17.20	17.40	17.90	17.20	16.50	17.50	16.60	17.00	20.30	21.00	19.30	19.10	20.50	20.20	20.30	20.60	18.80	18.20	19.50	19.80
[B] Specific Gravity Determination																						
Determination No.	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00
Pycnometer No.	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Weight of pycnometer + soil + water, Wpws (g)	162.70	178.30	162.70	178.30	162.50	177.70	162.70	178.30	162.60	177.75	160.46	164.90	160.53	165.24	164.15	163.84	159.98	165.11	162.98	177.70	160.28	165.14
Temperature, Tx(oc)	18.90	19.00	17.70	18.20	18.50	18.80	17.40	17.90	17.00	17.60	21.30	21.80	19.50	20.20	21.60	22.50	22.00	21.50	20.10	20.00	21.00	20.60
Weight of pycnometer + water at Tx, Wpw(atTx) (g)	147.38	163.20	147.08	162.80	147.08	147.08	147.30	147.30	146.98	162.20	144.82	149.45	144.81	149.45	148.63	148.32	144.79	149.41	147.68	147.68	144.81	149.45
Weight of dry soil, ws (gm)	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Conversion factor, K	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Specific gravity of soil at 20°c.	2.58	2.53	2.67	2.64	2.61	2.64	2.61	2.72	2.67	2.65	2.67	2.62	2.69	2.71	2.64	2.63	2.55	2.69	2.58	2.66	2.62	2.68
Average specific gravity of soil.	2.55		2.65		2.62		2.66		2.69		2.64		2.70		2.63		2.61		2.61		2.65	

Appendix A-3 Grain size analysis

Table II.1 Dry sieve analysis of TF at 2m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1164.40	0.00	0.00	0.00	100.00
No 4	4.75	1262.70	1264.90	2.20	0.22	0.22	99.78
No 8	2.36	990.00	1021.40	31.40	3.14	3.36	96.64
No 10	2.00	944.00	953.80	9.80	0.98	4.34	95.66
No 16	1.18	894.30	910.00	15.70	1.57	5.91	94.09
No 30	0.60	830.90	845.10	14.20	1.42	7.33	92.67
No 40	0.43	789.40	801.30	11.90	1.19	8.52	91.48
No. 50	0.30	750.40	769.00	18.60	1.86	10.38	89.62
No. 100	0.15	777.30	811.00	33.70	3.37	13.75	86.25
No. 200	0.08	765.30	786.20	20.90	2.09	15.84	84.16
Pan	-------	735.60	1576.80	841.20	84.12	99.96	-------
Total				999.60			

Table II.2 Wet sieve analysis TF at 2m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
21.40	0.25	1.03	0.0025	1.0275	8.36	0.01348	0.0780	88.74	84.89
21.40	0.75	1.029	0.0025	1.0265	8.63	0.01348	0.0457	85.52	81.80
21.50	1.00	1.0269	0.0024	1.0245	9.18	0.01348	0.0409	79.06	75.63
21.50	2.00	1.026	0.0024	1.0236	9.42	0.01348	0.0293	76.16	72.85
21.60	4.00	1.025	0.0023	1.0227	9.69	0.01332	0.0207	73.25	70.07
21.70	8.00	1.024	0.0023	1.0217	9.95	0.01332	0.0149	70.03	66.99
21.60	15.00	1.0238	0.0023	1.0215	10.00	0.01332	0.0109	69.38	66.37
21.60	30.00	1.022	0.0023	1.0197	10.48	0.01332	0.0079	63.57	60.81
21.60	60.00	1.021	0.0023	1.0187	10.75	0.01332	0.0056	60.34	57.73
22.20	120.00	1.02	0.0023	1.0177	11.01	0.01332	0.0040	57.12	54.64
22.70	240.00	1.0195	0.0022	1.0173	11.14	0.01317	0.0028	55.83	53.40
23.00	480.00	1.0185	0.0021	1.0164	11.41	0.01317	0.0020	52.92	50.63
21.40	1440.00	1.016	0.0025	1.0135	12.07	0.01348	0.0012	43.56	41.67

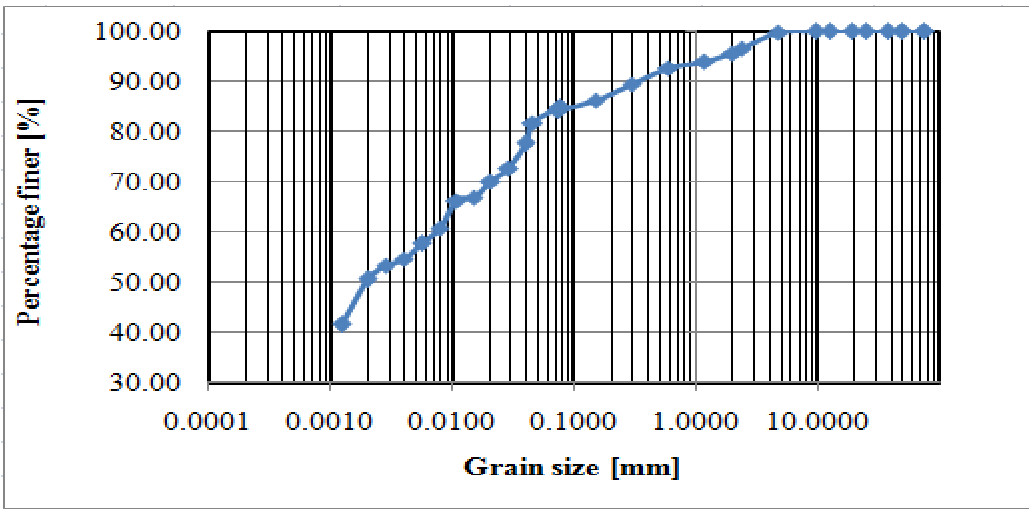


Figure II.1 Grain size distribution curve of TF at 2m

Table II.3 Dry sieve analysis of DDU at 1.5m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1170.40	6.00	1.00	1.00	99.00
No 4	4.75	1262.70	1271.60	8.90	1.48	2.48	97.52
No 8	2.36	990.00	1024.50	34.50	5.75	8.23	91.77
No 10	2.00	944.00	1009.20	65.20	10.87	19.10	80.90
No 16	1.18	894.30	943.90	49.60	8.27	27.37	72.63
No 30	0.60	830.90	883.30	52.40	8.73	36.10	63.90
No 40	0.43	789.40	845.60	56.20	9.37	45.47	54.53
No. 50	0.30	750.40	806.00	55.60	9.27	54.73	45.27
No. 100	0.15	777.30	862.00	84.70	14.12	68.85	31.15
No. 200	0.08	765.30	817.30	52.00	8.67	77.52	22.48
Pan	-------	735.60	870.40	134.30	22.38	99.90	-------
Total				599.40	99.90		

Table II.4 Wet sieve analysis of DDU at 1.5m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
21.00	0.25	1.0115	0.0025	1.0090	13.26	0.01391	0.1013	29.54	23.90
21.20	0.75	1.0105	0.0025	1.0080	13.52	0.01391	0.0591	26.26	21.24
21.00	1.00	1.0095	0.0025	1.0070	13.79	0.01391	0.0516	22.97	18.59
21.30	2.00	1.009	0.0025	1.0065	13.92	0.01391	0.0367	21.33	17.26
21.40	4.00	1.009	0.0025	1.0065	13.92	0.01391	0.0259	21.33	17.26
21.40	8.00	1.0085	0.0025	1.0060	14.05	0.01391	0.0184	19.69	15.93
21.50	15.00	1.008	0.0024	1.0056	14.18	0.01374	0.0134	18.38	14.87
21.60	30.00	1.008	0.0023	1.0057	14.18	0.01374	0.0094	18.71	15.13
21.60	60.00	1.0075	0.0023	1.0052	14.32	0.01374	0.0067	17.07	13.81
22.20	120.00	1.0075	0.0023	1.0052	14.32	0.01374	0.0047	17.07	13.81
22.30	240.00	1.007	0.0023	1.0047	14.45	0.01374	0.0034	15.43	12.48
21.90	480.00	1.007	0.0023	1.0047	14.45	0.01374	0.0024	15.43	12.48
21.60	1440.00	1.007	0.0032	1.0038	14.45	0.01374	0.0014	12.55	10.15

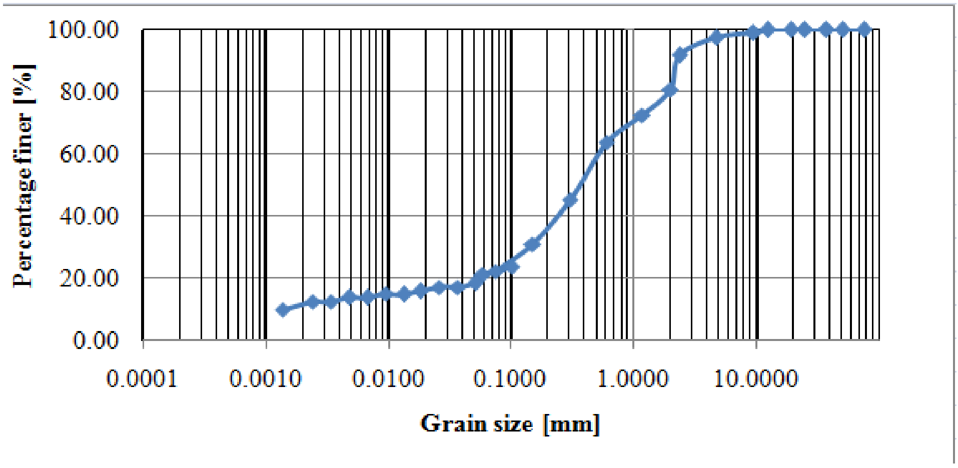


Figure II.2 Grain size distribution curve of DDU at 1.5m table II.5 Dry sieve analysis OF DDU at 3.5m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1164.40	0.00	0.00	0.00	100.00
No 4	4.75	1262.70	1275.40	12.70	2.12	2.12	97.88
No 8	2.36	990.00	1017.30	27.30	4.55	6.67	93.33
No 10	2.00	955.50	970.30	14.80	2.47	9.13	90.87
No 16	1.18	894.30	903.00	8.70	1.45	10.58	89.42
No 30	0.60	830.90	858.10	27.20	4.53	15.12	84.88
No 40	0.43	787.40	809.90	22.50	3.75	18.87	81.13
No. 50	0.30	750.40	780.50	30.10	5.02	23.88	76.12
No. 100	0.15	777.30	840.80	63.50	10.58	34.47	65.53
No. 200	0.08	765.30	816.30	51.00	8.50	42.97	57.03
Pan	-------	735.60	1077.55	341.95	56.99	99.96	-------
Total				599.8	99.96		

Table II.6 Wet sieve analysis of DDU at 3.5m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
21.60	0.25	1.022	0.0023	1.0197	10.48	0.01332	0.0862	63.28	57.50
21.60	0.75	1.0215	0.0023	1.0192	10.61	0.01332	0.0501	61.67	56.04
21.40	1.00	1.021	0.0025	1.0185	10.75	0.01334	0.0437	59.42	54.00
21.50	2.00	1.019	0.0024	1.0166	11.27	0.01340	0.0318	53.32	48.45
21.40	4.00	1.019	0.0025	1.0165	11.27	0.01348	0.0226	53.00	48.16
21.70	8.00	1.018	0.0023	1.0157	11.54	0.01332	0.0160	50.43	45.82
21.50	15.00	1.0175	0.0024	1.0151	11.67	0.01340	0.0118	48.50	44.07
21.50	30.00	1.017	0.0024	1.0146	11.80	0.01340	0.0084	46.90	42.61
22.20	60.00	1.016	0.0023	1.0137	12.07	0.01332	0.0060	44.01	39.99
23.00	120.00	1.0135	0.0022	1.0113	12.73	0.01317	0.0043	36.30	32.98
22.90	240.00	1.011	0.0022	1.0088	13.39	0.01317	0.0031	28.27	25.68
22.00	480.00	1.0105	0.0023	1.0082	13.52	0.01332	0.0022	26.34	23.93
21.50	1440.00	1.01	0.0024	1.0076	13.65	0.01340	0.0013	24.41	22.18

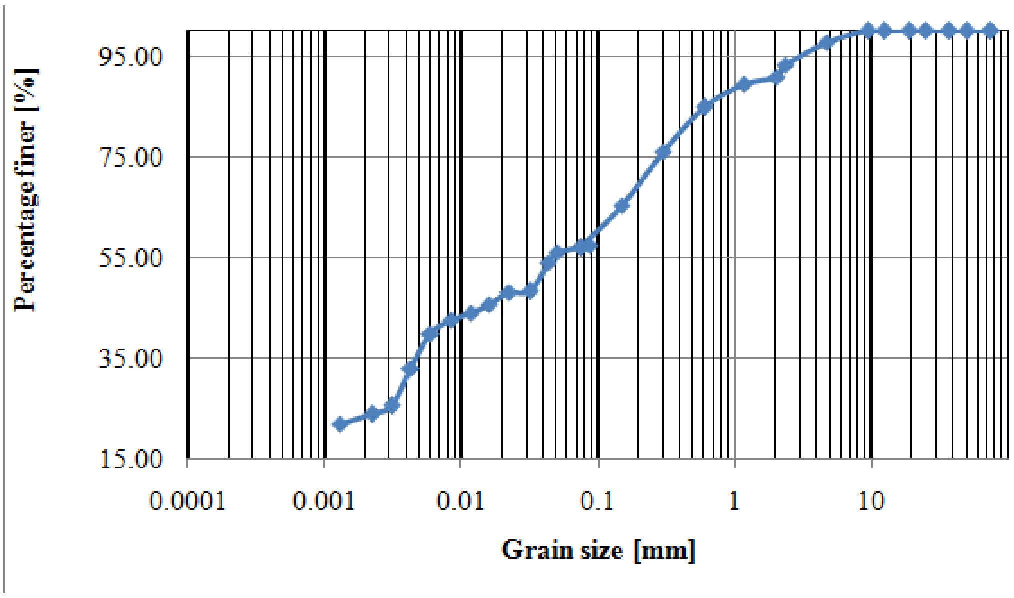


Figure II.3 Grain size distribution curve of DDU at 3.5m

Table II.7 Dry sieve analysis of TF at 4m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.50	1178.50	0.00	0.00	0.00	100.00
1/2"	12.50	1217.00	1217.00	0.00	0.00	0.00	100.00
3.8"	9.50	1164.50	1164.50	0.00	0.00	0.00	100.00
No 4	4.75	1263.10	1293.90	30.80	3.08	3.08	96.92
No 8	2.36	990.20	1024.60	34.40	3.44	6.52	93.48
No 10	2.00	944.10	951.30	7.20	0.72	7.24	92.76
No 16	1.18	894.30	906.70	12.40	1.24	8.48	91.52
No 30	0.60	831.00	845.30	14.30	1.43	9.91	90.09
No 40	0.43	789.60	799.20	9.60	0.96	10.87	89.13
No. 50	0.30	750.60	762.90	12.30	1.23	12.10	87.90
No. 100	0.15	777.40	809.20	31.80	3.18	15.28	84.72
No. 200	0.08	765.70	797.60	31.90	3.19	18.47	81.53
Pan	-------	1551.10	737.10	815.30	81.53	100.00	-------
Total				1000.0	100		

Table II.8 Wet sieve analysis of TF at 4m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
21.00	0.25	1.0302	0.0025	1.0277	8.31	0.01348	0.0777	88.77	81.90
21.20	0.75	1.029	0.0025	1.0265	8.63	0.01348	0.0457	84.93	78.35
21.00	1.00	1.028	0.0025	1.0255	8.89	0.01348	0.0402	81.72	75.40
21.30	2.00	1.026	0.0025	1.0235	9.42	0.01348	0.0293	75.31	69.48
21.40	4.00	1.022	0.0025	1.0195	10.48	0.01348	0.0218	62.49	57.66
21.40	8.00	1.021	0.0025	1.0185	10.75	0.01348	0.0156	59.29	54.70
21.50	15.00	1.018	0.0024	1.0156	11.54	0.01332	0.0117	50.00	46.13
21.60	30.00	1.015	0.0023	1.0127	12.33	0.01332	0.0085	40.70	37.55
21.60	60.00	1.014	0.0023	1.0117	12.60	0.01332	0.0061	37.50	34.59
22.20	120.00	1.012	0.0023	1.0097	13.13	0.01332	0.0044	31.09	28.68
22.30	240.00	1.011	0.0023	1.0087	13.39	0.01332	0.0031	27.88	25.72
21.90	480.00	1.0105	0.0023	1.0082	13.52	0.01332	0.0022	26.28	24.25
17.60	1440.00	1.01	0.0033	1.0067	13.65	0.01399	0.0014	21.47	19.81

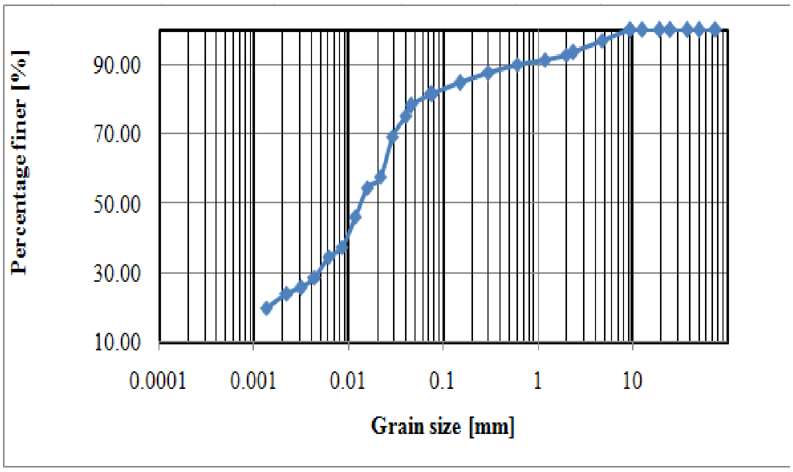


Figure II.4 Grain size distribution curve of TF at 4.0 m

Table II.9 Dry sieve analysis of AG at 3m

Total mass of sample, g 500

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1166.40	2.00	0.40	0.40	99.60
No 4	4.75	1262.70	1280.00	17.30	3.46	3.86	96.14
No 8	2.36	990.00	1040.40	50.40	10.08	13.94	86.06
No 10	2.00	955.50	990.78	35.28	7.06	21.00	79.00
No 16	1.18	894.30	945.30	51.00	10.20	31.20	68.80
No 30	0.60	830.90	890.54	59.64	11.93	43.12	56.88
No 40	0.425	787.40	815.34	27.94	5.59	48.71	51.29
No. 50	0.30	750.40	830.45	80.05	16.01	64.72	35.28
No. 100	0.15	777.30	892.10	114.80	22.96	87.68	12.32
No. 200	0.075	765.30	805.56	40.26	8.05	95.73	4.27
Pan	-------	735.60	756.00	20.40	4.08	99.81	-------
Total				499.07	99.81		

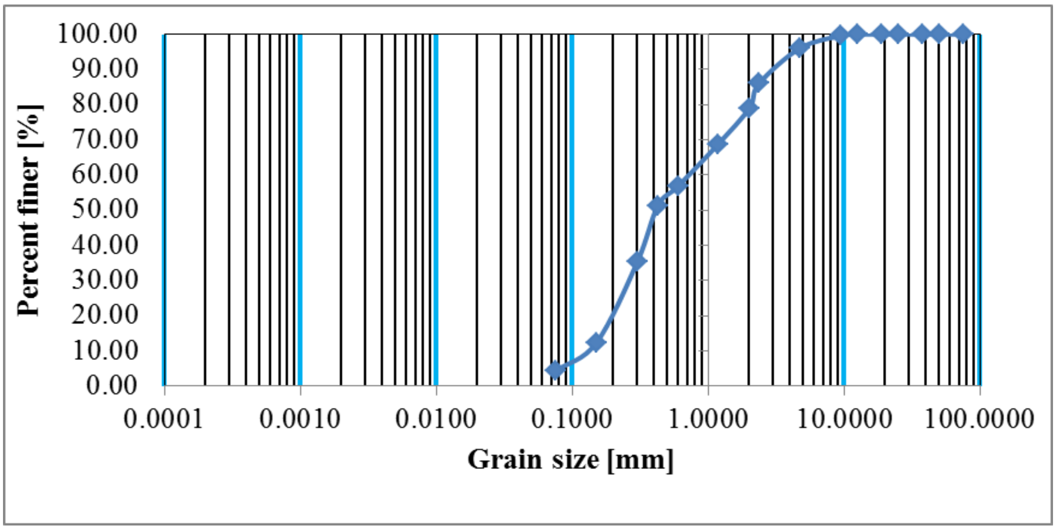


Figure II.5 Grain size distribution curve of AG at 3.0 m

Table II.10 Dry sieve analysis of DB at 3m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
					Total mass of sample, g		500
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1169.00	4.60	0.92	0.92	99.08
No 4	4.75	1262.70	1268.34	5.64	1.13	2.05	97.95
No 8	2.36	990.00	1010.68	20.68	4.14	6.18	93.82
No 10	2.00	955.50	980.78	25.28	5.06	11.24	88.76
No 16	1.18	894.30	947.30	53.00	10.60	21.84	78.16
No 30	0.60	820.90	934.80	113.90	22.78	44.62	55.38
No 40	0.425	797.40	816.30	18.90	3.78	48.40	51.60
No. 50	0.30	750.40	853.90	103.50	20.70	69.10	30.90
No. 100	0.15	777.30	838.40	61.10	12.22	81.32	18.68
No. 200	0.075	765.30	835.00	69.70	13.94	95.26	4.74
Pan	-------	735.60	759.10	23.50	4.70	99.96	-------
Total				499.80	99.96		

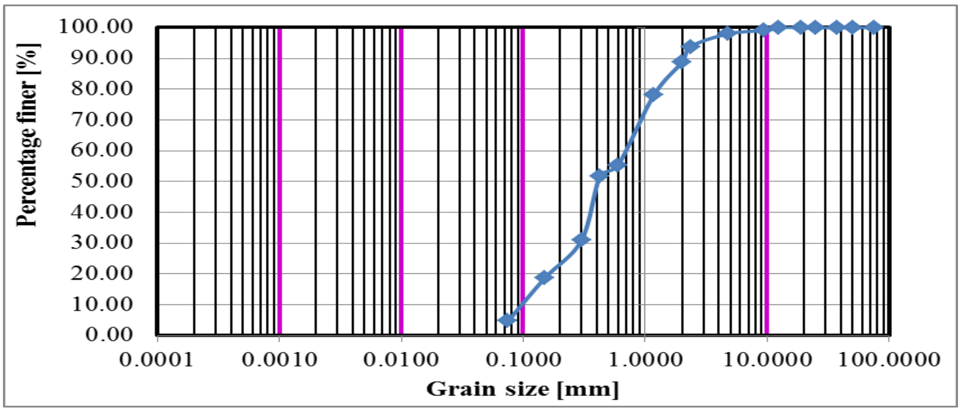


Figure II.6 Grain size distribution curve of DB at 3.0 m

Table II.11 Dry sieve analysis of NCF at 3m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1164.40	0.00	0.00	0.00	100.00
No 4	4.75	1262.70	1281.00	18.30	3.05	3.05	96.95
No 8	2.36	990.00	1060.60	70.60	11.77	14.82	85.18
No 10	2.00	944.00	990.65	46.65	7.78	22.59	77.41
No 16	1.18	894.30	956.67	62.37	10.40	32.99	67.01
No 30	0.60	830.90	876.98	46.08	7.68	40.67	59.33
No 40	0.425	789.40	826.54	37.14	6.19	46.86	53.14
No. 50	0.30	750.40	840.67	90.27	15.05	61.90	38.10
No. 100	0.15	777.30	889.65	112.35	18.73	80.63	19.37
No. 200	0.075	765.30	850.45	85.15	14.19	94.82	5.18
Pan	-------	735.60	764.50	28.90	4.82	99.64	-------
Total				597.81	99.64		

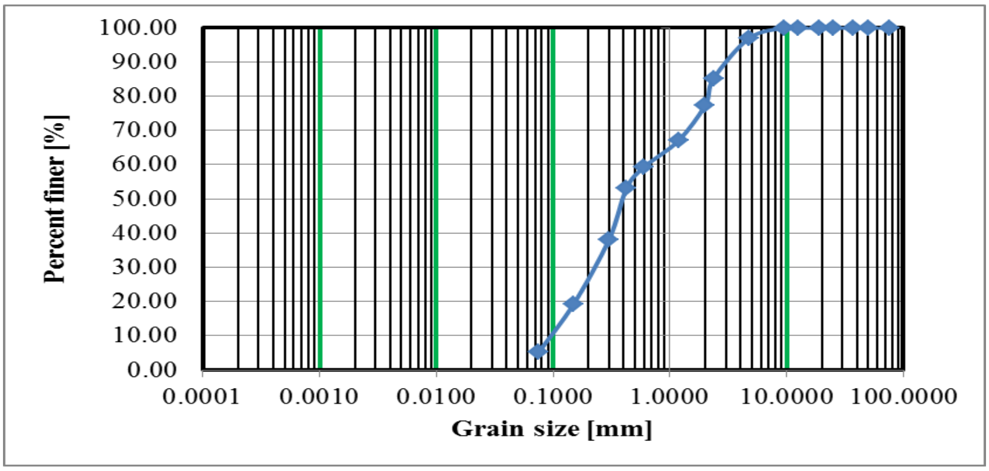


Figure II.7 Grain size distribution curve of NCF at 3.0 m

Table II.12 Dry sieve analysis of MPS at 3m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1216.50	0.00	0.00	0.00	100.00
3.8"	9.50	1164.40	1164.40	0.00	0.00	0.00	100.00
No 4	4.75	1262.70	1282.60	19.90	1.73	1.73	98.27
No 8	2.36	990.00	1018.23	28.23	2.45	4.19	95.81
No 10	2.00	944.00	966.43	22.43	1.95	6.14	93.86
No 16	1.18	894.30	913.20	18.90	1.64	7.78	92.22
No 30	0.60	830.90	854.10	23.20	2.02	9.80	90.20
No 40	0.43	789.40	819.43	30.03	2.61	12.41	87.59
No 50	0.30	750.40	798.34	47.94	4.17	16.58	83.42
No 100	0.15	777.30	848.43	71.13	6.19	22.76	77.24
No 200	0.08	765.30	823.43	58.13	5.05	27.82	72.18
pan	-------	735.60	1415.60	680.00	59.13	86.95	-------
Total				999.89			

Table II.13 wet sieve analysis of MPS at 3m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
20.50	0.50	1.0265	0.0026	1.0239	9.29	0.01344	0.0579	75.75	71.11
20.60	1.00	1.0260	0.0025	1.0235	9.42	0.01328	0.0408	74.49	69.92
20.70	2.00	1.0260	0.0025	1.0235	9.42	0.01328	0.0288	74.49	69.92
20.70	4.00	1.0250	0.0025	1.0225	9.69	0.01328	0.0207	71.32	66.94
20.40	8.00	1.0240	0.0027	1.0213	9.95	0.01344	0.0150	67.51	63.37
20.40	15.00	1.0230	0.0027	1.0203	10.22	0.01344	0.0111	64.34	60.39
20.40	30.00	1.0200	0.0027	1.0173	11.01	0.01328	0.0080	54.83	51.47
20.70	60.00	1.0180	0.0025	1.0155	11.54	0.01328	0.0058	49.13	46.11
20.80	120.00	1.0160	0.0025	1.0135	12.07	0.01328	0.0042	42.79	40.16
21.50	240.00	1.0150	0.0024	1.0126	12.33	0.01328	0.0030	39.94	37.49
21.70	480.00	1.0100	0.0023	1.0077	13.65	0.01328	0.0022	24.41	22.91
20.50	1440.00	1.0090	0.0026	1.0064	13.92	0.01344	0.0013	20.29	19.04

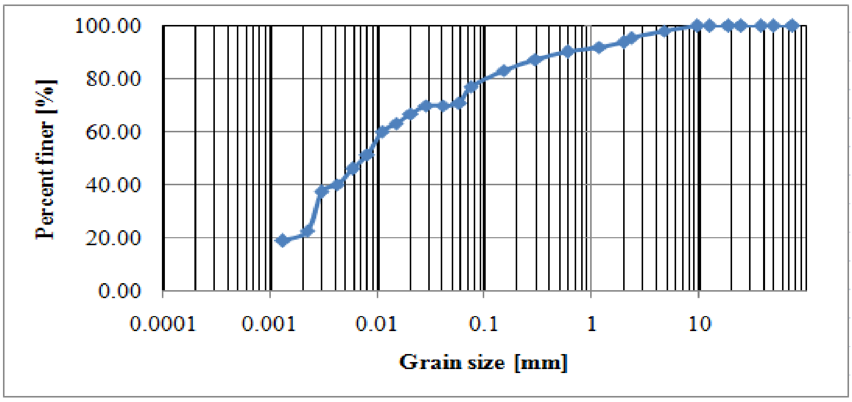


Figure II.8 Grain size distribution curve of MPS at 3.0 m

Table II.14 Dry sieve analysis of CTF at 2.5m

ASTM standard sieve	Sieve opening (mm)	Weight of sieve(g)	Weight of sieve + soil (g)	Weight retained (g)	Percentage wt. retained (g)	Cumulative Percentage Retained (g)	Percentage passing (%)
3"	75.00	1057.00	1057.00	0.00	0.00	0.00	100.00
2"	50.00	1199.00	1199.00	0.00	0.00	0.00	100.00
1.5"	37.50	1084.00	1084.00	0.00	0.00	0.00	100.00
1"	25.00	1248.00	1248.00	0.00	0.00	0.00	100.00
3/4"	19.00	1178.40	1178.40	0.00	0.00	0.00	100.00
1/2"	12.50	1216.50	1221.50	5.00	0.50	0.50	99.50
3.8"	9.50	1164.40	1171.10	6.70	0.67	1.17	98.83
No 4	4.75	1262.70	1333.70	71.00	7.10	8.27	91.73
No 8	2.36	990.00	1051.10	61.10	6.11	14.38	85.62
No 10	2.00	944.00	957.40	13.40	1.34	15.72	84.28
No 16	1.18	894.30	908.10	13.80	1.38	17.10	82.90
No 30	0.60	830.90	890.70	59.80	5.98	23.08	76.92
No 40	0.43	789.40	842.10	52.70	5.27	28.35	71.65
No 50	0.30	750.40	828.50	78.10	7.81	36.16	63.84
No 100	0.15	777.30	885.50	108.20	10.82	46.98	53.02
No 200	0.08	765.30	872.60	107.30	10.73	57.71	42.29
pan	-------	735.60	1158.53	422.93	42.29	100.00	-------
Total				1000.0	100.00		

Table II.15 wet sieve analysis of CTF at 2.5m

Temprature (oC)	Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrmeter Reading	Effective Dept (cm)	Coefficient K	Grain Size (mm)	Percentage Finer	Percentage Finer Combined
21.40	0.50	1.019	0.0027	1.0163	11.27	0.01348	0.0640	52.36	44.13
21.40	1.00	1.0185	0.0027	1.0158	11.41	0.01348	0.0455	50.75	42.77
21.50	2.00	1.017	0.0026	1.0144	11.80	0.01332	0.0324	46.25	38.98
21.60	4.00	1.0155	0.0026	1.0129	12.20	0.01332	0.0233	41.44	34.92
21.50	8.00	1.015	0.0026	1.0124	12.33	0.01332	0.0165	39.83	33.57
21.50	15.00	1.014	0.0026	1.0114	12.60	0.01332	0.0122	36.62	30.86
21.40	30.00	1.012	0.0027	1.0093	13.13	0.01348	0.0089	29.87	25.18
21.70	60.00	1.01	0.0024	1.0076	13.65	0.01332	0.0064	24.41	20.58
21.80	120.00	1.0095	0.0024	1.0071	13.79	0.01332	0.0045	22.81	19.22
22.50	240.00	1.008	0.0023	1.0057	14.18	0.01332	0.0032	18.31	15.43
22.70	480.00	1.007	0.0020	1.0050	14.45	0.01317	0.0023	16.06	13.54
21.30	1440.00	1.0065	0.0026	1.0039	14.58	0.01348	0.0014	12.53	10.56

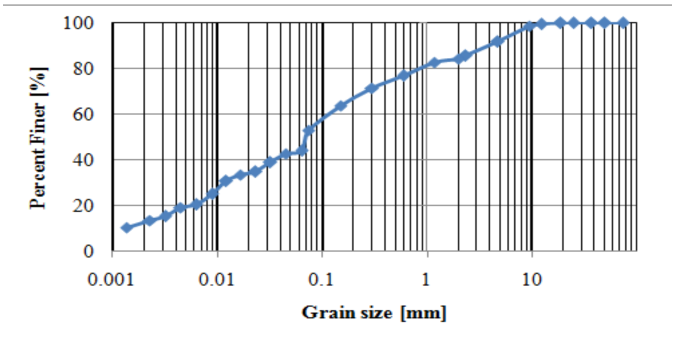


Figure II.9 Grain size distribution curve of CTF at 2.5 m

Appendix A-4 Atterberg Limit Test

Table II.15 l computation of Atterberg limit test results

Sampling Location -TF
Sampling depth 2m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	L1	MT2	MT4	SM2	PL	3C
Mass of container, g	15	15.7	15.7	15.8	15.3	15.1
Mass of container + Wet soil, g	37.2	33.6	40	33.6	19.6	19.7
Mass of container + Dry soil, g	30.4	28	31.6	27.1	18.4	18.5
Mass of water, g	6.80	5.60	8.40	6.50	1.20	1.20
Mass of dry soil, g	15.40	12.30	15.90	11.30	3.10	3.40
Water content, %	44.16	45.53	52.83	57.52	38.71	35.29
No of blows	38	34	26	18	37	

Liquid limit, % = 52 Plastic Limit, %= 37 Plastic Index, % = 15

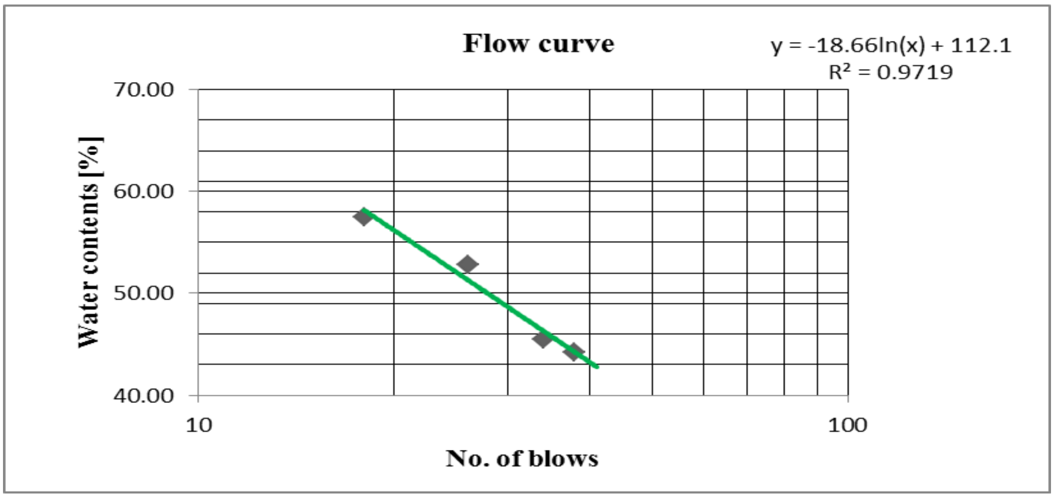


Table II.16 computation of Atterberg limit of DDU at 1.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4		
Container No	67B	3H	M22	L11		
Mass of container, g	18.50	20.40	21.86	19.00		
Mass of container + Wet soil, g	28.60	28.90	29.56	27.76		
Mass of container + Dry soil, g	27.30	27.63	28.21	26.12		
Mass of water, g	1.30	1.27	1.35	1.64		
Mass of dry soil, g	8.80	7.23	6.35	7.12		
Water content, %	14.77	17.57	21.26	23.03		
No of blows	34.00	26.00	22.00	16.00	NP	

Liquid limit, % = 18 Plastic Limit , %= 0 Plastic Index, % = 0

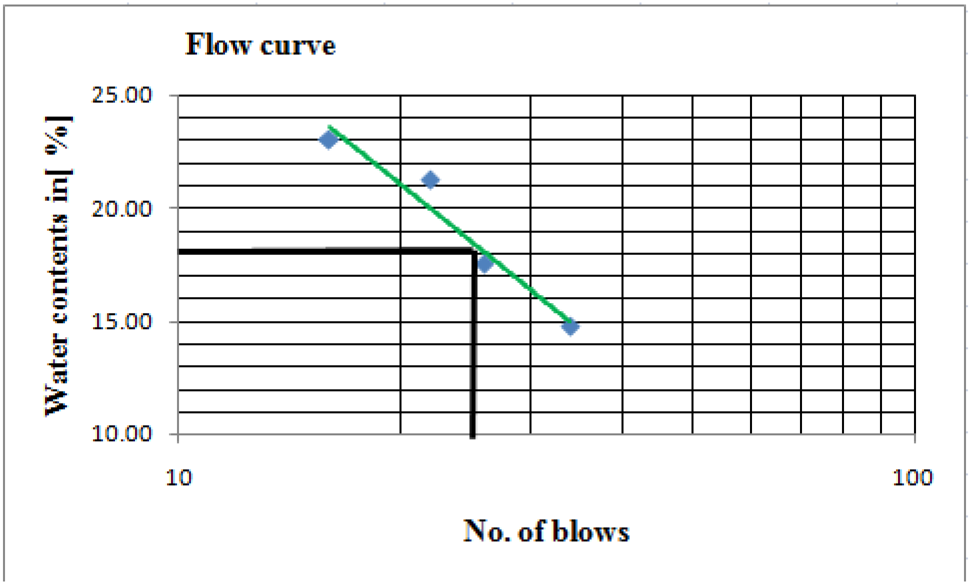


Table II.17 Compution of Atterberg limit of DDU at 3.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	HY	3L	M1	L2	P3	M10
Mass of container, g	29.10	15.80	15.60	14.00	11	10.8
Mass of container + Wet soil, g	43.00	33.30	49.80	40.20	16	14
Mass of container + Dry soil, g	40.00	29.20	41.30	33.60	15	13.26
Mass of water, g	3.00	4.10	8.50	6.60	1.00	0.74
Mass of dry soil, g	10.90	13.40	25.70	19.60	4.00	2.46
Water content, %	27.52	30.60	33.07	33.67	25.00	30.08
No of blows	35	30	20	15	28	

Liquid limit, % = 31 Plastic Limit , %= 28 Plastic Index, % = 3

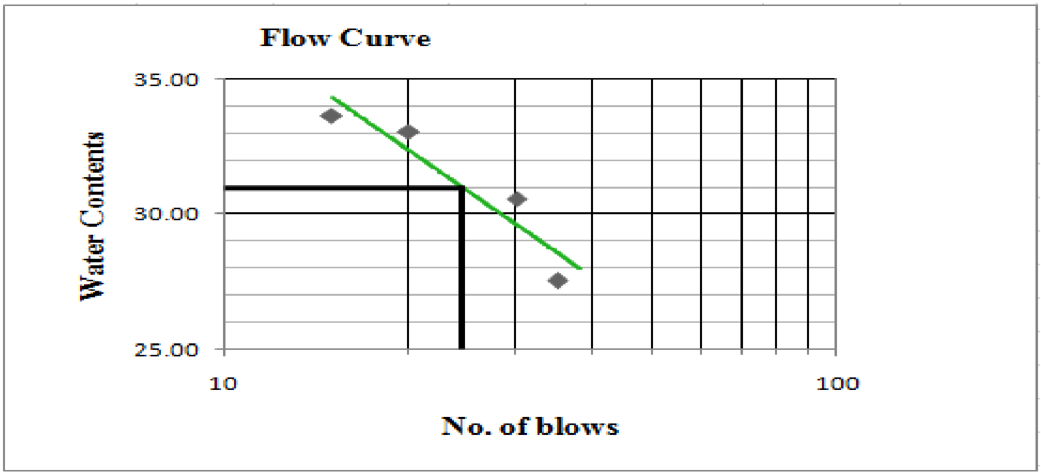


Table II.18 computation of Atterberg limit of TF at 4m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	T1	B	AD	H10	G1	M2
Mass of container, g	14.9	15.5	12	15.8	13.7	15
Mass of container + Wet soil, g	31	37.9	33.2	34.9	17.4	19.5
Mass of container + Dry soil, g	27	32.2	27.4	29.1	16.45	18.36
Mass of water, g	4.00	5.70	5.80	5.80	0.95	1.14
Mass of dry soil, g	12.10	16.70	15.40	13.30	2.75	3.36
Water content, %	33.06	34.13	37.66	43.61	34.55	33.93
No of blows	36	29	24	18	34.00	

Liquid limit, % = 37 Plastic Limit , %= 34 Plastic Index, % = 3

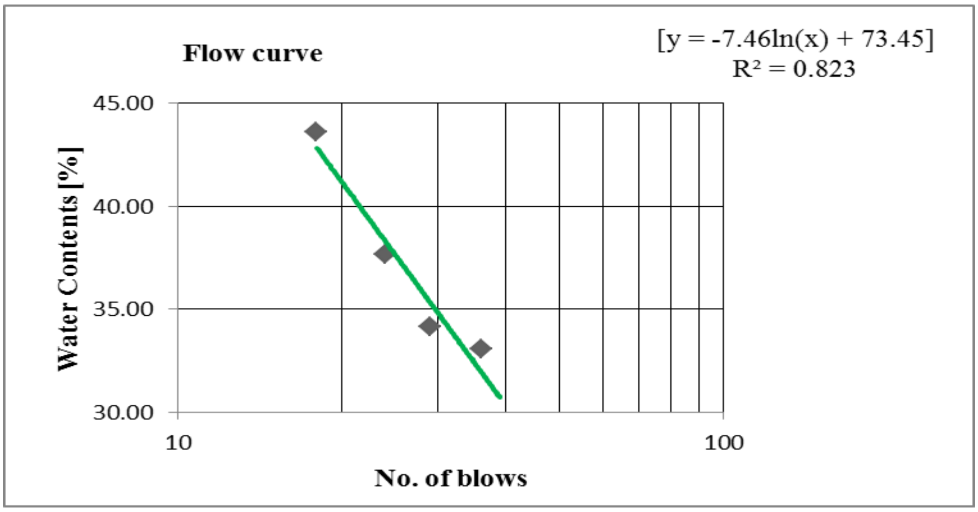


Table II.19 Computation of Atterberg limit of MPS at 3m

	Liquid Limit				**Plastic Limit**	
Trial No	1	2	3	4	1	2
Container No	HY	3L	M1	L2	P3	M10
Mass of container, g	29.10	15.80	15.60	14.00	13.05	9.65
Mass of container + Wet soil, g	42.05	40.64	42.90	47.94	15.5	13.7
Mass of container + Dry soil, g	38.70	33.88	35.25	38.22	14.91	12.8
Mass of water, g	3.35	6.76	7.65	9.72	0.59	0.90
Mass of dry soil, g	9.60	18.08	19.65	24.22	1.86	3.15
Water content, %	34.90	37.39	38.93	40.13	31.72	28.57
No of blows	34	27	22	16	30	

Liquid limit, % = 38 Plastic Limit, %= 30 Plastic Index, % = 8.0

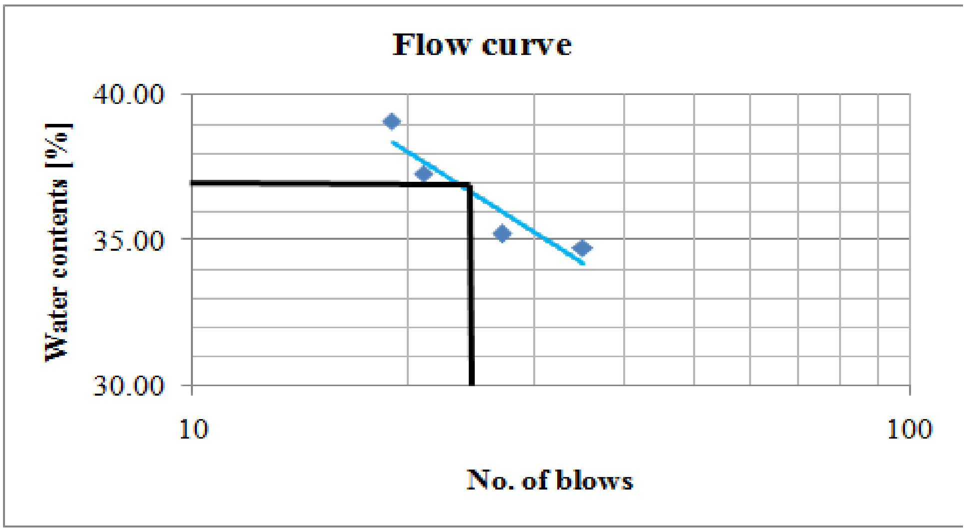
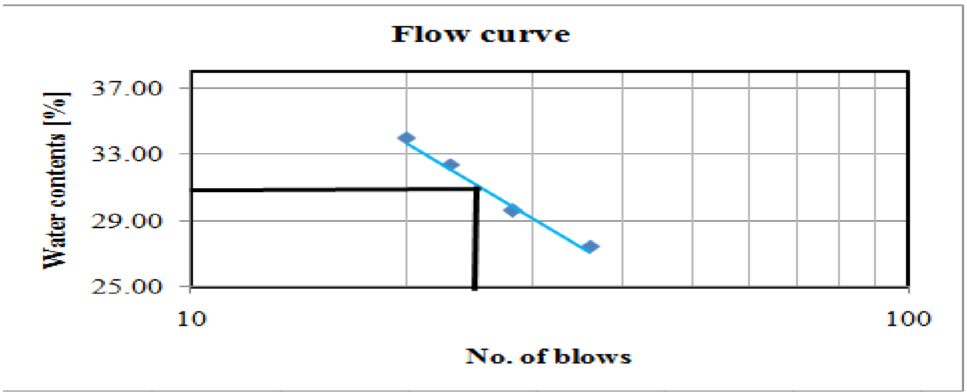


Table II.20 Computation of Atterberg limit of CTF at 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	67B	3H	M22	L11	H12	B10
Mass of container, g	18.50	20.40	21.86	19.00	16.40	24.00
Mass of container + Wet soil, g	36.78	43.65	53.67	45.78	45.67	54.34
Mass of container + Dry soil, g	32.84	38.34	45.89	38.98	39.08	48.27
Mass of water, g	3.94	5.31	7.78	6.80	6.59	6.07
Mass of dry soil, g	14.34	17.94	24.03	19.98	22.68	24.27
Water content, %	27.48	29.60	32.38	34.03	29.06	25.01
No of blows	36	28	23	20	27	

Liquid limit, % = 31.0 Plastic Limit , %= 27 Plastic Index, % = 4.0



Appendix A-5 Compaction Test

Table II. 21 Optimum moisture content and the maximum dry density computation of AG at 3m

Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4974.67	5046.78	5100.56	5128	5120
Mass of Compacted soil, g	1824.67	1896.78	1950.56	1978	1970
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.93	2.01	2.07	2.10	2.09
Water Content, %	4.80	8.45	10.78	14.39	19.33
Dry density, g/cm3	1.84	1.85	1.87	1.83	1.75

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	LL2	KH	MK	CC	M4	NN	23	65H	TT	AA
Mass of container, g	20.5	25.7	15.5	15.7	25	20	15.7	15.7	15.5	20
Mass of container + wet soil, g	65.34	56.45	73.56	49.09	53.98	65.09	46.88	75.44	68.55	76.55
Mass of ontainer + Dry soil, g	62.89	55.32	69.10	46.45	51.98	59.50	42.98	67.88	59.80	67.56
Mass of Water, g	2.45	1.13	4.46	2.64	2.02	5.59	3.90	7.56	8.75	8.99
Mass of Dry soil, g	42.39	29.62	53.6	30.75	26.98	39.5	27.28	52.18	44.3	47.56
Water content, %	5.78	3.81	8.32	8.59	7.41	14.15	14.30	14.49	19.75	18.90
Average Water content, %	4.8		8.45		10.78		14.39		19.33	
Dry Unit Weight, g/cm3	1.68		1.69		1.71		1.67		1.59	

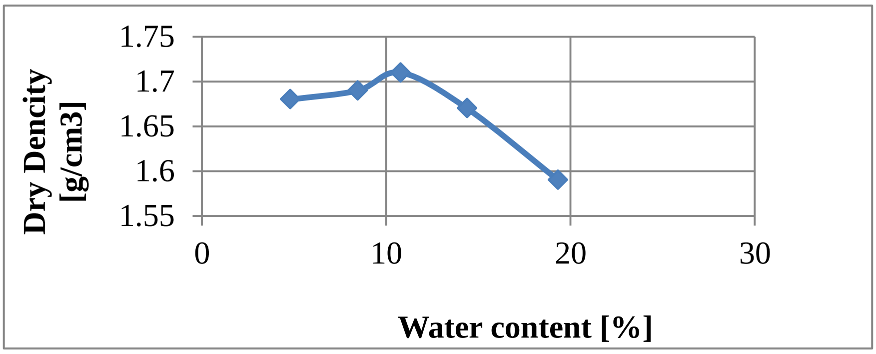
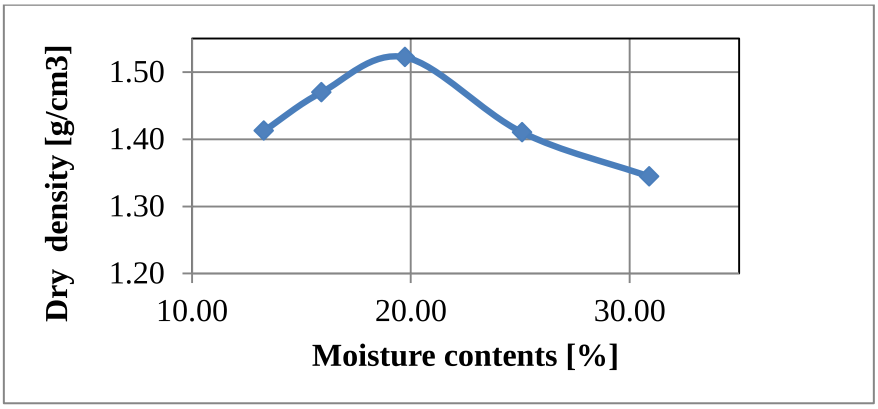


Figure II.8 compaction curve Shows MDD and OMC

Table II. 22 Optimum moisture content and the maximum dry density computation of DDU at 1.5m

Existing moisture content,(%) =					7.52
Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4660.5	4758.4	4870.5	4815.2	4811.4
Mass of Compacted soil, g	1510.5	1608.4	1720.5	1665.2	1661.4
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.60	1.70	1.82	1.76	1.76
Water Content, %	13.29	15.92	19.74	25.10	30.90

Dry density, g/cm3	1.41	1.47	1.52	1.41	1.34

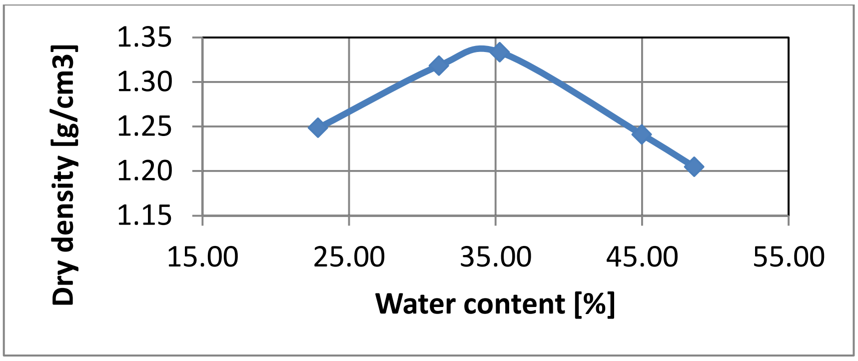


Exsisting Water Content		
	1	2
Conatainer No	B1	C22
Mass of container, g	20.0	15.5
Mass of container + wet soil, g	68.3	58.8
Mass of ontainer + Dry soil, g	65.0	55.7
Mass of Water, g	3.3	3.1
Mass of Dry soil, g	45	40.2
Water content, %	7.33	7.71
Average Water content, %	**7.52**	

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	T22	B22	L1	LL2	B5	MK	CC	T1	23	15
Mass of container, g	18.5	20.5	15.7	15.5	20	20.5	15.5	15.5	20	20
Mass of container + wet soil, g	60.34	53.89	56	52.89	65	59.4	70.2	60.3	65.4	72.45
Mass of ontainer + Dry soil, g	55.4	50	51.56	46.8	58.8	52	59	51.5	55.1	59.6
Mass of Water, g	4.94	3.89	4.44	6.09	6.2	7.4	11.2	8.8	10.3	12.85
Mass of Dry soil, g	36.9	29.5	35.86	31.3	38.8	31.5	43.5	36	35.1	39.6
Water content, %	13.39	13.19	12.38	19.46	15.98	23.49	25.75	24.44	29.34	32.45
Average Water content, %	13.29		15.92		19.74		25.10		30.90	
Dry Unit Weight, g/cm3	1.41		1.47		1.52		1.41		1.34	

Table II. 23 Optimum moisture content and the maximum dry density computation of DDU at 3.5m

Existing moisture content,(%) =					11.07
Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4598.3	4781.9	4853	4848.5	4839.5
Mass of Compacted soil, g	1448.3	1631.9	1703	1698.5	1689.5
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.53	1.73	1.80	1.80	1.79
Water Content, %	22.90	31.14	35.30	44.99	48.57
Dry density, g/cm3	1.25	1.32	1.33	1.24	1.20

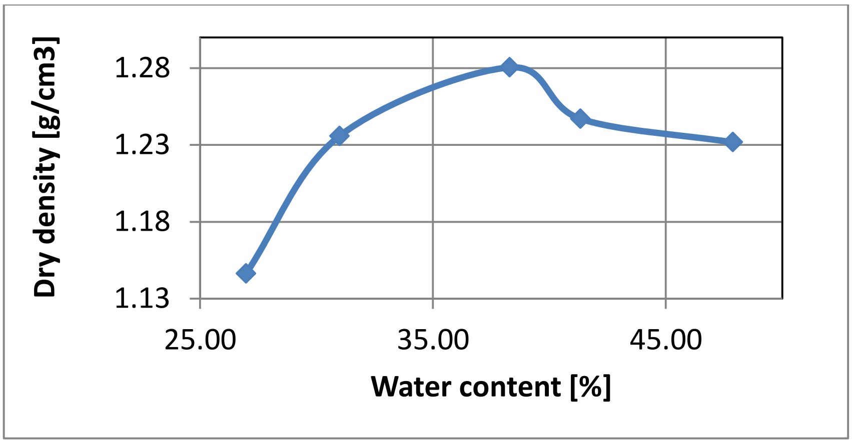


Exsisting Water Content		
Trial	1	2
Conatainer No	LL	MK
Mass of container, g	15.7	18.5
Mass of container + wet soil, g	65.4	75.3
Mass of ontainer + Dry soil, g	59.5	70.8
Mass of Water, g	5.9	4.5
Mass of Dry soil, g	43.8	52.3
Water content, %	13.54	8.60
Average Water content, %	**11.07**	

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	LL2	KH	MK	CC	M4	NN	23	65H	TT	AA
Mass of container, g	20.5	25.7	15.5	15.7	25	20	15.7	15.7	15.5	20
Mass of container + wet soil, g	60.45	53.76	56.88	50.67	61.23	59	72.45	65.76	58	74.8
Mass of container + Dry soil, g	53.8	48	47.5	42	51.8	48.8	53.3	51.7	54.1	49.3
Mass of Water, g	6.65	5.76	9.38	8.67	9.43	10.2	19.15	14.06	3.9	25.5
Mass of Dry soil, g	33.3	22.3	32	26.3	26.8	28.8	37.6	36	38.6	29.3
Water content, %	19.97	25.83	29.31	32.97	35.19	35.42	50.93	39.06	10.10	87.03
Average Water content, %	22.90		31.14		35.30		44.99		48.57	
Dry Unit Weight, g/cm3	1.25		1.32		1.33		1.24		1.20	

Table II. 24 Optimum moisture content and the maximum dry density computation of TF at 2.0 m

Existing moisture content,(%) =					13.71
Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4524.1	4678	4821.6	4813.8	4869.4
Mass of Compacted soil, g	1374.1	1528	1671.6	1663.8	1719.4
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.46	1.62	1.77	1.76	1.82
Water Content, %	26.98	33.99	38.29	41.33	47.87
Dry density, g/cm3	1.15	1.24	1.28	1.25	1.23

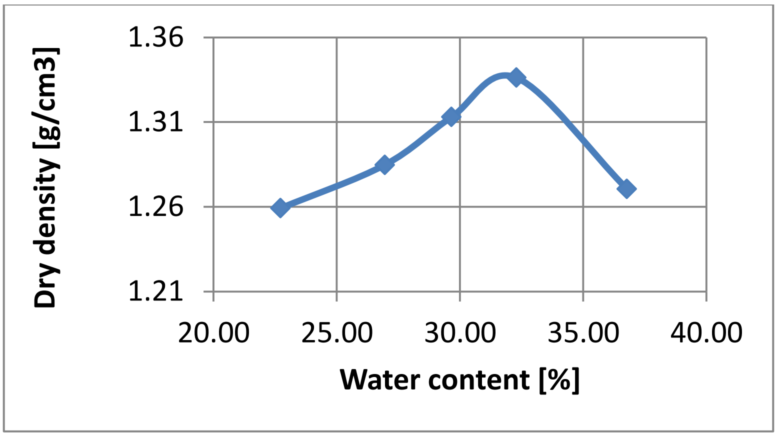


Existing Water Content		
	1	2
Conatainer No	TT	L1
Mass of container, g	20.5	15.7
Mass of container + wet soil, g	60.4	53.7
Mass of ontainer + Dry soil, g	55.4	49.3
Mass of Water, g	5.0	4.4
Mass of Dry soil, g	34.9	33.6
Water content, %	14.33	13.10
Average Water content, %	**13.71**	

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	A63	BL	MF	5	19	72	98	6	T15	A27
Mass of container, g	20.5	15.7	15.5	15	15.5	15	15.5	20.5	20.5	20
Mass of container + wet soil, g	68.5	55.09	62	73.7	55.08	71.23	50.65	56.87	52.98	62.56
Mass of ontainer + Dry soil, g	58.45	46.6	51.5	59.2	44.6	55	40.6	46	42.3	49
Mass of Water, g	10.05	8.49	10.5	14.5	10.48	16.23	10.05	10.87	10.68	13.56
Mass of Dry soil, g	37.95	30.9	36	44.2	29.1	40	25.1	25.5	21.8	29
Water content, %	26.48	27.48	29.17	32.81	36.01	40.58	40.04	42.63	48.99	46.76
Average Water content, %	26.98		33.99		38.29		41.33		47.87	
Dry Unit Weight, g/cm3	1.15		1.24		1.28		1.25		1.23	

Table II. 25 Optimum moisture content and the maximum dry density computation of TF at 4.0 m

Existing moisture content,(%) =					12.53
Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4608.6	4689.56	4756.98	4818.67	4790.45
Mass of Compacted soil, g	1458.6	1539.56	1606.98	1668.67	1640.45
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.55	1.63	1.70	1.77	1.74
Water Content, %	22.71	26.95	29.65	32.29	36.78
Dry density, g/cm3	1.26	1.28	1.31	1.34	1.27

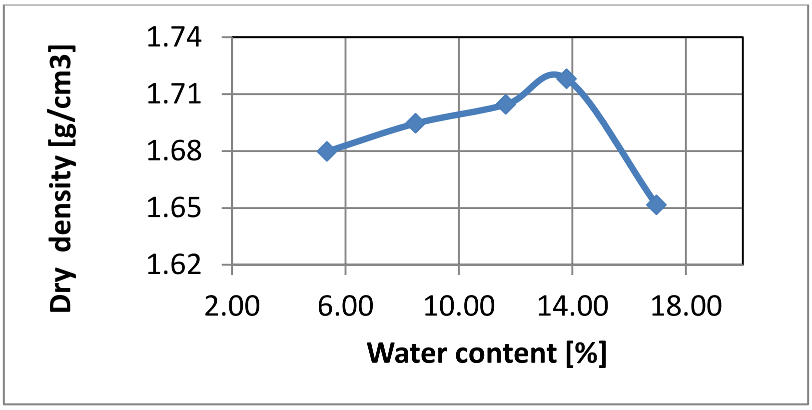


Exsisting Water Content		
	1	2
Conatainer No	KK	HH
Mass of container, g	15.7	20.5
Mass of container + wet soil, g	50.4	65.3
Mass of container + Dry soil, g	46.7	60.1
Mass of Water, g	3.7	5.2
Mass of Dry soil, g	31.0	39.6
Water content, %	11.94	13.12
Average Water content, %	**12.53**	

Water Content										
Test Trial	1		2		3		4		5	
Container No	TT	67.00	12.00	TL	AA	T5	BB	GG	KK	23.00
Mass of container, g	15.50	15.60	20.00	20.00	20.50	15.00	15.00	1.57	15.70	20.50
Mass of container + wet soil, g	54.67	48.65	60.00	63.40	70.00	68.56	54.78	48.67	50.00	80.56
Mass of ontainer + Dry soil, g	47.34	42.60	52.22	53.45	58.56	56.44	45.66	36.50	40.45	65.00
Mass of Water, g	7.33	6.05	7.78	9.95	11.44	12.12	9.12	12.17	9.55	15.56
Mass of Dry soil, g	31.84	27	32.22	33.45	38.06	41.44	30.66	34.93	24.75	44.5
Water content, %	23.02	22.41	24.15	29.75	30.06	29.25	29.75	34.84	38.59	34.97
Average Water content, %	22.71		26.95		29.65		32.29		36.78	
Dry Unit Weight, g/cm3	1.26		1.28		1.31		1.34		1.27	

Table II. 26 Optimum moisture content and the maximum dry density computation of DB at 3.0 m

Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4820.56	4885.34	4946.78	4995.67	4973.55
Mass of Compacted soil, g	1670.56	1735.34	1796.78	1845.67	1823.55
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.77	1.84	1.90	1.96	1.93
Water Content, %	5.35	8.48	11.05	13.80	16.96
Dry density, g/cm3	1.68	1.69	1.70	1.72	1.65

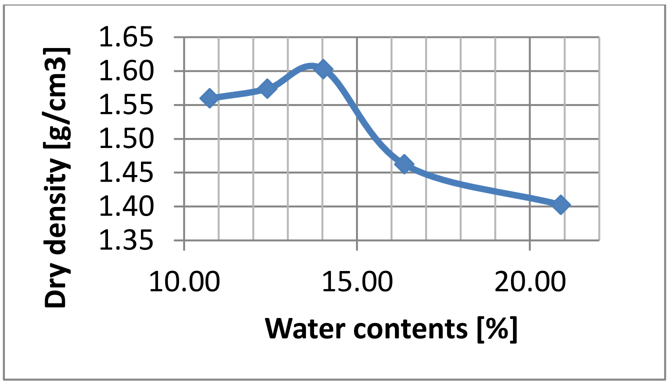


Existing Water Content		
	1	2
Container No	LL	MK
Mass of container, g	15.7	18.5
Mass of container + wet soil, g	67.8	71.2
Mass of container + Dry soil, g	64.6	67.6
Mass of Water, g	3.2	3.6
Mass of Dry soil, g	48.9	49.1
Water content, %	6.54	7.33
Average Water content, %	**6.94**	

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	LL2	KH	MK	CC	M4	NN	23	65H	TT	AA
Mass of container, g	20.5	25.7	15.5	15.7	25	20	15.7	15.7	15.5	20
Mass of container + wet soil, g	65.34	56.45	73.56	49.09	53.98	65.09	46.88	75.44	68.55	76.55
Mass of ontainer + Dry soil, g	62.45	55.32	67.10	47.67	49.88	62.20	42.69	69.00	60.66	68.56
Mass of Water, g	2.89	1.13	6.46	1.42	4.1	2.89	4.19	6.44	7.89	7.99
Mass of Dry soil, g	41.95	29.62	51.6	31.97	24.88	42.2	26.99	53.3	45.16	48.56
Water content, %	6.89	3.81	12.52	4.44	16.48	6.85	15.52	12.08	17.47	16.45
Average Water content, %	5.35		8.48		11.05		13.80		16.96	
Dry Unit Weight, g/cm3	1.68		1.69		1.70		1.72		1.65	

Table II. 27 Optimum moisture content and the maximum dry density computation of NCF at 3.0 m

Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4780.67	4820	4875.34	4756.24	4750.55
Mass of Compacted soil, g	1630.67	1670	1725.34	1606.24	1600.55
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.73	1.77	1.83	1.70	1.70
Water Content, %	10.75	12.41	14.03	16.38	20.90
Dry density, g/cm3	1.56	1.57	1.60	1.46	1.40

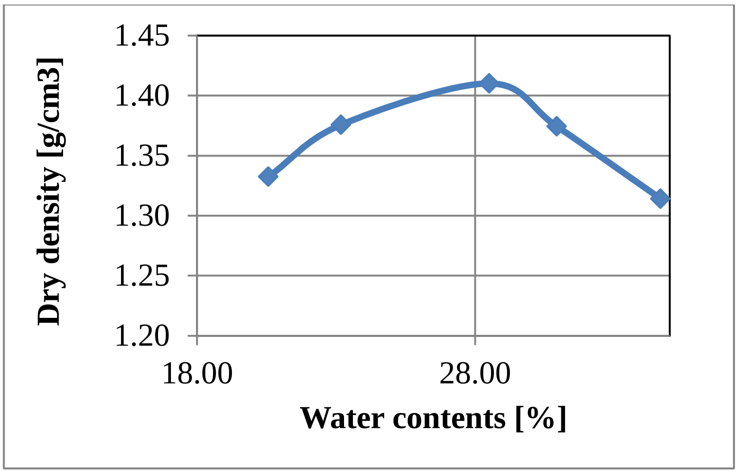


Exsisting Water Content		
	1	2
Conatainer No	KK	HH
Mass of container, g	15.7	20.5
Mass of container + wet soil, g	45.7	67.9
Mass of ontainer + Dry soil, g	44.2	65.8
Mass of Water, g	1.5	2.1
Mass of Dry soil, g	28.5	45.3
Water content, %	5.08	4.66
Average Water content, %	**4.87**	

Water Content										
Test Trial	1		2		3		4		5	
Conatainer No	TT	67.00	12.00	TL	AA	T5	BB	GG	KK	23.00
Mass of container, g	15.50	15.60	20.00	20.00	20.50	15.00	15.00	1.57	15.70	20.50
Mass of container + wet soil, g	60.44	65.46	56.88	76.45	74.66	59.66	74.55	48.67	56.83	60.43
Mass of ontainer + Dry soil, g	56.55	60.11	51.66	72.11	67.67	54.44	65.8	42.34	49.8	53.45
Mass of Water, g	3.89	5.35	5.22	4.34	6.99	5.22	8.75	6.33	7.03	6.98
Mass of Dry soil, g	41.05	44.51	31.66	52.11	47.17	39.44	50.8	40.77	34.1	32.95
Water content, %	9.48	12.02	16.49	8.33	14.82	13.24	17.22	15.53	20.62	21.18
Average Water content, %	10.75		12.41		14.03		16.38		20.90	
Dry Unit Weight, g/cm3	1.56		1.57		1.60		1.46		1.40	

Table II. 28 Optimum moisture content and the maximum dry density computation of CTF at 2.5 m

Determination Number	1	2	3	4	5
Mass of Mold, g	3150	3150	3150	3150	3150
Mass of mold+ Compacted Soil, g	4666.67	4749.65	4860.67	4848.78	4820.65
Mass of Compacted soil, g	1516.67	1599.65	1710.67	1698.78	1670.65
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.61	1.69	1.81	1.80	1.77
Water Content, %	20.57	23.18	28.51	30.95	34.68
Dry density, g/cm3	1.33	1.38	1.41	1.37	1.31



Exsisting Water Content		
	1	2
Conatainer No	KK	HH
Mass of container, g	15.7	20.5
Mass of container + wet soil, g	60.5	46.7
Mass of ontainer + Dry soil, g	57.3	44.7
Mass of Water, g	3.2	2.0
Mass of Dry soil, g	41.6	24.2
Water content, %	7.59	8.27
Average Water content, %	**7.93**	

Water Content										
Test Trial	1		2		3		4		5	
Container No	TT	67.00	12.00	TL	AA	T5	BB	GG	KK	23.00
Mass of container, g	15.50	15.60	20.00	20.00	20.50	15.00	15.00	1.57	15.70	20.50
Mass of container + wet soil, g	65.43	45.76	76.87	49.87	67.56	55.98	65.65	65.89	70.67	56.67
Mass of container + Dry soil, g	57	40.56	67.56	43.56	57.65	46.44	53.87	50.45	55.89	47.78
Mass of Water, g	8.43	5.2	9.31	6.31	9.91	9.54	11.78	15.44	14.78	8.89
Mass of Dry soil, g	41.5	24.96	47.56	23.56	37.15	31.44	38.87	48.88	40.19	27.28
Water content, %	20.31	20.83	19.58	26.78	26.68	30.34	30.31	31.59	36.78	32.59
Average Water content, %	20.57		23.18		28.51		30.95		34.68	
Dry Unit Weight, g/cm3	1.33		1.38		1.41		1.37		1.31	

Appendix B: 1-D Consolidation Test

I. Detail calculation of Pre-consolidation Pressure of Silt Soil

[A] In the Commencement of the test

Sampling location	TF
Sample type	Remolded
Ring Area, cm^2	19.63
Height of sample,mm	20
Seating load, Kpa	7
Initial void ratio, e_o	1.24
Initial moisture content, %	22.18
Specific gravity	2.66
Wet density, g/cm^3	1.46

[B] In the end of the test

Final moisture content, %	24.34
Dry specimen weight (m_s), gm	45.85
Dry density, g/cm^3	1.14
Height of solids (Hs), mm	8.78
Final void ratio, e_f	0.95

[C]Calculation table:

Applied pressure P[kPa]	Final Dial Reading [mm]	Change In Specimen Height [mm]	Final Specimen Height [mm]	Void Height,H_v [mm]	Void Ratio, e
Loading					
7	0.502	0.00	20.00	11.22	1.24
50	0.560	-0.56	19.44	10.66	1.21
100	1.010	-1.01	18.99	10.21	1.16
200	1.420	-1.42	18.58	9.80	1.12
400	1.940	-1.94	18.06	9.28	1.06
800	2.370	-2.37	17.63	8.85	1.01
1600	2.894	-2.89	17.11	8.33	0.95

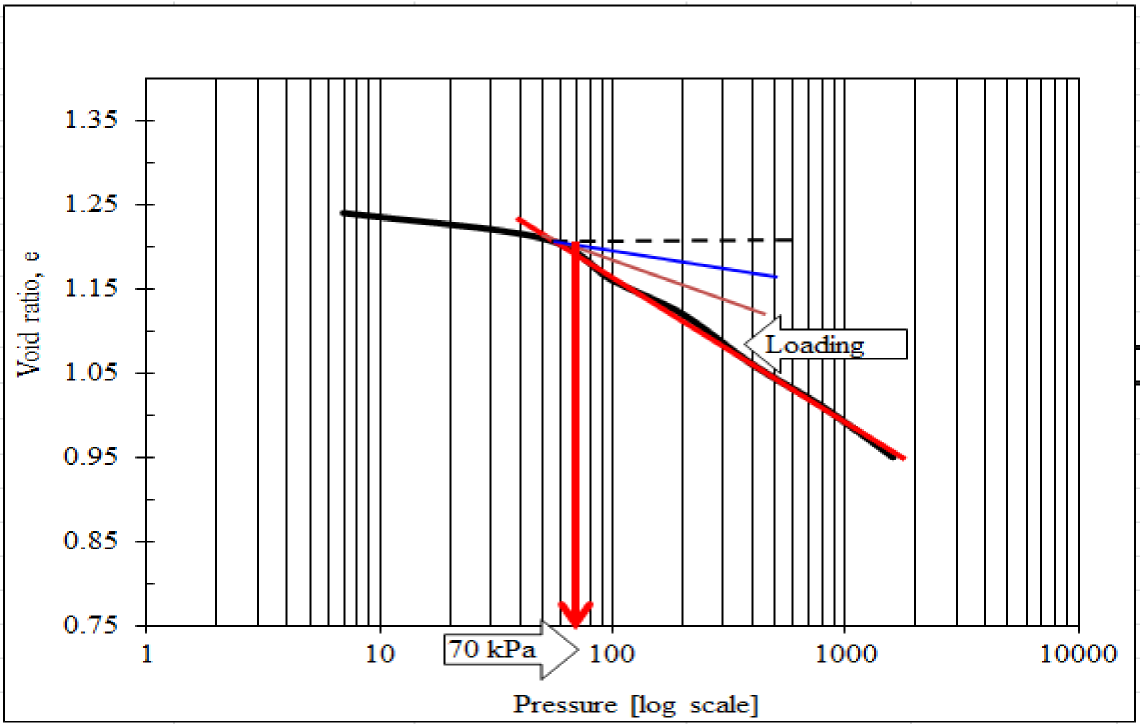


Figure II.10 Consolidation pressure Vs Void ratio of Silt soil

II. Determination of Pre-consolidation pressure of Silt Sand

[A] In the commencement of the test

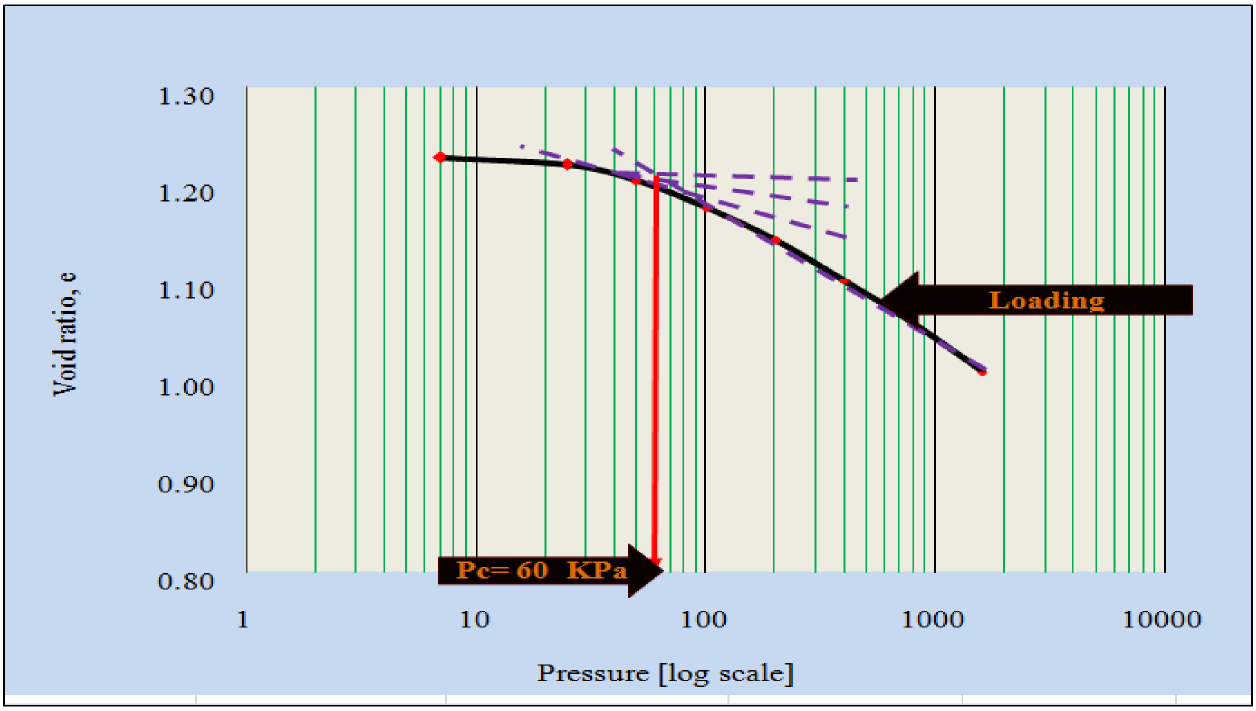
Sampling location	DDU
Sample type	Disturbed
Ring Area, cm^2	19.625
Height of sample, mm	20
Seating Load, Kpa	7
Initial void ratio, e_o	1.23
Initial moisture content, %	13.69
Specific Gravity	2.56
Wet density, g/cm^3	1.31

[B] In the end of the test

Final moisture content, %	15.80
Dry Specimen weight, gm	45.88
Dry Density, g/cm^3	1.15
Height of solids (Hs), mm	8.98

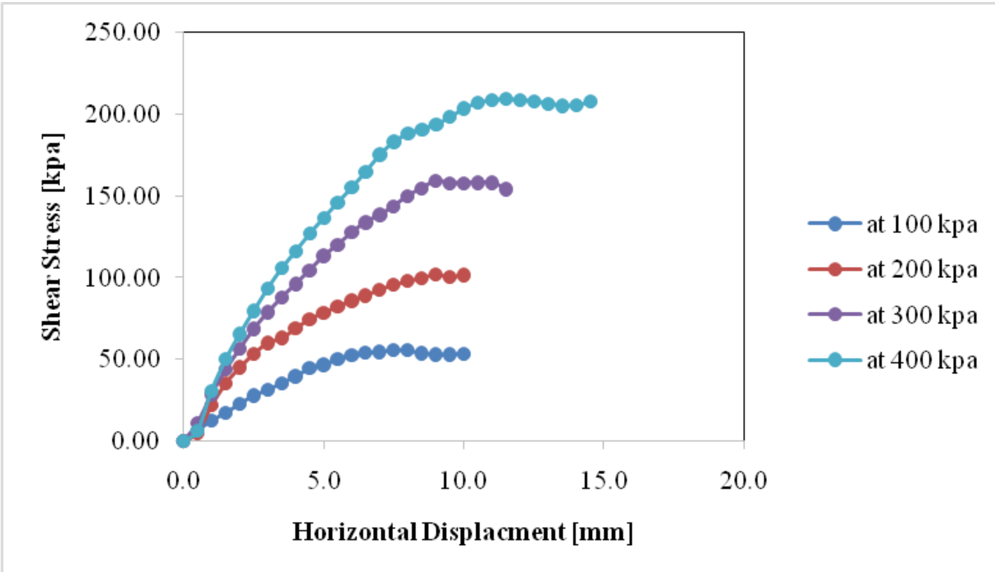
Final void ratio, e_f 1.01

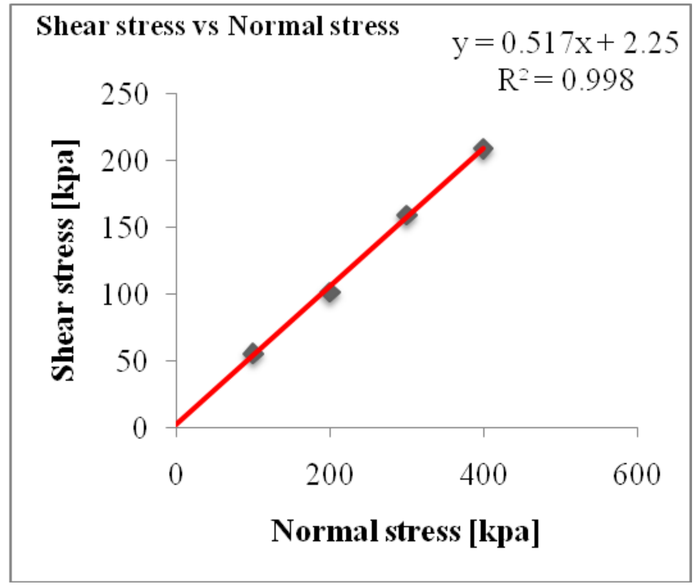
[C]Calculation table:					
Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, H_v (mm)	Void Ratio, e
Loading					
7	0.450	0.00	20.00	11.02	1.23
25	0.510	-0.06	19.94	10.96	1.22
50	0.660	-0.21	19.79	10.81	1.20
100	0.910	-0.46	19.54	10.56	1.18
200	1.210	-0.76	19.24	10.26	1.14
400	1.580	-1.13	18.87	9.89	1.10
800	1.980	-1.53	18.47	9.49	1.06
1600	2.430	-1.98	18.02	9.04	1.01



Appendix C: Direct Shear Test Results

Sampling Location		AG	Sample Depth, m:		3.00								
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 KN/div		Wet unit weight, kN/M^3:			20.33			
Length of sample :		60 mm	Rate of strain :		0.2 mm/min		Dry Unit Weight, kN/M^3:			18.36			
Width of sample:		60 mm	Moisture content, %		10.5		Sample Condition:			Disturbed			
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**			Applied Vertical Stress **400 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	33.00	23.10	6.47	25.00	17.50	4.90	56.00	39.20	10.98	32.00	22.40	6.27
1.0	3540	64.00	44.80	12.66	110.00	77.00	21.75	145.00	101.50	28.67	155.00	108.50	30.65
1.5	3510	87.00	60.90	17.35	176.00	123.20	35.10	219.00	153.30	43.68	250.00	175.00	49.86
2.0	3480	114.00	79.80	22.93	223.00	156.10	44.86	280.00	196.00	56.32	325.00	227.50	65.37
2.5	3450	138.00	96.60	28.00	262.00	183.40	53.16	338.00	236.60	68.58	392.00	274.40	79.54
3.0	3420	154.00	107.80	31.52	293.00	205.10	59.97	385.00	269.50	78.80	456.00	319.20	93.33
3.5	3390	173.00	121.10	35.72	305.00	213.50	62.98	426.00	298.20	87.96	512.00	358.40	105.72
4.0	3360	192.00	134.40	40.00	330.00	231.00	68.75	462.00	323.40	96.25	558.00	390.60	116.25
4.5	3330	213.00	149.10	44.77	355.00	248.50	74.62	498.00	348.60	104.68	604.00	422.80	126.97
5.0	3300	222.00	155.40	47.09	370.00	259.00	78.48	535.00	374.50	113.48	644.00	450.80	136.61
5.5	3270	235.00	164.50	50.31	385.00	269.50	82.42	562.00	393.40	120.31	682.00	477.40	145.99
6.0	3240	244.00	170.80	52.72	398.00	278.60	85.99	592.00	414.40	127.90	718.00	502.60	155.12
6.5	3210	249.00	174.30	54.30	408.00	285.60	88.97	615.00	430.50	134.11	756.00	529.20	164.86
7.0	3180	250.00	175.00	55.03	421.00	294.70	92.67	630.00	441.00	138.68	796.00	557.20	175.22
7.5	3150	252.00	176.40	56.00	430.00	301.00	95.56	648.00	453.60	144.00	824.00	576.80	183.11
8.0	3120	249.00	174.30	55.87	436.00	305.20	97.82	670.00	469.00	150.32	838.00	586.60	188.01
8.5	3090	239.00	167.30	54.14	440.00	308.00	99.68	684.00	478.80	154.95	842.00	589.40	190.74
9.0	3060	233.00	163.10	53.30	445.00	311.50	101.80	697.00	487.90	159.44	847.00	592.90	193.76
9.5	3030	231.00	161.70	53.37	435.00	304.50	100.50	684.00	478.80	158.02	858.00	600.60	198.22
10.0	3000	231.00	161.70	53.90	435.00	304.50	101.50	678.00	474.60	158.20	872.00	610.40	203.47
10.5	2970	0.00	0.00	0.00	0.00	0.00	0.00	672.00	470.40	158.38	878.00	614.60	206.94
11.0	2940	0.00	0.00	0.00	0.00	0.00	0.00	665.00	465.50	158.33	876.00	613.20	208.57
11.5	2910	0.00	0.00	0.00	0.00	0.00	0.00	642.00	449.40	154.43	870.00	609.00	209.28
12.0	2880	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	858.00	600.60	208.54
12.5	2850	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	847.00	592.90	208.04
13.0	2820	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	832.00	582.40	206.52
13.5	2790	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	818.00	572.60	205.23
14.0	2760	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	810.00	567.00	205.43
14.5	2730	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	810.00	567.00	207.69



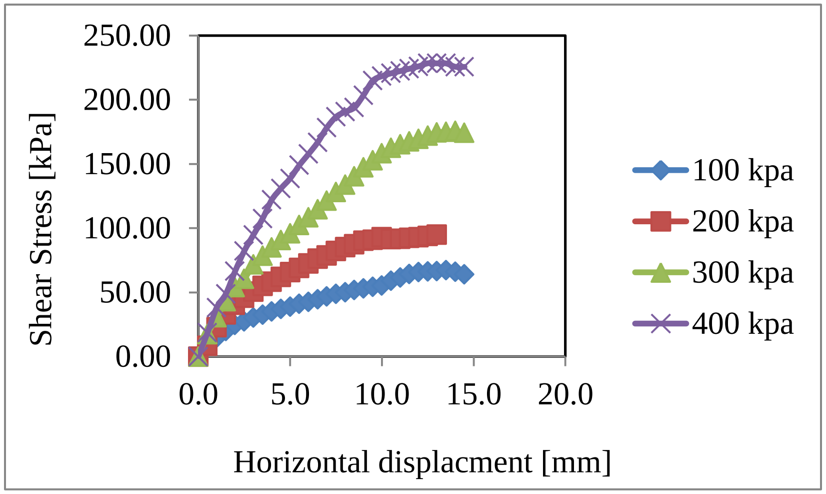


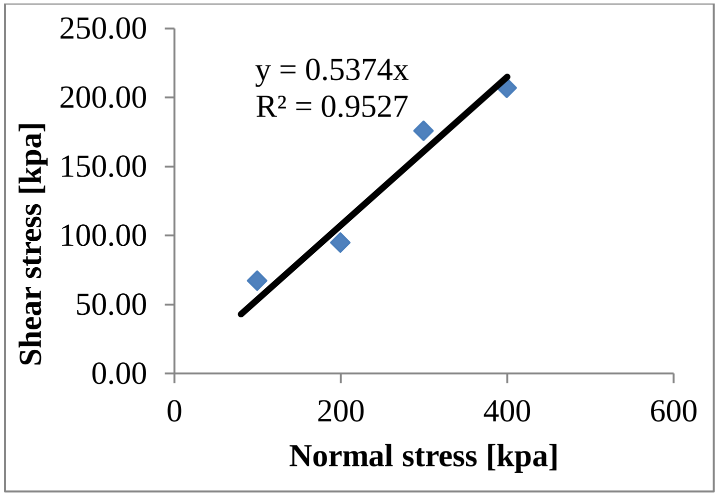
Normal Stress [kpa]	100	200	300	400
Shear Stress at failure [kpa]	56	101.8	159.44	209.3

Angle of internal friction (Ø), degree = 27.3 Cohesion (C), kn/m^2 = 2.25

Sampling Location		AG	Sample Depth, m:		3m								
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div		Wet unit weight, kN/M^3:			19.74			
Length of sample :		60 mm	Rate of strain :		0.2 mm/min		Dry Unit Weight, kN/M^3:			18.17			
Width of sample:		60 mm	Moisture content, %		8.5		Sample Condition:			Disturbed			
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**			Applied Vertical Stress **400 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	40.00	28.00	7.84	43.00	30.10	8.43	88.00	61.60	17.25	95.00	66.50	18.63
1.0	3540	74.00	51.80	14.63	116.00	81.20	22.94	155.00	108.50	30.65	193.00	135.10	38.16
1.5	3510	100.00	70.00	19.94	164.00	114.80	32.71	216.00	151.20	43.08	245.00	171.50	48.86
2.0	3480	122.00	85.40	24.54	200.00	140.00	40.23	268.00	187.60	53.91	330.00	231.00	66.38
2.5	3450	135.00	94.50	27.39	226.00	158.20	45.86	298.00	208.60	60.46	405.00	283.50	82.17
3.0	3420	148.00	103.60	30.29	247.00	172.90	50.56	350.00	245.00	71.64	463.00	324.10	94.77
3.5	3390	158.00	110.60	32.63	266.00	186.20	54.93	380.00	266.00	78.47	520.00	364.00	107.37
4.0	3360	168.00	117.60	35.00	280.00	196.00	58.33	408.00	285.60	85.00	586.00	410.20	122.08
4.5	3330	176.00	123.20	37.00	295.00	206.50	62.01	432.00	302.40	90.81	623.00	436.10	130.96
5.0	3300	183.00	128.10	38.82	310.00	217.00	65.76	452.00	316.40	95.88	654.00	457.80	138.73
5.5	3270	192.00	134.40	41.10	322.00	225.40	68.93	478.00	334.60	102.32	696.00	487.20	148.99
6.0	3240	197.00	137.90	42.56	335.00	234.50	72.38	502.00	351.40	108.46	730.00	511.00	157.72
6.5	3210	204.00	142.80	44.49	350.00	245.00	76.32	526.00	368.20	114.70	765.00	535.50	166.82
7.0	3180	212.00	148.40	46.67	358.00	250.60	78.81	552.00	386.40	121.51	810.00	567.00	178.30
7.5	3150	219.00	153.30	48.67	370.00	259.00	82.22	577.00	403.90	128.22	840.00	588.00	186.67
8.0	3120	223.00	156.10	50.03	380.00	266.00	85.26	597.00	417.90	133.94	850.00	595.00	190.71
8.5	3090	228.00	159.60	51.65	386.00	270.20	87.44	620.00	434.00	140.45	856.00	599.20	193.92
9.0	3060	232.00	162.40	53.07	394.00	275.80	90.13	644.00	450.80	147.32	890.00	623.00	203.59
9.5	3030	235.00	164.50	54.29	394.00	275.80	91.02	661.00	462.70	152.71	930.00	651.00	214.85
10.0	3000	237.00	165.90	55.30	398.00	278.60	92.87	678.00	474.60	158.20	936.00	655.20	218.40
10.5	2970	250.00	175.00	58.92	388.00	271.60	91.45	690.00	483.00	162.63	936.00	655.20	220.61
11.0	2940	258.00	180.60	61.43	385.00	269.50	91.67	694.00	485.80	165.24	934.00	653.80	222.38
11.5	2910	267.00	186.90	64.23	384.00	268.80	92.37	697.00	487.90	167.66	932.00	652.40	224.19
12.0	2880	270.00	189.00	65.63	382.00	267.40	92.85	698.00	488.60	169.65	930.00	651.00	226.04
12.5	2850	270.00	189.00	66.32	382.00	267.40	93.82	700.00	490.00	171.93	930.00	651.00	228.42
13.0	2820	268.00	187.60	66.52	382.00	267.40	94.82	703.00	492.10	174.50	920.00	644.00	228.37
13.5	2790	268.00	187.60	67.24	0.00	0.00	0.00	698.00	488.60	175.13	910.00	637.00	228.32
14.0	2760	260.00	182.00	65.94	0.00	0.00	0.00	693.00	485.10	175.76	890.00	623.00	225.72
14.5	2730	250.00	175.00	64.10	0.00	0.00	0.00	680.00	476.00	174.36	880.00	616.00	225.64
15.0	2700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Normal Stress [kpa]	100	200	300	400
Shear Stress at failure [kpa]	67.24	94.82	175.76	207



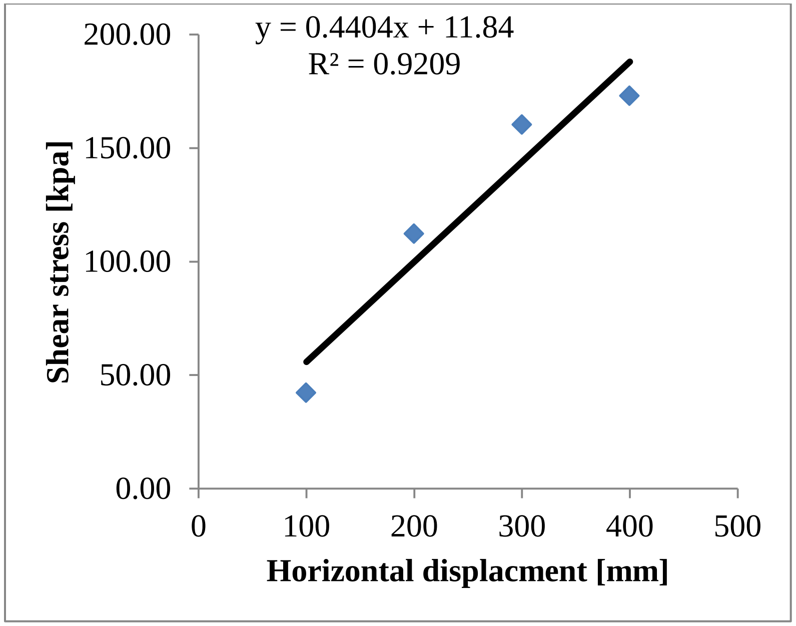


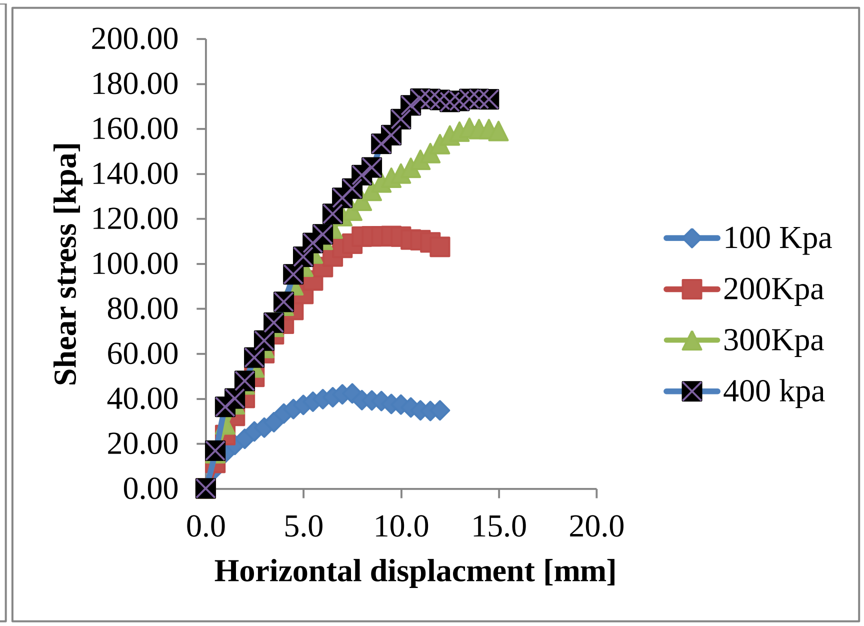
Angle of internal friction (Ø), degree = 26.97 Cohesion (C), KN/M2 = 0.96

Sampling Location	AG	Sample Depth, m:	3.00		
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div	Wet unit weight, kN/M^3:	20.62
Length of sample :	60 mm	Rate of strain :	0.2 mm/min	Dry Unit Weight, kN/M^3:	17.97
Width of sample:	60 mm	Moisture content, %	14.4	Sample Condition:	Disturbed

		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**			Applied Vertical Stress **400 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	45.00	31.50	8.82	58.00	40.60	11.37	80.00	56.00	15.69	86.00	60.20	16.86
1.0	3540	80.00	56.00	15.82	120.00	84.00	23.73	144.00	100.80	28.47	184.00	128.80	36.38
1.5	3510	97.00	67.90	19.34	162.00	113.40	32.31	188.00	131.60	37.49	201.00	140.70	40.09
2.0	3480	110.00	77.00	22.13	200.00	140.00	40.23	230.00	161.00	46.26	238.00	166.60	47.87
2.5	3450	125.00	87.50	25.36	245.00	171.50	49.71	265.00	185.50	53.77	287.00	200.90	58.23
3.0	3420	132.00	92.40	27.02	294.00	205.80	60.18	305.00	213.50	62.43	321.00	224.70	65.70
3.5	3390	143.00	100.10	29.53	332.00	232.40	68.55	348.00	243.60	71.86	357.00	249.90	73.72
4.0	3360	160.00	112.00	33.33	352.00	246.40	73.33	390.00	273.00	81.25	398.00	278.60	82.92
4.5	3330	168.00	117.60	35.32	378.00	264.60	79.46	430.00	301.00	90.39	453.00	317.10	95.23
5.0	3300	175.00	122.50	37.12	408.00	285.60	86.55	465.00	325.50	98.64	486.00	340.20	103.09
5.5	3270	180.00	126.00	38.53	432.00	302.40	92.48	488.00	341.60	104.46	510.00	357.00	109.17
6.0	3240	184.00	128.80	39.75	456.00	319.20	98.52	512.00	358.40	110.62	523.00	366.10	112.99
6.5	3210	186.00	130.20	40.56	473.00	331.10	103.15	530.00	371.00	115.58	560.00	392.00	122.12
7.0	3180	190.00	133.00	41.82	486.00	340.20	106.98	550.00	385.00	121.07	587.00	410.90	129.21
7.5	3150	190.00	133.00	42.22	490.00	343.00	108.89	556.00	389.20	123.56	600.00	420.00	133.33
8.0	3120	175.00	122.50	39.26	499.00	349.30	111.96	570.00	399.00	127.88	621.00	434.70	139.33
8.5	3090	173.00	121.10	39.19	495.00	346.50	112.14	584.00	408.80	132.30	630.00	441.00	142.72
9.0	3060	170.00	119.00	38.89	490.00	343.00	112.09	595.00	416.50	136.11	670.00	469.00	153.27
9.5	3030	163.00	114.10	37.66	486.00	340.20	112.28	598.00	418.60	138.15	680.00	476.00	157.10
10.0	3000	160.00	112.00	37.33	480.00	336.00	112.00	600.00	420.00	140.00	704.00	492.80	164.27
10.5	2970	153.00	107.10	36.06	470.00	329.00	110.77	605.00	423.50	142.59	723.00	506.10	170.40
11.0	2940	146.00	102.20	34.76	464.00	324.80	110.48	614.00	429.80	146.19	765.00	535.50	182.14
11.5	2910	143.00	100.10	34.40	455.00	318.50	109.45	620.00	434.00	149.14	768.00	537.60	184.74
12.0	2880	143.00	100.10	34.76	442.00	309.40	107.43	630.00	441.00	153.13	760.00	532.00	184.72
12.5	2850	0.00	0.00	0.00	0.00	0.00	0.00	639.00	447.30	156.95	754.00	527.80	185.19
13.0	2820	0.00	0.00	0.00	0.00	0.00	0.00	639.00	447.30	158.62	754.00	527.80	187.16
13.5	2790	0.00	0.00	0.00	0.00	0.00	0.00	639.00	447.30	160.32	740.00	518.00	185.66
14.0	2760	0.00	0.00	0.00	0.00	0.00	0.00	630.00	441.00	159.78	740.00	518.00	187.68
14.5	2730	0.00	0.00	0.00	0.00	0.00	0.00	623.00	436.10	159.74	730.00	511.00	187.18
15.0	2700	0.00	0.00	0.00	0.00	0.00	0.00	613.00	429.10	158.93	0.00	0.00	0.00

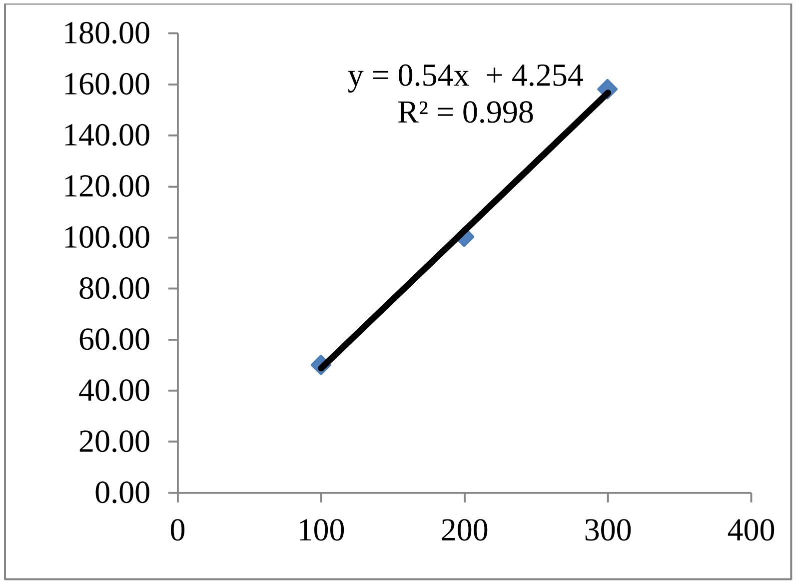
Normal Stress [kpa]	100	200	300	400
Shear Stress at failure [kpa]	42.20	112.28	160.32	173.68

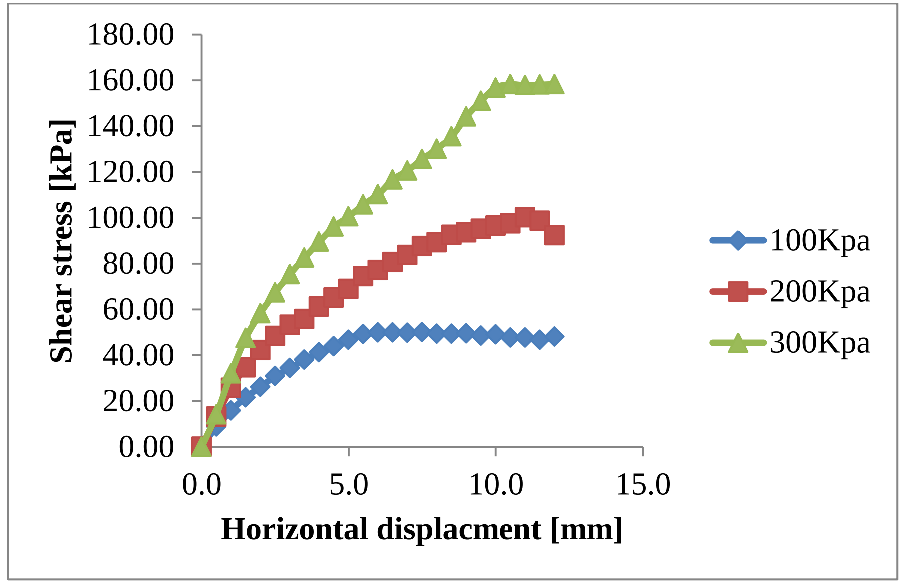




Sampling Location	AG	Sample Depth, m:	3m							
Thickness of sample:	25 mm	Ring Calib. Factor:	0.70 N/div		Wet unit weight, kN/M^3:					20.33
Length of sample :	60 mm	Rate of strain :	0.1mm/min		Dry Unit Weight, kN/M^3:					18.26
Width of sample:	60 mm	Moisture content, %	10.5		Sample Condition:					Disturbed
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	45.00	31.50	8.82	67.00	46.90	13.14	72.00	50.40	14.12
1.0	3540	80.00	56.00	15.82	130.00	91.00	25.71	162.00	113.40	32.03
1.5	3510	108.00	75.60	21.54	174.00	121.80	34.70	238.00	166.60	47.46
2.0	3480	130.00	91.00	26.15	210.00	147.00	42.24	290.00	203.00	58.33
2.5	3450	152.00	106.40	30.84	238.00	166.60	48.29	332.00	232.40	67.36
3.0	3420	168.00	117.60	34.39	260.00	182.00	53.22	368.00	257.60	75.32
3.5	3390	184.00	128.80	37.99	270.00	189.00	55.75	400.00	280.00	82.60
4.0	3360	198.00	138.60	41.25	294.00	205.80	61.25	430.00	301.00	89.58
4.5	3330	209.00	146.30	43.93	310.00	217.00	65.17	457.00	319.90	96.07
5.0	3300	220.00	154.00	46.67	325.00	227.50	68.94	474.00	331.80	100.55
5.5	3270	230.00	161.00	49.24	348.00	243.60	74.50	494.00	345.80	105.75
6.0	3240	231.00	161.70	49.91	357.00	249.90	77.13	510.00	357.00	110.19
6.5	3210	229.00	160.30	49.94	370.00	259.00	80.69	535.00	374.50	116.67
7.0	3180	226.00	158.20	49.75	380.00	266.00	83.65	548.00	383.60	120.63
7.5	3150	225.00	157.50	50.00	394.00	275.80	87.56	565.00	395.50	125.56
8.0	3120	220.00	154.00	49.36	398.00	278.60	89.29	580.00	406.00	130.13
8.5	3090	218.00	152.60	49.39	408.00	285.60	92.43	598.00	418.60	135.47
9.0	3060	216.00	151.20	49.41	409.00	286.30	93.56	630.00	441.00	144.12
9.5	3030	210.00	147.00	48.51	412.00	288.40	95.18	654.00	457.80	151.09
10.0	3000	210.00	147.00	49.00	414.00	289.80	96.60	672.00	470.40	156.80
10.5	2970	202.00	141.40	47.61	414.00	289.80	97.58	618.00	470.00	158.25
11.0	2940	200.00	140.00	47.62	421.00	294.70	100.24	610.00	464.00	157.82
11.5	2910	194.00	135.80	46.67	410.00	287.00	98.63	602.00	460.00	158.08
12.0	2880	198.00	138.60	48.13	380.00	266.00	92.36	600.00	456.00	158.33

Normal Stress [kpa]	100	200	300
Shear Stress at failure [kpa]	50.00	100.24	158.25

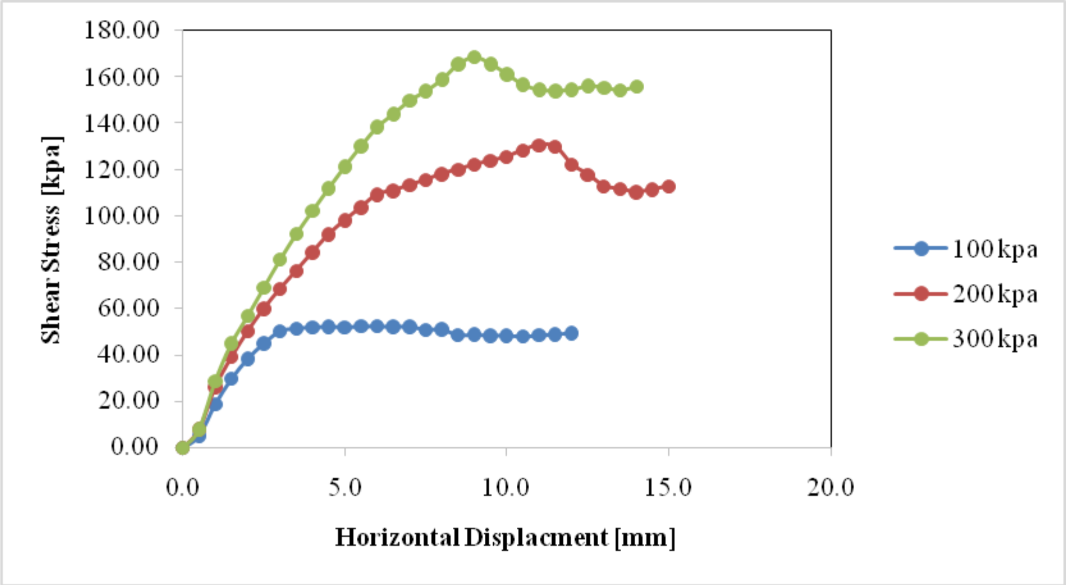


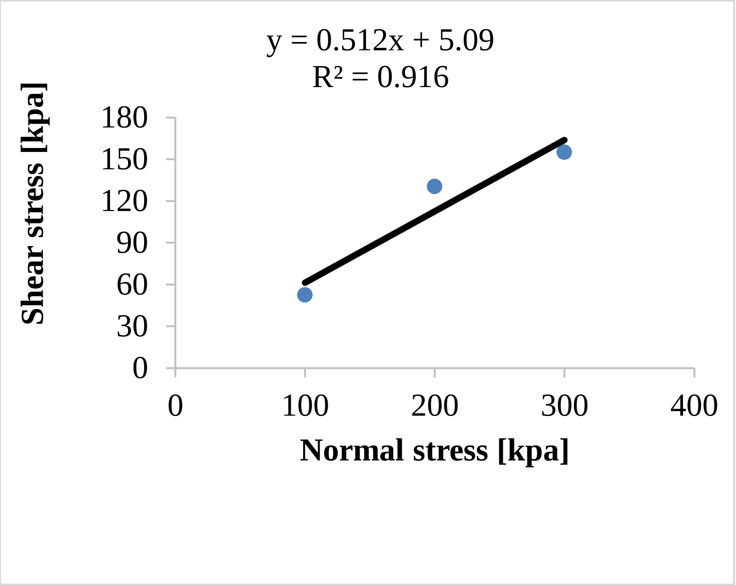


Angle of internal friction (ϕ), degree = 28.36 Cohesion (C), KN/M^2 = 4.25

Sampling Location		AG	Sample Depth, m:		3.00					
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div		Wet unit weight, kN/M^3:			20.33
Length of sample :		60 mm	Rate of strain :		0.2 mm/min		Dry Unit Weight, kN/M^3:			18.36
Width of sample:		60 mm	Moisture content, %		10.5		Sample Condition:			Disturbed
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	26.00	18.20	5.10	40.00	28.00	7.84	40.00	28.00	7.84
1.0	3540	95.00	66.50	18.79	132.00	92.40	26.10	145.00	101.50	28.67
1.5	3510	149.00	104.30	29.72	196.00	137.20	39.09	225.00	157.50	44.87
2.0	3480	191.00	133.70	38.42	250.00	175.00	50.29	282.00	197.40	56.72
2.5	3450	222.00	155.40	45.04	296.00	207.20	60.06	340.00	238.00	68.99
3.0	3420	246.00	172.20	50.35	335.00	234.50	68.57	396.00	277.20	81.05
3.5	3390	250.00	175.00	51.62	370.00	259.00	76.40	446.00	312.20	92.09
4.0	3360	250.00	175.00	52.08	405.00	283.50	84.38	490.00	343.00	102.08
4.5	3330	249.00	174.30	52.34	438.00	306.60	92.07	532.00	372.40	111.83
5.0	3300	246.00	172.20	52.18	463.00	324.10	98.21	572.00	400.40	121.33
5.5	3270	245.00	171.50	52.45	485.00	339.50	103.82	608.00	425.60	130.15
6.0	3240	243.00	170.10	52.50	506.00	354.20	109.32	640.00	448.00	138.27
6.5	3210	240.00	168.00	52.34	509.00	356.30	111.00	660.00	462.00	143.93
7.0	3180	238.00	166.60	52.39	515.00	360.50	113.36	680.00	476.00	149.69
7.5	3150	230.00	161.00	51.11	520.00	364.00	115.56	692.00	484.40	153.78
8.0	3120	228.00	159.60	51.15	527.00	368.90	118.24	708.00	495.60	158.85
8.5	3090	215.00	150.50	48.71	530.00	371.00	120.06	730.00	511.00	165.37
9.0	3060	214.00	149.80	48.95	534.00	373.80	122.16	736.00	515.20	168.37
9.5	3030	210.00	147.00	48.51	536.00	375.20	123.83	716.00	501.20	165.41
10.0	3000	208.00	145.60	48.53	538.00	376.60	125.53	690.00	483.00	161.00
10.5	2970	204.00	142.80	48.08	545.00	381.50	128.45	664.00	464.80	156.50
11.0	2940	204.00	142.80	48.57	548.00	383.60	130.48	648.00	453.60	154.29
11.5	2910	204.00	142.80	49.07	540.00	378.00	129.90	640.00	448.00	153.95
12.0	2880	204.00	142.80	49.58	503.00	352.10	122.26	635.00	444.50	154.34
12.5	2850	0.00	0.00	0.00	480.00	336.00	117.89	635.00	444.50	155.96
13.0	2820	0.00	0.00	0.00	455.00	318.50	112.94	438.00	438.00	155.32
13.5	2790	0.00	0.00	0.00	445.00	311.50	111.65	437.00	430.00	154.12
14.0	2760	0.00	0.00	0.00	435.00	304.50	110.33	435.00	430.00	155.80
14.5	2730	0.00	0.00	0.00	435.00	304.50	111.54	435.00		
15.0	2700	0.00	0.00	0.00	435.00	304.50	112.78	435.00		

Normal Stress [kpa]	100	200	300
Shear Stress at failure [kpa]	52.45	130.48	168.37

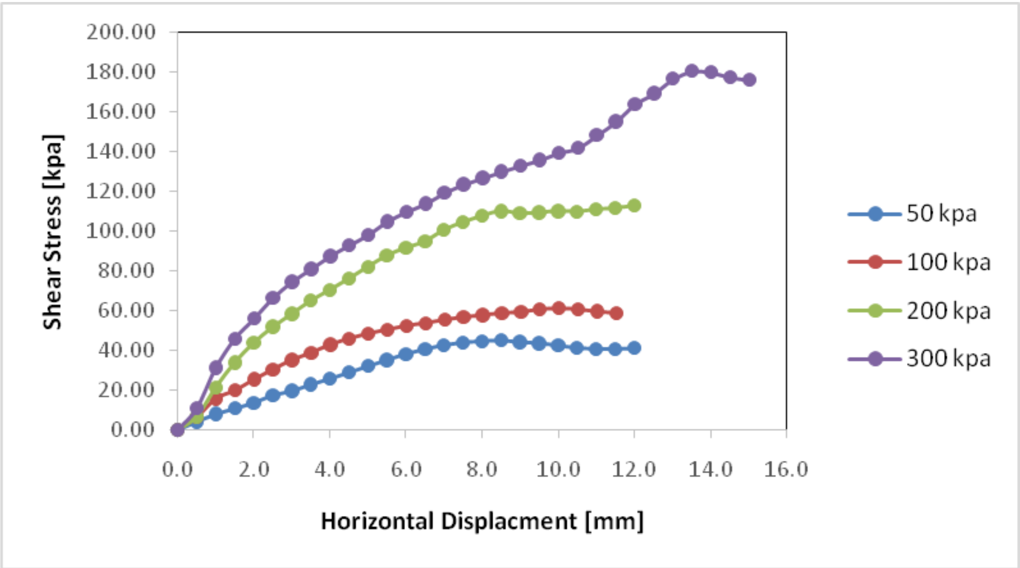


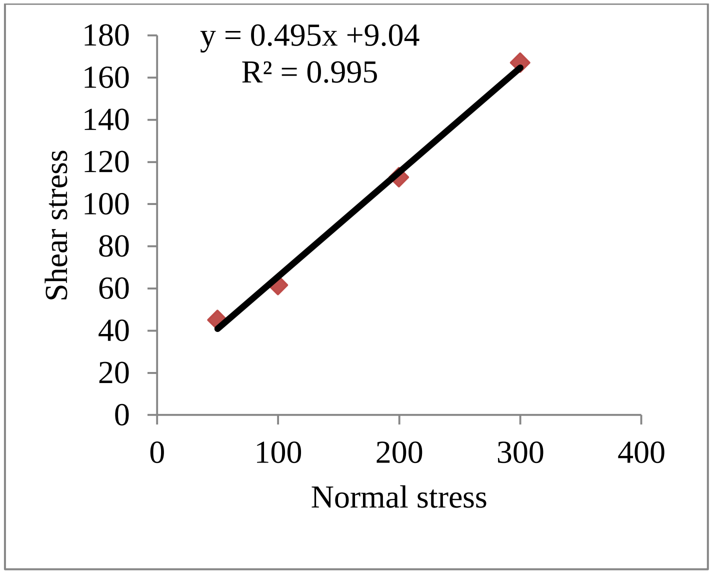


Angle of internal friction (Ø), degree = 27.00   Cohesion (C), KN/M^2 = 5.09

Sampling Location		DB	Sample Depth, m:		3.00								
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div		Wet unit weight, kN/M^3:			19.25			
Length of sample :		60 mm	Rate of strain :		0.2 mm/min		Dry Unit Weight, kN/M^3:			16.89			
Width of sample:		60 mm	Moisture content, %		13.5		Sample Condition:			Disturbed			
		Applied Vertical Stress **50 kPa**			Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	21.00	14.70	4.12	33.00	23.10	6.47	34.00	23.80	6.67	55.00	38.50	10.78
1.0	3540	40.00	28.00	7.91	80.00	56.00	15.82	108.00	75.60	21.36	158.00	110.60	31.24
1.5	3510	54.00	37.80	10.77	100.00	70.00	19.94	170.00	119.00	33.90	230.00	161.00	45.87
2.0	3480	68.00	47.60	13.68	127.00	88.90	25.55	218.00	152.60	43.85	278.00	194.60	55.92
2.5	3450	86.00	60.20	17.45	151.00	105.70	30.64	255.00	178.50	51.74	327.00	228.90	66.35
3.0	3420	96.00	67.20	19.65	173.00	121.10	35.41	285.00	199.50	58.33	364.00	254.80	74.50
3.5	3390	111.00	77.70	22.92	189.00	132.30	39.03	315.00	220.50	65.04	392.00	274.40	80.94
4.0	3360	124.00	86.80	25.83	207.00	144.90	43.13	338.00	236.60	70.42	420.00	294.00	87.50
4.5	3330	138.00	96.60	29.01	220.00	154.00	46.25	362.00	253.40	76.10	442.00	309.40	92.91
5.0	3300	152.00	106.40	32.24	230.00	161.00	48.79	387.00	270.90	82.09	463.00	324.10	98.21
5.5	3270	165.00	115.50	35.32	237.00	165.90	50.73	410.00	287.00	87.77	490.00	343.00	104.89
6.0	3240	178.00	124.60	38.46	244.00	170.80	52.72	424.00	296.80	91.60	508.00	355.60	109.75
6.5	3210	187.00	130.90	40.78	248.00	173.60	54.08	435.00	304.50	94.86	522.00	365.40	113.83
7.0	3180	195.00	136.50	42.92	253.00	177.10	55.69	457.00	319.90	100.60	542.00	379.40	119.31
7.5	3150	199.00	139.30	44.22	257.00	179.90	57.11	470.00	329.00	104.44	556.00	389.20	123.56
8.0	3120	200.00	140.00	44.87	259.00	181.30	58.11	480.00	336.00	107.69	565.00	395.50	126.76
8.5	3090	200.00	140.00	45.31	261.00	182.70	59.13	486.00	340.20	110.10	574.00	401.80	130.03
9.0	3060	194.00	135.80	44.38	261.00	182.70	59.71	476.00	333.20	108.89	582.00	407.40	133.14
9.5	3030	190.00	133.00	43.89	264.00	184.80	60.99	473.00	331.10	109.27	588.00	411.60	135.84
10.0	3000	183.00	128.10	42.70	264.00	184.80	61.60	472.00	330.40	110.13	598.00	418.60	139.53
10.5	2970	176.00	123.20	41.48	259.00	181.30	61.04	466.00	326.20	109.83	602.00	421.40	141.89
11.0	2940	172.00	120.40	40.95	252.00	176.40	60.00	466.00	326.20	110.95	623.00	436.10	148.33
11.5	2910	170.00	119.00	40.89	246.00	172.20	59.18	464.00	324.80	111.62	645.00	451.50	155.15
12.0	2880	170.00	119.00	41.32	235.00	164.50	57.12	464.00	324.80	112.78	675.00	472.50	164.06
12.5	2850	135.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	690.00	483.00	169.47
13.0	2820	135.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	712.00	498.40	176.74
13.5	2790	134.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	720.00	504.00	180.65
14.0	2760	133.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	710.00	497.00	180.07
14.5	2730	128.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	693.00	485.10	177.69
15.0	2700	128.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	680.00	476.00	176.30

Normal stress [kpa]	50	100	200	300
Shear Stress at failure [kpa]	45	61.6	112.78	167.48

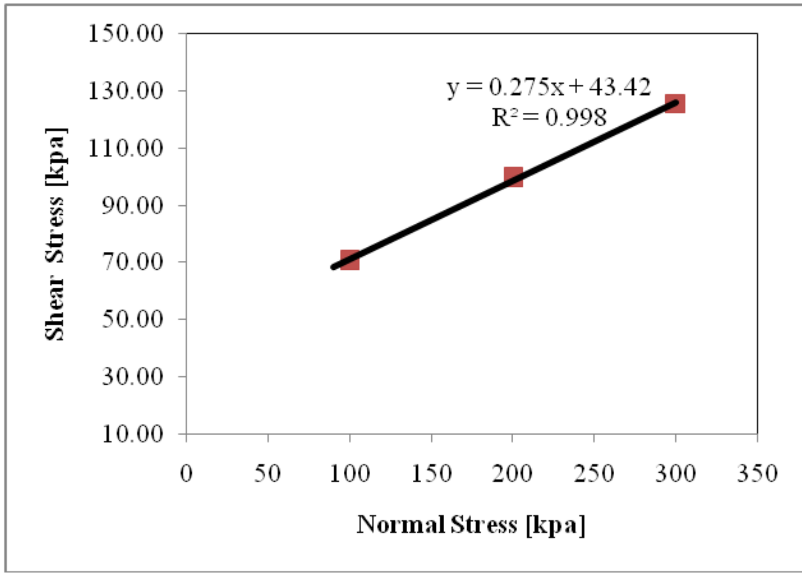


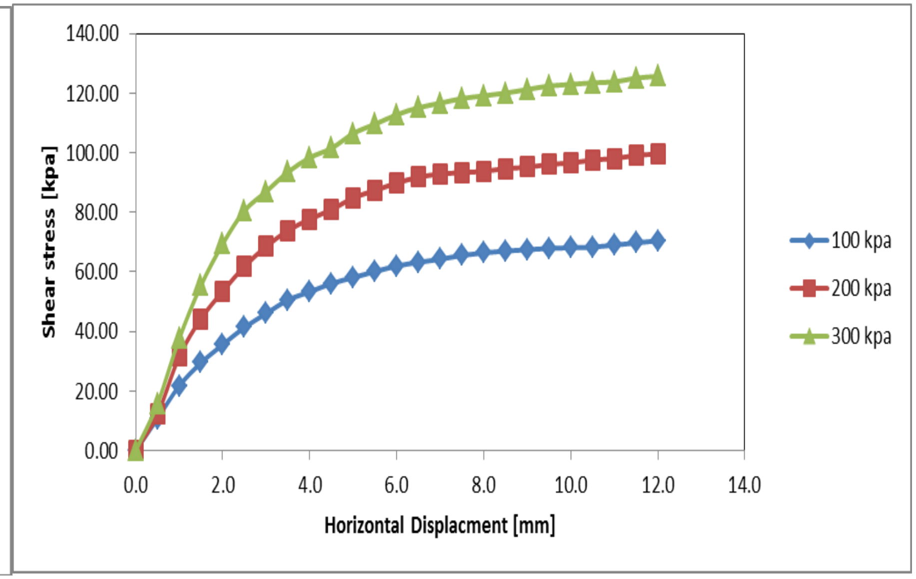


Angle of internal friction (Ø), degree = 26.01 Cohesion (C), KN/M^2 = 9.04

Sampling Location		TF	Sample Depth, m:		4.00					
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div		Wet unit weight, kN/M^3:			17.38
Length of sample :		60 mm	Rate of strain :		0.2 mm/min		Dry Unit Weight, kN/M^3:			13.16
Width of sample:		60 mm	Moisture content, %		32.0		Sample Condition:			Disturbed
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	55.00	38.50	10.78	62.00	43.40	12.16	80.00	56.00	15.69
1.0	3540	110.00	77.00	21.75	160.00	112.00	31.64	190.00	133.00	37.57
1.5	3510	148.00	103.60	29.52	222.00	155.40	44.27	278.00	194.60	55.44
2.0	3480	177.00	123.90	35.60	266.00	186.20	53.51	345.00	241.50	69.40
2.5	3450	204.00	142.80	41.39	305.00	213.50	61.88	397.00	277.90	80.55
3.0	3420	225.00	157.50	46.05	335.00	234.50	68.57	425.00	297.50	86.99
3.5	3390	245.00	171.50	50.59	358.00	250.60	73.92	453.00	317.10	93.54
4.0	3360	256.00	179.20	53.33	373.00	261.10	77.71	472.00	330.40	98.33
4.5	3330	267.00	186.90	56.13	385.00	269.50	80.93	483.00	338.10	101.53
5.0	3300	274.00	191.80	58.12	400.00	280.00	84.85	502.00	351.40	106.48
5.5	3270	281.00	196.70	60.15	408.00	285.60	87.34	512.00	358.40	109.60
6.0	3240	287.00	200.90	62.01	416.00	291.20	89.88	522.00	365.40	112.78
6.5	3210	290.00	203.00	63.24	421.00	294.70	91.81	528.00	369.60	115.14
7.0	3180	292.00	204.40	64.28	422.00	295.40	92.89	530.00	371.00	116.67
7.5	3150	295.00	206.50	65.56	420.00	294.00	93.33	532.00	372.40	118.22
8.0	3120	296.00	207.20	66.41	418.00	292.60	93.78	531.00	371.70	119.13
8.5	3090	296.00	207.20	67.06	418.00	292.60	94.69	530.00	371.00	120.06
9.0	3060	295.00	206.50	67.48	416.00	291.20	95.16	530.00	371.00	121.24
9.5	3030	294.00	205.80	67.92	416.00	291.20	96.11	530.00	371.00	122.44
10.0	3000	292.00	204.40	68.13	414.00	289.80	96.60	527.00	368.90	122.97
10.5	2970	290.00	203.00	68.35	414.00	289.80	97.58	524.00	366.80	123.50
11.0	2940	290.00	203.00	69.05	412.00	288.40	98.10	520.00	364.00	123.81
11.5	2910	290.00	203.00	69.76	412.00	288.40	99.11	520.00	364.00	125.09
12.0	2880	290.00	203.00	70.49	410.00	287.00	99.65	517.00	361.90	125.66

Normal Stress [kpa]	100	200	300
Shear Stress at failure [kpa]	70.49	99.65	125.66

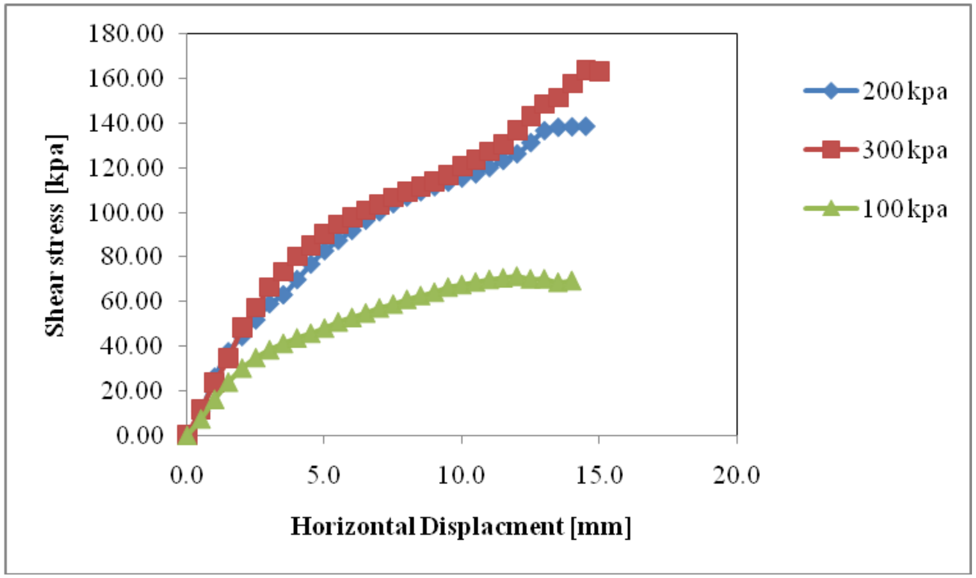


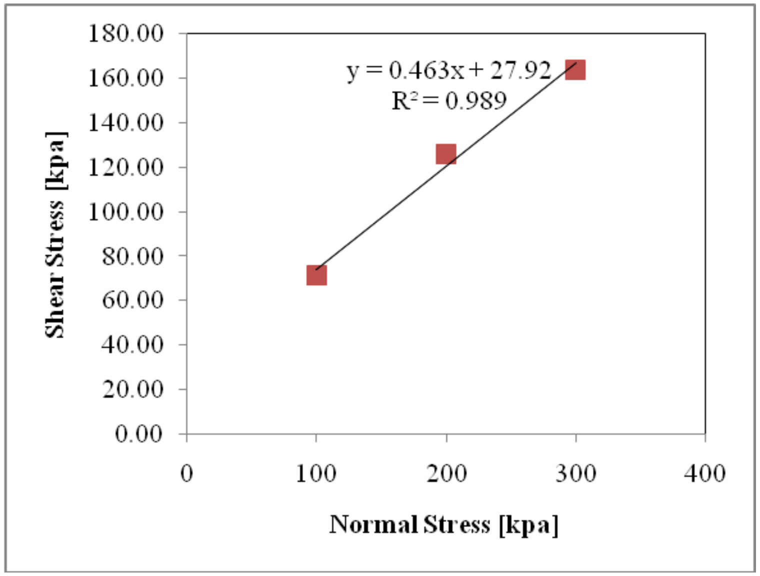


Angle of internal friction (Ø), degree = 15.38 Cohesion (C), KN/M^2 = 43.42

Sampling Location		TF	Sample Depth, m:		4.00					
Thickness of sample:		25 mm	Ring Calib. Factor:		0.70 N/div		Wet unit weight, kN/M^3:			14.34
Length of sample :		60 mm	Rate of strain :		1 mm/min		Dry Unit Weight, kN/M^3:			11.69
Width of sample:		60 mm	Moisture content, %		22.4		Sample Condition:			Disturbed
		Applied Vertical Stress **100 kPa**			Applied Vertical Stress **200 kPa**			Applied Vertical Stress **300 kPa**		
Horizontal Displacement [mm]	Corrected Area [mm2]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]	Proving Ring Reading	Shear Load [N]	Shear Stress [kPa]
0.0	3600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.5	3570	38.00	26.60	7.45	55.00	38.50	10.78	60.00	42.00	11.76
1.0	3540	82.00	57.40	16.21	132.00	92.40	26.10	120.00	84.00	23.73
1.5	3510	120.00	84.00	23.93	188.00	131.60	37.49	174.00	121.80	34.70
2.0	3480	150.00	105.00	30.17	220.00	154.00	44.25	240.00	168.00	48.28
2.5	3450	172.00	120.40	34.90	255.00	178.50	51.74	282.00	197.40	57.22
3.0	3420	188.00	131.60	38.48	288.00	201.60	58.95	325.00	227.50	66.52
3.5	3390	200.00	140.00	41.30	305.00	213.50	62.98	356.00	249.20	73.51
4.0	3360	210.00	147.00	43.75	335.00	234.50	69.79	386.00	270.20	80.42
4.5	3330	218.00	152.60	45.83	365.00	255.50	76.73	405.00	283.50	85.14
5.0	3300	227.00	158.90	48.15	390.00	273.00	82.73	426.00	298.20	90.36
5.5	3270	238.00	166.60	50.95	408.00	285.60	87.34	442.00	309.40	94.62
6.0	3240	245.00	171.50	52.93	425.00	297.50	91.82	453.00	317.10	97.87
6.5	3210	252.00	176.40	54.95	442.00	309.40	96.39	463.00	324.10	100.97
7.0	3180	260.00	182.00	57.23	455.00	318.50	100.16	471.00	329.70	103.68
7.5	3150	265.00	185.50	58.89	467.00	326.90	103.78	480.00	336.00	106.67
8.0	3120	272.00	190.40	61.03	476.00	333.20	106.79	488.00	341.60	109.49
8.5	3090	277.00	193.90	62.75	482.00	337.40	109.19	493.00	345.10	111.68
9.0	3060	281.00	196.70	64.28	487.00	340.90	111.41	498.00	348.60	113.92
9.5	3030	288.00	201.60	66.53	491.00	343.70	113.43	506.00	354.20	116.90
10.0	3000	290.00	203.00	67.67	494.00	345.80	115.27	518.00	362.60	120.87
10.5	2970	292.00	204.40	68.82	497.00	347.90	117.14	525.00	367.50	123.74
11.0	2940	294.00	205.80	70.00	504.00	352.80	120.00	535.00	374.50	127.38
11.5	2910	294.00	205.80	70.72	512.00	358.40	123.16	543.00	380.10	130.62
12.0	2880	294.00	205.80	71.46	519.00	363.30	126.15	564.00	394.80	137.08
12.5	2850	286.00	200.20	70.25	534.00	373.80	131.16	584.00	408.80	143.44
13.0	2820	283.00	198.10	70.25	550.00	385.00	136.52	599.00	419.30	148.69
13.5	2790	274.00	191.80	68.75	550.00	385.00	137.99	604.00	422.80	151.54
14.0	2760	274.00	191.80	69.49	545.00	381.50	138.22	623.00	436.10	158.01
14.5	2730	0.00	0.00	0.00	540.00	378.00	138.46	640.00	448.00	164.10
15.0	2700	0.00	0.00	0.00	540.00	378.00	140.00	630.00	441.00	163.33

Normal Stress [kPa]	100	200	300
Shear Stress at failure [kPa]	71.46	126.15	164.10





Angle of internal friction (Ø), degree = 15.38 Cohesion (C), KN/M^2 = 43.42

APPENDIX D: Cyclic Shear Test Results

Table D.1 Typical 5th cycle shear stress and shear strain values of TF silt soil at 100kPa axial stress and 2.5% shear strain

Cycle No.	Time	Axial Displacement [mm]	Axial Force [KN]	Ext .Axial Lvdt	Lateral displacement [mm]	Shear Force [KN]	*Shear* stress [τ]= $\frac{\text{Shear force}}{\pi*35^2}*10^3$	*Shear* strain [γ]= $\frac{\text{Lateral displacment}}{18.56}$
5	0	-3.709	0.25846	1.50606	-0.44807	-0.17848	-0.0464	-0.02414154
	0.019	-3.70745	0.25835	1.50905	-0.31662	-0.04854	-0.01262	-0.0170594
	0.038	-3.70522	0.25711	1.51202	-0.28136	-0.02839	-0.00738	-0.01515975
	0.057	-3.70382	0.25912	1.5134	-0.27927	-0.02596	-0.00675	-0.01504661
	0.076	-3.70296	0.26026	1.51393	-0.22475	-0.01035	-0.00269	-0.01210964
	0.095	-3.70187	0.2622	1.51617	-0.07141	0.010601	0.002756	-0.00384779
	0.114	-3.70164	0.26383	1.51701	-0.00187	0.036815	0.009571	-0.00010072
	0.133	-3.7003	0.26573	1.51761	0.038425	0.054486	0.014165	0.002070313
	0.152	-3.70053	0.26771	1.51824	0.101475	0.06851	0.017811	0.005467403
	0.171	-3.69981	0.26965	1.51863	0.160705	0.081846	0.021278	0.008658675
	0.19	-3.69973	0.27133	1.51906	0.212285	0.095793	0.024904	0.011437769
	0.209	-3.69967	0.2728	1.51943	0.254225	0.109418	0.028446	0.013697468
	0.228	-3.6993	0.2743	1.51973	0.290995	0.123073	0.031996	0.01567861
	0.247	-3.6997	0.27564	1.52019	0.320085	0.136682	0.035534	0.017245959
	0.266	-3.69933	0.27666	1.52047	0.361595	0.157349	0.040907	0.019482489
	0.285	-3.69927	0.27758	1.5208	0.379845	0.164319	0.042719	0.020465787
	0.304	-3.6991	0.27832	1.52108	0.391043	0.171258	0.044523	0.021069127
	0.323	-3.6993	0.27892	1.52117	0.408681	0.178181	0.046323	0.02201945
	0.342	-3.69881	0.27937	1.52131	0.419637	0.184405	0.047941	0.022609752
	0.361	-3.6989	0.2797	1.52143	0.426708	0.185297	0.048173	0.022990738
	0.38	-3.69895	0.27998	1.52154	0.445341	0.185009	0.048098	0.023994661
	0.399	-3.69878	0.28007	1.52148	0.447815	0.181909	0.047292	0.024127963
	0.418	-3.69913	0.28009	1.52147	0.463998	0.185601	0.048252	0.024999888
	0.437	-3.6987	0.27998	1.52152	0.456295	0.172139	0.044752	0.02458486
	0.456	-3.69915	0.27948	1.52142	0.446411	0.161311	0.041937	0.024052317
	0.475	-3.69864	0.27894	1.52125	0.437179	0.142297	0.036994	0.023554903
	0.494	-3.69915	0.27778	1.52061	0.418057	0.112649	0.029286	0.022524628
	0.513	-3.6993	0.27681	1.51947	0.371702	0.06926	0.018006	0.020027074
	0.532	-3.69901	0.27567	1.51807	0.312605	0.018486	0.004806	0.016842942
	0.551	-3.69778	0.26862	1.51798	0.11393	-0.02543	-0.00661	0.006138443
	0.57	-3.69604	0.26585	1.52121	0.112409	-0.02904	-0.00755	0.006056546
	0.589	-3.69664	0.26361	1.52089	0.082255	-0.03404	-0.00885	0.004431843
	0.608	-3.69615	0.26015	1.52048	0.019365	-0.05612	-0.01459	0.001043373
	0.627	-3.69695	0.25626	1.52053	-0.03462	-0.07139	-0.01856	-0.00186557
	0.646	-3.69689	0.25209	1.52043	-0.09754	-0.08551	-0.02223	-0.00525512
	0.665	-3.69747	0.24814	1.52009	-0.15515	-0.09889	-0.02571	-0.00835964
	0.684	-3.6975	0.24387	1.51966	-0.20571	-0.11124	-0.02892	-0.01108378
	0.703	-3.69821	0.23944	1.51927	-0.25311	-0.1234	-0.03208	-0.01363766
	0.722	-3.69853	0.2349	1.5187	-0.29152	-0.13532	-0.03518	-0.01570663
	0.741	-3.69898	0.23028	1.51817	-0.32382	-0.14628	-0.03803	-0.01744693
	0.76	-3.69961	0.22537	1.51772	-0.34842	-0.15698	-0.04081	-0.01877236
	0.779	-3.69987	0.22026	1.51727	-0.36721	-0.16655	-0.0433	-0.01978529
	0.798	-3.70064	0.21471	1.51682	-0.3819	-0.17428	-0.04531	-0.02057624
	0.817	-3.70081	0.20897	1.51655	-0.39173	-0.17605	-0.04577	-0.02110641
	0.836	-3.70199	0.20291	1.51614	-0.39958	-0.17886	-0.0465	-0.02152883
	0.855	-3.70253	0.19605	1.51589	-0.40515	-0.17736	-0.04611	-0.02182947
	0.874	-3.70302	0.18892	1.51556	-0.40844	-0.18144	-0.04717	-0.02200673
	0.893	-3.70439	0.18124	1.51531	-0.44782	-0.18802	-0.04888	-0.0241285
	0.912	-3.70539	0.17333	1.51506	-0.4643	-0.18567	-0.04827	-0.02499988
	0.931	-3.70682	0.16522	1.51474	-0.46105	-0.18536	-0.04819	-0.02484089

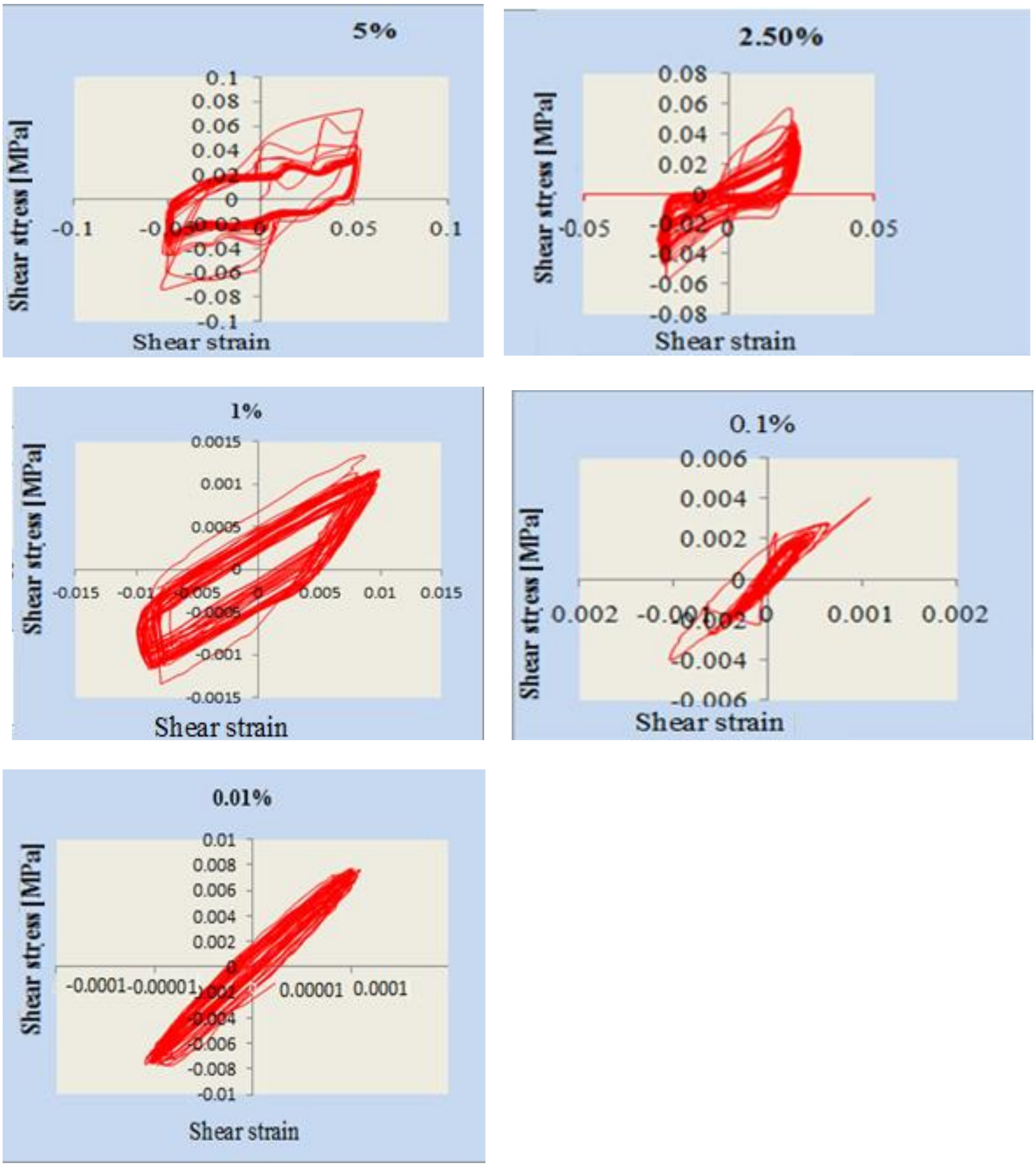


Fig1. Hysteresis loop of TF silt soil at 100 kPa axial stress for different strain levels

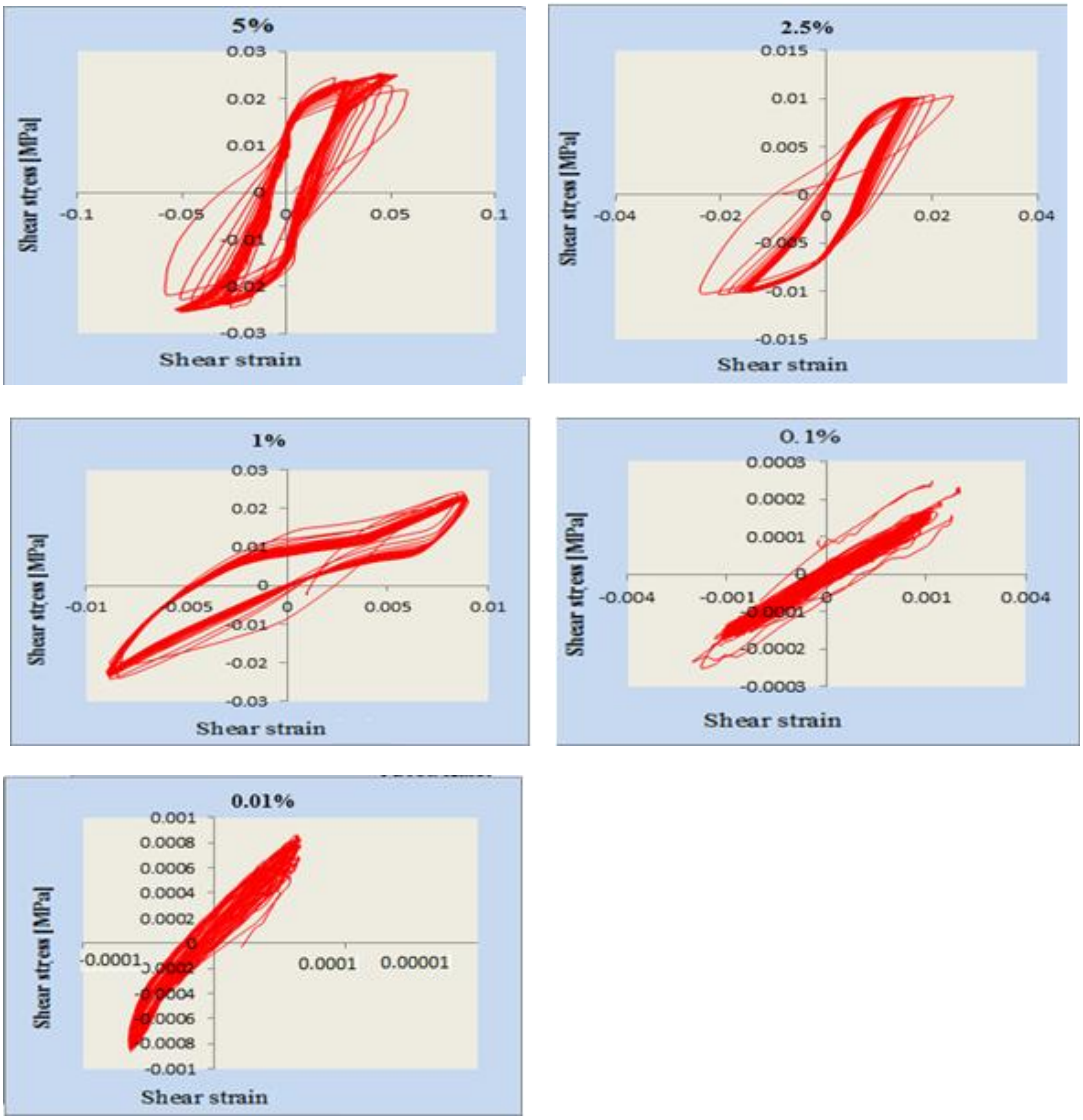


Fig 2 . Hysteresis loop of TF silt soils at 200 kPa axial stress for different strain levels

Table D.2 Shear modulus and damping ratio of TF silt soil under 200 kPa axial stresses for different strain levels

Cycles No.	**Strain level [%]**									
	0.01	**0.1**	**1**	**2.5**	**5**	**0.01**	**0.1**	**1**	**2.5**	**5**
	Shear modulus, G [MPa]					**Damping Ratio, D [%]**				
1	5.55	3.00	2.90	1.86	1.03	3.78	7.26	14.56	15.65	20.12
2	8.99	3.19	4.31	1.85	1.12	3.12	7.40	13.42	14.74	17.98
3	3.82	3.97	3.54	1.86	1.17	3.45	6.22	10.01	14.41	17.65
4	10.52	4.55	4.31	1.88	1.61	3.65	5.56	13.23	14.54	26.21
5	6.21	4.98	3.56	1.87	1.20	3.68	5.34	13.08	14.60	19.54
6	8.29	5.43	4.36	1.88	1.33	3.68	5.20	13.11	14.52	19.91
7	7.06	5.79	3.57	1.89	1.10	3.71	5.03	10.90	14.51	13.64
8	8.59	5.98	4.36	1.88	1.26	3.42	4.83	13.19	14.51	11.65
9	6.89	5.95	3.59	1.90	1.26	2.41	4.76	10.61	14.38	19.78
10	7.71	5.89	4.40	1.90	1.24	2.76	5.17	13.07	14.54	16.44
11	7.89	5.94	3.59	1.90	1.19	2.60	5.03	10.55	14.43	25.46
12	7.96	5.94	4.39	1.91	1.13	2.05	4.86	13.15	14.57	11.88
13	7.13	5.81	3.64	1.91	1.22	0.50	4.89	10.32	14.40	19.96
14	8.04	5.70	4.41	1.93	1.00	0.78	4.74	13.23	14.53	14.42
15	8.08	5.84	3.64	1.93	1.14	1.57	4.69	10.53	14.42	16.49
16	7.43	5.74	4.42	1.94	1.24	0.94	4.73	14.00	14.55	16.13
17	7.47	5.55	3.69	1.94	1.18	0.13	4.65	10.49	14.39	18.97
18	7.63	5.60	4.47	1.94	1.20	0.89	4.60	13.79	14.26	18.34
19	7.99	5.76	4.49	1.96	1.13	0.95	4.70	10.68	14.31	12.81
20	7.66	5.63	4.49	1.96	1.21	1.23	4.67	11.00	14.01	14.89
21	7.53	5.46	3.77	1.99	0.97	0.86	4.52	10.60	14.31	15.03
22	7.65	5.54	4.54	1.99	1.16	1.72	4.63	13.43	14.21	16.15
23	7.83	5.52	3.83	2.00	1.17	2.72	4.79	10.59	14.16	17.10
24	8.03	5.37	4.57	2.01	1.14	1.17	4.83	13.31	14.36	17.79
25	7.65	5.34	3.90	2.02	1.20	1.71	4.62	10.23	13.99	22.28
26	7.36	5.44	4.63	2.04	1.09	0.11	4.67	13.11	14.07	10.46
27	7.86	5.44	3.99	2.07	1.22	1.41	4.73	11.24	13.90	21.36
28	7.51	5.45	4.69	2.10	0.75	0.02	4.50	13.03	16.42	15.85
29	7.23	5.26	4.06	2.15	0.75	1.66	4.63	11.29	13.63	14.97
30	7.25	5.27	4.77	2.13	1.17	0.93	4.54	13.10	13.41	14.79
31	8.11	5.41	4.16	2.20	1.16	0.40	4.58	11.35	13.13	16.97
32	7.23	5.35	4.84	2.25	1.18	1.28	4.57	13.20	13.08	19.01
33	7.42	5.14	4.29	2.31	1.13	0.43	4.71	11.65	11.98	13.50
34	7.70	5.24	5.00	2.38	1.20	0.88	4.57	13.47	12.18	21.85
35	7.90	5.39	4.43	2.50	1.21	0.15	4.62	12.04	10.76	13.76
36	7.44	7.44	5.25	2.60	0.75	1.99	4.89	13.80	10.85	14.08
37	7.48	7.48	4.68	2.81	1.15	0.45	4.65	12.79	10.85	15.43
38	7.41	7.41	5.97	2.85	1.10	0.43	4.62	15.89	10.61	14.75
39	7.51	7.51	5.40	2.97	1.15	0.22	4.32	19.19	8.73	18.36
40	8.22	7.50	6.08	3.07	1.28	0.32	4.23	10.44	11.56	15.60

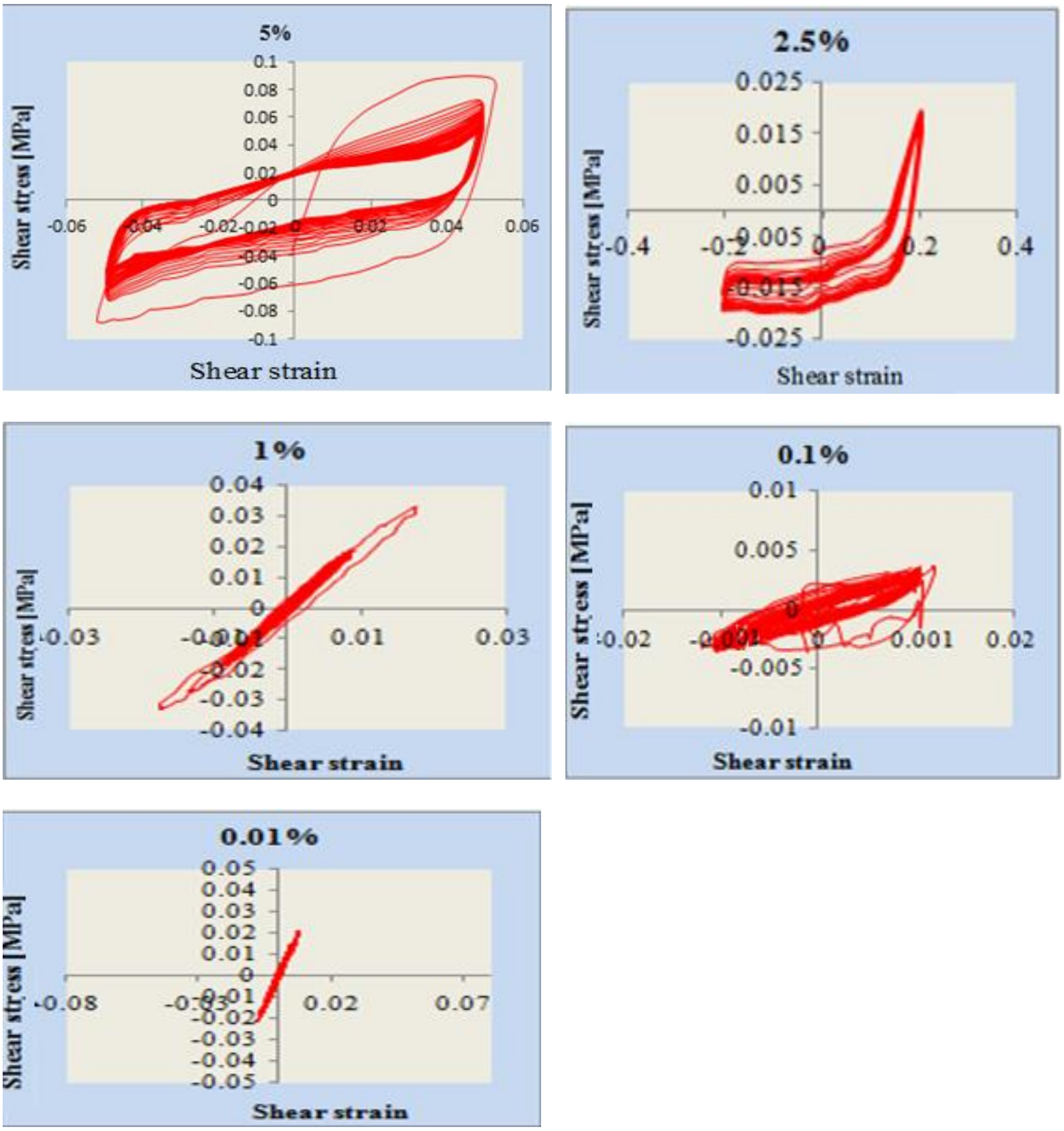


Fig 4. Hysteresis loops of silt soils under 400 kPa axial stress for different strain levels

Table D.3 Shear modulus and damping ratio of silt soils under 400 kPa axial stress for different strain levels

Strain level	**0.010**	**0.100**	**1.000**	**2.500**	**5.000**	**0.010**	**0.100**	**1.000**	**2.500**	**5.000**
Cycles No.	**Shear Modulus, G (MPa)**					**Damping Ratio, D (%)**				
1	12.10	10.42	7.60	5.98	2.50	3.46	4.69	6.98	11.02	14.06
2	12.22	10.62	8.53	6.79	2.79	2.38	3.68	4.71	10.71	13.88
3	13.47	10.48	8.21	6.46	2.81	1.06	3.71	4.83	10.46	12.99
4	13.43	9.77	7.81	6.41	2.83	5.06	5.09	3.96	10.67	13.66
5	13.73	10.40	8.10	6.50	2.88	2.93	3.73	4.64	10.67	13.83
6	13.85	11.17	8.24	7.35	3.56	2.35	3.73	4.83	9.69	11.56
7	14.53	11.24	7.91	7.53	3.80	2.50	3.02	4.06	9.14	12.33
8	14.31	10.55	8.24	7.51	3.38	2.08	3.02	4.63	9.95	11.81
9	14.44	11.23	8.22	6.96	2.85	3.54	3.90	4.84	9.64	14.21
10	14.21	11.04	8.03	6.60	3.00	1.55	3.78	4.63	9.05	13.20
11	14.26	10.80	8.23	6.90	3.50	1.98	2.64	4.54	9.48	12.61
12	14.00	11.19	8.15	7.03	3.66	1.33	3.74	4.90	9.09	11.52
13	14.23	10.97	8.06	6.76	3.96	1.74	3.51	4.30	11.56	12.63
14	14.77	10.98	8.27	6.79	3.70	1.71	3.43	4.36	8.84	12.23
15	13.76	11.00	8.18	6.76	3.00	1.72	3.45	4.69	8.61	13.11
16	14.11	11.25	8.02	6.73	2.91	1.18	3.25	4.47	8.62	13.53
17	14.21	10.98	8.29	6.64	2.91	2.27	2.93	4.59	8.64	12.65
18	14.09	11.17	8.33	6.81	2.92	0.46	3.24	4.74	8.57	13.46
19	14.30	11.32	8.08	6.82	2.94	1.89	3.40	4.33	9.08	12.80
20	14.32	11.10	8.27	6.68	2.94	2.12	3.33	4.66	8.66	12.04
21	13.70	11.35	8.26	6.74	2.95	1.70	3.59	4.98	8.69	12.64
22	14.41	11.26	8.14	6.71	2.96	1.89	3.71	4.35	8.76	13.53
23	14.08	10.91	8.26	6.72	2.97	1.90	3.06	4.65	8.86	12.76
24	14.15	11.09	8.17	6.75	2.97	1.75	3.88	4.96	8.75	13.54
25	14.71	11.17	8.08	6.69	2.99	1.35	3.20	4.69	8.86	12.66
26	13.94	11.29	8.25	6.66	3.00	1.44	3.75	4.61	8.87	13.47
27	14.56	11.08	8.26	6.74	3.01	1.53	3.19	4.94	8.75	13.68
28	14.68	11.27	8.12	6.77	3.04	1.33	2.89	4.76	8.93	12.88
29	14.68	11.14	8.21	6.67	3.06	1.83	3.47	4.87	8.84	13.55
30	14.59	11.19	8.26	6.71	3.08	1.33	2.70	4.88	8.96	12.89
31	14.43	11.08	8.16	6.70	3.09	1.49	3.59	4.72	8.71	13.64
32	14.41	11.03	8.38	6.70	3.11	1.03	2.79	5.15	8.93	12.77
33	14.18	11.03	8.32	6.74	3.13	1.88	3.10	5.15	8.70	13.59
34	14.14	11.17	8.44	6.67	3.18	2.01	3.77	4.58	8.70	12.63
35	14.41	11.22	8.88	6.65	3.21	0.78	2.85	5.55	8.90	13.69
36	14.43	11.11	8.36	6.76	3.22	1.37	3.72	6.00	8.78	12.74
37	14.43	11.12	8.94	6.81	3.32	1.16	3.28	3.90	8.69	13.35
38	14.44	11.07	10.65	6.68	3.20	1.96	2.86	5.30	8.90	8.25
39	14.58	11.24	11.65	6.74	3.11	1.14	3.29	5.00	8.97	13.22
40	14.89	11.04	8.98	6.77	3.79	1.61	2.88	4.04	8.01	11.06

Table D.4 Typical 5th cycle shear stress and shear strain values of AG sand soil at 100kPa axial stress and 2.5% shear strain

Cycle No.	Time	Axial Displacement [mm]	Axial Force [KN]	Ext Axial Displacement [mm]	Lateral displacement [mm]	Shear Force [KN]	*Shear* stress [τ]= $\frac{\text{Shear force}}{\pi * 35^2} * 10^3$	shear strain [γ]= $\frac{\text{Lateral displacment}}{19.03}$
	0	-6.88608	0.37746	2.24501	-0.32768	-0.0198	0.0025543	-0.0101185
	0.019	-6.88702	0.3652	2.24453	-0.26557	-0.0066	0.0014993	-0.0024586
	0.038	-6.88894	0.34893	2.24334	-0.19945	-0.00292	0.0031207	0.0007805
	0.057	-6.88991	0.33167	2.24192	-0.13425	0.00892	0.004051	0.002263
	0.076	-6.89266	0.31453	2.23965	-0.06628	0.01132	0.0046954	0.0042744
	0.095	-6.89497	0.29735	2.23654	4E-05	0.0174	0.0050384	0.0075259
5	0.114	-6.8958	0.29647	2.23561	0.06267	0.02524	0.0061245	0.0102924
	0.133	-6.89663	0.29832	2.23471	0.12057	0.0346	0.0072315	0.0125551
	0.152	-6.89729	0.2982	2.23354	0.1747	0.04356	0.0075589	0.0148769
	0.171	-6.89824	0.29808	2.23282	0.2262	0.0502	0.007377	0.0173162
	0.19	-6.89838	0.29803	2.23244	0.27206	0.06172	0.0078655	0.0193793
	0.209	-6.89875	0.29907	2.23219	0.31278	0.07268	0.0085255	0.0208508
	0.228	-6.89904	0.30147	2.23219	0.34891	0.08308	0.0089932	0.021640
	0.247	-6.89804	0.30413	2.23213	0.37978	0.09156	0.0095181	0.022109
	0.266	-6.89766	0.30623	2.23209	0.40539	0.10156	0.0099443	0.0225605
	0.285	-6.89784	0.30816	2.23217	0.42656	0.10796	0.0102041	0.0230252
	0.304	-6.89741	0.31031	2.23219	0.44347	0.11524	0.0107134	0.0235091
	0.323	-6.89715	0.31302	2.2323	0.45614	0.1194	0.0109109	0.0239228
	0.342	-6.89652	0.31606	2.23233	0.46215	0.11972	0.0105679	0.0240117
	0.361	-6.89666	0.31918	2.23237	0.46384	0.11684	0.0102769	0.0249168
	0.38	-6.8962	0.32243	2.23247	0.46401	0.11404	0.0090504	0.0239666
	0.399	-6.89563	0.32582	2.2325	0.46341	0.10756	0.0061557	0.0236585
	0.418	-6.89523	0.32925	2.23278	0.45938	0.09268	0.0022113	0.0226983
	0.437	-6.89386	0.33257	2.23369	0.45045	0.06796	-0.0008757	0.0209749
	0.456	-6.89126	0.33635	2.23698	0.42851	0.03564	-0.001993	0.0186006
	0.475	-6.88779	0.34013	2.24186	0.38513	0.00868	-0.0047682	0.0157389
	0.494	-6.88596	0.3439	2.24396	0.33129	-0.0082	-0.0050176	0.0115083
	0.513	-6.88585	0.34784	2.2449	0.26703	-0.01692	-0.007112	0.0061718
	0.532	-6.88679	0.35405	2.24453	0.19685	-0.02324	-0.006031	-0.0011933
	0.551	-6.88745	0.32668	2.24392	0.12406	-0.03172	-0.0075329	-0.0045326
	0.57	-6.88957	0.33943	2.24198	0.04976	-0.03668	-0.0072938	-0.0056678
	0.589	-6.89191	0.36466	2.23905	-0.02047	-0.03884	-0.0087594	-0.0066556
	0.608	-6.89472	0.39723	2.23616	-0.07483	-0.04612	-0.008697	-0.0101141
	0.627	-6.89526	0.39476	2.23538	-0.13121	-0.0506	-0.0082761	-0.0140496
	0.646	-6.89532	0.41446	2.23432	-0.18326	-0.05948	-0.0087542	-0.0157565
	0.665	-6.89618	0.42716	2.23367	-0.23278	-0.065	-0.0086762	-0.0168917
	0.684	-6.89678	0.43751	2.2331	-0.27764	-0.07396	-0.0093934	-0.0187348
	0.703	-6.89692	0.43697	2.23263	-0.31638	-0.0818	-0.0092011	-0.0211062
	0.722	-6.89706	0.44876	2.23241	-0.34945	-0.09044	-0.0095857	-0.022451
	0.741	-6.89678	0.47006	2.23229	-0.37798	-0.09884	-0.0100534	-0.0228788
	0.76	-6.89683	0.48673	2.23228	-0.4023	-0.10468	-0.0104016	-0.0231994
	0.779	-6.89658	0.50127	2.23228	-0.42178	-0.10956	-0.0106822	-0.0235052
	0.798	-6.89609	0.5104	2.2323	-0.43694	-0.11412	-0.0108433	-0.023737
	0.817	-6.89626	0.51252	2.23231	-0.44856	-0.11748	-0.0109109	-0.0239139
	0.836	-6.89535	0.49724	2.23242	-0.45651	-0.11932	-0.0108901	-0.0239992
	0.855	-6.89509	0.46769	2.23245	-0.46149	-0.11972	-0.0107342	-0.0240168
	0.874	-6.89486	0.43971	2.23268	-0.46375	-0.11812	-0.0105783	-0.0249079
	0.893	-6.89417	0.42094	2.23294	-0.46401	-0.11436	-0.0094246	-0.0239366
	0.912	-6.89374	0.39306	2.23326	-0.46232	-0.10804	-0.0054282	-0.0234558
	0.931	-6.89277	0.3827	2.2347	-0.45591	-0.08876	-0.001993	-0.0220889

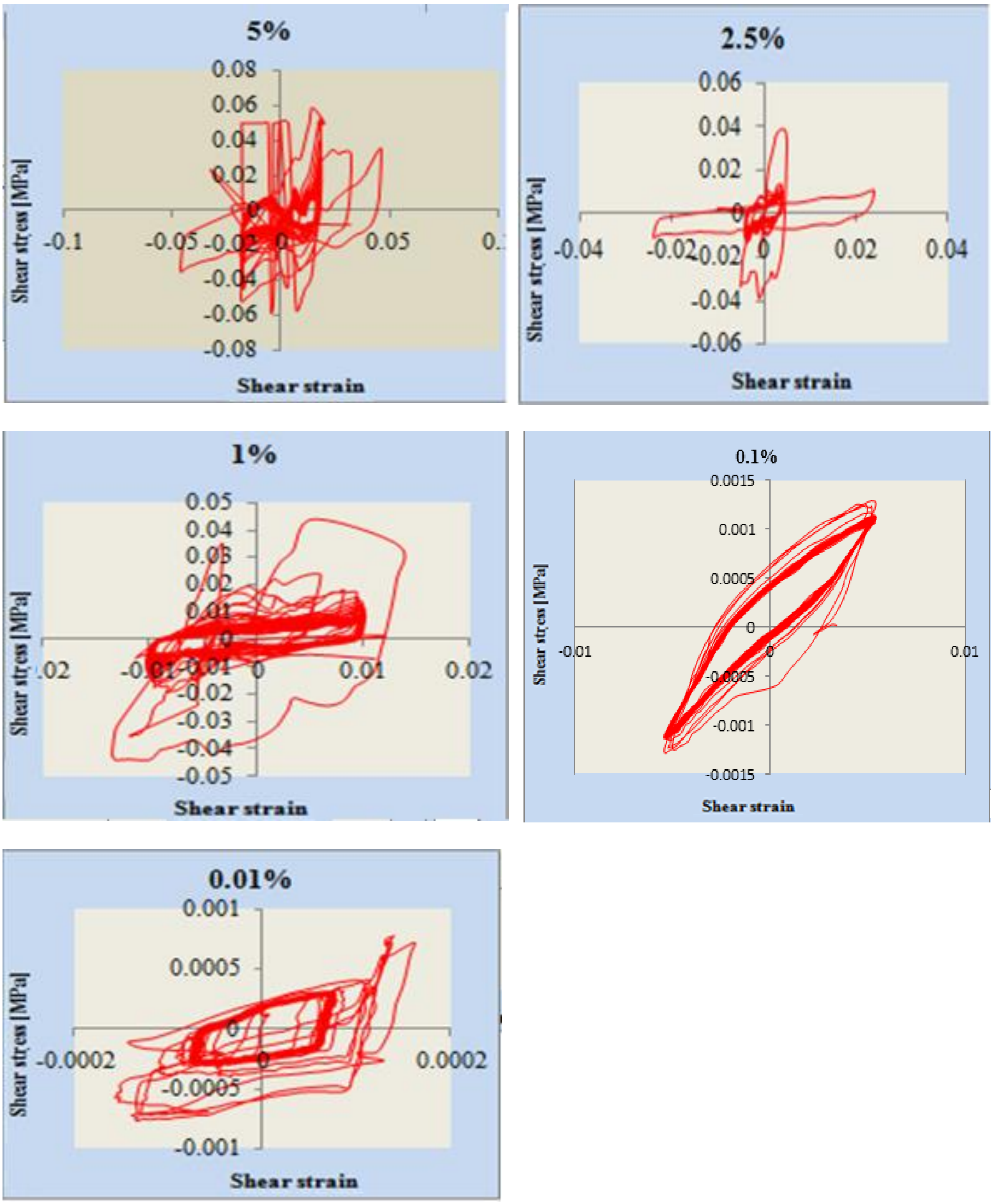


Fig 5. Hysteresis loops of AG sand soils under 100 kPa axial stress for different strain levels

Table D.5 Shear modulus and damping ratio of Sand soils under 100 kPa axial stress for different strain levels

Strain level	0.01	0.1	1	2.5	5	0.01	0.1	1	2.5	5
Cycles No.	Shear modulus, G [Mpa]					Damping Ratio, D [%]				
1	10.18	6.59	5.01	2.65	1.09	5.69	10.65	18.34	20.03	25.60
2	11.60	6.46	5.03	3.12	1.39	4.76	10.07	18.03	19.61	25.29
3	12.90	6.59	6.83	3.17	1.45	4.60	10.67	17.51	19.73	26.01
4	7.99	6.20	6.01	3.22	1.58	4.69	9.59	17.23	19.38	25.81
5	11.02	6.50	5.30	3.09	1.34	4.91	10.58	17.82	18.98	24.32
6	11.64	6.85	5.03	3.02	1.65	4.10	10.58	17.67	19.60	24.88
7	9.47	6.49	5.13	3.10	1.46	4.66	9.30	17.69	20.10	24.96
8	13.37	6.97	7.30	3.12	1.38	4.57	10.20	17.52	19.22	24.27
9	9.54	6.63	6.77	3.09	1.85	4.19	10.66	17.73	18.95	23.32
10	11.57	6.31	5.19	3.11	1.81	4.65	10.58	16.42	19.32	23.38
11	11.78	7.24	6.37	3.30	1.83	5.12	10.02	16.07	18.77	22.98
12	13.12	7.58	5.84	3.04	1.73	4.73	11.01	16.76	17.82	24.08
13	11.44	7.58	5.48	3.09	1.80	4.93	10.43	16.92	19.42	25.77
14	10.22	7.42	5.05	3.25	1.72	4.30	8.20	16.67	19.14	24.28
15	10.96	7.88	4.93	3.13	1.65	5.01	11.49	16.22	19.35	24.88
16	11.65	8.05	5.50	3.13	1.65	4.51	9.76	14.59	19.76	23.61
17	10.86	8.39	5.09	3.18	1.64	4.17	7.76	14.34	19.84	24.27
18	11.58	9.28	4.63	3.13	1.57	4.58	11.27	14.85	19.33	22.49
19	10.59	7.63	4.84	3.10	1.56	4.82	8.62	14.03	19.88	23.98
20	10.81	9.06	5.25	3.03	1.59	4.21	7.74	14.70	19.21	21.60
21	11.64	9.61	5.38	3.03	1.57	4.15	11.56	14.80	19.24	23.15
22	10.86	8.18	5.91	3.03	1.57	4.02	9.63	14.62	19.18	22.06
23	10.95	8.13	5.81	2.99	1.55	4.31	7.88	14.40	18.49	22.58
24	11.40	9.83	5.71	2.94	1.53	4.05	10.86	13.80	19.98	20.48
25	10.30	9.26	6.04	2.95	1.51	4.82	10.42	13.12	18.33	22.30
26	11.88	9.50	5.86	2.96	1.55	4.34	9.77	13.37	18.62	19.41
27	10.81	9.81	5.83	3.01	1.51	4.58	8.60	13.16	18.92	23.26
28	11.16	8.82	5.73	2.96	2.20	4.94	10.18	12.60	18.92	25.53
29	11.16	9.52	5.59	3.01	1.64	4.34	10.07	13.09	19.99	21.57
30	11.43	9.43	5.66	3.03	1.57	3.95	8.53	13.21	19.91	21.27
31	11.69	9.55	5.75	3.10	1.62	4.03	8.60	13.83	18.13	20.57
32	11.57	9.52	6.09	3.08	1.68	3.87	10.75	13.42	19.35	19.09
33	13.03	10.08	5.85	3.07	1.64	4.12	8.45	13.54	19.72	19.65
34	10.71	9.93	5.68	3.10	1.62	3.85	7.46	13.14	19.72	19.95
35	12.29	9.73	5.80	3.12	1.65	3.49	9.62	13.31	19.22	19.56
36	11.85	9.85	5.90	3.20	1.66	4.00	8.95	12.88	19.17	19.60
37	11.52	10.61	5.34	3.13	1.66	3.37	9.07	12.56	18.54	18.98
38	12.53	11.13	6.89	3.18	1.65	3.30	9.12	13.03	18.25	19.35
39	12.03	10.84	6.59	3.23	1.68	3.26	9.13	12.43	18.30	19.26
40	12.30	10.43	7.45	3.29	1.63	3.19	9.10	12.40	18.02	19.20

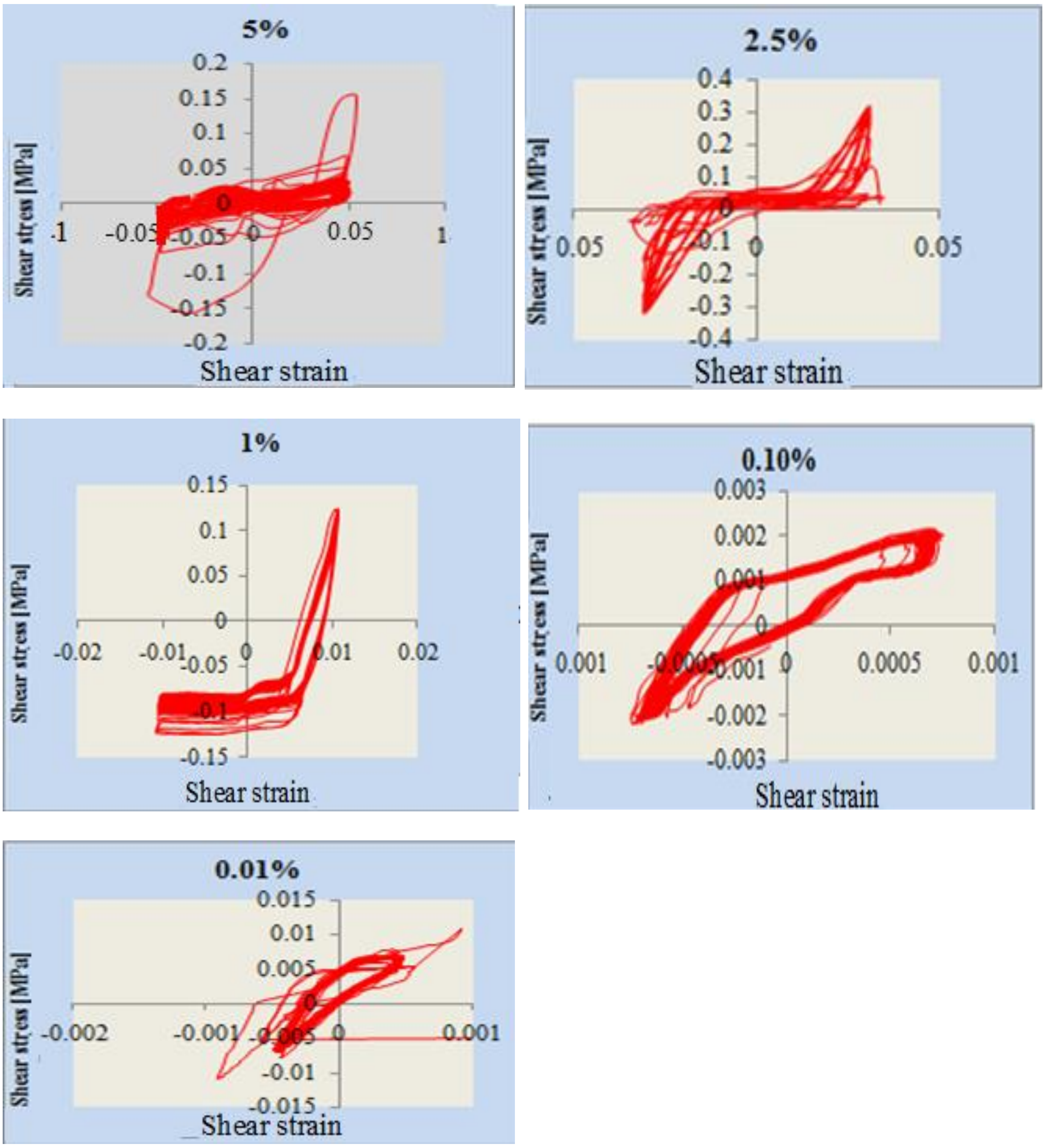


Fig 7. Hysteresis loops of sand soils under 200 kPa axial stress for different strain levels

Table D.6 Shear modulus and damping ratio of AG sand soils under 200 kPa axial stress for different strain levels

Strain level	0.01	0.1	1	2.5	5	0.01	0.1	1	2.5	5
Cycles No.	Shear modulus, G [Mpa]					Damping Ratio, D [%]				
1	15.67	9.97	7.51	4.89	2.06	4.90	10.09	15.28	18.66	25.18
2	14.53	11.87	7.45	4.87	2.52	4.48	9.24	15.54	17.89	28.35
3	22.51	11.65	7.80	5.03	2.26	4.88	8.37	15.12	17.65	26.84
4	18.09	13.23	9.50	5.32	2.03	3.30	9.31	13.60	17.66	23.42
5	23.08	11.64	8.93	5.02	2.06	4.68	9.58	13.55	17.54	24.52
6	23.47	13.74	8.82	6.00	2.16	3.90	9.52	13.34	18.00	23.06
7	22.56	12.62	8.93	6.31	2.31	3.42	9.52	13.36	17.56	21.87
8	20.29	11.82	8.80	6.46	2.63	3.69	8.79	12.68	18.66	22.64
9	22.41	11.86	8.80	6.64	2.86	3.90	8.79	12.67	17.43	22.24
10	22.74	12.47	8.76	5.74	2.71	3.69	8.94	12.50	17.65	22.28
11	21.56	11.95	8.68	5.98	2.86	3.24	8.70	12.39	18.69	22.42
12	22.81	11.91	8.62	5.59	4.52	3.70	8.93	12.75	17.37	22.39
13	21.38	11.90	8.51	6.13	4.42	3.57	8.99	12.68	16.35	21.20
14	22.04	12.26	8.45	6.25	3.85	3.65	8.36	12.23	16.94	20.97
15	22.29	12.18	8.51	6.26	3.80	3.59	8.64	13.16	16.56	22.08
16	21.63	11.76	8.47	6.25	4.07	3.09	8.75	12.51	17.57	21.04
17	23.05	12.01	8.37	6.30	4.58	3.46	8.57	13.43	16.91	21.34
18	22.74	12.32	8.37	6.31	4.33	3.32	8.60	13.26	17.54	21.72
19	22.62	11.99	8.42	6.33	4.62	3.47	8.68	13.40	16.76	20.90
20	21.62	11.72	8.36	6.31	4.32	3.54	8.45	13.26	17.19	22.00
21	20.80	11.73	8.23	6.32	3.15	3.15	9.10	12.73	16.60	23.12
22	23.36	12.15	8.20	6.37	3.15	3.47	8.49	13.03	16.63	20.59
23	22.69	12.06	8.30	6.36	3.53	3.19	8.32	12.83	16.43	21.69
24	22.79	11.85	8.24	6.35	3.00	3.50	8.61	13.48	17.43	23.28
25	21.13	12.09	8.13	6.35	2.93	3.59	8.60	12.42	16.35	23.58
26	21.04	12.31	8.12	6.39	3.37	3.19	8.44	13.45	16.38	21.66
27	22.21	11.59	8.17	6.39	3.30	3.60	8.51	12.72	15.89	21.91
28	20.87	11.83	8.12	6.39	4.34	3.21	8.42	12.99	16.57	19.10
29	20.87	12.14	8.12	6.37	3.68	3.56	8.75	12.60	16.14	19.78
30	21.74	11.67	8.35	6.43	3.67	3.51	8.48	12.69	16.54	18.68
31	21.66	12.26	8.30	6.42	4.01	3.31	8.50	10.71	15.19	18.90
32	20.89	11.87	8.13	6.44	3.13	3.62	8.40	11.52	16.50	20.46
33	22.22	12.09	8.09	6.44	3.28	3.23	8.51	12.68	15.96	20.66
34	20.92	12.25	8.04	6.45	2.61	3.47	8.75	12.38	16.28	19.46
35	21.79	12.30	8.06	6.47	2.86	3.54	8.60	13.89	16.37	18.08
36	21.80	11.94	7.98	6.48	2.57	3.25	8.40	12.63	16.35	18.10
37	20.53	12.67	8.00	6.48	3.34	3.71	8.76	13.52	16.32	22.16
38	20.80	12.17	7.99	6.47	3.87	3.22	8.55	12.97	15.61	20.52
39	21.01	12.65	8.01	6.50	4.12	3.36	8.38	13.38	15.12	19.12
40	22.32	12.90	8.99	6.49	4.67	2.63	8.04	12.03	15.09	18.90

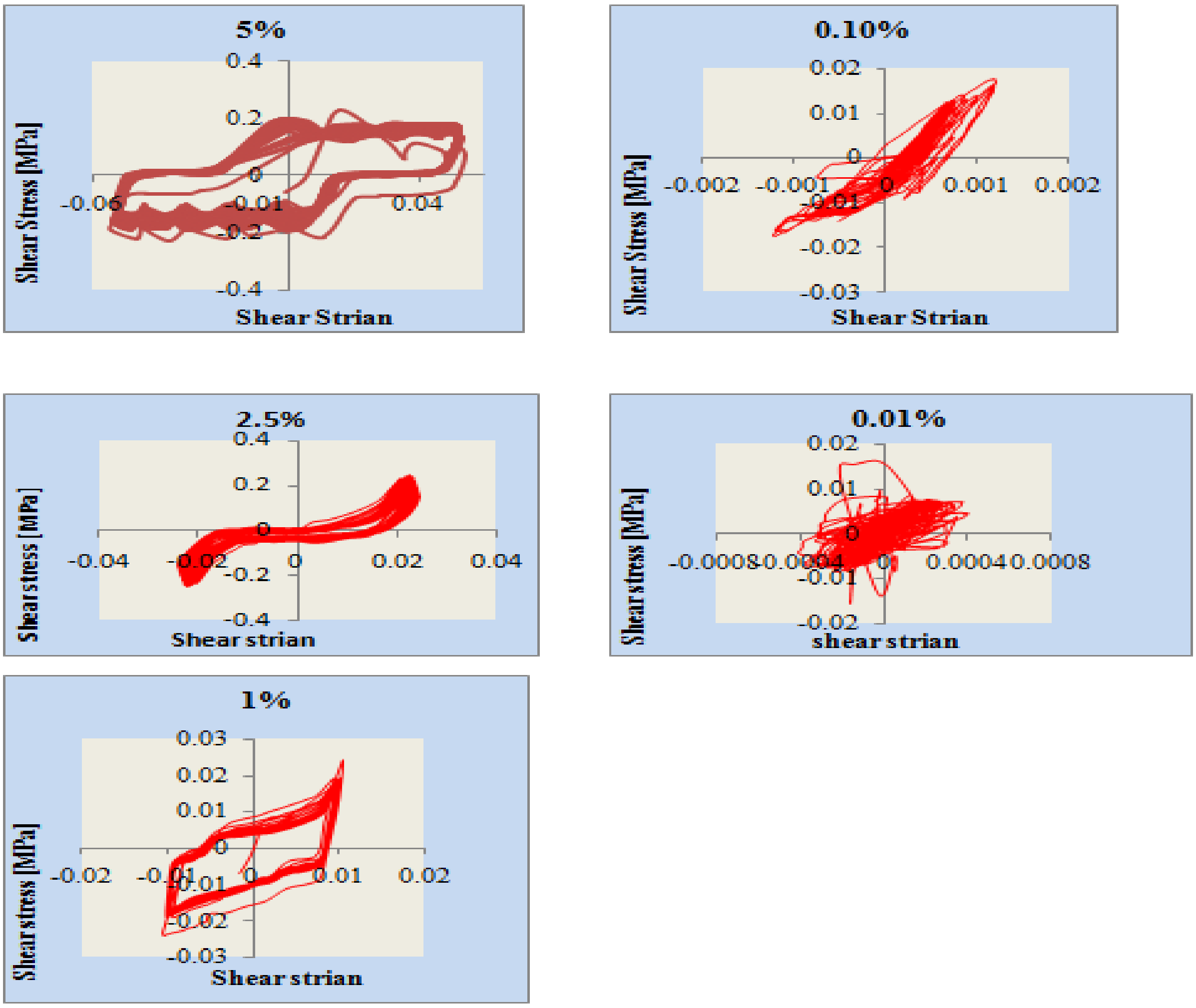


Fig 9. Hysteresis loops of AG sand soils under 400 kPa axial stress for different strain levels

Table D.7 Shear modulus and damping ratio of Sand soils under 400 kPa axial stress for different strain levels

Strain level	0.01	0.1	1	2.5	5	0.01	0.1	1	2.5	5
Cycles No.	Shear Modulus, G [Mpa]					Damping Ratio, D [%]				
1	18.32	15.10	13.09	6.28	2.32	3.11	8.05	14.34	16.50	18.49
2	19.56	17.56	15.79	6.34	3.55	1.91	7.55	13.67	16.50	17.11
3	18.99	18.03	14.06	6.42	3.50	2.41	8.00	11.06	16.09	16.29
4	26.65	17.02	14.91	6.53	3.54	1.80	7.34	9.45	16.27	16.22
5	37.80	18.98	14.61	6.57	3.50	2.54	7.30	12.06	16.13	17.15
6	17.98	18.12	14.12	6.65	3.51	3.06	6.32	10.78	15.88	16.84
7	20.05	15.06	14.69	6.73	3.60	2.65	6.95	11.34	16.23	17.26
8	18.38	16.89	14.56	6.81	3.59	1.96	6.06	8.06	16.23	16.99
9	20.32	18.09	14.13	6.89	3.68	1.93	5.92	8.73	15.79	17.51
10	19.19	16.73	14.15	6.97	3.72	3.35	7.02	10.24	15.79	16.85
11	22.92	14.77	14.71	7.11	3.90	3.15	6.81	9.46	15.86	17.02
12	18.79	16.60	14.16	7.22	3.79	1.94	6.03	9.38	15.64	16.80
13	29.48	16.23	14.64	7.33	3.93	2.41	7.55	12.15	15.69	17.32
14	19.92	16.77	14.57	7.41	3.93	1.96	8.62	11.65	15.13	16.72
15	24.98	16.16	14.23	7.56	4.11	2.83	7.56	11.16	15.07	16.89
16	29.48	16.81	14.75	7.71	4.23	3.60	8.46	10.91	14.93	17.22
17	23.42	17.64	14.63	7.80	4.15	2.48	7.27	10.18	14.84	17.09
18	32.73	17.01	14.19	7.95	4.32	2.65	7.91	9.74	14.75	17.13
19	37.99	16.71	14.70	8.13	4.21	2.07	7.91	10.25	14.42	16.94
20	27.16	17.29	14.69	8.30	4.37	2.21	7.06	10.24	14.73	17.02
21	28.50	17.28	14.22	8.40	4.22	2.97	7.27	9.77	14.11	16.92
22	34.25	16.80	14.71	8.55	4.22	3.42	7.40	10.26	14.40	16.80
23	24.67	16.12	14.74	8.72	4.21	3.08	7.78	10.29	13.94	17.11
24	27.15	16.95	14.25	8.91	4.45	2.84	7.46	9.80	14.26	16.83
25	30.99	16.94	14.67	9.10	4.28	1.93	7.07	10.22	13.96	16.74
26	30.23	15.96	14.59	9.30	4.46	2.05	7.46	10.14	13.26	16.78
27	30.89	16.06	14.26	9.53	4.32	2.21	7.61	9.81	14.00	17.76
28	30.30	16.72	14.61	9.72	4.54	1.85	7.58	10.16	15.50	16.55
29	30.34	17.75	14.55	10.22	4.41	2.38	7.20	10.10	13.79	17.57
30	28.09	17.25	14.20	10.18	4.56	2.34	7.30	9.75	13.96	16.61
31	30.19	16.51	14.62	10.37	4.54	2.05	7.51	10.17	13.70	17.29
32	31.56	16.98	14.57	10.67	4.53	2.21	7.20	10.12	13.48	16.54
33	31.34	18.00	14.00	10.66	4.53	1.64	7.17	9.55	13.45	17.10
34	30.67	17.41	14.56	11.09	4.45	1.57	6.78	10.11	13.44	16.76
35	31.48	16.77	14.54	11.19	4.66	1.49	7.17	10.09	14.08	16.83
36	31.68	17.17	14.13	11.12	4.55	1.55	7.08	9.68	16.78	16.57
37	31.34	17.19	14.38	11.23	4.64	1.21	6.97	9.93	16.78	16.76
38	31.82	17.89	14.54	11.02	4.50	1.24	7.22	10.09	17.27	17.33
39	31.41	17.67	14.24	11.17	4.65	1.69	7.20	9.79	13.29	16.61
40	32.43	17.95	14.58	11.37	4.44	1.17	6.06	8.93	12.03	17.73

APPENDIX E. Computation of maximum shear modulus, G_{max}

1. Computation of maximum shear modulus, G_{max} of Silt soil

Computation of the maximum shear modulus, G_{max} of the silt using Equation 2.4 rewritten below, and the calculated G_{max} is used to obtain the normalized shear modulus.

$$G_{max} = 3.23x \frac{(2.97\text{-}e)^2}{(1+e)} x\ (OCR)^k (\sigma'_o)^{k_o}$$

where: e = void ratio

k =dimensionless quantity which is a function of PI, taken from Table 2.1

The over consolidation ratio (OCR) of soil is expressed as;

$$OCR = \frac{\sigma'_c}{\sigma'_v}$$

σ'_v = present effective vertical stress

σ'_c =pre consolidation pressure

σ'_o = mean effective stress and equal to:-

$$\sigma'_o = \frac{(\sigma'_v + 2k_o\sigma'_v)}{3}$$

σ'_v = present effective vertical stress

K_o is coefficient of earth pressure at rest and estimated to 0.5 for these silt soils [22], From one dimensional consolidation test result pre-consolidation pressure was 70kPa, with PI value of 3, from Table 2.1 has k value of 0 and void ratio of 1.23 at the natural state.

Based on equation 2.4, the values of G_{max} can be calculated and presented in Table 1

Table 1 Computed G_{max} values with different axial stress

Axial load [kPa]	100	200	400
Over Consolidation Ratio, OCR	0.7	0.35	0.175
mean effective stress, σ'_o	66.66	133.33	266.66
Maximum shear modulus, G_{max} [MPa]	17.12	24.30	34.36

Typical computation of Normalized shear modulus values of silt soil determined using the G values of 5th cycle and the calculated $G_{max,}$ at 100kPa axial stress for 0.01% cyclic shear strain. From Table 4.7, G = 3.86 MPa

Thus, the Normalized shear modulus, G/G_{max}

$$\frac{G}{G_{\max}} = \frac{3.86}{17.12} = 2.23$$

2. Computation of maximum shear modulus, G_{max} of Sand soil

Computation of the maximum shear modulus, G_{max} of the sand using Equation 2.5 rewritten below, and the calculated G_{max} is used to obtain the normalized shear modulus.

$$G_{max} = 1000k_{2max}(\sigma'_m)^{0.5}$$

where, σ'_m is mean effective stress and equal to:-

$$\sigma'_{m} = \frac{\sigma'_v + 2\sigma'_h}{3}$$

.

where σ'_v is vertical effective stress and σ'_h is horizontal effective consolidation stress and and K_o is the coefficient of lateral pressure at rest. For cohesionless soils K_o is often taken to be 0.5[22]. And $\sigma'h = K_o\sigma'v$

Typical procedures to compute G_{max} of sand soil with e value of 0.60, K_{2max} value of 51 from Table 2.2 and at 100kPa axial stress.

$$\sigma'_m = \frac{(100 + 2*0.5*100)}{3} = 66.66kPa$$

$$G_{\max} = 1000*51(66.66)^{0.5}$$

$$G_{max} = 416{,}392\text{kPa}$$

Similarly, G/G_{max} of the silt and sand soil under 200 and 400 kPa axial stresses as a function of cyclic shear strain are calculated.